Forestry Handbook for British Columbia

Fifth Edition, PDF Part 1

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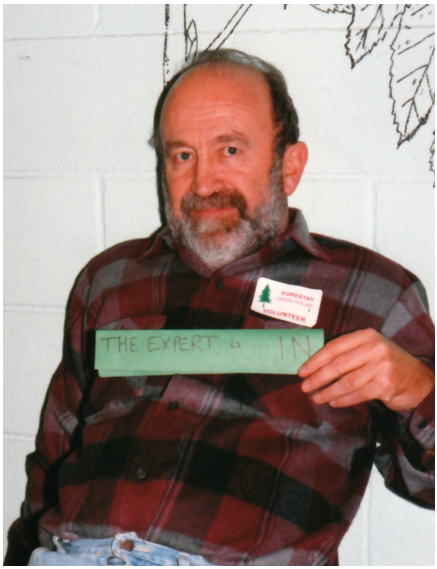
Dedication



John Worrall, or Worrall as he prefers to be known, is widely recognized and respected among alumni and current UBC students. Most of this reputation was acquired through teaching at the University of British Columbia (UBC). Worrall taught dendrology, public speaking and forestry in the Faculty of Forestry for 35 years. His academic achievements include five degrees, B.Sc. (1959) at Durham, B.S.F. (1963) at UBC, M.F. (1964), M.Phil. (1967) and Ph.D. (1968) at Yale.

However, Worrall has not achieved notoriety solely for his academic achievements. His teaching methods and extra-curricular activities have made him a legend with the undergraduates in Forestry for over three and a half decades. Present silviculture professor and ex-Worrall dendrology student Dr. Stephen Mitchell fondly recalled Worrall's lab exam which consisted of leaves and branches, but to make it more difficult the leaves would be cut so they resembled different species, such as cutting the lobes off oak leaves or cutting maple leaves into squares. This was designed to make students recognize leaves by venation pattern instead of simple morphology. He was also famous for memorizing students' surnames, so even if you sat at the back of the class he would still be able to find you and pick you out if you weren't paying attention, and know your name. Michael Main, a Malcolm Knapp Research Forest staff member, remembers being quite daunted while sitting in class when Worrall would ask a question and then unexpectedly turn and say "Any thoughts Main?"

Worrall's strange, but always meaningful, methods of education continue. Bart van der Kamp (Forest Sciences Department head) got a phone call recently about a yellow birch tree. When he asked the caller if they were sure it was a yellow birch the person on he phone said "Well, I did call someone in Forestry last year, but I've forgotten his name. He told me to bring a small twig. When I arrived in his office with my twig, he said chew it, what does it taste like? Wintergreen, I said. Yellow birch, he said". The original contact was no doubt Worrall, and this statement typifies his way of teaching and his depth of knowledge.

Worrall's greatest achievement is his connection with the Forestry undergraduate students, which was recognized during his retirement party in 2003. Worrall just wanted a small event with a BBQ and burgers, but 250 alumni, faculty and friends saw to it that this party was anything but small! People came from all over Canada. The retirement party however, did not mean that Worrall was leaving the Forestry

building as he now has an office on the first floor. He is still involved in many student activities, he organizes ping pong tournaments and can be found flipping burgers at Forestry Undergraduate Society (FUS) beer gardens.

His contribution to FUS events is outstanding; Worrall can usually be found enjoying himself, whether the event is in the Forestry building or at the Blarney Stone in downtown Vancouver. In the past he's arranged trips to visit the redwoods in California, and has taken students hiking on Mt. Frosty. He's also renowned for taking the odd stray student into his own home when they've turned up for the beginning of the year without housing.

He is also the only professor to have received the Forestry Killam award twice: a recognition for outstanding contribution to teaching in the Faculty of Forestry.

For all these reasons, and many more, Worrall is much loved by his students and alumni. The 1975 – 1989 Forestry alumni recognized Worrall's passion for trees and his encouragement of academic and cultural development of forestry students as they progressed through UBC. They began the now record-breaking John Worrall bursary (renamed as the Tree Enthusiasts Prize), which was set up to provide $1,000 a year for undergraduate aid, and is supported entirely by voluntary fund raising. The total amount raised so far is $19,500.

International exchange student Sam Coggins' first experience of Worrall was less than 24 hrs after arriving in Canada from England. Worrall drove a mini-van full of international students up to Williams Lake, a day before the interior fall camp, and gave everyone a quick introduction to forestry in BC. Needless to say, the normal 6 hour drive turned into 9 as Worrall insisted on showing the new students some BC scenery. Sam commented that he will never forget what Worrall has done for him and neither will others. Johann Baart (current undergraduate) sums him up as; professor, teacher, dendrologist, mentor, burger flipper, ping pong champ, truck lender, interior gardener, exterior gardener, encyclopedia of botany, Coconut icon, whale 'researcher', slide aficionado, job reference, landlord pro bono, surrogate father, and friend.

All this and more is what Worrall has been to countless undergraduate students that have come and gone through the Faculty of Forestry at UBC. His contribution to the student experience cannot be overstated. With a door that's always open and a cunning yet humourous glare, Worrall is to this Faculty what rainfall is to BC's coastal forests.

The undergraduate students and alumni of UBC Forestry dedicate this edition of the Forestry Handbook to a unique individual.

Thank you Worrall.

Foreword to Fifth Edition

After a record hiatus between editions, we are proud to introduce an all-new fifth edition of the Forestry Handbook for British Columbia. Since the first (1953) edition, which the students of the day were able to put together themselves, this new 800 page tome has involved the efforts of UBC students (undergraduate and graduate), staff, faculty and other experts from provincial and federal government agencies, consulting and professional organizations. We are grateful to all of those who have donated their time to this project. We would also like to thank Forest Renewal BC who provided two years of financial support for the initial coordination of this venture.

This fifth edition contains mostly new material. Every chapter has been re-written and several new chapters have been added. New topics to the fifth edition are chapters on visual resource management, fish and stream protection, ecosystem management and conservation biology, modeling stand and forest dynamics, and geographic information systems.

Finally, we would like to thank the Faculty of Forestry for embracing this project as part of the Faculty's fiftieth anniversary celebrations in 2002. With this support we were able to maintain the profile and momentum necessary to get all of the many pieces together (albeit, three years later!).

The Forestry Undergraduate Society

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FOREST POLICY

by

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FOREST POLICY

Evolution of Forest Policy in BC

In order to understand contemporary forest policy in British Columbia (BC) it is necessary to appreciate how it has evolved over the past century and a half. The development of forest policy in the Province since the first European settlements can be considered in five periods each characterized by different objectives reflecting public values and attitudes towards forest resources that prevailed at the time.

1850s – 1911: The pioneer era

The pioneer era spanned the period during which the Crown colonies of British Columbia and Vancouver Island were joined (1866), British Columbia joined the Canadian confederation (1871) and the transcontinental railway was completed (1885) giving BC access to booming markets on the Prairies, in eastern Canada and the United States. During this period the population of the province was small, but growing rapidly, and public revenues were modest. It was a period of pioneering development and industrial expansion. The objectives driving public polices towards forest resources included agricultural development, settlement, the generation of public revenue and the establishment and development of forest products' industries.

From the early 1800s until 1865, Crown grants, that involved transferring forest resources to the private sector, were the only means of allocating timber – a practice that continued until the turn of the century. In the latter half of the 19th century, large land grants were made to promote railway construction; among them, 5.6 million hectares to the federal government to build the Canadian Pacific Railway (CPR) and 760,000 hectares to the Esquimalt and Nanaimo Railway (E&N) on southeast Vancouver Island. Much of this land eventually reverted back to the province; however, the E&N lands remain and comprise the most important area of private forestland in the province. Today, there are about 2.5 million hectares of Crown granted forestland in BC; about 5% of the province's productive forestland base.

The practice of granting rights to harvest timber without alienating the land – a fundamental feature of BC's forest policy – first appeared in 1865 in the Crown Colony of Vancouver Island. Timber leases of an unlimited extent were offered to individuals or companies engaged in the manufacture of lumber. Licensees were provided with unrestricted rights to harvest all merchantable timber within the licensed area. Following harvesting the land reverted back to the Crown. Several forms of tenure of this nature were granted through to 1907.

Collectively, the various kinds of pre-1907 leases and licenses authorizing access to public timber became known as old temporary tenures (OTTs) and, subsequently, under the *Forest Act* of 1979 (British Columbia, 1996a), timber licenses. While timber licenses cover only a small portion of the province's forestland today. Some of the remaining licenses provide rights to high quality, primary forests on the southern BC Coast and Vancouver Island.

In 1907, in response to increasing concerns over the pace at which rights to Crown timber were being issued, the government stopped issuing licenses. In 1909, the first Royal Commission on forestry – the Fulton Commission – was established to conduct an assessment of public forest policies and to make recommendations concerning the future conservation, protection and utilization of the province's forest resources. The Commission's 1910 report (British Columbia 1910) made recommendations for the protection and further development of BC's forests. Crown ownership of forestlands was endorsed and short-term, competitive timber sales were recommended to provide access to public timber and encourage economic development.

1912 – 1947: Unregulated forest industry expansion

BC's first *Forest Act of* 1912 (British Columbia, 1912) adopted many of the Fulton Commission's recommendations. A system of *forest reserves*, known since 1979 as *provincial forests,* was established, a Forest Service under the direction of a chief forester – Mr. H.R. McMillan – was created and short term, competitive timber sale licenses became the only means for disposing of new cutting rights to Crown timber.

During the 1920s and 30s, technological innovations, expanding markets and public policies favorable to industrial expansion led to major growth of the forest industry, particularly on the BC Coast. Harvest rates and utilization standards were not regulated and reforestation was not funded. Advances in harvesting and transportation technology allowed loggers to access previously inaccessible timber and the forest industry advanced on a broad front. On the Coast, portable camps and itinerant loggers followed the industry while in parts of the Interior logging and small milling communities boomed and as quickly collapsed. The importance of timber sale licenses increased and by the early 1940s accounted for 25 percent of the provincial harvest, the rest originating from Crown granted land (40%) and old temporary tenures (35%).

By the early 1940s, the government faced two major concerns. A large and increasingly capital intensive forest industry sought more secure supplies of timber for further expansion and consolidation while foresters feared the consequences for future timber supplies of the unbalanced pattern of harvesting and inadequate reforestation. In 1943, these pressures resulted in the appointment of BC's second Royal Commission on forestry – the Sloan Commission.

Reporting in 1945 (British Columbia, 1945) Chief Justice Sloan made sweeping recommendations designed to lead the province towards sustained yield timber management. Sloan envisaged two main forms of management unit, private working circles in which private companies would manage Crown granted lands in combination with Crown lands on a sustained basis, and public working circles, managed by the BC Forest Service, where timber would be made available to independent loggers through competitive timber sales.

1947 – 1979: Sustained yield timber management

Amendments to the *Forest Act* in 1947, and subsequent legislation, introduced measures to bring both Crown and private lands under sustained yield timber management.

Two major types of sustained yield management unit were created – forest management licenses (FMLs) and public working circles.

FMLs were designed to combine Crown granted land, old temporary tenures and Crown land all to be managed under a single, approved working plan. They were initially granted in perpetuity, were freely transferable and many were conditional on the operation of a manufacturing facility. In 1956, FMLs became tree farm licenses (TFLs) with 21-year renewable terms.

Public working circles, which subsequently became known as public sustained yield units, (PSYUs) were managed by the Forest Service on a sustained yield basis, the timber being sold through short-term, competitive timber sales following cruising, appraisal to establish a reserve, or upset, price and advertising. However, by the mid-1950s an informal "quota" system had developed in PSYUs that allowed established operators a proportion of the allowable annual cut (AAC). While competitive bidding was legally required to obtain harvesting rights, regulations favored quota holders in the bidding process. By the early 1960's, competition for public timber had been practically eliminated and it became difficult, if not impossible, for firms to enter the industry unless they could acquire an existing quota. Quotas were transferable and Crown timber rights became increasingly concentrated in the hands of relatively few larger companies. These developments were justified as necessary by government to increase industrial stability and attract investment but, in fact, entrepreneurship was stifled and the competitive efficiency of the market place eliminated.

In 1948, the farm woodlot license, the forerunner of today's woodlot license (WL), was introduced. Farm woodlot licenses allowed farmers to add prescribed areas of Crown land to their private forest holdings, the whole to be managed on a sustained basis according to an approved working plan.

A 1951 amendment to the *Taxation Act* allowed private forestland owners to significantly reduce their property tax burdens if they undertook to manage their holdings as tree-farm lands in accordance with a sustained yield working plan.

During the years following the establishment of FMLs, the procedures for granting and administering them fell into disrepute and, ultimately, criminal proceedings found the Minister of Forests guilty of accepting bribes in exchange for granting licenses In 1955, these and other factors led to the province's third Royal Commission on Forestry. In his second report as Commissioner, Chief Justice Sloan (British Columbia, 1956), endorsed, with some qualifications, the policies that had been adopted as a result of his 1945 report.

In 1961, a pulp industry was superimposed on the interior sawmilling industry through the introduction of pulpwood harvesting agreements (PHAs). PHAs provided their holders, in return for a commitment to build and operate a pulp mill, options to acquire timber below sawmilling standards from designated PSYUs and to purchase residual wood chips from sawmills in the area. In fact, plentiful supplies of wood chips have seldom made it necessary for pulp producers to exercise their roundwood option.

In 1967, timber sale harvesting licenses (TSHLs) ushered in the concept of the volume-based tenure in BC This innovation allowed established operators in PSYUs to consolidate their quotas that were maintained by bidding on area-based timber sale licenses, into a single license - the TSHL - that provided the right to harvest a specified volume of timber from the PSYU each year for a period of 10 years. The precise area from which the volume could be taken was not specified in the license but was designated in short-term cutting permits for which the licensee had to apply from time to time during the term of the license. TSHL holders assumed more management responsibilities than quota holders, mainly for reforestation, and had to agree to log down to close utilization standards that gave them a one third increase in AAC. Within a short period of time, TSHLs became the principle means of public timber disposal within PSYUs.

In the early 1970s, increasing anxiety surrounding the sustainability of provincial timber supplies, lack of concern for the production of non-timber forest products and the structure of the forest industry – particularly the degree of corporate concentration and control over public timber resources – precipitated BC's fourth Royal Commission on Forest Resources – the Pearse Commission.

Appearing before the Pearse Commission, major forest companies argued for the *status quo* but with more secure tenure arrangements. On the other hand, independent loggers, contractors and manufacturers argued that a higher proportion of the province's timber supply should be made available on the open market. Several other groups advocated new forms of small area-based tenures that would provide an opportunity for individuals, cooperatives, small firms and communities to manage Crown forests for the production of logs and other forest products.

Central to Commissioner Pearse's concerns, as expressed in his 1976 report (British Columbia, 1976), was the need to reintroduce competition for public timber, provide incentives for timber management and manage public forests for a greater diversity of products. Many of Pearse's recommendations were subsequently adopted. However, his grave concerns about the lack of competition for Crown timber and its implications for increasing concentration in control over Crown forestlands, entry by new firms into the forest industry and industrial efficiency were never fully addressed.

1979 – 1992: Multiple use

Nineteen seventy-nine saw the passage of a new *Forest Act* (British Columbia, 1996a), replacing the Act of 1912, and the *Ministry of Forest Act* (British Columbia, 1996b). For the first time, the latter required that the Ministry of Forests manage Crown forestlands for multiple products having regard for the long-term economic and social benefits to the Province. Specifically mentioned are timber, range, fisheries, wildlife, water and outdoor recreation. Other legislative initiatives included a new process for determining allowable annual cuts, an improved reporting system on the state of the province's Crown forests and requirements for public participation in management decisions.

Some changes were made to the tenure system but, in terms of general structure, it remained essentially intact. The boundaries of PSYUs were rationalized and the new management units became known as timber supply areas (TSAs). The quota system was formalized by allowing holders of TSLs and TSHLs to consolidate them into Forest Licenses (FLs) – volume-based tenures with 15-20 year terms, generally replaceable every 5-years, and frequently appurtenant to manufacturing facilities. The terms for TFLs were changed from 21 years to 25 years replaceable every 10 years. Old temporary tenures were replaced by timber licenses. Farm woodlots became woodlot licenses (WLs) with maximum areas of 400 hectares of Crown land on the Coast and 600 hectares in the Interior and terms of 15 years, replaceable every 10 years. And, finally, some TSLs were reserved for small businesses. These small business sales were sold on a competitive basis to two categories of applicants – small loggers and small non-integrated manufacturers with no other access to public timber. Basic silviculture, consisting of those operations necessary to achieve "free to grow" forest stands of prescribed species composition following harvesting or other site disturbances, was introduced as a requirement on most classes of tenure.

In spite of the new commitment to multiple use and the planning procedures that accompanied it, timber remained dominant. This became particularly apparent during the 1982-84 economic recession when relaxed harvesting and management standards – euphemistically known as "sympathetic administration" – were allowed in an attempt to maintain economic momentum.

In 1987, the provincial government, aware of the shortcomings of the 1979 legislation, announced several changes in forest policy. A new stumpage system, mainly designed to exempt BC from the terms of US-Canadian *Memorandum of Understanding* on softwood lumber trade, was implemented. Five percent of major licensees' timber harvesting rights were reallocated to an expanded Small Business Forest Enterprise Program (SBFEP) and a proportion of small business sales were placed in a special category known as *bid proposals* that required applicants to compete not only on price but on their ability to create jobs and other regional benefits through the establishment of a further manufacturing facility. To discourage merger activity and free-up more timber for reallocation to the SBFEP, an acquired company could be required to surrender 5 percent of its authorized AAC. The financial burden for basic silviculture was shifted to tenure holders. Finally, a schedule was drawn up to dramatically expand the TFL system using 1982 amendments to the *Forest Act* enabling FL holders to surrender their licenses for area-based tenures.

Widespread and vigorous public opposition to the expansion of the TFL system took the government by surprise and after province-wide public hearings the initiative was abandoned. In 1989, a "permanent" *Forest Resources Commission* was appointed, under the chairmanship of Mr. Sandy Peel, to examine the effectiveness of TFLs as a form of tenure and, more generally, to advise the government on the state of the province's forestland base and recommend improvements for its management. In 1991, the Commission made public its first report – *The Future of Our Forests* (British Columbia, 1991a).

The 1980s saw increasing pressures from environmental NGOs for a new approach to forestry that would place more emphasis on integrated management designed to produce a broad spectrum of forest products in perpetuity while

maintaining the integrity of forest ecosystems. A major turning point for the global environmental movement was the publication in 1987 of the report of the *World Commission on Environment and Development* (Brundtland, 1987). The report introduced the term "sustainable development", a concept that captured the public's imagination, stirred governments to action and galvanized the efforts of the environmental movement worldwide. In Canada, sustainability was embraced as a national forest policy and in 1992, in the face of dramatically changing social values and mounting international environmental pressures on public policies towards forest resources; BC's new NDP government moved sustainable development to the top of the forest policy agenda.

1992 – 2001: Towards sustainability

In 1992, a Commission on Resources and the Environment (CORE) was mandated by the BC legislature to "develop, implement and monitor regional planning processes". The Commission addressed its task by producing a *Provincial Land Use Charter* that incorporated environmental, economic and social sustainability into a set of principles for land use planning The Commission concentrated its attention on four contentious regions: Vancouver Island; Cariboo-Chilcotin; West Kootenay-Boundary and East Kootenay. By 1995, strategic land use plans for these broadly-based regions were complete and the focus turned to the production of sub-regional plans through the Land Resource Management Planning process (LRMP) that involves multi-stakeholder committees, public consultation and inter-agency cooperation. To date, Land and Resource Management Plans have been completed for 73% of the province and the process is actively underway on an additional 12% of the land base.

In 1993, the Protected Area Strategy (PAS) was unveiled as part of the overall land use planning process (British Columbia, 1993). The objective of this strategy was to protect 12 percent of the province's area from industrial activity or development by the year 2000 in order to preserve viable areas representative of the province's main terrestrial, marine and freshwater ecosystem. Although some argue that certain ecosystems are still inadequately protected, the PAS achieved its goal and today approximately 12 million hectares of the province's land area is fully protected from commercial activities.

In 1992, a *Timber Supply Review* process was initiated in order to regularly review the timber supply and the allowable annual cut (AAC) in each of the province's 37 TSAs and 34 TFLs. Each review includes an estimate of the area's long-term sustainable harvesting level and an analysis of projected timber supplies, in terms of species composition and age, for the short-term (20 years), medium-term (21-100 years) and long-term (200 years or more). Alternative AAC scenarios are investigated in terms of their timber supply, environmental, economic and social implications. This information is used by the Chief Forester to determine AACs for each management unit. The first round of the timber supply reviews was completed in December 1996 and the second by December 2002. Work is now proceeding on the third round.

In 1994, the *Forestland Reserve Act* (British Columbia, 1996c) provided for a forest reserve to be established in order to minimize the impacts of urban sprawl and rural settlement on the forestland base, encourage responsible management practices

on forestland and promote conditions favourable to investment on private forestland. The reserve comprised designated Crown land and private land that met certain criteria as set out under the Act including prescribed environmental protection requirements, reforestation requirements and a commitment to manage the land according to the terms of an acceptable working plan.

Also in 1994, the *Forest Renewal Act* (British Columbia, 1996d) established a forest renewal plan administered by a Crown corporation named *Forest Renewal B.C.* The objectives of the plan included enhanced forest management, the relocation and retraining of displaced forest industry workers, the stability and development of forest dependent communities, environmental restoration and the promotion of the further manufacturing of wood products. Implementation of the plan was financed through a substantial surcharge on stumpage payments that became known as "super stumpage"

In 1996, the provincial *Forest Practices Code* came into full force. The *Code*, consisting of the *Forest Practices Code of British Columbia Act* (British Columbia, 1996e), regulations under the Act, Chief Forester's standards and guidebooks, was envisaged as BC's blueprint for the sustainable development of Crown forests. It prescribed forest practices and imposed standards, backed up by penalties for non-compliance, on tenure holders. The Code was designed to achieve sustainability, protect forest and related ecosystems and promote the production of multiple forest products. Implementation of the Code was facilitated through detailed planning and monitoring procedures including an independent *Forest Practices Board* responsible for auditing forest practices and investigating complaints lodged by the public.

The only structural change in the province's tenure system during this period was the introduction, in 1998, of a new form of Crown forest tenure – the community forest agreement. This new tenure, which was introduced in response to pressure from groups throughout the province for some autonomy in managing forestlands adjacent to their communities, represents an important departure from the traditional industrial tenure model that emerged in BC over almost 150 years of policy evolution. In addition to rights to harvest Crown timber, community forest agreements provide rights to manage and charge fees for botanical forest products and to any other prescribed products. Following a probationary period of 5 or 10 years, agreements may be granted for a period of 25 to 99 years. Planning requirements allow flexibility to accommodate community needs and adopt innovative and unconventional forest practices. The popularity of this new arrangement clearly demonstrates the enthusiasm of British Columbians for small-scale forest management under local control. When the call for community forest pilot proposals was made in September 1998, over 60 letters of interest were received and 27 proposals were delivered by January 15, 1999.

To date, 11 community forest pilot agreements (CFPAs) have been offered; 7 have been issued and 5 are operational under an approved working plan. CFPAs are geographically dispersed and vary in size from less than 500 hectares to more than 60,000 hectares.

2002 – Present: A "New Era" in Forest Policy

When BC's new Liberal Government assumed office in the spring of 2001 it faced a forest industry in decline – particularly on the Coast. A report on the Coast forest industry commissioned by the government and released in November, 2001 (Pearse, 2001) concluded that the sector faced a crisis as returns to capital declined, investment withered, aging plants and equipment were not being replaced, mills were closing and workers laid off at unprecedented rates. Important underlying causes of this situation were perceived as: declining opportunities and uncertainties in major product markets; regulations that that restricted the ability of the industry to respond to market conditions; excess manufacturing capacity relative to the available economically accessible timber supply; inflexible, overly bureaucratic and costly rules governing timber utilization and forest practices; insecurity and declining values of timber harvesting rights; and a stumpage system that takes no account of market values for timber, is inequitable, susceptible to abuse and a major irritant in the continuing trade dispute with the United States that claims that the system sets stumpage rates that are too low, thus giving Canadian lumber produces an unfair advantage in US markets. In response to these concerns, the current government, over the three year period it has been in office, has brought in amendments to forest policy that are more fundamental than any changes seen over the past fifty years or more.

Closely following their election victory, the government reorganized the resource ministries. In June 2001, a new Ministry of Sustainable Resource Management was established with a broad mandate that includes land use planning under the LRMP process – previously the responsibility of the Ministry of Forests. In January 2003, the Minister of Sustainable Resource Management introduced the concept of the Working Forest. Under this initiative, that is proving to be highly contentious and precipitated an extensive public consultation process, all Crown forestland in the province that is outside of protected areas and parks – about 45 million hectares – will be legally designated "the Working Forest of BC". Within the Working Forest, all existing land use planning procedures will apply, including regional land-use and resource management plans, but for those areas designated for commercial use access will be assured over the long-term subject to consultation and accommodation of First Nations. Under the plan, the Minister of Sustainable Resource Management will become solely responsible for designating land use objectives within the Working Forest. Removal of land from the Working Forest to protected area status will require a cabinet decision.

Within a few months of gaining office, the government repealed the *Forest Renewal Act* and replaced Forest Renewal BC with the Forest Investment Account (FIA). The FIA is financed through funds collected by the Ministry of Forests mainly in the form of stumpage; the budget being authorized annually by a vote of the legislature. While the Minister of Forests has sole decision making authority in respect of FIA programs and budgets, a Forest Investment Council has been established comprised of the Deputy Ministers of Forests, Sustainable Resource Management, and Water, Land and Air Protection, three licensee representatives and a representative from the forest research and development sector. The council receives progress reports on the various FIA initiatives, audits results and may

recommend changes to any element of the FIA program. FIA programs are delivered by the provincial government and by eligible Crown tenure holders but are administered by private sector firms and organizations. Programs currently financed through the FIA include the land based program, forest science, product development, international marketing, tree improvement, Crown land use planning and small tenures.

In the fall of 2002, following an extensive public review process, the foundation was laid for major changes in the Forest Practices Code that will reduce the regulatory burden on private sector companies and change the character of the Code from a "process" to a "results" based system. That is, the focus will be on the end results of forest management rather than the means by which they are achieved. Such a system, it is maintained, will encourage and award innovation and ensure that management goals are achieved in the most cost effective manner.

The legislation enabling these changes – the *Forest and Range Practices Act (British Columbia, 2002)* – was passed in November 2002 but will not be fully implemented until December 31, 2005. In the meantime, any activities already approved under the existing Forest Practices Code may continue and are governed by the *Forest Practices Code of British Columbia Act*. After December 31, 2005, all planning and on-the-ground work must comply with the *Forest and Range Practices Act* and regulations.

In the spring of 2003, the *Forestland Reserve Act* was amended. Removal of private land from the reserve was made simpler and without penalty and those sections were repealed that provided for the establishment of a Forestland Reserve Commission. The duties of this body have been assumed by the Agricultural Land Commission.

On March 26, 2003, the Government announced its Forestry Revitalization Plan. Contained within this plan are policy changes that will significantly transform the ways in which forests are managed, forest business is conducted and the forest industry is structured in BC.. Following the Plan's announcement, enabling legislation was quickly enacted including the Forest Revitalization Act in March, 2003 (British Columbia, 2003a), the Forest (Revitalization) Amendment Act (Bill 29) (British Columbia, 2003b), and the Forest Revitalization Amendment Act (N0.2) (Bill 45) (British Columbia, 2003c).

Perhaps the most radical feature of the Revitalization Plan is the reallocation of Crown timber harvesting rights. Although reallocation of harvesting rights along the lines outlined in the plan have been advocated by commissions of enquiry, analysts of forest policy and organizations, including environmental NGOs, for more than 25 years, no government to date has had either the incentive or the political will to make the necessary changes. Under the Plan, Crown tenure holders controlling more than 20,000 cubic metres of allowable annual cut in long-term, replaceable licenses; will be required to return 20 percent of their licensed harvest to the Crown. About 40 percent of the allowable cut made available will redistributed to First Nations, 10 percent to expanded woodlot license and community forest programs, and the remaining 50 percent will be sold through competitive auctions by the Crown.

A fundamental component of the Revitalization Plan is the replacement of the Comparative Timber Pricing System, that has been used throughout the province

since 1987, by the Market-Based pricing system. Under the new system, about 20 percent of the provincial allowable cut will be sold to the highest bidder through sealed tender, competitive auctions. Approximately half this volume will be from allowable cut returned to the Crown by all tenure holders with AACs greater than 200,000 m3, and the balance will be supplied from the volume that is currently sold by BC Timber Sales to registered small businesses. The practice of allocating AAC to small businesses will be discontinued. Under the new system, bidders will compete for timber sale licenses with terms of 4 years or less. Timber prices received at auction will be used to determine stumpage rates for that portion of the AAC that remains in long-term tenures. Prices for non-competitive timber will be adjusted downwards to reflect the costs of satisfying tenure holders' statutory obligations. The new stumpage system became operational on the Coast in the spring of 2004 but has yet to be implemented in the Interior.

Some other important policy changes introduced under the Revitalization Plan include: the abolition of minimum cut controls, the elimination of contractual requirements that wood harvested from Crown timber licenses be shipped to specific mills for processing (frequently referred to as "mill appurtenancy"); relaxation of the requirement that ministerial consent be obtained before Crown forest tenures can be transferred and elimination of the policy under which an acquired company may be required to surrender 5 percent of its authorized AAC.

Outstanding major issues

Forest policy in BC is in a state of flux. While recent policy changes have addressed some of the important problems, many major issues remain that are sources of enormous uncertainty within the forest sector. Two of these topics will be dealt with here – the aboriginal land question and the continuing conflict with the United States over trade in softwood lumber.

The Aboriginal land question

Section 35 of Canada's *Constitution Act* (1982) recognizes and affirms "existing Aboriginal and treaty rights". To be "existing" an Aboriginal right must not have been extinguished prior to the date the *Constitution Act* came into force.

Historically in BC few treaties were signed with First Nations and those that exist - Treaty 8 and the Douglas Treaties – cover only a small area of the province. In the late 1960s, the Nisga'a brought the question of Aboriginal title before the courts in *Calder vs. Attorney General of British Columbia*. This case eventually reached the Supreme Court of Canada. In 1973, in a majority decision (6:1), six Judges of the Supreme Court ruled that the Nisga'a had aboriginal title. Of these, three concluded that the Nisga'a still retain that title while three ruled that the title had been extinguished. The BC government continued to reject the validity of land claims maintaining that Aboriginal title and rights were extinguished in the Province at the time of colonization prior to BC's entry into the Canadian Confederation. In 1990, the BC government reversed its position and, following the report of a task force (British Columbia, 1991b) entered into the *Tripartite Treaty Commission Agreement* with the Federal government and First Nations that resulted in the creation of the *British Columbia Treaty Commission* (BCTC) in 1993.

The functions of the BCTC are to:

- coordinate the start of negotiations;
- assess the readiness of the parties to negotiate;
- monitor the progress of negotiations;
- allocate funds to enable First Nations to participate in negotiations; and
- prepare and maintain a public record of the status of negotiations.

The stages of the British Columbia treaty process include:

- Stage 1-Submitting a statement of intent to negotiate a treaty.
- Stage 2-Preparing for negotiations.
- Stage 3-Negotiating a framework agreement.
- Stage 4-Negotiating an agreement-in-principle.
- Stage 5-Negotiating a final agreement.
- State 6-Implementing the treaty.

Currently, there are 55 First Nations participating in the treaty process at 44 sets of negotiations accounting for about two-thirds of BC's aboriginal population. There are six First Nations still in stage 2, three in stage 3, forty-one in stage 4 – negotiating a treaty in principle – and five in stage 5 – negotiating final treaties having signed Agreements in Principle. To date, no negotiations have been concluded and treaties implemented.

Although the pace of negotiations has increased since 2002, the failure of the BCTC to implement a single treaty has created increasing uncertainty over the division of land title in BC that has had a major impact on resource based industries, particularly the forest industry. The future of long term tenure agreements and timber supplies has been brought into question with severe negative impacts on new industrial investments. Moreover, the situation has been exacerbated by a number of significant court decisions that have further strengthened the case for Aboriginal rights and title.

In 1984, the Gixsan and Wet'suwt'en Nations went before the Supreme Court of British Columbia claiming title and jurisdiction over 58,000 square miles of their traditional territories in northwestern BC (*Delgamuukw vs. British Columbia*). The court settled in favour of the defendant – the province of British Columbia – upholding the argument that all aboriginal land rights in BC were extinguished by laws of the colonial government before it became part of Canada in 1871. On appeal, the British Columbia Court of Appeal reversed the lower court's ruling. In December 1997, the Supreme Court of Canada brought down its landmark decision in the *Delgamuukw* case.

The Supreme Court did not make a decision on whether the Gitxsan and Wet'suwet'en had title to the lands they claimed but made a number of important statements about aboriginal rights and title and how the courts will approach such future cases. Most significantly, the Court confirmed that aboriginal title does exist in BC and that it is a constitutionally protected right in the land itself – not just the right to pursue traditional uses on the land. If First Nations decide to go to court to establish title to lands they have to prove that they occupied the land before 1846, the year Britain declared sovereignty over the area that became British Columbia. Then they have to prove some degree of continuity from that occupation until today. In establishing proof of title before the courts, First Nations'

oral histories, including traditional stories and songs, will be permitted. Both federal and provincial governments have the right to infringe on Aboriginal title but only in pursuance of a compelling and substantial purpose including economic development and environmental protection. However, a government's action must be consistent with the special fiduciary relationship that exists between the Crown and Aboriginal peoples. The province must consult with First Nations before granting any interest in aboriginal lands to others, but what form such consultation should take and whether First Nations' consent is required before proceeding is unclear. Where Aboriginal title has been proven to exist, cash compensation may be payable for previous infringement.

Following the Supreme Court of Canada's *Delgamuukw* decision, the province of British Columbia asserted that they only had an obligation to consult with First Nations on land use once aboriginal title had been determined. However, in 2002 two landmark rulings in the BC Court of Appeal held that the provincial government has a duty to consult with First Nations' on land use issues in any areas where title is in dispute and endeavour, in good faith, to seek workable accommodations between aboriginal interests on the one hand and the objectives of the Crown on the other.

The first case, *Taku River Tlingit First Nation v. Ringstad et al,* dealt with the issuance of a permit by the provincial government to reopen the Tulsequah Chief Mine in northwestern BC by building 160 km of access road across the Taku River Tlingit's traditional territory. In its majority decision the Court found that,

> *"The Tlingits have aboriginal rights within s. 35 of the Constitution Act, 1982, based on their aboriginal title to the site of Redfern's proposed mine and the portions of their territory that would be traversed and impacted by the road. The title of the Crown in right of British Columbia to the lands and resources in those areas, including mineral rights, is subject to the Tlingits' aboriginal title. The Certificate approves a Project that will unjustifiably infringe on the Tlingits' rights based on aboriginal title."*

and,

> *"when the ministers issued the Certificate they breached fiduciary obligations owed to the Tlingits by the Crown in right of British Columbia."*

In the second case, *Haida Nation vs. BC and Weyerhaeuser,* the Court ruled unanimously that that a "trust-like relationship" exists between First Nations and both the federal and provincial governments that is now is now usually expressed as a "fiduciary duty" owed by both the federal and provincial Crown to the aboriginal people. The court went on to discuss the Crown's obligations with respect to this "fiduciary duty".

> *"the fiduciary relationship between the Crown and aboriginal peoples may be satisfied by the involvement of aboriginal people in decisions taken with respect to their lands. There is always a duty of consultation. Whether the aboriginal group has been consulted is relevant to determining whether the infringement of aboriginal title is justified – The nature and scope of the duty of consultation will vary*

with the circumstances. In occasional cases, when the breach is less serious or relatively minor, it will be no more than a duty to discuss important decisions that will be taken with respect to lands held pursuant to aboriginal title. – In most cases it will be significantly deeper than mere consultation. Some cases may even require the full consent of an aboriginal nation –"

The Court ruled that the provincial government and Weyerhaeuser had not properly consulted the Council of the Haida Nations when renewing a tree farm license on Haida Gwai (Queen Charlotte Islands) and that a legally enforceable duty to consult will continue until the title and rights are determined by means of a treaty or through the courts.

These decisions served to significantly increase the uncertainty surrounding land and resource use in British Columbia and increased the pressure on the provincial government to accelerate the treaty process.

Important instruments used by the provincial government to balance and mitigate conflicting interests as the province moves towards treaty settlements are "interim measures agreements". Interim measures are designed to protect the interests of all parties prior to, and during the course of, negotiations and reduce the uncertainty caused by unresolved issues. They may affect the management and use of land and resources and frequently involve the creation of new interests. By providing access to and the development of resources they provide a means of dealing in a preliminary way with contentious issues, help build resource management capacity within First Nations, and provide smoother transition towards treaty implementation.

Interim agreements are particularly important with respect to forestlandand resources. Under the 2003 forestry revitalization plan the proportion of the allowable annual cut available to First Nations was increased to about eight percent, approximately equivalent to the proportion of First Nations' people in the rural population. In order to facilitate the allocation of this timber through negotiated interim-measures agreements, the provincial government has passed legislation enabling direct awards – tenure allocated without competition – to First Nations. Additionally, the government will share forest resources revenues with First Nations and, to this end, allocated $15 million in its 2003-2004 budget rising to $50 million by 2004-2005.

The softwood lumber issue

The ongoing softwood lumber trade dispute with the United States began in 1982 when the US Department of Commerce (DOC) investigated complaints from US forest companies about alleged subsidies arising from Canadian provincial stumpage systems. In 1986, faced with the imminent imposition of export duties, Canada agreed to place a 15% export tax on all softwood lumber exports to the US. The Canadian government terminated this agreement in 1991 giving rise to another round of countervailing duty investigations by the DOC. The new investigations also examined Canadian log export restrictions as an additional source of subsidy.

After a complex, protracted and inconclusive process, Canada agreed to enter into negotiations with the US that resulted in the 1996 Softwood Lumber Agreement establishing fixed quotas on Canadian softwood lumber entering the US. This

agreement expired on March 31, 2001.

In early April 2001, the US Coalition for Fair Lumber Imports filed a countervailing duty petition naming provincial stumpage systems and log export restrictions as sources of subsidy amounting to 39.9%. It also initiated dumping charges against Canadian softwood lumber producers. On August 10, 2001 the US DOC found that Canadian softwood lumber exports were subsidized and levied an import duty of 19.31% against shipments made on or after May 17, 2001. As in the case of previous countervailing tariffs, the Atlantic Provinces were exempted. On March 22, 2002 a further determination by the DOC found that Canadian companies were guilty of selling softwood lumber in the United States at below fair market value and levied additional anti-dumping import tariffs against individual companies averaging 9.67 percent and ranging from 2.26 percent to 15.83 percent. On April 25, 2002, the DOC revised its final determinations of countervailing and anti-dumping tariffs downwards to 18.79% and an average of 8.43%, respectively.

The import duties had a devastating impact on the BC forest industry, particularly on the Coast. Mills closed down, at least one major company, partly as a result of the tariffs, was placed on the verge of bankruptcy and thousands of workers were made redundant.

Each year, until the case is settled, an administrative review will be conducted to recalculate the duties on shipments during the previous year and to establish future duties. The first administrative review began on June 1, 2003 to review duties paid during the period April 1, 2002 to March 31, 2003. On June 3, 2004 the preliminary results of this review were released by the DOC which indicated a countervailable subsidy rate of 9.24%. – less than half the current rate of 18.79%. The final determination is expected in December 2004. Concurrently, a preliminary determination in the anti-dumping administrative review was released that found an anti-dumping margin averaging 3.98%, less than half the current rate being collected of 8.53%.

Canadian governments have sought a favourable settlement of the softwood lumber issue through both negotiation and legal channels. Negotiations between the US and Canadian governments started in the fall of 2001 to determine whether possible policy changes in Canada could lead to a mutually agreeable solution to the softwood lumber trade dispute. These talks ended in deadlock in March of the following year. On June 18, 2003 the DOC issued a draft Policy Bulletin that outlined the necessary changes in provincial forest policies that would result in the countervailing duty being revoked. In July, the Canadian government presented the DOC with a proposal which would reintroduce a quota system for Canadian lumber entering the US. The quota would replace existing tariffs while reforms in provincial forest policies were being implemented that would meet the requirements of the Policy Bulletin. On December 6, 2003 a tentative agreement on export quotas was reached by Canadian and US negotiators that was supported by the US Coalition for Fair Lumber Imports, however, the proposal was not enthusiastically received by some Canadian provinces and forest industry opinion was deeply divided. Negotiations continue as of November 2004 but no new proposals have been tabled for almost a year.

The federal government has initiated several challenges at the World Trade Organization relating to US – Canada softwood lumber trade issues with mixed

success. However, on March 22, 2004 the WTO ruled that the key factor on which the U.S. relied to make its determination of injury – an imminent and likely surge in imports of softwood lumber products from Canada – was not a result "that could have been reached by an objective and unbiased investigating authority." This decision was followed on April 13, 2004 by a further WTO ruling that found that elements of the US anti dumping determination regarding softwood lumber were inconsistent with the US's WTO obligations. This decision was appealed by the US but on August 11, 2004. The WTO Appellate Body rejected the appeal and upheld the panel's findings.

Legal avenues to overturn the US softwood lumber countervailing and anti-dumping tariffs have also been pursued through the North American Free Trade Agreement (NAFTA). In April 2002, the federal government requested NAFTA to conduct a review, under Chapter 19 of the Agreement, of the US subsidy and anti-dumping determinations. Following a number of decisions that resulted in the DOC being asked to recalculate and correct both its countervailing and anti-dumping duties, the NAFTA panel brought down its latest decision on August 31, 2004 in which they found that there was no evidence on record to support the DOC's assertion that a material threat to the US exists as a result of Canada's timber pricing policies.

Forestland Ownership and Tenure in BC

Forestland ownership

Ninety four percent of Canada's forests are publicly owned. The remaining 6% are in the hands of an estimated 425,000 private landowners. BC follows the national pattern of forestland ownership with 4 percent owned privately and 96 percent publicly of which approximately one percent comes under federal jurisdiction (Figure 1.)

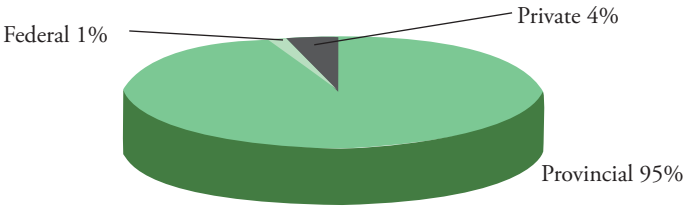

Figure 1: Forestland ownership in British Columbia.

When Great Britain assumed sovereignty of the land that is now known as British Columbia in the 1846, all land and resources, in accordance with contemporary colonial practice, was declared the property of the British Crown. In 1867, when the Canadian Confederation was founded, the *British North America Act* granted jurisdiction over most lands and resources, including forests, to provincial governments. Exceptions included those lands reserved by the Government of Canada for specific purposes – national defense for example – lands within Indian Reserves and lands beyond provincial boundaries. These arrangements were confirmed in the 1982 *Constitution Act.* Today, federal jurisdiction over forestry activities in the provinces is limited to reserved federal lands and Indian Reserves, external and inter-provincial trade and commerce, matters involving migratory

aquatic and terrestrial species that cross provincial boundaries, the authority to make and enforce international treaties and general powers to make laws for peace, order and good government of Canada

Following confederation, legislative initiatives were taken by the Canadian provinces, and by the federal government in the territories under its jurisdiction, to affirm the principle of public forestland ownership and, through the creation of forest reserves, protect Crown forestland from other uses. In BC an amendment to the *Land Act* in 1887 prohibited grants of land "chiefly valuable for timber". These provisions were strengthened by further amendments in 1896 that clearly defined "timberland" and restricted the sale of such land by the Crown. In 1947, restrictions on the alienation of timberland were extended to include all land best suited for forest production, whether timbered or not.

While public forestland ownership is firmly entrenched as a Canadian institution, recognition of Crown title is not widely understood or accepted by the Canadian public. Rather, Crown forestlands are regarded as the "people's lands" and open-access to resources other than timber and some minor products in certain areas, are regarded as customary rights that are staunchly defended. This situation severely constrains governments' policy alternatives and politicians across the country recognize that any suggestion that public forestlands be privatized, or that public access be significantly constrained, is bound to evoke immediate and widespread opposition.

Crown forest tenures

Although the majority of forestland in Canada is publicly owned, the capital equipment and plants for harvesting and processing timber are almost entirely in private ownership. As a result of this dichotomy, one of the leading policy questions facing governments throughout Canada, including BC since the earliest days of European settlement, has been the transfer of timber growing on publicly owned lands to the private sector.

Since British colonization, forest tenures have been created by transferring certain property rights to forest resources from the Crown to private sector individuals and groups for differing time periods and subject to various conditions and constraints. Different types of Crown forest tenure can be represented as falling along a spectrum (Figure 2).

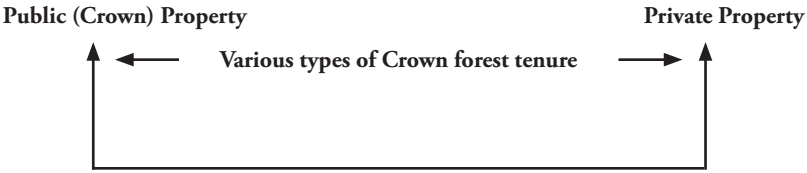

Figure 2: The forest tenure spectrum.

At the left hand extremity of the spectrum is public property that is characterized by complete Crown title to forestland and all the products it is capable of providing. At the right hand extremity of the spectrum is private property under which private individuals or groups hold unfettered title to forestland and all its products. The actual

rights transferred, the period over which they can be enjoyed, the limits imposed on these rights and the terms and conditions under which they can be exercised and maintained determine where a Crown forest tenure lies on the public-private spectrum. Some tenures have certain rights that approach complete private ownership; others are severely constrained and are situated towards the public end of the spectrum. Unfettered, complete private ownership of forestland is unknown in BC.

In granting private property rights, governments always retain title to wildlife, fish, water and subsurface minerals and the use of private forestland is regulated in a number of important ways. For example, owners of land Crown granted after March 12 1906 are subject to provincial log export regulations and all private holdings classified as managed forestland are subject to the forest practices regulations.

Forms of Crown forest tenure in BC

In addition to timber harvested on private lands, not included in tree farm licenses or woodlot licenses, commercial timber production in BC is carried out on five administrative units: timber supply areas; tree farm licenses; timber licenses; woodlot licenses and community forest agreements. The chief forester must determine an allowable annual cut (AAC) for each timber supply area and each tree farm license at least once every 5 years. The regional manager, or district manager, must determine an AAC for each woodlot license and the regional manager for each community forest agreement. Timber harvests on timber licenses are not regulated unless they are included within a tree farm license.

The Crown forest tenure system conveys rights to harvest designated types and volumes of forest products from Crown land. The *Forest Act* provides for 12 different tenure arrangements under which such harvesting rights can be granted. These include:

- forest licenses (FLs);
- timber sale licenses (TSLs);
- timber licenses (TLs);
- tree farm licenses (TFLs);
- pulpwood agreements (PAs);
- community forest agreements (CFAs);
- woodlot licenses (WLs);
- miscellaneous tenures: community salvage licenses; free use permits; licenses to cut; road permits; and Christmas tree permits.

Forest licenses and timber sale licenses can each be divided into two sub-categories. Timber sale licenses include a “major” replaceable, volume-based variant and an area-based, non-replaceable, variant. Forest licenses are generally replaceable but a small number are non-replaceable.

Table 1. shows the number of crown forest tenures in each major category, the allocation of the province’s allowable annual cut by tenure type and the volume harvested by land status – Crown tenure type, private land, and federal and First Nations' reserves. All the data is for 2002/2003.

In 2002/2003, the two major industrial tenures, tree farm licenses and forest licenses, accounted for 79 percent of BC’s allocated AAC – tree farm licenses 22 percent and forest licenses 58 percent. An additional 15 percent was allocated to small (average AAC of 6071m^3) short-term timber sale licenses administered by the Ministry of Forests under the Small Business Forest Enterprise Program (SBFEP).

Woodlot licenses, the only form of tenure designed to encourage small scale, sustainable forest management by individual citizens and small firms, accounted for about 1.8 percent of the AAC and community forest agreements less than 0.5 percent.

In 2002/2003, 89 percent of the provincial timber harvest originated from provincial Crown land, 11 percent from private land and a negligible volume from federal Crown land and First Nations' reserves. Tree farm licenses and forest licenses accounted for 15 percent and 48 percent of the provincial Crown harvest, respectively.

Table 1:
Number of licenses by type, allocation of AAC by license type, volume harvested by license type and land status – 2002/2003[a].

License Type and Land Status	Number of Licenses	Allocation of AAC by Type of License '000m^3	Volume Harvested by Type of License'000m^3
Crown land			
Tree farm license	34	15,538	12,212
Forest license (including replaceable and non-replaceable)	254	41,807	38,483
Woodlot license	816	1,305	2,481
Community forest agreement (pilots)	7	343	Included in "Other"
Timber license (within TFL)	Unavailable	Not applicable	2,308
Timber license (outside TFL)	Unavailable	Not applicable	583
Timber sale license (SBFEP[b])	1,752	10,636	11,432
Timber sale license (non-SBFEP)	6	1,681	Included in "Other"
License to cut	2,088	Included in Forest Service Reserve	Included in "Other"
Other [c]			3,509
Forest Service reserve		945	
Private Land			
Within a TFL			771
Outside of a TFL			7,782
Federal land and First Nations reserves			111
Total AAC 1998/99		72,255	
Total Volume Harvested 1998/99			79,672

[a] Source: Ministry of Forests Annual Report, Supplementary Financial and Statistical Information 2002/2003.

[b] Small Business Forest Enterprise Program (now BC Timber Sales)

[c] Includes licenses to cut, non-SBFEP timber sale licenses, community forest agreements and miscellaneous.

Characteristics of Crown forest tenures in BC

BC's Crown forest tenures, while they differ in terms of their original purposes and evolution, have much in common. In this section, the principal tenure types will be compared in terms of:

- the rights granted to tenure holders (sometimes referred to as "comprehensiveness");
- allotment type (i.e. area or volume-based) and size restrictions;
- transferability;
- duration and renewability;
- mutability (i.e. the extent to which the government can modify the terms of a contract prior to its expiration);
- operational requirements;
- planning, monitoring and enforcement procedures;
- fiscal obligations.

Rights granted to tenure holders

Apart from community forest agreements, the only right provided by the various forms of forest tenure in BC is a right to harvest Crown timber. Area-based licenses provide an exclusive right to Crown timber within the designated area under license. In the case of volume-based tenures – forest licenses and renewable timber sale licenses – rights are to an AAC within the boundaries of a specified timber supply area. In the case of community forest agreements, in addition to the exclusive right to Crown timber within the area covered by the agreement, the *Forest Act* provides rights to "harvest, manage and charge fees for botanical forest products and other prescribed products", leaving the door open to extend rights to any other forest products including various forms of outdoor recreation, water and even wildlife.

Allotment types and size restrictions

Compared to other provinces in Canada, a distinguishing feature of the Crown forest tenure system in BC is the importance of volume-based licenses. In 2002/2003, more than 60 percent of the provincial AAC was allocated through volume-based tenures.

Apart from woodlot licenses, neither area nor volume-based tenures are limited in size and many of the major industrial tenures tend to be very large indeed. The average size of tree farm licenses, in terms of allocated AAC, is 457,000 m^3, while the average AAC for forest licenses is about 165,000 m^3. In contrast, the average AAC for woodlot licenses is 1600 m3. Timber sale licenses that are sold competitively have an average AAC of about 6000 m3.

Transferability

All Crown forest tenures in BC with the exception of community forest agreements and some miscellaneous tenures, can be transferred to a third party once a ministerial notice to proceed has been obtained. Reasons for the minister to block a transfer are limited to concerns related to competition for timber, logs or chips.

Duration and renewability

With the exception of community forest agreements that, following a 5 or 10 year probationary period, can be granted for a term up to 99 years, no Crown forest tenure in BC has a term exceeding 25 years and most are less. Tree farm licenses and pulpwood agreements are granted for 25 year terms, most replaceable forest licenses for 20 years, woodlot licenses for 20 years, competitive timber sale licenses for 1 to 4 years. Timber licenses revert to the Crown when the old growth timber on them has been harvested.

No tenure in BC is renewable when its term expires. Rather, most are replaceable, after a designated number of years have elapsed, by a new license that has the same term as the one it replaces. Tree farm licenses and forest licenses are replaceable after the existing license has been in place for 5 to 10 years. For pulpwood agreements, woodlot licenses and community forest agreements, 10 years of the license period must elapse before the contract is replaceable. If a licensee chooses not to replace his or her license in the designated year, the license simply runs its term and then expires. For example, if a tree farm license is not replaced after 10 years, there is no other opportunity for replacement during the 15-year period before expiration. These arrangements provide the government with an opportunity to change the terms of tenure contracts, within statutory limits, every 5 to 10 years in order to reflect changing public priorities. On the other hand, if the new terms are unacceptable to a licensee, the license may continue under its original conditions until its term expires.

Mutability

In addition to introducing new terms and conditions to Crown forest tenure contracts at the time of replacement, the *Forest Act* provides a number of opportunities for the minister, or chief forester, to modify the AAC and/or licensed area of a tenure during its term. In other words, once signed, the contracts under which forest tenures are held are not immutable. For example, tree farm licenses and woodlot licenses can have their areas reduced by up to 5 percent without compensation at any time provided the land is required for non-timber uses. In the case of volume based tenures – forest licenses and replaceable timber sale licenses – the same general provision applies, however, in these cases the 5 percent reduction is in terms of the licenses' authorized AAC. Volume-based tenures may also have their authorized AAC reduced if, at any time, a new determination by the chief forester reduces the AAC of the timber supply area in which the tenures are located. This reduction in the AAC must be prorated amongst the tenures holders in the timber supply area concerned.

Operational requirements

Under the terms of their contract, licensees must meet a broad range of operating requirements. Holders of long term, area-based licenses are assigned more management responsibilities than those holding volume-based licenses. For example, tree farm licensees are responsible for total resource inventories, forest protection, timber supply analyses, integrated resources management and road construction and deactivation. Cut controls are enforced for most tenures. The only unregulated

timber harvesting taking place in BC is on private land and timber licenses not included in tree farm licenses. All licensees are required to reforest all land harvested to designated standards and meet the requirements of the provincial *Forest and Range Practices Act.*

Planning, monitoring and enforcement procedures

Planning monitoring and enforcement procedures are very similar for all tenures. For long term, area-based tenures – tree farm licenses, woodlot licenses and community forest agreements – a general management plan is required. For tree farm licenses this must be for at least 20 years and is updated and approved every 5 years. For all tenures, before harvesting can proceed on a specific block of timber, licensees must obtain a cutting permit. Cutting permits, that cannot be for a period exceeding 4 years, are only issued after certain planning requirements provided for in the *Forest Act* and the *Forest and Range Practices Act* have been fulfilled.

While day to day administration and performance monitoring is carried out by government staff, an independent body – the *Forest Practices Board* – is responsible for auditing forest practices of government and licensees and investigating complaints lodged by the public.

The *Forest and Range Practices Act* contains a comprehensive enforcement regime. Significant features of this regime include search and seizure powers; administrative orders such as stop-work orders and remediation orders; and fines that can be levied by officials or, for more serious offenses, by the courts. Maximum penalties include fines up to $1,000,000 or imprisonment for up to 3 years, or both. In order to facilitate appeals against administrative decisions, the *Forest Practices Code of British Columbia Act* makes provision for a standing *Forest Appeals Commission*. Decisions of this Commission may be appealed to the Supreme Court of British Columbia on questions of law and jurisdiction.

Fiscal obligations

All Crown forest tenure holders must pay stumpage, generally based on log scale, on all timber harvested. In most cases, an annual rent is also levied on a per hectare basis in the case of area-based tenures and on the basis of allocated AAC for volume-based tenures. For all tenures in the Interior, other than timber sale licenses administered by BC Timber Sales, stumpage payments are calculated using the Comparative Value Timber Pricing System. On the coast, prices determined through competitive auctions, administered by BC Timber Sales, are used to determine stumpage rates for timber harvested from other forms of Crown tenure.

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FOREST–LEVEL PLANNING

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FOREST–LEVEL PLANNING

Introduction

Forest-level planning shares two fundamental objectives with general asset planning. First, we want to forecast the production of goods and services from the forest estate (generation of income) and second, we want to assess the risk to the forest estate associated with these forecasts (protection of the asset). Forest estates are often more complicated than most assets because they carry a variety of economic, environmental and social objectives. These are typically large, complicated problems that require decision support tools to assist people in making decisions about the long-term consequences of forest management. The most common application of forest-level models is to provide technical support for setting the annual allowable cut on forest estates. Models are also used for policy analysis (e.g. design an effective and efficient policy), investment decisions (e.g. build a log processing facility), efficient allocation of inputs to outputs (e.g. silviculture budget towards high-value products), environmental assessments (e.g. habitat supply), identifying strategies to convert a forest to a target state (e.g. a target landscape pattern) and a host of communication demands (e.g. publics, customers, government and non-government agencies). Models allow us to explore multiple outcomes according to our assumptions, and to test how sensitive the outcomes are to these assumptions. Typical questions to be answered by a strategic forest model include:

- What harvest levels are possible?
- When do "bottlenecks" occur, what causes them, and what remedies are available?
- What are trends in projected growing stock?
- What is the timing and location of harvests by forest type?
- What is the timing and extent of silviculture treatments?
- What are trends in delivered wood costs, profitability and economic rent?
- What is the projected forest structure, and what is the risk of natural disturbance associated with it?
- Will the projected forest structure provide sufficient habitat for targeted species?
- What is the social-political risk associated with management scenarios?
- What are the most sensitive assumptions?

The length of the harvest plan, referred to as the planning horizon, is important. Typical planning horizons are 1-5 years for short-term, operational plans, 10-30 years for medium-term, tactical plans and over 200 years for long-term, strategic plans. These three levels form the planning hierarchy. At each level, specific questions need to be answered, so models and data requirements often change as we move through the hierarchy. Strategic plans answer the "what if" questions, tactical plans answer the "how" questions and operational plans answer the "when and

where" questions. Data and models become progressively more detailed as we move from the strategic level to the operational level. At the same time, uncertainties surrounding the forecast become progressively smaller as we move towards the operational level (Gunn, 1991).

Forest-level models have an enormous appetite for data, and data preparation often accounts for over 85% of the effort needed to prepare a plan. For example, it is necessary to explicitly define the timber harvesting landbase, timing and extent of stand treatments, volume and economic yields, costs, environmentally/socially sensitive areas and how they are to be treated, plus harvest flow policies. Because most of these factors are uncertain, especially over the longer planning horizons, sensitivity analyses needed to quantify the effects on outputs create additional data demands. Outputs from these models can also be voluminous and challenging to both the analyst and the audience. Outputs include a host of indicators related to timber production (harvest levels, growing stock, areas by treatment), environmental concerns (location and timing of habitat types, hydrology impacts) and social concerns (recreation and visual impacts).

A skilled analyst is essential for producing high quality forest plans. The analyst must specify data requirements, ensure quality control of data, be able to formulate models to simulate natural systems and management options, fully understand model behavior and results, plus clearly communicate this information to clients. In addition, the analyst has a duty to fully disclose the assumptions, limitations and uncertainties associated with the model and its results. Sometimes people refer to a model as a "black box" when they are struggling to understand it. A more appropriate definition of a "black box" is an analyst that cannot explain what his/her model does.

Forest planning models involve large geographic areas, long time horizons, uncertainties and conflicting objectives. They help us scope out possible futures and identify strategies for reaching the target forest. But we also need a strong dose of reality when evaluating these long-term projections. Natural systems are not fully understood and display high levels of variation. Markets fluctuate, harvest and milling technologies change and the social-political environment is in constant flux. The forest plan is not intended to be a forest management blueprint for the next 200 years. Rather, planning is a continuous process where the short-term is implemented, outcomes are monitored, forest conditions are updated, assumptions are revised and the process is repeated.

In the first section of this chapter, we present the classical methods for converting and regulating forests. This includes area and volume control, including the Austrian formula and Hanzlik's formula. In the second section, mathematical models based on simulation, optimization and heuristics are introduced along with their respective strengths and weaknesses. We describe how these algorithms work along with references to detailed mathematical formulations for those readers that seek more information. In the third section, inputs and determinants of timber supply are described. Topics include defining the timber harvesting landbase, productivity, utilization, treatments, protection, harvest priorities and harvest constraints. In the fourth section, we present strategies for filling shortfalls in the harvest schedule. Options such as shorter rotations, intermediate harvests, and modifications to harvest targets are explained. Section

five introduces methods for assessing non-timber outputs that are linked to the harvest schedule. We use habitat and landscape pattern as examples of non-timber outputs. The final section is devoted to professionalism and ethics expected of analysts and planners.

Classical Methods for Converting and Regulating Forests

The classical approaches are aimed at converting an existing forest to a regulated forest, and/or maintaining the forest in a regulated state. The forest can be regulated by either area control or by volume control. Area control is achieved when the age classes are of equal area, resulting in a constant area harvested every year. Volume control is achieved when a constant volume can be harvested every year. Methods such as the Austrian formula and Hanzlik's formula are used to convert unregulated forests to a regulated state by adjusting the harvest according to various levels of growing stock present during the conversion period (usually one rotation).

Area control

Area control is used to convert a forest with unequal age classes into a forest with uniform age classes over the period of 1 rotation. The annual harvest, expressed in area will be:

Annual harvest (ha/year) = total area of forest (ha) ÷ rotation age (years).

The number of age classes in the regulated forest will equal the rotation age or the number of harvest entries during the rotation age. For example, if we assume that the forest has one productivity type with a rotation age of 50 years, and that the forest is 800 ha, then we would harvest 800 ha ÷ 50 years = 16 ha/year. After 50 years, we would have a uniform age class distribution with 50 age classes ranging from 1 to 50 years of age. If we were to harvest once every decade, for 5 decades, then we would harvest 800 ha ÷ (5 decades) = 160 ha/decade. The advantage of area control is that it will convert the forest to a fully regulated state within 1 rotation. The two main disadvantages are: 1) harvest volumes will fluctuate during the conversion period, and 2) the method only considers the narrowly defined, single objective of regulation through area control. When different productivity sites and/or rotations ages are present within the forest, area control is generally applied to each productivity/rotation type. For more information on area control, including worked examples for even and uneven-aged management, we recommend Davis *et al.* (2001).

Volume control

With volume control, the decision is what quantity of volume to harvest each year. This decision depends on the growing stock and the increment of the forest, plus the owner's objectives. Several classical approaches to volume control are the Austrian formula and Hanzlik's formula. These methods are typically used to convert the forest to some desired state within a set conversion period, usually one rotation.

Austrian formula

The Austrian formula uses the increment of the forest in combination with present and future growing stocks to determine the annual harvest.

$$\text{Annual harvest } (m^3/\text{year}) = I + [(GS_0 - GS_f) \div c]$$

Where:
I = annual increment of the forest (m^3/year)
GS_0 = growing stock at time 0 (m^3)
GS_f = desired growing stock in the future (m^3)
c = conversion period (years)

If we have an 800 ha forest with an average increment of 10 m^3/ha/year, then I = 8,000 m^3/year. If the current growing stock (GS_0) is 240,000 m^3, the desired future growing stock (GS_f) is 200,000 m^3, and the conversion period is 20 years, then the annual harvest is:

$$\begin{aligned}\text{Annual harvest} &= 8{,}000 + [(240{,}000 - 200{,}000) \div 20] \\ &= 10{,}000\ m^3/\text{year}\end{aligned}$$

In this example, we increased the harvest above the increment in order to reduce the growing stock during the conversion period. If the current and desired future growing stocks are reversed, then we will decrease the harvest below the increment in order increase the growing stock over the conversion period:

$$\begin{aligned}\text{Annual harvest} &= 8{,}000 + [(200{,}000 - 240{,}000) \div 20] \\ &= 6{,}000\ m^3/\text{year}\end{aligned}$$

This approach of setting the harvest according to a growing stock adjustment over a conversion period has been widely used, especially in uneven-aged forests.

Hanzlik's formula

Hanzlik's formula was developed to guide the conversion of old growth surplus forests to regulated forests. It was generally believed that old growth stands had zero net volume increment, and to maximize timber production, these stands should be converted to vigorous new forests. The method was widely used in the US Pacific Northwest and in British Columbia (BC) prior to the development of computer-based harvest scheduling models. The formula is based on the volume of mature timber, the planned rotation age and the increment of the forest.

$$\text{Annual harvest } (m^3/\text{year}) = (V_m \div R) + I$$

Where:
V_m = volume of mature timber (m^3)
R = planned rotation age of future stands (years)
I = increment of the forest (m^3/year)

To demonstrate Hanzlik's formula, assume that our 800ha forest has the same increment (800 ha × 10 m^3/ha/year = 8,000 m^3/year), the planned rotation age for future stands is 60 years, and that it has 540,000 m^3 of old growth (mature) timber:

$$\begin{aligned}\text{Annual harvest } (m^3/\text{year}) &= (540{,}000 \div 60) + 8{,}000 \\ &= 17{,}000\ m^3/\text{year}\end{aligned}$$

Hanzlik's formula converts the old growth in one rotation to stands that will subsequently be managed on the planned rotation. The harvest during the conversion period is comprised of the mature timber and the increment. Determining the mature volume and planned rotation age are relatively easy, but estimating the potential increment in old, natural stands is more difficult. Harvest projections based on methods like Hanzlik's formula need to be regularly updated to reflect the current inventory of mature timber and the most recent estimates of increment.

Forest planning started with the classical methods, but has long since evolved to more advanced techniques capable of incorporating multiple forest objectives. Other than providing a quick check for certain timber indicators, they are rarely used. For further reading and to review examples of these classical approaches to forest regulation, we recommend Davis *et al.* (2001).

Computer–based Mathematical Models for Harvest Scheduling

Classical approaches like the Austrian formula and Hanzlik's formula provide little insight to whether harvests are sustainable beyond one rotation, they require many calculations for a range of growing sites and rotations over time, and they are largely limited to one objective. Computer-based models began to replace the classical methods of regulation during the 1960s and 1970s. These models were capable of quickly handling the large number of calculations necessary for multiple rotation problems on large forest estates. Early models tended to focus on single objectives such as maximizing harvest volumes or maximizing the net present value of harvests subject to constraints that regulated harvest flows (e.g. even-flow), ending inventories, age-class structure, and budgets. The concept of maximizing a single objective function subject to a set of constraints (e.g. linear programming) has its roots in operations research and management science. The debate about whether a particular forest resource should be treated as an objective or as a constraint within a forest level model is often heated, and it has led to a host of choices in the types of formulations and algorithms used. The following section describes common types of forest level models. It includes an overview of the algorithms and their respective strengths and weaknesses.

Simulation models

These models simulate the growth and harvest of forests according to an objective and a set of constraints. Simulation algorithms maximize either the harvest volume or the net present value of the harvest. One of the most important features of the simulation algorithm is its harvest priority – the order in which stands will be harvested. The basic steps in a harvest simulation algorithm are:

1. Read in initial inventory yield tables, simulation objective (e.g. maximize harvest volume), periodic harvest targets, harvest priority (e.g. oldest-first) and constraints.
2. Age the forest one time period (typically one decade). If the planning horizon has not been reached, go to step 3, otherwise stop.

3. Rank stands that are above the minimum harvest age according to the harvest priority.
4. While the periodic harvest target has not been satisfied and no constraints are violated, harvest the highest ranking stand within the harvest priority queue. If no stands remain in the harvest priority queue, go to step 2, otherwise go to step 5.
5. Update periodic harvest volume, constraint status and the harvest priority queue resulting from the harvest of this stand.
6. If the periodic harvest target is not satisfied, return to step 4, otherwise return to step 2.

The harvest is usually simulated to take place at the mid-point of the planning period so that it captures the average age of stands during the planning period. There are many harvest priorities possible, but the most common are oldest-first, highest difference between age and minimum harvest age first and closest distance to the mill first. Harvest flows are determined through iteration by adjusting the harvest targets and re-running the model until the desired flows are reached. Simulation models require considerable interaction with the operator who must adjust harvest targets, harvest priorities and constraints until an acceptable solution is found. Sensitivity analysis requires further operator intervention to vary inputs and quantify the effects on model outputs. Typical constraints control the maximum area in an early seral stage and the minimum areas in mature and old seral stages. Constraints can also be added to control harvest opening size and thus influence projected landscape patterns.

The main advantages of simulation models are: 1) they are easy to understand and use, 2) the sequential time-step approach allows them to divide very large problems into a series of smaller problems, 3) they can track many stand attributes, and 4) they have fast run times. Simulation models are excellent tools for quickly exploring the interactions between harvest interventions and forest dynamics. The main disadvantages are: 1) they require regular interaction with the operator, and 2) they don't produce optimal solutions. Application of simulation models in forest planning can be found in Nelson and Finn (1991), O'Hara *et al.* (1989) and Wallin *et al.* (1994).

Modifications can be made to simulation models to reduce the amount of intervention required by the operator, especially when determining harvest flows. A binary search algorithm can be used to automate the adjustment of harvest targets necessary to produce an even-flow harvest schedule. The binary search routine begins with an initial guess of the harvest level. The model is then run, and if the initial guess proves to be too high (i.e. a shortage occurs in some future period), the guess is revised downward. If the guess is too low (i.e. no shortages occur), the guess is revised upwards. Subsequent harvest targets will be half way between the two previous trials. This process is continued until the maximum, even-flow harvest is reached. When the harvest level is allowed to change over time (decline to long-term yield, or sequentially move up and down), look-ahead routines can be used to find acceptable harvest levels. Look-ahead routines make a trial harvest for 2-3 periods, and if the trial harvest works, the first period is implemented. If not, the trial harvest is revised until it does work. This routine is repeated in each time period. The length of the look-ahead trial harvest will vary depending on the complexity of the problem.

So far, we have been describing deterministic simulation models. By deterministic, we mean that: 1) it is assumed that all inputs are known with certainty, and 2) the sequence of events (harvest, growth, etc.) is fully determined once the harvest targets, priorities and constraints are defined. Simulation models can also be stochastic, where some inputs are defined by probability distributions and simulation events occur by sampling from those probability distributions. These models are then run several hundred or several thousand times until the outputs can also be described by probability distributions. Stochastic models are frequently used to understand how natural disturbances can effect the harvest schedule.

Optimization models

Linear programs

Linear programming (LP) models dominated harvest scheduling during the 1970s and 1980s. LP was quickly identified as a powerful operations research method that was suitable for applications in harvest scheduling. Navon (1971) used LP to develop Timber RAM, which was followed by the Multiple Use Sustained Yield Calculator (MUSYC) and finally the FORPLAN model (Stuart and Johnson, 1985). LP largely fell out of favour in the late 1980s when spatial harvest scheduling became popular, however, it continues to be an exceptionally good tool for problems with clear economic objectives, such as plantation forestry. Like simulation, LP has an objective function that is to be maximized (or minimized) subject to a set of constraints. Typical objective functions are to maximize net present value or to maximize total volume harvested. Unlike simulation, LP considers all stand treatments, in all time periods, simultaneously. The LP begins with an initial feasible solution, and at each iteration, the objective function is improved, while always maintaining feasibility. Provided that all necessary LP assumptions are met, and the problem is correctly formulated, the LP algorithm guarantees an optimal solution to the problem. For reference on LP assumptions, formulations and how the LP algorithm works, the reader is referred to Hillier and Lieberman (2001) and Davis *et al*. (2001).

There are two classical LP formulations for harvest scheduling problems. These are referred to as Model I and Model II (Johnson and Scheurmann, 1977). The Model I formulation creates decision variables that represent the entire sequence of treatments for a forest type. These treatments include the timing and intensity of reforestation, stand tending plus intermediate and final harvests. Each treatment schedule has a cost or return that is included in the objective function. The LP then chooses from these treatments such that the objective function is maximized (or minimized) and the constraints are satisfied. The resulting harvest schedule then identifies the amount, timing and intensity of stand treatments across the forest and through time.

The Model II formulation creates decision variables that represent the "birth and death" (regeneration and final harvest) of stands. When a stand is harvested it moves to a new, regenerated stand, and this may take place several times during the planning horizon. The main advantage of Model I is that it can track everything that happened on each forest type. The disadvantage of Model I is that a decision variable needs to be created for every timing choice (e.g. intermediate and final

harvest), so the resulting LP can become very large. Model II is unable to track every treatment on every ha, but it is very effective and efficient at moving stands to new regenerated stands under a variety of timing choices, including probabilities of how the existing stand is distributed into new regenerated stands.

Determining the harvest flow with a LP is easier than with a simulation model. The flow policy can be defined by constraints (e.g. even-flow, non-declining even-flow, sequential increases/decreases plus absolute upper and lower bounds). When the LP has found the optimal solution, the flow constraints will be satisfied. Running the LP requires little or no intervention from the operator; however, formulating the LP is a difficult task requiring considerable expertise. A typical LP problem will have several hundred thousand decision variables and ten thousand or more constraints. Errors in formulation that cause infeasibility often account for considerable debugging time. Matrix generators are used to create the mathematical equations needed by the LP solver. A report writer is also used to translate the cryptic LP solver output into tables and graphs that can be more easily understood. There are a series of post-optimality routines that are used for sensitivity analysis and problem insight. LP also produces shadow prices that provide important information on binding constraints and the value additional resources.

When the LP is correctly formulated, solution times are fast and the model can be quickly re-run to test the sensitivity of assumptions on the harvest schedule. The limitation of LP is that it cannot be used where binary decision variables are required, such as when modeling adjacency/green-up and/or road networks that are common in spatially constrained operational and tactical planning problems.

Goal programming

Goal programming is a form of linear programming where targets (goals) are set for objectives, and the program minimizes deviations from these targets. It is a way to include multiple objectives within a linear program. Goal programs have received limited attention in harvest scheduling, primarily because of the subjectivity in setting goal weights and because LP combined with sensitivity analysis offers a good alternative for assessing different levels of output for various "goals" (i.e. constraints).

Mixed integer programs

Mixed integer programs (MIP) are linear programs with additional constraints that force certain variables to be binary (i.e. take on a value of 0 or 1). Examples of binary variables are decisions to harvest a stand in its entirety (1) or not at all (0), or to construct a road (1) or not construct the road (0). Figure 1 is an example of a simple tactical planning problem that requires binary variables to model adjacency/green-up constraints and to construct a road network over several time periods.

Adjacency/green-up constraints prevent any 2 adjacent harvest units from being harvested in the same time period. These binary or integer variables are combined with continuous variables that tally harvest areas, volumes and other outputs such as net revenue – hence the name mixed integer programs. The addition of integer constraints greatly increases the difficulty in solving the problem, and the optimal solution is found by re-solving the LP hundreds and perhaps even thousands of times through a method called branch and bound. As the number of integer

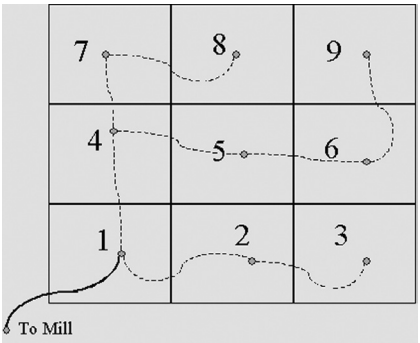

Figure 1:
Example of a simple tactical problem with adjacency/green-up constraints and a road network.

variables increases, the branching and bounding becomes computationally intensive. For this reason, MIPs are impractical for large areas and long time horizons. However, given sufficient time and computing resources, a correctly formulated MIP can be solved to optimality. These optimal solutions provide important benchmarks for testing other heuristics that are much faster at generating good solutions to mixed integer problems. For examples of integer programming applied to harvest scheduling problems the reader is referred to Nelson and Brodie (1990) and McDill and Braze (2000).

Heuristic models

The limitations of LP and MIP to incorporate spatial constraints on large forest estates, and over long time horizons, led to the development of heuristic algorithms for harvest scheduling during the 1990s. A heuristic is a problem solving method that utilizes self-educating techniques to continuously improve the solution. They do not optimize, but rather find better and better feasible solutions as they are executed. The most common are simulated annealing, tabu search and genetic

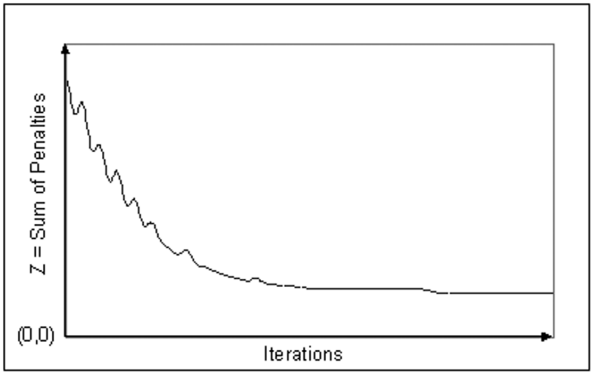

Figure 2:
Algorithms, like simulated annealing, attempt to minimize penalties that measure deviations from objective targets. According to a probability function, inferior moves are accepted to avoid convergence on local optima, although this declines as the number of iterations (random moves) increases.

algorithms. These algorithms, sometimes referred to as "soft heuristics" or "meta heuristics" all depend on random moves during their search for the best solutions. A typical "move" is to randomly switch the period in which a stand is harvested (or not harvested). If the move leads to an improvement, the new solution is accepted. Occasionally an inferior move is accepted as a means of diversifying the search to avoid convergence on local optima. The acceptance of an inferior move is controlled by a probability function that becomes progressively more restrictive as the total number of moves increases (Figure 2). These heuristics are exceptionally powerful algorithms for large, ill-structured problems where no direct search technique is available. Another important feature of these algorithms is that they readily accept multiple objectives. Similar to goal programming, targets are first set for each objective. Penalties are then applied to deviations from the targets, and the heuristic seeks to minimize these penalties by randomly altering the solution. Heuristics do not guarantee an optimal solution, but they are capable of generating very good solutions, and they are regularly used for solving very large problems with conflicting objectives.

Simulated annealing

Simulated annealing comes from studying the cooling of molten metal, where the cooling schedule is critical in determining crystal structures and hence the ultimate properties of the metal. The analogy in forest planning is that an initial solution has high penalties (high temperature) that need to be reduced through a cooling schedule (random moves and probabilistic acceptance of inferior moves) to a final solution that has very low penalties (low temperature) (Figure 2). Simulated annealing was first applied to harvest scheduling by Lockwood and Moore (1993) when they used the technique to test opening size on a large forest estate. It quickly gained acceptance with both academics and practitioners. While simulated annealing is a powerful algorithm, it is highly sensitive to parameters used to control the cooling schedule, the penalty functions and the weights applied to penalties for each objective. These models require that the cooling parameters be tuned for each problem, and that sensitivity analysis be conducted for penalty functions and objective weights. Van Deusen (1999) provides a good summary of these procedures.

Tabu search

Tabu search shares the method of random moves used by simulated annealing. However, it uses different diversification strategies, based on short- and long-term memory lists of where it has already searched. Like simulated annealing, it occasionally makes inferior moves (so called "tabu" moves) to avoid convergence on local optima. Tabu search also uses penalty functions to penalize deviations from objective targets. The algorithm attempts to minimize these penalties as the search progresses. Parameters of the tabu search algorithm also need to be tuned for the problem at hand, and sensitivity analysis of penalties and objective weights is necessary to fully evaluate its performance over a range of assumptions. A good example of this is found in Richards and Gunn (2000) where they used tabu search to develop a trade-off frontier for the cost of road construction and the opportunity cost of not harvesting stands at their optimal age. An early application of tabu search for solving adjacency problems is found in Brumelle *et al.* (1998).

Genetic algorithms

While simulated annealing and tabu search work on improving a single solution, the genetic algorithm works with a population of solutions. The algorithm selects higher valued solution from this population and then "breeds" them through random crossover of "genetic" material (segments of each solution are exchanged in the offspring). High valued solutions survive in the population and low valued solutions perish. Random mutations occur which alter the genetic makeup of some solutions. The process mimics natural selection by applying environmental pressure through a selection criterion that favours the best solutions. Because the genetic algorithm has many parameters, considerable experimentation is needed to tune these for optimal performance on each problem. Generally, simulated annealing and tabu search that work on a single solution are simpler and outperform genetic algorithms that work with a population of solutions. However, some success has been achieved by combining genetic algorithms with simulated annealing and tabu search (Bettinger *et al.* 2002).

Summary of heuristics

Heuristics can produce very high valued solutions, often within 1-3% of the best known solution, and close to the theoretic bounds identified with LP (Boston and Bettinger, 1999). They make significant improvements over an initial solution in the early stages of the search, with lesser gains found near the end of the search. A typical run would include several hundred thousand to several million random moves (iterations), depending on the difficulty of the problem and the conditions for terminating the search. These algorithms are attractive because they can include multiple objectives, and unlike simulation models, require little or no intervention from the operator to achieve the objectives. This is an important advantage for complex goals, such meeting patch size targets across the landscape. However, the high valued solutions that result are specific to a set of assumptions about model parameters, penalty functions and the weights assigned to each objective. In forest planning, we know that our assumptions are uncertain, so it is paramount that these models be tested under a range of assumptions that address this uncertainty. Finding the very best solution is often less important than finding a set of good feasible solutions that define a realistic outcome space.

Inputs and Determinants of Timber Supply

In its full context, forest-level planning begins with a review of the broad objectives for the estate, and then progresses into more detail about inventories, management objectives, constraints and assumptions. As we progress into the specifics, there is a common set of inputs necessary to determine timber supply, regardless of the forest, the objectives, or the model that will be used. Williams (1993) and Tanz (1993) identify 7 key inputs and determinants of timber supply: 1) conduct resource inventories, 2) define the timber harvesting landbase, 3) define productivity of the land-base, 4) define timber products, 5) define treatments and treatment schedules for stands, 6) define the level of protection and allowances for natural disturbances, and 7) define environmental and social objectives/rules affecting the harvest. These inputs and determinants of timber supply are explained in this section.

Resource inventories

Resource inventories of the forest estate must be conducted to determine the extent and location of both timber and non-timber resources. Typical inventories are terrain and soils, wildlife, fisheries, domestic and community watersheds, recreation, visual and ecosystems. Inventories classify the landbase into polygons that are necessary for subsequent planning. The final product will be a spatial database that links the polygons to their respective inventory attributes.

Define the timber harvesting landbase

The timber harvesting landbase identifies those areas within the forest estate where harvesting is both feasible and acceptable. It will exclude non-forested areas, low-productivity areas, non-commercial forests, other ownerships, reserves, environmentally sensitive areas and inoperable areas. Operability is based on the economic margin and therefore includes assumptions of harvest and milling technology, costs and prices. The operable area can and does change over time as these assumptions change.

Define productivity of the timber harvesting landbase

Within the timber harvesting landbase, site productivity must be classified to estimate current increment and to forecast future stand development under various management assumptions. Stand-level models project stand development and estimate volume yield, diameter distributions and height. Other stand attributes such as mortality, snags and understory that are important for habitat analysis are also projected at this stage.

Define timber products

The intended timber products must be known in order to effectively establish and manage future stands. Products can range from low quality pulpwood to high quality saw logs or even specialty products such as house logs and poles. Each product is linked to a series of management assumptions related to economics, stand management, and harvesting. Products also determine the level of utilization at harvest (e.g. log diameter and length) and therefore influence both the level of harvest and measures of the merchantable growing stock. For example, a forest producing pulpwood includes smaller stems in the merchantable growing stock than a forest producing high quality saw logs, all other factors being equal. Stand projection models and log-sawing models are often used to derive revenues and costs by log grade (diameter, length, quality, and species).

Define treatments and treatment schedules for stands

The site productivity, projected yields and desired products provide key information for designing the regeneration, stand tending and harvest strategies for each stand type. A sequence of treatments, beginning with regeneration and then progressing through stand tending, intermediate harvests, and the final harvest needs to be developed for each set of management assumptions. Each treatment is assigned a cost and an age window in which the treatment is to be applied. Treatments are often influenced by non-timber values, such as habitat management, hydrology concerns and visual impacts.

Define level of protection and allowances for natural disturbance

The level of protection, especially fire suppression, will influence the risk of losses to growing stock and consequently, potential reductions in harvest levels. Natural disturbances operate over a wide range of scale in both time and space. Endemic disturbances are reasonably easy to estimate and mange through salvage operations and/or as reductions to the annual harvest. Age classes and stand structure can also be manipulated over time to minimize the risk of endemic losses to known disturbance agents. Catastrophic disturbances are uncertain, and therefore impossible to predict. One strategy for dealing with this uncertainty is to maintain higher growing stocks than would otherwise be necessary.

Define environmental and social objectives/rules affecting the harvest

On public land, economic objectives for income generation, regional and community development, and employment are translated into harvest flow policies that moderate fluctuations in the harvest rate, and require that the long-term harvest be sustainable. The long-term harvest, or long-term sustained yield (LTSY), is the steady-state harvest reached following the conversion period. Examples of harvest flow policies are: 1) even flow (harvest never changes), 2) non-declining even flow (harvest can increase, but never decrease), 3) regulated decline to long-term sustained yield (for old growth surplus forests), 4) harvests sequentially fluctuate by a given percentage each period, and 5) harvests fluctuate freely within absolute upper and lower bounds. The type of flow policy will significantly affect harvests during the conversion period, especially in old growth surplus forests. Constraints can also be used to regulate (sustain) growing stock. Generally, once LTSY is reached, growing stock also stabilizes; however, linear programming models need an ending inventory constraint to ensure that the growing stock is not depleted in the end of the final period. Flow constraints can also be added to other outputs, such as net revenue, to sustain income and model intergenerational equity. The concept of a legacy forest, (i.e. what we inherit, we pass on), is central to our vision of sustainability.

Social objectives, such as recreation and visual quality, can also influence harvest and growing stock levels. Stand retention requirements designed to meet these objectives will lower harvests and increase growing stock. Environmental objectives, such as water quality and conservation of habitat can have similar effects. Sustainable forest management and related product certification schemes require that a set of criteria be identified as objectives to be sustained, and that indicators for each criterion be identified and reported in the forest-level plan. The central point is that timber supply is not just about economics; rather it is intricately linked to non-timber resources, value judgments, and sustainability.

Options for Improving the Harvest Schedule

When generating the harvest schedule, we often encounter shortfalls during the transition from existing stands to future stands. Mature timber may be lacking because of previous harvests and natural disturbances, or it may be present but unavailable because of non-timber objectives. The introduction of new harvest

regulations can suddenly make mature timber unavailable and thereby create harvest shortfalls. In some cases this only requires adjustments over 1-2 periods, while in other cases it may affect the entire harvest schedule, including the calculation of LTSY. It is important to note that LTSY is not a fixed number. It is calculated by summing across productivity types, the product of the mean annual increment (MAI) and the area of each productivity type (e.g. LTSY = Σ (MAI $\times$ ha)). The two components of LTSY are increment and area, but as shown in the previous section, these are affected by our assumptions about the inputs and determinants of timber supply.

Shortfalls also tend to happen near the end of a rotation when existing, mature stands become scarce and the future stands have not yet reached their minimum harvest age. These points are easily identified by modestly raising the harvest level above LTSY (Figure 3). When faced with shortfalls, there are a number of options that are available for improving the harvest schedule. In this section, we identify five of the most common options: 1) adjustments to the harvest flow policy, 2) silviculture investment, 3) intermediate harvests, 4) shortening rotation ages, and 5) combining forests with complimentary age classes.

Flow policy and conversion period

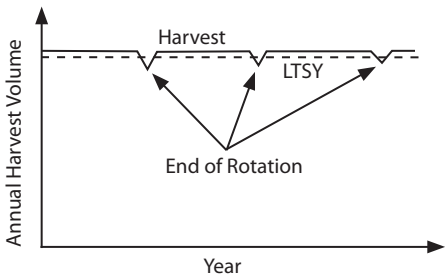

Figure 3: Harvest short-falls often occur at the end of the rotation.

There is almost an infinite number of ways to schedule the conversion period for an old growth surplus forest. Figure 4 shows two options for stepping the harvest down to LTSY, depending on the number of steps, step size and the length of the conversion period. Another option would be to harvest even more in the early periods, resulting in a temporary decline below LTSY near the end of the conversion period; however, drops below LTSY are generally frowned upon.

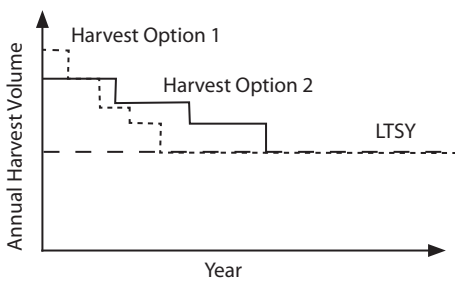

Figure 4: Two harvest scheduling options for the conversion period in an old growth surplus forest.

During the early stages of the conversion period, the average volume/ha and the average age of harvested stands will be high. Both will begin declining as the younger, future stands become an increasingly larger component of the harvest.

Silviculture investment

Investment in intensive silviculture will increase yields and harvests on future stands (LTSY), but in a deficit forest, there will be no gains from the existing stands and therefore no increase in the short-term harvest (Figure 5).

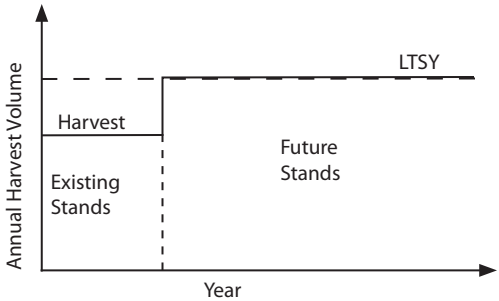

Figure 5:
In a deficit forest, silviculture investment increases LTSY, but does not lead to increased harvests in existing stands.

However, in a surplus forest with a non-declining even-flow policy, an increase in LTSY yield due to intensive management can lead to an increase in harvest of the existing stands (Figure 6). The assumption of increased future yields means that short-term harvests can increase without a subsequent falldown.

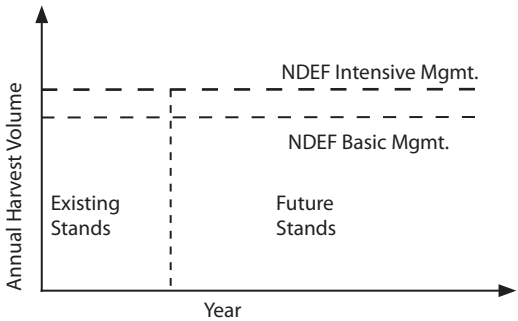

Figure 6:
In an old growth surplus forest with a non-declining even flow policy (NDEF), short-term harvest can be increased by investing in intensive management that raises the LTSY.

This phenomenon called the allowable cut effect (ACE) and it generates considerable controversy. Supporters of ACE argue that a small future investment in intensive management has a huge payoff in higher harvests today. Opponents of ACE argue that this is simply an anomaly of an overly restrictive flow policy (NDEF), plus they question whether these investments will actually be implemented when the future arrives.

Intermediate harvests

When faced with a scarcity of existing stands near the end of the rotation, one option is to fill the shortfall with intermediate harvests from the future stands (Figure 7). For example, commercial thinnings from the future stands may provide sufficient volume to maintain the harvest until these stands reach their minimum harvest age.

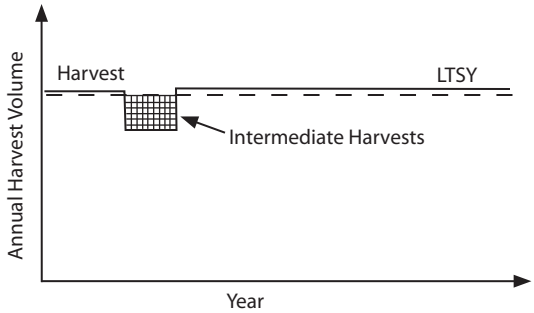

Figure 7: Intermediate harvests from future stands are used to fill the shortfall in harvest from existing stands.

If desirable, intermediate harvests could continue thereafter, and the long-term harvest would have both intermediate and final harvest components. Intermediate harvests can also be used to fill short-term drops in the harvest resulting from sudden implementation of regulations that limit the number of stands eligible for clearcutting.

Rotation age less than maximum mean annual increment

Shortening the rotation age is another strategy for reducing or eliminating harvest shortfalls when existing stands are scarce and future stands are below the minimum harvest age. This strategy assumes that a relatively minor reduction in the harvest age still produces merchantable products. Figure 8 shows harvest levels in a deficit forest when rotation ages are based on maximum mean annual increment (MMAI) and an age less than MMAI.

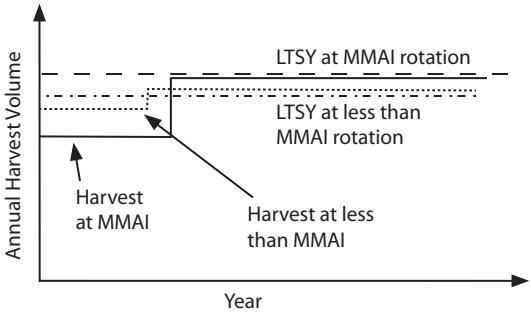

Figure 8: Shortening the rotation age below maximum mean annual increment (MMAI) provides early access to future stands, but also drops LTSY.

Shortening the rotation age provides early access to future stands, and thereby increases early harvests. However, shortening the rotation age below MMAI also drops the LTSY.

Combining surplus and deficit forests

Shortfalls, especially in deficit forests, can be reduced or eliminated by combining the forest with another forest that has a complementary age class structure (i.e. old growth surplus forest). The combined forests are then treated as the sustained yield unit, as shown in Figure 9. This is a common practice for private landowners that have the resources to acquire additional land and thereby capture the harvest synergies that result from the combined sustained yield unit. It is also used on public lands where a reorganization of forest compartments into new sustained yield units provides increased harvests to meet social policies such as regional development and employment.

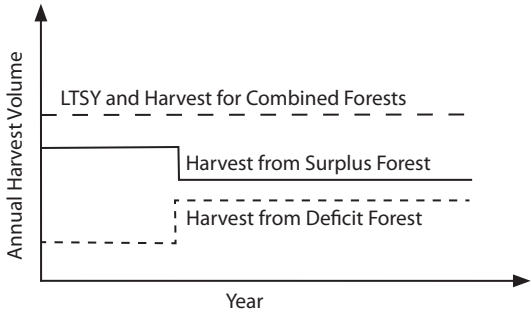

Figure 9: Combining deficit and surplus forests into a single sustained yield unit creates synergies that include higher harvests in the short-term.

Mixing options

Some of the previous options, on their own, may result in significant deviations from the original management assumptions. Typically, we try to improve the harvest schedule through minor adjustments to selected stands and or constraints. This may include adjustment to rotation ages, some intermediate harvests, some intensive stand management, slight modifications to the harvest flow and temporarily relaxing binding constraints (e.g. seral targets) in critical periods.

Assessing Non-timber Outputs

To monitor sustainability, criteria and indicators are defined for a spectrum of forest outputs and conditions, ranging from maintaining biological diversity to maintaining economic viability. This scope introduces complexity beyond what a single model or a single analyst can manage. A team of experts is required to provide both the modeling skills and the scientific credibility necessary to cover the scope of timber and non-timber outputs. Expertise is needed in stand-level modeling, harvest scheduling, hydrology, biological diversity, forest ecology, forest operations, economics, recreation, visualization and sociology. This team will use a suite of models to formulate and explore questions at various temporal and spatial scales. Rather than building one monolithic model, the team designs a decision support system with individual models and the necessary linkages for exchanging inputs and outputs.

Figure 10 is an example of output from a habitat model that assesses the abundance and distribution of seral stages through time. The habitat model imports stand ages and treatments from a harvest scheduling model, plus stand attributes

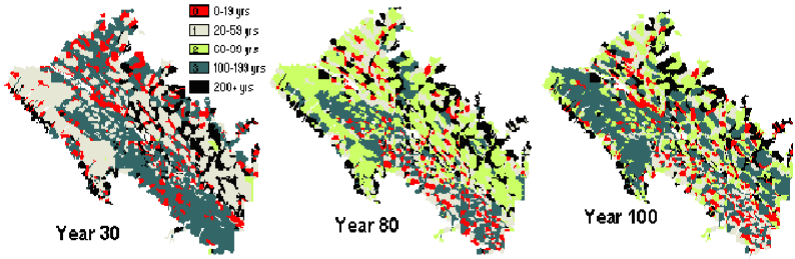

Figure 10:
Example of a harvest schedule imported into a habitat model for assessing the abundance and distribution of seral stages over time. (Source: SIMFOR model, Ralph Wells, Centre for Applied Conservation Research, University of BC).

such as snag and understory characteristics from a stand-level model.

Figure 11 shows a snap shot of a harvest schedule that was generated with a visualization model. The visualization model imports stand ages and treatments from the harvest scheduling model and stand attributes such as species, density, and height from the stand-level model. The visualization model is an important communication tool for explaining model forecasts to non-technical audiences. The decision support system includes links so that information gained from habitat, visualization and other non-timber models leads to revised assumptions and management scenarios in the stand-level and harvest scheduling models.

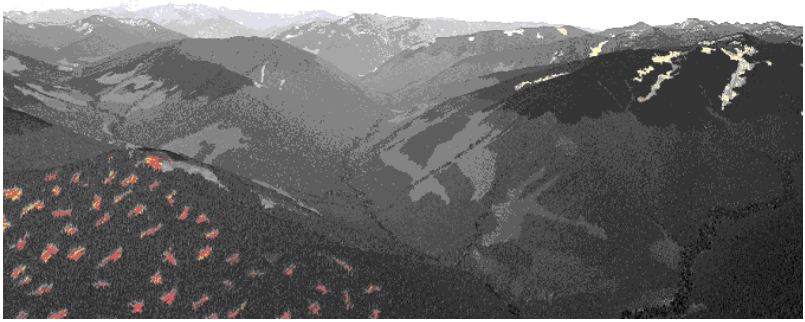

Figure 11:
Visualization of a harvest schedule. The visualization model imports the timing and treatment of stands from the harvest scheduling model and stand attributes from the stand-level model. (Source: Dr. Stephen Sheppard, Faculty of Forestry, University of BC).

Some portions of the forest estate are typically more contentious than others when it comes to managing timber and non-timber outputs. These compartments may require tactical and even operational plans to supplement the strategic planning process. The decision support system must be flexible enough to accommodate the different data and modeling demands at each level of the planning hierarchy. Good examples of evaluating timber and non-timber outputs under various management assumptions are provided by Wallin *et al.* (1994).

Professionalism and Ethics

We build our forest plans on a foundation of assumptions that describe our management intentions and how we expect the future to unfold. In this chapter we have noted the inherent uncertainty of natural forest systems and the uncertainty induced by humans through technology, economics and social/political change. We must always be cognizant that our models produce forecasts based on a set of assumptions, and that there are many possible outcomes. Occasionally, unpredictable events will produce outcomes that are beyond our control. The analyst has a duty to thoroughly test the sensitivity of these assumptions, along with key model parameters, so that clients appreciate the likely range of possible outcomes. We close the chapter with a quote on ethics from Davis *et al*. (2001):

"An Analytical Ethic for Forest Planners and Analysts"

1. "Distinguish between policy making and analysis and clearly separate and identify the facts and values in analysis presentations.
2. Document your work and say something about the accuracy and confidence to place on the data and analysis methods used.
3. Persistently try to ensure that decision makers and affected constituencies know all significant consequences of their choices – whether they want to know or not!
4. Call special attention to actions and policies that are likely to permanently impair the productive capacity of soil and water resources."

Acknowledgement

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BIOGEOCLIMATIC ECOSYSTEM CLASSIFICATION

by

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BIOGEOCLIMATIC ECOSYSTEM CLASSIFICATION

Introduction

British Columbia's diverse climate and topography produce a large variety of forested ecosystems. The diversity is both dazzling and in some respects daunting: such a range of ecosystems seems designed to test the acumen of even the most experienced forester. It was primarily to bring some order to the complex array of landscapes that the ecological classification of our province's landbase was undertaken.

This chapter describes the British Columbia Ministry of Forests' (BCMOF) ecosystem classification – its philosophy, principles, and methods, along with some examples of identification tools and applications. This system, termed biogeoclimatic ecosystem classification (BEC), is widely used in British Columbia (BC). Ecosystem classification gives foresters, biologists, agrologists, other resource managers, and naturalists a common framework for a fundamental knowledge of landscape ecology. It thus provides a basis for ecosystem management and other practical decision-making.

Since the 1983 publication of the fourth edition of the Forestry Handbook, an enormous amount of new information about forest ecology in BC has been gathered; ecosystem classification has become institutionalized; and several changes, modifications, and refinements have been made to previous schemes. In this chapter we also want to reinforce the concept of the ecosystem as the fundamental unit of ecology and management, for practical reasons and partly to counter some recent but retrograde rhetoric (compare Bunnell and Johnson, 1998; Pojar, 2000; O'Neill, 2001). Readers interested in more information on the classification should consult the appropriate regional field guides and reports published by the BCMOF[1].

A Brief History of Ecological Classification in BC

The first forester to classify the Canadian forests as a whole was B.E. Fernow (Howe, 1926), who produced a classification and map of 13 forest regions that were, essentially, climatic regions (Fernow, 1908; 1912). As chairman of the Forestry Committee of the Commission of Conservation of the Dominion government, Fernow also initiated a forest survey of BC. This work was undertaken by R.D. Craig and H.N. Whitford and took 5 years to complete. They classified forest types on the basis of composition, climate, soil conditions, and physiography. In addition,

[1] Up-to-date information on biogeoclimatic ecosystem classification and a list of recent publications is available at the BEC web site (www.for.gov.bc.ca/hre/becweb).

they treated each commercial tree species separately as to distribution, proportion of occurrence in the various types, silvicultural characteristics, rate of growth, and yield of marketable products. Whitford and Craig (1918) classified the forest lands of BC into 12 climatic types that are not much different from the 14 biogeoclimatic zones presently recognized by the BCMOF.

In addition to the federal work, small, local, essentially descriptive surveys were done by the provincial government from 1912 to the early 1940s. These surveys were probably a result of the establishment of a provincial forestry department in 1912.

In 1937, W.E.D. Halliday published *A Forest Classification for Canada*. In subsequent editions of 1959 and 1972, J.S. Rowe produced a classification and map with eight forest regions and numerous forest sections, based mainly on dominant trees and physical geography. BC has five of these forest regions, in addition to grassland and tundra regions.

Zoologists, for decades, employed a classification of biotic regions developed by Munro and Cowan (1947). This classification divided the province into 15 biotic regions that were used to describe the distribution of birds and mammals (Cowan and Guiget, 1975).

Soil surveys in BC began in the 1930s. In the 1940s, R.H. Spilsbury, who previously had been mapping soils, developed his site type approach to forest land classification. In 1947, this work culminated in a joint publication with D.S. Smith entitled *Forest Site Types of the Pacific Northwest* (Spilsbury and Smith, 1947). Spilsbury also collaborated with E.W. Tisdale in studies of soil-plant relationships in the southern Interior (Spilsbury and Tisdale, 1944), and with V.J. Krajina of the University of BC, shortly after the latter's arrival from Czechoslovakia in 1949. Krajina and Spilsbury worked together mostly in the Douglas-fir forests of Vancouver Island.

During the 1950s, the Research Division of the BC Forest Service was involved in ecological classification studies on Vancouver Island, in the central Interior, and throughout much of the range of lodgepole pine (see Illingworth and Arlidge, 1960). The Forest Service conducted several co-operative studies involving other organizations in the 1960s (e.g. Green and Keser, 1965; Lacate *et al.* 1965; Spilsbury *et al.* 1965; Sprout *et al.* 1966; Keser, 1969). These studies were primarily integrated systems of mapping and interpretation oriented to the needs of practicing foresters. Until the 1970s, however, there was only limited interest by forest managers in the practical application of an ecosystem classification (Schmidt, 1977). In the 1970s, the Forest Service embarked on an ambitious, province-wide program of ecosystem classification and interpretation. This program, following the biogeoclimatic classification system, is described in the next section.

Starting in 1949, V.J. Krajina began developing the biogeoclimatic ecosystem classification of the province. The original studies are too numerous to cite here (see Wali, 1988; Meidinger and Pojar, 1991). Krajina's system has been summarized in Krajina (1965, 1969), Bell (1971), Mueller-Dombois and Ellenberg (1974), Beil *et al.* (1976), Kojima (1981), Pojar (1983; 1985), Klinka and Krajina (1986), Pojar *et al.* (1987), Meidinger and MacKinnon (1989), Klinka *et al.* (1990) and Meidinger and Pojar (1991). Biogeoclimatic ecosystem classification (BEC) is the most pervasive ecological classification system in BC, not only because of the vigorous

heritage of Krajina and his co-workers, but also because both the BC Forest Service and forest companies have adopted the system for their own continuing use.

Roughly contemporaneous with Krajina's work was that of L. Hämet-Ahti, who proposed a vegetation zonation of the province in the Fenno-Scandian tradition of classification (Hämet-Ahti, 1965). This system is also fundamentally climatic, with zones stratified along gradients of latitude, altitude, and moisture.

The habitat type system developed by Daubenmire (1952; 1968) in eastern Washington and northern Idaho, and applied by the US Forest Service throughout the western United States was used briefly by MacMillan Bloedel Limited on their holdings in coastal BC (Packee, 1974; 1979). Compared to BEC, the habitat type system is simpler but relies mostly on vegetation, and in particular vascular plants. The habitat type approach was followed by A. McLean in south central BC (e.g. McLean, 1970), and by E.C. Packee (1976) and W.J. Beese (1981) on Vancouver Island.

The BC Ministry of Environment also developed an ecological classification for inventory and analysis of natural resources, called biophysical habitat classification (Demarchi and Lea, 1989). This approach originated with the Canada Land Inventory and the BC Land Inventory of the 1960s and early 1970s (see Lacate, 1969). Originally a system that emphasized separate component classifications and mapping (Walmsley, 1976; Walmsley and van Barneveld, 1977), it was revamped into an integrated, hierarchical system. To provide a regional physiographic and climatic context to the biophysical framework, Demarchi developed an "ecoregion" classification for BC (Demarchi *et al.* 1990; Demarchi, 1995; 1996). Within each ecoregion unit, biogeoclimatic subzones are used to help identify zonal climates and ecosystems. Within subzones, habitat units are mapped, based on surficial materials, topography, climate, soils, vegetation (including successional stages), and animal use (Mah *et al.* 1996). The biophysical/ecoregion classification has been used for identifying habitat capability and suitability for animals, for special projects dealing with wildlife habitat enhancement and development-related resource analyses, and as part of a "gap-analysis" approach to protected areas planning (Lewis and Westmacott, 1996).

The Nature Conservancy has developed a system of ecological classification that they have implemented in parts of BC while conducting international eco-regional planning. Within ecoregions (Bailey, 1998), ecological systems are defined and mapped (NatureServe, 2003). Although The Nature Conservancy follows the US National Vegetation Classification (Grossman *et al.* 1998; Jennings *et al.* 2002), the vegetation units are not always mapable at the scale used in planning. Therefore, "ecological systems" are defined for the ecoregion, mapped, and then evaluated for conservation importance based on their rarity and distribution. Ecological systems are groupings of plant associations that occur together on the landscape and that have similar ecological processes and environmental features. Examples described for coastal BC ecoregions include Subalpine Wetlands, Maritime Subalpine Parkland, *Tsuga mertensiana* Forests, and Blanket Bogs. Plant associations within these systems are then listed. For BC, the Conservation Data Centre of the Ministry of Sustainable Resource Management mostly uses the plant associations described by BEC to participate in this process.

One outcome of the Canadian program of environmental land survey is the

Ecoclimatic Regions of Canada (Ecoregions Working Group, 1989). Ecoclimatic regions are similar in concept to BC's biogeoclimatic subzones, but at the scale of mapping (1:7,500,000), the variation within the province was not adequately represented. Hence, this national effort mapped much of BC as generalized ecoclimatic complexes rather than regions.

At the highest level of ecological stratification of Canada is a classification of "ecozones" (Wiken, 1986; Ecological Stratification Working Group, 1996). In this scheme, BC is represented by 5 ecozones: Boreal Cordillera, Boreal Plains, Taiga Plains, Montane Cordillera, and Pacific Maritime. The Ecozones are very "uneven" in their diversity and disparity, and do not do justice to the ecological variation of the province. The Canadian ecozones are somewhat similar to the "ecoregion divisions" of Bailey (1998).

Biogeoclimatic Ecosystem Classification

Since 1975, the BCMOF has been systematically developing an ecosystem classification of the forest and range lands of the province (Schmidt, 1977). The classification is based, with some modifications, on Krajina's biogeoclimatic system developed in the 1960s and 1970s (see Krajina, 1969; 1972). The system incorporates primarily climate, soil, and vegetation data. The resulting biogeoclimatic ecosystem classification (BEC) provides a framework for resource management, as well as for scientific research.

Objectives

The goal of the ecosystem classification program of the BCMOF is the improvement of natural resource management in BC. To meet that goal, the overall objective of the program has been to develop a "permanent," land-based, ecological classification that reflects existing knowledge of the province's ecosystems and serves as a framework within which to manage resources. In other words, the classification program aims to both organize and apply our knowledge of the structure, function, and relationships of terrestrial ecosystems.

The program has five specific objectives:

1. To characterize, describe, and map the broad biogeoclimatic units (zone, subzone, variant) of BC;
2. to characterize and describe the major forest and nonforest sites (ecosystems) within each biogeoclimatic unit;
3. to provide aids to field identification of these biogeoclimatic and site units;
4. to develop management interpretations for the site units or groups of similar site units (treatment units);
5. to promote the concept of the ecosystem as the fundamental unit of resource management.

Over the past several years, the entire data base of the program (nearly 20,000 ecological plots) has been re-analyzed and synthesized from a provincial perspective. This has resulted in some changes to the classification and nomenclature, which are reflected in this chapter.

Principles and philosophy

A thorough characterization of BEC is given in Pojar *et al.* (1987). In an abbreviated account of that material, we present here the concepts and a summary of the classification.

Before describing the classification system, we must review some of the basic concepts.

Ecosystem

"Ecosystem" is the term used for the sum total of vegetation, animals, and physical environment in whatever size segment of the world is chosen for study (Fosberg 1967). Ecosystems are interacting complexes of living organisms (plants, fungi, bacteria, animals) and the physical environment (soil, air, water, bedrock) immediately affecting them. The ecosystem, as defined by Tansley (1935), has long served as the basic conceptual and functional unit of ecology. However, Tansley's concept of ecosystem is too broad to be easily integrated into a formal classification. Krajina (1960), therefore, proposed that Sukachev's (Sukachev and Dylis, 1964) "biogeocoenose" be adopted because, for practical purposes, he thought it best represented a basic ecosystem. A biogeocoenose is a special case of the ecosystem, but we use the two terms interchangeably here.

A terrestrial ecosystem (biogeocoenose) is a unit or portion of the landscape and the life on and in it. It is a landscape segment relatively uniform in the composition, structure, and properties of both the biotic and abiotic environments, and in their interactions.

Numerous organisms such as fungi, earthworms, bacteria, insects, birds, and mammals are as much a part of a forest ecosystem as are trees, shrubs, herbs, and mosses. Within the ecosystem exists a complex and dynamic set of relationships among these organisms and between them and their physical environment. For simplicity, however, the classification system deals primarily with two components of the ecosystem: vegetation and soil. The model of ecosystem function is that of Major (1951): vegetation and soils are products of climate, organisms, topography, parent material, and time. Plants and soil, considered simultaneously, integrate all ecosystem components and reflect ecosystem functioning. They are easy to observe and assess, and we consider them to be the most convenient and suitable ecosystem features upon which to base the classification.

Thus, an ecosystem can be, for practical purposes, characterized by a plant community (a volume of relatively uniform vegetation) and the soil polypedon (a volume, to the depth of the solum, of relatively uniform soil) on which the plant community occurs. An ecosystem has geographical bounds; its size is determined by the extent of the plant community and the associated soil polypedon. The lateral boundaries can be abrupt, but more commonly they are gradual. An individual ecosystem usually contains some variation in biotic and abiotic characteristics. But there are constant themes and repeatable patterns in the landscape, not chaos and contingency.

Climate

Climate is the most important determinant of the nature of terrestrial ecosystems. As used here, climate refers to the regional climate (Major, 1951; 1963) that influences

the ecosystems over an extended period of time. It is usually expressed as statistics derived from normals of precipitation and temperature; and is classified according to general atmospheric phenomena and their interactions (e.g. Koppen, 1936; Trewartha, 1968; Major, 1977). In BEC, climate is classified indirectly, using the concept of zonal ecosystems. Since climatic data are often lacking in many areas and climatic analysis alone will not produce a practical ecosystem classification, a reliable functional link between climate and ecosystems is needed. The concept of the zonal (or climatic climax) ecosystem provides this link.

The zonal ecosystem is that which best reflects the mesoclimate or regional climate of an area. The integrated influence of climate on the vegetation, soil, and other ecosystem components is most strongly expressed in those ecosystems least influenced by local relief or by physical and chemical properties of soil parent materials. Such ecosystems have the following characteristics:

1. Middle slope position on the meso-slope in mountainous terrain (meso-slope is the slope segment that directly affects site water movement); upper slope position in subdued terrain;
2. slope position, gradient, aspect, and location that does not result in a strong modification of climate (e.g. frost pocket, snow drift area, steep south or north aspect);
3. gentle to moderate (5-30%) slope; in dry or cold climates, on slopes to less than 5%; in wet climates, on slopes up to 50%;
4. soils that have: (a) a moderately deep to deep (50-100+ cm) rooting zone, (b) no restricting horizon within the rooting zone, (c) loamy texture with coarse fragment content less than 50% by volume, and (d) free drainage.

Hence, the biogeochemical cycles and energy exchange pathways of zonal ecosystems are relatively independent of local relief and soil parent material, and are in equilibrium with the regional climate.

Other ecosystems in a given area are influenced more strongly by local physiography and the physical and chemical properties of soil parent materials. They can be drier, wetter, richer, or poorer than zonal ecosystems; and overall they do not provide as clear a reflection of the regional climate.

Because zonal ecosystems are characteristic of the regional climate that dominates their development, they are used to characterize biogeoclimatic units, which represent broad geographical areas of similar macroclimate. The distribution of zonal ecosystems also determines the geographical extent of the biogeoclimatic units.

Climax and succession

The term "climax" in ecology and as we interpret it, refers to a condition of dynamic equilibrium, a steady state rather than a static endpoint. A climax ecosystem is in theory a stable, permanent occupant of the landscape, self-perpetuating unless disturbed by outside forces or modifying factors. The living components of a climax ecosystem are in equilibrium with the prevailing factors of the physical environment, and the member species are in dynamic balance with one another. "Climax" is a useful shorthand word for what we understand as the "shifting mosaic-steady state" (after Bormann and Likens, 1979). Certainly in BC, especially in humid regions, many old forests dominated by gap dynamics can be characterized as in a shifting

mosaic-steady state (i.e. climax), with little evidence of change at the landscape scale for hundreds and even thousands of years (Lertzman *et al.* 1996; Gavin *et al.* 1997).

In climax vegetation, the species of plants are self-perpetuating. Tree species of a climax forest are present as seedlings, saplings, and subcanopy and canopy trees. Similarly, climax shrubs, herbs, mosses, liverworts, and lichens are present in all stages from seedling or sporeling to maturity.

Climatic climax ecosystems reflect the development potential of the prevailing regional climate. Other types of climax ecosystems occur where certain environmental factors have a greater influence on ecosystem development than does the regional climate. An edaphic climax differs from the climatic climax due to extreme soil or substrate conditions such as very coarse texture, high base saturation, or poor drainage. A topographic climax reflects compensating effects of topography on local climate (e.g. a steep south slope). A topoedaphic climax results from the combined influence of soil and topography (e.g. shallow, stony soil on a steep south slope). A fire climax can result from recurrent wildfire.

Ecosystems arrive at climax through a process of change called ecological succession, the progressive development of ecosystems through time. The BEC system implicitly accepts the so-called traditional views of succession (Drury and Nisbet, 1973; Perry, 1994; Kimmins, 1997). Sequences of successional stages are called seres. Several seral or successional stages are recognizable in ecosystem development from, for example, an original bare surface to a mature forest. In theory, succession ends in a mature, climax ecosystem.

Many forest ecosystems in BC have escaped large-scale catastrophic destruction by fire, wind, and other agents (Parminter, 1998). Succession can continue over centuries; large tracts of climax forest still occur in the wetter parts of the province. Many other areas of BC are dominated by ecosystems that have not attained climax and perhaps never will. In such areas, the classification must be developed primarily with maturing seral stands (usually 70 years and older). Because seral stands usually exhibit definite successional trends, potential climax trees can be predicted from stand structure and relative shade tolerances of tree species. The understory in these stands is generally well developed and can be used as an indicator of site quality, successional development, and the potential natural vegetation of a site.

Ecological equivalence

The same climax vegetation can occur over a range of sites because of the compensating effects of environmental factors on plants. In consequence, even a climax plant association may represent ecosystems from different regional climates and with different soils. The plant community that develops on a particular site also varies according to the site, disturbance, chance, and time. The result is that several to many different plant communities can occur on the same site. To address the problems of environmental compensation and temporary variations in vegetation, ecosystems can be organized according to the principle of biological (Cajander, 1926) or ecological (Bakuzis, 1969) equivalence. This principle implies that sites with the same or equivalent physical properties have the same vegetation potential. This idea is the basis of the classification of sites in the BEC system.

Soil moisture regime

Soil moisture regime (SMR) is the average amount of soil water annually available for evapotranspiration by vascular plants over several years. Krajina (1969) adopted nine SMR classes (see Figure 1). Thus, in a relative sense, the driest soil in any regional climate is always "very xeric" (0) and the wettest is "hydric" (8). We use a subjective synthesis of soil properties to infer the **relative** soil moisture regime (Table 1).

Relative soil moisture regime		Soil nutrient regime: A very poor	B poor	C medium	D rich	very rich
Very Xeric	0					
Xeric	1					
Subxeric	2					
Submesic	3					
Mesic	4					
Subhygric	5					
Hygric	6					
Subhygric	7					
Hygric	8					

Figure 1: Edatopic grid of soil moisture and nutrient regimes.

To assess the moisture regime of a site quantitatively, Klinka and others (1984) suggested the use of a water balance approach. They proposed a classification of actual soil moisture regimes (ASMR), using the occurrence and duration of phases of water use, the ratio between actual and potential evapotranspiration (AET:PET), and the occurrence and depth of the water table (see Table 2).

The ASMR classes can be related to the relative soil moisture classes for each regional climate (Lloyd *et al.* 1990; Green and Klinka, 1994). In this report, ASMRs are used in the ecosystem descriptions.

Soil nutrient regime

Soil nutrient regime (SNR) is the amount of essential soil nutrients that are available to vascular plants over a period of several years. Complex relationships among climate, topography, soil, and organisms complicate evaluation of SNRs, especially if one is trying to determine quantitative criteria. We have adopted five SNR classes, which are presented in Figure 1. The sixth, used only where approprate, is an ultrarich category (F). The classes are assessed according to a subjective synthesis of soil properties (Figure 2).

Table 1: Relative soil moisture regime classes and characteristics[a].

Moisture regime	DEFINING CHARACTERISTICS		FIELD RECOGNITION CHARACTERISTICS						
				SOIL PROPERTIES					
	Description	Primary water source	Slope position	Texture	Drainage	Depth to impermeable layer	Humus form depth	Available water stor. cap.	Slope gradient
VERY XERIC 0	Water removed extremely rapidly in relation to supply, soil is moist for neglible time after ppt.	precipitation	ridge crests. shedding	very coarse (gravelly-S), abundant coarse fragments	very rapid	very shallow (<0.5 m)	very shallow	extremely low	very steep
XERIC 1	Water removed very rapidly in relation to supply, soil is moist for brief periods following ppt.	precipitation			rapid				
SUBXERIC 2	Water removed rapidly in relation to supply, soil is moist for short periods following ppt.	precipitation	upper slopes, shedding	coarse to mod. coarse (LS-SL), mod. coarse fragments	rapid to well	shallow (<1 m)	shallow	very low	steep
SUBMESIC 3	Water removed rapidly in relation to supply, water available for moderately short periods following ppt.	precipitation						low	moderate
MESIC 4	Water removed somewhat slowly in relation to supply, soil may remain moist for a	precipitation in moderately to fine-textured	mid-slope, normal, rolling	moderate to fine (L-SiL), few coarse	well to moderately well	moderately deep (1-2 m)	moderately deep	moderate	

	significant, but sometimes short period of the year. Available soil moisture reflects climatic inputs.	soils & limited seepage in coarse textured soils	to level	fragments					
SUBHYGRIC 5	Water removed slowly enough to keep the soil wet for a significant part of the growing season, some temporary seepage and possible mottling below 20 cm.	precipitation and seepage	lower slopes, receiving	variable, depending on seepage	moderately well to imperfect	deep (>2 m)	deep	high	slight
HYGRIC 6	Water removed slowly enough to keep the soil wet for most of the growing season, permanent seepage and mottling present; possible weak gleying.	seepage			imperfect to poor	variable, depending on seepage		variable, depending on seepage	
SUBHYGRIC 7	Water removed slowly enough to keep the water table at or near the surface for most of the year, gleyed mineral or organic soils; permanent seepage less than 30 cm below the surface.	seepage or permanent water table	depressions, receiving	variable, depending on seepage	poor to very poor	variable, depending on seepage	very deep	variable, depending on seepage	flat
HYGRIC 8	Water removed so slowly that the water table is at or above the soil surface all year, gleyed mineral or organic soils organic soils.	permanent water table			very poor				

[a]From Luttmerding *et al.* (1990).

Table 2: Classification of actual soil moisture regimes.

Distinguishing feature	Class
Rooting-zone groundwater absent during the growing season	
Water deficit occurs (soil-stored reserve water is used up and drought begins if current precipitation is insufficient for plant needs)	
Deficit > 5 months (AET/PET = 55%)	excessively dry
Deficit > 3 months but = 5 months (AET/PET = 75 but > 55%)	very dry
Deficit > 1.5 month but = 3 months (AET/PET = 90 but > 75%)	moderately dry
Deficit > 0 but = 1.5 month (AET/PET > 90%)	slightly dry
No water deficit occurs	
Utilization (and recharge) occurs (current need for water exceeds supply and soil-stored water is used)	fresh
No utilization (current need for water does not exceed supply; temporary groundwater table may be present)	moist
Rooting-zone groundwater present during the growing season (water supply exceeds demand)	
Groundwater table > 30 cm deep	very moist
Groundwater table > 0 but = 30 cm deep	wet
Groundwater table at or above the ground surface	very wet

Edatopic grid

The edatopic grid is a moisture/nutrient grid of relative SMR and SNR (Figure 1). For most regional climates, a grid of eight (0-7) RSMRs and five SNRs is used to display relationships among the site units occurring in the climate. Wetland classification requires a revised grid (see Figure 2 in Banner and MacKenzie 2000 or MacKenzie and Banner, 2001).

Classification system

The BEC system is a hierarchical classification scheme with three levels of integration: regional, local, and chronological (Figure 3). Coupled with this, BEC combines three classifications: climatic (or zonal), vegetation, and site. At the regional level, the vegetation/soil relationships are used to infer the regional climate; this climatic or zonal classification defines biogeoclimatic units. At the local level, ecosystems are classified, by vegetation and soils information, into vegetation and site units. At the chronological level, ecosystems are organized according to site-specific chrono-sequences. To do this, the vegetation units recognized for a particular site unit are arranged according to site history and successional status.

For practical purposes, users need only be concerned with the zonal and site classifications (Figure 4); the vegetation classification, however, is integral to developing both of these (Figure 5).

Vegetation classification

Vegetation is emphasized because it is considered to be the best integrator of the combined influence of a variety of environmental factors affecting the site, and because floristic criteria can be determined to differentiate units.

In keeping with the Braun-Blanquet approach (Westhoff and van der Maarel,

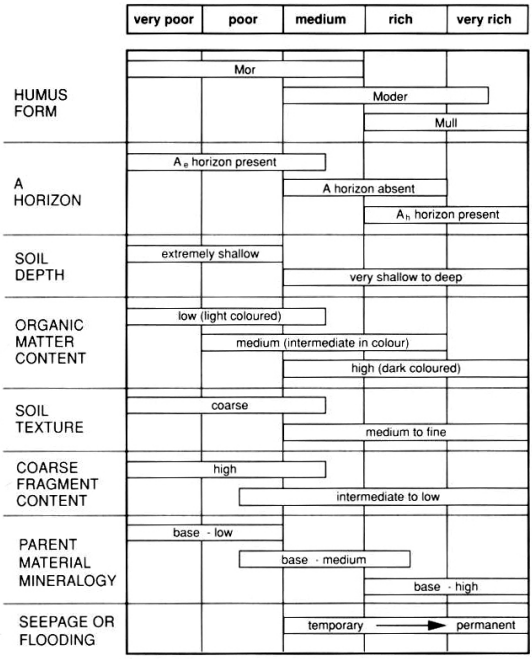

Figure 2: Relationships between site properties and soil nutrient regime.

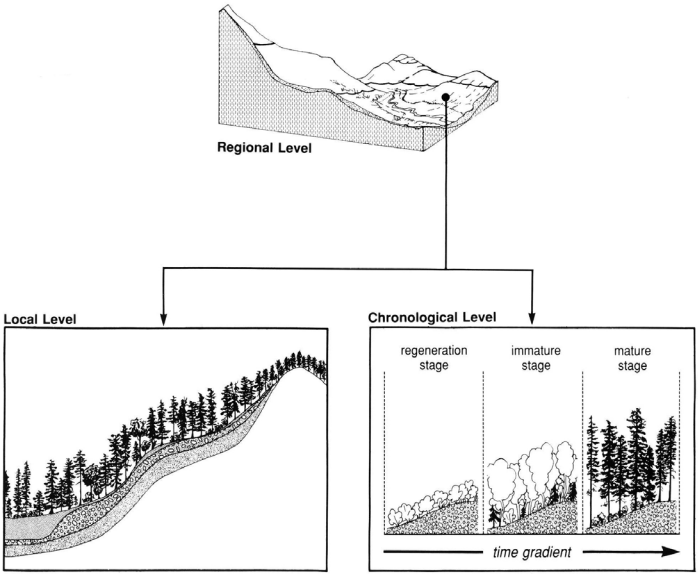

Figure 3: Levels of integration in the classification system.

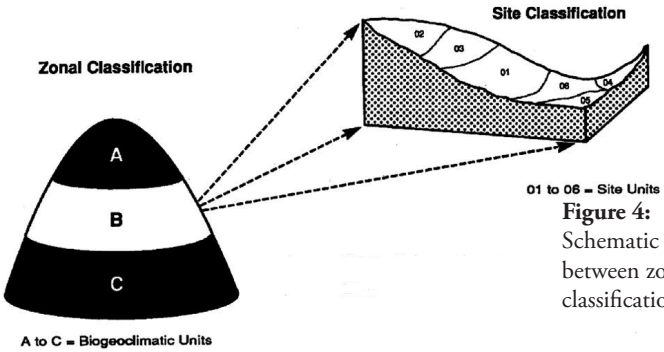

Figure 4:
Schematic relations between zonal and site classifications.

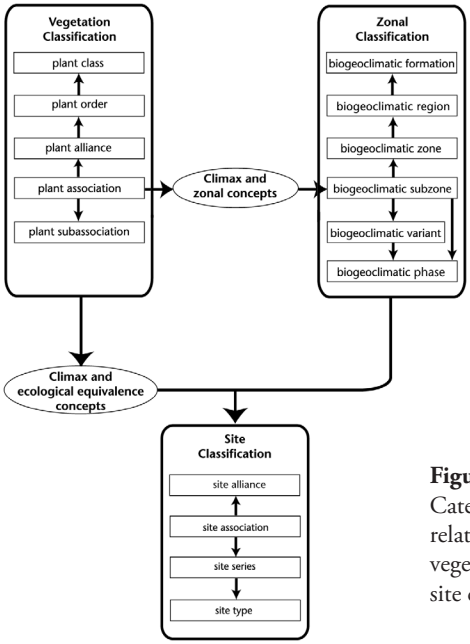

Figure 5:
Categories and relationships of vegetation, zonal, and site classifications.

1980), vegetation units are floristically uniform classes of plant communities. They are arranged in a hierarchy where the **plant association** is the basic unit; **alliances**, **orders**, and **classes** are groups of associations, and **subassociations** are divisions of an association (Figure 5). Vegetation units are differentiated using "diagnostic combinations of species" (Table 3). These are species that distinguish one vegetation unit from another, when considered within the context of the circumscribing vegetation unit from the next highest level. Determining diagnostic species requires comparison of tables of vegetation data and formation of a hierarchy. Tree species, or forest types, are emphasized at the upper levels of the hierarchy (classes/orders), understory vegetation at the lower levels.

Although the vegetation classification could be developed for any vegetation data, regardless of age of the stand or sward, we have concentrated on classifying the late successional ecosystems because they are most useful to our classification and its present application.

Vegetation units are named after plant species that dominate or characterize the unit (see, for example, Table 3).

Vegetation classification determines the plant associations and subassociations. These units are important for determining biogeoclimatic subzones and variants, and site associations.

Zonal (climatic) classification

Biogeoclimatic units are the result of zonal (climatic) classification and represent classes of ecosystems under the influence of the same regional climate. As in vegetation classification, there is a hierarchy of units, with the biogeoclimatic subzone being the basic unit (Figure 5). Subzones are grouped into zones, regions, and formations, and divided into variants or phases.

A **biogeoclimatic subzone** has a distinct climax (or late seral) plant association on zonal sites (Table 3). A subzone thus consists of unique sequences of geographically related ecosystems in which climatic climax ecosystems are members of the same zonal plant association. Such sequences are influenced by one type of regional climate. Because subzones are the basic units of zonal classification, they are the first to be recognized in the classification process.

Subzones contain considerable variation, for which we have provided the category of **biogeoclimatic variant**. Variants reflect further differences in regional climate and are generally recognized for areas that are slightly drier, wetter, snowier, warmer, or colder than other areas in the subzone. These climatic differences result in corresponding differences in vegetation, soil, and ecosystem productivity. The differences in vegetation are evident as a distinct zonal climax plant subassociation (Table 3). They can also be manifested as changes in the proportion and vigour of certain plant species, or as variations in successional development or the overall pattern of vegetation over the landscape. Differences in soils can be confined to the variation in intensity of certain soil-forming processes; they need not be markedly expressed in morphological features.

The **biogeoclimatic phase** accommodates the variation, resulting from local relief, in the regional climate of subzones and variants. A local climatic effect creates vegetation that is significantly different from the regional vegetation. The biogeoclimatic phase is useful in designating significant, extensive areas of ecosystems that are, for topographic or topoedaphic reasons, atypical for the regional climate. Examples could be extensive areas of grassland occurring within an otherwise forested subzone; enclaves of apparently coastal forest on moist, northeastern slopes in an interior, continental subzone; or valley-bottom, frost-pocket areas in mountainous terrain.

We group subzones with affinities in climatic characteristics and zonal ecosystems into **biogeoclimatic zones**. A zone is a large geographic area with a broadly homogeneous macroclimate. A zone has characteristic webs of energy flow and nutrient cycling and typical patterns of vegetation and soil. We characterize zones as having a distinct zonal plant order; that is, the vegetation classification groups

Table 3: Differentia and examples for classifications and categories of Biogeoclimatic Ecosystem Classification.

Category	Differentia	Example
Vegetation Classification		
Class	exclusive DCS[a]	Picea (glauca, engelman nii x glauca)
Order	exclusive DCS	Picea (engelmannii x glauca) – Pleurozium
Alliance	exclusive DCS	Picea – Vaccinium
Association	exclusive DCS	Picea – Vaccinium
Subassociation	exclusive DCS or non-exclusive DCS with 2 or more species	Picea – Vaccinium; typicum
Zonal Classification		
Formation	climatic group (Koppen/Trewartha)	Microthermal Coniferous Forest
Region	climatic type (Koppen/Trewartha); DCS derived from zonal and non-zonal climax ecosystems	Canadian Boreal Forest
Zone	zonal plant order (DCS derived from zonal climax ecosystems)	Sub-Boreal Spruce (SBS)
Subzone	zonal plant association (DCS derived from zonal climax ecosystems)	Moist Cold SBS (SBSmc)
Variant	zonal plant subassociation (exclusive or non-exclusive DCS derived from zonal climax ecosystems)	Babine SBSmc (SBSmc2)
Phase	zonal plant association or subassociation; local climate	Grassland IDFxh1 (IDFxh1a)[b]
Site Classification		
Alliance	range of biogeoclimatic subzones or variants, soil moisture regimes, soil nutrient regimes, and if appropriate, an additional environmental factor or property controlling vegetation of the parent plant alliance	Sxw[c] – Huckleberry
Association	range of biogeoclimatic subzones or variants, soil moisture regimes, soil nutrient regimes, and if appropriate, an additional environmental factor or property controlling vegetation of the parent plant association	Sxw – Huckleberry
Series	biogeoclimatic subzone or variant	SBSmc2/Sxw – Huckle berry
Type	one or more factors or properties that are identified as the major source of edaphic variation within the site association	SBSmc2/Sxw – Huckleberry/Sandy

[a] DCS = diagnostic combination of species; must include at least one differential, or dominant differential, species.

Differential (d): species that is clearly associated with more than one unit in a hierarchy; presence class III and at least two presence classes greater than in other units of the same category and circumscription.

Dominant differential (dd): species that does not meet the presence criteria above but shows clear dominance in more than one unit in a hierarchy; presence class III, mean species significance 5 and two or more significance classes greater than in other units of the same category and circumscription.

Presence classes as percent of frequency: I = 0-20, II = 21-40, III = 41-60, IV = 61-80, V = 81-100. Species significance classes and percent cover: + = 0.1-0.3, 1 = 0.4-1.0, 2 = 1.1-2.2, 3 = 2.3-5.0, 4 = 5.1-10.0, 5 = 10.1-20.0, 6 = 20.1-33.0, 7 = 33.1-50.0, 8 = 50.1-75.0, 9 = 75.1-100.

[b] IDFxh1 = Okanagan Very Dry Hot Interior Douglas-fir variant.

[c] Sxw = *Picea engelmannii x glauca.*

zonal plant associations in the category of plant order. Zones also have characteristic, prevailing soil-forming processes, and one or more typical, major, climax species of tree, shrub, herb, and/or moss.

Zones are usually named after one or more of the dominant climax species in zonal ecosystems (the Alpine Tundra Zone is a self-explanatory exception), and a geographic or climatic modifier.

Subzone names are derived from classes of relative precipitation and temperature or continentality. Variants receive short geographic labels.

Zones are given a two to four letter code, corresponding to the name. For example, the Coastal Douglas-fir zone code is CDF[2]. Subzone codes correspond to the climatic modifiers (Figure 6); variants are numbered from south to north; phases are noted by an alphabetic code. For example, ICHmc1a refers to the coastal (a) phase, of the Nass (1) variant, of the Moist Cold (mc) subzone, of the Interior Cedar – Hemlock (ICH) zone.

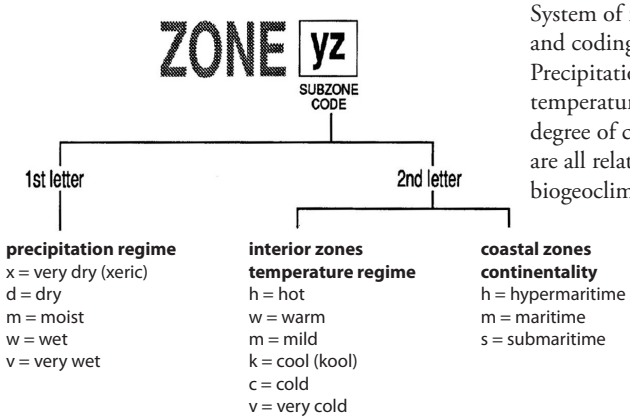

Figure 6: System of naming and coding subzones. Precipitation and temperature regimes, and degree of continentality, are all relative within the biogeoclimatic zone.

[2] Codes presented in Table 4

Site classification

Site units represent groups of sites or ecosystems that, regardless of present vegetation, have the same, or equivalent, environmental properties and potential vegetation. Vegetation units do not provide the most efficient, convenient, or stable framework for ecosystem classification because vegetation changes over time, thereby continually dating the results of its classification. As a result, the potential vegetation of a group of sites is used, along with selected environmental properties, to delineate site units.

The potential vegetation of a group of sites, as determined by our climax or near-climax plant associations and subassociations, provides the initial delimitation of site associations, the basic unit of site classification. The **site association** can be considered as all ecosystems capable of producing vegetation belonging to the same plant association (or subassociation, in some cases) at climax. Thus, a site association is a group of related ecosystems physically and biologically similar enough that they have, or would have, similar vegetation at climax. One site association can include a variety of disturbance-induced, or seral, ecosystems, but succession should ultimately result in similar plant communities at climax throughout the association. The use of plants from the climax plant association to name site associations does not imply that climax vegetation dominates the present landscape. Many ecosystems in the province reflect some form of disturbance and are in various stages of succession towards climax.

Site associations can be differentiated from one another by the range of environmental properties outlined in Table 3. It is these site properties that are used to identify a site association in an early successional stage. The site association is equivalent to the habitat type of Daubenmire (1968) and Pfister *et al.* (1977) and conceptually similar to the forest type of several European classifications (see Jahn, 1982).

The name of site associations follows the name of the parent plant association or subassociation as closely as possible. Common names of one to four species are used and tree species codes are usually substituted to shorten the name. For example, the parent plant association of the Sxw – Huckleberry site association is the *Picea – Vaccinium* plant association (Table 3).

A site association can contain ecosystems from several different climates and so be variable in actual site conditions. Dividing the association into **site series** using subzones and variants (Table 3) produces site units that are climatically, and therefore usually edaphically, more uniform. As a result, site series are more predictable in their response to management.

Site series have the same name as the site association, prefixed by the biogeoclimatic subzone or variant and a "slash" (see Table 3). Each site series is also given a two-digit numeric code. So, for example, the SBSmc2/Sxw – Huckleberry site series (Table 3) is coded SBSmc2/01 in all field guides and data forms.

Ideally, the name for a site series would incorporate features of physiography and soils, but in reality that is impractical. However, a reference to the SBSmc2/Sxw – Horsetail site series signifies the group of ecosystems that occur at the base of slopes or in depressions, over poorly to moderately drained fluvial, morainal, or lacustrine parent materials; which have developed Gleysols, Dystric Brunisols or Cumulic Regosols and Hydromoder or Mormoder humus forms[3]; which generally have an excess of soil water and an abundance of nutrients but often poor

soil aeration; and which at climax develop vegetation that can be characterized by the *Picea – Equisetum* plant association. Provided the classification is adequately described, explained, and understood, a relatively simple name can convey a great deal of useful information about individual ecosystems in the field.

To form edaphically more consistent units, site series are partitioned into **site types** according to one or more edaphic properties thought to affect ecosystem response to management. Site types reflect the compensating effects of various site conditions within a uniform climate which, together in different combinations, produce similar vegetation. Of all the ecosystem units, they are uniform in the largest number of environmental characteristics.

Site types are named with a single edaphic modifier and are given a two-digit numeric code. For example, the Sandy site type in Table 3 could be coded as follows: SBSmc2/01/02.

Often the site series is also the operational unit on which we base silvicultural and other management decisions. For example, to make prescriptions the forester usually only need know that a sub-boreal site belongs to the Pine – Huckleberry – Cladonia or the Spruce – Horsetail site series. In some cases, however, the site series must be subdivided into more operationally significant units. This is especially true of widespread site series that encompass a range of habitat conditions.

The **site phase** can be used for better site differentiation and identification. It is not a formal unit in the classification, but it can be used to subdivide site series or site types. For example, recognition of two general particle size classes (coarse and fine) as two phases of widespread sub-boreal site series gives much more meaning to silvicultural interpretations of these units. In other cases, site phases could be based on slope classes, aspect, parent materials, soil climate, or bedrock geology. Recognizing any change in such characteristics can be important because they influence an ecosystem's response to external disturbances. Use of the phase also allows more consistent prediction of ecosystem response to management treatments.

A phase is named according to the differentiating criterion and is given an alphabetical code. For example, a coarse-textured phase of a SBSmc2/01 site series would be coded SBSmc2/01a.

The representation of edaphic variation within the site series as site phases or site types is related to the number of sample plots and the perceived need for more consistent classes. Since site types are more edaphically uniform, a greater number of sample plots is required to characterize types adequately. A classifier may choose only to recognize phases where the data are limited. As well, where the "direct" interpretations to be made for the edaphically consistent units are few and straightforward and the edaphic variation is complex, the classifier could recognize a few phases instead of several to many types.

In some cases, another informal unit termed the site variation is used to describe vegetative trends or floristic features that diverge from the central concept of the association. Usually such variation is related to short-term successional factors and it involves recent stand history. Variations could be recognized on the basis of stocking, species composition of the tree stratum, understory structure and composition, etc. The variation is named according to the key differentiating species and is given a

[3] Humus form (forest floor) terminology after Green *et al.* (1993).

numeric code appended to the site series code following a period, e.g. SBSmc2/01.1.

The **site alliance** is an upper-level unit of the site classification hierarchy that groups similar site associations. The climax or near-climax plant alliances (or sometimes, suballiances) provide the initial delimitation of site alliances. Site alliances can be useful as a framework for interpretations that do not differ for individual site associations or site series, but are related to broader site factors.

Successional classification

Successional (often termed "seral") classification in BEC involves an integration of the site and vegetation classifications and the determination of structural stage of development. Klinka *et al.* (1985) and Hamilton (1988) have presented their concepts of how this would take place. Relatively little classification of successional ecosystems has occurred using BEC (see Klinka *et al.* 1985; DeLong, 1988; 2002; Lloyd *et al.* 1990; Williams *et al.* 2001), and there are some differences in the structural stages recognized.

Over most of our managed and natural forests there is a complex pattern of seral ecosystems. As previously explained, the BEC system makes sense of the array of ecosystems through site classification. After that, the sequences of successional ecosystems that occur on a site unit can be sorted into seral plant associations and seral structural stages. The result is the application of a seral plant association name to one or more seral stages. Depending on the use of the classification and the relationship between the seral stages and plant associations, the presentation will emphasize either the seral stage or the association. A code for the stage (or several stages) is used to identify the seral stage/association segment of a site series in field guides and data banks. For example, a pole-sapling stage of the SBSdk/01 would be coded SBSdk/01-PS. A recognized seral plant association is labelled with a four-letter code appended to the site series code. For example, the Trembling aspen (At) – Pink wintergreen seral association of the SBSmc2/01 is coded SBSdk/01-Atpw.

Methods

Field procedures of the BCMOF's classification program follow those detailed in the manual Describing Ecosystems in the Field (Luttmerding *et al.* 1990) and Field Manual for Describing Terrestrial Ecosystems (British Columbia, 1998). Analytic and synthetic methods adopted by the Ministry have been described by Klinka *et al.* (1979) and Britton *et al.* (1996), and are similar to those of Krajina (e.g. Brooke *et al.* 1970; Wali and Krajina, 1973; Kojima and Krajina, 1975). The methods are summarized here.

Plot sampling

Field sampling is stratified on the basis of biogeoclimatic units and soil moisture and nutrient regimes. Based on reconnaissance and other available information, tentative biogeoclimatic units are often delineated before plot selection. An edatopic grid (Figure 1) is used as an aid to stratification within each biogeoclimatic unit. We try to sample five or more plots representing each of the possible combinations of moisture and nutrients. Intensity of sampling varies according to the areal extent of the ecosystem, its apparent diversity, and its importance for resource management. Sampling intensity also depends on available access and the nature and scale of the project.

We sample selectively. Sample plots are located in habitats that are as uniform as possible; heterogeneous, transitional, or disturbed sites are avoided. To date, most sampling has been confined to climax or near-climax ecosystems. Plots are located so as to represent particular combinations of moisture and nutrients (see Table 1, Figure 2). Slope position, indicator plant species, relative tree growth, soil texture, seepage, and base status of parent materials, are used as clues to moisture and nutrient regimes. The professional judgement of experienced fieldworkers in selecting representative ecosystems is an important part of the approach.

The smallest unit of sampling in ecosystem studies is the "sample plot" (also termed "sample plot" by Mueller-Dombois and Ellenberg [1974] for vegetation sampling, and termed "pedon" by Soil Survey Staff [1975] for soil sampling). Plot size in forest stands is usually 400-500 m^2; plot shape is variable but usually square or rectangular. Plot size is reduced for grassland, wetland, or alpine sampling. At each site, the standardized provincial site, soil, humus form, vegetation, and mensuration data sheets are completed according to the procedures in Luttmerding *et al.* (1990) or British Columbia (1998).

Analysis

The information collected from the sample plots must be analysed and integrated into a usable classification. To do this, we code vegetation and selected soil, physical, and mensurational data for tabulation using a computer program called VPro, developed by the Forest Science Program, BCMOF. VPro is the culmination of several data compilation and reporting programs developed over the past 25 years. The first of these was VTAB, a program developed by Klinka and Phelps[5] and Emanuel[5, 6]. The BC Forest Service provided additional data analysis tools (Meidinger *et al.* 1987) and eventually embarked upon the development of an integrated data storage and analysis system (Britton *et al.* 1996). The result is VPro, a program that stores, sorts, organizes, and presents these data; it does not perform any classification. This procedure aids in the traditional Braun-Blanquet method of classification by tabular analysis (see Mueller-Dombois and Ellenberg, 1974), mainly by reducing manual procedures and transcription errors.

VPro allows users to enter, error-check, view, organize, and query data, import data from VTAB or VENUS[7], export to data analysis software (i.e. PC-Ord), and produce environment, vegetation, and summary vegetation tables. The classifier specifies the tentative ecosystem units, relying largely on personal knowledge

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[4] Klinka, K. J.P. Kimmins, J.T. Standish, and S. Phelps. 1977. Initial data synthesis in the synecological classification. BCMOF, Vancouver, BC. Unpublished manuscript.

[5] Emanuel, J. 1985. A vegetation classification program. University of British Columbia, Faculty of Forestry, Vancouver, BC. Unpublished manuscript.

[6] Emanuel, J. 1990. VTAB-PC Version 1.0. Software and documentation for personal computer version of VTAB. BCMOF, Victoria, BC.

[7] VENUS, a program developed by BCMOF and Ministry of Sustainable Resource Management primarily for data entry: www.env.gov.bc.ca/ecology/dteif/venus.html

and judgement. The program summarizes environment and vegetation data according to the specified units. The summary vegetation table then presents species presence (frequency of occurrence in sample plots) and mean cover or species significance (an estimate of both cover and abundance) for all plant species in all differentiated units. Successive working tables can be rapidly produced; additions, corrections, and rearrangements can be easily made.

The classifier generally groups plots by tentative biogeoclimatic unit and by estimated moisture/nutrient regime. The vegetation tables list species by stratum or layer (trees, shrubs, herbs, etc.) in order of presence and mean percent cover for each ecosystem unit. Plots or groups of plots that are floristically different may be separated or moved to another group. Plots that appear similar in moisture and nutrient regime are experimentally merged. Similar groupings from other biogeoclimatic units are compared and then fit into the vegetation hierarchy. Through this process of computer-assisted, experimental grouping, rearrangement, and refining of groups, the plant and site associations are defined (Poore, 1962). Site associations may then be subdivided into site series, types, or phases, often on the basis of edaphic factors as summarized by the environment tables.

Mapping

Biogeoclimatic mapping begins with a review of available ecosystem classifications within or near the mapping area. Biogeoclimatic units are characterized and summarized in synopsis form. A draft map, based on physiography and the extrapolation of elevational limits, may be prepared. Field mapping is done along selected transects by ground and air survey. The ground survey includes brief descriptions (rapid reconnaissance) of vegetation and soils; special attention is paid to zonal ecosystems. Boundaries drawn in the field are based on the type and occurrence of zonal ecosystems, floristic combinations, and the distribution of azonal, edaphic climax ecosystems. Final boundaries are drawn after fieldwork and data analysis has been completed. Boundaries outside transects are extrapolated on the basis of elevation and physiography. In the early years of biogeoclimatic mapping, the final maps were prepared manually and usually transcribed onto mylar for printing. Now, the modeling and mapping is done using GIS software and digital base maps (Eng and Meidinger, 1999). The use of TRIM digital base maps allows the mapping to be completed at a larger scale (e.g. 1:20,000) and then presented at an appropriate scale, usually smaller (e.g. 1:50,000 – 1:250,000).

A revision (at 1:2,000,000) of Krajina's maps of the biogeoclimatic zones of BC has been prepared by the BCMOF (1988, 1992, 2003). Colour biogeoclimatic unit maps, including zones, subzones, and variants, of the coast and northern Interior have been mapped at scales of 1:250,000 to 1:600,000 (Nuszdorfer *et al.* 1984; 1994; McLeod and Meidinger, 1986; Pojar *et al.* 1988; Coupé and Steen, 1998). Print files of colour maps for each Forest District are available from the BCMOF, Research Branch web site (www.for.gov.bc.ca/hre/becweb/resources/maps/index.html).

Ecosystem mapping assists area-specific land management by providing managers with information on the location and distribution of site units.

Banner *et al.* (1996) and Resources Inventory Committee (1998), updating Mitchell *et al.* (1989), outline the methods for terrestrial ecosystem mapping in BC, using experience to date (e.g. Klinka *et al.* 1980b; Banner *et al.* 1985; Mitchell and Eremko, 1987).

Ecosystem mapping follows sampling and classification. A key to site units may be prepared, using readily identifiable features of the vegetation and physical environment. The Resources Inventory Committee terrestrial ecosystem mapping (TEM[11]) procedures (Resources Inventory Committee, 1998) use the traditional approach of air photograph delineation of ecosystem polygons. Mapping is based on a combination of ground and air surveys and interpretation of available air photographs (usually 1:15,840, 1:20,000, or 1:50,000). Photo-interpretation relies on characteristics of the tree layer and identifiable environmental characteristics such as elevation, topographic position, and slope gradient. Map delineations are tentatively labelled as to their component site units and are then field-checked to verify boundaries and labels. Mapping units are usually a combination of site series, more specific site conditions (called site modifiers), and structural stage. A polygon can be one or more site units, depending upon the intensity and scale of mapping.

Modelling of ecosystem relationships, using digital terrestrial inventory data to produce ecosystem maps, is becoming more common due to lower costs. Procedures for predictive ecosystem mapping (PEM) are available from Resources Inventory Committee (1999). The BC Forest Service has developed a model for predictive ecosystem mapping called EcoGen (Meidinger *et al.* 2000).

British Columbia: The Environmental Setting

Introduction

BC is a large and diverse province, more variable physically and biologically than any comparable region in Canada. The province spans 11 degrees of latitude and 25 degrees of longitude and covers 948,600 km^2. Mountains feature prominently in the geography, environment, and culture of BC; so too does the coast, which is intricate in detail and fringed with islands throughout its length.

Broadly speaking, BC is a cool, moist, mountainous, forested region. However, the province also has areas with Mediterranean-type, semi-arid, subarctic, and alpine climates. It has extensive plateaus, plains, and basins as well as several roughly parallel series of mountains. Forests dominate the vegetation but there are also extensive areas of grasslands, wetlands, scrub, and tundra. Nine of the ten main groups of soils (soil orders) found in Canada occur in BC, as do nearly all 31 major subdivisions of the soil orders (great groups).

This section describes the general physical and biotic features of BC in terms of physiography, climate, soil, and vegetation. Much of the information has been drawn from Valentine *et al.* (1978) and Meidinger and Pojar (1991). The intent is to set the stage for the discussion of the application of biogeoclimatic classification to BC's terrestrial ecosystems, each of which represents a distinctive combination of climate, physiography, vegetation, and soil.

Physiography

Valentine *et al.* (1978) divided BC into five primarily physiographic regions (Figure 7) based on the 10 primary subdivisions of Holland (1976).

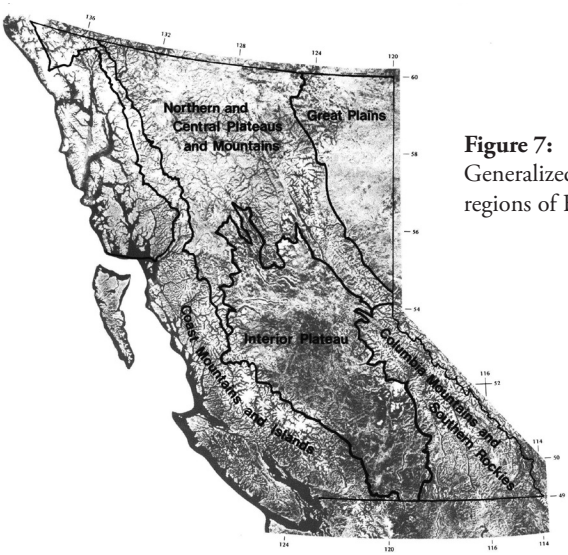

Figure 7:
Generalized physiographic regions of BC.

Coast Mountains and Islands

Two parallel mountain belts (the discontinuous St. Elias – Insular mountains and the Coast – Cascade mountains) and an intervening, largely submerged Coastal Trough form this region. Glacial landforms, including cirques that occur at all elevations, dominate the St. Elias and Queen Charlotte Mountains. Vancouver Island consists largely of glacial landforms and erosion surface remnants. The terrain of the Coast and Cascade mountains is typical of intrusive igneous rocks that have undergone mountain glaciation. Within these mountains, thick deposits of glacial drift are restricted to valley bottoms and adjacent lower slopes. However, the lowlands and islands of the Coastal Trough often have thick blankets of drift, although they also include some large areas of glacially scoured rock surfaces.

Interior Plateau

The flat to gently rolling uplands of this region represent a mature, low relief landscape capped by lava flows in some areas. The northern two-thirds of the region (Fraser and Nechako plateaus) is largely undissected except by the Fraser River and its major tributaries. The degree of dissection is much greater in the southern part of the Interior Plateau (Thompson Plateau), where the Fraser and Thompson rivers occupy deep, steep-sided valleys. The eastern margin of the region (in the Quesnel, Shuswap, and Okanagan highlands) also has relatively rugged, deeply dissected terrain. Thick deposits of glacial drift mantle virtually the entire surface of the Interior Plateau, except for rock outcrops, lava cliffs, and steep, rocky slopes above the entrenched rivers.

Columbia Mountains and Southern Rockies

The Columbia Mountains, the southern Rocky Mountain Trench, and the southern Rocky Mountains make up this region which occupies southeastern BC. Four rugged mountain belts (the Monashee, Selkirk, Purcell, and Cariboo mountains) together constitute the Columbia Mountains. Glacial drift is widespread on floors and gentler lower slopes of the intervening valleys; steeper slopes consist of rock outcrops and rubbly colluvium. The floor of the steep-sided, depressional Rocky Mountain Trench is covered by glacial and fluvial deposits. The southern Rocky Mountains are built of folded and faulted sedimentary rocks; the topography reflects the structural control of the bedrock. The distribution of drift in the Rockies is similar to that in the Columbia Mountains, but colluvial landforms are more widespread. The well-jointed sedimentary rocks of the Rockies disintegrate rapidly to form talus slopes and rubbly colluvial fans and aprons.

Northern and Central Plateaus and Mountains

This region contains a diverse collection of plateaus, mountains, and plains north of roughly 56°N latitude. The northern plateaus (the Stikine and Yukon plateaus, primarily) display the flat to rolling topography of mature erosional surfaces, and are variously dissected by streams. Pleistocene ice covered virtually all plateau areas and left widespread deposits of drift. The mountain systems (Skeena, Cassiar, Omineca, and northern Rocky mountains) in this region are lower and more subdued than the Coast and southeastern mountains. Deep drift is widespread in broad valleys, while the mountains themselves commonly have a thin cover of drift except on the higher ridges and peaks. The Nass Basin and Liard Plain are relatively low-elevation areas of gentle topography included within the region. Both areas have extensive drift cover and numerous lake basins.

Great Plains

The plains occur over flat-lying or gently dipping sandstones and shales in north-eastern BC. Surfaces are generally flat to gently rolling, with little relief except where they are incised by the Peace and Liard rivers and their tributaries. Most of the region is covered by drift, including large areas of outwash gravels and sands and some lacustrine clays and silts, as well as extensive till plains.

Climate

Climate also reflects the dual nature of BC's environment – the fundamental themes of the mountains and the sea. The Pacific Ocean and the mountains are the two major determinants of the province's climates. The Pacific is a reservoir of heat and moisture. In winter, frontal systems spawned over the North Pacific move onto the coastline and eastward across the province, encountering successive mountain barriers that trend northwest-southeast, or roughly perpendicular to upper air flow. The mountain ranges largely determine the overall distribution of precipitation and the balance between Pacific and continental air masses in the various regions of BC. The wettest climates of BC (and Canada) occur on the coast, especially near the mountains on the windward slopes of Vancouver Island, the Queen Charlotte Islands, and the mainland Coast Mountains. Here,

moist air carried by prevailing westerly winds drops large amounts of rain or snow as it is forced up the mountain slopes. The air descends over the eastern slopes and is warmed by compression, causing the clouds to thin out. The pronounced rainshadow cast by the massive Coast Mountains results in the driest climates of BC, located in the valley bottoms of the south-central Interior. The air releases additional moisture as it again ascends the Columbia, Omineca, and Cassiar mountains, and finally the Rocky Mountains.

Not only do the mountains impede eastward-moving air masses, they also restrict the westward flow of cold continental Arctic air masses from east of the Rocky Mountains. Thus, except for the unprotected Great Plains Region of the northeast, BC has a more moderate winter climate than does the vast central part of Canada.

The prevailing westerlies weaken during the summer. The summer climate is controlled by a large, semi-permanent high pressure centre in the Pacific, which greatly reduces the frequency and intensity of Pacific storms. The Interior in spring has little precipitation, but early summer is often relatively wet. By mid-summer, however, interior storms and precipitation decline again. In middle and late summer the "Pacific high" often exerts dominance over western North America, sometimes giving warm, clear weather to much of BC.

Soil

Many different kinds of soil have developed throughout BC as a result of different intensities of soil-forming processes, including the interaction of parent material, climate, biota, topography, and time. The Canadian System of Soil Classification (Soil Classification Working Group, 1998) has been developed to order and label the different soils. It groups soils according to the way they are formed. Nine major groups of soils (soil orders) occur in BC.

Brunisolic soils occur primarily in forested areas where relatively low rates of weathering have induced only moderate development from the original parent material. The slow weathering and/or restricted development may be due to climate (long winters and low temperatures in cold climates, lack of soil moisture in dry climates), coarse texture of the parent materials, or the geological youth of recently deposited parent material.

Dark, fertile Chernozemic soils have formed primarily under grasslands in the warm, dry, south central interior of the province. Chernozems are typical of areas where low rainfall, high summer temperatures, and high rates of evapotranspiration inhibit tree growth, limit soil leaching, and lead to the accumulation of organic matter in the topsoil.

Cryosolic soils contain permafrost and occur as mineral soils at high elevations and as organic soils in the peat bogs of northeastern BC. Low soil temperatures inhibit chemical reactions and microbial activity, but physical weathering is active.

Gleysolic soils are saturated for long periods of the year and their profiles show evidence of anaerobic, reducing conditions. Gleysols occur throughout the province wherever water does not drain away as fast as it is added to the soil. Gleysols dominate high water-table areas in the lower Fraser Valley, and are also widespread over some of the large flat plains of northern BC. Elsewhere they occupy depressions on plateaus or lower, moisture-receiving slope positions in mountainous terrain.

Soils of the Luvisolic order are characterized by a zone or horizon of clay accumulation in the subsoil as a result of leaching from above. This clay-rich horizon may restrict penetration by roots, air, and water. Luvisolic soils have formed under forest cover in areas which have either higher rainfall or lower temperatures with less evapotranspiration or finer textured parent materials than areas dominated by Brunisolic or Chernozemic soils. Luvisolic soils cover much of the Interior Plateau and a large part of the Great Plains.

Organic soils consist mainly of organic matter and develop mostly under saturated conditions where dead vegetation accumulates faster than it is decomposed. Organic soils typically occupy poorly drained depressions and support wetland vegetation, although they can also develop on sloping terrain in very wet climates. However, the Folisols are a group of organic soils formed under upland forest conditions, are freely drained, and are commonly found on the north coast and in coastal subalpine forests. Organic soils dominate the landscape along the north coast and in parts of the Great Plains.

Podzolic soils generally form under coniferous forest in temperate, wet or cold, moist climates. Podzols are typically well drained, coarse textured, and undergo intense leaching of clay, organic matter, iron, and aluminum from upper to lower mineral horizons. Podzols dominate most of the coastal region, the interior wet belt, and the mountain systems of BC.

Regosolic soils are very weakly developed and often very shallow, although some can have significant accumulations of organic matter in the surface layer. Regosolic parent materials are only slightly modified because they are recent (as on floodplains or beaches), unstable (as on eroding slopes), or in harsh environments where rates of chemical weathering and microbial activity are very low. Regosols do not cover extensive areas in BC except in the high mountains.

Soils of the Solonetzic order contain high amounts of exchangeable sodium or sodium and magnesium salts in the subsoil. The salts cause the soil to become sticky and massive when wet, and very hard and blocky when dry. The high salt content limits plant growth and in some cases only salt-tolerant plants survive. Solonetzic soils are common in dry parts of the southern Interior, but are restricted
to poorly drained depressions. In these areas, soil water drains into the depressions where it evaporates, leaving an accumulation of salts. In the Peace River district of northeastern BC, saline soils are widespread in some areas. Here the salts originate in saline marine bedrock.

Terrestrial vegetation

The vegetation of BC ranges from wet coastal forest to dry interior grassland, from sea level salt marsh to alpine tundra, and from Garry oak parkland to black spruce muskeg. Numerous systems of vegetation classification exist and could be applied to the province's plant cover. However, for the brief outline that follows, a primarily physiognomic scheme based on that of Fosberg (1967) seems most appropriate.

Coniferous forest

Evergreen coniferous forest dominates the province's vegetative cover. The majority of the coastal forest at low to medium elevations is dominated by western

hemlock (*Tsuga heterophylla*)[9] and western redcedar (*Thuja plicata*), with Douglas-fir (*Pseudotsuga menziesii)* abundant in the south and amabilis fir (*Abies amabilis*) and Sitka spruce (*Picea sitchensis*) abundant in the north. Arbutus (*Arbutus menziesii* – a broad-leaved evergreen tree) typically joins Douglas-fir in much of the drier forest near the sea in the Strait of Georgia region. Mountain hemlock (*Tsuga mertensiana*), amabilis fir, and, to a lesser extent, yellow-cedar (*Chamaecyparis nootkatensis*) predominate in the coastal subalpine forest.

Ponderosa pine (*Pinus ponderosa*) and Douglas-fir dominate the dry forest, parkland, and savanna of the southern Interior. Western larch (*Larix occidentalis*), a deciduous conifer, is a common associate in southeastern BC.

Lodgepole pine (*Pinus contorta* var. *latifolia*) and Douglas-fir form extensive stands over much of the southern half of the Interior Plateau. Douglas-fir gradually drops out from the northern half, where white spruce (*Picea glauca*), hybrid white spruce (*P. engelmannii* x *glauca*), and subalpine fir (*Abies lasiocarpa*) join lodge-pole pine as the dominant conifers.

The wetter parts of the Columbia and Southern Rocky mountains region are occupied by forests of western hemlock and western redcedar, with admixtures of western white pine (*Pinus monticola*), Douglas-fir, western larch, grand fir (*Abies grandis*), Engelmann spruce (*Picea engelmannii*), hybrid white spruce, and sub-alpine fir.

The upper elevation forest and parkland of the southern two-thirds of interior BC consist primarily of mixtures of Engelmann spruce, subalpine fir, and lodgepole pine, with whitebark pine (*Pinus albicaulis*) fairly common on drier sites.

The low and middle elevation forest of northern BC is boreal in character and dominated by white spruce, black spruce (*Picea mariana*), and lodgepole pine. Northern subalpine forest consists primarily of white spruce and subalpine fir.

Deciduous forest

Trembling aspen (*Populus tremuloides*) is the most widespread and abundant deciduous tree species in BC. Aspen stands (which may occur as closed forest or in parkland) are abundant throughout the Interior Plateau and in the boreal forest region, but they are less frequent in the wetter parts of the southeastern province and at higher elevations, and are uncommon at the coast.

Red alder (*Alnus rubra*) is a fast-growing pioneer species that forms dense stands on much cut-over or otherwise disturbed land all along the Coast.

Black cottonwood (*Populus balsamifera* ssp. *trichocarpa*) commonly forms alluvial forests throughout the province, except on the outer coast. Balsam poplar (*P. balsamifera* ssp. *balsamifera*) largely replaces black cottonwood in northern BC.

Paper birch (*Betula papyrifera*) is widespread in the Interior but seldom dominates extensive stands. It usually occurs in mixture with conifers and other deciduous trees.

Bigleaf maple (*Acer macrophyllum*) is common in second-growth forest in southwestern BC, but it also rarely dominates stands.

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[9] Nomenclature follows Douglas *et al.* (1998-2002) for vascular plants; Stotler and Crandall-Stotler (1977) for the liverworts; Anderson *et al.* (1990) for the mosses; and Esslinger and Egan (1995) for the lichens.

Garry oak (*Quercus garryana*) is virtually restricted to southeastern Vancouver Island and adjacent Gulf Islands, where it forms a distinctive type of deciduous forest and parkland or savanna.

Scrub

Shrubby vegetation dominates the landscape in parts of three **lowland areas** of BC:

1. the dry southern Interior, where *Artemisia tridentata* (big sagebrush), *Ericameria (=Chrysothamnus) nauseosus* (rabbit-brush), and (locally) *Purshia tridentata* (antelope-brush) join several grass species to form closed and open scrub types, generally called shrub-steppe;
2. the North, where a medium-tall scrub of willows (*Salix* spp.) is abundant in burned-over areas, and a low scrub of dwarf evergreen shrubs (*Ledum groenlandicum* [Labrador tea], *Chamaedaphne calyculata* [leatherleaf]) or of willows and *Betula nana* (scrub birch), together with stunted black spruce, covers much of the extensive peatlands of the Great Plains Region;
3. the outer northern Coast, where a scrub of stunted shore pine (*Pinus contorta* var. *contorta*), yellow-cedar and redcedar, hemlocks, and *Juniperus communis* (common juniper), *Ledum groenlandicum, Gaultheria shallon* (salal), *Kalmia microphylla* ssp. *occidentalis* (bog-laurel), *Vaccinium* spp. (blueberries and huckleberries), and *Empetrum nigrum* (crowberry) forms part of the coastal muskeg that is widespread on flat to moderately sloping peatlands.

Scrub is also dominant at **high elevations** throughout the province. Willows form subalpine and alpine scrub over much of the Interior; *Betula nana* often occurs with the willows, especially in the North. Species of *Vaccinium* form high elevation scrub, especially on coastal and snowier interior mountains. Slide tracks and some north coastal alpine communities are dominated by *Alnus viridis* ssp. *sinuata* (Sitka alder). Dwarf scrub is another widespread, abundant form of high elevation vegetation. Dwarf shrubs, evergreen-leaved (such as *Cassiope* and *Phyllodoce* spp. [mountain-heathers], *Empetrum nigrum, Dryas* spp. [mountain-avens]) or deciduous (*Salix* spp. *Vaccinium* spp.*),* dominate many subalpine and alpine heath and tundra communities.

Elsewhere in the province scrub can be extensive or (more often) localized, and usually develops after fire or as wetland vegetation.

Grass

In this treatment, grass vegetation consists primarily of grasses and other grass-like plants. Hence, as a form of vegetation it includes marshes and grassy tundra as well as typical grassland vegetation.

Grasslands dominated by bunchgrasses, other grasses, and also shrubs occur in valley bottoms and on several plateaus in southcentral BC, from the Riske Creek area in the Chilcotin district south to the international border. Similar grasslands occupy smaller areas in southeastern BC. *Pseudoroegneria spicata* (bluebunch wheatgrass; formerly known as *Agropyron spicatum*) is the most widespread and dominant species. Other abundant or frequent species include *Festuca altaica s. lat.* (Altai fescue; including *F. scabrella*, rough fescue),

F. idahoensis (Idaho fescue), *Poa sandbergii s. lat.* (Sandberg's bluegrass), *Koeleria macrantha* (junegrass), *Bromus tectorum* (cheatgrass), *Hesperostipa comata* (needle-and-thread grass*), Achnatherum (=Stipa) richardsonii* (spreading needlegrass), *Hesperostipa curtiseta* (porcupinegrass; formerly known as *Stipa spartea* var. *curtiseta*), *Poa pratensis* (Kentucky bluegrass), *Artemisia tridentata, A. frigida* (pasture sage), and *Ericameria (=Chrysothamnus) nauseosus*.

The drier, rainshadow areas of southwestern BC have small pockets of grassland, usually on warm, rocky, south-facing slopes, and are associated with dry woodland of Douglas-fir, arbutus, and Garry oak. These vernal grasslands are dominated by annual species of *Bromus* (bromegrass), *Vulpia* (fescue), and *Aira* (hairgrass). They include many introduced species as well as showy, spring-flowering forbs, and are closely related to the annual grasslands of Oregon and California.

In the northern two-thirds of the province, lower elevation grasslands are usually localized and restricted to steep, south-facing slopes. Some typical species are *Elymus trachycaulus* (slender wheatgrass), *Festuca altaica*, *Calamagrostis purpurascens* (purple reedgrass), *Achnatherum richardsonii, Achnatherum nelsonii* (stiff needlegrass; formerly known as *Stipa columbiana*), *Leymus innovatus* (fuzzy-spiked wildrye), *Poa glauca* (glaucous bluegrass), *Artemisia frigida,* and *A. campestris* (northern wormwood).

High elevation grass vegetation occurs throughout the province in the drier alpine areas. Dominant grasses vary from south to north, but include *Festuca altaica* (now including former *F. scabrella*), *F. viridula* (green fescue), *F. brachyphylla* (alpine fescue), *Poa arctica* (arctic bluegrass), *Hierochloe alpina* (alpine sweet-grass), and *Calamagrostis purpurascens*. Species of the sedge family often dominate or co-dominate the vegetation. Some typical species are *Carex phaeocephala* (dunhead sedge), *C. spectabilis* (showy sedge), *C. microchaeta* (small-awned sedge), *C. nardina* (spikenard sedge), *C. albonigra* (two-toned sedge), *C. scirpoidea* ssp. *pseudoscirpoidea* (single-spiked sedge), *C. capitata* (capitate sedge), and *Kobresia myosuroides* (Bellard's kobresia).

Wetland grass types include several different kinds of marsh and fen vegetation. Freshwater marshes and fens are usually dominated by sedges or grasses. Some typical species include *Carex aquatilis* (water sedge), *C. utriculata* (beaked sedge), *C. vesicaria* (inflated sedge), *C. nigricans* (black alpine sedge), *Schoenoplectus acutus* and *S. tabernaemontani* (great bulrush; formerly *Scirpus lacustris s. lat.*), *Trichophorum caespitosum* (tufted clubrush), *Phalaris arundinacea* (reed canary-grass), and *Phragmites australis* (common reed), among many others. Coastal saline marshes are frequent but usually not extensive; their most characteristic dominant species are *Carex lyngbyei* (Lyngbye's sedge) and *Deschampsia cespitosa* (tufted hairgrass). Alkaline marshes occur in the dry southern Interior and have species such as *Distichlis spicata* var. *stricta* (alkali saltgrass), *Muehlenbergia asperifolia* (alkali muhly), *Hordeum jubatum* (foxtail barley), *Juncus balticus* (Baltic rush), *Schoenoplectus* spp. (bulrush), *Salicornia europaea* (European glasswort), and *Suaeda depressa* (seablite).

Broad-leaved herb

Timberline meadows are the only widespread, natural, broad-leaved herbaceous vegetation type in BC. Such meadows are most abundant at high elevations of the

southern two-thirds of the Interior of the province. Typically they include *Senecio triangularis* (arrow-leaved groundsel), *Veratrum viride* (false hellebore), *Valeriana sitchensis* (Sitka valerian), *Erigeron peregrinus* (subalpine daisy), and *Lupinus arcticus* (arctic lupine). Somewhat similar (but usually with more *Heracleum maximum* [cow-parsnip] and *Epilobium angustifolium* [fireweed]) meadows occur at middle elevations here and there, often associated with aspen forests, but typically such moist montane meadows are small, localized, and almost invariably disturbed – usually by grazing.

Seasonal herb meadows also occur locally in the Strait of Georgia region and in some openings in the dry forest of the southern Interior.

Bryoid

Vegetation dominated by mosses, liverworts, or lichens usually occurs in environments too harsh for vascular plants. BC, for example, has raised *Sphagnum* bogs, rock outcrops partially covered by lichens and mosses such as *Racomitrium, Polytrichum*, and *Dicranum*, and alpine lichen tundra.

Biogeoclimatic Zones

The BCMOF currently recognizes 14 biogeoclimatic zones in the province. This section provides a brief overview of the zones; in-depth descriptions of each zone are available at the BCMOF web site[10].

The 14 zones are presented in Figure 8. Eight representative cross sections from four segments of the province are shown in Figure 9. These display typical elevational sequences of biogeoclimatic zones from the eight areas. For example, in Cross Section One (Dall Lake to Tetsa River), the sequence is Boreal White and Black Spruce zone at lower elevations, Spruce – Willow – Birch zone at middle elevations, and Alpine Tundra at the higher elevations.

Climatic characteristics for the biogeoclimatic zones are summarized in Table 4 using selected climate variables and stations. A few long-term climate stations were chosen for each zone to demonstrate the range of regional climates. It is not possible to show the complete range of climatic conditions in a zone because the distribution of climate stations does not represent the entire landscape.

Table 5 shows the occurrence and abundance of tree species in the zones. Figure 10 compares the zonal vegetation of the 14 zones, i.e. the vegetation occurring on zonal sites.

Ecosystem Field Guides

In applying the BEC classification to resource management in BC, users must identify site units. This involves identifying the biogeoclimatic subzone and variant and the site unit. Two types of products are required to do this: maps of biogeoclimatic subzones and variants, and field guides to site identification.

[10] www.for.gov.bc.ca/hfd/pubs/Docs/Srs/SRseries.htm.

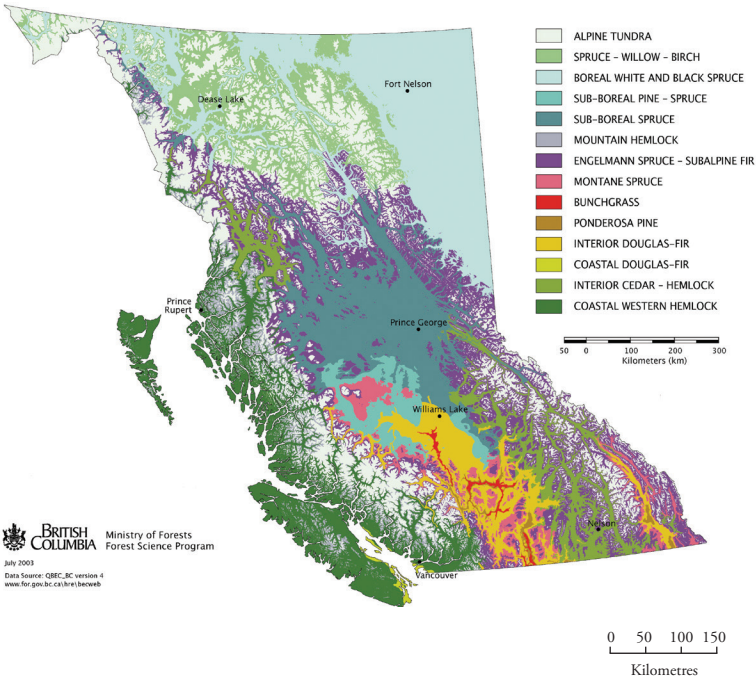


Figure 8:
Biogeoclimatic zones of BC.
See inside back cover for a larger full colour version of this map.

Identifying biogeoclimatic units

Identifying the biogeoclimatic subzone and variant generally involves locating the site in question on a biogeoclimatic map and then confirming the mapping with field observations ("ground-truthing") near the site location. The biogeoclimatic map products discussed in the "Mapping" section are of various scales and, therefore, resolution. Most mapping is general (at scales of 1:100,000 – 1:250,000) and therefore requires field confirmation for any site location. Even large-scale mapping (1:20,000 – 1:50,000) requires confirmation for specific sites, for biogeoclimatic mapping is a representation of regional climates, and not all areas are ground-checked in the mapping process. As well, it is difficult to map regional climates, even at a large scale, where climatic gradients are gradual (e.g. plateau landscapes) or transitional.

The ecosystem classification field guides, usually entitled A field guide to site identification and interpretation … (for a specified area), contain information required to confirm the biogeoclimatic unit in the field (e.g. Lloyd et al. 1990, Braumandl and Curran, 1992, Banner et al. 1993, Green and Klinka, 1994, DeLong et al. 1990; 1993; 1994; Steen and Coupé, 1997). These clues include location, elevation range, zonal and distinguishing vegetation, zonal soils, and other descriptive text. By observing elevation,

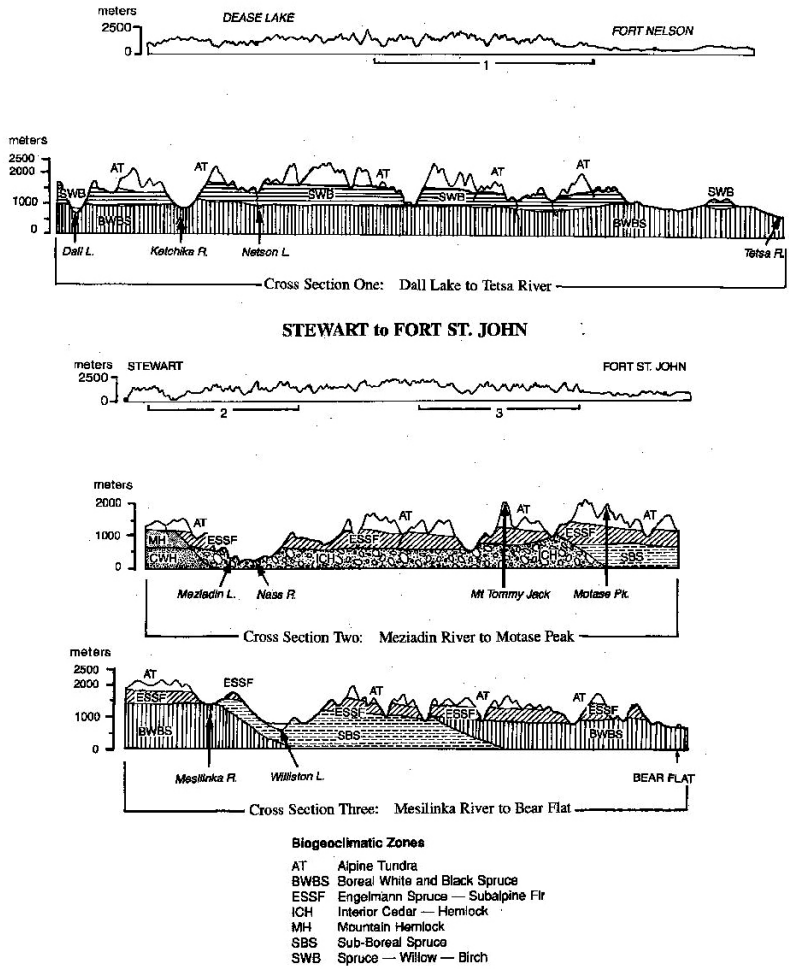


Figure 9:
Eight representative cross sections of biogeoclimatic zones. (continues in next pages)

vegetation and soils *en route* to the site, subzone/variant can be confirmed efficiently by combining this contextual knowledge with site attributes (see Figures 11 and 12).

On-site data required for confirming the biogeoclimatic unit is usually recorded on a site identification form. The Ground Inspection Form (British Columbia, 1998) can be used because it has data fields for location, site, soil and vegetation data.

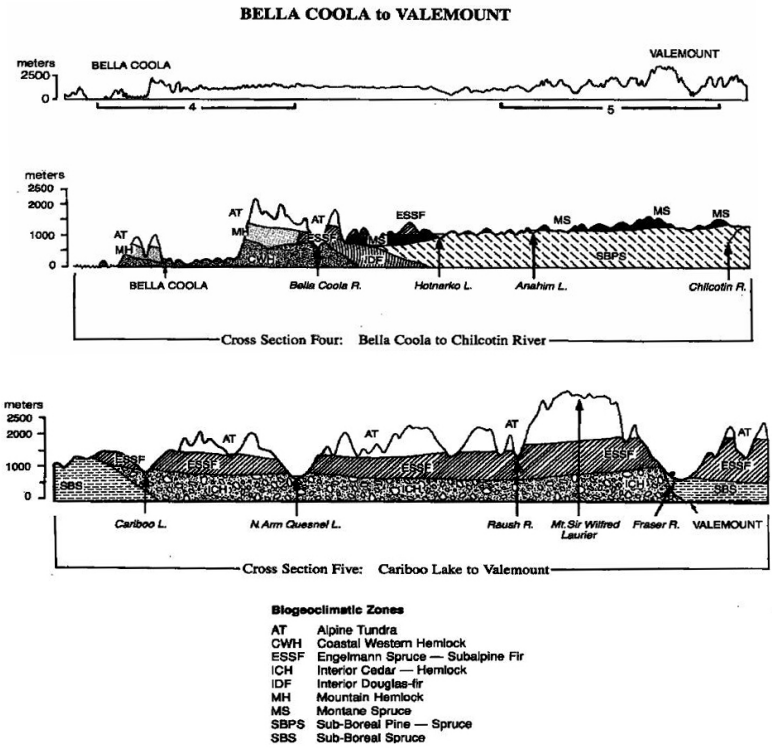


Figure 9:
(cont'd.): Eight representative cross sections of biogeoclimatic zones.

Describing and identifying site units

Site identification begins with the description of the site, soil, and vegetation characteristics of the site. A site could be an ecologically uniform portion of a proposed cutblock or wildlife habitat area, or a pre-determined plot, e.g. a forest productivity plot, representing a "stratum" in a sampling design. The procedures for site identification are designed for a homogeneous site, i.e. a site that is fairly uniform in its site, soil and vegetation features and is of a reasonable size. A site should be large enough to allow for the description of an area of about 400 m^2 – the size of the sample plot used in the field sampling to develop the classification (at least 400 m^2 for forests). Describing sites smaller than this may be acceptable in some non-forested ecosystem types, but in forested areas, small "sites" may merely represent "noise".

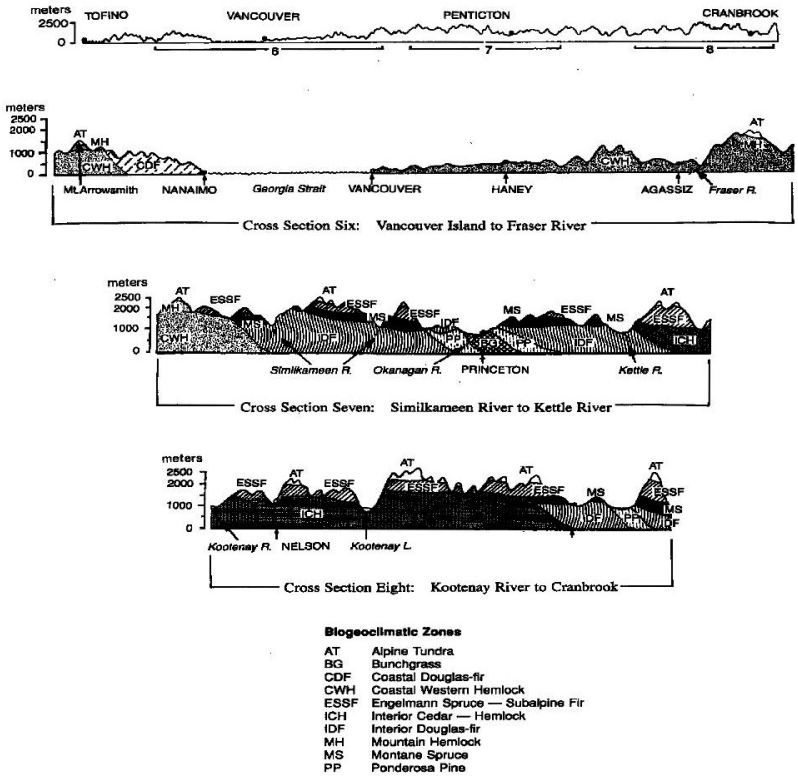


Figure 9:
(cont'd.): Eight representative cross sections of biogeoclimatic zones.

Site description data are usually recorded on a site identification form. Both the Ground Inspection Form (British Columbia, 1998) and the Site Assessment Form (Appendix 9, Green and Klinka, 1994) have fields for entering the location, site, soil and vegetation data necessary to identify a site unit, using the field guide aids and descriptions. Instructions and tools for completing the Ground Inspection Form are found in the *Field Manual for Describing Terrestrial Ecosystems* (British Columbia, 1998). Useful aids, such as soil moisture and nutrient regime, soil texture, parent material, rock type, and humus form keys, are found in the appendices of most site identification field guides.

Identifying a site unit involves using the aids and descriptions in the site identification manuals to "name" the site unit. The site units are presented by biogeoclimatic unit, so we recommend determining the "correct" biogeoclimatic unit at the outset. The aids to site identification vary somewhat by field guide, but

Table 4: Climatic characteristics for the biogeoclimatic zones of BC.

Zone	Range and reference station	Lat. (°')	Lon. (°')	Elevation (m)	Mean annual precip. (mm)	Mean summer precip. (May-Sept) (mm)	Mean precip. of driest month (mm)	Mean precip. of wettest month (mm)	Driest Month	Wettest month
AT	Old Glory Mtn.	49 09	117 55	2,347	755.5	287.0	40.0	84.1	Jul	Dec
BG	Max			558	335.7	174.5	17.3	55.4		
	Min			297	205.6	98.0	8.0	27.3		
	Kamloops	50 40	120 20	379	241.7	111.4	8.0	36.1	Mar	Jan
BWBS	Max			840	50..7	305.3	24.3	879.0		
	Min			382	327.1	144.7	8.3	41.1		
	Fort Nelson A	58 50	122 35	382	451.8	297.9	16.7	84.3	Apr	Jul
CDF	Max			223	1,262.6	238.3	38.6	232.9		
	Min			8	647.2	107.3	13.4	119.2		
	Victoris Int'l A	48 39	123 26	19	872.9	141.9	18.1	157.3	Jul	Dec
CWH	Max			671	4,386.8	1,162.0	151.0	625.4		
	Min			0	990.2	159.3	16.8	145.7		
	Haney UBC RF Admin	49 16	122 34	143	2,140.1	467.8	65.5	331.7	Jul	Dec
ESSF	Max			1,862	1,995.4	424.5	64.8	297.4		
	Min			863	514.1	204.6	26.6	57.4		
	Boss Mountain	52 06	120 53	1,532	1,177.1	401.6	63.5	140.6	May	Dec
ICH	Max			1,085	1,1419.0	439.3	57.2	224.3		
	Min			314	497.7	199.9	21.4	57.8		
	Revelstoke	51 00	118 12	456	1,063.7	325.0	51.4	177.0	Apr	Jan
IDF	Max			1,128	1,198.9	290.7	37.6	208.8		
	Min			122	295.1	107.5	13.5	34.8		
	150 Mile House	52 07	121 56	738	414.2	214.0	15.8	60.7	Apr	Jun
MH	Hollyburn Ridge	49 23	123 12	930	2,954.3	694.4	106.9	434.8	Jul	Dec
MS	Max			1,554	663.8	252.1	38.5	108.1		
	Min			1,128	380.8	158.2	17.9	45.2		
	Peachland Brenda Mines	49 52	120 00	1,520	638.3	197.0	29.3	89.1	Apr	Dec
PP	Max			939	604.5	270.3	30.7	77.6		
	Min			244	319.5	86.3	11.0	34.5		
	Kelowna	49 54	119 28	354	332.2	136.3	15.3	45.1	Apr	Dec
SBPS	Max			1,219	517.8	299.8	21.1	86.5		
	Min			914	464.1	242.6	20.8	36.4		
	Alexis Creek Tautri Creek	52 33	123 11	1,219	464.1	242.6	20.8	57.6	Apr	Jun
SBS	Max			1,245	1,588.2	352.6	36.8	278.7		
	Min			488	438.9	188.9	15.2	49.8		
	Prince George A	53 63	122 40	676	628.3	300.8	27.4	68.2	Apr	Aug
SWB	Cassiar	57 17	129 50	1,078	699.5	275.1	25.7	84.2	Apr	Oct

Zone key

AT	Alpine Tundra
BG	Bunchgrass
BWBS	Boreal White and Black Spruce
CDF	Coastal Douglas-fir
CWH	Coastal Western Hemlock
ESSF	Engelmann Spruce - Subalpine Fir
ICH	Interior Cedar - Hemlock
IDF	Interior Douglas-fir
MH	Mountain Hemlock
MS	Montane Spruce
PP	Ponderosa Pine
SBPS	Sub-Boreal Pine - Spruce
SBS	Sub-Boreal Spruce
SWB	Spruce - Willow - Birch

Table 4 (cont'd)

Mean Annual snowfall (cm)	No. of months with snow	Mean annual temp (°C)	Mean temp. coldest month (°C)	Extreme min. temp (°C)	Mean temp. warmest month (°C)	Extreme max. temp (°C)	No. of months with mean temp. (°C) >10	No. of months with mean temp. (°C) <0	No. of frost free days	Frost free period (days)	Accumulated degree (°C) days Above 5	Accumulated degree (°C) days Below 0
551.4	12	-1.8	-11.1	-37.8	9.5	27.2	0	7	103	21	427	1,763
99.6	9	10.0	-2.7	-22.2	22.4	43.9	6	4	252	181	2,516	878
50.5	6	5.9	-10.8	-42.8	18.0	37.2	5	2	182	122	1,771	230
67.2	71	8.7	-5.4	-38.3	21.4	41.7	5	3	236	166	2,320	418
268.8	12	1.3	-17.7	-47.2	16.6	40.6	3	7	172	115	1,268	2,742
134.9	9	-2.9	-24.5	-58.9	12.0	30.6	2	5	119	44	709	1,692
186.5	10	-1.4	-23.8	-51.7	16.6	36.7	3	5	146	106	1,266	2,643
95.2	6	10.5	4.1	-11.7	18.0	406	6	0	349	304	2,121	43
17.2	5	9.2	1.8	-21.1	15.4	31.1	5	0	260	155	1,794	9
49.9	6	9.5	3.1	-15.6	16.3	36.1	5	0	305	201	1,863	25
840.8	9	10.5	4.7	-10.6	18.7	40.6	6	5	344	272	2,205	493
25.5	5	4.5	-6.6	-30.6	13.1	22.8	3	0	188	116	1,059	5
81.6	7	9.2	1.4	-20.0	16.8	35.0	5	0	291	198	1,882	59
1,431.0	12	1.8	-7.9	-35.6	13.3	35.6	2	6	140	79	801	1,189
246.5	9	1.1	-10.9	-46.7	11.3	28.3	2	5	110	32	629	879
782.1	11	1.1	-10.1	-41.1	12.1	31.1	2	6	140	75	671	1,189
733.6	9	8.9	-2.9	-26.1	20.8	42.8	5	5	243	184	2,140	820
122.3	7	4.1	-10.1	-46.1	16.3	33.3	4	2	169	95	1,267	238
421.8	8	6.9	-6.1	-34.4	19.0	40.6	5	3	221	149	1,808	468
283.4	10	9.6	-2.6	-26.7	21.3	43.3	5	5	279	204	2,366	1,260
82.0	7	1.6	-13.1	-50.0	13.2	33.9	3	2	101	24	903	235
144.5	9	4.2	-10.7	-45.0	15.8	36.1	4	5	163	79	1,346	906
820.2	10	5.0	-2.3	-26.7	13.2	33.3	3	2	198	126	919	307
397.8	11	4.7	-7.8	-37.2	17.4	36.7	4	5	177	126	1,310	890
193.2	9	1.7	-12.5	-43.9	13.2	33.5	3	5	107	20	891	847
397.8	10	2.7	-7.8	-38.9	14.2	33.5	3	5	152	92	991	884
170.8	9	9.6	-2.7	-26.7	21.6	42.2	6	5	256	173	2,442	816
8038	6	4.8	-8.6	-45.6	17.2	36.1	5	2	166	89	1,505	258
96.9	7	8.6	-3.3	-31.1	20.4	38.9	5	3	226	160	2,075	268
195.2	10	2.5	-12.3	-42.8	14.3	33.3	3	7	152	61	1,044	1,405
177.5	9	0.4	-13.8	-51.1	9.2	31.1	2	5	85	12	697	1,140
195.2	10	0.4	-13.8	-51.1	11.6	32.2	2	5	85	12	697	1,405
378.9	10	5.0	-7.7	-38.3	16.9	40.6	5	5	182	119	1,510	1,369
110.5	8	1.7	-14.6	-51.7	12.9	32.2	3	4	130	45	884	792
241.7	9	3.3	-12.1	-50.0	15.1	34.4	3	5	170	85	1,198	1,057
395.0	11	-3.2	-19.2	-47.2	11.2	29.4	1	7	103	37	534	2,298

Table 5: Occurrence[a] of trees in the biogeoclimatic zones of British Columbia.

Gymnosperms	BG	PP	IDF	ICH	MS	SBPS	SBS	BWBS	SWB	MH	CDF	CWH	ESSF	AT[b]
Abies amabilis (amabilis fir)	–	–	–	+	–	–	–	–	–	+++	–	+++	(+)	–
A. grandis (grand fir)	–	–	++	++	+	–	–	–		–	++	+	–	–
A. lasiocarpa (subalpine fir)	–	–	–	++	+++	(+)	+++	++	+++	++	–	+	+++	–
Chamaecyparis nootkatensis (yellow-cedar)	–	–	–	–	–	–	–	–	–	+++	–	++	(+)	–
Juniperus scopulorum (Rocky Mountain juniper)	+	+	++	–	–	–	+	(+)	–	–	++	(+)	–	–
Larix laricina (tamarack)	–	–	–	–	–	–	(+)	++	–	–	–	–	–	–
L. lyallii (alpine larch)	–	–	–	–	–	–	–	–	–	–	–	–	++	–
L. occidentalis (western larch)	–	+	+++	++	+++	–	–	–	–	–	–	–	+	–
Picea engelmannii (Engelmann spruce)	–	–	+	++	+++	–	–	–	–	+	–	–	+++	–
P. engelmannii x *glauca* (hybrid white spruce)	–	(+)	++	++	+++	+	+++	–	–	–	–	–	++	–
P. glauca (white spruce)	–	(+)	+	–	+	+++	++	+++	+++	–	–	–	+	–
P. glauca x *sitchensis* (Roche spruce)	–	–	–	++	–	–	–	–	–	(+)	–	++	–	–
P. mariana (black spruce)	–	–	–	+	–	–	++	+++	+	–	–	–	–	–

Table 5 (cont'd)

Gymnosperms	BG	PP	IDF	ICH	MS	SBPS	SBS	BWBS	SWB	MH	CDF	CWH	ESSF	AT[b]
P. sitchensis (Sitka spruce)	–	–	–	–	–	–	–	–	–	+	+	+++	–	–
Pinus albicaulis (whitebark pine)	–	–	–	–	–	–	–	–	–	+	–	–	++	–
P. banksiana (jack pine)	–	–	–	–	–	–	–	(+)	–	–	–	–	–	–
P. contorta (lodgepole pine)	(+)	–	+++	++	+++	+++	+++	+++	++	+	++	++	+++	–
P. flexilis (limber pine)	–	–	(+)	–	–	–	–	–	–	–	–	–	(+)	–
P. monticola (western white pine)	–	–	+	++	+	–	–	–	–	+	+	++	+	–
P. ponderosa (ponderosa pine)	+	+++	+++	+	–	–	–	–	–	–	–	–	–	–
Pseudotsuga menziesii (Douglas-fir)	+	++	+++	++	+++	+	++	–	–	(+)	+++	+++	+	–
Taxus brevifolia (western yew)	–	–	+	++	–	–	–	–	–	–	++	++	–	–
Thuja plicata (western redcedar)	–	(+)	++	+++	+	–	+	–	–	+	++	+++	+	–
Tsuga heterophylla (western hemlock)	–	–	+	+++	+	–	(+)	–	–	++	+	+++	+	–
T. mertensiana (mountain hemlock)	–	–	–	+	–	–	–	–	–	+++	–	+	++	–
Acer macrophyllum (bigleaf maple)	–	–	+	–	–	–	–	–	–	–	++	++	–	–
Alnus rubra (red alder)	–	–	–	–	–	–	–	–	–	–	+++	+++	–	–

Table 5 (con'td)

Gymnosperms	BG	PP	IDF	ICH	MS	SBPS	SBS	BWBS	SWB	MH	CDF	CWH	ESSF	AT[b]
Arbutus menziesii (arbutus)	–	–	–	–	–	–	–	–	–	–	++	+	–	–
Betula neoalaskana (Alaska paper birch)	–	–	–	–	–	–	–	++	–	–	–	–	–	–
B. occidentalis (water birch)	+	+	+	(+)	–	–	(+)	+	–	–	–	–	–	–
B. papyrifers (paper birch)	+	+	++	++	+	–	++	++	–	–	+	+	–	–
Cornus nuttallii (western flowering dogwood)	–	–	+	–	–	–	–	–	–	–	++	++	–	–
Populus balsamifera spp. *balsamifera* (balsam poplar)	–	–	–	–	–	–	+	++	+	–	–	–	–	–
P. balsamifera spp. *trichocarpa* (black cottonwood)	+	+	+	++	+	+	++	+	–	–	++	++	+	–
P. tremuloides (trembling aspen)	+	++	+++	++	++	+	+++	+++	+	–	+	+	+	–
+[c] (bitter cherry)	++[c]	–	–	+[c]	–	–	–	++	+	–	–			
Quercus garryana (Garry oak)	–	–	–	–	–	–	–	–	–	–	++	(+)	–	–
Rhamnus purshiana (cascara)	–	–	–	++[d]	–	–	–	–	–	–	++	+	–	–

[a] Occurrence classes: +++ (abundant); ++ (common); + (present but uncommon); (+) (very rare); – (absent).
[b] Tree species occur only in krummholz form in the Alpine Tundra zone.
[c] *P. emerginata* occurs in these zones, but only rarely as a (small) tree.
[d] Rarely as a small tree.

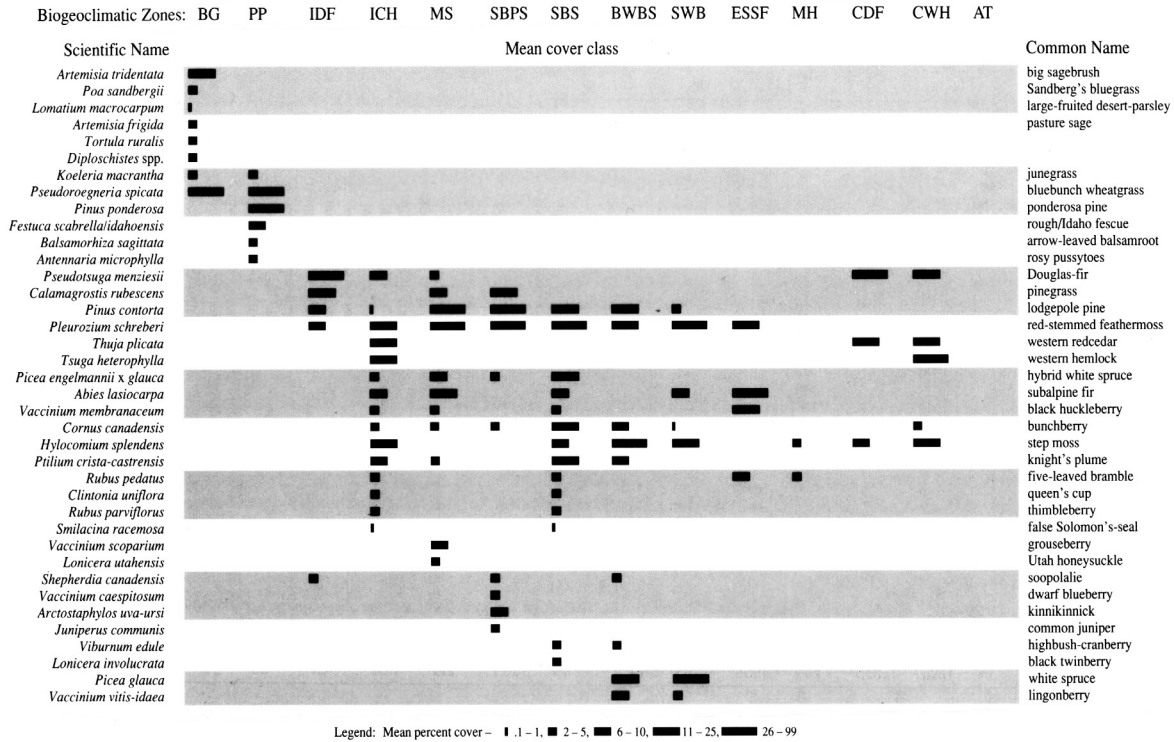


Figure 10: Zonal vegetation of the biogeoclimatic zones of BC.

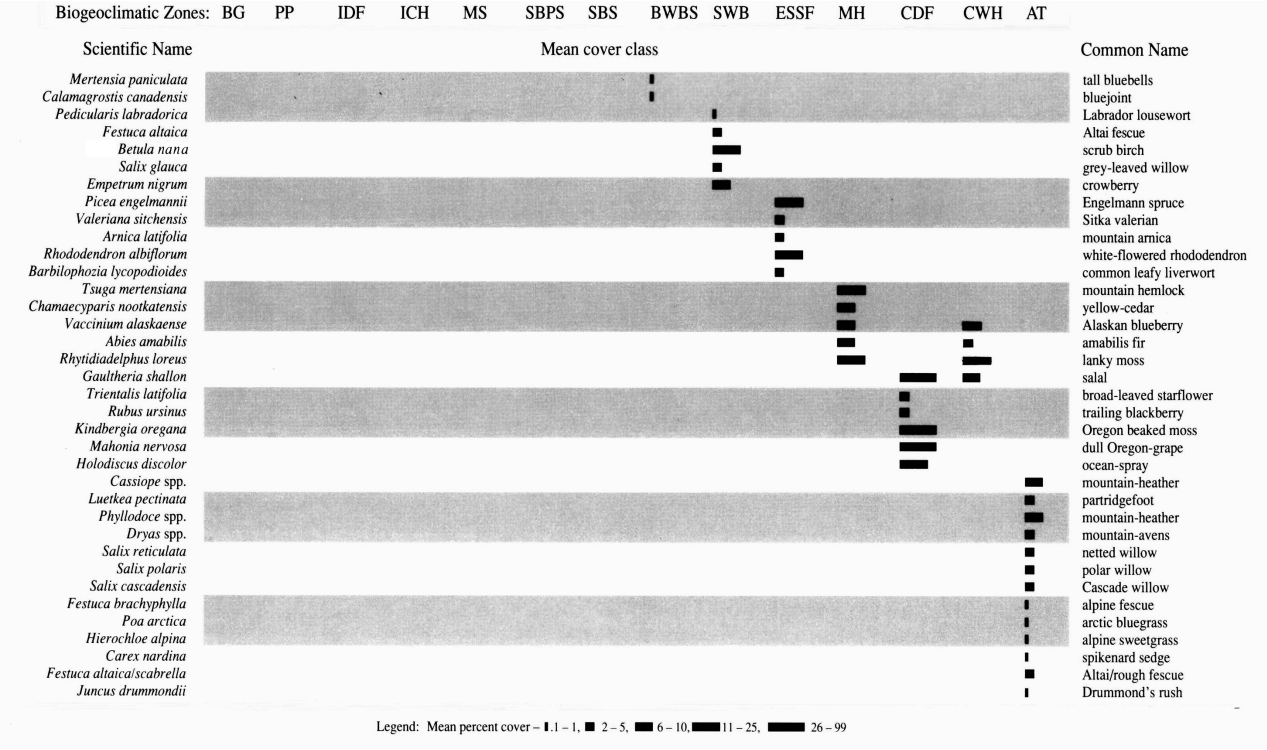


Figure 10: (cont.).

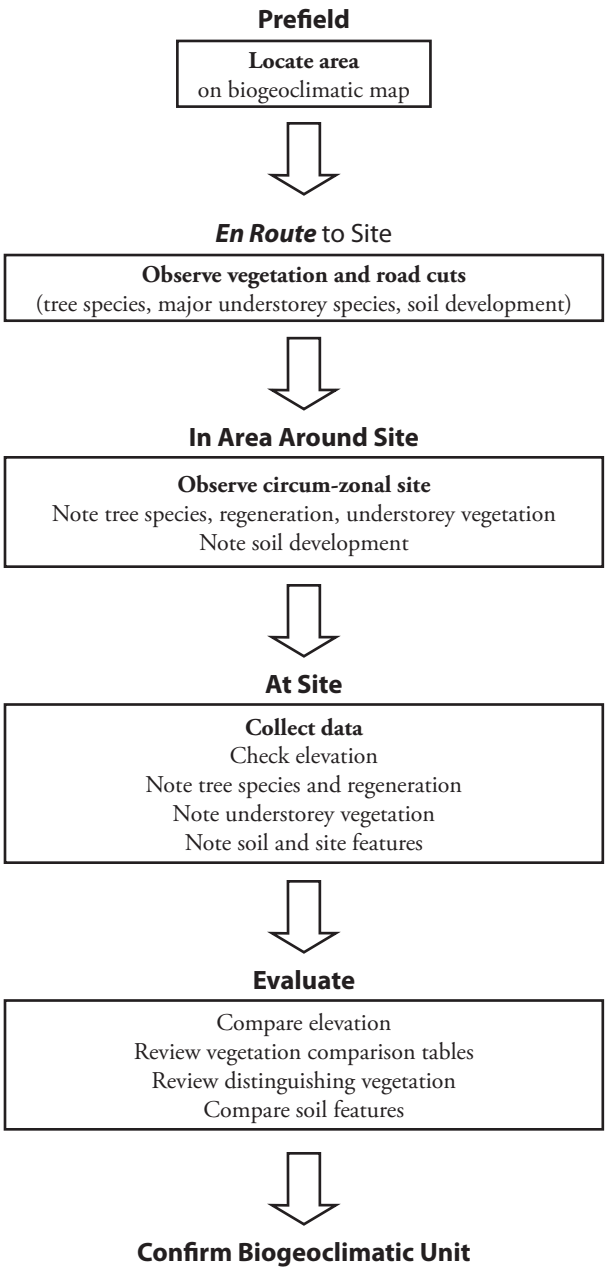


Figure 11:
Procedure for confirming biogeoclimatic unit.

SBSwk1

SUB-BOREAL SPRUCE
WET COOL SUBZONE
WILLOW VARIANT

The SBSwk1 occurs in the northeastern portion of the Cariboo Forest Region and adjacent portions of the Prince George Forest Region. In the Cariboo Forest Region (1473 km^2), it dominates the rolling terrain along the western edge of the Quesnel Highland north of the Cariboo River. It also extends eastward in valley bottoms into the more dissected and rugged landscapes of the Quesnel Highland and Cariboo Mountains. The SBSwk1 occurs just below the ESSFwk subzone and has the highest precipitation and coolest temperatures of the SBS Zone in the Cariboo Forest Region. Elevations are generally 900–1250 m.

Distinguishing Adjacent Units from the SBSwk1

The **ESSFwk1** occurs above the SBSwk1 throughout its distribution in the Cariboo Forest Region. The **SBSmw** occurs below the SBSwk1 along most of its border, although the **ICHwk4** occurs below the SBSwk1 in the lower Cariboo River valley. The **ICHmk3** borders a small portion of the SBSwk1 near Spectacle Lake along the southwestern boundary of Bowron Park. It occurs at similar elevations but in apparently warmer climates than the SBSwk1.

In the **ESSFwk1**, zonal sites have:
• white flowered rhododendron, red elderberry, and Sitka valerian.

In the **SBSmw**, zonal sites have:
• common Douglas-fir and prince's pine;
• little or no oak fern, three-leaved foamflower, or five-leaved bramble.

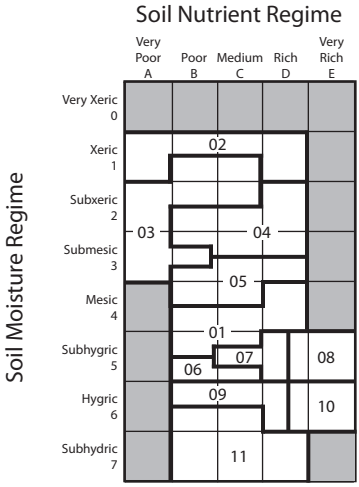
In the **ICHwk4**, zonal sites have:
• western redcedar and western hemlock;
• frequent Douglas-fir.

In the **ICHmk3**, zonal sites have:
• western redcedar and Douglas-fir;
• prince's pine;
• little or no oak fern.

Figure 12:
Example of field guide description of a biogeoclimatic unit and the features that distinguish it from adjacent biogeoclimatic units.

every guide contains the following two tools for each biogeoclimatic unit:

- edatopic grid. The grid portrays the relative soil moisture and nutrient regime of each site series (e.g. Figure 13).
- vegetation table. These tables (e.g. Figure 14) compare the mature to climax vegetation composition of site series by showing the presence and abundance



SBSwk1 Site Series

01 Sxw - Oak fern
02 Pl - Huckleberry - Cladina
03 Pl - Huckleberry - Velvet-leaved blueberry
04 SxwFd - Knight's plume
05 Sxw - Huckleberry - Highbush-cranberry
06 Sxw - Pink spirea - Oak fern
07 Sxw - Twinberry - Oak fern
08 Sxw - Devil's club
09 Sxw - Horsetail
11 SbSxw - Scrub birch - Sedge

Note: SBSwk1/10 occurs in the Prince George Forest Region but has not been noted in the Cariboo Forest Region.

Figure 13:
Example of an edatopic grid portraying site series moisture/nutrient ranges.

of selected dominant and indicator species.

Most other field guides also contain the following aids for each biogeoclimatic subzone or variant:

- Landscape profile or mesoslope diagram. The slope profile depicts the typical location of site units with respect to slope position and parent material (e.g. Figure 15).
- Key or "flowchart" to site units. The keys and flowcharts are generally presented as a series of paired statements or lists of vegetation and environmental features that help to "key out" the site unit (e.g. Figure 16).
- Table of site features or environmental table. Tables summarizing selected environmental features of each site unit can be used to compare values among units (e.g. Figure 17).

Two field guides (Banner *et al.* 1993, Steen and Coupé, 1997) also contain brief descriptions of the site units, which help the user better understand the central concept or essence of the site unit (e.g. Figure 18).

Site identification often involves reconciling the outcome of the various aids. The edatopic grid, landscape profile, and table of site features allow for an **environmental analysis** of the site unit – the vegetation tables provide for a **vegetation analysis** of the site unit. The key to site units often combines environmental and vegetation characteristics. In many cases, the results are consistent and site identification is certain. However, there will be times when the outcomes are inconsistent. This could be for various reasons, e.g. the site is not homogeneous or an important site factor was not described (e.g. soil pit not deep enough) or the vegetation does not clearly reflect the site conditions.

The environmental analyses can be inconsistent with the vegetation analysis if the "wrong" choice was made in a key or if the site conditions are "odd." If

SBSwk1 Vegetation Table[a]

	Site Unit	02	03	04	05	01	06	07	08	09	11	
Tree Layer	*Pinus contorta*	▮▮▮▮▮	▮▮▮▮▮	▮▮▮▮▮	▮▮▮▮	▮	▮▮	▮			▮	lodgepole pine
	Abies lasiocarpa	▮▮▮	▮▮▮		▮▮▮▮	▮▮▮▮		▮▮▮	▮▮▮▮▮	▮▮▮	▮▮▮	subalpine fir
	Picea engelmannii x *glauca*		▮▮▮	▮▮▮	▮▮▮▮▮	▮▮▮▮▮	▮▮▮▮▮	▮▮▮▮▮	▮▮▮▮	▮▮▮▮▮	▮▮▮▮	hybrid white spruce
Shrub Layer	*Sorbus scopulina*	▮▮▮	▮	▮▮▮	▮▮	▮						western mountain ash
	Spiraea betulifolia	▮▮	▮▮▮	▮▮	▮▮▮	▮				▮		birch-leaved spirea
	Vaccinium membranaceum	▮▮▮▮▮	▮▮▮▮▮	▮▮▮▮▮	▮▮▮▮	▮▮▮		▮	▮	▮	▮	black huckleberry
	Vaccinium myrtilloides		▮▮▮▮				▮▮					velvet-leaved blueberry
	Amelanchier alnifolia		▮	▮▮▮	▮▮	▮▮	▮▮					saskatoon
	Acer glabrum			▮▮▮								Douglas maple
	Lonicera involucrata		▮	▮▮	▮▮▮	▮▮▮	▮▮▮▮▮	▮▮▮▮▮	▮▮	▮	▮▮	black twinberry
	Rubus parviflorus		▮	▮▮	▮▮▮	▮▮▮	▮▮▮	▮▮▮▮	▮▮			thimbleberry
	Spiraea douglasii						▮▮▮▮			▮	▮	hardhack
	Sambucus racemosa							▮▮▮	▮▮	▮		red elderberry
	Oplopanax horridus								▮▮▮▮▮			devil's club
	Ledum groenlandicum										▮▮▮	Labrador tea
	Betula glandulosa										▮▮▮▮	scrub birch
Herb Layer	*Clintonia uniflora*		▮	▮▮	▮▮▮	▮▮▮	▮▮		▮			queen's cup
	Aralia nudicaulis			▮▮▮	▮							wild sarsaparilla
	Gymnocarpium dryopteris	▮▮		▮▮▮	▮▮▮	▮▮▮▮▮	▮▮▮	▮▮▮▮▮	▮▮▮▮▮	▮		oak fern
	Cornus canadensis	▮▮▮	▮▮▮▮	▮▮▮	▮▮▮▮▮	▮▮▮▮	▮▮▮▮	▮	▮▮▮	▮▮▮▮	▮▮▮	bunchberry
	Streptopus roseus	▮▮		▮▮	▮▮▮	▮▮▮	▮▮	▮▮▮	▮▮	▮▮▮		rosy twistedstalk
	Smilacina stellata				▮▮▮	▮		▮				star-flowered false Solomon's-seal
	Tiarella trifoliata				▮	▮▮	▮▮	▮▮▮	▮▮▮	▮▮▮		foamflower
	Smilacina racemosa				▮	▮	▮▮▮	▮▮	▮▮	▮		false Solomon's-seal
	Dryopteris expansa					▮	▮▮	▮▮▮	▮▮▮▮▮	▮▮▮		spiny wood fern
	Veratrum viride					▮▮▮	▮▮▮		▮			Indian hellebore
	Galium triflorum						▮▮▮	▮▮	▮▮	▮		sweet-scented bedstraw
	Equisetum spp.						▮▮	▮▮▮		▮▮▮▮▮	▮▮▮	horsetails
	Potentilla palustris										▮▮▮	marsh cinquefoil
	Carex disperma									▮	▮▮▮	soft-leaved sedge
Moss Layer	*Cladina* spp.	▮▮▮	▮▮▮									reindeer lichens
	Cladonia spp.	▮▮▮	▮	▮▮								cladonia lichens
	Dicranum spp.	▮▮▮▮	▮	▮▮			▮▮					heron's-bill mosses
	Peltigera spp.	▮▮▮	▮▮▮	▮▮	▮	▮	▮▮▮	▮	▮▮▮		▮▮	pelt lichens
	Pleurozium schreberi	▮▮▮▮▮	▮▮▮▮▮	▮▮▮▮▮	▮▮▮▮▮	▮▮▮▮▮	▮▮▮	▮▮▮▮	▮▮▮	▮▮▮▮	▮▮▮▮	red-stemmed feathermoss
	Hylocomium splendens	▮▮▮			▮▮▮▮	▮▮▮▮		▮	▮	▮▮▮▮	▮	step moss
	Brachythecium spp.			▮▮▮		▮▮	▮▮▮	▮▮▮	▮▮▮	▮		ragged mosses
	Rhytidiadelphus triquetrus				▮▮▮	▮▮▮	▮▮▮	▮▮▮	▮▮▮▮	▮▮		electrified cat's-tail moss
	Mnium spp.				▮	▮▮▮▮	▮▮▮	▮▮▮▮▮	▮▮▮▮▮	▮▮▮▮		leafy mosses
	Sphagnum spp.									▮	▮▮▮▮	sphagnum

[a] Species abundance: ▮ present in 40–60% of plots surveyed; ▮▮ >60% of plots, mean cover <1%; ▮▮▮ >60% of plots, mean cover 1–7%; ▮▮▮▮ >60% of plots, mean cover >7–15%; ▮▮▮▮▮ >60% of plots, mean cover >15%

Figure 14: Example of a vegetation table comparing presence and abundance of selected species for each site series.

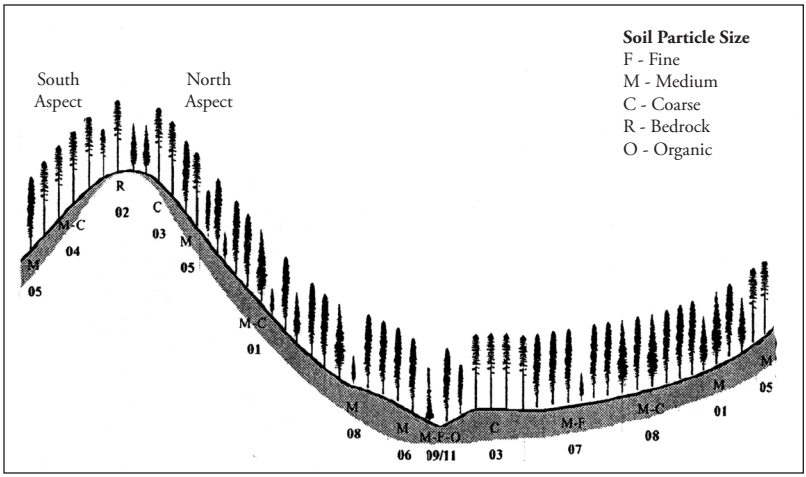


Figure 15:
Example of a landscape profile or mesoslope diagram (see Figure 13 for site series names).

inconsistencies result, the site description should be reviewed and then the site reidentified through the keys and other tools. Re-evaluate each feature to see whether the "correct" choice was made. Then emphasize the attributes that are certain, varying the others while using the keys and other tools.

The vegetation tables and information in the keys were derived from data from late-seral or climax ecosystems. Differences in species composition or cover can be expected in earlier developmental stages, due to dissimilar light conditions or disturbance factors or chance. This can complicate vegetation analysis because "indicator" species may not be present through all stages of stand development. Where this occurs, more emphasis should be placed on the results of the environmental analyses of the site unit.

Site identification on recent cutblocks or densely stocked plantations can be challenging due to the "condition" of the vegetation and changes to the surface soil or humus layer (forest floor). Harvesting or site treatment can alter the uppermost humus layer or disturb the surface soil horizons in some areas. Exposing the forest floor to heat and insolation can change humus form type (by increasing rate of decomposition). Humus type and presence of certain surface soil horizons (e.g. Ah, Ae) are used in some of the site identification tools, so field surveyors should try to determine whether significant changes have occurred in the area they are trying to identify. Digging a small soil pit in several locations may help determine whether or not the soil has been disturbed. Often areas near stumps are the least disturbed by harvesting or site preparation equipment. These areas can also harbour plant species that indicate site conditions, for disturbed areas are more likely to be invaded by weedy species.

Another option to site identification in cutblocks or plantations is to determine whether or not an adjacent, older stand is on the same type of site. If so, vegetation and surface soil characteristics can be evaluated there. It is because of the difficulties in site identification on disturbed sites that a preharvest evaluation of site unit is conducted.

Key to Site Units of the SBSwk1

1a. Soils shallow (<80 cm) to bedrock and no significant seepage water input; slope position usually crest or upper; bedrock outcrops often present.

2a. Soils predominantly very shallow (<35 cm) over bedrock; slope position mostly crest; cladonia and cladina lichens abundant (>5% cover); moisture regime very xeric or xeric.
SBSwk1/02 Pl – Huckleberry – Cladina

2b. Soils predominantly deeper; bedrock often not exposed; slope position mostly upper, occasionally crest; cladonia and cladina lichens not abundant; moisture regime xeric or subxeric.

3a. Douglas maple cover >1% and velvet-leaved blueberry absent or incidental; slope gradient >20% **and** slope aspect predominantly south or west.
SBSwk1/04 SxwFd – Knight's plume

3b. Douglas maple cover <1%; velvet-leaved blueberry usually present; slope gradient <20% or, if steeper, then slope aspect predominantly north or east.
SBSwk1/03 Pl – Huckleberry – Velvet-leaved blueberry

1b. Soils deeper (>80 cm), or significant near-surface seepage water input; slope position various but seldom crest; bedrock outcrops usually not present;

4a. Soil texture sand or loamy sand, and no evidence of seepage water or water table within 100 cm of surface; slope position predominantly mid, upper, or level; velvet-leaved blueberry present.
SBSwk1/03 Pl – Huckleberry – Velvet-leaved blueberry

4b. Soil texture finer or, if sand, then evidence of seepage water or a water table within 100 cm of soil surface; slope position various; velvet-leaved blueberry usually absent or incidental.

Figure 16:
Example of a portion of a key to site units demonstrating paired statements.

If neither the vegetation nor the environmental analysis provide a reasonable identification, check if the area is in a climatic transition or whether the biogeoclimatic unit is correct. It may be necessary to identify the site series using the tools from an adjacent biogeoclimatic unit and then determine which unit best "fits" the site conditions. It could also be possible that an unclassified site unit has been found and that the classification does not have a category for the site being assessed.

Consistently accurate site identification improves with experience. It is important to recognize that classification creates units from sample data and that some sites may not be classified and others may be transitional due to site or climatic conditions.

Site Series	Site Features of SBSwk1 Site Series 01	02	03	04	05
Key Features	zonal and other gently to steeply sloping sites with mesic or near-mesic moisture regime	very dry ridge and hill crests and upper slopes with very thin (<35 cm) soils over bedrock; bedrock usually exposed	mostly dry sandy soils soils on gentle (some steep) slopes; also dry, shallow (40-80 cm) soils on N and E aspects and gentle S and W aspects	steep S and W aspects with shallow (40-80 cm) loamy soils or deep loam soils that have a high coarse fragment content	wide ridge of sub-mesic sites: upper slopes, broad crests, and gentle S and W aspects with deep loamy soils
Soil Moisture/ Nutrient Regimes	mesic, subhygric / poor – rich	xeric / very poor – rich	xeric – submesic / very poor – medium	subxeric, submesic / poor – rich	submesic, mesic / poor – rich
Slope Position	upper – lower	crest	crest, upper, mid, level	mid, upper	upper, mid, level
Slope Aspect	all	all	all	SE, S, SW, W	all (N or E on steep slopes)
Slope Grade (%)	0–50 (70)	0–30	0–70	>30	0–50 (70)
Soil Texture	gravelly loamy, sand, silty	gravelly loamy	sand, gravelly sand	loamy, gravelly loamy	loamy, gravelly loamy
Humus Form and Thickness (cm)	Hemimor, Hemihumimor 3–8	Xeromor 1–3	Hemimor, Xeromor 1–8	Hemimor 3–8	Hemimor 3–8
Occurrence / Size / Distribution	predominant / large / wide	uncommon / small / wide	common / medium / wide	uncommon / small / wide	common / medium / wide

Figure 17: Example of an environmental table comparing site and soil attributes for a subset of site series in the SBSwk1.

Site Units of the SBSwk1

Zonal Site Series **01 Sxw – Oak fern Site Series** dominates the SBSwk1 landscape, occurring from upper to lower slope positions on medium-textured soils. It occurs on gentle and steep slopes and on all slope aspects. Climax tree species are hybrid white spruce and subalpine fir. Spruce is the principal canopy species, while subalpine fir is the principal tree species in the regeneration layer. Subalpine fir as well as lodgepole pine are often present in the canopy. Since wildfires have been less frequent than in other portions of the SBS in the Cariboo Region, lodgepole pine stands are also less common. The undergrowth of mature forests has a moderate cover of shrubs, consisting of several species. Black twinberry and black huckleberry are among the most abundant. The herbaceous layer has a moderate cover of low-growing species including oak fern, bunchberry, rosy twistedstalk, and stiff clubmoss. Moss cover is nearly continuous.

Drier Sites Sites drier than those of the zonal site series are moderately common, occurring on ridge tops, shallow soils, sandy soils, and steep south-facing slopes. These sites are distinguished by having more lodgepole pine, birch-leaved spirea, and western mountain-ash than do mesic and wetter sites. Moist-site species such as spiny wood fern, sweet-scented bedstraw, and leafy mosses are uncommon.

02 Pl – Huckleberry – Cladina Site Series occurs on upper slopes and ridge tops where bedrock is very near (<35 cm) the surface. These are small, localized sites with a vegetation distinguished by abundant ground lichens. The mature forest canopy is typically dominated by lodgepole pine or subalpine fir. Low shrubs, especially black huckleberry and dwarf blueberry, are abundant, but the herbaceous layer is typically sparse. Moss cover is relatively patchy, occurring mostly on microsites with deep soils.

Figure 18:
Example of brief descriptions articulating the central concepts of two site units.

Mapping site units

Application of the classification often involves mapping the site units for an area. For example, a satisfactory preharvest silviculture prescription requires ecological stratification of the proposed cutblock. Stratification involves the delineation of ecologically uniform areas with subsequent site description and identification within the polygon delineations.

Depending upon the scale of mapping and the landscape, a polygon delineation may include one to many site units. The main objective of stratification is to delineate map polygons with as few site units as possible. Simple map polygons, i.e. those with only one site unit, allow for straightforward prescriptions. Polygons containing several site series require more complex prescriptions, unless the site series have the same prescription for a particular practice.

Information on mapping site units is contained in each field guide, in the

Silviculture Prescription Data Collection Field Handbook (Curran *et al.* 2000), and in the terrestrial ecosystem mapping procedures (Resources Inventory Committee, 1998).

Applications

A multifactor, integrative, hierarchical classification can be put to many uses, depending on the parameters incorporated in the classification and the needs and objectives of its users. Sound management of natural resources requires knowledge and understanding of large amounts of information about diverse yet interrelated physical and biological resources, including water, soil, timber, range, wildlife, and recreation. Traditionally, resource managers have carried out separate inventories of each resource of importance in an area, then attempted to analyse the different factors and weigh the consequences of various combinations of uses. In contrast, we recommend an integrated approach facilitated by BEC.

An ecosystem classification organizes knowledge about various resources, at both generalized and detailed levels. It provides a framework for the presentation of information, interpretations, and predictions about ecosystems. It serves as a common denominator for developing, comparing, and evaluating management strategies, and predicting the consequences of management decisions on complex systems. Hence, ecosystem classification is well suited to helping us achieve the objectives of integrated resource management.

As a natural taxonomic classification (i.e. one based on the characteristics of ecosystems themselves), BEC provides an ideal framework for both resource management and scientific research, including plant autecology and synecology, soil investigations, climatology, and biogeography.

The influence of the BEC system in resource management in BC has grown steadily since the mid-1970s. BEC is now the common "language" that foresters, biologists, agrologists, other resource managers, and naturalists use to describe and communicate about BC's diverse terrestrial ecosystems. The BEC system is commonly used in forestry (MacKinnon *et al.* 1992), and in concert with the Ecoregion Classification system (Demarchi, 1996), provides an ecological framework for conservation and wildlife management (Mah *et al.* 1996). This section provides an overview of how resource managers in different fields have used the BEC system to help them manage the resources, and how the BEC system can be used for integrated management in our province.

The BEC field guides present "interpretations," not "prescriptions." Interpretations are derived from basic operational and research information and are developed for various uses and for different levels in the BEC system (examples in Table 6). They are intended as guidelines for users in developing ecosystem-specific prescriptions that best meet current management objectives.

Silviculture prescription

The need for an ecological system to guide silviculture decision making was the primary reason for the initiation of BEC. Silviculture interpretations for tree species selection and prescribed burning were the first ones developed using the BEC system. These interpretations have always been presented in the regional field guides and have been used by field personnel to prepare site prescriptions.

Table 6: Examples of direct and indirect interpretations within the BEC system.

BEC level	Direct interpretations	Indirect interpretations
Subzone	Seed planning zones; natural disturbance types	Representation in conservation area design.
Site Series	Stocking standards; tree species selection; site index estimates	Grouping of site units for mechanical site preparation; site sensitivity rating for slashburning
Site Association		Grouping of site associations for associations for wildlife interpretations (forage species, habitat components)
Plant Association	Rare ecosystem conservation	

Regional field guides then are the operational link between site identification of BEC ecosystems and a site prescription.

The BEC system is an integral part of the development of the silviculture prescription. Users stratify the area to be harvested into environmentally homogeneous blocks, which are then described in terms of soil, site and vegetation characteristics (Curran *et al.* 2000). The site series or site phases are identified for each block recognized in the setting, using the field guides. The silviculturist then turns to the interpretive section of the field guide for suggested treatment options. Site treatment options that are presented take into account our understanding of ecosystem function and the accumulated body of experience in dealing with similar ecosystems.

Each site identification and interpretation field guide includes silviculture interpretations for tree species selection. Some guides provide other interpretive information. For example, the field guide for the Cariboo Forest Region (Steen and Coupé, 1997) includes vegetation potential in its silviculture considerations for forested site series (Figure 19). The intent of the tables is to provide basic interpretations and principles that a silviculturist can use to develop a silviculture prescription for a site.

Using the interpretive information, the field forester develops a "Site Plan" (formerly "Silviculture Prescription"). They consider the field guide interpretations (e.g. site preparation, species and stock type selection, and stand tending activities), local site conditions, the desired end product, economics of various options, potential pest problems, etc. and then prescribe the treatments for different parts of the block. The site plan is filed, but the site classification, site description and management prescription information is recorded on a computerized history record system (e.g. ISIS, MLSIS) where it is available to assist resource managers in post-harvest decision making.

Other BEC-related tools are available to assist the silviculturist in developing site prescriptions. Stocking standards, along with ecologically adapted tree species for regenerating sites, are presented for all site series in the Establishment to Free

SBSwk1 Site Series – Silviculture Considerations

Site series	Ecologically adapted tree species	Principal site factors limiting tree establishment and early growth: No or limited canopy	Principal site factors limiting tree establishment and early growth: Canopy present	Vegetation potential and complex
01	P:Fd (near SBSmw) Pl Sxw S:Bl D:Act	***summer frost*** Fd ***light deficits (vegetation overtop)*** **Fd**, **Pl**, Sxw, **Act** ***snowpress***	 Fd **Fd**, **Pl**, Sxw, **Act**	medium (S and W aspects) to high (N and E aspects); Mixed shrub - moist forb • shrub cover often increases significantly 3-4 years following logging; burning reduces shrubs, but herbaceous cover usually well developed within 3-4 years, especially on N aspects, after broadcast burning.

- survival and growth of planted **Pl**, **Sxw**, and **Bl** generally adequate to restock clearcut sites if vegetation controlled at planting spot; in partial cuts, survival and growth of **Pl** likely poor in tree-shaded microsites;
- survival and growth of planted **Fd** generally poor, except on steeper slopes in western portions of SBSwk1, near the SBSmw;
- prompt planting following harvesting/site preparation will improve restocking success;
- Pl natural regeneration ingress rates poor due to thick forest floor, dense shrub and herb vegetation, and cool temperatures;
- natural regeneration ingress of **Sxw** and **Bl** will likely restock sites with low vegetation cover and exposed mineral soil near mature stand edges and in partial cuts;
- broadcast burning reduces above-ground vegetation for 3-4 years, depending on intensity of burn and slope aspect;
- snowpress damage greatest where tall herbaceous vegetation is abundant;
- advance **Bl** <25 cm tall is generally of good form and vigour, and its growth releases following canopy opening.

Figure 19: Example of silviculture considerations used in developing a site prescription. In the "Ecologically adapted tree species" column, P = primary choice, S = secondary choice, D = deciduous.

Growing guidebook (BCMOF, 2000a). These Forest Practices Code guidelines represent a provincial correlation of the tree species selection information in the regional field guides, updated with site productivity information (BCMOF, 1997). For coastal forests, Klinka and Varga (1999) developed an electronic support tool that provides further assistance in selecting ecologically viable tree species, reproduction cuttings, and regeneration methods. The information on the CD represents an integration of the existing Vancouver Region guide (Green and Klinka, 1994) with new information obtained from the literature and research, and offers a broader set of options for management of coastal ecosystems.

BEC interpretations have largely been developed on an ecosystem-specific basis. In providing interpretations for site preparation, however, other approaches have generally been shown to be more effective. These are termed "indirect" interpretations, as they are not provided on a site unit basis, but rather on site and soil properties. For example, Coates and Haeussler (1989) group site units with similar ecological properties into "treatment units" in considering mechanical site preparation options in north central BC. For prescribed burning, the work of Green and Klinka (1994) presents another approach to providing interpretations, as an aid to slashburning decision making. Each block's sensitivity to fire is assessed, based on soil and site characteristics (Figure 20).

Vegetation management

Another stand-tending consideration is the amount and timing of competition from non-crop vegetation that can be expected on a site. Much work was done in the period 1985–1995 by ecologists, silviculturists, and vegetation management specialists, on identifying the characteristics of competing vegetation (Coates *et al.* 1990; Newton and Comeau, 1990) and the range of treatment options for major competing vegetation complexes (Biring *et al.* 1996; Simard *et al.* 2001). Operational summaries for vegetation management have been compiled for the most common vegetation complexes in BC (BCMOF, 1997; 2000b). Most of the regional field guides include interpretations for the vegetation potential or brush hazard of a site unit. Harper *et al.* (1999) produced a provincial correlation of regional interpretations of forest vegetation potential and brush hazard, which can be consulted for cross-referencing information in similar ecological units.

The interest in vegetation response to certain site preparation treatments spurred the development of various operational trial protocols for long-term monitoring. Examples of protocols that use the BEC system as a framework in their design, analysis and communication of results include EXPLORE: Experimental design Protocol for Long-Term Operational Response Evaluations (Biring *et al.* 1998), PROBE: Protocol for Operational Brushing Evaluations (Simard, 1993), and TRENDS: Treatment regime evaluation – Numerical decision support manual (NIVMA, 1996). Foresters can use the results from monitoring as an empirical basis for predicting secondary succession on an ecosystem-specific basis, and to support future decisions for treatments on similar sites.

Classification data that describe the environmental components of a variety of ecosystems often yield sufficient information to characterize some aspects of the autecology of species. This information was synthesized for tree species, for example, in Krajina (1969), Pojar (1985), and Klinka *et al.* (2000). Three reports of particular

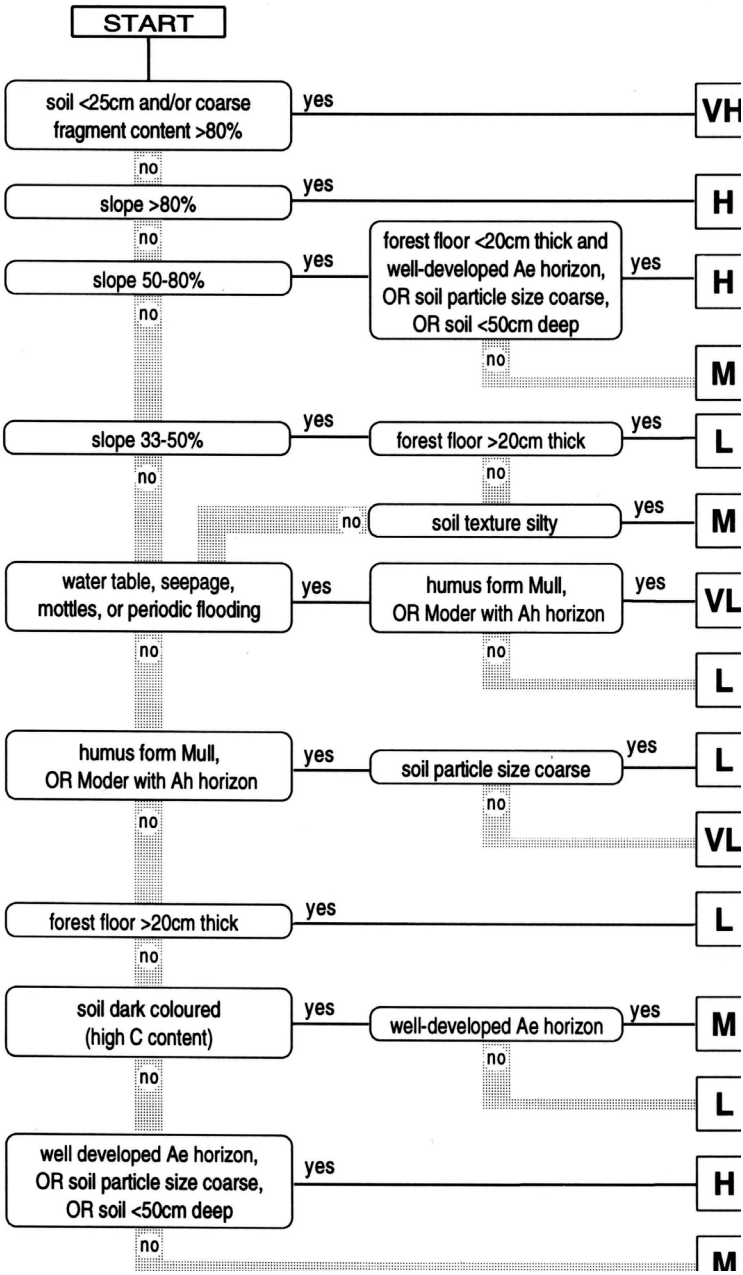


Figure 20: Key to site senstitivity to slashburning (from Green and Klinka, 1994). VH = very high, H = high, M = medium, L = low, VL = very low.

note to silviculturists characterize the most productive Douglas-fir ecosystems (Klinka and Carter, 1980; Klinka *et al.* 1981) and Engelmann spruce ecosystems (Klinka *et al.* 1982) in southwestern BC. In these reports the sites producing the best growth of Douglas-fir and Engelmann spruce are identified and described in terms of their soil, site and vegetation characteristics. Silvicultural interpretations are suggested for these most productive ecosystems.

Range

Another area where the BEC system has proven useful, but less than it could be, is in range management, in particular in integrated management involving forestry and range concerns on Crown land. For broad-scale range planning, the *Rangeland Handbook of BC* (Campbell and Bawtree, 1998) summarizes range values and their forage production potential by biogeoclimatic zone. An overview by Wikeem *et al.* (1993) of Crown land forage resources in British Columbia includes descriptions of the most important biogeoclimatic zones for forage production and their characteristic plant communities.

Although the main focus of the BEC system was initially forested ecosystems, some regional field guides include descriptions of grassland communities occurring within the Bunchgrass, Ponderosa Pine and Interior Douglas-fir zones (Lloyd *et al.* 1990; Braumandl and Curran, 1992). In the Kamloops Region guide (Lloyd *et al.* 1990), grassland or 'open range' sites are described for a grassland phase in three Interior Douglas-fir subzones – IDFxh1a, IDFxh2a, and IDFdk1a. More recently, work is nearing completion on a grassland classification (Coupé *et al.*[11]) that will assist users in classifying sites and developing management prescriptions. The guide is intended to support the assessment of the condition of the range resource by providing descriptions of the vegetation, site and soil characteristics for late seral/climax plant communities in good condition. Successional trends are described for each of the site units, particularly in response to grazing. For further information, refer to Range Management, this volume.

Wildlife habitat

As with range management, combinations of vegetation and site units are appropriate as wildlife habitat interpretive units. Some BEC regional guides include wildlife interpretations with various levels of detail. For example, in the Prince George region SW guide (DeLong *et al.* 1993), wildlife interpretations present the important forage species and special habitat components for identified successional stages of groupings of site associations. In the Prince Rupert region guide (Banner *et al.* 1993), the wildlife section is an overview of wildlife species and habitats for each of the biogeoclimatic zones and their subzones, blue- and red-listed species, and characteristic species. Stevens (1995) produced a compendium on the vertebrate diversity in BC, showing the distribution and habitat use of amphibians, reptiles, birds, and mammals within the framework of biogeoclimatic ecosystem classification.

The BCMOF also uses biogeoclimatic units to represent regional climates for

[11] Coupé, R.A., O. Steen and K. Iverson. A guide to grassland and related sites identification and interpretation for the Cariboo Forest Region. Working draft.

wildlife management purposes. In *Handbook for Timber and Mule Deer Management Co-ordination on Winter Ranges in the Cariboo Forest Region*, Armleder *et al.* (1986) use the Cariboo Region field guide (Cariboo Forest Region 1987) to delineate "snowpack zones" of the Cariboo Forest Region. These "snowpack zones" are then used as a broad planning tool for integrated forestry/wildlife use of Crown lands in the Cariboo Region. Biogeoclimatic units were also used by Nyberg *et al.* (1990) in defining snowpack zones for deer and elk habitat management on BC's south coast.

Many wildlife applications arose from landscape planning requirements for large-scale mapping of BEC site units and structural stages, and the development of wildlife capability and suitability models (see Figure 21). By combining the mapping and habitat ratings, interpretive maps can be produced to show areas ranked by their habitat value and use for wildlife species, e.g. Tweedsmuir-Entiako (Cichowski and Banner, 1993) and Itcha-Ilgachuz caribou (Young and Roorda, 1999) and grizzly bear on the coast (Banner et al. 1986) and in the Quesnel Highlands (Applied Ecosystem Management Ltd. 2002). A further application of habitat mapping is in developing wildlife habitat models aimed at modelling habitat supply for various purposes, including timber supply and individual wildlife species.

The BEC system also provides a framework for the development of management guidelines whereby relationships within similar ecosystems with similar disturbance histories can be explored. Management guidelines currently under development for Coarse Woody Debris (CWD) are using biogeoclimatic zones and site alliances to group and analyze data. For further information, refer to Wildlife Management, this volume.

Biodiversity

The Bruntland Commission (WCED, 1987) and the United Nations 1992 conference on Environment and Development (The Earth Summit) brought about global awareness of the linkages between human activity and environmental issues. In recognition of the need to address environmental concerns, a number of regional and provincial planning processes were initiated in the early 1990s to maintain genetic, species, and ecosystem diversity in BC – many of which incorporated the BEC system in their planning framework. For example, the Prince Rupert Forest Region produced a synopsis and management discussion of biodiversity, stratified by biogeoclimatic unit (Radcliffe *et al.* 1994; Steventon, 1994). The British Columbia Protected Areas Strategy used Ecosections and BEC subzones/variants as a framework for describing the level of representation of natural diversity in BC protected areas (Lewis and Westmacott, 1986).

The Biodiversity guidebook (BCMOF and BC Environment, 1995) provided a process for meeting biodiversity management objectives – at both the landscape and stand level – and practices designed to reduce the impacts of forest management on biodiversity, within targeted social and economic constraints. Within the guidebook, the Natural Disturbance Type (NDT) was used to categorize the range of natural variability in severity and frequency of disturbance experienced by ecosystems in BC. The five NDTs describe specific regimes that apply to all natural disturbances (e.g. wildfire, wind, insect outbreaks). Biogeoclimatic units were assigned to each NDT based on available disturbance periodicity data and best estimates of their historic fire cycles and severities to assist in landscape planning decisions (Figure 22).

The Conservation Data Centre (CDC), established in 1991 in partnership with

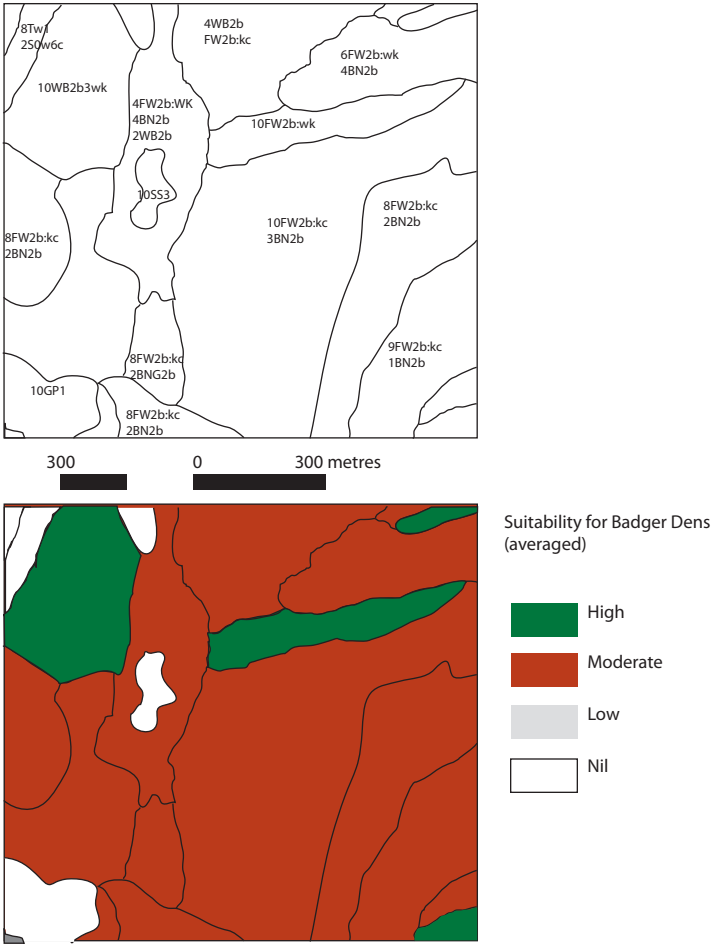


Figure 21:
Example of wildlife suitability mapping derived from terrestrial ecosystem mapping. Area is in IDFxh1 biogeoclimatic variant; number preceding each map label component is a decile of areal extent; next two uppercase letter codes are mostly BEC site series: BN = /96 Kentucky bluegrass – Stiff needlegrass, FW = /91 Idaho fescue – Bluebunch wheatgrass, GP = gravel pit, SO = Saskatoon – Mock orange, SS = Saskatoon – Common snowberry, TA = talus, WB = /93 Bluebunch wheatgrass – Balsamroot; seral plant association codes are appended to the end of the map unit label as two lowercase letters, wk = $ Bluebunch wheatgrass – Knapweed, kc = Knapweed – Cheatgrass; other map label components refer to "site modifier" or "structural stage" (see Resources Inventory Committee, 1998).

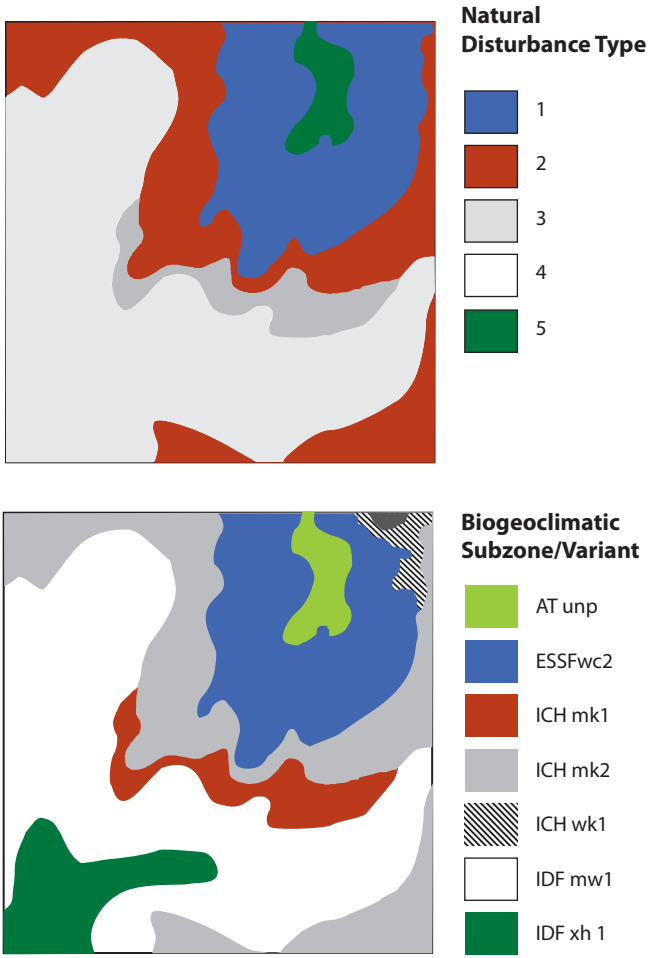


Figure 22:
Example of Natural Disturbance Type (NDT) mapping derived from biogeoclimatic subzone/variant mapping.

the Ministry of Environment, Lands and Parks, has the mandate to identify those species and ecosystems that have become endangered or threatened in the province, and to compile this information into an accessible and usable form. The CDC uses the BEC vegetation classification as the basis for most of their plant community types and lists their "red" and "blue" community types by BEC site units, e.g. CWHvm1/08. BEC program ecologists have assisted the CDC with the rarity rankings for plant community types.

Wetlands are an important element of biodiversity and in much of BC provide ecosystem services disproportionate to their often limited extent on the landscape. Management guidelines for forested wetlands have been presented in regional field guides and other associated manuals. Although non-forested wetlands have generally

been neglected in BEC field guides, Steen and Roberts (1988) prepared a guide to non-forested wetland classification and management for one area in the Cariboo. The Riparian Management Area Guidebook (RMAG) (BCMOF, 1995), a Forest Practices Code manual, dealt with classification of wetlands in a fairly simple way, primarily based on wetland size, in order to set widths for "riparian management areas" around wetlands. In order to help managers deal with wetlands sustainably, MacKenzie and Moran (2003) produced a field guide to wetland identification. Although a guide to wetland interpretation is in development, some general management interpretations exist in the present guide. These deal primarily with wildlife habitat requirements in wetlands, but also present grazing and timber harvest management considerations.

Site productivity

Classification of a forest into site units provides a suitable framework for both ecosystem-specific management and study of relationships between site quality and forest productivity because the same factors used to characterize site quality (i.e. climate, soil moisture regime, and soil nutrient regime) may also be used as independent variables in simple synoptic models describing growth performance of trees. Klinka and Carter (1990) examined these relationships for disturbed, immature, coastal Douglas-fir ecosystems in the Very Dry and Dry Maritime Coastal Western Hemlock subzones, and found that only the models based on categorical site variables continued to have a good relationship with site index. Similar studies have been carried out for other species, including western hemlock, western redcedar, lodgepole pine, interior spruce and subalpine fir and trembling aspen (Kayahara and Pearson, 1996; Wang and Klinka, 1996; Kayahara *et al.* 1997, 1998; Chan and Klinka, 2000; Nigh *et al.* 2002).

Those studies contributed to work in the early 1990s on development of tools for providing improved estimates of site productivity in timber supply analysis, particularly for old growth stands or very young stands, where conventional methods (i.e. site index curves and growth intercept models that require tree measurements) could not be applied reliably. In 1994, the SIBEC project was initiated to model relationships for site index estimation using BEC site series. Regression analyses based on available data were used to produce the first approximation of the SIBEC site index estimates for BC (BCMOF, 1997). With the SIBEC estimates, a user can assign a site index that reflects the potential productivity for a given species to a site that has been classified to BEC site series.

With the link to BEC site series, the SIBEC estimates may be applied at the stand and forest level (Mah and Nigh, 2003). Silviculturists can use the estimates in selecting tree species for regeneration and in the prioritizing of treatments on managed stands. At the forest level, ecologically-based yield analyses are made possible by combining SIBEC estimates with predictive or terrestrial ecosystem mapping (Olivotto and Meidinger, 2001). Results from the Old Growth Site Index (OGSI) project (Nussbaum, 1998) show that the productivity of sites presently supporting old forest stands is generally underestimated in current forest inventory's site index attribute. The productivity of sites presently occupied by repressed lodgepole pine stands is also underestimated by conventional methods. The potential productivity of sites with old forests or repressed pine stands is better reflected in the SIBEC estimates (providing the assumptions of the approach are all realized), and these estimates are applied to post-harvest regenerated stands, in modelling or site management.

BEC and Climate Change

The Earth's climate is warming – by about 0.6°C in the past 100 years, with the largest increase occurring in the past 30 years. Although increases in average temperature have an impact, it is likely that changes in climatic extremes have a far greater impact on species and ecosystems. For example, in some regions, minimum temperatures are increasing at a faster rate than maximum temperatures. In these areas, freeze-free periods are increasing, changing the snow-free period and ice extent (Walther *et al.* 2002). Climatic extremes will impact species directly, altering reproduction and survival, and ultimately affecting persistence, extirpation, and migration.

It is clear that recent climate changes have affected a wide range of organisms, impacting phenology, the range and distribution of species, and the composition and dynamics of ecosystems (Walther *et al.* 2002). Atmospheric CO_2 is expected to have doubled by late this century and many impact studies attempt to predict what might happen at that time. We can predict some of the effects of climate change on those species whose autecology we understand, or at least whose climatic limits we know. If these are dominant or keystone species, we can predict how their change in distribution or range could impact various ecosystems. However, ecosystems are aggregations of species that interact amongst themselves and with the abiotic environment. Species behave individualistically. At least some of the species within an ecosystem will respond differently to the changing climate and environment, changing the ecosystem itself – as has happened in the past (Davis and Shaw, 2001). Populations of insects and diseases are already responding in unexpected or unprecedented ways (Harvell *et al.* 2002; Woods, 2003), as are introduced species. Feedback and other interactions within an ecosystem, including below ground processes and nutrient dynamics, complicate predictions about what could happen (Stenseth *et al.* 2002). Changing climate could result in very different communities of organisms occurring on some portions of the landscape.

BEC is an ecosystem classification. It has a strong climatic and vegetation basis. If the climate and vegetation communities change significantly, the classification itself will have to be updated. It is difficult to predict what will happen. Hebda (1997) provides a summary of what could happen in some biogeoclimatic zones with the changing climate. The Alpine Tundra zone will likely shrink as the elevation of treeline and timberline increases. The Bunchgrass Zone and grassland ecosystems in the dryer climates could expand due to increased soil moisture deficits. Wetlands in the boreal and sub-boreal could change from black spruce bogs to fens or marshes due to the warmer climate.

Whatever the changes, there will be some lag time between the changing climate and the effect on ecosystems. BC is dominated by forests and trees are generally long-lived. Changing climate is likely to have a greater impact on reproduction than survival in the "sensitive" areas, so established trees will likely survive for some time after their regeneration is impacted. There may be some impact on growth rates, which should be considered in the mid-term in timber supply modelling.

It is likely that the biogeoclimatic zones of the future will differ from those of today. Some will be very similar, with their range and distribution somewhat modified. It is also possible that some new zones will result – new climates with new combinations of species.

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WATERSHED PROCESSES

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WATERSHED PROCESSES

Introduction

Forests and water are linked in a variety of ways. Availability of water is an important control on forest species distribution and tree growth, while forests influence a range of hydrologic processes, such as the interception of precipitation and melting of snow. Forest operations, including road construction and maintenance, harvesting and site preparation, can influence hydrologic processes, stream water quality and in-channel aquatic habitats. The potentially negative effects of these operations must be considered in forest planning and management. These interactions between forests and water can be considered at the scale of an individual site, forest stand or hillslope, or at the scale of a watershed.

Watersheds are defined as those areas that could contribute water by down-slope flow to a stream channel, upstream of a specified point of interest. The point of interest would depend on the specific situation, but could be, for example, the mouth of a tributary stream where it flows into a larger stream, or the location of an intake for a community water supply. The boundary of a watershed is called a drainage divide, and is defined by topographic heights of land. In North America, the terms **catchment** and **drainage basin** are often used synonymously with water-shed. In Britain, however, the term watershed is normally used to refer to the drainage divides.

Water, sediment, nutrients, and organic matter generally flow from the head-waters to lower reaches under the force of gravity, although fish migration, particularly that of anadromous salmon, may be an important vector for upstream movement of food energy, nutrients, and organic matter. Because of the dominant downstream movement of water, energy, dissolved substances, sediment, and organic matter, disturbances on hillslopes in the upper reaches of a watershed may eventually influence downstream reaches some distance away. It is this connectivity that necessitates consideration of the hydrologic impacts of forest operations within a watershed context.

This chapter reviews forest hydrology and the influences of forest management on watershed processes, with a specific focus on British Columbia (BC). It also addresses related topics, including riparian management, watershed assessment and watershed restoration. The intention is not to provide comprehensive topical reviews, but rather to describe and illustrate the key processes and their management implications.

Physical Hydrology

Hydrologic regimes in BC

British Columbia encompasses a variety of climatic and physiographic settings, giving rise to a range of hydrologic regimes (Eaton *et al*. 2002). A broad distinction may be made between coastal and interior regimes. Coastal areas have higher levels of precipitation and thus greater unit stream discharges. Furthermore, coastal areas have climates moderated by their maritime exposure, leading to a greater proportion of winter precipitation falling as rain, especially at lower elevations. Interior watersheds have a stronger snow accumulation/snowmelt influence, with low flows tending to occur in late summer to winter and high flows in the spring-summer freshet.

Coastal regimes can be subdivided into three broad classes, based on the fraction of watershed area lying above the seasonal snow line and the presence of glacier cover. The seasonal snow line is the elevation above which a substantial snow cover accumulates through winter, with the main melt occurring during spring. Below the seasonal snow line, snow cover is transient, accumulating and melting one or more times each winter, and possibly not at all at the lowest elevations. The seasonal snow line lies at about 600 to 1,000 m in southern BC, but the upper boundary will be higher to the south and lower to the north. The seasonal snow line decreases with distance from the coast, and also varies from year to year.

In coastal watersheds dominated by elevations lower than the seasonal snow line, winter rainstorms generate most peak flows, sometimes augmented by melting of a transient snow cover. Rain events that occur when a substantial portion of a watershed is snow covered are commonly called **rain-on-snow** events. In watersheds with substantial areas lying above the seasonal snow line, spring snowmelt can generate the annual flood in some years. In both these cases, annual low flows tend to occur in late summer or early autumn, prior to the onset of the autumn-winter storm period. In watersheds with more than a few percent glacial cover, high flows occasionally occur in late summer during periods of high glacial melt, sometimes augmented by a late summer rain event. In high mountain watersheds in the central and eastern portions of the Coast Mountains, annual low flows tend to occur in winter, when most of the precipitation falls as snow. However, even in these higher elevation watersheds, such as the Lillooet, the highest peak flows tend to occur during winter rain-on-snow events (Moore, 1991).

Interior regime watersheds are dominated by spring high flows for both plateau and mountainous terrain, though the mountainous watersheds tend to have a longer freshet period with a later peak flow. Low flows can occur during late summer through winter. In plateau watersheds, lakes and wetlands can attenuate streamflow response to both individual events and the seasonal snowmelt. Some watersheds in the interior mountain chains of BC have significant glacier cover, which can maintain flows during late summer.

Forests and precipitation

Precipitation falling onto a forested area may fall directly through canopy gaps to the forest floor (**direct throughfall**) or it may be intercepted by canopy foliage, where it may drip off the foliage (**indirect throughfall**) or evaporate back to the

atmosphere (**interception loss**). A relatively small amount of rainfall reaches the ground by flowing down tree stems (stemflow). A significant proportion of incident rainfall may be lost following interception. Interception loss tends to be greater for coniferous canopies than for deciduous. Also, it increases with stand age, reflecting the increase in leaf area index and hence the potential for interception. Published studies from around the world have reported annual or seasonal values of about 15% of incident rainfall being lost for deciduous canopies to over 30% for mature or old growth coniferous canopies (e.g. Ford and Deans, 1978; Neal *et al*. 1993; Beaudry and Sagar, 1995; Spittlehouse, 1998).

In coastal areas, fog is intercepted by trees and condenses onto the canopy, and then may drip to the forest floor. This fog drip represents an input of water to forested areas in addition to precipitation, and may be a significant source of water in some coastal watersheds (Harr, 1982; 1983). It is sometimes referred to as **occult precipitation**.

Snow interception loss is more difficult to measure than rainfall interception loss, and has often been estimated by comparing snow accumulation in openings to that under a forest canopy. Snow accumulation is typically around 30% greater in openings (Toews and Gluns, 1986). One problem in interpreting clearcut-forest differences in snow accumulation is that they could also be caused by preferential deposition of snow into clearings, as a result of airflow patterns over and within the opening, or by re-distribution of snow originally intercepted in the forest canopy. Troendle and King (1987) found that cut blocks in the North Fork of Deadhorse Creek, Colorado, had 30% more snowpack water equivalent than was measured in the forest. However, they found that the mean snow accumulation at the watershed scale did not change following harvesting, suggesting that the higher snow accumulation in the cut blocks was dominantly the result of preferential deposition and/or redistribution. At Fool Creek, Colorado, on the other hand, watershed-averaged snow accumulation increased following harvesting, indicating a decrease in interception loss, in addition to preferential deposition (Troendle and King, 1985).

Another confounding process occurs when canopy snow melts and drips onto the snowpack below. In these cases, some or all of the canopy drip may percolate through the snowpack and infiltrate the soil. This water is not really lost to the watershed, even though it does not get measured as part of the snowpack under the canopy. Under these conditions, a comparison of the snowpack under the forest canopy with that in an opening would tend to overestimate the true amount of interception loss.

Forests and snowmelt

Snowmelt rates vary with the amount of energy available for melting. The dominant energy exchanges are net radiation, including both short- and long-wave, and the sensible and latent heat exchanges from the overlying air. Heat conduction from the underlying soil can be important for moderating winter snowpack temperatures, but tends to be a minor energy source during the main melt periods. The key controlling meteorological variables are incident solar radiation, air temperature, humidity and wind speed. Melt rates tend to vary strongly with air temperature, and typically decrease with increasing elevation.

Forest harvesting generally increases snowpack melt rates. Removal of the

forest canopy exposes the snowpack surface to greater incident solar radiation. In addition, higher wind speeds in clearcuts can increase sensible and latent heat inputs compared to under a forest canopy (Berris and Harr, 1987; Adams *et al.* 1998). The net result is that snowpack melt rates in open sites are on the order of 30 to 50% higher than under a forest canopy (e.g. Toews and Gluns, 1986). However, intercepted snow held in the canopy may have greater surface exposure to energy inputs than snow on the ground in a cut block, and would melt more rapidly (Berris and Harr, 1987).

During the main spring melt period, snowmelt rates tend to be highest during periods of clear, settled weather, in which the low wind speeds limit the contributions of sensible and latent heat, and net radiation dominates the energy available for melting snow. In these periods, snowmelt varies strongly with aspect, being higher on south-facing slopes (in the Northern Hemisphere), due to the aspect-dependence of incident solar radiation.

In contrast, mid-winter rain-on-snow events typically involve relatively warm, humid air, high wind speeds and low solar radiation. During these events, melt rates in clearcuts would be generated mainly by sensible heat transfer from the relatively warm air, condensation onto the snowpack, and in some cases by the sensible heat of rainfall (Berris and Harr, 1987), and may significantly augment rainfall, increasing the magnitude of flood peaks relative to unlogged conditions. Relative rates of water delivery to the soil between forest and clearcuts can be complicated if snow is held in the canopy, which would melt faster than the ground snowpack either under the canopy or in a cut block. However, if there is a significant snowpack on the ground, compared to the amount of snow held in the canopy, the effect of canopy melt is unlikely to be important except for lower magnitude events (Harr, 1986).

Evapotranspiration

Evapotranspiration includes all processes by which water returns to the atmosphere as water vapour, and includes interception loss, transpiration from plants, and evaporation from bare soil and open water bodies such as ponds and lakes. Interception loss has been discussed earlier, in the context of precipitation and snow processes.

Evaporation from bare soils during a dry period typically exhibits two stages. In the first stage, the soil is relatively moist and the hydraulic conductivity high enough that upward water movement through the soil can meet the rate of evaporation from the soil surface. Stage one evaporation is often called **demand limited**, because the evaporation rate is limited by the **atmospheric demand** imposed by factors such as the intensity of solar radiation, air temperature, humidity, and wind speed. In the second stage, the soil moisture drops to a point that the low hydraulic conductivity in the surface layer limits the rate of upward water movement, effectively limiting the rate of evaporation. Stage two evaporation is **supply limited**, because it is the rate at which the deeper soil layers supply water to the surface that controls the evaporation rate.

Transpiration is a plant physiological process in which water diffuses into the ambient atmosphere through openings on the leaf surfaces called stomata. At the same time, the leaves take up atmospheric CO_2 via the stomata for photosynthesis. The degree of opening of the stomata depends on the turgor pressure in the guard

cells, which bound the stomatal opening. Turgor pressure is increased by the movement of potassium ion into the guard cells, which lowers the osmotic pressure and draws water into the guard cells from the epidermal cells (Tyree, 1999). Many plant species have evolved to increase the stomatal opening during environmental conditions favourable to photosynthesis, such as high sunlight and high atmospheric CO_2. Many species also limit the degree of stomatal opening to minimize water loss and avoid desiccation at times when water uptake from the soil may be limited, particularly in response to low soil moisture content and/or low atmospheric humidity.

Like soil evaporation, transpiration may also exhibit a supply-limited phase during prolonged dry spells, particularly for low, shrubby vegetation with shallow rooting depths. Because trees can extract water from a deeper layer of soil, the transition from a demand-limited transpiration rate to a lower supply-limited rate may be delayed, allowing a greater total water loss from the soil. Forest harvesting should thus decrease total evapotranspiration by decreasing both interception loss and transpiration.

One outcome of decreased transpiration after forest harvesting is that soil moisture levels should remain higher through the summer and there may be greater groundwater recharge. Adams *et al.* (1991) found that soil moisture content in a clearcut site in the Oregon Cascades, measured from the surface to a depth of 120 cm, averaged 10 cm more than in an adjacent forested site. Prior to logging, there was no statistically significant difference in soil moisture content between the two sites. These increases declined and, five years after logging, the logged site had 2 cm less soil moisture content than the forested site. The authors inferred that the declining surplus and shift to a slight deficit reflected the rapid increase in plant growth, primarily by species including fireweed, vine maple and snowbrush.

Runoff processes

The term **runoff** is used in a variety of ways. Climatologists use it to refer to the difference between precipitation and evapotranspiration. In a watershed context, that definition would be equivalent to the total amount of water leaving a watershed either as streamflow or as groundwater outflow over a time interval for which changes in watershed storage can be considered negligible. However, hydrologists frequently equate runoff with the amount of water leaving a watershed as streamflow. The term **subsurface runoff** is sometimes used to refer to water leaving a watershed as groundwater. Adding to the confusion, runoff is occasionally used to refer to **overland flow**, which refers specifically to water that flows over the soil surface. In this chapter, the term **runoff processes** refers to the processes and hydrologic pathways by which hydrologic inputs (rain, snowmelt, fog drip) become watershed outflow.

Infiltration and generation of Hortonian overland flow. The maximum rate at which water can infiltrate a soil is called the infiltration capacity or the infiltrability. If the rainfall and/or snowmelt intensity exceeds the infiltration capacity, some of the incident water will flow downslope over the soil surface as Hortonian overland flow (named for the American hydrologist R.E. Horton). It is also called **infiltration-excess overland flow**. In a freely draining soil, the infiltration capacity will be greater than or equal to the saturated hydraulic conductivity of the soil

surface. Undisturbed forest soils in the Pacific Northwest normally have sufficiently high hydraulic conductivities that infiltration capacities are rarely if ever exceeded by rainfall and/or snowmelt intensities (Cheng, 1988). Infiltration is aided by the presence of vertical macropores fed by flow concentration within the overlying organic horizons (deVries and Chow, 1978).

Hydrophobicity (also known as water repellency) and restricted infiltration can occur in situations in which mineral soil grains become coated with organic compounds. Barrett and Slaymaker (1989) found such layers to occur naturally in shallow soil layers in subalpine forests at sites across southern BC. Forest fires may induce hydrophobicity through the vaporization of organic compounds due to the heat of the fire and their re-condensation onto mineral soil grains in cooler layers below the surface (Letey, 2001). These layers may impede infiltration and produce Hortonian overland flow, as has been documented, e.g. in South Africa (Scott, 1993) and the Colorado Front Range (Huffman *et al.* 2001). Henderson (1981) found a higher tendency to water repellency in soils in south coastal BC that had been subjected to slashburning following clearcutting than in unburned clear-cuts or old growth. However, he reported little evidence for widespread overland flow at the hillslope scale that could be attributed to fire-induced repellency.

At many sites, particularly in the interior, harvesting is conducted with skidders, which can cause compaction of the soil surface and thus potentially result in generation of Hortonian overland flow. The significance of this soil compaction and resulting Hortonian overland flow would depend on how much of the watershed area was disturbed, as well as whether the skid trails directed water to the natural drainage network. Tracked machinery such as hoe-forwarders and feller-bunchers can also cause soil compaction, especially if used when soil moisture levels are high.

Excavated trails and constructed haul roads typically have compact surfaces with lower permeability than the forest floor, and can generate Hortonian overland flow in even moderate rainstorms (Luce and Cundy, 1994). The significance of this overland flow at the watershed scale would depend on the fraction of a watershed covered by logging roads and landings, as well as how well connected these surfaces were to streams via ditches and culverts.

Downslope flow. Following infiltration, water flows downhill dominantly as subsurface stormflow (Harr, 1977; Cheng, 1988), promoted by effective saturated hydraulic conductivities that typically range from 10^{-4} to 10^{-3} m/s (Megahan and Clayton, 1983; Cheng, 1988; Hutchinson and Moore, 2000). A major component of subsurface stormflow occurs as a saturated layer perched above the contact between the soil and the underlying till or bedrock (Figure 1) (Hetherington, 1982; Anderson *et al.* 1997; Hutchinson and Moore, 2000). This flow pathway is sometimes called **throughflow**. Depending on the local geology, water exchanges may occur between the saturated soil layer and the underlying bedrock. For example, Anderson *et al.* (1997) showed that a significant amount of water infiltrated from the soil into fractures in the underlying sedimentary bedrock at a site in the Oregon Coast Range, then re-emerged into the soil some distance downslope. The shallow saturated layers typically respond rapidly (i.e. within minutes to a few hours) to stormwater inputs (e.g. Pierson, 1980; Sidle, 1984; Jackson and Cundy, 1992; Fannin *et al.* 2000).

Roads can influence downslope water movement by intercepting subsurface flow and diverting it along ditch lines, especially where the road cut extends down

to relatively impermeable bedrock or compacted glacial till (e.g. Hutchinson and Moore, 2000) (Figure 2). In cases where the soil is much deeper than the road cut, the underlying bedrock is highly fractured, or the road bed is constructed of highly permeable material, little flow interception may occur, and a significant portion of water may flow downslope below the road surface (e.g. Megahan, 1972).

Runoff and sediment draining from the road network can flow into stream channels via two pathways: roadside ditches draining directly to streams, and

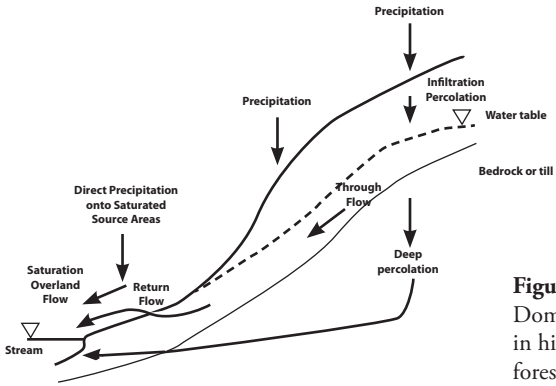

Figure 1: Dominant runoff pathways in highly permeable, forested watersheds.

roadside ditches draining to culverts that feed water into incised gullies (Wemple *et al.* 1996). In other cases, ditch flow may be diverted back onto the slope below a road by a drainage relief culvert, where it will re-infiltrate and flow downslope as sub-surface flow (Figure 2). In the latter situation, the road may not increase the rate of transmission of water to the stream channel, but rather act to redistribute subsurface flow laterally across the slope. For steep valley-side streams without well-defined watershed boundaries, this redistribution could transfer water from one small stream to the next.

Saturation overland flow. In near-stream zones, the water table may rise to the soil surface during storm or snowmelt events due to the inputs of rain and/or melt directly onto the riparian zones, plus contributions of subsurface stormflow from surrounding hillslopes. These zones of saturated soil can generate **saturation overland flow** (SOF), which flows directly to the stream channel. Saturation overland flow includes water seeping to the surface (return flow) as well as precipitation or snowmelt falling directly onto the saturated zone (Figure 1). Depending on the topography, these areas may expand during events and during the wet season in response to a rising water table, then contract between events and during the dry season. Saturation overland flow may be significant in watersheds with relatively wide riparian zones, particularly in relatively low-gradient terrain (e.g. Taylor, 1982). In steeper headwater watersheds, riparian corridors tend to comprise only a small portion of the watershed, and may be important for runoff generation only during dry periods (e.g. Sidle *et al.* 2000), when most of the rain falling onto hillslopes is retained within the soils.

Influence of antecedent soil moisture content. Following long dry spells, especially during summer and early autumn, the soils in a watershed may have low moisture contents. Under such conditions, much of the rain falling during a storm may percolate only part way into the soil, with most being held in the upper layers

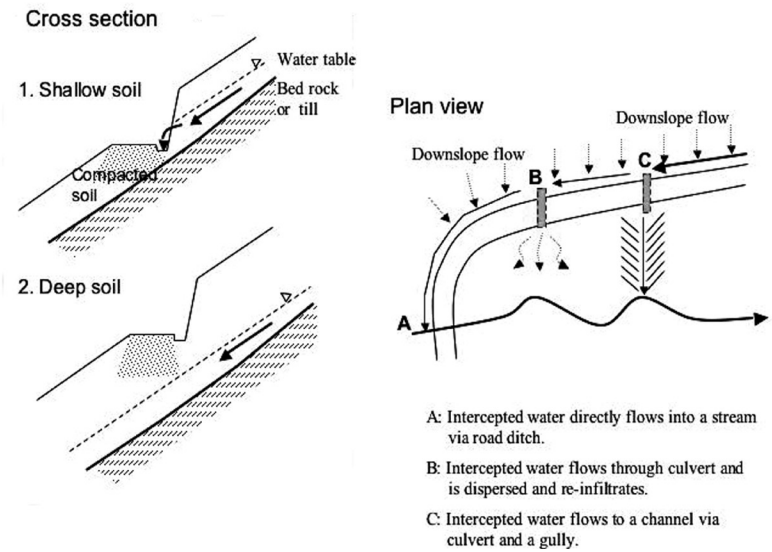

Figure 2:
Influences of logging roads on downslope water flow.

by capillary pressure. Only rain falling onto relatively damp near-stream zones with high water tables or onto relatively impermeable surfaces such as roads may end up becoming stormflow. Subsequent rains would allow deeper penetration through the soil and ultimately subsurface stormflow, once the soil mantle has been fully wetted up. In coastal watersheds, this wetting up period represents a transition between the summer low-flow period and the winter period dominated by storm runoff.

Soil moisture may also influence the early stages of snowmelt. If snow accumulation follows a dry autumn, much of the early meltwater released from the snowpack may be held in the soil, reducing the amount of effective snowmelt run-off until after snowmelt infiltration has recharged the soil mantle. On the other hand, if the autumn preceding snow accumulation was rainy, then the soils would be relatively wet and snowmelt runoff may be generated earlier in the melt period.

Influence of soil frost. Soils in high elevation and interior regions of the province may freeze during winter, particularly if freezing conditions occur prior to significant snow accumulation. Rapid freezing of very wet soils can result in "concrete frost," which has low permeability and can restrict infiltration (Proulx and Stein, 1997). Where soils are relatively dry at the time of freezing, or the soil structure is highly aggregated, the soil frost will be loose and friable, or honeycomb in structure, and will not restrict infiltration. However, even with honeycomb frost, overland flow can occur where a relatively impermeable ice layer forms at the base of the snowpack (Price and Hendrie, 1983). The occurrence and hydrologic significance of soil frost can vary dramatically through a watershed due to variations in soil properties, and from year to year, depending on weather conditions during the freezing period (Proulx and Stein, 1997; Nyberg *et al.* 2001). There appears to have been little study of the hydrologic effects of soil freezing in BC or how it is influenced by forest harvesting.

Stream-groundwater interactions

Streams can be connected to groundwater systems in three ways: (1) the water table slopes toward the stream from both sides; (2) the water table slopes away from the stream on both sides; and (3) the water table slopes toward the stream from one side and away from the other. Because groundwater generally flows from areas of higher water table to lower, situations (1) and (2) represent "gaining" and "losing" situations, for which the streamflow would increase and decrease in the downstream direction, respectively. The third situation involves flow-through, and whether the stream gains or loses flow depends on the relative magnitudes of inflow to and outflow from the two sides. **Flow-through** reaches tend to occur where a stream meanders through a low-gradient area, in which the groundwater flow is parallel to the general valley alignment. That is, the groundwater flow tends to short-cut the meander bends. A fourth situation can occur, in which the water table lies below the stream. These streams lose flow in the downstream direction.

Riparian groundwater plays an especially important role during periods of low flow. In watersheds with shallow soils and steep hillslopes, baseflow is normally supplied by drainage of water stored in the riparian zone, which may be fed by a slow movement of water from the hillslopes (Hewlett and Hibbert, 1963). Transpiration by riparian vegetation may extract riparian groundwater that would otherwise discharge into the stream, producing a diurnal decrease in streamflow, followed by recovery at night (Hewlett, 1982; Bond *et al.* 2002).

Two-way exchanges of water (hyporheic exchange) may occur between the stream channel and the riparian zone, across the bed and banks (e.g. Harvey and Bencala, 1993). The short-cutting flow described above is one example. These exchanges are also often associated with changes in gradient along the channel. For example, water tends to flow into the bed and out into the banks at the head of a riffle, then re-emerge into the stream at the head of the downstream pool. These exchanges can influence stream temperature patterns and biogeochemical processing (e.g. Bilby, 1984; Wondzell and Swanson, 1996a,b; Malard *et al.* 2001; Story *et al.* 2003).

Synchronization of processes

An important issue in understanding the hydrologic effects of forestry operations at the watershed scale is synchronization of runoff generation. For example, snowmelt tends to be accelerated in clearcuts as compared to forests (e.g. Toews and Gluns, 1986). In some situations, this could de-synchronize snowmelt over a watershed and reduce peak flows. Verry *et al.* (1983) found that clearcutting 50% of a low-relief peatland watershed resulted in two relatively low magnitude peak flows in place of a single, higher peak flow. The first peak resulted from snowmelt in the cut area; the second occurred several days later in response to melting of the forest snowpack. After the remaining upland area was clearcut, snowmelt was re-synchronized over most of the watershed, and peak flows increased compared to the flows that would have occurred in the absence of clearcutting. On the other hand, partial clearcutting could possibly synchronize snowmelt over a watershed and increase peak flows. For example, clearcutting of north-facing slopes or high-elevation areas could advance the timing of melt from those areas and synchronize it with melt on forested south-facing or lower-elevation slopes. King and Tennyson (1984) suggested that subsurface flow interception by logging roads and ditches may

desynchronize inputs from those parts of the watershed drained by the road network and the rest of the watershed, but this effect has not been verified by field studies.

Hydrologic recovery

An important consideration in forest management is hydrologic recovery. As a new forest regenerates, the hydrologic impacts of forest harvesting should decline through time. For example, Hicks *et al.* (1991) found that the increase in annual water yield following a 25% patch-cut in the Oregon Cascades persisted for only about 25 years. In contrast, Troendle and King (1985) found that the increase in peak snowpack water equivalent due to harvesting in a Colorado watershed had only a weak negative correlation with time, suggesting that recovery would require many decades. For practical applications, recovery curves can be developed that relate the percent recovery to pre-logging conditions to some index of stand development, typically canopy height. Some studies have examined hydrologic differences among stands of different ages and used a space-for-time substitution to infer rates of hydrologic recovery. Hudson (2000) used this approach to develop recovery curves for snow accumulation and ablation rates (using canopy height as a predictor variable) at a site in south coastal BC. Winkler (2001) compared snow accumulation and melt in clearcuts, juvenile and mature stands to infer recovery rates in the southern interior of BC. Winkler found that mature spruce-fir forests had 20 to 30% less snow than a clearcut, while juvenile pine had 14% less. The rate of snow melt in the mature forest was 40% that in the clearcut, while melt rates in a juvenile pine stand were 80-90% of the clearcut rate. Melt began earlier in the clearcut and juvenile stands than in the mature forest.

Recovery curves are important in calculating the Equivalent Clearcut Area (ECA), which is a commonly used index of the cumulative hydrologic impact of forest harvesting, discussed in a later section on "Watershed Analysis and Management." There are two important sources of uncertainty in the application of recovery curves. One is that the changing hydrologic function of a growing forest stand may depend on species, tree spacing, climatic characteristics and site topography, so that curves determined at one site may not apply to another. Another is that forests influence a range of hydrologic processes such as evapotranspiration, snow accumulation and melt. The way in which these interact to influence variables such as soil moisture and streamflow is not simple. A 50% recovery in terms of snow accumulation or melt may not represent a 50% recovery in peak flow magnitudes.

Watershed-scale studies

Approaches. The most statistically rigorous approach to quantifying the effects of forest operations on streamflow is a paired-watershed experiment, which is a form of before-after/control-impact (BACI) design. These experiments involve monitoring at least two watersheds, which are initially unlogged. At some point during the study, logging or some other "treatment" is applied to one watershed, while the other remains untreated to serve as an experimental control. Monitoring continues for some time after logging. A regression of streamflow in the treatment watershed (e.g. peak flow, low flow, annual runoff) against the paired streamflow in the control watershed for the pre-treatment period is used to estimate what the flow in the

treatment watershed would have been had forestry operations not been conducted. The difference between observed streamflow in the post-logging period and that predicted from the pre-treatment regression provides an estimate of the treatment effect. The success of such experiments depends on how well paired the two watersheds are in terms of geology, soils, topography and vegetation. In addition, the watersheds should be in close proximity to minimize differences in precipitation inputs and other climatic variables. A further requirement is that data are collected for a long enough period of time, both before and after logging, to provide sufficient degrees of freedom for detecting treatment effects with statistical significance. However, hydrologic recovery during the post-treatment period may complicate the statistical detection of the treatment effect. A major problem in generalizing the results is that the treatment effect will depend on the details of the forest operations and on watershed characteristics, which are unique to the treatment watershed. A practical challenge is that conducting such experiments requires significant long-term commitment of funds and effort.

An alternative approach to designed experiments is to use existing streamflow data. Retrospective studies involve an after-the-fact pairing of unlogged watersheds with logged watersheds for which some pre-logging data exist (e.g. Cheng, 1989; McFarlane, 2001). These should yield valid results if the watersheds are reasonably adjacent and well matched in terms of topography and vegetation. A related approach is to conduct a chronosequence analysis, in which trends in streamflow in a suite of watersheds with different management histories are correlated with changes in land use and/or climatic variables. These studies can also involve after-the-fact pairing to help separate the effects of land use change from climatic variability (e.g. Bowling *et al.* 2000). However, these studies are generally less powerful, in a statistical sense, than paired-watershed designs.

A third approach is to use computer simulation models. This approach is attractive in that alternative treatments can be applied to the same watershed (e.g. Whitaker *et al.* 2002). In western North America, the Distributed Hydrology-Soil-Vegetation Model (DHSVM) developed by Wigmosta *et al.* (1994) has been applied to this purpose in several studies (e.g. Bowling *et al.* 2000). The model DHSVM represents a watershed using a gridded digital elevation model (DEM), typically with a 25 m grid spacing. Processes including interception, snow melt, and transpiration are simulated as vertical one-dimensional fluxes at each grid cell, while subsurface and surface flow is routed downslope from cell to cell. The model can account for the effects of the road network on flow routing (Bowling and Lettenmaier, 2000). However, it requires more input data than are typically available in operational contexts, and even where the data are available, a significant amount of time by highly trained hydrologists is required to calibrate and run the model.

Results of paired-watershed studies. Paired-watershed experiments in BC include those at the rain-dominated Carnation Creek watershed on Vancouver Island (Hetherington, 1982), the snowmelt-dominated Penticton Creek watershed in the Okanagan drainage, and the rain-dominated Flume Creek watersheds on the Sunshine Coast near Gibsons. A range of paired-watershed experiments has also been conducted in the western United States and Alberta. These may provide at least qualitative information on the hydrologic effects of forest management. However, differences in climate, geology and glacial history limit the transferability of quantitative results. The following points summarize some key results.

1. Annual water yields generally increase following forest harvesting in both coastal and interior watersheds (Harr *et al*. 1982; van Haveren, 1988; Cheng, 1989), although there are some anomalous cases in coastal environments which might be related to decreased fog drip (Harr, 1983).
2. Low flows tend to become less extreme after logging in coastal basins (e.g. Harr *et al*. 1982). One published exception was related to establishment of hardwoods in the riparian zone, which possibly produced greater transpiration losses due to their lower stomatal control, leading to greater extraction of riparian groundwater and thus lower baseflow (Hicks *et al*. 1991). Another exception was apparently related to decreased fog drip (Harr, 1982).
3. Fewer studies have examined the effect of harvesting on low flows in snowmelt-dominated watersheds. Available evidence suggests they should increase (i.e. baseflow should be higher) as a consequence of decreased transpiration loss during the growing season (e.g. Cheng, 1989).
4. Harvesting and road building can increase the magnitudes of peak flows resulting from low to moderate size events in both rain- and snow-dominated watersheds (van Haveren, 1988; Jones and Grant, 1996; Beschta *et al.* 2000). In most studies, road building and harvesting occurred either simultaneously or in close succession, so it is difficult to separate their effects. Recovery to pre-logging conditions may take up to 20 years or more (Jones and Grant, 1996).
5. The greatest relative increases in rainfall peak flows in coastal watersheds are often associated with the relatively low-magnitude events in early autumn (e.g. Hetherington, 1982). Much of the increase may be due to the higher soil moisture status resulting from decreased growing-season transpiration following logging, which allows a greater fraction of incident rainfall to become runoff.
6. Effects on peak flows for coastal watersheds appear to diminish with event magnitude, and appear to be negligible for large, infrequent events (Beschta *et al*. 2000). A major caveat to this latter point is that few large, infrequent events have been sampled in experimental studies. A problem in generalising from available data is the great range in response that can be observed, depending on the nature of the events generating peak flows, as well as details of the road and harvesting systems (Harr, 1986; Jones and Grant, 1996).
7. Although there is some evidence that partial clearcutting can reduce peak flows by de-synchronizing snowmelt (Verry *et al*. 1983), many studies in snowmelt-dominated watersheds have found that harvesting increased freshet peak flows by up to 50% and in some cases more, even for cutting of only 30% or so of the watershed area (Troendle and King, 1987, Cheng, 1989). In some cases, the absolute magnitude of the increase has been positively related to spring snow accumulation, and thus should increase with increasing event magnitude. However, few studies have reported how relative (percentage) increases in peak flows vary with return period.
8. Some studies in snowmelt-dominated watersheds have not found statistically significant increases in peak flows (e.g. Troendle *et al*. 2001). However, Troendle *et al*. (2001) did find an increase in the frequency of days with flows higher than the bankfull discharge, which could have significance for sediment transport and channel morphology.

Watershed geomorphology

Watersheds and their stream networks are hierarchical structures comprised of hillslopes, zero order basins and stream channels. Zero order basins are concave areas within a hillslope or on a ridge, which are convergence zones for water and sediment from upslope areas, but which are unchannelled. They can play an important role in runoff generation (Tsuboyama *et al*. 2000) and in some geological settings may be source areas for debris flows (Dunne, 1998). Stream reaches can be categorized as being perennial (continuous flow year-round), ephemeral (exhibit seasonal drying) and intermittent (flow only during water-input events). Ephemeral and intermittent reaches tend to be found most commonly in the headwaters. During the wet season, and particularly during rainfall and/or snowmelt, the wetted stream network tends to expand headward; it then contracts between events and during the dry season. The spatial continuity of the wetted channel can be important in relation to fish movement and access to habitat.

The size or scale of a stream can be expressed in terms of its immediate physical dimensions (e.g. bankfull width) or its contributing watershed area. It is also often expressed by stream order, as introduced by R.E. Horton. In the Horton system, the headmost channels are assigned order 1. Where two order 1 channels join, the reach below the confluence is designated order 2. In general, when any two segments with the same order join, the segment below the confluence is assigned an order 1 greater than that of its tributaries. A related measure is stream magnitude, computed as the number of first-order streams upstream of the segment of interest. A problem with both stream order and stream magnitude is that they depend on the scale of map being used. For example, in coastal BC most stream reaches that would be identified as order 1 on the basis of field inspection are not even shown on 1:50,000 scale topographic maps.

Channel characteristics display a generally orderly progression down the stream network, with downstream decreases in both channel gradient and the size of bed material, and downstream increases in discharge and channel width, depth and velocity (Figure 3) (Church, 1996). The upper reaches tend to be closely coupled with the adjacent slopes. That is, the hillslopes may deliver sediment directly to the channel via bank erosion or mass movement processes such as landslides. Lower reaches with well-developed alluvial floodplains are decoupled from the adjacent hillslopes, and are more influenced by fluvial processes. Streams in high plateau regions may deviate from this pattern, with relatively lower-gradient reaches in the headwaters, particularly through wetland complexes, with steeper reaches downstream, where the channels incise downward through the surficial material and bedrock of the plateau to the level of major river valleys.

Channel morphology can be simply categorized in three broad types as defined for the Channel Assessment Procedure (Hogan, 2001), although more complex classification systems have been developed (e.g. Montgomery and Buffington, 1997). Step-pool and cascade-pool reaches are typically most common in the steepest, most headward portions of the stream network (gradients > 4%), while riffle-pool reaches dominate the lower, floodplain reaches (gradients < 4%). With the exception of large streams, which have sufficient depth and velocity to float wood and move it downstream, woody debris can play an important role in all three channel types. The precise role will depend in part on the orientation and depth of submergence of the wood. Wood pieces that are roughly perpendicular to the flow and completely

submerged will form pools downstream through the erosive action of water spilling over the obstruction; wood oriented at an angle to the current may divert flow against one channel bank, encouraging bank erosion; and wood aligned parallel to the bank may protect it from erosion. In general, the presence of wood in a channel enhances the complexity of channel morphology and provides valuable fish habitat.

In watersheds subject to landslides and debris flows and torrents, substantial amounts of wood may be delivered to a channel in single events, forming large jams (Hogan and Ward, 1997). Other episodic mechanisms that can introduce large quantities of wood to a channel include windthrow and bank erosion during floods. Jams can also form through downstream migration of single pieces during high flow events. Large jams can effectively store significant amounts of sediment for decades, in extreme cases producing sediment storage zones extending a distance of 100

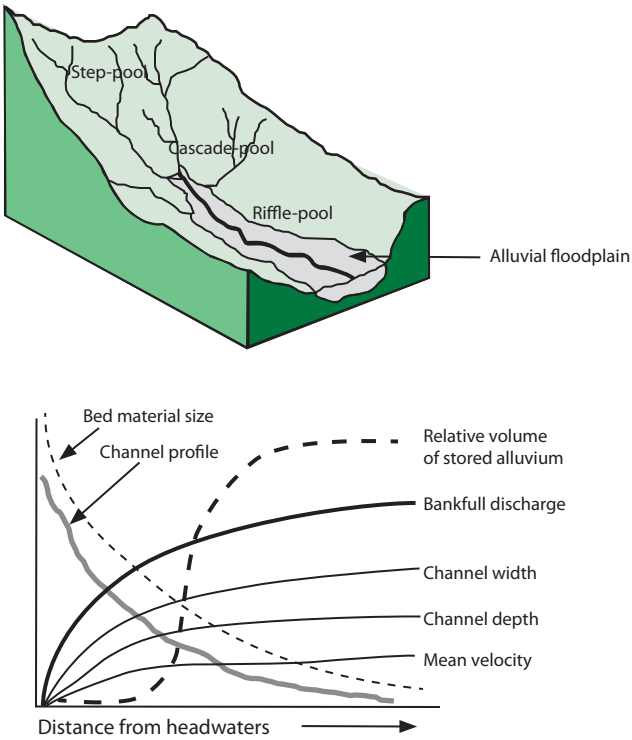

Figure 3:
Channel characteristics within the geomorphic context of a watershed [adapted from an original diagram in Hogan and Ward (1997)].

bankfull widths upstream of the jam. In the early stages of a jam, up to a decade or so after formation, fish habitat may be reduced. Through time, as the integrity of the jam declines and the channel begins to migrate around it, channel complexity will increase, in particular with the formation of side channels which can act as low-velocity refugia at times of high flow velocity in the main channel. The episodic inputs of large volumes of wood at different times and places, combined with the time it takes for a channel to adjust to these inputs, result in the diverse, complex fluvial environments that characterise pristine watersheds, especially in coastal steepland areas.

The morphology of a channel, as expressed by its width, depth, velocity and planform, reflects an adjustment to the governing conditions of water flows and channel slope (which control the power of the stream to move sediment), the quantity and calibre of sediment supplied to the reach, and the resistance of the bank material to scour. The adjustment occurs through transport of the bed and bank material and hence changes in the channel dimensions. A change in any of the governing conditions will result in a change in channel morphology. For example, an increase in peak flows or a decrease in bank strength, due to removal of riparian vegetation, may allow greater bank erosion and thus produce channel widening. Channel changes may impair the quality of fish habitat and are thus of concern to forest managers.

Water quality

Water quality is important in relation to domestic and community water supply and to aquatic habitat. For example, increases in summer temperatures can cause morbidity or mortality in salmonids. Of particular concern is the Bull trout, which is a blue listed species which favours cold water streams. Water chemistry changes and increases in suspended sediment concentrations can be important for both drinking water and aquatic communities.

Stream temperature

As water flows through a stream reach, its temperature may change as a result of energy exchanges across the water surface and channel bed, inputs of groundwater and tributary inflow, and hyporheic exchange (Figure 4). The exchanges across the water surface include net radiation, sensible heat exchange with the atmosphere and latent heat exchange with the atmosphere. The heat input of precipitation is typically much less than 1% of the total energy input to a stream (Webb and Zhang, 1997), and can be neglected for most purposes.

Forest harvesting that involves the removal of riparian cover would increase solar radiation inputs to and longwave losses from the hydroriparian zone. In addition, sensible and latent heat exchanges may increase due to increased wind speeds. Brown (1969, 1985) found that, during the day, energy inputs to a stream within a clearcut were dominated by solar radiation. Sensible and latent heat exchanges were an order of magnitude smaller.

Streams in the Pacific Northwest subject to clear-cutting with no riparian buffer have experienced increases in summer maximum temperatures of up to about 7°C (Johnson and Jones, 2000) and, in an extreme case, as high as 15^0 C (Brown and Krygier, 1970). Effects on summer minimum daily temperatures do not appear to

be as marked (Feller, 1981; Johnson and Jones, 2000). Summer daily temperature ranges after logging have ranged up to about 7 to 8°C, compared to pre-logging ranges of up to about 2 to 3°C (Feller, 1981; Johnson and Jones, 2000). Winter temperatures have received less attention. Feller (1981) found short-lived, modest increases in winter temperatures following logging in south coastal BC and decreases following logging and slash burning, though there was no clear explanation for these divergent patterns.

Riparian buffers can moderate temperature increases following logging by maintaining some level of shade over the stream. Post-logging summer stream temperature increases of up to 3°C have been observed in situations where sparse or partial-retention buffers have been left (Harr and Fredriksen, 1988; Macdonald *et al.* 2003a). Windthrow in the riparian buffer and associated loss of shade can reduce the effectiveness of buffers for temperature control (Macdonald *et al.* 2003b).

Streams headed by shallow lakes and wetlands tend to be warmer than streams headed by springs or small seeps (Mellina *et al.* 2002). These streams tend to cool in the downstream direction, even through clearcuts. Situations where streams flow from cut blocks into a lake or wetland do not appear to have been studied. Energy

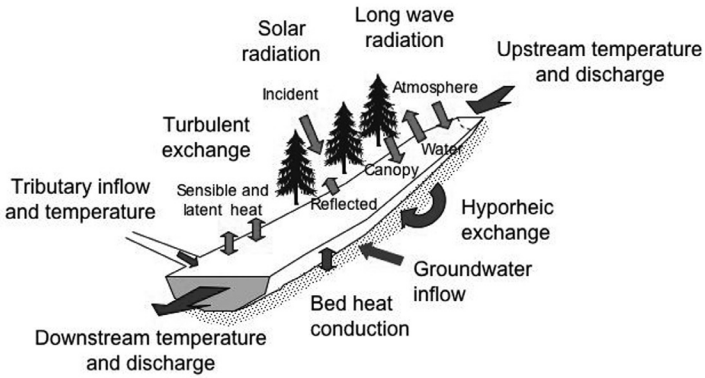

Figure 4:
Factors governing temperature change along a stream reach.

exchange processes in those environments may cause a re-setting of temperature consistent with the serial discontinuity concept (Ward and Stanford, 1983), such that the effects of forest harvesting upstream of lakes and wetlands would not be detectable in downstream reaches.

Stream temperatures tend to recover toward pre-logging conditions as vegetation regrows in the riparian zone. Recovery can occur as quickly as within 5-7 years (Brown and Krygier, 1970; Feller, 1981) to as long as 15 years (Johnson and Jones, 2000). There is conflicting evidence regarding the efficacy of low, shrubby vegetation in providing shade. Brown and Krygier (1970) observed a decrease in treatment effect in association with growth of alder, salmonberry, elderberry and vine maple in the riparian zone. On the other hand, Hewlett and Fortson (1982) presented evidence that low, brushy vegetation was less effective than taller trees at moderating water temperatures for a stream in the Georgia Piedmont.

Forest roads and their rights-of-way have a similar influence to cut blocks in

terms of enhanced solar radiation inputs. Another possible effect of forest roads is the interception of groundwater and its conveyance to a stream via ditches. The ditch flow would be exposed to solar radiation and warm. Hence, not only would the cooling effect of groundwater inflow be lost via interception, but it would also be replaced by warm water. In a study in central BC, Herunter *et al.* (in press) found maximum summertime warming of over 2°C across a 50 m right-of-way, 1.4°C across a 30 m right-of-way, and about 0.4°C across a 20 m right-of-way.

Warming of headwater streams following clearcut harvesting is unlikely to have a significant warming effect on a larger stream, unless the total discharge from clearcut-influenced tributaries is a significant proportion of the flow in the main stem (Brown, 1985). Even then, there may not be a significant downstream impact, due to cooling by energy exchange between the mainstem stream and its immediate environment. However, there may be a local impact in the vicinity of the tributary junction. Cool-water areas tend to occur where headwater streams flow into larger, warmer streams. These areas may be important thermal refugia during periods of high temperatures in the main stem. Bilby (1984) identified four distinct types of cool-water areas in a fifth-order stream, including lateral seeps, pool-bottom seeps, cold tributary mouths and areas of hyporheic exchange in the bed. The cool-water zones associated with tributary mouths were cooler than the other three types. Moreover, the other three types had depressed dissolved oxygen levels, as low as 50% of the saturation value. Thus, the tributary mouths should be particularly valuable refugia. An important consideration in managing small streams, therefore, is the protection of the function of these streams in providing cool-water refugia.

An important issue in forestry contexts is whether and how quickly streams cool after flowing out of a cut block and into undisturbed forest. If streams cool rapidly, then any deleterious effects of increased temperatures may not extend far beyond the cut block, the cumulative effect on larger stream segments may be negligible, and cool-water areas at tributary mouths could be protected by leaving a "cooling reach" between the cut block and the main stem. Furthermore, if streams cool in shaded reaches, it may be possible to ameliorate stream warming by retaining tree cover as a patch over a portion of the stream rather than as a thin, linear buffer, which may be subject to greater risk of blowdown.

Several studies have reported streams cooling after flowing from an open area into forest, with observed temperature decreases of up to several degrees over 100-200 m (Greene, 1950; Levno and Rothacher, 1967; McGurk, 1989; Keith *et al.* 1998; Story *et al.* 2003). One shortcoming with these studies is that downstream temperature changes were monitored only after logging. Without pre-logging data, the magnitude of the net downstream effect cannot be evaluated. For example, a stream may have cooled 5°C after flowing out of a clearcut and into a shaded reach, but still may be warmer than it would have been prior to the upstream harvesting.

Fine sediment and turbidity

Fine sediment is the material that is frequently transported by streamflow, including the clay, silt and sand fractions (Church, 1998). It can produce a range of problems in aquatic systems. It impairs water quality for domestic use and can interfere with fish. For example, fine sediment can damage fish gills, high turbidity can reduce the effectiveness of sight-feeders, and fine sediment entrained into bed gravels

can reduce their permeability and the supply of dissolved oxygen to fish redds (Newcombe and MacDonald, 1991). Forest operations can increase the rate of fine sediment input to streams in several ways. Increased fine sediment represents one of the greatest forestry-related water quality risks.

Quantitative expression. Fine sediment can be quantitatively expressed as either suspended sediment concentration (SSC), typically in milligrams of sediment per liter of water, or as turbidity, which is a measure of the "cloudiness" of water. The standard unit is the Nephelometric Turbidity Unit (NTU), defined by the amount of light scattering that occurs in a standardized solution of formazine in water. SSC is typically measured by taking a water sample from the water column, either manually or with an automated pump sampler, then extracting the sediment by filtering. Turbidity can be measured using optical sensors, which measure the degree to which light transmission is impeded by suspended particles. A statistical relation between SSC and turbidity can be derived, but the relation will depend on the sediment mineralogy and the particle size distribution, which can vary through time, even at a single location.

Sediment sources. Sediment available for transport is generated by mobilization of soil or surficial sediments via erosion processes. These involve the separate processes of particle detachment, transport and deposition. Particle detachment involves the separation of mineral grains from the soil mass or overburden to which they were attached, by processes including surface erosion, dry ravel, needle ice formation, mass wasting or channel scour.

Surface erosion occurs through the action of water, either by rain impact on an exposed mineral soil surface and/or the shear stress imposed by overland flow. In undeveloped forested watersheds, surface erosion is generally limited to exposed mineral surfaces at landslide scars, since the high infiltration capacity inhibits the generation of Hortonian overland flow, and the soil surface is protected by the surface organic horizons and root network. Soil disturbance by construction of roads and landings, and by log-skidding, can create new sources of fine sediment. The use of tracked machinery, such as hoe-forwarders, may also cause soil disturbance. Sediment generated by soil disturbance directly adjacent to a channel, such as occurs where roads cross streams, will be easily transported into the stream. However, the impact of sources further away from the stream channel will depend on whether the sources are connected to the stream by a continuous line of overland flow. If not, then the sediment would be deposited on the soil surface before reaching a stream channel. For example, Henderson and Toews (2001) estimated that only 36% of the sediment eroded from road surfaces was delivered to the channel network in water-sheds in southeastern BC.

Glaciolacustrine and glaciomarine sediments are common in many regions in BC. These fine-grained deposits are prone to surface erosion and failures associated with piping and gullying. Road building in these materials can accelerate these processes, increasing sediment production.

Mass wasting involves the downslope movement of surficial material under the force of gravity. Dry ravel is a form of mass wasting that occurs during dry weather, particularly on steep exposed surfaces such as road cuts. When the exposed material becomes air-dry, there is no longer any surface tension associated with water films surrounding the mineral grains, and the material can roll or slide down the slope,

often dislodging other particles. During extended periods of dry weather, dry ravel can produce significant sediment inputs to ditches, where it can be picked up by ditch flow during autumn rain storms. Dry ravel can also occur in association with surface frost and needle development, which displaces soil particles outwards from the exposed surface, allowing them to fall downslope under the force of gravity.

Mass wasting may also take the form of translational movements such as debris slides, torrents and avalanches. These involve the rapid failure of a shallow layer of hillslope material comprising a mixture of mineral soil, rock fragments, organic material and water. Alternatively, mass wasting may occur through slower, rotational movements (earthflows and slumps), usually occurring in finer-grained material. Although gravity is the dominant force resulting in downslope transport during mass wasting events, water may play an important role, particularly in triggering an instability by increasing the pore pressure within the soil mass, which in turn reduces the internal frictional resistance to movement.

Forest operations can increase the frequency of landsliding in several ways. Redirection of hillslope flow by roads and their drainage systems can cause localized increases in water table levels and pore pressures to the point that a failure occurs. Die-off and decay of tree roots following harvesting reduces the internal cohesion of the soil mass. There is a critical period from about 5 to 15 years following logging, in which the strength of dead roots has decayed below critical levels, and before new roots become sufficiently established to restore soil cohesion (Sidle, 1992). In addition, if roads are poorly drained or become inundated by a plugged culvert, the road bed may become saturated and fail (Brown, 1985). Another potential cause of road-related landslides is decay of organic material incorporated into the road bed (Beschta, 1978).

Landslides may introduce extra sediment to a stream if the slide reaches the channel or some portion of the drainage system that is directly connected to the channel network. Even after the initial input of sediment from a landslide has been transported downstream, the unvegetated landslide scar can provide an ongoing source of sediment. Re-vegetation of landslide scars reduces this problem, and also may stabilize the slope. Landslide processes and mitigation measures are discussed in more detail in the chapter on forest operations.

Channel scour occurs when the shear stress associated with streamflow exceeds the resistance of bed and/or bank materials. This process can introduce new material into the channel from the banks, as well as re-entrain fine material that had previously been deposited in the bed. It can be accelerated by logging-related increases in peak flows, as well as loss of bank strength associated with removal of streamside trees. Windthrow of streamside trees can introduce sediment via the upturned root wads. This is potentially a hazard associated with riparian buffer strips, which can experience significant blowdown. However, in most cases the quantity of sediment generated by tree-throw appears to be relatively small compared to the amount of sediment stored in the channel upstream of woody debris (Grizzel and Wolff, 1998).

Glaciers are important sources of fine sediment in many mountainous regions in BC. This sediment is produced by abrasion of the underlying bedrock as the glacier slides over it. Proglacial lakes may trap some of this sediment, but a significant amount may remain in suspension in the water column and exit the lake to influence downstream reaches (Richards and Moore, 2003).

A number of studies have estimated the sediment budgets of harvested watersheds or used sediment characteristics to identify the dominant sources of sediment and the pathways by which it is delivered to a channel. In both coastal and interior watersheds, roads are a dominant source of fine sediment in most harvested watersheds (Reid and Dunne, 1984; Christie and Fletcher, 1999; Jordan, 2001). The majority of road-generated sediment can originate from a relatively small fraction of the road network if there are major variations in the erosion potential of the road surfaces (Henderson and Toews, 2001). Sediment generation from roads is strongly influenced by the intensity of road usage. Reid and Dunne (1984) found that intensely used roads generated 130 times more sediment than abandoned roads. In addition, road maintenance can increase sediment production. For example, Jordan (2001) found that the first storm that occurred following grading of road surfaces generated a significant increase in stream turbidity.

Suspended sediment dynamics and effects of forestry. Suspended sediment concentrations (SSC) in stream water depend on the transport capacity of the flow and the supply of sediments. During high flows, the rate of supply tends to be the limiting factor. In rain-dominated watersheds, SSC typically increases during the early portion of the hydrograph rise, as transport capacity increases and sediment storage is accessed by the rising water level and increased shear stress. The available sediment supply is often exhausted before the streamflow peaks, so that SSC usually peaks and drops off earlier than streamflow. This process produces clockwise hysteresis in a plot of SSC against streamflow; that is, SSC tends to be higher on the rising limb than on the falling limb. In a sequence of storms, the first storm may have the highest SSC, with successive storms having decreasing SSC, unless erosion processes generate new supply (Paustian and Beschta, 1979). Hysteresis has also been recorded in some snowmelt-dominated watersheds, with an initial flush of sediment associated with the early part of the seasonal hydrograph rise creating the highest SSC, followed by declining SSC, even if discharge remains high (Henderson and Toews, 2001; Richards and Moore, 2003). However, in some watersheds, each period of high snowmelt-induced runoff during the spring freshet can produce similar peak levels of turbidity (Jordan, 2001). This high level of variability within and between storm and snowmelt events means that high sampling frequencies and/or continuous recording of turbidity are required to monitor the full range of suspended sediment variations in a stream, especially for the purpose of detecting the effects of land-use on suspended sediment (Beschta, 1978).

Relatively few paired-watershed studies have examined the effects of forest operations on SSC in western North America. One study in the Oregon Coast Range showed that suspended sediment yields (i.e. total annual output of suspended sediment from a watershed) doubled after road building in one watershed and tripled after clearcutting and slash burning in another (Brown and Krygier, 1971). In the case of road building, the sediment yields appeared to recover to pre-logging conditions within three years. However, in the case of logging and slash burning, yields remained elevated for four years, but recovered to pre-logging conditions by the fifth year (Beschta, 1978). The intensity of road usage following logging was not specified; changes in intensity could have influenced the pattern of sediment production. These results cannot confidently be transferred to other situations, particularly considering changes that have occurred over the last two decades in

relation to harvesting methods and road layout, construction and maintenance. In a study in small watersheds in the Oregon Cascades, the occurrence of debris flows, some related to logging activity, dominated suspended sediment yields and obscured the effects of the cut blocks and roads on sediment generation (Grant and Wolff, 1991).

Water chemistry

A range of water chemistry parameters can be influenced by forestry operations. For example, harvesting can affect nutrient cycling and thus the concentrations of nutrients in stream water. Decompsition of organic debris left in a channel can consume dissolved oxygen (DO). Silvicultural operations often involve application of organic chemicals such as herbicides and pesticides. In addition, rain and snowmelt in contact with logs at dry-land sorts and logyards can generate leachate which can have a significant toxicity when it runs off into adjacent bodies of water (Orban *et al.* 2002). The fates of silvicultural chemicals and logyard runoff lie beyond the scope of this chapter.

Nutrients and other dissolved substances can be input to a watershed either through weathering of soil and bedrock, or from the atmosphere via fixation by plants or by wet and dry deposition. Wet deposition involves input dissolved in rain or held on snow crystals, while dry deposition occurs by adsorption of materials onto leaf surfaces or the soil, where it can be washed off by subsequent rains or taken up into the leaf, e.g. through the stomata. Forests tend to have "tight" nutrient cycles, in which dissolved materials are taken up by plants from soil water before they can be delivered to the stream by downslope flow. However, harvesting can disrupt this cycling and increase the amount of dissolved solids that exits the water-shed via streamflow, resulting in higher solute concentrations in streamwater and greater export to downstream water bodies. The major management concerns relate to the possibility of drinking water standards being exceeded, particularly for nitrate, and the possibility of eutrophication in receiving water bodies. Eutrophication involves the acceleration of algal production by nutrient inputs. Algal blooms can inhibit oxygen transfer across the water surface, and the decomposition of algal detritus consumes dissolved oxygen. The net effect is to produce low DO concentrations, especially in low-velocity streams and lakes, which can cause fish die-off and shifts in species assemblages.

The effects of forest operations on stream nutrient concentrations have been studied in a range of ecosystems. A seminal study at Hubbard Brook, New Hampshire, found nitrate concentrations in a small, logged watershed were 41 and 56 times greater than in the control watershed in the first two years after clearcut harvesting of hardwood forest, and exceeded the drinking water standard of 10 mg/L NO_3-N (Likens *et al.* 1970). Herbicide had been applied to inhibit re-vegetation. Subsequent studies in other regions found qualitatively similar findings, but with much less dramatic increases in nitrate. For example, clearcutting and slashburning a small watershed in the Oregon Coast Range produced slight increases in nitrate concentrations in streamwater, with maximum concentrations of about 2.1 mg/L, much below the drinking water standard (Brown *et al.* 1973). Similar results were found for two watersheds in southwest BC, one of which was subjected to clear-cutting and the other to clearcutting followed by slash burning (Feller and Kimmins, 1984). Nitrate concentrations recovered to pre-harvest levels after 2-3 years, while

potassium concentrations remained elevated for several years. Feller (1989) found that application of glyphosate to 45% of a small watershed in southwestern BC to control brush increased streamwater concentrations of most chemical species, particularly potassium, magnesium and nitrate. Although elevated above pre-logging levels, nitrate concentrations never exceeded drinking water standards.

Forest operations can reduce streamwater DO in two ways. Because the saturation levels of DO decrease with temperature, any logging-related increases in stream temperature may decrease DO. In terms of salmonids, the water quality standard for DO in BC is 5 mg/L as an instantaneous minimum, with a higher standard of 9 mg/L during the buried embryo/alevin stage (British Columbia, 1997). The saturation level of DO would drop below 9 mg/L for temperatures exceeding 18°C, and temperature alone would not reduce DO to 5 mg/L, for the normal range of stream temperatures experienced in BC. In addition to the effect of increased temperature, chemical oxidation and/or biological decomposition of organic debris left in a stream following logging can consume DO. Inputs of organic matter to a stream and the resulting increase in biochemical oxygen demand (BOD) can be minimized through careful harvesting practices, in particular by leaving a riparian buffer along the stream. Even where high BOD does reduce dissolved oxygen, the stream's DO may recover via re-aeration within a relatively short distance downstream of the sources of BOD, especially if the stream is highly turbulent (Brown, 1985).

Riparian management

Riparian vegetation plays an important role in stream morphology and ecology. The canopy provides shade and moderates stream temperatures, and also provides inputs of nutrients and energy via litter fall. Treethrow within the riparian zone supplies woody debris, which helps create channel complexity and enhanced fish habitat in the form of pools and sediment storage zones. Tree roots help stabilize channel banks and resist erosion. The riparian zone is also an important terrestrial habitat, particularly for amphibians.

In recognition of the ecological values of riparian zones and their influences on stream morphology and function, silvicultural prescriptions in most jurisdictions in the Pacific Northwest require the designation of a riparian management zone along streams. This management zone may involve restrictions including no-machine zones and partial or full retention of standing trees. In BC, Washington and Oregon, different levels of riparian protection are assigned to different stream classes, with greater protection (i.e. wider buffer strips) for streams used for community water supply or with significant fisheries values. The criteria for stream classification and requirements for riparian protection vary amongst the various jurisdictions in the Pacific Northwest, reflecting the lack of consensus on necessary levels of riparian protection (Young, 2000). One problem in this approach to riparian protection is that the buffer strips may be vulnerable to windthrow; studies have documented cases in which up to 92% of the reserved trees blew down (Grizzel and Wolff, 1998). One approach to mitigate the risk of windthrow is to leave wide buffers. Another is to trim the tree crowns to reduce their wind drag. This operation is conducted by specially designed trimmers suspended from helicopters.

Watershed analysis and management

Watershed analysis comprises a set of procedures for assessing the current state of a watershed, including the impacts of past natural disturbances and forestry practices, as well as the potential impacts of future activities (Montgomery *et al.* 1995). By the 1990s, watershed analysis procedures had been adopted to aid forest management in the Pacific Northwest by a number of agencies and on lands under a range of jurisdictions, including state, private, and federal in the United States, and crown land in BC (Montgomery *et al.* 1995; Chatwin, 2001).

In BC, an early incarnation of procedures for watershed analysis and management was the use of critical thresholds, specifically based on the notion of limiting the rate of cut to, for example, 33% of a watershed over 25 years (Chatwin, 2001). The crudeness of this approach and its inability to account for site-specific factors led to attempts to incorporate more process considerations. One example was the Fish-Forestry Interaction Project (FFIP) Model (Marmorek *et al.* 1998), which coupled sets of empirical relations to predict the cumulative effects of forestry operations and natural disturbances on channel morphology and stream habitat. Although it would be desirable to apply models with a strong physical basis, these have proven expensive and difficult to apply due to the extremely high levels of input data and processing required. To date, application of this sort of model has been restricted to streamflow simulation via the DHSVM (Whitaker *et al.* 2002).

An alternative approach is the expert panel, which employs ranked responses to a series of questions by a set of experts to assess the sensitivity of a watershed. However, this approach has been abandoned in BC since it was too coarse and identified too many watersheds as requiring more detailed study and analysis (Chatwin, 2001).

Watershed assessment procedures developed and adopted beginning in the mid-1990s evolved from a system based on indicators, which are surrogate measures to represent watershed processes and sensitivity to development, to a system based on professional assessment by qualified practitioners (Chatwin, 2001). Separate procedures were developed for coastal and interior regions, acknowledging the broad differences in hydrologic regimes across the province. The Coastal Watershed Assessment Procedure (CWAP) assumes that the hydrologic regime is rain and/or rain-on-snow dominated, while the Interior Watershed Assessment Procedure (IWAP) assumes that the hydrologic regime is snowmelt-dominated. Both procedures incorporate analyses of hillslope stability and sediment sources, channel stability and sensitivity to forest operations, and the potential hydrologic impact of forest harvesting and roads.

A commonly used indicator for quantifying the cumulative hydrologic impact of forest harvesting and other disturbances is the Equivalent Clearcut Area (ECA). It weights clearcut areas according to the degree to which hydrologic recovery has been achieved by regenerating vegetation. For example, a fresh clearcut area would be assigned a weight of 1.0, and decreasing weights would be assigned to clearcuts of increasing age and/or tree height, according to empirically determined relations. Although ECA is relatively simple to compute and apply as a management criterion, it has not been found to be an effective predictor of the hydrologic influence of forest harvesting (Scherer, 2001). The locations and areas of cutblocks may be more important controls on hydrologic influences than an aggregated measure such as ECA. The IWAP attempts to overcome some of this criticism of ECA by weighting

clearcuts according to elevation. Snowmelt-generated peak flows in mountainous watersheds tend to occur when snow has completely melted from the lower 40% of the watershed area. That is, the lower 40% of the watershed does not actively contribute melt during peak flow, so that clearcuts in that elevation range do not have as much hydrologic impact as clearcuts in the upper 60% of the watershed (Gluns, 2001; Whitaker *et al*. 2002). A more fundamental limitation of the use of ECA as an indicator of the impact of forest harvesting on watershed processes is that it does not capture effects of riparian harvesting or logging roads on riparian function, slope stability, sediment generation and channel stability. Watershed analysis procedures need to consider a suite of indicators to account properly for the full range of potential impacts.

At the time of writing, forest management in BC is shifting directions from a prescriptive regime involving rule-based procedures to a "results-based" regime, which specifies the results to be achieved during forest development, rather than the specific practices to be followed. The implications for watershed assessment are currently not clear.

Watershed restoration

Many watersheds have been adversely affected by past forest practices and other resource extraction activities, particularly by logging-induced landslides, erosion from logging roads and logging of mature timber to the streambanks. In 1994, the Province initiated a Watershed Restoration Program to accelerate the recovery of streams and watersheds from these impacts. A range of operations may be used to address these impacts, including the following (Slaney and Martin, 1997):

- reduction of road erosion, either by re-working the road bed to restore the natural hillslope contours and thus the pre-logging drainage pattern, or by deactivation;
- revegetation of hillslope scars to reduce sediment generation;
- restoration of streamside trees through silvicultural activities to ensure the eventual recruitment of large woody debris to the stream and strengthen stream banks;
- emplacement of boulders, large wood and other structures in the channel to create favourable habitat for fish;
- restoring fish access along the channel and rehabilitation of off-channel fish habitats in flood plains; and
- addition of nutrients to streams and lakes to improve productivity.

In planning watershed restoration activities, the watershed context must be considered. For example, if a channel has been impacted by increased landslide activity related to forest roads, operations should first focus on stabilizing the hillslopes before addressing in-channel conditions. Similarly, if channel instability has resulted from loss of bank strength following removal of riparian vegetation, efforts should first focus on restoring bank strength.

Watershed restoration operations are expensive, and their efficacy has not yet been well documented, particularly in relation to long-term processes such as woody debris recruitment.

Concluding comment

Although there is a reasonable qualitative understanding of watershed processes and the potential effects of forest operations, there are considerable knowledge gaps that limit our ability to make accurate, quantitative predictions about the effects of specific forest practices in specific places. As these gaps are filled by future research, there will be an ongoing need to reconsider and revise forest practices.

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FISH AND STREAM PROTECTION

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FISH AND STREAM PROTECTION

Introduction

The objective of this chapter is to overview the factors and issues involved in how watershed management, with a focus on timber management, influences fish and their habitat in British Columbia (BC). The aim is to provide a basic understanding of: stream ecosystems, the life histories and habitat requirements of stream dwelling fish, how the ecology of fish and stream ecosystems is affected by forestry practices, and, how we can reduce and prevent the negative interactions between forestry and aquatic ecosystems that often occur. The primary focus of this chapter will be on an examination of streams, as this freshwater ecosystem is much better studied than others (e.g. lakes, wetlands, estuaries) in terms of interactions with forestry. However, references will be made, where possible, to other aquatic ecosystems. Meehan (1991) and Northcote and Hartmann (2004) provide a much more thorough examination of the roles of forestry and other land uses on aquatic ecosystems, than is provided herein.

Although there are over 10,000 species of freshwater fish, this chapter will make reference to only an extremely small fraction of those, specifically those that occur in the family Salmonidae (the salmon, trout and charr family). There are several reasons for this. First, this family of fish is widespread across BC thus they have diverse habitat requirements – maintaining and protecting their habitat ensures the protection of habitat needs for other aquatic (and riparian) organisms. Second, most of the past research examining interactions between forestry and fish have studied salmonid fishes – unfortunately this also means that most stream protection guidelines have a 'salmonid' bias. Third, they support the most valuable commercial and recreational fisheries in Canada – fisheries for Pacific salmon generate over $1 billion of revenue annually (Anon., 1995; 2002). Fourth, salmonids are important components of food webs in both freshwater and marine environments. Fifth, particularly in western Canada, salmonids are integral to mythology, spiritual integrity, and local economies of First Nations. Sixth, salmonids are an icon for the general public, with abundant salmon confirming a healthy and pristine environment. The long-term productivity and sustainability of salmonid stocks is highly valued by our society.

Stream Ecosystems

Energy resources

It is understood that an ecosystem is composed of the biological community, the community's resources, and the physical and chemical environment within which the community and resources exist. The primary resource is 'energy' (as organic carbon) which can be categorized based on its origin and pathway into

a stream. '**Autochthonous energy**' is organic carbon which is created directly by aquatic plants via photosynthesis. '**Allochthonous energy**' is organic carbon which is imported into a stream from outside sources. There are three forms of autochthonous sources of energy, that is, three forms of aquatic plants, their prevalence depends on stream size, gradient and amount of sunlight. Phytoplankton are microscopic aquatic plants, sometimes termed algae, that exist suspended in the water column. They are found only in very low gradient and slow rivers and streams (< 1 m/s flow). As they are easily flushed out of systems, they do not figure prominently in most small streams in BC but can be found in backwater areas of large rivers and sloughs, and in lakes and estuaries. They are a main food source for zooplankton, which are suspended microscopic invertebrate animals.

Periphyton are common aquatic plants found in fast moving streams and shallow rivers. They are also termed algae but unlike phytoplankton, they are found attached to surfaces of submerged hard substrates (e.g. rocks, pebbles, logs), thus they are able to live in fast flowing waters (> 1 m/s). The unicellular forms are called 'diatoms' which exist in very thin layers on submerged surfaces and help contribute, along with microscopic bacteria and fungi, to the extremely slippery nature of wet rocks and boulders. It is difficult to see diatoms with the naked eye. Diatoms are a preferred prey item of many types of substrate dwelling invertebrate animals. Multicellular periphyton are termed blue-green algae and are composed of long filamentous structures which make them highly visible on hard surfaces in streams. They are not readily eaten by many invertebrates because they sometimes contain toxins, are relatively low in nutrient value and are hard to digest. However, when dead, their detritus is often consumed by invertebrates (Murphy and Meehan, 1991). High levels of sunlight and dissolved nutrients, as can be created from harvesting streamside trees, can cause a community of periphyton to shift from diatoms to blue-greens. This could affect energy transfer via food web processes, as will be summarized below.

Vascular macrophytes are the third type of aquatic plant. Their growth form depends on water velocity and depth. In slow water, macrophytes float and are not rooted into the substrate. In fast water, macrophytes need to be rooted and usually do not have emergent parts. In shallow and slow water, emergent forms (rooted and non-rooted) are typically found. The emergent parts of these plants are food sources for invertebrates, however, the submerged parts with their hard, lignified walls and low nitrogen content are not easily consumed. Macrophytes decompose much faster than terrestrial leaves that fall into streams – dead macrophytes lose 50% of their weight in one week whereas leaves lose only 5-25% of their weight. Thus, it would seem that macrophytes are an extremely important component of aquatic food webs, yet aquatic plants contribute to less than 20% of total instream detritus. The remaining 80% has terrestrial origins (i.e. is allochthonous energy; Murphy and Meehan, 1991).

There are several sources of allochthonous energy. The first and most important is leaf and needle litter from riparian vegetation. When litter enters a stream, a small component of its organic matter (about 15%) dissolves out (termed dissolved organic matter or DOM) and is directly available to bacteria and fungi (Murphy and Meehan, 1991). The remaining 85% is locked away and is only 'released' when it is fed upon by bacteria, fungi and invertebrate animals. Were it not for

these organisms, streams would be entirely choked with leaf litter. Woody debris is not an important allochthonous energy source because microbes and invertebrates have difficulty breaking down lignified structures. The second major source of allochthonous energy is as DOM from groundwater and soil erosion. Up to 25% of all organic input to streams can come from this, however it can be relatively poor in nutrients. The remaining sources of organic matter input all involve movements of animals and can be quite seasonal in their importance. Mammals such as cattle and deer bring nutrients and organic carbon from land to streams via their fecal matter when they come to streams to drink or cool down in summer months. Beavers can flood large riparian areas which can facilitate the movement of organic matter into stream channels. Adult salmon, which are migrating upstream to their natal streams to spawn, bring with them bodies full of marine-derived nutrients and organic matter which are released into streams upon their death following spawning. In the autumn, up to 50% of phosphorus in streams can come from salmon carcasses (Rand *et al.* 1992). In areas with spawning salmon, over 25% of nitrogen in riparian trees has marine origins (Helfield and Naiman, 2002). Throughout the summer and early autumn, large numbers of insects drop into streams either on purpose as part of their mating, or accidentally, being blown out of trees. In all cases where organic matter enters streams, it is the fungi and bacteria which are responsible for converting this energy into biomass which is useable by other biota (Figure 1).

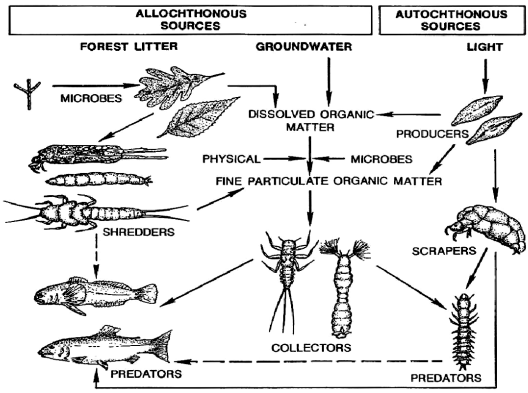


Figure 1:
Energy sources for energy-flow pathways in, and the trophic structure of woodland stream ecosystems. Deciduous leaves, photosynthesis by diatoms, and dissolved organic matter in groundwater are major energy sources. Genera that typify consumer functional feeding groups are the shredders, collectors, scrapers and predators. Litter microbes are shown as hyphomycetes fungi. The dashed arrow indicates infrequent exchange. Not drawn to scale. Taken from Murphy and Meehan (1991).

Energy flow and food webs

With the noted exception of upstream migrations of salmon, the transport of most organic matter is downstream. The slower this material moves through any given stream section, the more likely it is that this material can be used as a food source

(directly by microbes and the invertebrates which feed on them, and thus indirectly by fish which feed on the invertebrates) in that section. Instream features that slow water down, such as boulders, logs, and rooted macrophytes promote the retention of litter, salmon carcasses, and other dead organic matter thereby helping to make the extraction of energy by microbes more efficient. This process of organic matter transport, retention, use and export is referred to as 'spiralling'. Generally, spiralling is greater in small streams because of numerous large boulders and logs (Murphy and Meehan, 1991).

The main factors that limit authochthonous energy production in streams are dissolved nutrients (nitrogen and phosphorus), sunlight, and temperature. Authochthonous production in most small forested streams in BC is primarily limited by sunlight. In coastal and northern regions where riparian trees have been harvested thereby permitting high light levels reaching streams, nutrients can become the limiting factor, particularly if these streams no longer have large salmon runs. It is possible that in southern and interior regions, temperature could become a limiting factor. The main factor that limits the processing of allochthonous energy is the rate of microbial activity which tends to increase with increasing levels of dissolved nutrients and increasing temperatures. Not all allochthonous material decomposes at the same rate. For instance, deciduous litter decays much quicker than coniferous litter because of the latter's waxy cuticles and lower nitrogen content (Murphy and Meehan, 1991).

There are several hundred species of stream dwelling aquatic invertebrates (many of which are larval forms of terrestrial insects) but they can be crudely classified into 'functional feeding guilds' based on their feeding habits (Figure 1). 'Shredders' eat living or decaying vascular plants and litter, and while some can obtain nutrition from plants, most of their energy comes from ingesting the microbes that are decomposing the vegetative matter. Shredders facilitate microbial decomposition (up to 20% higher rates) by exposing more surface areas for fungi and bacteria to feed (Murphy and Meehan, 1991). Within one year, most accumulated instream litter can be reduced to fine particles by shredders, in contrast it takes hundreds of years for submerged large wood to break down. 'Scrapers', as their name suggests, scrape the thin layers of periphyton off hard substrates. 'Collectors' filter feed off of drifting algae or filter detrital material out of bottom sediments. Shredders can facilitate the feeding of collectors by providing additional drifting matter. 'Predators' swallow invertebrates or pierce them and ingest fluids. Energy flows in complex ways throughout stream food webs, but regardless of the primary source of energy or how invertebrate guilds interact, the top predator is usually fish (Figure 1). Fish are thus influenced by any process that affects energy flow between periphyton and invertebrates, or among invertebrate guilds.

Stream dwelling salmonids are predators on all guilds of aquatic invertebrates. Salmonids are visual predators and require some light to locate prey. Because they use vision to hunt, prey movement is a key element as moving objects are easier to see than stationary ones. Prey size is also important with bigger prey being easier to locate. Invertebrate prey are normally captured while they are 'drifting' down-stream in the water column. Invertebrates actively enter the drift as a means to move from one habitat to another for purposes of dispersal, reproduction, feeding, and avoiding competitors or predators. Drifting may also be inadvertent due to sudden changes in

flows. Generally, salmonid diets reflect the composition of the drift, although some avoidance and preference of certain prey types are shown. In summer months, up to one third of the drift could be from terrestrial invertebrates which have dropped into streams. Over 20,000 invertebrates per metre of stream width per day have been recorded moving downstream. The number of invertebrates drifting tends to peak near dawn and dusk, and not surprisingly, these are also the times when salmonid feeding is highest (and for the same reasons, its also the best times to be out fishing in your favourite trout stream!). There are also seasonal trends to salmonid foraging that closely follow periods when invertebrates are highly active (e.g. during their reproduction, or during metamorphosis from aquatic to terrestrial life stages). Additional information on stream ecosystems can be found in Murphy and Meehan (1991).

Origin and Distribution of Freshwater Fish in BC

The present fish community composition has been shaped by four features: post-glacial re-colonization factors (e.g. glacial refuge locations), abiotic factors (e.g. gradient and water quality), biotic factors (e.g. competition/predation), and human introductions and removals. Detailed information can be found in McPhail and Carveth (1992).

Post-glacial re-colonization

About 15,000 years before present, most of what is now BC was covered under an ice sheet up to one km thick. Two small areas of the province were not covered by ice, one situated at the northern tip of Vancouver Island and the other at the eastern tip of Graham Island in Haida Gwaii, and some fish populations would have existed there. However, this means that most fish species are recent immigrants, in geologic terms, to BC. Because the ice sheet retreated to the north and east (e.g. the area that is now Vancouver Island and the Lower Mainland was the first to be 'deglaciated'), most immigrants came in from two main 'refuge' drainage areas. These were the Chehalis route (via the Olympic peninsula in what is now western Washington State) and the Columbia route (which is now eastern Washington State) situated in the southern and eastern portions of the province. Thus, fish faunas in the lower Fraser valley are similar to those in western and northern Washington State (e.g. presence of endangered species Nooksack dace (*Rhinichthys cataractae*) and Salish sucker (*Catostomus catostomus*). The Great Plains and Yukon colonization routes brought fish into the north-eastern portions of the province and also enabled fish from distant eastern areas to reach BC (Figure 2). Thus, especially in northern BC, the fish fauna is similar to that in parts of the prairies and northern Ontario (e.g. presence of northern pike (*Esox lucius*) and yellow perch (*Perca flavescence*)). Migration routes often only existed for a few hundred years as meltwater lakes and outlets constantly changed, therefore fish with tolerance for cold water were more likely to recolonize, thus most of BC's fish fauna have cool and cold water preferences.

Abiotic factors

The single most important abiotic factor limiting the distribution of fish species is gradient. Over 75% of the province lies above 1000 m, and the majority of rivers

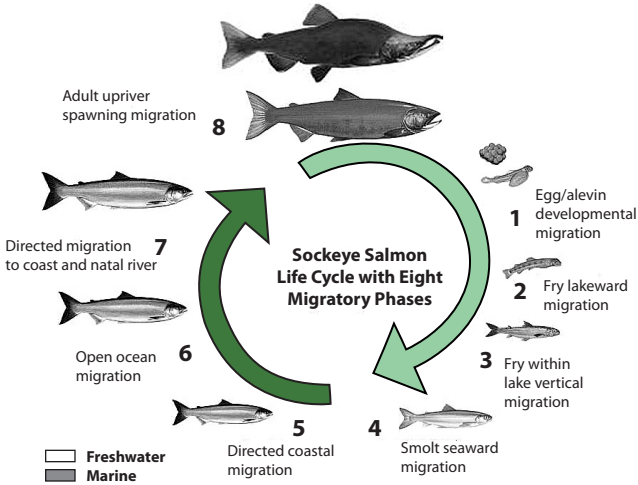


Figure 2:
Typical life cycles of anadromous salmonids.

have high gradients. Generally, the steeper the river, the fewer the number of species that will occur. For example, 13 fish species occur in the Cottonwood River near its confluence with the Fraser River, only 8 species can be found upstream in the Cottonwood after ascending 50 metres in altitude, and only 4 species exist upstream after ascending an additional 100 metres in altitude (McPhail and Carveth, 1992). With increasing gradients, river velocities increase and other swimming obstacles such as rapids and waterfalls, increase in prevalence. Species with poor swimming abilities (e.g. those within the minnow family – Cyprinidae) cannot ascend fast water and thus are limited in their distribution, whereas most salmonids have relatively good swimming abilities and are more widespread. There are also several water quality features that have likely affected the distribution of fish species in this province.

Acidity

A pH of 4 will kill most species. In northeastern BC, shallow bog lakes have naturally very low pH and contain only acid-tolerant species (e.g. finescale dace (*Phoxinus neogaeus*) or brook stickleback (*Culaea inconstans*).

Oxygen

When oxygen levels are below 4 mg/l, most free-swimming salmonids exhibit stress and become ill and if exposed for too long to these levels, will die. Eggs usually require higher oxygen levels than free-swimming individuals. Levels below 2 mg/l cause rapid death in most salmonid species and life stages. Some species (e.g. in the family Cyprinidae) are more tolerant of low oxygen.

Temperature

Some species cannot tolerate high temperatures (above 25°C will kill most salmonids, above 32°C will kill cyprinids, above 35°C will kill centrarchids). The mortality may be partly caused by lowered oxygen concentrations in warm water, as much as by the direct affects of temperature on enzyme and physiological functions.

Biotic factors

Predatory exclusion of one species by another is a possible mechanism affecting present day species distribution. Although there have been no studies in BC, there is evidence from Alberta that predatory northern pike (*Esox lucius*) have eliminated some minnow species (which are small sized prey) from small lakes (Robinson and Tonn, 1989). This may have occurred in northern BC where pike are native. There is little evidence of competitive exclusion by fish species in BC, but this is difficult to research and it may have occurred.

Human introductions and removals

About 20 fish species have been introduced to BC by humans, primarily brought from eastern portions of Canada or the US for purposes of recreational fishing such as brook trout (*Salvelinus fontinalis*), brown trout (*Salmo trutta*), and large mouth bass (*Micropterus salmoides*), for aesthetics such as goldfish (*Carassius auratus*), carp (*Cyprinus carpio*), pumpkinseed (*Lepomis gibbosus*), or accidentally arising from bait bucket transfer (e.g. some minnow species). Atlantic salmon (*S. salar*) have been accidentally introduced via sea-pen aquaculture. Many lakes have had certain 'undesirable' fish species (e.g. some minnow species) removed by management agencies. This practice is no longer being used and was never used on a large enough scale to eliminate a species from its entire provincial range.

Community composition

Despite its large landmass, BC has a relatively depauperate native fish fauna, with only 90 species of which about one quarter are non-native. There are four main families of fish: Salmonidae (salmon, trout, charr, whitefish, grayling) comprising 23 species, Cyprinidae (minnows) comprising 20 species, Cottidae (sculpins) comprising 7 species, and Catostomidae (suckers) comprising 5 species. Although the salmonidae are prevalent, they do not form the majority of all species (25% of all species) which means that forestry guidelines which focus on salmonids, may not be appropriate for the majority of fish species in the province. Most fish species in BC are geographically widespread (except for the non-native introductions) and most native fish are tolerant to a wide temperature range. However, a few native species (about 18) have very restricted geographic ranges and therefore are vulnerable to extinction arising from local changes in habitat. Resource managers need to be very careful in some watersheds where these species occur. For instance, stickleback species (*Gasterosteus spp.*), which occur nowhere else in the world, occur in a few small lakes in and around Vancouver Island. The Salish sucker and Nooksack dace, only occur in Canada in a few streams in the southern Fraser Valley. A unique dwarf sculpin (*Cottus aleuticus*) exists only in Cultus Lake in southern BC. Additional information on rare BC fish

species can be found in Cannings and Ptolemy (1998). Specific details on regional and provincial distribution, and taxonomic keys for identifying BC fish species, can be found in McPhail and Carveth (1994).

Protection of native fishes

Presently there is little legal protection for fish species in BC. The federal *Species At Risk Act* will protect endangered species on federal lands but may not protect species on non-federal lands. The provincial *Wildlife Act* protects fish species listed as endangered by the BC Ministry of Water Land and Air Protection (e.g. Nooksack dace and Salish sucker), but does not protect other fish species. The federal *Fisheries Act* and provincial *Forest and Range Practices Act* protects fish habitat, but not fish directly. Protecting habitat is a rational conservation tactic but as fish use many different habitats (each life stage is different), each habitat type must be fully understood and protected in order to ensure protection of a species. Additional information on federal and provincial legislative responsibilities for fish and habitat protection in BC is outlined in PFRCC (1999).

Ecology of Pacific Salmonids

Species description

There are five species of Pacific salmon in BC: sockeye (*Oncorhynchus nerka*), pink (*O. gorbuscha*), chum (*O. keta*), chinook (*O. tshawytscha*) and coho (*O. kisutch*). All are anadromous meaning they mature at sea and return to freshwater to spawn. Some populations of Dolly Varden char (*Salvelinus malma*), bull trout (*S. confluentus*), cutthroat trout (*O. clarki*) and rainbow trout (*O. mykiss*) are also anadromous. Anadromous rainbow trout are called steelhead trout. Some populations of sockeye are not anadromous and are called kokanee salmon. Salmon and trout do not eat during spawning migrations and must rely solely on energy reserves. Pacific salmon die after they spawn (termed 'semelparous'), whereas trout and charr can spawn more than once (termed 'iteroparaous').

General life history

Fertilized eggs (2-9 mm diameter) hatch from gravel nests in one to three months (see Figure 2). Alevins (10-15 mm) reside in gravel and emerge in one to five months. Alevins have egg sacs which means that foraging is not necessary. If the population is anadromous, fry emergence (10-20 mm; spring or summer) is followed by dispersal into one of three habitats: estuary, lake or stream. If non-anadromous, fry disperse only into lakes or streams. The dispersing fry are called parr and remain so until they either enter salt water or mature in freshwater. Smoltification, which involves a suite of physiological, morphological and biochemical changes, occurs to parr to prepare them for seawater. Smoltification will occur from a few days to four years after fry emerge. Parr will have seasonal movements between summer and winter habitats (e.g. between lakes and streams) for up to five years. If the population is anadromous, before the five years are up they will head to the ocean to mature, otherwise they will mature in freshwater. Immature salmonids in the ocean also move between summer and winter areas. Mature adults from ocean, lake or stream environments actively migrate to natal

spawning grounds. Salmonids tend to return to the same stream to spawn from which they originally came. See Meehan and Bjornn (1991) and Groot and Margolis (1991) for additional details.

Habitat requirements

Stream dwelling salmonids require habitat for three basic purposes: i) rearing which involves feeding, growing, and avoiding predators and other adverse conditions; ii) spawning which involves migrating and reproducing; and iii) egg incubation which involves egg survival.

Rearing

Rearing habitat provides unique 'niches' (suitable spaces) for different species and sized fishes to survive and grow. As high growth rates usually leads to enhanced survival in individual fish, the ability to grow fast is paramount for successful rearing. The following is a consideration of relevant factors that affect salmonid growth while rearing.

Water temperature

Because fish are ectothermic heterotherms (body temperature controlled by, and varies with, external temperatures), changes in temperature affects activity and feeding rates. Salmonids have cold water preferences, generally in the range of 12 to 15°C (Bjornn and Reiser, 1991). In summer months, riparian over-stream canopy usually prevents temperatures from rising much above 15°C. Preferred temperatures are usually ones which provide the most efficient conversion of food to body tissue, hence, leading toward maximum growth rates. They vary among species and populations. If salmonids encounter temperatures that are too warm, their metabolism accelerates, too cold and their ability to be active and hence feed, is reduced. Thus, as temperatures deviate from preferred levels, growth can be reduced.

Oxygen

Oxygen declines in streams when temperatures increase and also when extremely large amounts of detrital material oxidizes while decomposing. Juvenile salmonid growth rates decline rapidly, and can even become negative (e.g. fish lose weight), as dissolved oxygen concentrations decline. In coho fry, growth rates start to decline when oxygen falls below 5 mg/l, and becomes negative below 3 mg/l (Bjornn and Reiser, 1991).

Suspended sediments

In natural systems with modest loads of suspended sediments (e.g. 0.1 – 1.0 g/L in the lower Fraser River), rarely are loads high enough to cause significant changes in growth or affect survival of salmonids. In some instances, juvenile salmonids actually use the turbidity caused by suspended sediments as 'cover' to hide from predators enabling safer foraging. In some glacial fed systems where loads can reach 14-15 g/L, it is suspected that gill damage and reduced feeding could occur which may negatively affect survival (Lake and Hinch, 1999). Fry tend to be more susceptible than parr.

Nutrients

Stream nutrients come from a variety of sources but primarily from leaf litter, soil run-off, and in recent decades, significant amounts can come from atmospheric deposition of nitrogen which originated from combustion of fossil fuels. Pulses of nutrients enter streams during the spring floods and storms. Growth rates of fish are greater when stream nutrients are high because higher nutrient levels results in increased periphyton and benthic invertebrate production (Bjornn and Reiser, 1991).

Streamflow, velocity and depth

Together these three variables create the physical three-dimensional volume within which fish live. They interact with local channel morphology to create 'habitat units' (e.g. pools, riffles, glides, cascades) which each have unique properties and are preferred by different fish species and different life stages. For instance, juvenile coho salmon prefer slow and deep water (e.g. pools), juvenile steelhead trout prefer shallow and fast water (e.g. riffles), and juvenile Dolly Varden prefer transitional areas between pools and riffles. In this way, species can segregate themselves thereby reducing interspecific competition for food and promoting individual growth. Habitat units change character with changes in season, climate, and geology (Bjornn and Reiser, 1991).

Cover

Cover is any feature that offers shelter from predators or unfavourable environmental conditions (e.g. water depth, turbulence, large rocks, undercut banks, overhanging riparian vegetation, instream logs and macrophytes). Many forms of cover serve to increase 'energy spiralling'. The availability of cover varies with season and can depend on streamflow and rainfall. It is clear that individual juvenile salmonids can grow much bigger, and populations can be more productive, when cover is amply available (Fausch and Northcote, 1992).

Final word on rearing habitat

Providing that temperature, oxygen, suspended sediments and nutrients (the 'thermo-chemical habitat') are all at levels that are not limiting the growth of salmonids, then 'physical habitat' becomes an important consideration affecting foraging. Because there are species- and age-specific rearing habitat preferences, streams with diverse physical habitat have the potential to rear not only more fish, but more species and more age classes within species. For instance, young of year cutthroat trout prefer stream centre plunge pools created by logs or boulders, but prefer pools with logs near streambanks as they get older. Young of year steelhead trout prefer riffles or glides but require plunge pools as they get older. Unique foraging niches are created by interactions between cover, streamflow, water velocity and depth (Bjornn and Reiser, 1991).

Spawning migration

When mature, all salmonids make migrations from rearing areas to spawning areas. This may involve only short distances, such as from a lake to a nearby stream, or more extensive distances from the centre of the Gulf of Alaska in the northeast Pacific Ocean

to streams 1,000 km inland. All spawning migrations are made on reserve energy as feeding does not occur so factors which affect energy use will affect spawning success. The discussion below focuses on features that cause delay and hence enhance energy expenditure. Spawning migration habitat is affected by many of the same features which influence successful rearing. There are optimum temperature ranges for which migration is energetically efficient. Temperatures that are much warmer or colder than spawners have been experiencing will delay the migration (as they must slow down or even stop in order to acclimate). High temperatures (e.g. above 18°C) can also cause outbreaks of disease and spread parasites among migrants who are already weakened because they are only weeks away from death (in the case of many salmon species). Low dissolved oxygen levels (e.g. < 5 mg/L) can prevent or delay fish from migrating. Natural loads of suspended sediments are not known to impair migrations, although exotic odours (e.g. arising from volcanic ash or landslides) may slow migrations as salmonids use odour as a cue for locating natal streams. High streamflows can slow migrations as will obstructions like rapids and debris jams. Adult salmon can jump obstacles that are 1-2 m in height, but this depends on the nature of the obstacle and the burst speed and leaping ability of the fish (Bjornn and Reiser, 1991).

Egg incubation

Nests (termed 'redds') are dug into a cobble substrate with the caudal fin of the female to depths ranging up to 30 cm. They range in area from about 0.2 m^2 in rainbow trout to 10 m^2 in chinook salmon. Females select the nest site and males compete among each other for access to females. Eggs are layed, fertilized and then recovered with cobble by the female. Several factors can affect successful incubation. Fine suspended sediments can settle over the eggs and into the spaces between cobbles preventing effective gas exchange between eggs and water. There are differences among species which may be related to egg sizes. For instance, chinook salmon with its large eggs seem to be able to tolerate higher amounts of fine sediments that have settled on them than cutthroat trout which have much smaller eggs. For all species, ample dissolved oxygen (at least 8 mg/L) is required for survival of developing eggs (Bjornn and Reiser, 1991). Decomposition of nearby organic matter can also reduce gas exchange by taking away dissolved oxygen. Eggs can withstand short periods of being exposed to air, as may happen if water levels drop, but usually for not more than a few hours. Eggs can survive over a broad range of temperatures (4-14^{0}C), but warmer temperatures result in more rapid development and earlier hatching (Bjornn and Reiser, 1991). In slow moving northern and interior BC streams, ice may penetrate the redds and can cause mortality of eggs. Even moving water can have anchor ice form on the substrate and penetrate redds. This can arise if the riparian overstorey is missing and water is able to 'super-cool'.

Feeding, Growth and Survival

Territoriality

Stream dwelling salmonids are territorial and highly aggressive to competitors. The fact that territories exist means that food, at some time during the year, is in limited supply. In general, territory size is related to the availability of food which in turn is affected by the actual abundance of drifting prey and the number of competitors.

Large fish can acquire food and defend territories better than small fish, therefore, size (and hence growth) is important for obtaining food. When food availability is low, and it leads to a slower body growth rates, body growth is 'density-dependent'. If changes in food availability have no bearing on body growth rates, then growth is termed 'density-independent'. Seasonal changes in water temperature can often cause density-independent body growth. When food is readily available, as can happen during certain times in the spring or fall in BC streams, then territories would be small, aggressive encounters with competitors minimal, and more fish occupying a given area of river.

Body size: Bigger is better

Body growth usually ceases in the winter when water temperatures drop below 5-7°C. Fish often move from foraging habitats into over-winter habitats where they can seek cover from either high winter flows (in coastal BC areas) or ice-choked frigid streams (in interior BC areas). For instance, juvenile coho in coastal areas move into off-channel floodplains where flows are slow, whereas in interior areas they move into groundwater fed streams which are often warmer than mainstems and which do not freeze. Off-channel areas are frequently only ephemerally 'wetted' and may in fact be dry riparian zones during the summer – a reminder that riparian and other non-wetted near-stream areas should be treated as fish habitat in many watersheds. Considered a major 'bottleneck' for fish population sustainability, winter survival is a critical factor especially during a fish's first year of life. Over-winter survival in fish is generally related to body size. There are a number of factors that contribute to this relationship. Because their metabolism slows in cold water, fish are unable to effectively feed and typically lose weight during the winter. Small fish have small lipid reserves so they are more likely than big fish to starve during this period. Also, small fish get excluded from the best refuges by big fish exposing small fish to greater risks of being 'flushed' out of a stream or segment of a stream by high winter flows, and/or are placed at greater risk to predation. Because small fish are slower and weaker swimmers than large fish, small fish are able to avoid displacement by flows and less able to avoid being predated upon. In summary, there is an intimate link between feeding, growth and survival in stream dwelling fish. Any habitat alteration that affects feeding or territorial behaviour (e.g. affects food abundance or acquisition) can influence survival of individuals and hence population abundance.

Freshwater versus ocean habitat

While freshwater habitat is obviously important to salmon and trout, for anadromous populations, ocean habitat is also important. But what is the relative role of these two habitat types – which is the most critical one? It turns out that on average about 50% of the natural mortality that occurs in rearing, post-larval stage salmon occurs in freshwater, the other 50% in the ocean. However, the relative contribution varies among species, and among years. In his review, Bradford (1995) found that species like pink and chum, which spend only a few months in freshwater as juveniles, have good freshwater survival rates (average of 57 and 65%, respectively). Species that spend over a year in freshwater as juveniles such as coho and sockeye have much lower freshwater survival rates (average of 36 and 42%, respectively).

Habitat and population growth: Enhancing fish populations

Table 1 presents an example of a general survival schedule for individuals in a population of coho salmon that mature at 4 years of age. Based on the stage-specific survival rates in the example, in one generation the population size would have increased by 50% (two adult spawners gave rise to three adult spawners). Under this scenario the population is growing, and, depending on public policy and the size of the fish population, the population may be able to support a fishery which, if managed properly, would harvest the 'surplus' fish.

Table 1:

General survivourship schedule for individuals in a population of coho salmon that mature at 4 years of age. While this is a hypothetical case, the stage-specific survival rates and abundance values are realistic estimates that can occur in nature. Italicized values represent successful freshwater habitat enhancement which results in increased adult abundance.

Life history stage	Habitat	Percent survival from previous stage	Abundance
Spawning ground adults	freshwater	–	2
Fertilized eggs	freshwater	–	2,500
Swim-up fry (egg to emergence)	freshwater	10	250
Summer fry (spring to fall)	freshwater	50	125
Winter fry (fall fry to spring smolts)	freshwater	30 *(40)*	38 *(50)*
Pre-adults (smolts to sea age-1)	ocean	20	8 *(10)*
Adults (sea age-1 to mature)	ocean	50	4 *(5)*
Adults (on spawning grounds)	freshwater	75	3 *(3.75)*

Habitat enhancement efforts are usually directed towards increasing survivour-ship of particular freshwater life stages with the goal of increasing the adult population size. Assuming the life stage (and habitat component) that is limiting population growth can be identified, it may be possible to facilitate population growth. In our example, if we assume that habitat enhancement can increase smolt survival from 30 to 40% (see italics), and all other survivorship levels remained constant, this could result in nearly one additional adult returning to spawn (a 33% increase in smolts created a 25% increase in adults). While this is the principle behind all freshwater habitat enhancement (or rehabilitation) programs, it is worth noting that if ocean habitat is at its carrying capacity, or if its carrying capacity and hence ocean survival rates are declining, these desired outcomes may not be realized. This was the case during much of the 1990s in BC when a great deal of effort and money went into stream habitat rehabilitation through the Watershed Restoration Program and the Fraser River Action Plan. The Pacific Ocean was in a naturally low productivity cycle through much of the 1990s which meant that ocean survival rates were extremely low. For instance, survival rates of ocean dwelling coho salmon in the Strait of Georgia declined from

about 20% in the early 1980s to 1% in the mid-1990s. Thus there were very few adult coho salmon returning to streams in the Lower Mainland which had enhanced or rehabilitated habitat. In general, adult salmon abundance declined during the 1990s in BC, however there is evidence that ocean productivity levels are increasing and there have been very good returns of adults of most salmon species in 2001 and 2002 (PFRCC, 2002).

Life-stage specific survival patterns are also an issue that will affect the success of hatchery supplementation programs. The addition of fry or smolts from hatcheries to the wild may not generate more adults if the carrying capacity of any of the latter life stage's habitat has been reached. Supplementation could thus negatively affect wild populations through increased competition with hatchery fish. Additional pros and cons of supplemental hatcheries are discussed in Ross (1997).

Effects of Forest Harvest on Salmonids

Forest harvest activities and effects on habitat

Although there are many different types of forestry practices which have the potential to affect salmonids and their habitat, an overview of only three which have been known to create large problems for salmonids will be provided. These include clear-cut harvesting on hillslopes, the presence of forestry roads, and clearcut harvesting of the riparian zone. Rarely do these harvest activities occur in isolation, so their impacts can be simultaneous and cumulative. In the chapter 'Watershed Processes', a review was provided of how forestry can affect stream: flows, sediment movement, temperature and chemistry. These details will not be repeated, instead, a focus will be placed on how changes to these abiotic features affect aspects of salmonid habitat and energy sources.

Streamflow

Runoff can increase in spring and summer months in years immediately following clearcutting hillslopes as a result of an increase in the amount of impermeable surfaces in the watershed (due to soil compaction caused by heavy equipment, and the presence of roads and landings) and from a reduction in water storage capacity (Chamberlin *et al.* 1991; Furniss *et al.* 1991). Increases in streamflow can reduce the distinctness between habitat units (e.g. between pools and riffles) which could affect availability and effectiveness of fish cover habitat, and alter aspects of territoriality and feeding.

Nutrients

Short-term increases in input of nutrients to streams can result from clearcutting hillslopes and riparian areas, and this can be further enhanced by site preparation activities (e.g. scarification or fertilization). Nutrient addition could lead to an increase in stream primary productivity and hence serve to increase production of aquatic invertebrates, which are prey for fish. However, as light tends to be the factor that most limits primary production in small BC streams, increasing nutrient levels may have only modest affects on fish unless over-stream canopy cover is also reduced (e.g. by riparian logging).

Sediments

Mass movements of soil (also termed mass wasting, avalanches or torrents) into streams occur naturally but the frequency is exacerbated by some forestry activities, in particular the presence of roads (Chamberlin *et al.* 1991). Mass movements of soil and debris into streams can eliminate instream cover habitat (by removing large boulders and woody debris) and destroy undercut bank cover habitat. Coarse sediment deposition can cause streams to become shallower and wider, leading to 'de-watering' of channels during summer low flow periods. Even if the channel remains watered, it may become disconnected from its original banks, having no contact with undercut bank habitat, and thus, having less contact with shading and food provided by riparian vegetation.

Surface erosion of fine sediments into streams can originate from and be facilitated by forestry roads, landings, skid trails, failed stream crossings, and clearcuts on hillslope and riparian areas. Once in streams, fine sediments can fill spaces between spawning gravels and limit oxygen availability to eggs, and can contribute to infilling of pools, thus reducing the availability of cover habitats. The removal of streamside trees can contribute to bank erosion and contribute to widening of the stream and infilling of pools.

Incident solar radiation

The removal of streamside trees can lead to changes in stream temperature patterns, increases in autochthonous energy production, and decreases in oxygen availability (an inverse variant with temperature). An increase in incident solar radiation can cause increases in the average and maximum daily temperature in summer months in coastal northwest Pacific region streams (e.g. Hall *et al.* 1987; Young *et al.* 1999). In some southern coastal and interior locales, temperatures can reach or exceed 30°C following streamside harvest, temperatures which are well above lethal levels for salmonids (Bjornn and Reiser, 1991). As light is one the main limiting factor of primary production in small BC streams, an increase in solar radiation usually increases primary production. If fish are stressed by extremely high temperatures, they are likely not to benefit from the enhanced primary production. However, in northern or cool regions where temperature warming is not into lethal levels, the streams may generate enhanced growth conditions for fish by the increased production rates of invertebrate prey, warm temperatures which are 'optimal' for growth of fish, and by increased length of the foraging and growing season. Streams which are under strong groundwater or lake influence, such as in central and northern interior regions of BC, may have their thermal regimes, and hence fish habitat, less influenced by the harvest of streamside tress (Mellina *et al.* 2002).

Organic matter input

Logging slash (debris) often finds its way into streams and this can result in a decline in dissolved oxygen as the fine organic matter decays. If solar radiation levels are also elevated, the oxygen decline could be exacerbated by the warmer temperatures. Slash can generate some physical in-stream habitat complexity and thus provide some aspect of cover for fish, though it would not be very stable and could be easily dislodged by winter flows.

Leaf litter input from riparian trees is a critical source of energy for food webs in small streams. With the removal of streamside trees, nearly all of the input of allochthonous energy is eliminated. Also reduced would be inputs of a direct fish food source – terrestrial insects which fall from streamside trees.

Large woody debris

With the harvest of streamside trees, the future recruitment of large woody debris (LWD) into a stream is reduced or eliminated. When in a stream, LWD contributes to the creation of habitat units (e.g. pool-riffle sequences) needed for different life stages and species, stabilizes banks and undercut habitats, and also provides direct cover for fish. For LWD to be 'functional', it must be relatively large, thus older and bigger trees are better for these processes. In addition to reducing in-stream habitat stability, a reduction in LWD will lead to a reduction in organic matter spiralling, and to a decrease in gravel sorting which is needed to provide appropriately sized spawning gravels for different species of fish. In BC, large coniferous trees (i.e. western redcedar) are the ones most likely to be harvested from riparian areas, and these are the ones that generate the most stable LWD for streams. Because of its decay resistance, cedar trees can be functional pieces of in-stream LWD for several decades. Fast growing deciduous trees (i.e. aspen or alder) will rapidly grow in riparian areas following logging and they will start to recruit into streams in as few as 10 years. However, they are smaller and decompose much more rapidly than coniferous riparian areas, and so, they cannot provide the same function in terms of habitat creation, maintenance or stability as coniferous LWD.

Road crossings

Forest roads frequently cross streams and all crossing must allow efficient passage of water, as well as fish (Fish Stream Crossing Guidebook, 2002). Because salmonids disperse, move and migrate throughout watersheds, crossings need to facilitate movements, both upstream and downstream, by fry as well as adults. Crossing structures can be barriers to movement if: outfalls become perched (e.g. a hanging culvert), water velocities are excessive, water depth is insufficient, turbulence creates confusing cues, or, there are no resting pools at the entrance or within the structure (Furniss *et al*. 1991). Structures range in design, cost and likelihood of creating a barrier. Standard corrugated cylindrical pipes are very common, inexpensive and are the most likely to be or create barriers for fish movements. Natural bottomed culverts, or culverts with bottom-alternating baffles are more expensive, but provide lower water velocities and resting pools, which can benefit fish passage. Most expensive are bridges, but these are the least likely crossing structures to hamper fish movements. There are several considerations in understanding whether a structure is creating a barrier to movement. One issue is the fish's leaping ability. If a culvert is perched above the stream surface, fish will have to be able to leap into it. The success of this will vary among species and life stages, as well as with the leaping location. Pools of a certain depth are required for salmonids to initiate a leap. Another important issue is their burst swimming abilities, a behaviour which enables fish to swim for short periods (usually less than 20 seconds) at maximal speeds. If water velocities are greater than burst speeds, or if the structure is so long that burst

swimming must cease before exiting the structure, then the structure could be a barrier. Burst speeds range up to eight m/s or higher for adult salmonids and one to two m/s for juveniles (Furniss *et al.* 1991). Clearly, structures must be used that can pass the weakest swimming individuals, which are normally the juveniles.

How much fish habitat is lost by the presence of road crossings? Habitat as defined by the Canadian *Fisheries Act* includes spawning, nursery, rearing, food supply and migration areas on which fish depend directly or indirectly in order to carry out their life processes. Obviously the channel at a stream crossing is fish habitat, but so are adjacent riparian (streamside vegetation) areas because they contribute food and modify channels. A recent audit of BC road crossings, which were all built since implementation of the Forest Practices Code in 1994 found that non-embedded corrugated metal pipes caused the highest losses on instream habitat (Harper and Quigley, 2000). Forty-three m^2 of bank and benthic habitat was lost per pipe crossing, compared to 11 m^2 lost per bridge crossing, and 2 m^2 lost per log crossing (e.g. a natural bottom culvert). Furthermore, 25% of all pipe crossings were impassable by fish due to either water velocity barriers or because they had become inaccessible at their downstream end. Thousands of square metres of up-stream habitat was thus unavailable at those crossings. In addition, the audit found that about 400-700 m^2 of riparian habitat was lost at each stream crossing simply due to the presence of the road. Maybe this doesn't seem like a lot but multiply it by the hundreds of crossings that are installed each year on fish-bearing streams in BC and the audit suggests that we could be losing over 300,000 m^2 of fish habitat each year, of which about 30% is stream channel habitat alone.

Summary

The combined effects of mass soil movements, surface erosion, and riparian logging are readily evident in some BC coastal watersheds which have experienced high levels of forest harvest (Figure 3a and b). The standard symptoms include: a relatively wide and shallow stream, few pools (few pool-riffle sequences), shallow pools, straight channel (low sinuosity) with no clearly defined banks (is separated from original banks), and low abundance of LWD. Often the existing LWD is not functional (e.g. is parallel with flows or not in the wetted width). Historically, logging on hillslopes and in the riparian, and the development of extensive forestry road networks, were activities that occurred simultaneously and which created a multitude of changes to fish habitat and energy flow processes. Many of these changes are still readily evident today, and present-day habitat is still impacted from these historical activities.

Cumulative and long-term effects on fish

It is nearly impossible to assess how growth or survival of salmonids is affected by any of the individual factors listed above as their influence can be cumulative or even synergistic. Observing the impacts on salmonids is further complicated by the fact that many disperse or migrate away from logged watersheds during portions of their life. For example, the factors that influence growth and survival in the ocean can compound or mask changes to fish populations in freshwater habitats. Logging cannot be blamed for dramatic decline in ocean survival of coho salmon during the

1990s yet this decline may compound already poor growth conditions in freshwater areas where logging negatively impacted habitat. On the other hand, high ocean survival rates during the 1980s may have masked poor freshwater survival rates in areas where logging altered habitat. Without careful monitoring of these different life stages and habitat types, it is difficult to assess how forestry truly affects fish. Water-shed and whole-stream experiments provide some of the best information on the roles of these factors and on how habitat and fish respond to forestry practices over different time scales. Below is an overview of important whole-stream experiments designed to examine forest impacts on stream fish.

Alsea Watershed study

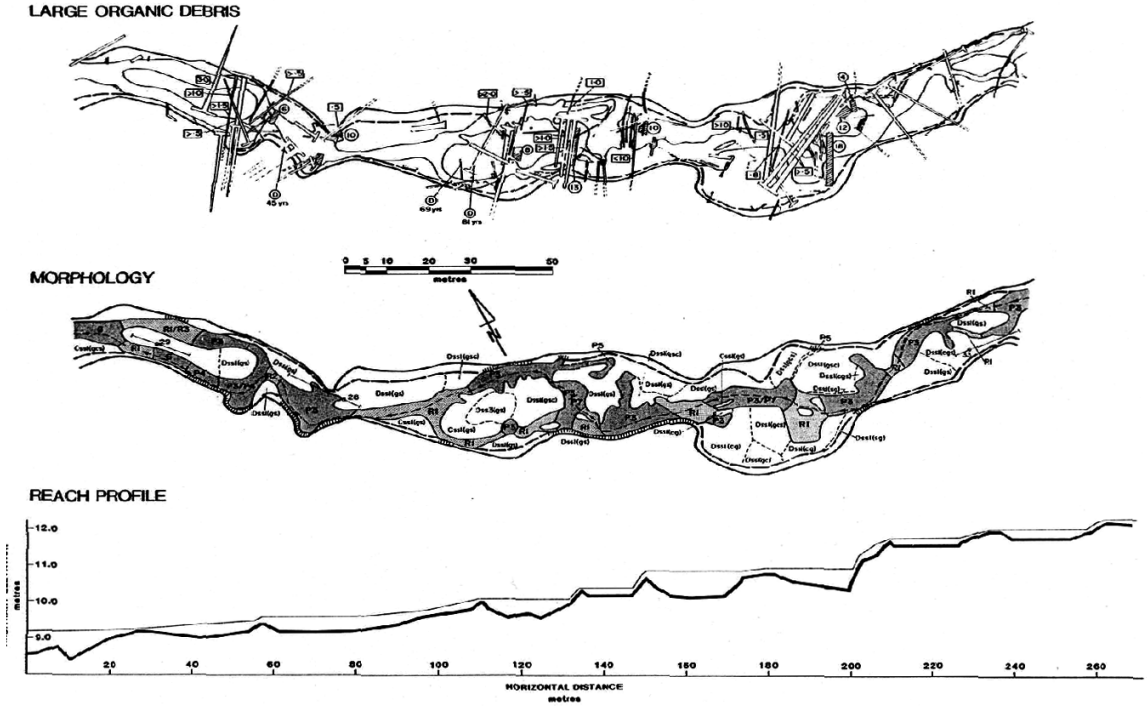
This was the first long-term study designed to measure effects of logging on anadromous salmonids in small streams (Hall *et al.* 1987; Hicks *et al.* 1991). Three small watersheds situated on the coast of Oregon were used: one was completely clearcut, one was patch clearcut with some intact riparian areas, and one was a control. Streams were monitored from 1959 to 1973 with logging occurring in 1966. Following logging, the clearcut stream had about 50% lower abundance of cutthroat trout compared to pre-logging levels. Abundance of trout actually increased post-logging in the other two streams (Figure 4). High temperatures, low oxygen, reduced LWD recruitment and fine sediment intrusion have all been implicated as causes of the reduced fish production in the clearcut stream. Interestingly and unexplainably, following logging, all streams (as well as the control) had lower production of coho salmon smolts.

Carnation Creek study

Situated on the west coast of Vancouver Island, BC, Carnation Creek is the site of the longest continuous study of the effects of forestry practices on biological and physical processes in North America (Tschaplinski, 1998; Holtby and Scrivener, 1989). One component of this study has been the monitoring of salmonid populations, since 1970, through 5 pre-logging, 6 during-logging, and 22 post-logging years. As with the Alsea study, forest harvesting had complex and variable effects on fish species and life stages. Chum salmon has been most negatively affected with the number of post-logging adults being one-third the level measured during pre-logging (a decline of 60%) (Figure 5). About one third of this decline can be attributed to reductions in egg-to-fry survival resulting from decrease quality of spawning and egg-incubation habitats in the lowermost stream reach. The other two thirds were attributed to unfavourable ocean survival conditions.

Coho salmon showed very complex changes. Juvenile coho salmon (fry) decreased by about 50% following logging, a result of a loss in pool and off-channel cover habitats (Figure 6). However, the overwinter survival of coho fry increased following logging because the warmer water temperatures resulted in a one month earlier emergence of the fry from their eggs which enabled the fry to grow bigger than before logging. Bigger fry were better able to survive the winter – a phenomenon which lead to a 50% increase in the number of smolts produced, following logging (Figure 7). However, this increase in smolt abundance did not translate into large adult returns (Figure 8). These declined by 30% following

Stream A


LARGE ORGANIC DEBRIS
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Stream B

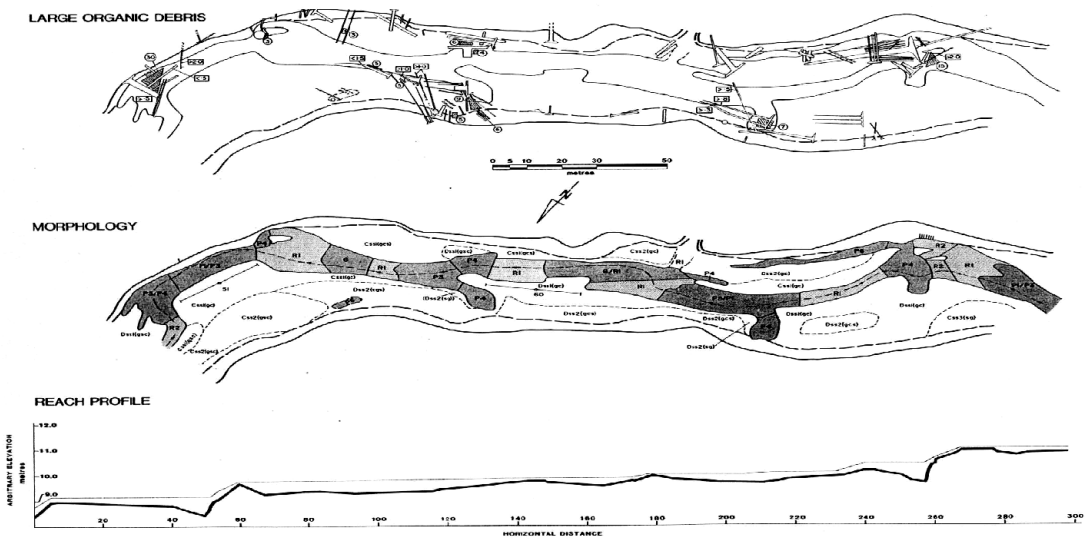

Figure 3: Aerial and profile views of a stream in a watershed with no logging impacts (A) and with extensive logging impacts (B). The top aerial view for each stream illustrates the relative size and position of LWD in the channel and the bottom aerial view illustrates the position of the wetted channel and pool (dark grey) and riffle (light grey) locations. Assessments were made in summer in streams from the Queen Charlotte Islands. Note that stream B is much shallower, wider, having fewer pool/riffle sequences, and fewer and smaller LWD. The wetted channel in stream B is separated from the original banks and the channel has little sinuousity or complexity relative to stream A. The LWD in stream B is positioned relatively parallel with stream flow in contrast with that in stream A. Perpendicular positioned LWD is an indication of stable habitat. Taken from Hogan (1986).

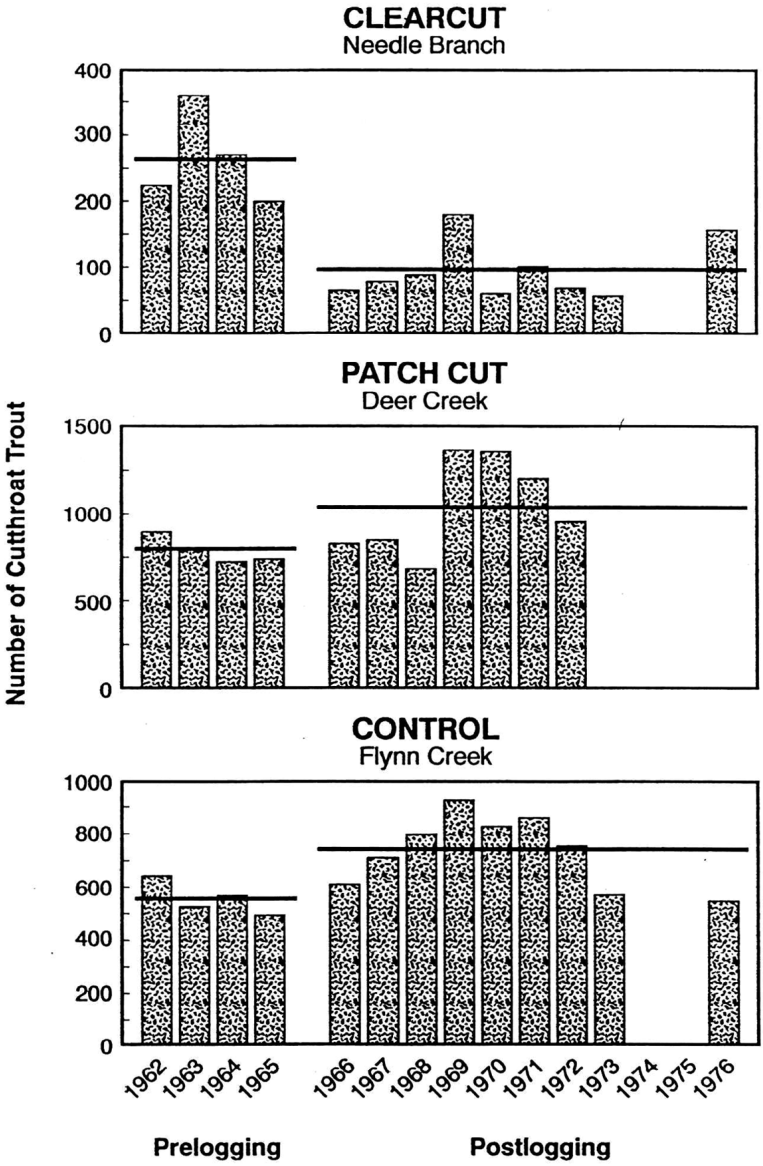

Figure 4:

Estimates of juvenile cutthroat trout population sizes in three streams in the Alsea Watershed Study. Taken from Hicks *et al.* (1991).

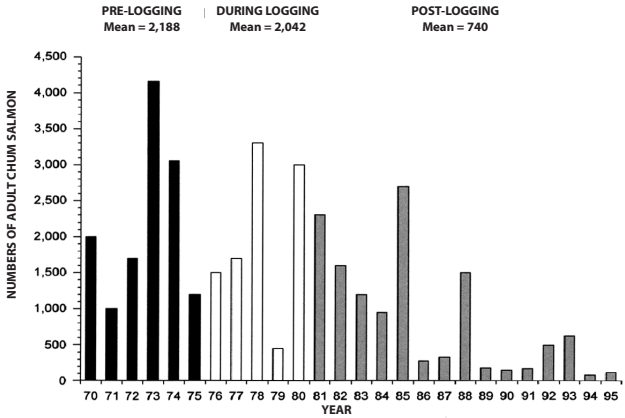

Figure 5:
Annual returns of adult chum salmon to Carnation Creek between 1970 and 1995. Taken from Tschaplinksi (1998).

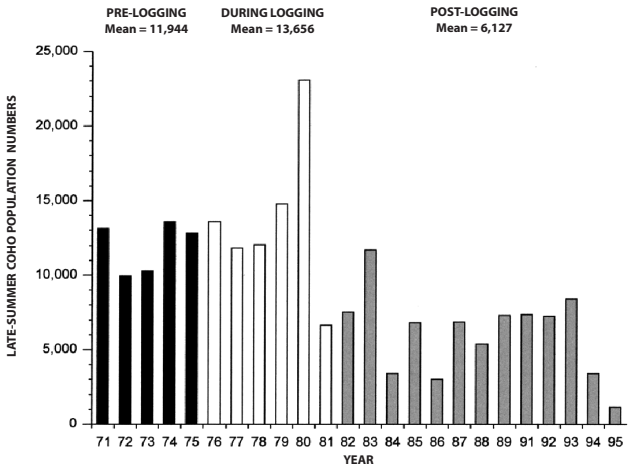

Figure 6:
Abundance of juvenile (fry) coho salmon rearing in September and October in Carnation Creek, between 1971 and 1995. Taken from Tschaplinksi (1998).

logging which was partly attributable to depressed marine survival conditions and to the fact that smolts migrated to sea several weeks earlier than during pre-logging (due to warm stream temperatures) and thus encountered very unproductive ocean conditions.

East Creek case study

Most long-term whole-stream studies of fish/forestry interactions have focussed on anadromous populations of salmonids. East Creek is located in the University of

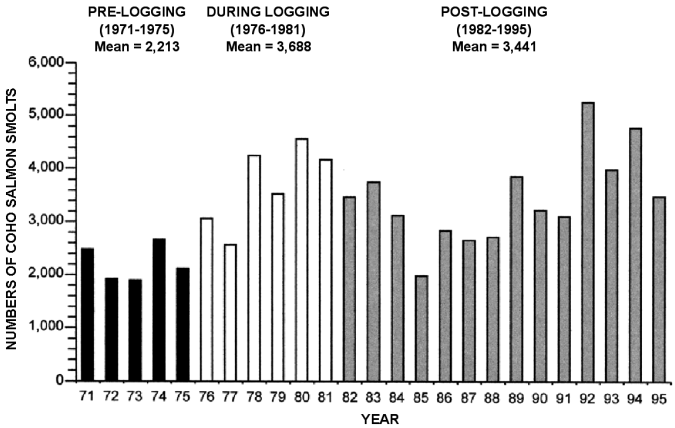

Figure 7:
Number of coho salmon smolts migrating out of Carnation Creek in the spring, between 1971 and 1995. Taken from Tschaplinksi (1998).

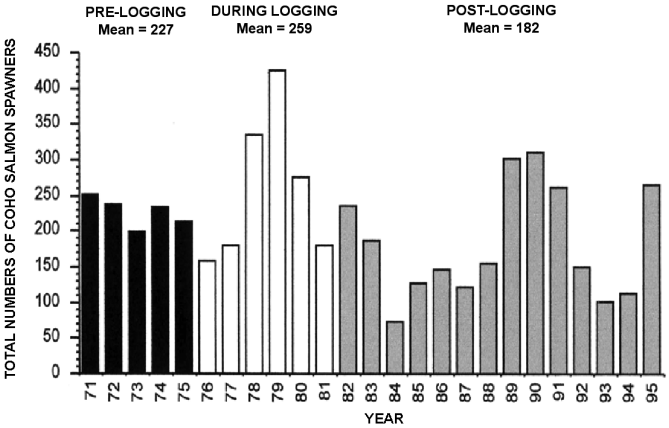

Figure 8:
Annual returns of adult coho salmon to Carnation Creek between 1971 and 1995. Taken from Tschaplinksi (1998).

British Columbia Malcolm Knapp Research Forest, located 60 km east of Vancouver BC. This study (Young *et al.* 1999) was the first to examine a non-anadromous population (cutthroat trout) and was also the first to examine a species in allopatry, that is, with no fish competitors present, a factor which can confound interpretations in whole-stream studies. In 1973, two sections of East Creek watershed were logged, one to the streambank with removal of all existing LWD from the channel and hillslopes (section A), and the other to the streambank but retaining all LWD and logging slash in the channel and on hillslopes (Section B). An upstream section was used as a control (Section C). Habitat and fish were monitored intermittently over 25 years. Over this period, trout densities in sections B and C did not appear different,

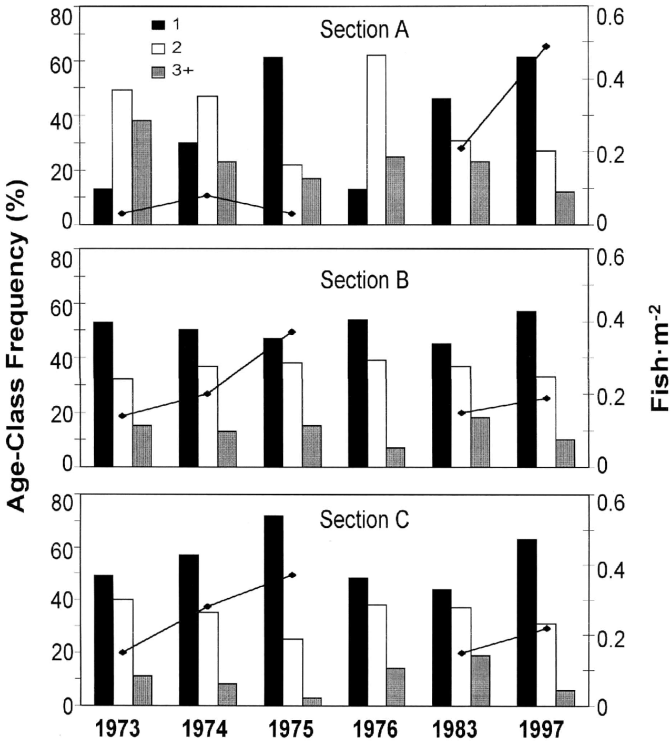

Figure 9:
Age-class frequency (bars) and density (dots) of cutthroat trout captured in late summer in three reaches of East Creek. In 1973, section A was logged to the streambank with removal of all existing LWD from the channel and hillslopes, section B was logged to the streambank but all LWD and logging slash was retained in the channel and on hillslopes. Section C was used as a control. Taken from Young *et al.* (1999).

nor did water temperatures or amount of pool habitat differ. In years immediately following logging in section A, trout density was 5-10 times lower (Figure 9) than in the other two sections owing to lethally high water temperatures and the near absence of pool habitats. By 1983, temperature and fish density in section A was similar to that in the other sections. By 1997, pool habitat abundance had increased significantly in section A and trout density was nearly twice that in the other sections. Trout density in A was however comparable to other nearby non-logged streams which had similar gradients and floodplain characteristics, suggesting that trout populations had recovered to pre-logging levels.

Models of stream and fish recovery following logging

Most of what we know about the long-term effects of logging on salmonid fish and their habitat comes from case-study experiments that have a duration of less than 30 years (see studies above) or from synoptic comparative survey studies wherein many

streams with different 'time-since-logging' histories have been sampled over a relatively short time period and logging impacts are inferred from the time series (e.g. Murphy *et al.* 1986). The former methodology usually lacks replication and often lacks appropriate control situations, whereas the latter methodology lacks evaluation of pre-logging conditions. Thus neither is perfect. Results from both types of these empirical studies have been used to generate a variety of 'models' to illustrate how fish and their habitat will change and recover over time following logging (e.g. Gregory *et al.* 1987; Hartman and Scrivener, 1990; Murphy and Meehan, 1991). Figure 10 is an attempt to provide a summary of such model predictions for fish and habitat and demonstrate the range of potential outcomes for fish depending on how specific components of habitat and energy flow are altered following logging. The basic assumption is that these watersheds have experienced typical logging situations wherein large components of the hillslopes were clearcut (e.g. > 40%), most of the riparian was harvested, and logging road networks existed in the watershed. Also, these models are based on harvesting 'old growth', little research has been done to evaluate if these models are appropriate for logging different aged forest stands. The predictions for periods longer

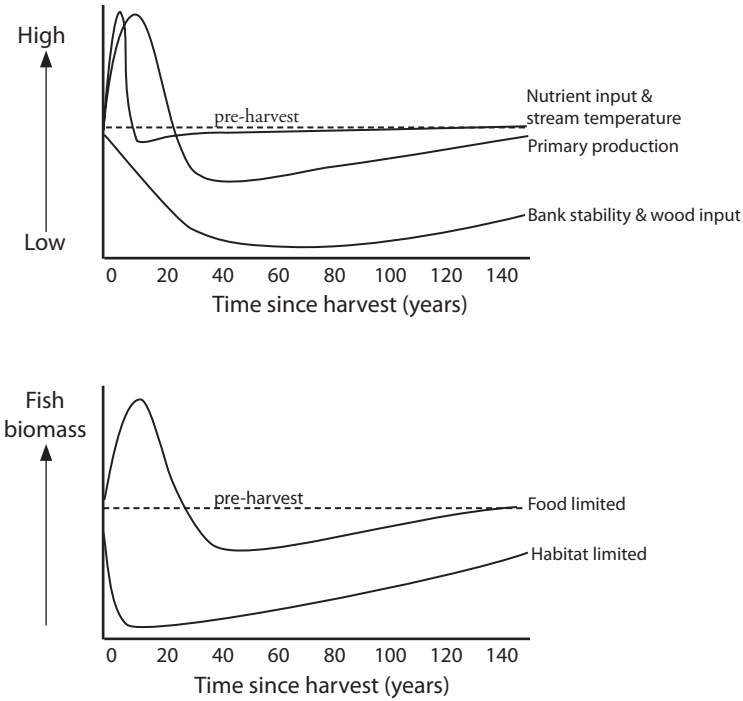

Figure 10:
Model predictions examining how habitat and fish may respond following watershed logging. The top panel illustrates the types of responses that primary production, nutrients and temperature, and physical habitat often display. The bottom panel illustrates the two different responses of fish biomass to these habitat changes. All model predictions are relative to pre-harvest levels (dotted line). See text for sources of model predictions.

than 40 years since harvest are based solely on comparative surveys and thus should be considered very tentative.

Two modelled outcomes representing the full range of responses that fish biomass could demonstrate are given in Figure 10. Fish biomass is a reflection of population density and average size and is an index of the amount of fish 'tissue' that exists in a population. A small population of large fish could have the same biomass as a large population of small fish. The 'physical habitat' response illustrates a situation where changes to physical habitat are the dominant factors affecting the fish population, and the interaction with fish biomass tends to be strongly negative. For instance, this could be a situation where immediately after logging, mass wasting events and surface erosion of soils causes the banks to destabilize widening the channel, eliminating undercut bank cover, removing LWD, filling in pool cover habitat, and separating the wetted channel from the original banks. It may also be a situation where stream temperatures reach lethal levels immediately after logging. Generally these events occur immediately after logging (and in unstable terrain with poorly built roads, landslides can continue to occur in subsequent years) so biomass declines rapidly for the first 10 years or more. Not until the hillslopes regain some element of stability does biomass stop decreasing. Because spawning gravels and rearing pools have been destroyed, and the elements that create and maintain these (i.e. LWD) could have been removed by debris torrents, recovery of fish will be very slow and may follow a time trajectory that parallels that of future LWD recruitment. This recruitment may take well over 100 years.

The 'food' response illustrates a situation where changes in energy availability is the dominant factor affecting the fish population, and the interaction with fish biomass is positive early following logging then negative later on. For instance, this could be a situation where physical habitat remains stable following logging but the opening of the over-stream canopy caused by the harvest of riparian has led to a large increase in primary production which has translated into more fish prey and hence more fish biomass. This increase in biomass continues for the first 10 to 20 years following logging as growing conditions continue to improve during this period as impacts of slash, and minor surface erosion etc disappear. Good growing conditions could be facilitated by warmer temperatures that are not lethal,a short-term pulse in nutrient run-off, and increasing contributions of leaf litter coming from regenerating riparian vegetation. Growth conditions start to diminish as second growth riparian vegetation starts to close over the stream, reducing instream primary production. Twenty to 30 years following logging, fish biomass may be the same as it was before logging. There is good evidence that biomass will be reduced below pre-logging levels because second-growth riparian is denser than old growth thus less light will penetrate and autochthonous energy production will diminish. It will presumably remain low until the riparian vegetation 'thins' with succession thus enabling higher levels of primary production in latter years.

Geographic regions, salmonid life stages and species

These models could be made applicable to any area, but are probably better suited to certain regions. For instance, the food limitation model may be most applicable in areas with stable, moderate terrains, particularly in northern latitudes, whereas the

physical habitat model may be most applicable in areas with steep, unstable terrains, particularly in southern latitudes. In some circumstances, life stages or species, within the same watershed, may respond according to both models. For example, coho salmon smolts from Carnation Creek fit the 'food limitation' model for the 20+ years of data available (good growing conditions enhanced their size giving them good over-winter survival), yet coho and chum salmon fry from the same period and stream fit the 'physical habitat limitation' model (poor rearing habitat reduced survival rates).

Conclusions

There are two take home messages from these models.

1. The models offer very divergent predictions for the first 20 to 30 years following logging so it would be difficult to predict which trajectory fish biomass may follow. It is possible that positive growth conditions may be offset by negative habitat changes resulting in no net change to fish biomass over this time period. This may have been what transpired for trout in Section B of East Creek.
2. Stream and watershed rehabilitation programs attempt to address the obvious problems that have caused the 'physical habitat' responses, for example by creating new off-channel spawning and rearing habitat, enhancing instream physical habitat, stabilizing stream banks, deactivating logging roads etc. (Slaney and Zaldokas, 1997; Williams *et al*. 1997). But both models predict that fish biomass will be below pre-logging levels after 30 to 40 years following logging. This means that even streams where fish seem to respond initially favourably to logging, may over time become less productive for fish. Foresters could take an active role in preventing this decline in fish biomass by actively managing riparian areas (e.g. through careful thinning or strategic planting) so that banks remain stable, but light penetration to the stream remains as high as it was before logging.

Buffer strips and fish habitat protection

Buffer strips (also called leave strips or reserve zones) are intact areas of riparian trees left immediately adjacent to a stream or other body of water. Their purpose is to protect the stream from the impacts of forest harvesting that occurred in the upslope areas. In the 1970s in BC, buffer strips started to be placed along some valuable salmon streams. However this was a voluntary management action that was infrequently used because the belief was that these strips would typically blow over (termed 'windthrow') not long after they were created. By the late 1980s and early 1990s, the Coastal Fish-Forestry Guidelines (CFFG), also a voluntary set of rules, was developed and recommended various types of management actions, including the use of buffer strips,when harvesting near streams. By the late 1990s, the Riparian Management Area Guidelines (RMAG) of the *Forest Practices Code Act* legislated rules for buffer widths which varied according to stream width, fish species presence and the likelihood that the buffer would suffer windthrow. In both the CFFG and RMAG, 30 metre buffer strips were recommended for moderate to large sized salmon or trout bearing streams. There is some scientific basis for this number. For example, in coastal old growth, 30 metres is the maximum distance from the

stream bank that LWD can recruit into streams (Murphy and Koski, 1989). Also, it has been shown in studies comparing streams of differing buffer widths to be the minimum width where stream invertebrate diversity is at a maximum (Newbold *et al.* 1980) and the width that limits light levels reaching the stream to levels similar to that in streams with no riparian logging.

Do buffer strips work?

Although there are many evaluations of buffer strips and their role in land management, there are only a few comprehensive studies that have demonstrated that they indeed protect fish from impacts of logging. The Alsea watershed study overviewed above was the first to show that leaving intact riparian strips could protect fish (see Patch Cut stream in example above). In a very extensive comparative survey conducted in the summer on 18 stream reaches in southeast Alaska, Murphy *et al.* (1986) convincingly showed that riparian buffers protected habitat and fish. Specifically, they showed that stream reaches with no buffers had higher bank instability, lower pool volume, fewer undercut banks, and higher algal production compared to stream reaches with no logging. The reaches with buffer strips were always intermediate in habitat responses between these extremes. Fish responses varied among species and life stages but in general supported the notion that buffer strips protected fish (Figure 11). Specifically they found that coho salmon and Dolly Varden parr densities did not differ between sites with no logging and sites with buffers, but sites with clearcuts had relatively lower densities. In fact, coho parr were nearly absent in clearcut reaches. Interestingly, coho fry densities were higher in both clearcut and buffered reaches, presumably because these newly emerged fish were responding to the elevated primary production at these sites. However, the lack of over-winter physical habitat meant that fry were unable to survive the winter and become parr the following summer in the clearcut reaches. Buffer strips seemed to have no positive benefits for rainbow trout.

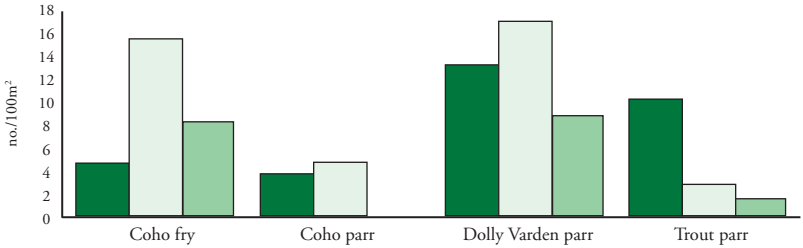

Figure 11:
Densities of fish in 18 reaches of south-eastern Alaska streams. Six reaches were surrounded by old growth riparian (black bars), six reaches had buffer strips applied to at least one of the two banks with adjacent hillslopes being logged (white bars), and six reaches had their riparian timber clearcut on both streambanks (grey bars). Taken from Murphy *et al.* (1986).

Final word on buffer strips

Although it is well accepted that buffer strips protect fish and habitat, there have been few experimental evaluations to date of how different widths or shapes of buffer strips affect fish and stream ecosystems. Furthermore, there has been little research of any kind in on buffer strip effectiveness in areas other than coastal regions. Until this type of work is conducted, practitioners should view guidelines with extreme caution. Adaptive management experiments are required to adequately evaluate the buffer width and configuration issue. In addition, it should be possible to manage riparian areas in such a way as to protect instream habitat and at the same time enhance fish production through careful riparian thinning or planting (refer to food limitation model above).

Forestry and Salmonid Stock Status in BC

Stocks spawn in a particular system, at a particular season, or in the same place at a different season, and do not interbreed substantially with other spawning groups. They are groups of populations that possess unique adaptive traits to local conditions (traits include behaviours, morphology, life history characteristics). Stocks are the building blocks of Pacific salmon species, and it is at the stock level that conservation and rehabilitation of salmon should take place.

The most recent evaluation of Pacific salmon and anadromous trout stock status in BC was completed in the mid 1990s (Slaney *et al.* 1996). Also included in the data were stocks from the Yukon Territory. Identified were 9,663 stocks but only 5,487 (57%) had adequate data to evaluate status. Nearly all of these were not at risk of extinction, however, 624 (6.4%) were considered at high risk because of their declining and low population size, and a further 142 (1.4%) were known to have gone extinct – this is likely an underestimate. It was difficult to ascribe individual causes of the declines in the high-risk stocks though habitat destruction from forestry and other land-use practices was certainly a major issue. Most of the known extinctions were caused by habitat degradation, primarily resulting from urbanization and hydropower development. Most of the stock extinctions have occurred in the Lower Mainland, Squamish and Columbia regions. Between 15 and 20% of all streams in the Lower Mainland have disappeared, due to urbanization, taking with them stocks of salmon and trout (Anon. 1997). Hydro development and the resultant blockage of migration routes and destruction of habitat that accompany it account for most of the other extinctions. There is no compelling evidence that fisheries have contributed to stock extinction, however overharvest by both commercial and recreational fisheries have helped push stocks, particularly ones with habitat problems, into the high risk category.

Although forestry practices have caused damage to salmon habitat, and may have caused elimination of some local populations, there is only one solid documented case where a forestry practice caused the extinction of a stock in BC. This was the upper Adams sockeye stock which was helped to extinction by a splash dam that was built in 1908 at the upper end of the Adams River. The dam was used to store water to flash-float logs down river which unfortunately caused migration blockages, channel dewatering and habitat destruction. It was removed in 1945 but the stock by then was long extinct. In recent decades, sockeye have recolonized this area, helped in part by introductions of individuals from nearby populations (Williams, 1987).

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WILDLIFE ECOLOGY AND MANAGEMENT

by

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WILDLIFE ECOLOGY AND MANAGEMENT

Introduction

The term "wildlife" in modern use includes more than animals that at one time were termed "game", such as ungulates, bears, ducks, and grouse. A broad definition would include all wild, living organisms. This latter definition has been increasingly adopted as governments move to a more broadly-based mandate associated with protection of all biodiversity. There is still greater focus on vertebrate animals by management agencies since we often know more about that group of animals. Moreover, they are considered umbrella species (rightly or wrongly) for other biodiversity and it has greater public acceptance. The definition of "wildlife" used by the government of British Columbia (BC) to date includes all vertebrates (excluding fish in most cases) as well as endangered and threatened species. A more workable definition in the context of this chapter is that it includes terrestrial vertebrates including mammals (excluding marine mammals), birds, amphibians, and reptiles.

BC has a large percentage of the wildlife species found in Canada, although our total diversity is still small relative to more southern regions. The province covers nearly 1 million km^2, and has an enormous biogeographic variation in ecoregions due to variation in climate, topography, etc. BC is home to over 440 species of terrestrial wildlife (~250 species of birds, 142 mammals, 22 amphibians, and 18 reptiles). Of those species, about 340 are forest dependent for some portion of their life cycle (Bunnell and Kremsater, 1990). The number of vertebrates that regularly occur in the province swells to about 630 when seasonal migrants are included. Over 180 species (or subspecies) of our terrestrial vertebrates are considered to be threatened or endangered (on our provincial red or blue lists).

Management – ultimately a wildlife manager or a forester can usually only affect habitat type (condition) and supply. There may be occasions when more direct interventions to increase or decrease numbers of particular vertebrates may be necessary, but usually we are concerned with providing habitat that can meet a number of common needs for a range of wildlife species. Habitat refers generally to the areas used by particular species of wildlife. We refer to management at a very large scale as a coarse filter approach, i.e. that for many species some amounts of protected area and some diversity of habitats in managed forests will be sufficient to meet their needs.

A successful manager is one that is able to predict accurately the outcome of a specific management action. Prediction is an important aspect of scientifically-based management, as we prefer to be able to say that such-and-such an action will result in a specific change in the population size of a particular animal. To make such predictions we need to know the habitat requirements of a species, the limitations on its populations, and its interaction with other species in the food web.

Predictions are based on previous studies and management experiments in which specific hypotheses were tested to determine the mechanisms leading to a particular change. The ability to predict provides greater certainty to management decisions, allows for effectiveness to be carefully evaluated, and permits the consideration of alternate actions. Where outcomes do not match predictions, we can revise our predictive model and re-evaluate, the heart of adaptive management.

A person responsible for wildlife management has to provide for a number of requirements of species. Individuals need to be able to have habitat in adequate supply to provide for their food supply (and that of their offspring), places where they can avoid predators, areas to avoid the high metabolic costs associated with surviving extreme conditions of winter and summer, and habitat for reproduction (e.g. nest sites, denning areas, mating areas, etc.). It is also critical that populations of sufficient size are maintained that prevent populations from experiencing the threats of local extinction associated with low numbers, genetic inbreeding, and lack of mates. All these requirements generally point to the maintenance of habitat, broadly defined, which is something a land manager has a large influence on. Direct management through culling and special protection are much more involved and problematic, and should be the approach of last resort.

This chapter is divided into a series of sections on the needs of individual animals, population dynamics and community interactions, and examples of practical means of providing for particular wildlife species. Having good information on the numbers of individuals in a population and the trends in those numbers is the basis upon which decisions are made, and so there is a section at the end reviewing methods for estimation of numbers.

The individual animal

All individuals have several common needs, to eat, to avoid being eaten, and to reproduce. Animals find solutions to these needs in a variety of ways and foresters need to be able to provide for those needs at the stand and forest level. Typically this is through habitat management, either protection, creation, maintaining connectivity, or other active interventions.

Food, nutrition and energy balance

Animals need to find sufficient food to support their basal metabolism (maintaining cellular functions, regulating body temperature, keeping heart, brain and lungs functioning, etc), growth, activity, and reproduction. Food varies in space and time (e.g. seasonally, between years). They need to be able to get enough food energy to maintain their body temperature and key physiological functions, and if there is more they can use that energy to grow and reproduce. Some foods are more digestible than others, and we can divide animals into three categories, herbivores (plants as food), carnivores (other animals as food), and omnivores (eat plants and animals). Strictly speaking, all animals are incapable of digesting cellulose, the primary constituent of plants, and therefore have to rely on specialist microbes to digest cellulose for them (either ruminants such as deer, moose, sheep, etc. or hindgut fermenters such as rodents and rabbits). Herbivores are often described as browsers (feeding on woody tissue and leaves) or grazers (eating grasses and herbs),

although many species do both. Herbivores also include species that feed on seeds and fruits, such as many birds.

Acquiring energy from food is a regular activity for animals, and takes up a large portion of their lives. However, energy intake is not the only goal for most animals since they need specific nutrients that they may not be able to get solely from their regular food. For instance, calcium is a nutrient important to bone and teeth, antlers and horns, as well as for neural signalling and other physiological processes. Given that antlers (deer family: mule deer, white-tailed deer, moose, elk, caribou) are deciduous (drop off annually) and can weigh several kg, an individual needs to gain a considerable amount of calcium each year (the horns of Bovidae – sheep, goats, bison, are permanent and continue to grow through life). Calcium may be scarce in some places and animals may have to find it in "salt licks" where higher concentrations are found in the soils or rock outcrops. They can also get it from gnawing on bones and egg shells. Having a balanced diet may depend on getting all of the essential nutrients and vitamins, and not just energy intake. Therefore, protection of sites such as "salt licks" will be important to wildlife management.

The metabolism of an organism varies seasonally. Birds and mammals maintain a relatively constant body temperature and there are a number of ways to reduce the magnitude of the difference between body temperature (T_b) and temperature of the surrounding environment (ambient temperature – T_a). The difference between T_a and T_b will determine how much body heat could be lost (or needs to be lost if it is too warm). Thus, when it is cold an animal may have to increase their metabolic rate substantially to maintain their body temperature, requiring a large amount of energy. To reduce the temperature differences animals can use habitat (shelter from wind, shelter from rain or snow, thermal protection from long-wave radiation by being under closed canopy) or physiological means (thicker fur, insulating fat, raising of fur or feathers). Many animals that do not migrate and remain active through the winter are unable to maintain their body weight because of the high costs of keeping warm, low amounts of food available during winter, and the generally low quality of food available in winter (especially for herbivores). Providing habitat for winter use by animals is an important management consideration to reduce their energetic outputs at a time when resources are generally scarce.

Thermal cover is a term used to describe features of the habitat that minimise the difference between ambient temperatures and body temperatures. Thermal cover includes dens, tree cavities, closed canopy forest, insulation provided by snow or soil, etc. Another kind of cover is sometimes referred to as shelter cover, although sometimes included as thermal cover, and includes mechanisms that provide shelter from precipitation or wind. Since the way these affect organisms is through changes in the heat exchange mechanisms (convection, conduction, radiation, evaporation), shelter cover can be considered synonymous with thermal cover.

Some mammals and birds can go into hibernation, torpor, or dormancy (all slightly different from a physiological point of view) to reduce their body temperature and thereby lose less energy. Bats, hummingbirds, and perhaps others can go into torpor during rest where their body temperatures drop considerably. Some animals hibernate, such as ground squirrels and bears, and their winter dens or burrows need to be mapped and protected. Ground squirrels and marmots may spend up to 8 months of the year in hibernation, pushing the limits for the amount

of energy stored as fat prior to entering hibernation. Any additional stresses that reduce energy intake, or change the thermal properties of their dens and burrows is cause for concern (e.g. this may be implicated in the problems facing Vancouver Island marmots – see below).

Amphibians and reptiles do not regulate their body temperature to a set level, and their activity is limited in part by external temperature. They also do not use as much energy as birds and mammals in order to maintain a set body temperature, allowing them to use more of their energy for growth and reproduction. These animals overwinter in a type of dormancy either in hibernacula (e.g. snake dens where many snakes may congregate), in the muddy bottoms of ponds, or underground in burrows. Protection of overwintering sites is therefore also important to maintenance of species' populations. In particular snake hibernacula can represent a very large proportion of a local population and therefore are given special protection under the Managing Identified Wildlife Strategy (one of the forest practices guidebooks).

Food quantity and quality varies through time. For instance, black-tailed deer, *Odocoileus hemonius* is an herbivore that feeds on herbaceous plants, shrubs, lichens, and even conifer needles. In one study the food quantity and quality for black-tailed deer were studied throughout the year for free-ranging deer and found that the amount and nutritional value of food was lowest during the winter (Parker *et al.* 1999). These findings were consistent with the fact that deer put on relatively large amounts of fat during the summer and autumn that allow them to survive through the winter when food supply does not meet their energetic needs. Deer lose a large percentage of their body reserves during winter (Parker *et al.* 1999) and if they lose too much they can die. The same is true of many kinds of animals that are non-migratory and remain active through the winter, and this is a challenging time of year for survival of most wildlife, especially young. For a manager this means that providing good foraging areas during summer and providing thermal cover during winter and good winter range are important habitat management objectives for animals such as deer, mountain caribou, and many others.

While animals are foraging or carrying out their daily activities, they are vulnerable to being seen and killed by predators. We refer to that risk as "risk of predation" and animals aim to reduce that risk by foraging in a way that allows them to be vigilant (watchful) for predators and be able to escape from the predator (e.g. Lima, 1988). Physical habitat that reduces the chance that a predator will see or capture an individual is called **security cover**. This feature of habitat may include a visual screen of vegetation, or other means of hiding or escaping predators, e.g. burrows, coarse woody debris, etc. and is an important consideration in providing for habitat through silvicultural means.

Reproduction

Reproduction replaces individuals and maintains populations, and can involve a number of strategies. Females and males find each other through a number of ways and mating is often based on one of 4 mating systems – promiscuous (e.g. frogs mating as swarms in ponds), polygynous (males have multiple partners, e.g. elk), polyandrous (females have multiple partners – rare, but occurs in phalaropes), and monogamous (or serial monogamy where there is only one partner at a time).

Reproduction can be direct or delayed. Delayed implantation is a strategy possessed by a number of mammal species such as black and grizzly bears, and most of our weasels (otters, mink, fisher, wolverine, marten, etc.). This delayed implantation is a physiological adaptation that allows the embryo to suspend development until the timing is best for development, i.e. birth at an appropriate time of year.

Some species of wildlife have traditional areas that they use as mating areas. Some ungulates use the same area each year for male competition and for mating. Some species of grouse meet on leks where they display. Many other species are territorial and males defend their territories against other males of their species. Disruption of territorial structure for species such as grizzly bears may have negative effects on social structure and survival of cubs (Wielgus and Bunnell, 2000) if females come into contact with aggressive males.

Young animals are particularly vulnerable to predation and this is one life stage where high rates of mortality to predation and other losses can seriously affect a population's persistence in an area. Females often go to particular areas to give birth away from other members of the species, such as in caribou and other ungulates. Protection of habitat, such as nest sites and areas used by youngsters, is considered a particularly important activity and the BC government's Managing Identified Wildlife Strategy (1999) includes special provisions for nesting habitats.

Tree cavities are a habitat feature used by more than 50 species of wildlife in BC (woodpeckers, songbirds, some weasels, squirrels, etc.), mostly for rearing young. Cavities typically only occur in older and larger trees, which if not provided for in stand-level plans, can disappear from intensively managed areas. This is a special attribute often associated with old growth forests and discussed further below.

Groups of animals – populations and interactions with other species

The basic group of any animal is the population, and this is usually the scale at which management takes place. This is a group of the same species that potentially interact, such as the breeding population (e.g. the group within some large watershed that rarely move outside of that geographic area). Populations may be separated by mountain ranges or other barriers that reduce movements, although not necessarily to zero (rare movements between populations allow for gene flow and colonization). Foresters need to consider sustaining populations of species such that their numbers do not drop or make them vulnerable to decrease in the long term. This usually requires management at the forest and landscape scale to maintain connectivity, habitat through which an animal can disperse effectively.

The number of individuals (usually in density – numbers per some unit area) is usually set by the supply of habitat or food, something we call the *carrying capacity* of the environment. Carrying capacity (denoted K in population models) varies considerably amongst habitats and years, so it is not really a constant as some texts imply. If we know the carrying capacity we can predict the numbers of individuals across similar habitats, and this is sometimes used to generate broad estimates based on ecosystem mapping exercises, although it requires caution and many assumptions.

Small, isolated populations are very vulnerable to local extinction (loss of a population, not the whole species) and a major goal of management must be to minimise the chance of driving numbers to small populations. There are several

reasons. First is the simple loss of individuals and habitat that is usually progressive and deterministic. Second, there are sources of variation from year to year, known as environmental stochasticity, that could end up reducing populations (or increasing them) because of changes in food supply, predators, or even climate. Loss of several individuals from a small population will be more serious than losses of the same proportion from a large population. If there are reductions in sequential years, it could put the population into an unrecoverable decline (Gilpin and Soule, 1986). Third, as populations get smaller it is possible to get chance changes in sex ratio where all individuals are of the same gender, or at least highly skewed. There are several cases where the last five or so of a species were all the same gender and effectively extinct. And fourth, there can be genetic consequences if small populations become inbred (limited gene pool) or simply have limited genetic variation amongst them. There are many good examples of genetic problems in small populations. For all these reasons the smaller a population becomes, the risk of local extinction increases.

Some species require the company of other individuals, e.g. a herd, flock, pack, etc. Rates of mortality may be higher for individual animals and reproductive (and mating) success may be lower if land management diminishes group structure. Thus, social structure within a species is an additional consideration beyond simply maintaining habitat for individual animals. There are several reasons that a group may fare better than individuals or small groups. While foraging an individual needs to maintain vigilance for predators reducing an individual's foraging time, whereas in a group, that vigilance can be shared on average allowing each individual to forage longer. Evidence indicates that as group size increases the chance of seeing and evading an approaching predator increases (the "many eyes" hypothesis). Being a member in a group may also dilute the risk of being caught by a predator if that risk is spread across all individuals, and better yet if the individual can be near the middle of the group (the "selfish herd" hypothesis). In rare situations there can be group defence, such as muskox forming a ring to defend the group against wolves or birds mobbing a predator. A group may also be better able to find resources if they are patchily distributed (e.g. seed-eating birds or geese), or if hunting success increases (e.g. wolves). For these reasons and others it is important to maintain social structure and herd sizes if possible.

Populations sometimes increase and individuals must leave to find a place to settle, or populations may experience declines and depend on immigration from other areas to maintain their numbers (the "rescue effect"). This movement of individuals from one area to another, more or less permanently, is called dispersal. Movements from one area to another and back (e.g. summer range and winter range) is known as migration. To maintain the ability of individuals to migrate or disperse depends on providing appropriate habitat between areas, a concept known as **connectivity**. The broad-scale maintainance of populations by allowing for dispersal between populations (and the rescue effect) results in a metapopulation (a "group of populations"), which is considered to be a more stable entity than individual populations, and therefore an objective of wildlife and forest management.

Interactions between species

All species are part of a biological community that includes its predators, its food, shelter (vegetative cover), competitors, parasites, and species with which it may not even interact. These interactions are important to consider in management, as an action that affects one species, may have unwanted impacts on other species, or may not work if other parts of the community are not taken into consideration.

Wildlife species are susceptible to disease and parasites, and in many situations these diseases can be fatal. Wildlife can get viruses, bacteria, ticks, worms of various sorts, protozoans, fleas, etc. Some specific examples are *Brucella* (a bacterial disease), *Pasteurella* (a type of pneumonia), brainworms and lungworms (nematodes), and *Leucocytozoa* sp. (a blood protozoan). Most often these diseases act in a density dependent fashion. As populations increase in density, individuals may be more physiologically stressed (lower food supply, more interactions) and therefore more susceptible to disease overcoming their immune abilities. In addition, at higher densities there are more individuals and higher rates of interaction (increases as n times n-1, a geometric rate of increase) and likely more infected individuals to come in contact with. Evidence from bighorn sheep show that the prevalence of the pneumonia (*Pasteurella* sp.) and mortality rates are correlated with reaching high densities (Monello *et al*. 2001).

Wildlife can also carry diseases that have impacts on humans – West Nile virus (mostly in birds such as crows and jays), *Giardia* ("beaver fever"), *Cryptosporidium*, various worms from the guts and organs (mostly experienced by hunters), "Lyme" disease (caused by spirochaete bacteria, including *Borrelia*, the causative agent of "Lyme" disease). Wildlife can also transmit diseases into domestic livestock, such as brucellosis (caused by the bacterium *Brucella*) that can move from elk or bison into cattle, where it has more severe effects.

Competition between species can occur when species share similar resources and it affects their rate of growth, survival, or reproduction. These shared resources may be for food, burrows, tree cavities, etc. The evidence to demonstrate competition is rarely sufficient to satisfy scientists completely, but most recognise that it can and probably does occur. In BC there are some examples, especially for the use of tree cavities, which can be in short supply relative to all the species and individuals that use them (Newton, 1994).

Predation – there are very few species that don't have some predators, even if it's only their young that are vulnerable. Some species can be preyed upon, but ultimately have their numbers determined primarily by their food supply. In some cases predators can strongly suppress the numbers of a prey species, pushing prey numbers into what is referred to as a "predator pit". At these low densities the relatively few individuals remaining may find refuge in areas free of predators or where they can more effectively escape predation. Prey populations "escape" the predator pit because predator populations can vary through time allowing prey to increase sufficiently that predators can't increase as fast, or when resources for a prey species likewise allow more rapid increase than normal.

Predators normally are larger than their prey and as a corollary (a generalisation) have slower rates of reproduction. That can result in a prey population increasing rapidly, a predator slowly catching up in terms of numbers, then being sufficiently abundant to suppress prey numbers. These kinds of interactions can cause cycles

in predator-prey numbers, typically when there are few alternative prey for the predators. Two classic examples of this are for snowshoe hare and lynx interactions (Krebs et al. 1995), and moose – wolf interactions (Messier, 1991; Peterson, 1995). Most predators and prey do not show these cycles, but predation can cause problems when there are increases in alternate prey that cause increased predator numbers. For instance, the putative 20th century increases in moose numbers in BC are thought to have led to higher wolf population numbers, which in turn are thought to have increased predation pressure on mountain caribou, a species that appears not to withstand intensive predation.

Management of predators is a controversial action that has been proposed in many forms for the protection of other species. Wolf control (culling) has been used several times in BC to allow populations of ungulates (mostly hunted species) to increase (Seip, 1992). Other instances of predator control, including wolves, golden eagles and cougar, have been suggested for the protection of species such as Vancouver Island marmot, but to date appear not to have been implemented. Predator control is not a publicly-accepted form of wildlife management, but there are times when it may be necessary to consider this an option.

Species interact in a food web, which includes their food, predators, parasites, competitors, and other species. Interactions within foodwebs can be complex and produce complicated sets of interactions, some of which can yield "surprises" when not fully considered in management actions. Complex interactions and indirect effects are those interactions that are mediated through food web interactions and not predictable easily from the interactions of pairs of species, such as predators and prey. The snowshoe hare cycle, which was thought to be predominantly driven by predation by lynx, turned out to be a much more complicated set of interactions than expected, and were only realised by large-scale experimentation in the Yukon Territories (Boutin *et al*. 1995; Krebs *et al*. 1995).

Ecosystems

Some species may have an effect on their ecosystem disproportionate to their biomass, and these are known as *keystone species* (Paine, 1980; Power *et al.* 1996). Species may also be known as *ecosystem engineers* if their activities modify the physical environment. Beavers can be considered as a keystone species and an ecosystem engineer due to their large impact on the environment and many other species that is disproportionate to their actual biomass in the forest. A species can be an ecosystem engineer (defined as modifying the physical environment) without being a keystone species. Primary cavity nesters (in BC all are woodpeckers) may be keystone species since there are many species that depend on these species (weak primary excavators, or secondary cavity nesters) for their nest cavities (Martin and Eadie, 1999).

Management Issues, Trials and Solutions

In addition to general measures that aim to protect wildlife, there are particular types of habitats and particular species that require more focused management attention. At the broadest level, the most "coarse filter", we have protected areas across the province. The intent of these protected areas (parks, special management

zones, etc.) is to protect areas of habitat that serve a majority of species, but won't necessarily serve all species. Other species need particular management strategies, such as those that need particular habitats (e.g. old growth specialists, cavity nesters, riparian dependents) or need large spatial scales with particular limits on industrial activities (e.g. grizzly bears and mountain caribou).

We often speak of different scales of management, the largest scale being the most "coarse filter" and usually at the level of protected areas, regional plans, and conservation plans for species such as grizzly bear. These coarse filter approaches were dealt with in the Biodiversity Guidebook of the 1995 Forest Practices Code. Sometimes protection of species with large area requirements, such as grizzly bears, are considered *umbrella species* for other organisms, as in an umbrella that protects all other species using the same habitat. There is little evidence that this works for all other species, but it does help many. At the next scale of management – the next "filter" – would be the Riparian Management Area Guidelines since it too protects habitats that may be useful for many species. For instance, riparian reserves serve to maintain densities of some species of small mammals (Cockle and Richardson, 2003) and amphibians. Some species pass through these management filters and require an even finer filter approach, i.e. a species-specific strategy, formulated by the government in their Managing Identified Wildlife Strategy. In all of these cases it is important to recognise that most of these guidelines are educated guesses and need to be rigorously tested, but some action is necessary in the short term. If these guidelines prove to be successful or inadequate, we can modify them with increased understanding.

Some classes of wildlife management issues

Old growth dependents: There are many species that are known to be dependent on old growth forest characteristics for various reasons. Some of these species require that habitat for its supply of large, old trees with large branches for nests, such as the northern goshawk, and marbled murrelets. Some species appear to be associated with these oldgrowth forests because of the understory development present and the security cover it provides, e.g. northern flying squirrels. Other species that depend on old trees for cavities (see below) find those characteristics primarily in old forests. There are other characteristics of old growth forests upon which various species depend, not all of which are well understood. The amounts of woody debris and its decay class on the ground are highly dependent on the forest history. Harvesting severely reduces the amount of woody debris (an important element of habitat and cover for many species), through reducing supply and breaking up existing pieces.

Riparian dependents: Riparian areas represent a very small proportion of the forested land base, and yet >70% of species in the province are known to occur there (Raedeke, 1989; Kelsey and West, 1998). These areas are usually highly productive, and provide water and additional kinds of habitats for foraging and reproduction (Richardson *et al.* - in press). It is easy to think of species that are tied directly to riparian areas, such as beavers, ducks, herons, muskrats, tailed frog, water shrew, river otters, etc. This is a huge topic and provincial guidelines for stream, lake and wetland protection are also intended to provide for wildlife habitat.

Cavity nesters: Over 50 species in BC depend on cavities for some portion of their life history requirements, often as nest sites. This includes both birds and mammals. For instance, bears (grizzly and black) make day dens in the base of old

trees. Woodpeckers (12 species in BC) all nest in standing trees, either dead or dying, usually of a particular decay class (2, 3 or 4), and often of a particular minimum diameter (small diameter trees have insufficient internal space for a nest depending on the size of the woodpecker species). Many other species of birds (chickadees, northern spotted owls, tree swallows, goldeneye ducks, etc.) and mammals (red squirrels, flying squirrels, marten, etc.) either use cavities created by woodpeckers or natural holes (secondary cavity nesters). Some of these species are capable of a small amount of enlarging cavities if the wood is soft, and they are known as weak primary excavators (e.g. Martin and Eadie, 1999). In general, old, dying and dead trees are rare in most forests, so the supply of these as habitat may limit the numbers of cavity nesters (Newton, 1994). Management to maintain old and dying trees (wildlife trees) remains controversial because of the safety concerns and implications for area harvested. As the industry moves more to uneven-aged silvicultural systems this may solve the supply issue, but this needs to be carefully evaluated.

Large woody debris: Large woody debris (LWD) on the ground is used by many species as security cover, thermal cover, or simply as convenient runways through the forest. Many small mammals use LWD for all these functions. Amphibians are often associated with LWD because of the cover and moist conditions it provides them. Forest snakes, such as the rubber boa, also make use of LWD for cover and as a place to search for prey. The amount and future supply of LWD is reduced by forest management, because the rotation age is too short in many places to supply LARGE woody debris. In addition, existing LWD on the forest floor either decays or it may be broken up during falling or skidding operations.

Small and isolated populations: Small populations have higher probabilities of going locally extinct, i.e. the population in a particular area disappears. This is also more likely to occur if there is no "rescue effect" resulting from immigration of dispersing individuals, and this is particularly likely if the population is isolated in some way. The decline or loss of these small populations is the cause of species becoming threatened or endangered in many instances. Small populations are vulnerable for several reasons. With few individuals there is a higher probability that the natural variation in population size could hit zero or near to zero, referred to in conservation biology as environmental stochasticity. Very small groups of individuals can also experience demographic effects, such as all males, or no individuals of reproductive age, etc. There are also genetic effects that have been documented for small populations, leading to decreased reproductive rates and reduced survival rates. Whenever possible, the remedy to this possibility is to maintain self-sustaining populations, ensure connectivity for immigration and emigration, and to manage for metapopulations (as opposed to isolated populations).

Problem wildlife: Some species cause problems for forestry by eating seedlings, stripping bark, eating foliage, or browsing leaders. Some examples include voles, deer, porcupines, mountain beaver, snowshoe hare, etc. Control of these species is usually not feasible through culling, as most have very high rates of reproduction and many of them are small. Various means to reduce browse damage have been tried, most with little success, such as various chemicals that may scare herbivores, either scent of predators or blood of other animals. Various chemicals that taste bad have been tried, e.g. camphor, by spraying it on seedlings (Sullivan *et al.* 2002). Silvicultural tactics to reduce damage can be used, such as increased spacing between seedlings that reduces security cover (Sullivan *et al.* 2002). Trees have been bred with higher than usual concentration of bad-tasting chemicals, and these may have some limited success in

areas that are particularly affected by herbivores.

Browse protectors have been used in many places with some success. These can be costly to buy, install, and maintain (e.g. from snow press or by being knocked over by ungulates). Some of these products enhance leader growth and do protect young trees to some extent. In addition to expense, these browse protectors may also lead to young trees with unwanted growth characteristics that may affect future wood quality.

Problem wildlife can also include human-wildlife encounters. To a wildlife manager these may be very important, especially those that threaten human life, such as cougar and bear attacks. These are usually handled by provincial conservation officers. Other problems from wildlife include damage to crops (forage crops, apples, etc.) by deer and other ungulates. Other encounters with wildlife can include property damage, burrows that affect cattle, urban wildlife (skunks, raccoons, coyotes), etc.

Hunting and trapping: Hunting and trapping are regulated activities in BC requiring permits from the province. These permits have many restrictions and also serve to limit the numbers of individuals involved in these activities and where they hunt or trap. For hunting regulations are set for each wildlife management area, and each region may be divided into a number of wildlife management areas. Another means to control hunting is through limited entry hunts (LEHs) whereby hunters enter a lottery for a limited number of permits to hunt particular species. There are a number of other provisions that govern hunting, such as measures for fair chase (e.g. no shooting from helicopters) and for age and sex restrictions (usually biased to older males). Trapping for furbearers (marten, wolverine, hare, etc.) is a traditional First Nations activity and also carried out by non-native trappers. There are in excess of 3200 registered trap lines in BC. Trappers are given licences to particular trap lines, which they self manage. The standard layout of trap lines is to build a "no trap" buffer between trap lines that can be more than twice as wide as the actual trap line to ensure there is an area to maintain populations of furbearers. Wildlife managers are responsible for ensuring that trap lines are protected from other land use activities, and forest managers need to be aware of hunting and trapping activities in a forest district, as it affects development plans.

Wildlife viewing: Ecotourism based around watching wildlife is an important, and often underappreciated, economic activity in BC. Tourists from around the world come to experience wildlife in our province, including watching grizzly bears, eagles, salmon migrations, whale-watching, etc. Birdwatching is a major recreational activity and many residents and non-residents of the province spend money to travel and watch birds throughout the province.

Species at risk

Threatened or endangered species or subspecies are designated by the province and by the national Committee on the Status of Endangered Wildlife in Canada (COSEWIC). Those species that are at highest risk of endangerment are on the "red list" and those that are vulnerable to becoming endangered are on the "blue list". In BC (2004) we have 86 species on the red list and 94 species on the blue list. Some of the reasons for species being at risk include a long list of human activities. Here, we consider a few particular species where forest management is thought to be a

direct cause of endangerment, along with some suggestions for solutions.

***Mountain caribou*:** This ecotype of the woodland caribou found in isolated herds in the southern mountains of BC from Prince George to the US border has a double migration each year. The world's entire distribution of this form of caribou lives in BC, Alberta, and Idaho, although the largest proportion of them are in BC. It spends summers in the alpine, autumn and early winter in valleys, winter in the subalpine (ESSF), and spring back in the valley bottoms. The species is very vulnerable to predators, such as wolves, cougars, and bears. In the past decades the numbers of these caribou have been in decline for most of the 13 herds in BC. It has been suggested that the three biggest threats are predators, loss of winter habitat, and winter recreation activities. Predator numbers are thought to be supported by the increase in moose in the past century and expose the mountain caribou to a greater predation pressure when they are in the valley bottoms than they experienced historically. Usually mountain caribou escape predation pressure during winter by being in deep snow at subalpine elevations. However, increases in snowmobile use appear to have contributed to packing of the snow and allowing predators access to subalpine areas. This is in addition to some observations of direct impacts on caribou trying to evade snowmobilers and being trapped in avalanches. During winter caribou subsist (negative energy balance that would be worse without lichens) on arboreal lichens (*Alectoria*, *Bryoria*), a slow-growing group of species that only get to a volume or biomass worthy of consumption by mountain caribou on old growth trees. Forest harvesting in the ESSF may be reducing the overall biomass of lichens available and the rate of growth on regenerating trees. The management for this species is highly controversial and probably requires controls on all the causal factors. Suggestions of predator control as one means of protecting them resurfaces regularly, but is not a sustainable long-term option.

Grizzly bear: The grizzly bear requires large territory sizes and needs to be managed at a large scale. The management of grizzly bear is highly controversial for several reasons, including the absence of agreed-upon estimates of numbers, lack of a parameterised demographic population model, hunting is allowed, and its endangerment in the lower 48 states of the United States. This is a highly politicised species with several stakeholders holding very different aspirations for the species' management. The provincial government stands by its estimate of 10,000 to 13,000 grizzly bears in the province (Fuhr and Demarchi, 1990) and has allowed hunting on a limited number each year (about 240 per year in the 1990s). There have been a couple of management activities for the species, including setting aside large protected areas and building a conservation strategy. There is a proposal being considered to set a minimum protected portion of the species' populations in each of 6 regions, numbering around 100 – 250 in each region (Wielgus, 2002). These protected individuals would experience no hunting pressure and ensure that some portion of the population was better able to maintain or increase its numbers, potentially to supply excess individuals as dispersers to areas outside the protected zone. The management of this species is part of higher level plans that the forest manager needs to be aware of. At the stand level there are prescriptions for stand management to maintain good habitat, including good berry production, usually by maintaining low tree densities through thinning.

Vancouver Island marmot: This large rodent is similar to other marmots, but as a distinct species is found nowhere else than in a few isolated alpine areas on Vancouver Island. The numbers may be fewer than 50 remaining in the wild. This species has been considered endangered for a number of years because of its declining numbers, small total numbers, isolation of populations, and the continued threat to its habitat. One of the putative causes of endangerment of this species (remember that we can't do detailed studies or experiments to test this on an endangered species) is forest harvesting and the marmots mistakenly settling into clearcut areas that in the short term resemble their alpine habitats. Recall that marmots often spend up to 8 months in hibernation and rely on their fat storage for that duration. If the insulation usually provided by deep snow is not present the burrows may be colder than those with greater snow cover at higher elevations. These colder conditions require more metabolic energy to remain above freezing than if the burrow were better insulated. Also, these sites eventually regenerate to forest and that may reduce the quality of these areas further for marmots that have mistakenly settled there. Predation may also be a factor. Remember that these are just hypotheses, but in many cases with endangered species we have to take these possible explanations seriously, otherwise we run the risk of not acting soon enough to prevent the demise of a species.

Marbled murrelet: The marbled murrelet is a seabird that spends a great deal of its life offshore, feeding on fish. Its connection with forestry is that it is one of the class of species that nests more or less obligately in old growth trees. The typical nesting habitat for this species are old trees with very wide side branches, usually at least 30 cm in diameter, moss-covered on which they lay their single egg each year (maybe in alternate years) in a depression in the moss. These nest platforms typically also have another large branch just above, which provides protection from some kinds of predators. The species is still relatively abundant, but strong downward trends in its numbers, and the advancing loss of old growth trees for nesting, resulted in the species being listed as threatened. The species currently receives provisions in the Managing Identified Wildlife Strategy for protection of trees where there are active nests. There are interim measures proposed for the protection of this species from forestry activities. Research on the species is ongoing and may eventually indicate why the numbers are declining as quickly as they are.

Northern spotted owl: The northern spotted owl is a species that has gained notoriety in the Pacific Northwest for its widespread impact on the forest industry. A pair of spotted owls may require an area up to 3500 ha, mostly of old growth. There is variation in the kinds of habitats used by spotted owls, shown by a very extensive body of research in the US since the mid 1980s (e.g. Noon and Franklin, 2002). The species requires old growth trees with cavities for nesting. The young owls find better protection from predators (such as great-horned owls) in old growth forests. Foraging habitat was thought to be primarily in old growth forests with extensive understory, which provides habitat for one of its main prey, the northern flying squirrel (Carey *et al.* 1995). In other parts of its range it may also prey on woodrats, some species of which are found at forest edges and second growth forests. In BC the species is found in the southwest portion of the province, mostly in the Vancouver, Chilliwack, Lilloett, and Merritt Forest Districts. The trend in BC appears to be strongly downward (Blackburn *et al.* 2002) although the reasons are unknown. In 1995 BC set up special management zones around the areas where

the species was known to occur, with the intention that this special protection would provide high quality habitat for the owls known to occur in BC. Recent evidence indicates that even these special management areas have not stopped the decline of this species in BC. Because of the high public profile of this species and its association with old growth forest, it remains a high priority species for the provincial government.

Practical aspects of wildlife management

Identification

Putting a name to a species is critical and there are many species that look alike. It is easy to confuse species that may be endangered with ones that may be extremely common. Errors of identification can result in lost time and money, or costly law-suits and loss of goodwill. Carry up-to-date field guides. Consult with credible biologists (those with a highly-regarded reputation).

Methods for estimating numbers, movements and population status

One needs to know how many individuals there are of a species of interest, to determine if the numbers are going up, down, or staying relatively constant. We also need to know if a management action is having the desired effect on a population.

Trapping and sampling – Methods for trapping or sampling depend on the species of interest and the information required. This information would be available from a biologist, either from one of the universities, government office, or consultants. Any kind of capture or handling of wildlife requires permits from the provincial government.

There are three general classes of population estimates, each with benefits and limitations. These are indices of abundance, relative abundance, and density estimates (number per area).

Method	Advantages	Limitations	Examples
Indices	Fast, inexpensive, gives trends	No actual number, many potential biases	Scat surveys
Relative abundance	Inexpensive, gives counts, trends	No actual number, many potential biases	Winter bird hunting returns
Density	Actual numbers, demographic information	Expensive, long-term, can be biased	Mark-recapture (group or individual marks) or sampling

The estimation of density depends to a large extent on being able to distinguish animals that have been seen previously from those not seen before. This typically means marking animals somehow. The best approach is for animals to be uniquely marked, i.e. each individual with a different number or slightly different mark (e.g. different colour combinations). Animals can be marked with ear tags (most mammals), leg bands (birds), coloured elastomer dye injections under the skin

(amphibians), PIT tags (most species), hair dye or bleach (mammals), and coloured paint marks (birds and reptiles). In some cases individuals can be distinguished by careful study of individual marking patterns in their skin or by collecting bits of hair for DNA analysis.

All of these methods depend on the "dilution" method, usually called capture-mark-recapture (or mark-recapture) methods. In the simplest form this is based on solving a simple ratio based on catching some number of individuals, marking them, and releasing them back into the population. We then resample the population, usually a day or a few days later (allowing for mixing within the population), and look at the ratio of marked to unmarked individuals. The ratio of marked to unmarked individuals in the second sample should be the same as the ratio of our initial sample to the whole population. This method depends on several assumptions, some of which we have difficulty being sure of. One assumption is that the population is "closed", i.e. immigration and emigration are very small contributors to the change in numbers between our sampling times. We also have to assume that animals that are marked keep their marks, and are no more likely or unlikely to be killed than animals that are not marked. Likewise, we have to assume that animals that have been trapped once are just as likely to be trapped again as they were the first time, i.e. they do not learn to avoid traps or go preferentially into them (they are often baited).

The methods for mark-recapture estimates of numbers have become increasingly sophisticated in the past 15 years. Good sources of information on mark-recapture methods are to be found in Krebs (1999), and Anderson *et al.* (2000).

Habitat supply models

We rarely have the resources to do extensive inventories for most wildlife species, and in fact for most species we have almost no detailed information on numbers and habitats. For those species where there are estimates of population numbers for some areas, e.g. grizzly bears, habitat supply models have been used to estimate total numbers. These models typically determine the relative value of particular kinds of habitats, which may be capable of supporting some estimated density of bears (or other species). Rather than try to estimate numbers across the whole province this habitat mapping seems like a good way to determine numbers cheaply. Habitat type or quality may be estimated by GIS, land inventory, or even by remote sensing, thereby providing extensive coverage that would not be possible from intensive surveys for population estimates. An important point to realise is that habitats are not always filled to "capacity", and in many instances even prime habitat may be vacant, depending on other influences on populations. Thus, habitat supply models may be a useful tool if used cautiously and recognising the assumptions behind the models.

The estimation of numbers is how we determine the status and trends of population numbers, as well as the effect of management. Good management depends on reliable data.

Other specialists: BC Ministry of Water, Land and Air Protection have the mandate to manage wildlife, as wildlife is a provincial jurisdiction. They also have staff with knowledge of many species, especially in a local context. BC Ministry of Forests also has staff that do research with wildlife and can provide advice. The

Canadian Wildlife Service (CWS) of Environment Canada is the federal agency that is involved in wildlife management, particularly for migratory species and for species at risk. The CWS role in wildlife management is constitutionally intended to be to co-manage with provincial authorities. Consulting biologists may be able to provide advice.

Key concepts for forest wildlife management

Representation: Maintain elements of all ecosystem types, structure types, and BEC variants.

Remnant sizes: One size won't fit all, so ensure a variety of remnant sizes, especially some large ones.

Riparian habitats: Protect riparian habitats, especially in patches rather than thin reserves, wherever possible.

Standing dead and coarse woody debris: Maintain structural elements critical to cavity nesters and other species that use downed wood.

Connectivity: Ensure populations do not become completely isolated by forest management, including roads and other operations.

Ensure effective, self-sustaining populations are maintained: The key to long-term persistence of populations is a large enough population to maintain itself and not be vulnerable to the threats associated with small, isolated populations.

Wildlife habitat Areas: Special designs for some species that might not be taken care of through other management efforts.

Bottom line:

Don't apply the same design to every piece of forest.
Maintain diverse stand, forest, and landscape structures.

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A lot of information on wildlife and their management from the British Columbia government is available through their website at www.gov.bc.ca, particularly in the Ministry of Water, Land and Air Protection.

RANGE MANAGEMENT

Condensed from Rangeland Handbook for BC

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History of Range Use

A knowledge of the past helps us to understand the present and plan for the future. The vegetation we see today is a product of past disturbances such as fire, weather, logging, grazing, floods, mechanical disturbance, or combinations of these things. Both man and nature have been manipulating ecosystems for thousands of years – not just since the arrival of white men. Ecosystems are alive and constantly changing regardless of human activities. For example, the distribution and populations of some native ungulates have undergone major changes which are not easily explained. We know very little about thousands of other species of plants, animals, and insects which may have disappeared, or arrived, without our knowledge. We do know there were very few species here 10,000 years ago when most of British Columbia (BC) was covered with ice.

For thousands of years the grassland, forest, and riparian ecosystems with associated streams provided food, clothing, fuel, shelter, and recreation for the native people. The introduction of horses greatly improved their lifestyle by providing labour, easier travel, improved trade, food, and recreation. Cattle and domestic sheep were introduced into southern BC about a century later. During the late 1800s the number of horses and cattle increased rapidly.

By 1900 most of the grasslands were overgrazed. Recognition of overgrazing and the application of range science has brought outstanding improvement during the past fifty years. Now the goals have changed. Where the objective was forage for domestic animals and wildlife, we have recognized the need to manage for biodiversity, recreational needs, fish habitat, etc. The range has served us well for thousands of years and we now understand many of its capabilities and limitations. We can continue to use it for a variety of purposes provided we make decisions based upon experience supported by available information. We should recognize mistakes of the past and use our knowledge to avoid similar mistakes in the future.

In the 1800s virtually all domestic animals grazed the range year-round. Today very few domestic animals graze Crown range for more than six months. If the number of livestock using Crown range in 1990 were the same as in 1890 the actual use of range in 1990 would be less than half of what it was in 1890 due to the elimination of year-round grazing. In 1890 virtually all the domestic livestock grazing occurred on the grasslands of the Southern Interior, whereas today the forest lands provide more than one-half of the grazing in this area, and nearly all the grazing in central BC and the Peace River region.

BC's rangeland also supports an impressive array of wildlife. There are literally hundreds of species of amphibians, reptiles, birds, and mammals associated with the grasslands, shrublands, wetlands, and open forests. Amongst mammals, for example, can be found the tiny pygmy shrew weighing only about 4 grams, and moose, our largest mammal, weighing up to 600 kilograms. The majority of these vertebrates have been adapting to the unique conditions of this rangeland, and to each other, for thousands of years. Stock grazing need not be disruptive or destructive to these rangeland inhabitants if carried out with proper care and management.

The historical record for many wildlife species is sparse because the animals were small, inconspicuous, secretive, or of little interest. However, larger animals such as the ungulates have received greater attention and a relatively accurate historical record of their abundance and distribution remains.

Impact of fire on the range

Fire, or the absence of fire, has done more to affect the vegetation of the BC interior than any other factor since the last ice age. First Nations peoples used fire for thousands of years to remove brush and facilitate travel, encourage more palatable forage for game animals, promote growth of berries or other edible plants, warm themselves, cook with, provide light and frighten predatory animals, enhance habitat for furbearers, kill trees for firewood, herd wildlife, signal neighbours, and to burn their enemies range, or to flush them from hiding.

Before the arrival of white men the native peoples were probably responsible for most fires, although lightning was also a contributing cause. When David Thompson's party descended the Kootenay River … "they emulated a common native practice by setting ground fires to clear the brush and attract game to the new growth that would follow" (Nisbet, 1994). The impact of burning by natives was greatly reduced in the late 1800s because disease had reduced their numbers, and they were confined to reservations. Very large, hot fires occurred throughout most of the BC interior in the early 1900s, however, it is uncertain whether these fires were deliberately set or if they were started by accident. Settlers burned to clear land for crops and gardens and prospectors burned in order to see mineral outcrops. Fires were also lit to provide employment during depression years. Ranchers set fires to maintain or extend the grasslands and wild hay meadows and to provide earlier and more palatable forage for their livestock. Fires were also set to clean up slash after logging and railway tie cutting. Thus smoke was constantly present some summers during the 1930s.

By the 1960s the BC Forest Service had developed a very sophisticated and effective fire control system. During previous years they had been acquainting the public with the evils and dangers of forest fires. Since the sixties there have been relatively few large or hot fires. Due to the absence of fire the forest vegetation is creeping into the grasslands and replacing rough fescue with Douglas-fir and lodgepole pine in some areas. Trees are now growing where they probably never grew before. Timber harvesting has now replaced fire as the major factor affecting the ecosystems of the BC interior.

Rangeland Ecosystems

Rangelands, or range, is a type of land, generally non-cultivated, which provides forage for wildlife and livestock in addition to other products and values (Heady and Child, 1994). Forage includes both herbaceous plants (grasses, grass-like plants, and forbs) and browse (woody species) which are consumed by grazing animals as food. Water, wildlife, meat, and forest products in addition to recreation, biodiversity, aesthetic, and spiritual values are derived from rangelands.

Major types of rangeland include desert shrublands, grasslands, savanna woodlands, forests, alpine, and Arctic tundra areas (Holechek *et al.,* 1998). In BC, rangelands are predominantly forested but also include important grassland, meadow, wetland, and alpine areas. The forage available within different rangeland types varies with local climatic, topographic, and soil conditions. Riparian areas are important ecological elements within each of these range types. They are defined by the vegetation which occurs next to the banks of streams, lakes, and wetlands in an area dominated by

continuous high moisture content (MoF and BCELP, 1995). Refer to chapter 8 of Rangeland Handbook for BC (Campbell and Bawtree, 1998) for further detail.

Rangeland vegetation types may be either permanent or temporary. Permanent rangeland in BC includes grassland, forested, and alpine range. Temporary rangelands may follow disturbances such as fire or logging in closed forests. Fire and logging are disturbances which can increase the amounts of light and heat reaching the soil and vegetation. This can result in higher forage production and creation of temporary rangeland until the forest canopy closes over again.

Rangelands are extensively managed ecosystems compared to cultivated agricultural lands which are intensively managed. Extensive management means lower agricultural production per hectare and is generally associated with a lower level of production inputs. Production inputs may include management time, seeding, fertilization, irrigation, pest control, watering facilities, and fencing. Intensive management generally provides higher production per hectare, but this increase is associated with higher levels of production inputs.

Rangelands can be compared to an imaginary, self-correcting, self-renewing, perpetual motion machine. They will provide resources indefinitely if what is taken from them is within their capacity for self-correction and renewal. Production of forage and other products from rangelands can be completely independent of agronomic inputs like cultivation, seeding, fertilization, irrigation, and pesticides. This is a natural advantage of rangelands, even though their productivity may seem low compared to cultivated grasslands. The comparatively high production of forage from cultivated grasslands is dependent upon regular inputs.

Range Management Objectives and Planning

The Society for Range Management defines range management as: "A distinct discipline founded on ecological principles and dealing with the use of rangelands and range resources for a variety of purposes. These purposes include use as water-sheds, wildlife habitat, grazing by livestock, recreation, and aesthetics, as well as other associated uses" (Society for Range Management, 1989). It follows that the objectives of range management would include reference to the stated uses or purposes for managing range.

Objective is defined as: "something sought or aimed at", such as a target or goal (Allen, 1996). Successful rangeland management begins by establishing clear objectives. The primary objective of any range management program should always be to maintain or improve the integrity, or proper functioning, of watersheds. A range manager may see a need to improve the functioning ability of a watershed by enhancing the catch, storage, and safe release of water. Although soil erosion occurs naturally, range managers must ensure that their activities do not lead to accelerated erosion and soil loss. In BC, soil erosion is usually caused by water, although it may also result from wind and mechanical disturbance. The primary objective to minimize soil erosion is appropriate in BC where steep slopes, rapid snow melt and resultant runoff, heavy rainfalls, and fine textured soils are not uncommon, and are frequently associated with soil loss. Adequate vegetative cover throughout a water-shed is essential for preventing soil erosion. Therefore, management objectives should include maintenance or improvement of appropriate vegetation to reduce surface runoff and soil erosion. Trees are required on steep slopes and the banks of creeks where there is potential for strong water flows.

Grass and shrubs may be adequate on the more gentle slopes. The protection of soil and water resources must never be sacrificed for other goals. Protection of these resources will ensure habitat for fish and wildlife, forage for livestock and wildlife, trees for wood products, recreational values, and an aesthetically pleasing landscape. For example, a range manager may desire to maintain or improve the ecological condition of riparian areas to enhance waterfowl cover, shade for fish, or bird nesting sites. These objectives can be met by various management techniques, which may include a change in a particle livestock grazing scenario. However, objectives need to be tempered with practicality and the capability of the ecosystem to produce the desired products.

Objectives may be influenced by land ownership, politics, personal biases, site capability, economic return, etc. and any of these may restrict, or even prohibit a particular use. They become more complicated when multiple uses such as wildlife, livestock grazing, and forest harvesting are considered. Multiple use objectives are frequently appropriate, but implementation requires knowledge and skillful management, and when they exceed the ability of management to achieve, are destined to failure. Economic returns should be considered because greater returns from range-lands are realized from multiple uses, rather than a single use. A rancher may desire increased economic returns from his available forage resource through increased calf or yearling weights. The objective may well be to improve the quality, or quantity of forage within a given pasture. This may require different management techniques, such as establishing a new grazing system, changing livestock control measures, or plant community stimulation and manipulation using techniques such as fertilization, fire, weed control, etc. A concurrent objective might be to enhance habitat for certain wildlife species.

At times the management input costs to meet objectives may exceed the return. This may be justified on public lands, and at times on private lands, over a short-term. In the long-term private land management needs to provide a return on investment. Even on Crown lands, management objectives need to recognize that tenure holders must realize a profit from their total operation in order to justify the associated user fees and management costs.

"Sustainable rangeland management implies that the use of the resource will not jeopardize future productivity." Sustainability is obviously an objective all range managers must subscribe to, and must be examined in terms of time and space. For example, the sustainability of forest practices must be examined while considering the harvest rotation. Livestock grazing is considered in terms of grazing rotation and annual weather patterns. Weather, particularly rainfall, may well have a greater impact on sustainability of soil cover than livestock grazing. Care is required to ensure that management objectives support sustainability under adverse climatic conditions. Monitoring then becomes an objective in order to confirm that management practices are sustainable. Thus, range planning objectives must consider:

- what is ecologically feasible;
- what is managerially feasible;
- what will optimize the value of rangeland resources;
- the affect on other range users; and
- measurement of vegetation response.

Range management by objective requires sound planning, implementation, monitoring, and replanning in order to be successful.

Range Plant Communities and Grazing

Vegetation of rangelands in BC is among the most diverse in North America because of the wide variations in climate, soils, topography, and historical use of range throughout the province (Wikeem *et al.* 1993). This diversity makes classification and management of the province's range resources very challenging.

Five primary physiographic regions are recognized in BC. These are the North and Central Plateaus and Mountain, the Great Plains, the Columbia Mountains and Southern Rockies, the Interior Plateau, and the Coast Mountains and Islands (refer to Ch. 16, this volume for further detail on ecosystem classification in BC). Most rangeland used for livestock grazing in BC lies on the Interior Plateau between the Coast Range and the Rocky Mountains and Southern Rockies, particularly in the East Kootenay, and east of the Rocky Mountains on the Great Plains from south of Dawson Creek to the Fort Nelson area. Throughout these physiographic regions, elevation and latitude play important roles in determining the general vegetation types that are available for domestic grazing and wildlife use. Grasslands, dry forest, montane forest, subalpine forests, alpine, and wetlands all contribute to the range resource.

Forestlands total nearly 80% of the area of Provincial Crown range. Although grasslands occupy only about 1.2 million ha, they produce approximately half of the forage available for domestic livestock grazing and perhaps 90% of this area is privately owned. In addition, more than five million hectares of wetlands are wide-spread throughout BC supplying forage and habitat for domestic livestock and wildlife (van Ryswyk *et al.* 1992).

A number of plant communities occur within each general vegetation type. Plant communities are aggregations of plants on the landscape that have similar requirements for growth (McLean, 1979). From a livestock management view, plant communities are used to identify range sites and predict the site potential to produce forage. In addition, they provide habitat and forage for wildlife. Changes in the plant community are used as indicators to measure the success of achieving management objectives and to assess ecosystem health.

Comparative nutritional value of forages and plant parts

Holechek *et al.* (1989) provides information regarding the nutritional value of forages. Grasses, forbs, and browse all differ in their potential to meet the nutritional requirements of livestock and wildlife. Undoubtedly, a wide variety of plant types provides the ideal opportunity for grazing animals to select the forages and plant parts that best satisfy their needs for protein, minerals, vitamins, and energy.

During their growing seasons, forbs are generally more nutritious than shrubs in terms of protein and phosphorus concentrations; grasses provide lower levels of protein and phosphorus than either forbs or shrubs. In terms of energy, however, just the opposite is true. Grass leaves and stems generally provide higher concentrations of cellulose (energy), with lower levels of lignin, compared to forbs and shrubs at similar stages of plant development.

Shrubs generally have higher levels of protein and phosphorus than either grasses or forbs during dormancy. This perhaps explains why livestock, when left on the range after plants have become dormant, may start to browse on shrubs.

The leaves, flowers, fruits, and seeds of plants are generally more palatable and more digestible than stems and twigs. The lower nutritive value of stems is due to higher lignin and crude fibre content and lower fat, phosphorus, protein, and simple carbohydrate content than in other plant parts.

Grazing season

The effect of defoliation of forage plants also depends on the season of grazing. Generally, plants are little affected if defoliation occurs during dormancy because photosynthesis has already ceased. Plants may also quickly recover from defoliation early in the growing season because there is still time for the plant to produce new growth while moisture and temperature levels remain favourable.

The most critical time for defoliation of grasses usually occurs just before the plants begin flowering and setting seeds. This is because carbohydrate stores are still recovering from winter dormancy, and the rapid part of the growing season is coming to an end because of declining soil moisture. Defoliation of bluebunch wheatgrass during this "early bloom stage" often decreases forage yield by as much as 15%. Defoliation at this time also reduces flowering potential for the following year, and increases the likelihood of winter mortality. If heavy defoliation occurs repeatedly during early bloom, bluebunch wheatgrass decreases as a proportion of the plant cover, and may virtually disappear from the plant community after only a few years.

Overgrazing

The potential effects from continuous or repeated heavy utilization, particularly at the time of year when a plant is most susceptible to damage, may well lead to an overgrazed situation. Severe defoliation reduces a plant's ability to survive the winter or withstand droughts. Individual plants become weak, and ultimately die. If severe defoliation continues year after year, changes in the plant community will also occur. Preferred forages are replaced by weedy species that are more resistant to grazing. These weedy species are usually less palatable, and are often less productive. This overgrazed state generally reduces the value of rangelands for forage, livestocks, and wildlife production.

Overgrazed plant communities also bring about changes in the physical micro-environment of forage plants. As a plant's leaf mass declines under repeated severe grazing, the plant is less able to intercept rain and trap snow. More moisture is added to the soil, but less is retained because the plant's root mass has also been reduced by improper grazing. The result is increased runoff and erosion. The amount of bare soil is often greater on overgrazed sites because the cryptogamic cover has been reduced by trampling. Cryptogams play an important role in retaining surface moisture of soils, and once eliminated, require as long as 20 years to recover (Holechek *et al.* 1989).

Grazing systems

Grazing systems are designed by range managers to control the grazing period in individual range components or designated pastures. Management objectives determine the level of utilization of general or key species (Council for Agricultural

Science and Technology, 1996). This is determined prior to turnout and would consider when a pasture is grazed, how long grazing will occur, level of use, and recovery time between grazing periods. The various kinds of animals and their respective age or sex (i.e. cow-calf pairs or yearlings) utilize range topography and associated plants differently. Range managers consider this when they design a grazing system. For example, cattle prefer grass and lower elevations, while sheep like grass and are content on higher or more sloped terrain. Thus, many factors may contribute to the range manager's choice of a grazing system.

Vegetation control methods

Humans are constantly manipulating vegetation for a variety of reasons. Plants may be economically valuable or undesirable, aesthetically pleasing or unpleasant, nutritious or poisonous. Methods used to influence vegetation generally come under six headings: manual, fire, water, chemical, biological, and mechanical. All of the above methods are tools which may be used for vegetation control, or which may occur naturally.

Weed management

Definitions for undesirable plants, most often referred to as "weeds", range from plants that interfere with land management objectives to plants that man has not yet found beneficial. Whatever definition is used, it is clear that weeds have economic, ecological, and aesthetic implications for man and/or his activities. These plants develop in response to disturbed and natural environments and interfere with our management objectives. Regardless of how we change production systems, or what habitats we create, undesirable plants will adapt to that system, or habitat, and will be recognized as "weeds" (Bridges, 1994).

Noxious weeds are usually non-native species introduced to BC through human activities. These can invade new habitats and increase very rapidly because they lack the host of natural agents that aid in regulating populations in their countries of origin. The BC *Weed Control Act* imposes a duty on all land occupiers in the province to control designated noxious weeds. Depending on current distribution, and the potential threat to resources, weeds are listed in the Regulations as requiring control within all regions of BC, or only within the boundaries of specified regional districts (Cranston *et al.* 1998). Of forty species legislated, only fourteen have caused serious damage, or threaten to seriously impact the integrity of BC grazing lands. Included in this list are the knapweed complex (diffuse and spotted), hound's-tongue, Dalmatian toadflax, rush skeleton-weed, leafy spurge, sulphur cinquefoil, scentless chamomile, tansy ragwort, oxeye daisy, and the hawkweeds (orange and yellow). Common crupina and yellow star-thistle, although they have not yet been found in BC, are legislated noxious weeds due to their proximity to our border as resident plants of Washington and Idaho.

Undesirable plants may also be species that are native to the province. These include Douglas' water hemlock, lupine, and timber milk-vetch that have toxic principles which may effect livestock production, or plants that spread and increase in density due to our manipulation of habitat.

Land managers must put a priority on maintaining a healthy, competitive,

natural resource base, rather than on using "quick fix" but short-term solutions such as herbicide applications. The long-term solution to rangeland weed management is a combination of sound range management, effective biological control, judicious herbicide use, and a high level of public awareness and responsibility. A generalized objective for weed management is the promotion of a healthy plant community that is relatively weed resistant, while still meeting other objectives such as forage production, wildlife habitat, or recreational land maintenance (Sheley *et al.* 1996). The goal is to reduce weed infestations and develop more desirable plant communities.

Noxious weeds, often referred to as "biological pollutants," have gained a competitive advantage over native vegetation in BC because the natural predators (usually insects and diseases) that evolved with them in their natural environment were left behind. The majority of our noxious weeds originated in Europe and Asia. Combined with the lack of natural predators, these weeds have adapted and become very aggressive in BC. This has occurred through production of large quantities of highly viable and easily spread seed, by survival of extensive rooting systems, through palatability factors that deter harvest by grazing animals, and possibly through excretion of compounds that inhibit growth of other plants.

Livestock Behaviour and Management

Rangeland, private or Crown, is an integral part of the total resources of a ranch. How this resource is integrated into the operation has a major impact on the overall ranch performance. Management considerations include: breed choice (cow size and milking ability), availability of labour, grazing systems, and availability and cost of other forage sources. Each ranch is different and what works on one may not work on another. A periodic analysis of resources and a frequent assessment of management practices are important.

Breeding herd efficiency for a cow/calf producer, or efficiency of gain for a yearling operation, are factors that influence financial success. Pounds of calf produced per cow overwintered, percent calf crop, and weaning percent are methods of measuring cowherd efficiency, while weight gain is the measure of yearling performance. When livestock are on range, whether they are cow-calf pairs or yearlings, some target levels for production are useful in order to assess the management program. Reproductive and weight-gain records are valuable for monitoring animal performance. However, annual weather variations also need to be considered when analyzing production information.

Grazing behaviour

"Grazing is a fundamental biologic process on both land and aquatic systems and is important to energy flow through the ecosystem. The biotic systems on North American rangelands developed over millions of years as a co-evolution of grazing animals and the native plant communities" (Burkhardt, 1997). Livestock behaviour plays a major role in the relationship between grazing animals and plant communities. Range managers can take advantage of livestock behaviour to meet management objectives, minimize deleterious grazing effects, and enhance animal production. This can be a challenge and is an art as well as a science.

Silviculture and Grazing

Forest range accounts for approximately 11 million ha, or more than 80%, of the total area of Crown range grazed by cattle in BC. This resource provides an important part of the forage requirement for the livestock industry supply spring, summer, and fall range. Much of this range occurs on harvested forestlands where integrated use is the main land management objective. These areas provide important temporary range for cattle, for up to 20 years on some sites, and can be highly productive when they are seeded with domestic forages (Nordstrom, 1984).

Until 1900 most livestock were produced on the grasslands alone and almost no use was made of the timbered ranges. Conflicts between range and forestry users began to emerge on mid- and high-elevation forests in the Southern Interior when extensive clearcut logging started in the early 1960s. Logging provided new opportunities for integrated use of forestland, but foresters were concerned that forage seeding, followed by trampling and browsing by livestock, would affect forest regeneration on plantations.

Effects of livestock grazing on timber production

Livestock can affect conifer regeneration by removing needles, and by girdling, browsing, and trampling. Sheep generally damage tree seedlings by browsing and cattle by trampling. Both cattle and sheep can inflict damage by removing needles and girdling trees, but most commonly these effects result from other sources such as small mammals and insects.

Benefits of livestock grazing

Timber production and livestock grazing can be compatible with careful planning and proper management. Several studies indicate that livestock grazing may: (1) have minimal or no effect on forest regeneration (2) promote seedling growth (Nordstrom, 1984; Sharrow and Leininger, 1983), and (3) enhance long-term forest production.

Grazing often releases conifers from competition with other plant species growing in the forest plant community. When livestock graze preferred forage plants, more water, nutrients, and light may be available for tree seedling growth, but this will vary among sites.

Recreation Management

The rangeland resources of the BC interior offer many opportunities for recreational pursuits. Recreational use of rangelands has increased dramatically during recent years and includes a multitude of activities such as camping, fishing, bird watching, hiking, skiing, horseback riding, hunting, trail biking, cultural heritage pursuits, all terrain vehicle (ATV) use, etc. Many recreational uses have little impact on the range resources, but improper or careless use can cause changes that may threaten plant communities, individual plants, and animals (Chutter, 1997).

Future Importance of Rangelands

There is no question as to the future value of rangelands throughout the world; however, there will undoubtedly be much debate and discussion as to what economic and social values are placed on these resources. Certainly the world population will likely continue expanding at a rate that will place increased pressures on our ability to provide food and shelter.

The human body is made up, to a large degree, of nitrogenous material contained within cellular structure. Therefore, food containing an abundant amount of nitrogen is essential in the diet. Meat is rich in nitrogen and is very digestible compared to the nitrogenous material contained in cereal grains and certain vegetables where it is often tied up in cellulose, an indigestible material. As a result, meat is an important part of the diet of all advanced countries (Sampson, 1923). It is interesting to note that in 1923 rangelands were considered an important resource for future food production. The natural vegetation of rangelands can be converted to useful products, such as protein, very efficiently through grazing livestock. Future food requirements for humans will likely become even more dependent upon the rangelands to supply an economical source of protein. Society depends upon our rangelands for food, recreation, and wildlife habitat. Thus, proper management of this invaluable resource is critical to guarantee a sustainable supply of those products desired by society.

Administration of Crown Range in BC

This discussion is intended to give an overview of some important range management administration topics. In the event of errors and omissions, the legislation and corrections take precedence.

Administration structure

The MoF is organized with the Range Section in Forest Practices Branch, Forest Stewardship Division and regional and district range staff in Field Services Division. Range Section deals with development of and advice about policy, legislation, practices and procedures associated with the management and use of Crown range (including procurement and establishment of biological control agents for invasive plants). Field Staff deal with operational administration and monitoring of agreements, range use plans, range use plan effectiveness, invasive plant control programs (both biological and chemical) and planning and facilitating the production and allocation of Crown forage. Range is not a stand-alone program but depends upon other MoF components: protection (for fire control and prescribed burns); silviculture (for wood fibre and Crown forage integration); planning (for meeting forage production goals and integrated resource targets); engineering (for roads); and other branches, sections, or ministries (for legislation, associated resource data, personnel and financial management, and others). All administration levels cooperate to serve the needs of their clients in MoF, other government ministries and agencies, current and potential agreement holders, various interest groups, and the general public.

MoF administers livestock grazing on Crown range through the provisions of the

Range Act and the *Forest Practices Code of British Columbia Act* (the Code), which as of 2002 is under review. Additionally, MoF has administered the management plans associated with Grazing Leases, which are issued under the *Land Act*. Since these leases are not Crown range and the Code does not apply to them, the grazing lease management plans are considered contractual requirements. *Range Act* section 10(3) enables the replacement of a lease with a licence or permit under the *Range Act*, however, the responsible ministries must be in agreement on the replacement. It should be noted that the following discussion applies only to Crown range so does not include grazing leases.

"Crown range" is defined in the *Range Act* as "Crown land included within the boundaries of a range district, but does not include Crown land that is subject to a lease under the *Land Act*". See the *Range Act* for definitions of Crown land and range districts or the *Land Act* for information on *Land Act* leases.

"Livestock" is defined in the *Range Act* as "animals of the genus bos, horses, mules, asses, sheep, goats and any prescribed animals, but does not include wildlife designated under the *Wildlife Act*, exotic game animals, buffalo, swine or poultry". There are no prescribed animals, i.e. no animals included in the range regulation.

Crown range is administered for integrated use and management, therefore all the forest resources considered in the Code and the *Ministry of Forests Act* are considered. Crown forage includes grasses, forbs, shrubs, trees, lichens and mosses. Consequently the use and management of these by range clients has ecosystem implications for all forest resources and users. With this point in mind, the forage and other habitat requirements of wild ungulates, birds, other animals and plants are considered in the awarding of new agreements, replacing existing agreements and development of Range Use Plans.

Clients who are issued *Range Act* agreements fall into four broad categories: livestock producers who raise cattle, horses, sheep and occasionally other livestock; commercial recreation businesses who mainly use horses to transport clients and supplies (including Guide Outfitters, Trail Ride Operators, Guest Ranches, Packing Operators and other businesses); non-commercial recreation users (including individuals or groups of people who use horses or other livestock to transport themselves and their supplies while hunting, fishing, sightseeing, photographing or engaged in other recreational activities on Crown range), and; persons carrying out vegetation management activities (including the use of sheep or other livestock to control vegetation which is generally authorized through a silvicultural prescription or a special use permit). The MoF (under *Range Act* section 9.2) can also carry out vegetation management activities to improve Crown range condition.

Forage harvested through grazing is measured in a unit called an "animal unit month", AUM, which is defined in the *Range Act* as "the amount of forage required for one month by an average animal of the genus bos, aged 6 months or older". Over the past three decades cattle grazing Crown range have become larger, with increased weight gains, and consequently the actual forage consumption per animal unit has increased by approximately 30-40%. The increased forage consumption is not obvious in historical data due to the way an AUM is calculated.

Range Act and *Forest Practices Code of British Columbia Act* Agreements

Range Act agreements are area and quantity based. The district manager has statutory authority for most decisions related to government issuance and administration of *Range Act* agreements. There are several agreements which can be issued under the authority of the *Range Act* or the Code. These vary in how the Crown forage is harvested (grazing or hay cutting); the term of the agreement (from ten years to a few days); whether or not a conditional replacement may be issued by the district manager, and; holder's right for a conditional replacement (see Table 1 for agreement particulars and Table 2 for provincial allocation information).

The District Manager may include, in the agreements, terms and conditions to ensure proper resource management and effective integrated resource management that are consistent with the *Range Act,* the Code; or regulations under those acts.

Replacement of *Range Act* Agreements

Most Crown range grazing is authorized through grazing licences. A licence holder, for grazing or for hay cutting, has the conditional right under *Range Act* section 16, to be issued a replacement licence. A grazing permit may be replaced by a permit or a licence under *Range Act* sections 10(1) and (3) but a permit holder has no statutory right to a replacement permit.

Temporary permits are used for situations where forage is temporarily available and non-replaceable permits (which are infrequently used) are available when an award of a replaceable permit is inappropriate because of a known future change in land use or when an unqualified applicant is awarded a vacancy (see subsequent discussion on awarding agreements).

Supply, Demand and Awarding Crown Forage

The long-term supply of Crown forage has been declining due to forest ingrowth, forest encroachment, invasive weeds, changing land use and human settlement impacts. Additionally, the supply has decreased as a result of reduced scarification and forage seeding following harvesting of trees. Variation can also occur on a short-term basis due to cycles in weather patterns which can directly affect plant growth.

Meanwhile the demand for Crown forage has grown because of an increased provincial beef cow herd, larger cattle with increased weight gains, increased commercial and non-commercial recreation, and fluctuations in wild ungulate populations. In 2001, there were 188,632 cattle, 5,298 horses, and 2,090 sheep on Crown range.

In the process of awarding an agreement, the district manager considers all uses of Crown forage and requirements of higher level plans. The district manager may also utilize informal plans to evaluate forage supply opportunities and forage demand before replacing or awarding new *Range Act* agreements.

Subject to statutory requirements, Crown forage on a specified area of Crown range may be awarded by the MoF District Manager as:

Table 1: Agreements for harvesting forage from Crown range, related conditions of replacement and *Range Act* reference

(a) Enabling Act	(b) Agreement	(c) Harvesting	(d) Term	(e) Replaceable	(f) Conditional Right of Replacement	(g) Management Plan Requirement
Range Act	licence	grazing (s. 5)	10 years	yes	yes	Range Use Plan
Range Act	licence	hay cutting (s. 8)	10 years	yes	yes	Range Use Plan
Range Act	permit	grazing (s. 6)	one day up to 5 years	yes	no	Range Use Plan
Range Act	permit	hay cutting (s. 9)	one day up to 5 years	yes	no	Range Use Plan
Range Act	non-replaceable permit grazing	(s. 6 and reg. s. 9(c))	one day up to 5 years	no	not applicable	Range Use Plan
Range Act	non-replaceable	(s. 9 and reg. s. 9(c))	one day up to 5 years	no	not applicable	Range Use Plan permit hay cutting
Range Act	temporary permit	grazing (s. 7)	up to one year	no	not applicable	Range Use Plan
Range Act	temporary permit	hay cutting (s. 9.1)	up to one year	no	not applicable	Range Use Plan
Range Act	Written authorization cutting (s. 9.2)	grazing or hay	district manager discretion	no	not applicable	written vegetation management requirements for specified purposes
Code Act[a]	silvicultural	grazing	district manager discretion prescription	no	not applicable	written silvicultural management requirements
Code Act[a]	special use permit	grazing	district manager discretion	no	not applicable	written management conditions

[a] *Forest Practices Code of British Columbia Act.*

- a management increase for a grazing licence (*Range Act* section 5(a)(iv);
- a management increase for a hay cutting licence (*Range Act* section 8(a)(iv);
- a temporary grazing permit (*Range Act* section 7);
- a temporary hay cutting permit (*Range Act* section 9.1);
- an advertised competitive vacancy (*Range Act* section 10 and related sections);
- an unadvertised direct grazing award of 100 AUMs or less (*Range Act* section 14.1(1)(a));
- an unadvertised direct hay cutting award of 10 tonnes or less (*Range Act* section 14.1(1)(b));
- a grazing or hay cutting licence or permit needed by and advertised in conjunction with a permit, lease or licence to occupy Crown land granted under the *Land Act (Range Act* section 14.1(1)(c));
- an advertised direct award to an existing holder of a like agreement to effect an equivalent exchange of AUMs or tonnes *(Range Act* section 14.2(1)(c));
- an advertised direct award of a grazing or hay cutting permit or licence to the holder of a permit, lease or licence to occupy Crown land granted under the *Land Act (Range Act* section 14.2(1)(b));
- an unadvertised direct award of a grazing or hay cutting permit to manage recreational, fisheries, wildlife or other ecological values (Range regultion section 6(a));
- an unadvertised direct award of a grazing or hay cutting permit or licence if there is only one practicable applicant (Range regulation section 6(b));
- an unadvertised direct award of a grazing or hay cutting permit or licence as compensation for reduction in AUMs and loss of range developments resulting from a deletion of Crown range area (*Range Act* section 29); and
- an unadvertised one year increase of up to 10% to the holder of a licence or permit when the forage is available due to favourable growing conditions.

Management increases are infrequently applied for. Temporary grazing permits are typically used to facilitate use of forage which is available for one year. This is usually due to non-use by a person who holds a licence or permit. The other means of awarding Crown forage, with the exceptions of vacancies discussed below, are not frequently used but are used when the district manager considers the circumstances are appropriate.

A policy regime of: ***appurtenancy*** (agreement legally appurtenant to (a) agreement holder's owned and leased land or (b) *Land Act* agreement in case of commercial recreation); ***commensurability*** (related to forage production capability of agreement holder's appurtenant land); ***livestock ownership and control*** (agreement holder required to own or legally lease livestock that are grazed under the agreement (i.e. authorized livestock), and; ***over-wintering of authorized livestock*** is in place to encourage a continuing, stable, economically viable cow-calf beef industry. The ownership of cattle requirement is used to promote development of high quality, disease-free herds. Stability in the herd also retains the learned herd behavioral patterns that enable better control of the animals while on Crown range. When these policy requirements are considered

Table 2: A summary of grazing and hay cutting agreements by Regions and Districts 2001

REGIONS AND DISTRICTS	GRAZING AGREEMENTS				HAY CUTTING AGREEMENTS					
	Licences Permits and Non-Replace-Permits	AUMS Authorized	AUMS used	AUMS not used billed (s.10)	AUMS not used not billed	Licences and Permits	Tonnes Authorized	Tonnes used	Tonnes not used billed (s.10)	Tonnes not used billed
CARIBOO REGION:										
100 Mile House	133	89,973	79,060	1,920	8,993	15	267	140	0	127
Chilcotin	104	71,292	65,852	4,782	658	30	688	688	0	0
Horsefly	40	15,836	15,496	0	340	4	70	45	0	25
Quesnel	93	31,663	31,017	646	0	13	372	372	0	0
Williams Lake	88	111,623	110,367	1,256	0	18	383	383	0	0
Regional total	**458**	**320,387**	**301,792**	**8,604**	**9,991**	**80**	**1,780**	**1,628**	**0**	**152**
KAMLOOPS REGION:										
Clearwater	17	6,567	6,567	0	0	0	0	0	0	0
Kamloops	147	106,696	106,696	0	0	1	10	10	0	0
Lillooet	36	17,269	14,378	2,891	0	0	0	0	0	0
Merritt	60	116,223	116,223	0	0	0	0	0	0	0
Penticton	55	45,210	43,475	969	766	2	96	96	0	0
Salmon Arm	44	12,538	10,841	1,599	98	0	0	0	0	0
Vernon	79	35,594	33,898	0	1,696	0	0	0	0	0
Regional total	**438**	**340,097**	**332,078**	**5,459**	**2,560**	**3**	**106**	**106**	**0**	**0**
NELSON REGION:										
Arrow	7	1,273	1,273	0	0	0	0	0	0	0
Boundary	77	30,117	30,117	0	0	1	5	5	0	0
Cranbrook	93	35,735	32,107	2,208	1,420	0	0	0	0	0
Columbia	3	313	313	0	0	1	30	30	0	0

Invermere	45	15,389	14,057	0	1,332	0	0	0	0	0
Kootenay Lake	8	3,030	2,410	560	60	0	0	0	0	0
Regional total	**233**	**85,857**	**80,277**	**2,768**	**2,812**	**2**	**35**	**35**	**0**	**0**
PRINCE GEORGE REGION:										
Dawson Creek	125	63,971	63,971	0	0	3	381	381	0	0
Fort Nelson	27	9,950	9,950	0	0	0	0	0	0	0
Fort St. James	6	609	609	0	0	0	0	0	0	0
Fort St. John	108	48,026	42,404	5,075	547	0	0	0	0	0
Mackenzie	11	1,608	1,608	0	0	1	16	16	0	0
Prince George	62	12,973	12,012	961	0	2	15	10	5	0
Robson Valley	35	4,430	4,391	39	0	0	0	0	0	0
Vanderhoof	42	15,444	15,444	0	0	3	35	25	0	10
Regional total	**416**	**157,011**	**150,389**	**6,075**	**547**	**9**	**447**	**432**	**5**	**10**
PRINCE RUPERT REGION:										
Bulkley-Cassiar	63	8,828	8,828	0	0	3	47	47	0	0
Kispiox	7	916	916	0	0	0	0	0	0	0
Lakes District	66	11,488	11,488	0	0	1	27	27	0	0
Morice	48	10,814	10,062	752	0	2	50	50	0	0
Regional total	**184**	**32,046**	**31,294**	**752**	**0**	**6**	**124**	**124**	**0**	**0**
VANCOUVER REGION:										
Campbell River	1	474	474	0	0	0	0	0	0	0
Chilliwack	4	171	171	0	0	0	0	0	0	0
Mid-Coast	5	506	506	0	0	0	0	0	0	0
Squamish	3	162	162	0	0	0	0	0	0	0
Regional total	**13**	**1,313**	**1,313**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Provincial total	**1,742**	**936,711**	**897,143**	**23,658**	**15,910**	**100**	**2,492**	**2,325**	**5**	**162**

(taken from 2001 post-billing report as at January 23, 2002)

in a competitive framework, along with other factors such as proximity of applicant's ranch to Crown range and applicant's management performance on Crown range, the results are frequently inconclusive as to who should be awarded the advertised Crown forage.

This poses some problems since, at a provincial scale, the demand for Crown forage at current fee levels exceeds the supply and when a "vacancy" is advertised under *Range Act* section 10(2) and (4) there are from two to eight applicants in most situations. When there is more than one applicant, "who gets to use the advertised Crown forage" remains a contentious and problematic aspect of range management.

These issues are well understood by current and many prospective holders of *Range Act* agreements and the policy framework is generally supported by the cattle industry. There has been some progress in streamlining the vacancy process but the high value of, declining supply of, and increasing excess demand for Crown forage means the issues surrounding awarding of advertised Crown forage will continue to be important.

Fees for Yearly Use of Authorized Forage and Administration Fees

The annual dollar amount for authorized yearly use for a grazing agreement is the number of AUMs multiplied by (i) 20 cents plus (ii) a coefficient related to a three year average live beef cattle price. The annual dollar amount for authorized yearly use for a hay cutting agreement is the number of tonnes multiplied by (i) 60 cents plus (ii) a coefficient related to a three year average live beef cattle price. Three AUMs have the same annual forage fee as one tonne. See range regulation section
11 for details.

Range Act section 11(4) lists situations under which the annual dollar amount may be reduced due to extenuating circumstances, most of which are related to range resource management issues.

There are no fees associated with range use plans but the range regulation contains a set of administration fees to recover costs associated with agreement application, issuance, amendment and transfer.

Transfer of *Range Act* Agreements

A holder of a *Range Act* agreement is able to assign the agreement to the person who purchases the appurtenant land but is required to provide the district manager with an assignment. The assignment is subject to the district manager's consent and the agreement may be cancelled under certain circumstances.

There are no *Range Act* provisions for sale of agreements and the value of the agreement is capitalized into the appurtenant land. In conjunction with the policies mentioned earlier, these "rules" collectively affect the structure, conduct and performance of the BC Beef Industry.

Change or Deletion of Crown Range Area

Compensation for loss of range developments, Crown range and related loss of forage is restricted to the provisions of *Range Act* section 26 through 29. Compensation may be made in the form of a licence or permit or cash payment. When compensation for loss of Crown forage it is in the form of cash payment, it is related to the fee charged for authorized yearly use.

Integrated Resource Management and the *Forest Practices Code of British Columbia Act*

The Code requires that the district manager must be satisfied that an operational plan (for Range this is called a Range Use Plan) or amendment will adequately manage and conserve the forest resources of the area to which it applies (Code section 41). One of the great challenges in integrated resource management is defining responsibilities and liabilities for tenures with overlapping use. Since more than 70% of Crown forage authorized in agreements comes from forested rangelands, the majority of range agreements provide rights over lands which are also included in the *Ministry of Forest Act*. All agreement holders are required to provide adequate statutory management, provide management that ensures plans are adequate and effective, and work together to resolve operational problems.
The coordination of timber harvesting, silvicultural activities and grazing is a continuous activity as cattle typically use newly harvested areas until canopy closure renders them ineffective for grazing.

Livestock control is an important aspect of grazing livestock. A *Range Act* agreement holder is responsible for fences and other developments. However, a person who removes or renders ineffective a natural range barrier, such as a dense forest, must mitigate the effect of the removal or ineffectiveness (Code section 69). In general, a *Range Act* agreement holder has flexibility in selecting resource inputs (grazing schedule, range riding, salting, water developments, fencing, etc.) but once the range use plan becomes effective, the holder must comply with the plan or successfully have the plan amended.

The district range staff monitor implementation and effectiveness of range use plans. They also provide awareness information and some management extension to *Range Act* agreement holders. Enforcement is provided by MoF Compliance and Enforcement staff. Range section staff in conjunction with some regional or district staff, consultants and other MoF staff develop resource material, train range and other staff, and communicate with clients on range resource management topics.

Further information

The following references are intended to provide interested persons with additional sources of information. Since most of the proceeding information is intended only as an introduction, it is not complete and more thorough analysis of cited documents should provide greater clarity.

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VISUAL RESOURCE MANAGEMENT

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VISUAL RESOURCE MANAGEMENT

Introduction

This chapter is meant to be both a general reference tool on Visual Resource Management and an in-depth resource on issues of visual resources and forest management in British Columbia (BC). The chapter is intended for use primarily by forestry students and forest managers. It is mainly drawn from reviews by Picard and Sheppard (2002a), Picard and Sheppard (2002b), Sheppard (1999a), Picard (2002), and Sheppard (2004).

The conflict between timber resources and aesthetics has been a major issue for over 30 years in North American forestry. It helped fuel the "clearcut crisis" of the 1970s on the US National Forests, and led to the imple-mentation of a major program of Visual Resource Management (VRM) in the US Forest Service. This in turn has led to the development of visual resource management programs in other regions and jurisdictions, such as British Columbia (BC). Here, conventional forest management has often been seen as being in conflict with aesthetics and other resource values associated with tourism, recreation, and aspects of community quality of life. More recently, it has been recognized that the systems in place for VRM may themselves conflict with other sustainability objectives.

Visual Resource Management (VRM): The Basics

Some key definitions

It is important to clarify the definitions of a few key terms used in this chapter, which may have a variety of meanings to different people, and are commonly used inappropriately.

Landscape

Within the context of forests, this term holds different meanings for different types of professionals. To the forester, it means a geographic scale over which the forest may be modelled and managed: usually, at the scale of a watershed or expanse of land where multiple timber harvesting operations or other management activities may occur (e.g. approximately 10,000–250,000 hectares). To a visual resource manager or landscape architect, it can mean the holistic visual appearance of a place or area together with the underlying biophysical and cultural factors which affect perception and the quality of experience of the viewer: landscapes are usually defined and described in terms of spatial character, visible features, and sense of place. In this chapter, it will be used in the former sense to avoid confusion for readers more familiar with typical forestry terms; aesthetic or perceptual characteristics will be described in terms of the visual landscape or visual characteristics.

Aesthetic quality

Aesthetics here refers to the human response to landscapes which result from the perceptual characteristics of the environment and the observer's sensory experience. This experience includes both sight and other senses, such as perception of sounds, smells, touch, temperature, etc. The aesthetic response is considered to be affective, rather than cognitive (Porteous, 1996), and interacts with internal factors such as psychological and emotional state. Aesthetic qualities are therefore capable of inducing or influencing human emotions, mood, and levels of satisfaction with the environment, and can be pleasurable or the reverse.

Visual quality

In this chapter, visual quality is considered to be the part of aesthetic quality that is due to visual characteristics of the landscape, and not a general term to describe visual characteristics themselves.

Visual quality objectives

This term is used here to refer to the specific policy objectives (or target levels of visual quality) used by government agencies such as BC Ministry of Forests (BCMoF).

Viewsheds

Viewsheds are used as a specific term describing the mappable visible area as seen by an observer from a given location or locations.

Visualization

Visualization as used here is defined as a visual depiction of landscape conditions, which displays terrain and other recognizable geographic features in perspective view, with varying degrees of realism (Sheppard and Salter, 2004).

Visual Perception and Landscape Description

This section reviews some basic principles of visual perception and landscape characteristics, which govern how observers see landscapes. Most of the concepts described here can be objectively described and measured, if necessary, as visual characteristics of the landscape.

Fundamental visual characteristics of landscapes

Authors such as Gibson (1979) and Fellerman (1986) describe in depth the process of vision and various influences on visual perception of landscapes. Key aspects of the **physiology of vision** include visual acuity and contrast, which enables detection, and recognition of landscape elements, the field-of-view (horizontal and vertical extent), and the nature of eye movement, which automatically records visual information from certain points within the field-of-view. Vision is affected by variables of light transmission within the visible spectrum.

Litton (1968) in his seminal work *Forest Landscape Description and Inventories,* was the first to develop comprehensive principles for analysing the visual

characteristics of larger scale natural landscapes. This work has been supplemented since by many others, such as: the US Forest Service (1973) handbook *National Forest Landscape Management, Vol. 1;* subsequent research on the US Bureau of Land Management's Visual Resource Management Program (Smardon *et al.* 1983); the BC Ministry of Forests (BCMoF, 1981) *Forest Landscape Handbook;* and landscape visualization texts (e.g. Sheppard, 1989). This body of work typically defines certain **visual elements**, which can be used to describe the perceptual characteristics of landscapes. These elements usually include:

- Colour (hue, value, and chroma),
- Texture,
- Scale (in absolute terms, relative to landscape scale, or relative to human scale),
- Form (comprising three-dimensional (3-D) forms and two-dimensional (2-D) shape),
- Line/edge,
- Position in the landscape,
- Movement in the landscape.

These elements can be used to describe the visual characteristics of the landscape and its principal components: landform, vegetation, water bodies, human land uses and structures, and atmosphere. The combination of these visual elements (Figure 1) form the landscape patterns and spatial (3-D) structure that we see (US Forest Service, 1973).

Figure 1:
The pattern of logging can be described in terms of colour contrast, shape of the opening and scale relative to the landscape.

Litton (1968) also discusses various perceptual relationships which affect how we see the landscape. These relationships include: **diurnal/seasonal aspects of temporal variation** (such as lighting direction, shade/shadow, weather, seasonal reflectance from snow, and screening by vegetation); **viewing distance and scale effects** (influenced by the curvature of the earth, atmospheric effects, and view blockage); **observer position** (superior, normal, or inferior with respect to the landscape being viewed); and **observer motion** (affecting the effective field-of-view and viewing sequence).

Various organizational frameworks for inventorying and classifying larger scale landscapes have been suggested by Litton (1968) and Litton and Tetlow (1978). These frameworks exist on a hierarchy of scales, as follows:

Landscape Continuity – a regional or larger scale landscape type which are fairly continuous and consistent over vast areas (e.g. as revealed in 1:1,000,000 mapping).

Landscape Province – a landscape type, which may be quite extensive (e.g. as revealed in 1:250,000 mapping), but exists within (and are distinctively different from) the larger matrix or continuity which surrounds them, e.g. a mountainous area surrounded by plains.

Landscape Unit (here termed "Visual Unit") – a distinct area of recognizable unified character, often defined by spatial enclosure such as basins, valleys, watersheds, etc. (e.g. as revealed in 1:50,000/100,000 mapping).

Landscape Setting – a locally defined landscape, often associated with a specific place, which is often defined by a central feature such as a lake or distinctive landform, (e.g. as revealed in 1:20,000 mapping).

Each of these landscape scales can be described in terms of geographic extent, boundaries/edges, landform, vegetation, water forms, and focal attractions/local features. These spatial scales can be related to other landscape description systems such as physiographic regions, biogeoclimatic zones, and ecosystems, but cannot be expected to correspond closely with any one of them, due to the integrative nature of the essentially visual experience: a visual landscape is defined by the totality of what is seen, not just what it consists of. The US Forest Service (1974) defines the typical regional or sub-regional combination of landscape components as a "Characteristic landscape", meaning the naturally established landscape being viewed. A similar concept is defined within BC by Yeomans (1983) as sub regional "VRM (Visual Resource Management) Areas".

The visual unit level (as defined above) most closely approximates the scale of the forester's meaning of the word "landscape", although visual units can range from small valleys to very large basins. Visual units have been mapped as the basis for visual assessment in many studies, such as the landscape evaluation of much of Northeastern BC (Sheppard and Tetlow, 1976). This study applied unit descriptors of visual characteristics which are similar to those now commonly used in many larger scale inventories, as follows:

- Scale (extent),
- Boundary definition,
- Spatial configuration/proportions,
- Landscape patterns,
- Unifying/detailed features,
- Other sense-of-place indicators.

The visual landscape inventory system used by the BCMoF (1997c) also recognizes landscape subdivisions at a sub-unit level, termed Visual Sensitivity Units. These represent dominant landform components (e.g. a particular hillside or valley floor), which in combination make up the setting of a particular viewpoint or a whole visual unit. A more detailed description of the Visual Landscape Inventory (BCMoF, 1997c) can be found in the Recreation chapter.

In any natural landscape situation, various landscape compositional types can be identified (Litton, 1968; US Forest Service, 1973), as follows:

a) Fundamental/large scale compositions (spatial configurations):

- Panoramic: offering wide, unobstructed views over a large area;
- Feature: views dominated by a major landscape feature such as a mountain peak or waterfall;
- Enclosed: views confined by enclosing elements such as forest edge or hills (Figure 2);
- Focal: views focused in a particular direction by the alignment of topographic or other landscape components, e.g. a view down a narrow valley.

Figure 2:
A landscape composition that is weakly enclosed by the forest edge and low hills.

b) Supportive/small scale compositions:

- Canopied: views within a forest stand, with overhead closure.
- Detailed: close-up views of small scale landscape features, e.g. wildflowers.
- Ephemeral: views of short-lived or rapidly changing landscape features, such as hoarfrost effects on trees or reflections in lakes.

These landscape compositional types influence both what the observer looks at as well as the type of aesthetic experience received, as discussed further below.

Landscape visibility

Beyond the broad organization of landscape spaces, many visual assessment studies attempt to measure the visibility of specific points or objects in the landscape, as seen from certain viewing locations. This is often termed viewshed mapping or "Seen Area" analysis (Fellerman, 1986). Clearly, visibility factors are critical in determining whether or not there can be a direct visual impact from a particular forest operation or natural disturbance.

Visibility of landscapes depends upon the viewer location. Viewpoints are usually identified as certain use areas (e.g. recreational sites, residential areas, or other community gathering points) and travel routes. These can be specific points, often termed Key Observer Points (KOPs) (US Bureau Land Management, 1980; BCMoF, 1997c), or linear travel sequences (Litton, 1968). Selection of appropriate viewpoints for analysis is often conducted with knowledge of relative observer concerns (see below). Observer position (elevation) makes a considerable difference in terms of what can be seen of a particular forest landscape.

Visibility is limited by topography, vegetative screening, man-made structures, atmospheric conditions, and, over long distances, by the curvature of the earth. Fellerman (1986) describes in some detail the quantitative aspects of these limits.

Visibility can be described in terms of viewing distance, viewing angle (horizontal and vertical), and visual penetration (the extent to which observers can see through screens or filters of intervening objects, such as tree belts (Sheppard, 1989; USFS, undated:1).

Techniques used to map visibility include:

- Linear map notation (e.g. Litton, 1968),
- Map cross-sections,
- Manual mapping of visible areas from on-the-ground-viewpoints,
- Computer viewshed analysis (e.g. using Arcview/GIS GRID or TIN files[1]).

Change in the landscape

Spatial variation in the visual characteristics of landscapes is routinely evaluated in visual assessment practice and the literature, as described above. However, temporal change is not treated as comprehensively. Short-term conditions such as lighting direction and seasonal effects may be addressed (Litton, 1968), but longer-term changes are rarely evaluated. Change of landscapes over time are usually evaluated in terms of visual impact prediction for specific projects (e.g. Blair, 1986). Even here, there is a tendency to assess "before and afters", rather than an extended evolution of landscape characteristics over time; there is also often very little consideration of changing conditions over time under the status quo position. Further discussion of visual impact prediction is provided below, and the impact of natural disturbances and timber harvesting are also reviewed.

The visual landscape dynamics of natural disturbance regimes, succession, and spatial flows of energy and materials, are seldom evaluated in depth. The rise of landscape ecology (Forman and Godron, 1986) has focused more attention on some visual descriptors of the results of natural disturbance events, in the form of a classification of landscape mosaics into tesserae, patches, corridors, networks, matrix, etc. These can of course be quantified and described in terms of homogeneity/heterogeneity; size; shape; edge condition/types, etc. However, the guiding purpose of this is to understand the ecological structure, not the aesthetic qualities of the landscape. A few specific studies have investigated the effects of insect damage on visual parameters (such as Clay and Marsh, 1996a and 1996b).

Visual landscape change monitoring is still in its infancy in practice. Litton's (1973) practical advice on establishing Landscape Control Points across a landscape from which to measure its change proved to be decades ahead of its time, and has rarely been implemented. Limited examples of such techniques have been documented in places such as the Tahoe Basin and Columbia Gorge National Scenic Area (Sheppard, 1997).

Aesthetic Theories and Perception Research

There has been a long history of recorded theories of landscape aesthetics in the western world, dating back to Classical Greece. In considering the relationship between visual characteristics of the forest and people's enjoyment of the landscape, the more recent theories which are of greatest potential usefulness fall into two main

[1] Please refer to the Geographic Information Systems (GIS) chapter of this book for further detail on this topic.

camps: the instinctive versus the culturally derived.

Evolutionary theories of aesthetics

Several authors have developed theories, which invoke instinctive, conscious or subconscious reactions to landscapes as the primary reasons for aesthetic response. Orians (1986) has applied habitat theory to humans, wherein the human race evolved through the selection of habitats, which improve survival. The recognition of such habitats is therefore associated with positive emotions. Orians (1986) points out that early man is believed to have evolved in the African savanna, and that many cultures still show a preference for open landscapes with trees in a matrix of grassland.

Prospect-refuge Theory (Appleton, 1996) offers further explanation of such human responses, whereby people see beauty in particular spatial and biophysical configurations which offer them the best advantage for survival and well-being; in short, conditions which allow people to see without being seen. Prospect can be defined as providing opportunities to see a large area of the landscape, as obtained from open vantage points with superior observer position and offering panoramas views. Refuge offers shelter and the option of hiding from predators, enemies, or other hazards, and is associated with forests, caves, and accessible buildings. This also would explain the importance of the forest edge to people, where both prospect and refuge can be found together.

Kaplan *et al.* (1998) have developed an information processing theory which includes evolutionary aspects of aesthetic responses, notably the importance of mystery or curiosity as provided by a landscape. Essentially, landscapes which promise the discovery of new information through continuing travel, such as a winding path or valley corridor, are found to be attractive.

Cultural theories of aesthetics

Porteous (1996) reviews the developing theories and cultural tastes for scenic landscapes over the centuries. He describes the classical movement in art in 18th Century Europe with its emphasis on symmetry and clarity of form; the emerging taste for the "sublime" grandeur of nature; and the picturesque movement in art which extolled the virtues of the visually-varied, rough-around-the-edges, but comfortable pastoral landscapes of the English countryside. These cultural influences are thought by some to affect how people react to landscapes today.

Many other possible cultural explanations for aesthetic responses have been described. Jackson (1986) defines the rural vernacular landscape as a managed aesthetic ideal which is primarily agrarian and tied to the community scale, wherein those who disturb and manage the land subscribe to a socially defined aesthetic which creates *"a visible, well-defined, permanent sign of membership in the community"* (p.73). Along similar lines, Nassauer (1995) argues that people at the community scale like to be seen as good neighbours, with an orderly, well managed, productive landscape that conforms to society's higher ideals; this landscape can be at odds with more "messy" natural ecosystems. Sheppard (2001) has suggested that the one of the operative indicators of landscape quality may be evidence of "visible stewardship" (Figure 3), which goes beyond maintenance and control of the landscape, and demonstrates human attachment to, symbiosis with, and affection for the land.

Figure 3:
Signs such as this at Bear Lake in the Okanagan can convey the care taken by foresters in planning forest management activities.

Kaplan *et al.* (1998) describe the importance of familiarity of the landscape and positive signs of human use as contributing to aesthetic preferences. Goodey (1986) notes that people who live primarily in cities show a love for peaceful, unfolding, green landscapes which evoke nostalgia and the sense of an ideal. Rapid change is feared, whereas there is knowing or unknowing acceptance of gradual change. Goodey (1986) also discusses the possible influence of modern media in developing a taste for certain landscape conditions, based on sometimes distorted, sanitized or exaggerated pictures.

Many of these cultural theories imply a negative association with large scale or rapid landscape disturbance. Radically altered landscapes are no longer familiar, may appear chaotic in relation to the previous pattern or surrounding patterns, and may symbolize threats to the orderly path of civilization and human comfort which are embodied in more recognizable and obviously controlled landscapes. This may also draw upon inherent responses to disturbances such as fire or flood, which would have represented major recognizable hazards to survival (Appleton, 1996).

Perception research results

A brief review of the extensive literature on environmental psychology and aesthetic preference testing indicates certain common patterns. The research of authors such as Kaplan *et al.* (1998), Noe (1988), Craik (1986), and Daniel and Boster (1976), suggests for example that people questioned in perception testing generally like:

- More natural scenes,
- Open vistas with landscape depth (multi-ridged),
- Spaced trees with smooth ground texture,
- Maintained orderly landscapes with recognisable signs of human use and culture,
- Recognisable historic features and traditional landscapes.

The same studies suggest that people generally dislike:

- Open large expanses with uniform vegetation cover,
- Blocked physical access,
- Immediate foreground views of vegetation with heavy (impenetrable) visual screening and high tree densities,
- Downed wood/debris in foreground,
- Unrelieved monumental architecture,
- Chaotic or highly cluttered scenes.

However, the findings of typical preference testing research cannot be automatically transferred to practice in forest landscape management. What people say when sitting in front of a projection screen may be very different from what

they actually feel or how they would actually behave if confronted with the same scene in real life. The **informational and behavioural context** can have a major effect on the aesthetic response. Anderson (1981), for example, demonstrated that the information context provided along with the landscape scene directly altered response: the same scene described as a natural forest was rated significantly better by one group than a comparable group which was told it was a managed forest.

Preferences also vary with the **type of person** and cultural or professional background. Brand (1999) describes the result of public opinion polling in Australia which reveals at least three distinct groups in society: the "deep green" group which is strongly anti-development and opposed to the harvesting of timber; the "green pragmatists", who are concerned about forests but recognize that resource production is necessary; and the "cornucopians" who exhibit a highly pro-development and pro-consumption attitude. These three groups are demographically distinct in terms of age, sex and educational level.

Lastly, preference for landscape conditions is also affected by the **process** through which landscape changes are planned and implemented. Kruger (2001) points out that from a social and cultural perspective, it is not only the end result (i.e. the visual condition of the forest), but also the process of arriving at the condition that is critical. A process which includes considerable public involvement and ownership in decision making for the resource may significantly alter the acceptability of harvesting, based on the tempering of instinctive or socially-constructed aesthetic preferences by additional knowledge or a more comprehensive perspective.

More details on forest landscape perception studies are provided below.

Methodologies for Visual Landscape Assessment and Management

Various methodologies for visual resource assessment have been documented and applied to large-scale forested landscapes, under the auspices of government-mandated VRM programs and other less official methods. These methodologies interpret the visual characteristics of landscapes and aesthetic therories, in order to classify landscapes and prioritise areas or features as inputs to land management systems. Priorities are often based on importance, sensitivity, or risks due to management activity. These methodologies also provide a possible framework for modelling of visual characteristics and aesthetic effects of future forest disturbance.

The US Forest Service Visual Management System (VMS) (1974) was the grandfather of most of today's systems applied to forestry. Its structure, advantages, and disadvantages have been reviewed by Smardon (1986). This system effectively placed visual resources on a par with other resource values, by providing a semi-quantified, fairly defensible approach to mapping visual characteristics, and assigning priorities for visual landscape protection. This system originated the concept of "Visual Quality Objectives" (VQOs), as target levels of acceptable change in visual landscape conditions. The system also explicitly equated departure from natural appearing conditions with reduced visual quality, primarily on the basis of research by Newby (Undated) which showed that the public visiting the US National Forests held an expectation of naturally-appearing landscape character.

The original VMS has recently been replaced in the USA by a similar but

modified system called the Scenery Management System (SMS) (US Forest Service, 1995). This system responds somewhat to new trends which have emerged in forest management over the last two decades, by providing for an increased role of community constituents in the landscape inventory and planning process, increasing the systems' integration with ecosystem management approaches, and recognizing more fully the positive aesthetic role of culturally appropriate anthropogenic effects on the landscape.

The BCMoFs current system of Visual Landscape Management (BCMoF, 1995c) represents an evolution from the original US Forest Service Visual Management System. The Visual Landscape Inventory procedures (BCMoF, 1997c), while considerably more detailed, complex and quantified than the US Forest Service basic procedure, address most of the same concepts and assumptions on desirable visual characteristics of the forested landscape. One of the key differences is the greater importance attached in the BC system to the relative scale of human alterations to the landscape. The system has been largely successful to-date in maintaining an image of natural-dominated landscapes in the more popular front-country areas of BC.

In general, all these systems address the following major aspects of visual landscapes (see below for definitions):

- Visual quality,
- Landscape visibility,
- Viewer concern.

In addition, they typically incorporate to some extent or another, the concept of existing visual condition (how visually disturbed the natural landscape is at present) and visual absorption capacity (VAC).

Visual quality

This aspect of visual assessment most directly addresses the theories and preferences discussed above. Classically, the USFS (1974) VMS approach recognizes that landscapes with the greatest **variety or diversity** have the greatest potential for high scenic value, using indicators such as slope, rockform, vegetation pattern, and water forms. The landscape can therefore be mapped by experts in terms of its "Variety Class" within a regional landscape character type, as Class A-Distinctive, B-Common, or C-Minimal. The new SMS approach (US Forest Service, 1995) uses similar concepts of Scenic Attractiveness, while the BCMoF (1997c) uses a

Figure 4: The road and erosion scars on the steep mountainside introduce strongly contrasting elements in this view, although the ski-run clearings attempt to emulate natural patterns of avalanche chutes.

"biophysical rating", meaning the extent to which the biophysical characteristics of a visual landscape unit create visual interest and draws people's attention. Other practitioners have developed methodologies which recognize less definable indicators of visual quality (though still based on perception testing results), such as vividness, variety, intactness, and unity (FHWA, undated).

Anthropogenic influences have until recently been viewed as positive features only where they represent limited, traditional (usually pastoral or historic) features of largely rural cultures. Most anthropogenic features are treated as negative "visual intrusions" by default in the prevailing management systems. Assessments of Existing Visual Condition (eg. BCMoF, 1997c) evaluate the level of intrusion or alteration apparent within a landscape, in terms of visual quality (Figure 4).

Visual sensitivity

Classically, as used by the USFS (1974), visual sensitivity levels are defined as a measure of people's concern for the scenic quality of the landscape. While this can be obtained directly from community representatives, in most cases, visual sensitivity is assessed based on a set of assumptions about what viewers are likely to care about.

Visual sensitivity as defined here, includes the concepts of landscape visibility (how the landscape is viewed) and viewer concern (how much they care about the visual characteristics of the landscape). The key indicators usually used include a few quantifiable and mappable factors:

- Type of viewer: recreation users, sightseers/visitors, and residents are commonly considered to be the most concerned,
- Number of viewers (use volumes),
- Visibility and viewing distance: foreground and middleground views are most sensitive,
- Viewing duration and frequency: the more you see it, the more you care,
- Other viewing conditions: e.g. roadside screening, direction of view, view angle, etc.
- Land designation/policy indicators: e.g. parks, wilderness area, scenic area, scenic highway corridor, designated urban viewshed.

The US Forest Service (1974, 1995) mapping procedures include:

- Classification of use areas /travel routes by type and volume of user,
- Composite viewshed mapping from these areas,
- Division of viewsheds (visible area maps) into Distance Zones (foreground, middleground, and background),
- Combination by overlaying maps to integrate sensitivity levels (1- Highest, 2-Average, 3-Lowest) and distance zones.

The BCMoF procedure (1997c) uses similar concepts of Viewer Rating and Viewing Conditions. In essence, this part of the assessment weights those areas which are seen most closely and most often by people with a high expected concern for aesthetics in that area. Landscapes which are more seldom seen, or seen mainly by workers, for example, are typically considered to be less sensitive to human disturbance (on visual grounds): in general, the policy is "out of sight, out of mind".

Visual absorption capability (VAC)

VAC is defined as a measure of the landscape's ability to absorb alteration and maintain its visual integrity (BCMoF, 1997c; 2001a). It expresses the likelihood that a landscape change will be noticeable, and serves as a general predictor of visual impact. It describes how well a landscape disturbance might fit in to the landscape. Typical indicators of VAC (BCMoF, 1997c) include:

- Slope (angle and screening),
- Vegetation pattern (colour, texture, orientation, uniformity),
- Soil erosion potential,
- Soil colour,
- Landform screening/surface variations,
- Vegetation screening,
- Vegetation regeneration rates,
- Aspect (lighting direction, regeneration potential),
- Other anthropogenic features/urban clutter.

The BCMoF system classifies land as having high, medium, or low VAC, using several of these factors (Figure 5). Typically, the steeper the slope and the more uniform the surface patterns, the harder it is to design a forest intervention which will be unnoticeable or acceptable to the public.

Figure 5: Much of this landscape has low visual absorption capability due to uniform vegetation on steep slopes, though the natural openings increase VAC in the centre of the scene.

Composite VRM classes

In most VRM systems, the above factors are combined in an overlay mapping process to develop priorities for management and protection of visual resources. These take the form of VQOs in the original US Forest Service System (1974), Scenic Integrity Objectives in the SMS (US Forest Service, 1995), and Visual Sensitivity Classes in the BCMoF system. The BC Visual Sensitivity Class is defined as an

> *"...overall measure of the sensitivity of the VSU (Visual Sensitivity Unit) to visual alteration. It is an assessment of the likelihood that carrying out forest practices or other resource development activities in the VSU would give rise to some degree or kind of criticism or concern."*
>
> (BCMoF, 1997c, p. 44).

The classes are typically used as an overall guide to the desired visual characteristics of the managed landscape, and the nature and degree of visual

alteration which is permitted. In BC, official targets for visual quality may be established, and are then termed VQOs which are defined as follows (BCMoF, 1981 and 1995c):

- Preservation: no visible activities,
- Retention: activities are not visually evident. They repeat the line, form, colour, and texture of the landscape (Figure 6),
- Partial Retention: activities are visible but remain subordinate to the characteristic landscape,
- Modification: activities are visually dominant but have natural appearing characteristics; they must borrow from natural form and line to such an extent and on such a scale that they are comparable to natural occurrences,
- Maximum Modification: activities are dominant and out of scale, but appear natural in the background. This VQO also applies to natural disaster areas, e.g. fires, insect infestations, and windthrow.

Figure 6: Partial cutting activities near the skyline in this front-country area of the Slocan Valley are not visually evident, meeting a VQO of Retention.

The extent to which such composite measures, when adopted as policy in a given area, serve to protect important visual characteristics and constrain other resource values is a subject of some debate in BC (see further discussion in next section). Bell (1998, p. 16) has summarized the use of VRM classes as follows:

> *"Efforts at scenic management, such as the US Forest Service's Visual Management System, or the British Columbian version, have either tried to reduce impacts by keeping the scale of activities as small as possible or screened away out of sight."*

Expert-based VRM systems such as those applied to public forest lands in North America can be criticized for not incorporating more direct public input into their prioritisation and decision-making procedures, in order to increase sensitivity to local or visitor levels of concerns, and promote understanding of the longer-term consequences of management decisions in visually sensitive areas.

Visual impact assessment

Methods of predicting and assessing the visual impacts of specific management activities, in a forestry setting, generally relate to comparison with the desired standards established

in the VRM classes (see above). Thus, a proposed timber harvesting operation would be assessed in terms of the expected visual condition relative to the VQO established for the area (e.g. Fairhurst, 2000). This requires determining whether and to what extent the activity would be visible (using techniques such as viewshed mapping). Often, visual simulations or visualizations (Figure 7) are used to assist the process by depicting the expected visual condition of the landscape (Daniel and Meitner, 2001;BCMoF, 1995a; Sheppard, 1989). Visual impact assessments are one component of a holistic integrated design process for forest management (Campbell, 2001).

Figure 7: Visualisations of different harvesting treatments (using Visual Nature Studio software):

a) Aggravated retention

b) Dispersed retention (75% removal)

The BC Forest Service system, as documented in BCMoF (1995a, p. 12), also evaluates harvesting plans on criteria of design (*"Does it exhibit elements of good visual design?"*), and scale (*"What portion of the visual landscape do existing alterations and proposed operations represent in perspective view"*). The latter originated the practice in BC of calculating the "percent alteration" of views, as a key (if not the sole) indicator of overall visual impact (BCMoF, 1995c), despite the importance of other visual elements such as shape, edge conditions and colour contrast.

Certain agencies such as the US Bureau of Land Management (BLM), have developed more structured and comprehensive methods of assessing visual impacts. The BLM's Visual Contrast Rating procedure (US BLM, 1980) evaluates visible landscape modifications in terms of strong to weak/inevident contrasts, rated numerically for form, line, colour, and texture on all landform, water body, and vegetation components of the landscape. However, research on people's perceptions in relation to the Visual Contrast Rating scores failed to support the validity of the BLM contrast rating method (Smardon *et al.* 1983).

Natural Disturbances, Timber Harvesting and Aesthetics: A Review of Literature and Selected Case Studies

This section reviews in more detail some of the more relevant research and practice on the visual characteristics of natural or anthropogenic disturbance of forested landscapes. As such, it addresses works on both the strictly perceptual characteristics of disturbance, and their effects on people.

The aesthetics of natural disturbance

Relatively few studies have been conducted on the aesthetic impacts of natural disturbance. Drawing on Botkin's book Discordant Harmonies (1990), Bell (1998, p.5), observes that natural disturbances are presented in our culture as *"negative and unusual elements to be suppressed, fought or killed if possible".* The public appears to poorly understand the role of natural disturbance, and many in society believe that destruction of the forest is irreversible.

Gobster (1995) believes that cultural forces have led to forest landscape preferences which embrace an orientation to a static, visual mode of landscape experience, and an aversion to the death of trees and the "messiness" which results from landscape disruption and change (Figure 8).

There are a few research studies which have focused on perceptions of natural disturbances. Clay and Marsh (1996b) conducted spectral analysis of light wavelengths to distinguish perceived colour differences between healthy and insect-damaged coniferous stands. Buyhoff and Leuschner (1978) found a statistical relationship between scenic beauty (measured with perception testing using the Scenic Beauty Estimation technique) and the amount of forest insect damage. Iverson (1997) recorded a drop in property values of viewlots near Sedona, Arizona, of over 25% immediately after an extensive fire. Boxall *et al.* (1996), in a study of forested parks in eastern Manitoba, found that fires occurring within the last ten years had a strong negative effect on the route choice of back-country canoeists; the same result was found with the early regrowth of jack pine forest, which correlates closely to recent fire events. However, interestingly, the most preferred route choices were associated with jack pine forests which resulted from fires 55-65 years ago.

Figure 8: People tend not to like chaotic or messy scenes from recent fires.

In general, the research evidence appears to bear out the claims of Bell (1998)

and Gobster (1995) as discussed above. However, there is clearly in some situations a strong temporal influence on aesthetic responses to natural disturbance, as demonstrated by the findings of Boxall *et al.* (1996) and by common sense. The visual importance of forest succession is also emphasized by Bacon (1995), who recommends management strategies for highway viewing corridors which provide viewers with exposure to a variety of seral stages in forest growth. Brown (1987) asserts that scenic beauty modelling exercises have commonly ignored the dynamic aspects of aesthetics in part because *"there is some evidence that time is not a major concern"* (Brown, 1987, p. 400), but this comment appears to refer to the stability of people's judgements of scenic quality over time where landscape conditions are not changing radically. He also notes, however, that additional research is needed on the time element of aesthetics. There is, for example, little research on the extent to which knowledge of forest succession (e.g. as provided through interpretation of natural disturbance events) affects people's aesthetic responses. The increased popularity of Mt. St. Helens after the volcanic eruption would appear to suggest that at least some kinds of natural disturbance could create a very "attractive" landscape to some kinds of sightseers.

The aesthetics of timber harvesting

Much of the literature on the aesthetics of forest management (e.g. Bergen *et al.* 1995; Brown and Daniel, 1986; Brush, 1979; Hull *et al.* 1984; Hull and Buhyoff, 1986; Hull e*t al.* 1987; Ruddell *et al.* 1989; and Rudis *et al.* 1988) focuses on the foreground viewing situation found within the forest canopy, e.g. along roadways and trails. All of these articles use variations of psychophysical models (e.g. the Scenic Beauty Estimation method) to investigate parameters of forest aesthetics. Many of the findings are consistent throughout this research. Less dense stands with larger stems, high complexity and good visual penetration are found most attractive. Downed wood and visual screening from dense stands are consistently found unappealing. Hull and Buyhoff (1986) have looked in depth at Scenic Beauty Temporal Distributions (SBTDs) addressing the effect of time since harvesting on aesthetics, and found that, at the stand level, rotation age was the most important factor in determining scenic quality.

Of greater relevance to the issue of landscape-level disturbance by forest management practices are those studies which address a variety of views of forested landscapes, both foreground and distant. Drawing upon both research and practical experience, Gobster (1995) and Bell (1998) see the same general patterns of negative aesthetic reaction to timber harvesting as those described for natural "destruction". Gobster notes that visual preferences generally decrease as the perceived degree of disruption (i.e. sudden change, perceived destruction, and "messiness") increases, and that people tend to prefer smaller clearcuts over larger ones. Bell (1998) suggests that one reason for the unpopularity of forestry is that it is perceived to destroy ecosystems.

There are a number of specific studies which document examples of the negative effects of forestry on larger scale scenic landscapes specifically. Schuh (1995) reports the results of a public perception study conducted for Weyerhaeuser in Washington State. He found that participants perceived a waste of resources

when slash and snags remained on site, and that conventional even-aged management is often at odds with the public's visual expectations. Bradley (1996) cites the following harvest practices that people do not like in the Pacific Northwest: leaving "messy" residual material; disposal of residual materiel through burning; colour contrast; square or rectangular harvest units and clearcuts on ridges; and inadequate buffer strips between the viewer and a clearcut.

Palmer *et al.* (1995) address mid-range views of clearcuts in the White Mountain National Forest in New Hampshire. The researchers found a consistent decrease in perceived scenic value as the harvest intensity (represented as percentage of the viewshed, presumably measured in plan view) increased from 0 to 5%. The most severe change in scenic value occurred between the no-cut condition and the 1% removal intensity. Their research suggests that 10-14 acre (4-6 hectares) clearcuts sustained a smaller reduction in scenic value than both smaller (4-5 acre or 1-2 hectares) and larger (20-30 acre or 8-13 hectares) cuts, although some aspects of the research procedure, such as using small photographs to obtain viewer preferences, raise doubts about the validity of the study conclusions. The study found no significant variation in responses due to viewpoint or to the distribution of the visible clearcuts (scattered or clustered).

Ribe (2004) and Marc (2004) review results of various types and levels of partial cutting harvesting treatments, as seen in Figure 9 (see discussion below).

Various studies provide recommendations on ways to minimize the negative visual impacts of timber harvesting. Bradley (1996) suggests the following practices for landscape level treatments:

- Reduced size of cutblock units,
- Even distribution of cutblocks across the landscape,

Figure 9:
Studies show that people tend to prefer partial cutting with dispersed retention (as in the middle of this scene), over clearcutting or patch cutting (as shown near the ridgeline in this scene).

- Curved and undulating edges to cutblocks,
- Feathered edges to cutblocks,
- Harvest lines diagonal to ridgelines,
- Selective cutting,
- Trees retained in groups,
- Minimal number of yarding corridors, and
- Few midslope roads.

The US Forest Service (undated: 2) Agriculture Handbook No. 559 on timber, provides more silviculturally precise design criteria and guidance for six major timber types found in the USA, including Douglas-fir, Sitka spruce-western hemlock, and lodgepole pine. Many of these recommendations consider both stand level and landscape level treatments in some detail, including both clearcut and partial cut techniques as appropriate to the forest type. General design criteria applied include edge treatment of cutblocks, shape, scale, and distribution of harvest units, applied with the general aim of repeating natural landscape characteristics.

The BCMoF (1995e) Visual Landscape Design Training Manual also provides extensive recommendations on forest design to avoid or minimize negative visual impacts. The manual advocates a particular system of landform and land feature analysis, emphasizing "visual forces" of ridgelines (linear convexities) and valleys (linear concavities) as form-giving patterns with which to shape management activities, in harmony with natural landscape patterns. Specific guidance on design of harvest units includes eliminating right angles; straight edges cutting at or near right angles to the contour; edges following contours; parallel-sided shapes; symmetrical shapes; and long, straight edges.

Other recommendations for specific situations, such as skylines, travel corridors, and use of alternative harvesting techniques are also provided. These recommendations appear to be based largely on practical experience in BC and principles established by the the UK Forestry Commission.

Some authors have cited beneficial effects of timber harvesting on scenic quality, though again mainly in the foreground landscape. Bacon (1995) describes a plan to use timber harvesting to reveal and accentuate views along a road coridor, as well as to increase the diversity of age classes and achieve greater visual variety. Sheppard (1974) advocated a similar approach using thinning in key areas to improve viewing opportunities in plans for recreational forest areas in the East Kootenays. McDonald and Litton (1998) concluded that scenic values were enhanced by manipulation of understorey and logging of overstory vegetation along a roadway, even ten years after the original management activity. Gobster (1995) notes that light silvicultural treatments where visual penetration within the stand is increased, often result in preferred conditions relative to unmanaged stands. Beneficial impacts at the landscape level are less commonly identified, although the US Forest Service (1974) advocates harvesting to increase the visual variety of extensive landscapes with monotonous forest cover and minimal contrast of form or colour.

Impacts of VRM on Timber Values – A Literature Review

There is a widespread belief that VRM is a major constraint on timber resources. In an attempt to gauge the impact of VRM on timber availability, specific North American studies that shed light on this relationship are examined in this section. These studies took place in different locations, under different levels of VRM, and in different harvesting conditions; they therefore illustrate a wide range of VRM impacts on timber availability. They are discussed in terms of overall effects on timber supply and availability, impacts on timber harvesting costs, effects on delay of harvesting due to green-up requirements, and limits on the area available for harvesting.

Fight and Randall (1980) attempted to assess the cost ($/acre) of enhancing visual quality of forestlands (to meet a Partial Retention VQO[2] from middle-ground) in the Mt. Hood National Forest,Oregon. The same silvicultural treatments (planting, precommercial thinning, commercial thinning and a final cut) were undertaken on pairs of similar areas and the same volume was harvested but using different approaches (one using conventional practices, and one using practices designed for visually sensitive areas). Visual sensitivity was addressed through a combination of large planting stock, thorough slash cleanup, staged timber removals, long rotations and shaped harvest blocks in small units. Consequently, there was an increased cost at roadside of about 14%. No impact of VRM on the timber availability (in terms of m^3 available) was found.

Stier and Martin (1997) looked into the financial impact of visual and forest cover constraints for private forestland owners along a river-way valued for recreation (WI, USA). In this case, three visual zones were established:

River Edge Zone: 25 m on each side of the river with a "no touch" rule.

Bluff Zone: 30 m on each side of the skyline as seen from the river, where only selective logging (removing 30% on average of the basal area) was allowed.

River View Zone: All land occurring between the two previous zones. No clearcuts over 2.5 ha in size were allowed and no more than 1/3 of the land could be clearcut per 10-year period. Adjacency constraints were applied and if partial cut was used, up to 50% of the basal area was allowed for removal.

The projected impact was modelled over a 15-20 year period for five management scenarios (control, unregulated selected thinning, unregulated diameter-limit cut, basal area regulated thinning and regulated patch clearcut). Reductions in present value of forestlands ranged from 0% up to 18% due to visual and forest cover constraints. However, the magnitude and direction of the impacts on timber supply could not be estimated from current stand conditions alone (Stier and Martin, 1997). For example, "high-grading" harvests undertaken to meet visual quality constraints, while allowing some flow of timber, may reduce the short-term financial impact of visual constraints but may jeopardize future harvests and worsen the long-term impact. Also, the impact of VRM on timber supply critically depends upon what is believed the owner would do if there were no such visual restrictions.

[2] VQO definitions under the US Forest Service Visual Management System (USFS, 1974) are similar to those defined under BC's system.

In other words, VRM may not have much of an impact if the land is not to be logged for other reasons (other regulations, poor market conditions, water quality, soil stability, etc.). The critical measure is not percent of merchantable timber, but percent of otherwise available timber. This finding emphasizes the importance of the assumption that licensees would harvest more wood in visual zones in the absence of visual management.

In another study conducted for a road corridor in California, it was found that VRM increased timber availability as well as improving the scenery by opening up views (McDonald and Litton, 1998). The harvest method used, was a combination of commercial thinning, non-commercial thinning and brush removal. Thinnings were based on a cross-section of the initial stand, respecting initial ratios of species composition and diameter classes (per species). The Basal Area was removed by 27% (and 53% of the trees) was removed along a roadside, enhancing the view and meeting the equivalent of a Partial Retention VQO as defined in BC (McDonald and Litton, 1998). These results highlight the importance of linking landscape architecture and silviculture as a way to preserve visual quality and recreational experiences while allowing some harvesting.

In BC, Clay (1998) successfully achieved a Retention VQO in phase one of a harvesting approach using irregular strip shelterwood in the Nelson Forest Region. The long-term management scenario includes a rotation of 90 years with entries every 30 years (three entries total), removing approximately 180 m^3 per ha at each entry. Clearcut strips, sandwiched between partial cut strips and then reserve strips, were harvested in the first entry. At the next stage, the reserve strips will be partially cut and the initial partial cut strips will be clearcut (at the second entry). In the third and last entry, the initial reserve strips (partially cut in the second entry) will be clearcut and the cycle will start again. Volumes harvested through this staged removal were not compared with those that could be harvested with clearcutting over a 60-year rotation, but costs were estimated to be 20% higher than clearcutting. However, cost increases are expected to decline with increased experience (Clay, 1998). Key points in this successful operation included the involvement of highly motivated loggers in all aspects of layout and harvesting.

Still in BC, in the Robson Timber Supply Area (TSA), the use of clearcutting in conjunction with partial cutting (via uniform selective harvest) within scenic areas was analysed in relation to its impact on timber supplies and availability (Industrial Forestry Services Ltd. and BCMoF, 1998). The results of this analysis show that both short-term timber availability and long-term timber supply will increase when partial cutting is chosen over clearcutting in the more visually constrained areas. More specifically, partial cutting 22% of the stands within scenic areas could increase timber availability by as much as 58% and timber supply by 36% (Industrial Forestry Services Ltd. and BCMoF, 1998). These results may be underestimated since it was assumed in this study that there are no current visible alterations in Visual Landscape Units, which is unlikely to be the case. Another interesting point brought up in this study is that silviculture foresters, intimately familiar with partial cutting, were of the opinion that any stand can be partially cut, while licensees, also experienced with partial cutting, believed the opposite (Industrial Forestry Services Ltd. and BCMoF, 1998). This suggest that more research is needed in the economic viability and benefits of partial cutting approaches.

In coastal BC, a similar study was conducted in the Strathcona TSA, which evaluated timber availability using partial cutting versus clearcutting in scenic areas subject to VQOs (Timberline Forest Inventory Consultants Ltd. and Rowe, 1999). This study concluded that wood availability in scenic areas is increased considerably (by 36% to 46%, depending on the scenario considered) with the use of partial cutting and that most of this increase comes from the areas under a Partial Retention VQO. These gains are achieved despite the relatively small proportion of areas considered suitable for partial cutting (14-25%) (Timberline Forest Inventory Consultants Ltd. and Rowe, 1999). Once again, it was found in this study that partial cutting could be carried out in most stands in the Strathcona TSA, but that increased costs were also a limiting factor. The study noted that without partial cutting, much of the timber is otherwise unavailable.

Another study on the effects of partial cutting on the timber supply of the Arrow, Cranbrook and Golden TSAs (Wang and Pollack, 1998) found that a gain in annual harvest of 2-3% could be achieved in the first decade as a result of partial cutting in areas subject to VQOs. In the Arrow TSA, Decade 1 harvests are expected to increase by 3-5% from the use of partial cutting (Wang and Pollack, 1998). It is important to note that these results are TSA-wide increases achieved from partial-cutting-only portions of the TSA (i.e. areas under retrictive VQOs), which means that the local increase or benefit from partial cutting may be significantly higher in specific and highly constrained areas (e.g. Slocan Valley). However, the study reports that the Arrow TSA already uses partial cutting on 25% of the area harvested and on 35% in areas subject to VQOs, and concludes that the partial cutting potential gain is already being utilized in the Arrow TSA (Wang and Pollack, 1998). This may not be the case however, since other recent documents indicate that approximately 90% of the harvesting in the Arrow is carried out under an even-aged management regime (BCMoF, 1999). This difference may be due to the definition given to "partial cutting". Wang and Pollack (1998) define partial cutting as a two-stage treatment in which all of the volume is removed in two passes, while the BCMoF document (1999) defines partial cutting as harvesting that falls under uneven-aged management regimes. They also found that the annual harvest increase (or decrease) that could be achieved through the use of partial cutting was very sensitive to the determination of minimum economic volumes (for partial cutting). This last finding stresses once again the importance of economic viability in the success of any partial cutting operation.

In the Nelson Forest Region, Crampton (1995) located areas subject to VQOs that could benefit from visual rehabilitation and therefore have an impact on short and long-term timber supplies. The rehabilitation of existing clearcuts in visually sensitive areas was the main focus of this study for short-term wood opportunities (Crampton, 1995). Applying this approach in the Arrow District led

[3] Percent denudation is one of the current measures used by the BCMoF to quantify how much visible landscape alteration is permitted in a visual landscape unit at any one time, in order to meet a given VQO. Percent denudation is expressed as a range of percent (%) area cleared (seen in plan), using clearcutting, that is allowed in any given Visual Quality Class (or VQC). These percent denudation ranges are to be applied planimetrically to the total "green" area (forested area, whether operable or not) and were derived for the purposes of modelling clearcutting operations in Timber Supply Reviews (TSRs) (BCMoF, 1998a). The related concept of percent alteration is defined below.

to increased acceptable percent denudation[3] figures from 15% to 25% for a Partial Retention VQO (allowing 10% increase for example) and from 30% to 40% for a Modification VQO (also allowing a 10% increase). These increases yielded a short-term volume of 17,875m^3 over an area of 55 ha (at 325 m^3/ha) throughout the Arrow Forest District. However, the rationale for such percent denudation increases is not clear. It is assumed that these increases are the result of active visual landscape design and visual rehabilitation of specific cases. Also, the study does not consider the use of partial cutting as a mean to "unlock" timber within those areas constrained by VQOs.

A crucial point in assessing the impact of VRM on timber availability is the determination of how long it would take for harvested stands to be considered as "visually healed". This process of restoring a "natural" visual appearance directly affects the time lag before more logging activities are allowed in its vicinity. In BC, the concept used to make such a determination is called Visually Effective Green-up (VEG): "the stage at which regeneration is perceived by the public as newly established forest" (BCMoF, 1998a). However, the US Forest Service has used the notion of Effective Alteration (EFFALT), which they define as: "percent of *noticeably altered* lands at any one time" (US Forest Service, 1981). They define "noticeably altered" as extending through post-harvest regenerated stands that are noticeable as visual contrasts. This presumably means that the US system has a more severe effect on timber availability, due to longer delays before achieving visually acceptable "green-up". Since VEG determines the point in time at which a given stand ceases to contribute negatively to visual quality, this could cause major variations in VRM impacts on timber availability. In general, the sooner VEG is reached, the lesser the impact of VRM on timber availability for any level of VQO.

The notion of anthropogenic alterations used in defining adherence to VQOs in BC is expressed in terms of percent (%) "visible alteration" (as measured in perspective from ground views).[4] However, in assessing the impact of VRM on timber supply, "percent denudation" (as measured in plan) is applied (BCMoF, 1998a). This conversion between percent alteration in perspective and the percent denudation in plan mainly depends on the slope, tree height, viewing angle, and viewing distance (Marc, 1999, pers. comm.). Whenever possible,[5] this conversion should be calculated on a case-by-case basis for greater accuracy, since it may affect significantly the management of visual resources as well as the available timber under a given VQO. In practice, recent studies have shown that the percent alteration ratio between plan and perspective ("P2P") is about 2:1 on average (Marc, 1999, pers. comm.).

Paquet and Belanger (1997) worked with sensitive recreational landscapes in

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[4] Percent alteration being defined as: the scale of any type of disturbance to a landscape caused by human activity, including cutblocks, expressed as a percentage of a land-scape or the total scene seen in perspective (BCMoF, 1997a).

[5] BCMoF (1998a) recommends the middle value of the percent denudation range (see Table 1), using clearcutting, to be modelled when a full visual landscape inventory and analysis are lacking. However, where visual landscape design is actively practised, a greater percent denudation value for clearcutting in each Visual Quality Class may be used (BCMoF, 1998a). Higher Visual Absorption Capability (VAC) will also allow for greater percent denudation values for clearcutting in each VQC (BCMoF, 1998a).

Quebec's boreal balsam fir forest type, and found that people tested in perception studies reacted adversely to even very low levels of clearcut activity. However, most felt that a certain level of clearcut was acceptable (up to approximately 25% of the visible landscape in a photographic slide, as measured in perspective), when seen in a single cutblock situation in middle-ground views with rolling terrain; harvesting activity that occupied 50% or more of the visible landscape was considered unacceptable by most people (Paquet and Belanger, 1997). When the cutblocks were distributed as smaller patches over the visible landscape, they were found to have higher acceptability, closer to 50% with the majority of tested groups.

In the West Kootenays, Berris and Bekker (1989) also explored public preferences for forested landscapes with varying levels of landscape alteration. Results indicated that preferences are most affected by the presence or absence of highly visible alteration, and second by the drama of the landscape (Berris and Bekker, 1989). A high degree of correlation was found between public preferences and the BCMoF VQOs.

In a large public perception study of BC residents, the BCMoF (1996a) found that the acceptability of forest scenery in middle-ground landscape views of clear-cuts varied substantially with the Existing Visual Condition (EVC) and the scale of alteration.[6] People consistently showed high levels of acceptability to more natural-appearing conditions (e.g. EVC classes of Preservation and Retention, with percent alteration of approximately 0-1.5% of dominant landforms seen in perspective), and high levels of unacceptability to landscapes with EVC of Maximum Modification (approximately 5-30% alteration) (BCMoF, 1996a). More specifically, alterations greater than 6% (of a Visual Landscape Unit as seen in perspective) were rated as neutral to unacceptable (BCMoF, 1996a, p. 14). These results appear to indicate that BC conditions (more mountainous, with steeper slopes, and possibly other cultural, biophysical, and visual factors) result in what appears to be much lower thresholds of percent alteration than the 25% and 50% figures obtained in the Quebec study[7] (Paquet and Belanger, 1997).

For the purpose of timber supply modelling, Region 5 (California) of the US Forest Service (1981), using the EFFALT system, attempted to equate VQOs with maximum percentages of land that can be in an altered state at any one time. These percentages range as follows:[8]

Retention VQO:	0 to 30% alteration (15% avg.)
Partial Retention VQO:	4 to 40% alteration (22% avg.)
Modification VQO:	10 to 50% alteration (30% avg.)
Maximum Modification VQO:	30 to 60% alteration (45% avg.)

[6] EVC refers to the same definitions of level of visual alteration as VQOs, but reflects actual rather than desired conditions. A team of visual landscape management specialists (BCMoF and consultants) assessed EVC for the BCMoF perception studies (1996a and 1997a).

[7] The BCMoF study (1996a) used percent alteration of the dominant landform (within the total photo area) while the Quebec study (Paquet and Belanger, 1997) used percent alteration of the total photo area. The alteratio n figures obtained in the Quebec study would represent an even greater percent alteration if applied to the dominant landform instead of the entire photo area.

[8] It is assumed that percentages are to be applied planimetrically.

It is interesting to compare the BC figures (BCMoF, 1996a) with those generated by the EFFALT method used by Region 5 (California) of the US Forest Service. It will be noted that the US percent averages of land that could be altered under VQOs using these calculations are considerably higher than in BC, even when taking into account that the BC figures reflect percent alteration in perspective while the US Forest Service figures reflect percent alteration in plan. Also, the range of overlap across VQOs is substantially greater, indicating more flexibility in the use of this approach in the US. All of these factors suggest that the BC system of percent alteration may be significantly more restrictive than in the US. However, this may be compensated for by the shorter time required for green-up (VEG) in BC (as discussed above); also, landscape conditions (e.g. drier, more open forests) in the US National Forests of California may permit more timber removal under a given VQO due to higher visual absorption of human activities.

In a public perception study of partial cutting, the BCMoF (BCMoF, 1997a) found that higher levels of partial cut removal were associated with lower levels of visual quality. Certain stand variables were correlated with professional evaluations of the post-harvest EVC: the best statistical predictors of EVC came from a combination of basal area removed, percent volume removed, percent stems removed, and average heights of residual trees. The study also found a correlation between EVC classifications used by visual landscape specialists and public perceptions of scenic quality. The study yielded no strong statistical relationship between participant's scenic quality judgements and stand variables directly (perhaps due to the limited sample of sites available). However, the study does suggest that using partial cut techniques, even with severe visual constraints, permits *much higher timber volumes* to be harvested under the more restrictive VQOs than would ever be possible with clearcutting. For example, with trees 25 m high, and 60% volume removal, there is a 90% chance (or greater) of meeting a VQO of Partial Retention (BCMoF, 1997a).

Literature review summary

From this review, it is clear that there is general agreement on many of the major relationships between forest management activities (particularly those involving conventional clearcutting) and visual quality, although many of the details in site-specific applications are less straightforward. Two key points however, should be discussed here:

1. There appears to be a difference between reactions to the visible evidence of anthropogenic disturbance (e.g. harvesting), versus the long-term results of that disturbance. This is not simply a temporal issue, whereby the longer the time from the disturbance, the higher the scenic value; there appears to be a threshold at which time people generally no longer recognize the area as disturbed by humans. Thus, active logging, erosion, cleared areas before green-up, and road scars, for example, are signs of ongoing or recent disturbance, i.e. rapid change; the same areas once regenerated, even though continuing to change under natural forces, appear to have higher scenic value to people. In studies of public perceptions of Visually Effective Green-up in BC, the BCMoF (1994b) found a significant threshold with trees between the visible stand height of 3 and 8 m, in both summer and winter conditions.

2. The aesthetic response to forested landscapes is not just a result of the visual appearance of the forest; the view of a cutblock may be a symbol or trigger for many other emotional or cognitive responses, which originate in other sources of information, e.g. cultural background, recent news events, etc. Bell (1998) cites various reasons for negative reactions to forest management activity, such as the belief that timber harvesting is unethical, and that forest management ignores the will of the local people. Various authors (such as Bell, 1998; Jones, 1995; and Kruger, 2001) stress the importance of the communications and decision-making process in influencing the reaction of the public to what they see in the forest. Gobster (1995) advocates the improved understanding of ecological processes as a basis for a more informed landscape preference or "ecological aesthetic". Schuh (1995) and Bradley (1996) note the beneficial impact of interpretive signs in reducing negative reactions to views of timber harvesting. Based on the experience of community forests such as North Cowichan in BC, Sheppard (2001) has speculated that increased activity by local forest managers working in the community, (demonstrating care for the local landscape), rather than reduced forest management activity, may result in higher community acceptance of timber harvesting.

Various studies suggest that in forested landscapes, aesthetic public preferences decrease as the amount of visible landscape alteration increases (BCMoF, 1996a; BCMoF, 1997a; Berris and Bekker, 1989; Paquet and Belanger, 1997). Accordingly, traditional VRM approaches using VQOs have assumed that increased visual sensitivity constrains timber supply (BCMoF, 1998a). The most common impacts of VRM on the timber resource found in the literature include higher harvesting costs and some reduction in timber availability. However, not all VQOs have an impact on timber availability (e.g. Modification and Maximum Modification may place less spatial constraints on clearcutting, than other legislative requirements such as adjacency). In more visually constrained areas, the use of alternative cutting practices, as opposed to conventional clearcutting, appears to offer potential gains in timber availability, based on reviewed literature.

Also, increased volume harvest does not necessarily correlate with reduced visual quality. The opposite has been shown to occur and various partial cut practices have proven successful in meeting VQOs in visually sensitive areas (BCMoF, 1997a; Clay, 1998; Fight and Randall, 1980), and even in increasing both timber availability and aesthetic quality (McDonald and Litton, 1998).

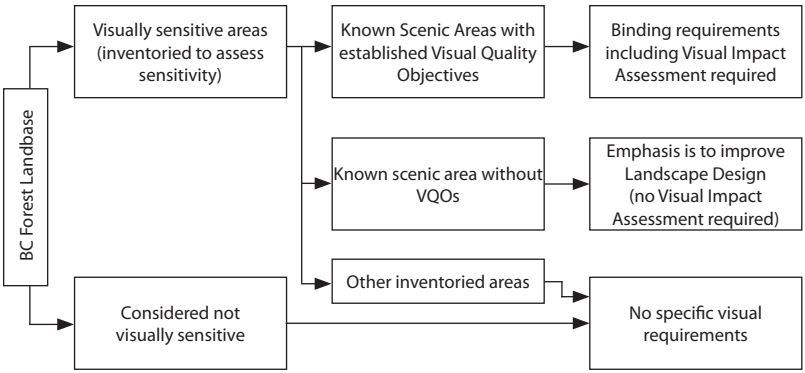
Finally, determining the true impact of VRM on timber availability requires careful analysis and depends on:

- the extent of overlapping constraints from other non-timber resource values and policies (which limit the impact of VRM on timber supply, as pointed out by Stier and Martin (1997)),
- the forest practices used (e.g. clearcutting or partial cutting),
- the extent of VQO coverage and the class of VQOs (i.e. more restrictive Preservation, Retention and Partial Retention VQOs versus less or not restrictive Modification or Maximum Modification),
- VEG tree height requirements of the particular area, since it may directly affect timber availability if different from the typical 3 m free-to-grow requirement (for BC).

In addition, it is possible that the impact of VRM on timber supply also depends upon the policies and decision-making styles of managers, as discussed in more depth for BC in the following section.

Overview of Visual Resource Management Implementation in BC

The BCMoF's objective regarding visual resources has been to find a balance between protecting visual resources and to minimize the impact of such protection on timber supply, consistent with a report on the impact of the Forest Practices Code on timber supply[9] (BCMoF, 1996c). Despite its breadth, this objective clearly states that the BCMoF would take into account visual resources in the management of the provincial forests as long as they do not affect timber supply too much. Exactly how this balance is to be maintained is unclear but it appears that the BCMoF had the goal of keeping the overall FPC impact on timber supply to no more than 6% (BCMoF,



1996b; BCMoF, 1996c), taking VRM into account. However, until this target figure is reached, visual resources would be managed as summarized in Figure 10, which provides managers with considerable flexibility in how to apply VRM.

Figure 10:
Visual Resources Management procedures for different areas within British Columbia (adapted from BCMoF, 1998b).

In BC, a potentially important issue influencing the effect of VRM on timber supplies and availability is the role of the District Manager. Unless otherwise stated in a Higher Level Plan (HLP), the District Manager has been provided with considerable discretion in terms of managing (or not managing) visual resources (BCMoF, 1998a). The District Manager has the latitude to determine the intensity and extent to which VRM will be conducted, including deciding whether or not to establish VQOs, based on the initial Visual Landscape Inventory. They also have

[9] See BCMoF (1996b) for the complete report reference.
[10] Unless the management of visual resources or VQOs have been established/determined through a HLP.

the latitude to modify the management of Visual Resources if the impact on timber supplies is judged to be too great. The District Manager can vary VQOs by relaxing or tightening them[10] by moving to a lower or higher Visual Quality Class (BCMoF, 1997b; BCMoF, 1997d; BCMoF, 1998c). However, once the decision to manage for visual resources is made (especially once VQOs have been established), it is unclear to what extent established VQOs can be dismissed. No documentation was found stating that established VQOs can be cancelled; on the other hand, no limitation is set on the "relaxation" of established VQOs. Therefore, one could assume (theoretically), that established VQOs could be "relaxed" to the point of being negated, but this still needs confirmation. BCMoF documents also mention that "given the sensitivity around this issue, it is important that this process ("relaxing" VQOs) be carried out in a prudent and rational manner" (BCMoF, 1998c, p. 20). No further guidance is given on the meaning or interpretation to be made of "prudent and rational". From the licensee's point of view, visual resources need to be protected to the satisfaction of the District Manager.

While the legislation and policy seems to permit considerable flexibility and variation in District Manager's stance on VRM, the theoretical possibility of eradicating VQOs might not be politically feasible in practice since the procedure to "relax" established VQOs encourages external input and consultation (BCMoF, 1997d; BCMoF, 1998c). In this procedure, the BCMoF recommends that the District Manager consult and review the proposed VQO "relaxation" with the public (BCMoF, 1997d) and the stakeholders such as the Ministry of Small Business, Tourism and Culture (BCMoF, 1998c). The first step is to prioritise the scenic areas in terms of their visual sensitivity and the potential timber supply or availability gain, and then to evaluate each visual sensitivity unit within the scenic areas for its potential to increase timber supplies by relaxing the VQOs.

Implications and options for VRM in BC

The prevailing philosophy of the current system of VRM has been criticized as safeguarding the "front country" at the expense of the environmentally pristine back-country (as discussed in Sheppard, 2001). However, as a result of the Forest Practices Code (FPC) (BCMoF, 1995d), scientific arguments for biodiversity and ecosystem management, lobbying by environmental and eco-tourism groups, and the extensive logging of many back-country valley bottoms, much remaining merchantable timber in the less visible parts of the landscape is no longer as available for logging. Outside the Northern Coastal old growth forests and the mountain-pine beetle infestation areas in the Interior, in many areas such as the West Kootenays there is a shortage of available timber,[11] relative to historic levels. This puts pressure back on the more visible slopes closest to the communities and highways, with maturing second-growth timber where VRM constraints have typically been highest. Many of these areas are also showing increased signs of poor forest health, due to fire suppression, lack of management, and perhaps climate change.

How is this dilemma to be resolved? Options include:

[11]In the case of the Arrow TSA, the current available timber practically equals the Allowable Annual Cut (AAC), leaving licensees with very little or no manoeuvrability (Arrow Forest License Group, 2000)

1. Maintain the visual constraints as they have been managed in the past, and accept the continuing reduction in timber availability as the less visible areas are used up or become unavailable. This situation is likely to continue in areas where VQOs have already been established, and conventional cutting practices are maintained.
2. Relax visual constraints, and permit expanded conventional harvesting in the front-country. This is an avenue now open to District Managers in deciding whether to impose or relax VQOs, whereby the Ministry of Forests (BCMoF, 1998c) may offset constraints on timber availability through this more flexible approach to VRM. With this approach, there is the risk that visual objectives will be compromised and public outcry will arise from affected communities, tourism providers and visitors. This situation seems to have arisen in the Inside Passage of BC, in the North Coast TSA, where recommended VQOs were relaxed in 1998 to reduce their impact on timber supply (BCMoF, 2000). Despite this relaxation, visually sensitive areas are still being avoided by the licensees, putting increased harvesting pressure on the remaining timber harvesting landbase. In response to this situation, the Chief Forester raised the spectre of an AAC reduction in the North Coast TSA, unless more harvesting took place in the visually sensitive areas of the Inside Passage (BCMoF, 2000): a "cut it or lose it" type of approach.
3. Explore alternative planning procedures and timber harvesting practices such as partial cutting which may meet visual objectives in the front-country, and are more acceptable to local communities, but permit timber extraction at levels substantially higher than is possible with clearcutting under typical procedures (Marc, 2004). In addition, as pointed out by McDonald and Litton (1998), linking landscape design with silviculture may improve both timber yields and visual scenery, or at least, it can help mitigate the impact of VRM on timber supplies and vice-versa. With increasing concerns about forest health and fire risk reduction in the urban-wildland interface, more options for alternative harvesting approaches are becoming available, although impacts on other resource values (e.g. biodiversity) are poorly understood.

It is also often assumed that VQOs are used as a defacto indicator of public acceptance of forest management (Sheppard, 2001). However, if public pressures are more constraining than the established VQOs themselves, the impact of VRM on timber availability is effectively eliminated since the most restrictive constraint determines what management will prevail. It is also possible that differences in the degree of visual constraint between different districts may become more marked, reflecting the priorities of the district and the inclinations of the individual District Manager.

As pointed out earlier (Stier and Martin, 1997), the impact of any VQOs depends on the assumption that more timber would be harvested in the absence of such visual management regimes. This is far from being clear in many contentious locations around BC where harvesting has been avoided in many areas subject to more restrictive VQOs, due to public pressures, and higher operating costs associated with VQOs (BCMoF, 1994a; BCMoF, 1994c). There are also other

regulations and biodiversity/forest cover constraints for community watersheds, etc. that could significantly reduce the effective impact of VQOs on timber supply and availability (BCMoF, 1995b) or even eliminate the impact of VQOs if these other values were more constraining on the cut.

Relationships Between Harvesting Practices, Timber Availability and Visual Quality in BC

Given familiarity with the basics of VRM, and after reviewing case studies and the BC Visual Resource Management (VRM) system, this section explores further the potential for alternative planning procedures and timber harvesting practices such as partial cutting to meet visual objectives in visually sensitive areas, while permitting timber harvesting or other management activities at levels substantially higher than is possible with clearcutting under current procedures and regulations. Emphasis is placed in particular on approaches to partial cutting and improved landscape design. What potential do these tools have in making BC's substantial second growth timber reserves in sensitive front-country locations more accessible for harvesting and/or management, while maintaining acceptable visual quality?

The policy and procedures affecting VRM in BC can be used as the framework for a theoretical quantification of effects of VQOs on timber availability. It should be noted that the procedures used by the BCMoF for timber supply analysis typically presume the use of clearcutting as the dominant harvesting practice. However, a study of public perceptions of partial cutting relative to the extent of timber removal, as described in the review of literature (BCMoF, 1997a), enables quantitative comparisons of effects of alternative timber harvesting practices on timber availability under VQOs. In this study, representatives of the public ranked photographs showing different levels of landscape alteration/denudation from timber harvesting (clearcuts and partial cuts), based on their visual quality. Scenes used represented a range of stand types, slope/landform conditions, and harvesting designs. The partial cutting examples were selected to represent "uniform distribution of residual trees" (i.e. BCMoF, 1997a, p.2): in other words, partial cutting with no discernible pattern (unlike strip cuts or patch cuts).

In essence, the BCMoF perception studies suggest that people react more adversely to a specific harvest volume if it is clearcut than if it is partially cut. The study found that partial cut areas with a high proportion of stems removed tended to be rated as higher in visual quality than clearcuts with similar or even lower volumes removed. The participants' responses were significantly correlated with VQOs (levels of landscape alterations) resulting from the harvests. The implication is that VQOs may be met with higher basal area removals if partial cutting is used than if clearcutting is used. The results obtained have been used by BCMoF to factor in the impact of VRM in Timber Supply Reviews (TSR) by establishing expected norms for "percent denudation" (for clearcuts) and basal area removal (for partial cuts), thus providing guidelines for harvesting which meets given VQOs (see BCMoF, 1998a). It should be noted that the number of examples shown to participants with either very low or very high volume removals (Preservation and Maximum Modification VQOs) in the partial cutting study was small, which casts some doubt on the reliability of these results at these extreme levels of basal area

removal. Further testing of perceptual responses in this range is required.

The reason for the apparent timber volume advantage of partial cutting where VQOs exist seems to be primarily associated with the screening effect of residual trees. Except with the steeper slopes and highest viewing angles, a relatively small number of residual trees is able to filter and block open views of disturbed ground, as well as softening or eliminating abrupt cut block edges, and often maintaining the appearance of a continuing forest canopy. This makes the amount of landscape alteration very hard to detect or measure: partial cutting, at least in those forms that avoid rectilinear strips or patches, is simply much less noticeable to the public, and also less distinguishable from natural vegetation patterns. It may also convey to the public a stronger or clearer sense of "care" on the part of forest managers (Sheppard, 2001).

By extension, then, the lack of visibility of the "cut block" frees partial cutting from the limitations of "percent alteration" and adjacency. The majority of a hillside or visual landscape unit could in theory be harvested by partial cutting without necessarily reducing the level of visual quality.

The percent denudation allowable when clearcutting is used to meet VQOs, as well as percent basal area allowable for partial cutting to meet given VQOs, are presented in Table 1.[12] Timber available is defined as what could be harvested at any one time while meeting a given VQO, taking into account previously harvested areas which have not yet achieved Visually Effective Green-up (VEG)[13] (BCMoF, 1994b). Thus, for example, according to the BCMoF (1998a) timber availability projections, a VQO of Partial Retention typically can be met with from 5.1% to 15% denudation (measured in plan) of a Visual Sensitivity Unit[14] (often a discrete hillside – see Figure IIa), other factors being equal. By contrast, the BCMoF figures indicate that the same VQO can be met[15] with a basal area removal of 65-70% with certain partial cutting practices. This could potentially extend over much of the Visual Sensitivity Unit (Figure IIb).

In practice, since considerable portions of the Visual Sensitivity Unit often fall into the non-operable category, the actual % denudation suggested to meet a particular VQO with clearcutting, is a higher % of the "green operable" area (Figure IIc). This ratio of green operable to green non-operable is generally estimated at 2:1 on average across BC (Marc, 1999, pers. comm.) and could allow for one and a half time as much denudation of available stands (when clearcutting is used). Figures using a 2:1 green operable/green inoperable ratio were also included in Table 1 for comparison purposes. However, as shown in Table 1, partial cutting approaches still yield greater timber availability under the most commonly applied VQOs

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[12] Table 1 is inserted at the end of the document to facilitate reading.

[13] VEG is usually expressed in tree height and varies depending on slope, distance, stand attributes, etc. As an example, a VEG of 5 meters was modelled in TSR 1 for the Arrow Forest District (BCMoF, 1994a). It is also important to note that partial cutting is not subject to VEG or to the adjacency constraints.

[14] A Visual Sensitivity Unit (VSU) is a distinct topographical unit as viewed from one or more viewpoints, delineated based on the homogeneity of the landform and of biophysical elements comprised in a scene (BCMoF, 1997c).

[15] With a probability of 70% or greater (BCMoF, 1998a).

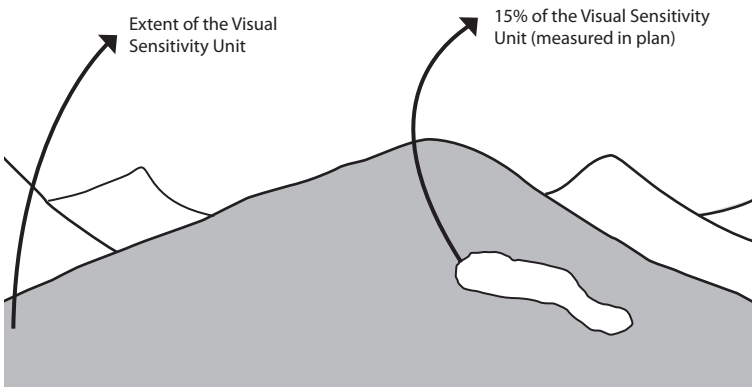

Figure IIa:
Percent denudation guideline to meet a Partial Retention VQO with clearcutting.

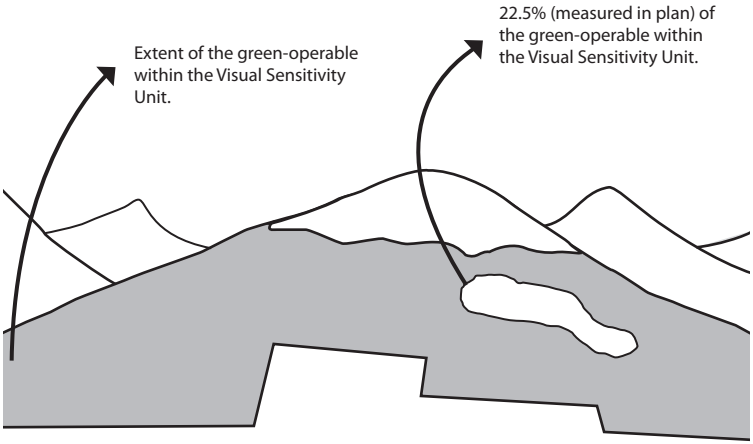

Figure IIc:
Percent denudation for clearcutting within green operable areas to meet a Partial Retention VQO.

(Retention, Partial Retention, and Modification), assuming that percent denudation is roughly equivalent to basal area removal, at the landscape unit level.

From Table 1, for any VQO, the greatest short-term timber availability occurs when partial cut is considered. Similarly, for any given timber availability, highest visual quality is achieved when using partial cutting. This is due to the assumed avoidance of percent alteration/denudation limits (i.e. cut block limitations) with partial cutting. This, along with public preferences for partial cutting techniques in visually sensitive areas (as per reviewed literature), indicates potential to increase

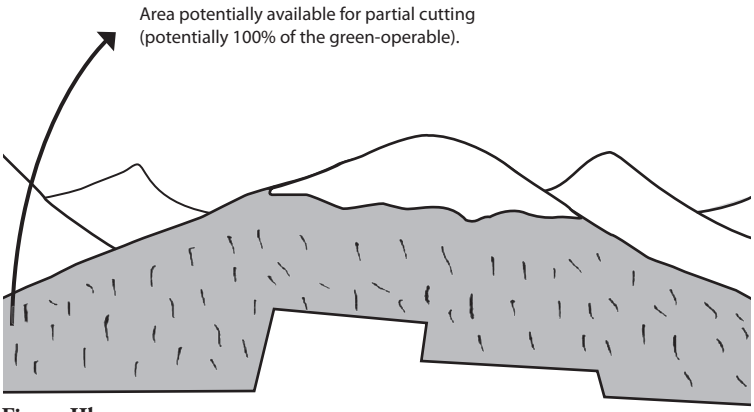

Figure IIb:
Partial cutting to meet a Partial Retention VQO.

Table 1:
VQOs associated with different levels of timber removal under clear-cutting and partial cutting (derived from BCMoF, 1998a).

VQOs	Clearcutting		Partial Cutting
	Percent (%) denudation (as measured in plan)	Percent (%) denudation with a 2:1 green operable/ green non-operable ratio	% Basal area available for partial cutting[a]
Preservation	0–1	0–1.5	–[16]
Retention	1.1–5	1.6–7.5	5–45
Partial retention	5.1–15	7.6–22.5	65–70
Modification	15.1–25	22.6–37.5	95
Maximum modification	25.1–40	37.6–60	–[17]
No VQO	100[18]	100	100[19]

[a] The basal area available for partial cut represents the basal area that could be harvested and retain at least a 70% probability of meeting the established VQO (BCMoF, 1998a).[20]

[16] No value is available for the Preservation and Maximum Modification VQOs because of the small sample used for these VQOs, in the perception study (BCMoF, 1997a) on which these figures are based.

[17] Id.

[18] Theoretical assumption of available timber under No VQOs and with no other legislative constraints.

[19] Id.

[20] The probability cut-off of 70% or better (which contributes to the discontinuities observable in the range of percentage basal area removal in the last column of Table 1) comes from a recommendation for timber supply analyses stated in BCMoF (1998a). No extrapolation was made to fill these gaps since the BCMoF documents (1998a) did not provide guidance on how to direct such extrapolation.

either the available timber or the visual quality of given landscapes by applying a shift in harvesting techniques. This is to be expected given the relatively low percent denudation available for harvest under VQOs with clearcutting and the high percentages of basal area apparently available with partial cut as suggested by the BCMoF (1998a) data (see Table 1).

However, some issues need to be considered before attempting to apply these hypothetical findings to the real world of forest management. Principal among these are the following:

1. Inaccuracies in assigning the same percentage of basal area in clearcutting to percent denudation. One of the assumptions made in the above comparison of clearcutting and partial cutting is that the recommended percent denudation values provided by BCMoF (1998a) are equivalent to percent basal area available (i.e. a ratio of approximately 1:1). In other words, we assumed that to clearcut "X" percent of a landscape would result in "X" percent of basal area removal for that same landscape. This assumption is only true if the basal area is constant over the landscape, which would most likely not be the case in a "real world" situation. Basal area is a stand-level attribute, while percent denudation is a landscape-level attribute. High landscape variability of basal area may also reduce the validity of using basal area averages. However, despite this inaccuracy, the theoretical approach presented above still reflects trends in the VRM-timber availability relationship.

2. Cutblock size and extent of partial cutting. While extensive partial cutting over an entire landscape, unlike clearcutting, may theoretically meet VQOs, there is inevitably a physical limit to individual harvesting blocks and the rate at which a finite pool of labour and equipment can harvest the entire forest landscape. It has not yet been established that partial cutting over entire land-scapes in BC would meet VQOs, since the limited samples used in perception testing do not contain such large scale harvesting blocks. However, preliminary analysis of certain case studies using innovative partial cutting techniques over entire hillsides (e.g. Timfor's operation at Knight Inlet) show that visual quality may be maintained while allowing significantly more timber to be removed (Sheppard *et al.*, 2004). In the latter case study (Sheppard *et al.*, 2004), the extensive use of partial cutting, landscape design, and alternative management approaches resulted in Forest Stewardship Council (FSC) certification being provisionally granted, in addition to yielding increased timber availability.

3. Under partial cutting, rotation length, regeneration and growth rates under partially shaded conditions, species regenerated and the sustainable rate of cutting may also reduce the initial volume advantage of partial cutting over clearcutting under VQOs over the long run. Some forms of partial cutting may not be compatible with management goals of emulating natural disturbance in some forest types.

4. Other overlapping constraints: as discussed earlier, other resource values and policies (e.g. water quality, biodiversity requirements) may limit the areas available for harvesting, and the resultant available timber. If partial cutting is subject to the same restrictions from other resources values as clearcutting, this would reduce the apparent "partial cutting gain" over clearcutting under VQOs, particularly in visual landscape units with higher VQO Intensities where clearcutting is the most tightly constrained. Some forms of selection harvesting over large areas may impact biodiversity, for example, through snag reduction.

5. Feasibility and cost viability of partial cutting: various factors may combine to limit or even exclude the possibility of partial cutting, e.g. silvicultural and productivity requirements, risk of windthrow, disease, worker safety, operational costs, and difficulty of harvesting in steeper terrain (Nyland, 1996).
6. The spatial extent of the visual sensitivity units within which the percent alteration or percent denudation is calculated can be critical. 5% of a large hillside or valley can permit large openings whereas 10% of a small unit may restrict harvests to patch cuts with a different set of cost/volume ratios.

Other less obvious factors may reduce the partial cutting potential gain over clearcutting under VQOs. Planning and permitting procedures, which are geared for clearcutting, combined with the relative lack of experience with partial cutting in industry and government, may add to the "red tape", complexities, and delays in approving partial cutting operations. Also, the apparent relative losses in volume with clearcutting under VQOs may be reduced in practice by application of the maximum percent denudation levels recommended in the BCMoF (1998a) procedures, rather than using the average levels. The application of skilful forest design, as advocated in the training manuals for the BCMoF (1995e), may also allow higher volumes to be removed with clearcutting or mixed harvesting systems while still attaining VQOs. As indicated earlier, the relationships shown in Figure II may also exaggerate the advantages of partial cutting at higher volume removals, since we have very little information on public judgements of visual quality at these levels. There may also be fears on the part of industry that reduced growth rates under partial cutting may lead to reduced Annual Allowable Cut allocations.

However, where alternative harvesting techniques with at least some kinds of partial cutting can be shown to be feasible, and within the range of low to moderately high basal area removals, there appears to be a strong possibility that VQOs may cease to act as a major constraint on the timber resource relative to other resource constraints.

However, despite available evidence which suggests that for any given set of VQOs, the greatest timber availability occurs when partial cutting is used, there would appear to be different visual effects with different partial harvesting techniques for a given volume removal. A uniform partial cut shows residual trees having an evenly distributed pattern throughout the harvested area, for the same basal area removal rate. There is a wide range of partial-cut harvesting techniques and silviculture systems, ranging from low-intensity thinnings which are almost imperceptible in the landscape to seed tree and wildlife patch techniques that may look like clearcutting to most people. The notion of perceptible thresholds in the effect of timber harvesting on the visual integrity of the forest may have major implications for the public acceptability of the practice of Variable Retention (for example) as an alternative to clearcutting, as espoused by (originally MacMillan Bloedel Ltd.) Weyerhaeuser Company (Anonymous, 1999).

Conclusions

Despite the potential for partial cutting to accommodate significant amounts of timber harvesting in visually sensitive areas, many concerns need to be addressed before such actions can be implemented. Among these, forest health implications, potentially reduced growth rates, increased costs in planning time and field layout,

longer approval processes, potential increased risks for forest workers, and windthrow are just a few. Definitive studies evaluating alternative harvesting strategies are needed to be able to document the likely effectiveness of partial cutting in visually sensitive areas. Such research should include: modelling growth and yield linked to partial cutting, assessing cost effects, long-term supply impacts of partial cutting, approval delays (if any), rotation length, etc. At the same time, pinpointing public perception visual thresholds for partial cutting activities, monitoring costs, tracking of constraint overlapping, and testing of different designed harvesting patterns need to be carefully analysed.

Meanwhile, the percent alteration measures currently used under a clearcut system with VQOs are useful in predicting timber supply impacts, but may be overly limiting in some cases at the forest design/cut-block planning level. In the authors' opinion, they should not be used uniformly as a rigid timber supply constraint in practice or as the dominant visual design determinant. Instead, increased landscape design resources and training are needed to deliver the more flexible solutions promised by the BCMoF (1998b) – without loss of visual quality. VQOs do appear to be useful as an effective and defensible performance standard, both in the front-country and increasingly in backcountry recreation and ecotourism settings. Further work is needed to explore inconsistencies in the methods used to estimate the impacts of VRM on timber availability and other resources/values, i.e. between the TSR/AAC modelling process, official VRM policies, spatially explicit modelling exercises, and actual implementation on the ground.

In summary, where BC resource managers are concerned with accessing a limited timber supply while maintaining visual quality in the front-country, available strategies would include the following:

- Maintain VQOs in visually sensitive areas as is currently done, along with the current procedures for percent alteration limits for clearcutting, but whenever possible, use certain partial cutting approaches to maintain visual quality.
- Maintain VQOs as they are now, but remove percent alteration/denudation as the effective performance standard, and use better landscape design to allow greater flexibility, e.g. through larger irregular openings, feathering, etc. To be effective, this would require much more training than is given now, as well as many more landscape architects and landscape foresters than are currently employed in BC.
- Relax VQOs selectively and use a public education program, alternative planning processes, and perhaps an ecological aesthetics movement, as advanced by Gobster (1995), to convince the public that certain practices which are currently unpopular, may be ecologically desirable, particularly when traded off against back-country or old growth preservation. The success of this latter strategy may depend upon increased community involvement and ownership of the design and decision-making process.

The need for such strategies would be further increased if visual qualities in the back-country were to be more proactively managed in recognition of tourism opportunities and public pressure, while limiting impacts on timber availability. Allowing some timber flow from the front-country, via visually acceptable harvesting techniques and landscape design, may provide an effective trade-off and allow

such recognition of visual quality in the back-country. Front country areas, often harvested at the turn of the century, may offer more volume, higher site index, reduced fire risk and shorter hauls, while the back-country/higher elevation areas may in some cases have less volume, lower site index, and longer hauls. Such a shift in location of timber harvesting to more visible areas, rather than less visible areas, will require a major effort on the part of industry to exhibit "visible stewardship" of these much-loved front-country places (Sheppard, 2001).

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RECREATION MANAGEMENT

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RECREATION MANAGEMENT

Introduction

Traditionally in North America, the management of forested lands has been primarily concerned with the effective and efficient harvest of timber. However, there has been a shift in forest management to a more holistic paradigm that recognizes the value of non-timber forest amenities including aesthetics and outdoor recreation (Prins *et al.* 1990). While the continued extraction of one of the world's most significant renewable resources is an important aspect of modern forest management, it is no longer sufficient for this to be the sole concern of the forester. Outdoor recreation participation has grown in North America, especially after World War II, due to increases in leisure time, incomes, access, and population (Stankey *et al.* 1990). British Columbia (BC) has not been immune to these increases: between 1984 and 1994, the BC Ministry of Forests (1995a) reported a 35% increase at managed recreation sites and trails. Indeed it is largely because of the relevance of these factors that outdoor recreation in BC requires careful consideration in natural resource management and planning – the recreating public is competing for many of the same resources and landscapes that are desirable for forestry.

For many people (especially those who are not associated with the forestry profession), the pursuit of an outdoor recreation activity provides the impetus to interact with forested landscapes and is therefore the basis for much of the general public's impressions of forestry as a whole. For these people, outdoor recreation experiences are shaped in part by the setting within which these activities take place (i.e. forest outdoor recreation becomes the interface through which people experience forested landscapes and it is through this interface that people develop affinities or attachments for certain places, be they in parks or on Crown land). This is one of the reasons that it is important for forest managers to consider outdoor recreation when engaging in forest planning. People expect the areas that they visit and play in (and have become attached to) to be *cared* for. Not only do people *want* their forests cared for, but foresters have a professional responsibility to act as in the best interests of the society whose resources they are charged with managing. It is for these reasons that recreation deserves our attention in this handbook.

The word *recreation* literally means to recreate or restore. This renewal and refreshment occurs through participation in an activity that is pleasurable and is free of typical demands or restraints – it reflects a conscious choice to disengage from work. Outdoor recreation then, is the pursuit of a pleasurable activity during leisure time that takes place outside, or more specifically, in the natural environment. These sentiments are reflected in the British Columbia Ministry of Forests' (BCMoF) definition of recreation:

> …any mental or physical revitalization as the voluntary pursuit of leisure time. Outdoor recreation is recreation that takes place out-of-doors, and forest recreation takes place in a forest or wildland setting (1991, p. G9).

Outdoor recreation is best conceived of as a field of study rather than as a discipline in itself, for it brings many disciplines to bear on particular issues or problems, and can be both interdisciplinary and multidisciplinary. As a field, outdoor recreation focuses attention on activities that are pursued in leisure time; in the context of forestry, these are activities that take place in forested landscapes.

The BCMoF (1995a) has recognized the role that social science can play in recreation resource management: "Social research can improve knowledge about the use, value and demand for outdoor recreation and public perception studies support many aspects of recreation management" (p. 189). Among some of the more traditional disciplines that study recreation and contribute to a fuller understanding of the subject are sociology, psychology, landscape architecture/landscape planning, geography, economics, and political science. Studies and research in forestry, business, and medicine have also helped to further the understanding of outdoor recreation issues and concerns. In addition, there are a number of recreation, park, leisure studies and tourism programs that are making major contributions to the subject of recreation. Indeed one of the challenges facing people who study outdoor recreation is the integration of the research findings from these disciplines into concise outdoor recreation theory. We have chosen to highlight some of the research topics from a few of the more traditional disciplines that study recreation (see Table 1); however, this list is not exhaustive.

Table 1:
Some examples of recreation research areas of traditional academic disciplines.

Discipline	Research Topic Examples
Economics	Utility theory, choice, and value.
Geography	Spatial behavior and location theories.
Landscape Architecture	Recreation site design and landscape level planning.
Psychology	Focus on the individual, perception and cognition, learning, attitude & behavior.
Sociology	Social structure and change, group behavior, institutions, status, norms, conflict.

Economics is an important discipline in the study of outdoor recreation; in this context, economics deals with the allocation of scarce resources and may concentrate on maximization, optimization, and cost effectiveness of a variety of recreation benefits. Applications of economic analysis to recreation and tourism include: estimation and prediction of demand and supply, valuation, determination of regional economic impacts, and use of economic analysis in management, marketing and policy decisions. Many of our societal decisions have economic assumptions at their root, and the desire to be able to quantify both market and non-market

values for inclusion in decision-making tools such as cost/benefit analysis has led economists to develop a number of methodologies that are used to estimate dollar measures of economic values associated with recreation. Some of the methods most commonly used to accomplish this task are: market price, hedonic pricing, travel cost, benefit transfer, substitute cost and contingent valuation/choice methods. For further discussions of these methodologies see, Bateman and Willis (1999), Boardman *et al*. (2001), Loomis and Walsh (1997), Adamowicz *et al.* (1998), Boxall *et al*. (1996) and Tietenbuerg (2000).

Over the last 60 years, geographers have developed robust spatial theories and methods of spatial analysis that address them (Golledge and Stimson, 1997).These theories have been applied to issues related to recreation planning and management and have contributed to our understanding of these fields. Examining the locations, movements and interactions of people engaged in recreational activities within the environment has become an area of interest to today's geographers. This has been done at many scales and has led to a better understanding of regional human-environment relations, a significant factor in learning how to effectively balance human needs and environmental protection. Additionally, a number of spatially explicit models of recreation behavior have been developed using the capabilities and theories of modern day geographic information systems (e.g. Deadman *et al.* 1994 and Gimblett *et al.* 1999; 2001a; 2001b). For further discussion on geography's contribution to recreation we suggest readers consult Carlson (1980), Hall and Page (1999), Mitchell (1994), and Smith and Mitchell (1990).

Landscape architecture and landscape planning have made valuable contributions to the management of outdoor recreation through the development of management and planning tools and through the application of design to the planning process. Naussauer (1995; 1988) has suggested that the adoption of a principle of care or neatness can have an effect on people's perceptions and attitudes toward landscapes. Management tools like the *Limits of Acceptable Change*, *Visitor Activity Management Process*, and the *Visitor Impact Management* process have assisted park planners and landscape managers in providing recreation opportunities that are enjoyable and meet the desires of people using areas for recreation, while at the same time taking other landscape values in to account such as ecology (Payne and Graham, 1993; Stankey *et al.* 1990). Other planning tools that have been developed include inventory tools like the *Recreation Opportunity Spectrum* and the *Recreation Features Inventory*; these tools are being used in BC to keep track of recreation opportunities and to allow for recreation to be considered in forest landscape planning. These planning and inventory tools are described later in this chapter.

Sociological methods and theory have been used to examine the behaviour of groups of people that participate in outdoor recreation. These groups may be centered on a particular recreation activity like rock climbing, backcountry skiing, or hunting, or reflect larger segments of society like demographic groups. Not only do groups of recreation participants seek out particular activities, these groups may also desire similar experiences and settings in which to engage in their activity (e.g. Twynam and Robinson, 1997). A better and fuller understanding of how groups of people organize themselves, and how these groups interact with the environment in which they pursue recreation can help to determine which activities are popular

or exist in an area, and may also assist in the management of the areas that support the activities that are desired (e.g. Robson *et al*. 2000).

Psychology differs from sociology in its focus, as it deals with individual people instead of groups of people. Psychological research into outdoor recreation has included investigations of the motivations of people for pursuing certain activities (e.g. Csikszentmihalyi, 1990; Jones *et al.* 2000), and how people assess and perceive the landscapes that they interact with (e.g. Meitner and Daniel, 1997; Weidemann *et al.* 1997). Virden and Knopf (1989) have examined the psychological relationships between recreation activity, desired experiences and preferred environmental setting. In addition, an interesting body of research investigating the effects of people's experiences with environments on psychological well-being, physiological systems, and health outcomes was pioneered by Roger Ulrich, a noted environmental psychologist (see Ulrich *et al.* 1991; Ulrich, 1984; and Parsons *et al.* 1998).

Most social science research that has focused on outdoor recreation has been a combination of sociology and psychology, and has been termed *social-psychology*. Social-psychology has also had an influence on recreation research as demonstrated by Mannell and Kleiber (1997). Other categories of social-psychological research includes: leisure studies (e.g. Jackson & Burton, 1999) recreation participation and its constraints (e.g. Crawford *et al.* 1991); recreation choice and behaviour (e.g. Haider and Hunt, 1997); and social interaction and its processes among recreationists and social groups and the nature and quality of recreation experience and its beneficial consequences. Manning (1999) provides an excellent synopsis of the role of the social sciences in outdoor recreation research and is a must read if you have an interest in this area.

Outdoor Recreation Use and Trends in BC

Outdoor recreation in BC is growing, both in popularity, and in significance. In response to this trend, the BC Ministry of Environment, Lands and Parks (BCMELP) launched a comprehensive eco-tourism and adventure travel strategy to address what has been termed the *green economy* (or financial return on services and products that focus on the natural environment, or that consider environmental impacts); BCMELP also recognized that participation in outdoor recreation activities provide significant benefits in terms of quality of life and human health (BCMELP, 2001). It should be noted that in the summer of 2001 BCMELP was split into the Ministry of Sustainable Resource Management (BCMSRM) and the Ministry of Water, Land and Air Protection (BCMWLAP) both of which now share the responsibility for the management of recreation concerns. For example parks and protected areas management falls under the jurisdiction of BCMWLAP, while general landscape planning falls under the jurisdiction of BCMSRM.

The popularity of outdoor recreation is reflected in the number of British Columbians that have visited a park or protected area: 90% have visited a protected area at least once in their lifetime and 60% of residents visit protected areas on an annual basis. There is strong sentiment among British Columbians that provincial parks should be protected from privatization and commercialization (The Legacy Panel, 1999).

In June of 1999, amendments to the *Park Act* protected 1.4 million hectares of land as Class A Parks[1] – this represents a 22.5% increase in the area of parkland and ecological reserves from 1989-1999; in 1993-1994 there were 1.8 hectares of parkland for each BC resident, by 2000-2001 this had increased to 2.8 hectares despite an increase in provincial population (BCMELP, 2001). This increase in the amount of parkland may have been a response to the increases in park visits: between 1993 and 1999 park visitation increased 16.86% to 26.5 million visitors annually; however, park visits decreased in 2000 to 23.5 million visits (an increase of only 3.82% from 1993). Alternatively, this may simply represent a desire to set aside more public land for future generations. Whatever the reason, it is clear that land set aside for recreational purposes has increased; this underscores the need for resource managers with an understanding of the relevant dimensions of outdoor recreation.

The public's pursuit of outdoor recreation in British Columbia does have some positive economic benefits to the province. For the period 1993-2000, the annual revenue that was retained by park facility operators increased 35.85% to $10,625,000 (BCMELP, 2001). A study by the BC Ministry of Water, Land and Air Protection (BCMWLAP) found that the total expenditures related to provincial parks in 1999 was $533 million, 90% of this figure was estimated to be visitor expenditures (33% of these expenditures came from out-of-province visitors); for every dollar invested in parks by the Government, ten dollars was spent by park visitors (BCMWLAP, 2001).

However, the provision of, and public participation in, outdoor recreation is not limited to parks and protected areas. Public forestlands (i.e. Crown land) also provide outdoor recreation opportunities; indeed some activities, such as hunting and the use of ATVs and other motorized recreational vehicles, are not permitted in parks – provincial forestlands are the only places that these opportunities can be pursued.

The BC landbase is 94.8 million hectares; the BCMoF administers 81.9 million hectares (86%) of this landbase (BCMoF, 2001). Of the land that is under BCMoF jurisdiction, roughly 60% is productive forestland – these landscapes also provide settings that are attractive for outdoor recreation. The BCMoF (1995a) reported that during the ten-year period spanning 1984-1994, outdoor recreation use increased 35% at managed recreation sites and trails. A total 88 million user-days was reported for outdoor recreation use on provincial public lands for 1992-1993.

In 1995, the BCMoF reported that 18 million hectares (roughly 22%) of provincial forest land had special recreation values (BCMoF, 1995a); typically this *specialness*, or significance, is based on three criteria: recreation feature uniqueness, scarcity and attraction capability (BCMoF, 1995c). It is significant features, like the Mackenzie Heritage Trail in the Chilkooten, the Meager Creek hot springs near Pemberton, or the large redcedar grove near Cougar Mountain up Sixteen Mile Creek north of Whistler, that attract people to provincial forests; 51 million

[1]Parks are categorized into three levels of protection: Class A Parks have the highest level of protection; Class B Parks only allow for resource extraction activities that do not interfere with recreation (this category is being phased out, only two parks remain in this category); and Class C parks, which have the same degree of protection as Class A Parks, but are managed by local parks boards (Haddock and Brewster, 1999).

visitor days were recorded for provincial forests in 1993 (BCMoF, 1995a). Table 2 illustrates some of the recreation activities that people engage in.

Table 2: 1994 Outdoor recreation participation by activity in BC.

Recreation Activity	% Annual Participation
Hiking	59
Camping	49
Fishing	45
Downhill skiing	27
Canoeing/kayaking	20-25
Overnight camping	16
Cross country skiing	15
Hunting	10
Snowmobiling	7

Adapted from BCMoF, 1995a, p. 179.

A 1990 survey of BC Forest Service recreation site visitors found that 62% of respondents preferred natural settings to recreate in, and that 72% of respondents indicated that they would not use recreation sites that were located in recently logged areas (BCMoF, 1995a). Not only do people prefer settings that appear cared for (Naussauer, 1995; 1988), but some also prefer wilderness or backcountry settings. Outside of parks, 51 million hectares of provincial forests do not have roads in them, 37% of these (19 million hectares) are in commercial forests.

A ten-year review and analysis of forest, range and recreation resources in BC attempted to address the implications of possible resource scarcity or surplus (BCMoF, 1995a). This analysis found that the economic benefits of outdoor recreation in BC provincial forests was valued at $3 billion for 1993, expenditures for that year contributed $2.4 billion to BC's economy (88% from BC residents), and the net economic value was calculated as $867 million (84% from BC residents). The economic value of doubling designated wilderness areas in 1993 was also examined, and estimated to be $160 million (76% of this value was attributed to existence and bequest values, while the remaining 24% was attributed to option or use values). Total actual expenditures for outdoor recreation on Crown lands (which includes use in national, provincial and regional parks) was calculated at $4 billion/year (80% from BC residents), and the annual net value was estimated as $1.5 billion (BC residents accounted for 74%). Non-resident outdoor recreation expenditures in the province were valued at $780 million (BCMoF, 1995a).

The demand for outdoor recreation opportunities in BC is significant. When this demand is considered in light of the economic returns that recreation enthusiasts contribute to the provincial coffers, as well as intangible advantages that include improved quality of life, increased productivity, and assorted health benefits (Ulrich, 1984; Ulrich *et al.* 1991), it becomes apparent that outdoor recreation is a forest amenity that has become entrenched in BC resource management.

Outdoor Recreation and Provincial Legislation

Provincial legislation and policy pertaining to outdoor recreation in BC applies to all provincial Crown land outside of parks (i.e. all forested and non-forested land under provincial jurisdiction and non-municipal and rural settlements), but does not apply to private land, national and provincial parks, and other protected areas (i.e. regional parks and municipal lands) (BCMoF, 1995b). The management of provincial forestland for outdoor recreation can be expected to change due to changes in legislation and forest tenures (for example, community forestry tenures in BC require that non-timber values, such as recreation, must be managed for explicitly).

Until recently, the BCMoF's Recreation Management Policy recognized that recreation was a resource that included the full spectrum of recreation values and opportunities from scenic landscapes and wilderness areas to cultural and historic landmarks and developed facilities. The BCMoF's management of recreation would maintain and enhance these resources and balance all forest uses; this responsibility was informed through the identification of the recreation needs and interests of society through an ongoing consultation and discussion with the public (BCMoF, 1997a; 1991).

The recent review of governmental core services concluded that the management of recreation sites and trails would no longer be priority of the BCMoF. As a result, the management of all BCMoF recreation sites and trails will be transferred to other agencies and organizations (including forestry companies) or cancelled – this reorganization is scheduled to be completed by March 31, 2004. The new Results-Based Code will be sensitive to local stakeholder concerns and certification systems. While no longer an explicit management concern, recreation opportunities will be addressed through mechanisms like locally specified quality of life/benefits to society criteria and indicators. Community and social values and needs will continue to be a concern of provincial forest managers. The BCMoF is considering options for continuing to provide outdoor recreation opportunities in the province that include encouraging local communities and community groups to accept responsibility for the management of outdoor recreation opportunities and facilities. Although this transition away from integrated forest value management is in its early stages, there is some concern that the divestment of recreation resources may dilute provincial operating and environmental standards.

Outdoor Recreation Management Tools Used in BC

A number of tools are available for the management of outdoor recreation on provincial Crown land in BC. These tools have been divided into inventory tools (i.e. the *Recreation Resources Inventory*) and outdoor recreation management tools.

The Recreation Resources Inventory

There are a variety of tools that can be employed for the management of outdoor recreation, and for the integration of outdoor recreation into forest planning and management; the use of these tools can help provide the evidence of care for public lands that people demand. One challenge in managing recreation resources is the

difficulty of putting the somewhat abstract amenities provided by the physical environment that contribute to the overall recreational resource into practice.

In 1992, an analysis of BC's cultural, recreation, and tourism inventories identified 38 separate inventories that were maintained by different government agencies and levels of government that varied widely in geographic scope, level of detail, and resource focus. These inventories largely reflected the interests and mandates of the body that coordinated them and, due to the number of inventories and the number of bodies that was responsible for them, the information was not coordinated in a comprehensible fashion (Economic Planning Group *et al.* 1992).

The 1992 report, made recommendations for improving the state of cultural, recreation, and tourism inventories in order to facilitate better data sharing and maintain a high standard of data quality. Among the recommendations that were made were to: coordinate the inventories across government agencies and levels; to manage the data using a Geographic Information System (GIS); and set standards for common data requirements such as (i) assessment of resources (e.g. significance, capability, suitability, sensitivity, and vulnerability), (ii) robust and transparent data (e.g. quality of attribute and spatial data, sources, status and ownership of data, and the coordination of cartographic standards), and (iii) ensure that the data could be coordinated and integrated with other information (e.g. market, financial, economic and community information) (Economic Planning Group *et al.* 1992). To this end, the Recreation Resources Inventory (RRI) was developed to aid in identifying critical landscape features to be included in the landscape planning process.

The BCMoF has used the Recreation Resources Inventory to monitor and catalog recreation amenities. The BCMoF uses four separate recreation inventories to catalog these recreation resources: the Recreation Opportunity Spectrum, the Recreation Features Inventory (RFI), the Visual Landscape Inventory (VLI), and the Recreation Facilities Inventory (see Figure 1).

All four inventories noted above are used in land use planning and in forest operations planning to provide information about the recreation resources and amenities that are present in the planning area. The VLI and the RFI are used by the BCMoF in the Timber Supply Review (TSR) process and are also used by the Chief Forester to aid in the determination of Annual Allowable Cut (AAC). The Recreation Facilities Inventory identifies, both spatially and in an attribute database, the location, status, characteristics and structures that are associated with the forest recreation campgrounds, trails and interpretive sites that are managed by, or have been recognized by, the BCMoF.

The BCMoF is directed through legislation to develop and maintain ROS, RFI and VLI inventories. The Ministry of Sustainable Resources Management is primarily responsible for maintaining the Recreation Resources Inventory, although some responsibilities are shared with the BCMoF. The inventories have been coordinated by the Senior Recreation Inventory Forester of the Archaeological and Recreation Inventory Section of the Terrestrial Information Branch of the Ministry of Sustainable Resources Management.

It is important to note that all of the inventories that constitute the Recreation Resources Inventory are descriptive tools. They are provide information about what should be managed and are not intended to provide management direction, nor act as management prescriptions. Management goals and objectives are determined by government policy and though the consideration of public input.

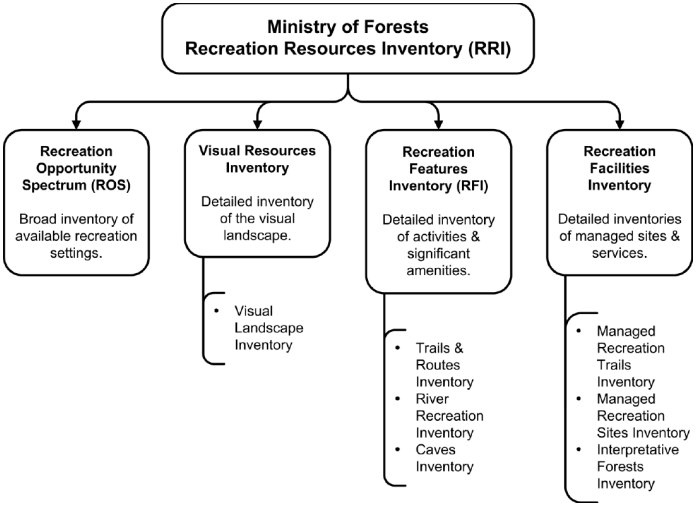

Figure 1:
Components of the BCMoF Recreation Resources Inventory (adapted from BC-MoF, 1998a).

The Recreation Opportunity Spectrum

The ROS was developed in the United States in the late 1970s as a tool to help policy makers and land managers respond to an increase in outdoor recreation use as well as other impacts on natural resources (including wilderness areas). It allows for macro (or regional) planning in a variety of settings. The management of outdoor recreation had become complex and required inter-agency cooperation for its management, as well as its integration with natural resource management. The ROS was created so that the diverse range of outdoor recreation opportunity settings could be identified and assessed according to a standard set of principles and definitions. An outdoor recreation opportunity setting is defined as "the combination of physical, biological, social, and managerial conditions that give value to a place" (Clark and Stankey, 1979, p. 1). The ROS considers opportunity in terms of three dimensions: the demand for activity opportunity (e.g. skiing or canoeing), demand for setting opportunity (e.g. backcountry or front country), and demand for experience opportunity (e.g. seeing one other recreation party or seeing seven other recreation parties) (Driver, 1989).

The basic assumption of the ROS is that outdoor recreation quality can be secured through the identification and provision of a diverse set of recreation opportunities. By identifying and providing a range of settings, "from the paved to the primeval" (Nash, 1973), managers can offer recreation opportunities that will appeal to broad segments of the public as well as for future generations (Clark and Stankey, 1989; Driver, 1989). This principle has been recognized in the management of outdoor recreation in BC:

> A recreation opportunity is the availability of choice for some-one to participate in a preferred recreation activity within a preferred setting and enjoy the desired experience.
>
> (BCMoF, 1998b, p. 1)

The BCMoF uses the ROS to catalog areas of BC according to their current states of remoteness, naturalness, and expected social experience, and to provide land use planners and resource managers with information about existing outdoor recreation opportunities and settings. The information can be used to incorporate recreation opportunities into TSR, and can also assist in the development of recreation guidelines in Higher Level Plans and forest district level recreation planning (BCMoF, 1998b). The ROS can be used to estimate the effects of management decisions, and may be applied to integrate outdoor recreation supply and demand information into other outdoor recreation management frameworks (see below); information that is derived from ROS analysis is applicable for most landscape planning exercises (Nilsen and Tayler, 1997).

In BC, the ROS identifies seven opportunity settings (or *classes*) along a continuum; these classes are identified and described in Table 3. The factors that distinguish one ROS class from another are remoteness, naturalness, and social experience. Remoteness is measured in terms of access and the size of the areas being considered (*e.g.* larger tracts of undisturbed forestland that are further away from roads are needed for more primitive areas); in BC, the size and distance from road criteria have been increased from the USA standard for Semi-primitive and Primitive classes. The level of naturalness that is necessary for a particular ROS class is determined by the presence and degree of motorized use and evidence of human use (i.e. infrastructure). Social experience accounts for the degree of opportunity to experience things such as solitude and closeness to nature, as well as the degree of challenge that is available and the level of self-reliance necessary to have an enjoyable recreation encounter.

Clark and Stankey (1989) suggest that when all of the ROS classes are available, changes in recreation demand can be accommodated more readily than if they were not, by virtue of a diverse set of recreation opportunity settings. It should be noted that it is a relatively easy task to change an area's recreation setting from a primitive state to a more developed one (e.g. from *Semi-Primitive Non-Motorized* to *Roaded Modified*) – one need only improve motorized access and increase the amount of infrastructure; however, the same does not hold true for movement in the other direction. In order to change a recreation setting from some state of development to a more primitive state (e.g. *Semi-Primitive Motorized* to *Primitive*), access must be discontinued and the area must be left to reclaim any evidence of human development; while possible; it must be recognized that this process may take a long time – the full benefit of this shift may not be appreciated for generations.

Recreation Features Inventory

The Recreation Features Inventory (RFI) is a descriptive tool that catalogs biophysical, cultural and historic landscape features and assesses their recreational value within a local context. The RFI assesses recreation features that are present in a landscape and divides that landscape into discrete sub-components based on biophysical features that have recreational value. These subcomponents are called *Recreation Feature Polygons* (RFPs), and form the basis for the RFI. The public may be also asked to provide input to this process to aid in an assessment of the recreational value, or *significance*, of an area. Each RFP has four classifications associated with it: recreation features; recreation activities that are associated with

Table 3: ROS polygon delineation standards (BCMoF, 1998b, p.13).

ROS Class	Factors					
	Remoteness		Naturalness		Social Experience	
	Distance from road (km)	Size (ha)	Motorized Use	Evidence of Humans	Solitude/Self-reliance	Social Encounters
Primitive (P)	> 8	> 5000	• Occasional air access, otherwise no motorized access or use in the area.	• Very high degree of naturalness. • Structures are extremely rare. • Generally no site modification. • Little on-the-ground evidence of other people. • Evidence of primitive trails.	• Very high opportunity to experience solitude, closeness to nature; self-reliance and challenge.	• Very low interaction with other people. • Very small party sizes expected.
Semi-Primitive Non-Motorized (SPNM)	≥ 1 from a 4-wheel-drive road.	≥ 1000	• Generally very low or no motorized access or use. • May include primitive roads and trails if usually closed to motorized use.	• Very high degree of naturalness. • Structures are rare and isolated except where required for safety or sanitation. • Minimal or no site modification. • Little on-the-ground evidence of other people.	• High opportunity to experience solitude, closeness to nature, self-reliance and challenge.	• Low interaction with other people. • Very small party sizes expected.
Semi-Primitive Motorized (SPM)	≥ 1 from a 2-wheel drive road	≥ 1000	• A low degree of motorized access or use.	• High degree of naturalness in the surrounding area as viewed from access route. • Structures are rare and isolated. • Minimal site modification. • Some on-the-ground evidence of other people. • Evidence of motorized use.	• High opportunity to experience solitude, closeness to nature, self-reliance and challenge.	• Low interaction with other people. • Small party sizes expected.
Roaded Natural (RN)	≤ 1	N/A	• Moderate amount of motorized use within the area. • May have high volume of traffic	• Moderate degree of naturalness in surrounding area. • Structures may be present and more highly developed. • Moderate site modification.	• Moderate to high opportunity to experience solitude, closeness to nature, self-reliance and	• Moderate interaction with other people. • Small to large party sizes expected.

			through the main travel corridor.	• Some on-the-ground in evidence of other people. • Some on-site controls. • Typically represent main travel corridors and recreation areas that have natural-appearing surroundings.	challenge.	
Roaded Modified (RM)	≤ 1	N/A	• Moderate to high degree of motorized use for both access and recreation.	• Low degree of naturalness. • Moderate number of more highly developed structures. • Highly modified in areas, generally dominated by resource extraction activities. • On-the-ground evidence of other people and site controls.	• Low to moderate opportunity to experience solitude, closeness to nature, self-reliance and challenge.	• Moderate to high interaction with other people. • Moderate to large party sizes expected.
Rural (R)	≤ 1	N/A	• High degree of motorized use for both access and recreation.	• Very low degree of naturalness. • Complex and numerous structures, high concentrations of human development and settlements associated with agricultural land. • Obvious on-the-ground evidence of other people and on-site controls.	• Low opportunity to experience solitude, closeness to nature, self-reliance and challenge.	• High interaction with other people. • Large party sizes expected.
Urban (U)	≤ 1	N/A	• Very high degree of motorized use for both access and recreation.	• Very low degree of naturalness. • Highly developed and numerous structures associated with urban development. • Very high site modification. • Obvious on-the-ground evidence of other people and on-site controls.	• Very low opportunity to experience solitude, closeness to nature, self-reliance and challenge.	• Very high interactions with other people. • Very large party sizes expected.

those features; the significance of the features and the associated activities, and the sensitivity of those features to development or recreation use (BCMoF, 1998a). The RFI records each RFP as a spatially geo-referenced map linked to an alpha-numerically coded attribute database. The *Recreation Features Inventory: Standards and Procedures Manual* (BCMoF, 1998a) should be consulted for a complete listing and definition of these classifications and codes.

The recreation features that are described in the RFI are based on biophysical, cultural and historic elements that are present in a landscape. The biophysical features include shoreline and hydrological elements, water bodies, vegetation, glacial and landform characteristics and wildlife elements. Human-developed features that are described in the RFI include trails, campsites, and cultural, historic and other human-made developments. Up to eight recreation features can be identified for any RFP, but only the three most significant features are included in the map label (BCMoF, 1998a).

The recreation activities that are identified in the RFI are based on their existing or *potential* occurrence in the RFP. Activities that do not currently take place in a RFP but lend themselves to the biophysical or human-developed features are included in the inventory – this permits resource managers to consider future recreation uses of an area. As with the recreation features, up to eight activities may be described in the database but only the three most significant are included in the map label.

The significance of an RFP is rated on a four-point scale (very high, high, medium and low) based on the relative importance of the recreation features and their associated activities to other RFPs within the forest district. RFP significance is based on either a single or combination of factors, including: activity attraction capability, uniqueness, scarcity, scenic view, current recreation use and accessibility. Significance factors are noted for each RFP. An RFP that has been rated *very high, high* or *medium* for significance must include a statement outlining the rationale for the rating.

The RFP sensitivity classification indicates the resiliency or vulnerability of the RFP to potential alterations caused by resource development. This classification identifies the recreation feature that, regardless of its significance, relative to the other features present, is the most sensitive to use or development. Sensitivity is ranked on a three-point scale from *high* (i.e. development would have a major impact) to *low* (i.e. development would have a low impact). The type of alteration that dominates the RFP is also noted – examples of alteration may include timber harvest openings, power lines, transportation routes, human-made structures, or recreation use. Any RFP that has been rated *high* or *medium* for sensitivity must include a statement outlining the rationale for the rating. Finally, if the RFP or feature being described has provincial recognition (e.g. by Land Resource Management Plans, Regional Landscape Plans or Tree Farm License Plans), then this is noted.

Other inventories are included under the umbrella of the RFI: the *River Recreation Inventory*, the *Caves Inventory*, and the *Recreation Trails And Routes Inventory*. These inventories are not currently as fully developed or as complete as the RFI but were initiated to recognize more specific values that these features provide to outdoor recreation participants.

The *River Recreation Inventory* is an expansion of the river feature that is included

in the RFI and is divided into three river recreation elements: river features, river experience class, and white water class. Each element is inventoried separately, though it may be carried out at the same time. The information cataloged as *river recreation features* is similar to the information that is collected for the broader features classification of the RFI. However, this inventory is limited to those features that fall within approximately ten meters of the high water level of either river shore. It also includes other attributes such as: dominant river pattern, river recreation activities, mode of travel to the river, access distance from nearest road and boat launch types. A river is delineated into separate zones based on the combination of features identified with it. These zones are then assessed for feature significance and feature sensitivity as per the RFI. The *river experience class* is similar in scope and theory to the ROS. However, a river is delineated into separate zones and rated, based on what is seen and heard while floating the river and on the duration of the experience rather than on the distance a river is from a road. The *whitewater classification* provides information about the difficulty of running the river, and is based on the *International Whitewater Classification* system (a six-class classification from *easy* to *extreme*) (BCMoF, 1995c). Currently, these *River Recreation Inventories* have been piloted on three rivers: the Cowichan, Nanaimo, and the Chilliwack rivers; data is available for two other rivers, but are not complete inventories.

The *Cave Inventory* provides more specific information on caves and karst features that should have been identified in the RFI, and includes data on the location, type of cave, dominant rock type, geological formation, and length of all known passages. Caves contain fragile ecosystems and formations that require careful management to maintain their integrity, for this reason, management recommendations are made (BCMoF, 1995c). Presently, the *Cave Inventory* contains data for Vancouver Island Forest Districts but could be applied across the province. This inventory is classified information, to protect the caves from vandalism and inexperienced spelunkers.

The third inventory that falls under the umbrella of the RFI is the *Recreation Trails and Routes Inventory*. This database is similar to the River Recreation Inventory, as it is based on the delineation of zones along linear recreation features that are approximately ten meters on either side of the trail or route. Other information collected includes: the trail name, the feature significance of the trail or route, and the trailhead's distance from the nearest road. This inventory is still in development.

The *Backcountry Monitoring Inventory* tracks the condition of backcountry areas using permanent and temporary sampling locations to assess the status and change in environmental conditions over time. This inventory tracks attributes such as percent vegetation cover, percent exposed mineral soil and tree reproduction and uses statistical analyses to project the level of environmental deterioration or reclamation (BCMoF, 1995c). This inventory has been used in a few selected back-country areas in the province.

The detail and amount of information that is identified and cataloged in the RFI makes it a powerful tool for resource management, as it allows for the inclusion of recreation features and activities (as well as management considerations) in operational planning. The information provided by the RFI, as well as the other inventories under its umbrella is spatial; this allows resource managers to both recognize the recreation values that may be present in an area, and to assess the impacts of development or other changes to forestland.

Visual Landscape Inventory

The importance of visual considerations in forest management has been generally accepted; indeed, the public tends to judge forest management by how it looks (Sheppard and Harshaw, 2001). People are drawn to attractive landscapes, or areas that have aesthetic qualities; coincidently, these areas frequently contain merchantable timber or other resource values (BCMoF, 1994). For a more thorough discussion of visual resource management see the following chapter by Picard and Sheppard in this volume.

The *Visual Landscape Inventory* (VLI) delineates, classifies and catalogs visually sensitive areas of BC so that conflicts between forest practices and resource development and public expectations can be mitigated. The VLI is typically conducted in areas that are visually sensitive (e.g. travel corridors, view points, and recreation features). The VLI is a tool that is used to record information about a landscape's visual condition, characteristics and sensitivity to alteration by identifying and delineating visually sensitive areas and units and describing these *Visually Sensitive Units* (VSUs) using a standard set of measures. These measures include *existing visual condition*, *visual absorption capacity*, *biophysical and viewing characteristics*; these measures are used to determine the unit's Visual Sensitivity Class. This information assists resource managers in determining suitable land uses and developments, as well as management objectives and prescriptions (unless otherwise noted, the *Visual Landscape Inventory: Procedures & standards manual* (BCMoF, 1997b) was used as the source for this section). The VLI classifies and records provincial viewpoint location, information, and photography taken from these sites; these data are recorded as a separate layer that link primarily to the VLI but can also be associated with any of the other recreation inventories.

The *existing visual condition* is a baseline assessment of the current (at the time of the inventory) level of human alteration that is apparent in a landscape; any future development proposals will be measured against this baseline condition. The existing visual condition is expressed as a *visual quality class*, and is initially based on the percentage of non-visually effective green-up (or scale of existing alteration); this determination does not include natural openings. These classes and the associated non-visually effective green-up percentages are described in Table 4.

The other factors that are considered in establishing the final existing viewing condition are the *influence of visual landscape design*, the *influence of site disturbance*, the *influence of vegetative colour and texture*, and other considerations that present themselves on a unit by unit basis. The influence of visual landscape design is an assessment of development on the landscape, and the degree that these developments have considered visual landscape design principles (see BCMoF, 1994 for further discussion of these principles). The influence of landscape design is rated as: *high* – square or sharp angles are evident, does not follow natural features, and hard edges; *moderate* – the design demonstrates some effort to lessen the visual impacts of the development, a degree of natural character is maintain; and *low* – the natural character of the landscape is preserved through the recognition of natural features and there is evidence of care, feathered edges have been used to reduce the contrastof the development with the adjacent undisturbed area. If no human-made

Table 4: Existing visual condition classes and characteristics.

Visual condition class	Characteristics	Percent non-visally effective green-up
Preservation (P)	No visible human-caused alterations	0%
Retention (R)	Human-caused alterations are visible but not evident	0-1.5%
Partial Retention (PR)	Human-caused alterations are evident but subordinate and therefore not dominant	1.5%-7%
Modification (M)	Human-caused alterations are dominant but have natural appearing characteristics	7%-20%
Maximal Modification (MM)	Human-caused alterations are dominant and out of scale	20%-30%
Excessive Modification (EM)	Human-caused alterations are excessively and greatly out of scale	>30%

Adapted from BCMoF, 1997b.

alterations are apparent, then the influence of visual landscape design assessment is not applicable. The types of alteration that are present in a visually sensitive unit are also cataloged (i.e. harvest openings, power lines, quarries, etc.).

The *influence of site disturbance* is an evaluation of the degree to which site disturbances (e.g. roads, trails, landings) are visible. In this context, site disturbance refers to exposed, or disturbed, soil that may cause long-term reductions in visual quality – this evaluation incorporates the position and shape of the disturbance, potential soil erosion problems, as well as the amount and placement of debris and roads. The rating of the influence of site disturbance ranges from high (where site modification is dominant) to not applicable (where there is no visual evidence of disturbance). Descriptions of the ratings for influence of site disturbance are: *high* – there is a high contrast between the site and the surrounding area and disturbances are obvious (e.g. road patterns, evidence of erosion and debris); *moderate* – the level of disturbance begins to dominate the view, but there may be some indication of erosion or sidecasting; and *low* – there is no evidence of erosion or sidecasting, and the level of site disturbance is minimal.

The *influence of vegetative colour and texture* measures the amount of *visually effective green-up* (VEG) that is present in the disturbed area and the effect that VEG has on mitigating past disturbance. The influence of vegetative colour and texture is rated on a three-point scale from *high* (where VEG is effective in screening past disturbance) to *low* (where new clearcuts may be visible, or past disturbances have only begun to be rehabilitated); this rating may not be applicable if there are not any previous disturbances.

The final existing visual condition rating is based on a consideration of the initial existing visual condition rating (i.e. percent and the scale of existing alteration) and the factors discussed above. A certain degree of professional judgment is also used to determine the final rating.

The biophysical characteristics of landscapes can determine the amount of

alteration that a landscape can withstand without affecting its visual character or integrity. The v*isual absorption capacity* (VAC) is an assessment of a landscape's ability to absorb this sort of change, and is rated *high*, *moderate* or *low*. This rating is based on four elements of the landscape: *slope*, *aspect*, *surface variation*, and *landscape cover*. Slope, or the steepness of the surface of the VSU, affects the landscape in three principle ways: as the slope of a landscape increases, so too does the visible area of that landscape; slope also determines the degree of screening that vegetation will provide and affects the viewing perspective of that landscape.

Aspect, or the direction that a slope faces, affects the amount, quantity and direction of light that reaches a slope. North facing slopes are generally shaded (due to the sun's position) and appear duller and less detailed, while south facing slopes receive direct sunlight which makes colour, textures and details more vivid; north facing slopes can mask, or absorb, alteration better than south facing slopes. The ratings for aspect are *high* (northerly facing, or flat slopes), *moderate* (east or west facing slopes), and *low* (southerly facing slopes).

Surface variation is the range of different land surfaces, or topography, that are present in a VSU. A landscape surface that is uneven contains benches or gullies, or rolls, can absorb alterations more easily than a landscape that is even (e.g. steep, uniform slopes). Surface variation is measured on a three-point scale, from *high* to *low*.

The contrast of landscape cover elements, or *rock/soil/vegetative variety*, can affect the VAC of a VSU. Less variety of ground cover tends to highlight differences more than varied amounts and kinds of rock, soil and vegetation types. The variation of the amount of rock, soil and vegetation type is rated on a three-point scale from *high* to *low*.

The biophysical characteristics of a VSU are measured by a *biophysical rating*, which is an assessment of the degree of viewer interest and attention that a landscape has. The biophysical rating, based on biological features or landforms, is determined through the consideration of six factors: *slope*, which has the opposite affect on bio-physical rating than it does on VAC – a steep slope presents prominent landscape feature to the viewer and is likely to draw and keep their attention than a gentle slope; *aspect*, which is based on a similar rationale as that applied to VAC; *edge*, or the characteristics of the boundary between the VSU and the biophysical features within it (*e.g.* a shoreline or a skyline); *topographic variety*, which rates diverse topographic elements as more interesting to a viewer than uniform topographic elements; *vertical relief*, or the height of a VSU; and the *vegetative variety* present in a VSU. The biophysical rating assessment is rated on a three-point scale from *high* to *low*. The presence of water features and adjacent scenery also has an effect on the assessment of a VSU's biophysical rating; studies have demonstrated that people are attracted to water, and it can be expected that the presence of a water feature will draw and keep a viewer's attention and interest.

The general circumstances under which a VSU is viewed, or the *viewing condition*, can have an influence the sensitivity rating of the VSU. The viewing condition is based on an assessment of four factors: the *viewing distance*, *viewing frequency*, *viewing duration*, and *viewing angle*. The distance from the viewing

location and the VSU can influence the amount of detail, texture and contrast, as well as the colours that are perceived by viewers; viewing distance is often described as being foreground (< 1km from the VSU), midground (1-8 km from the VSU), and background (>8km from the VSU); as the distance between the viewer and the VSU increases, the level of detail that can be discerned decreases. The number of viewpoints that a VSU can be seen from contributes to the viewing frequency; the more opportunities that there are to see a VSU, the higher the viewing frequency. The amount of time that people have to observe a VSU is called the viewing duration – as the duration increases, so does the likelihood that the landscape will be scrutinized and the sensitive elements of the VSU made more apparent. Viewing angle is a measure of the position and perspective between the viewer and the landscape feature that is being seen. The viewing angle can be direct or oblique. When direct, the viewer is parallel to, and looking right at the viewing feature – this viewing angle may be more sensitive to alterations, as they are likely to be seen; alternatively, when the viewing angle is oblique, or on the periphery of the viewer's vision – this viewing angle is not as sensitive to alteration. Viewing angle is rated on a three-point scale from *high* (direct view) to *low* (an oblique view).

The final viewing characteristic that is taken into consideration in the VLI is the *viewer rating*. The determination of the viewer rating is based on the number of people likely to see the VSU, and on an assessment of viewer expectations and preferences. To gauge what viewer expectations and preferences may be, public input is solicited. Viewer rating is measured on a three-point scale from *high* (the number of viewers and expectations have a high influence on the visual sensitivity) to *low* (the number of viewers and expectations have a low influence on the visual sensitivity).

All of the ratings for the visual factors discussed here (*existing visual condition*, *visual absorption capacity*, *biophysical and viewing characteristics*) are combined to determine the VSU's *visual sensitivity class*, a measure of the VSU's overall sensitivity to alteration. The five visual sensitivity classes (VSC) are illustrated in Table 5.

The VSC is an estimate of the amount of public concern or criticism that may ensue if the visual resources of a particular landscape are negatively altered. These concerns may include economic ramifications, like a negative impact on tourism, or social impacts, like detrimental effects on recreation experiences. The BCMoF's recognition of visual resources is an important step to considering the full range of values that forested landscapes hold. The BCMoF (1995c) suggests that the primary focus of Visual Resource Management is to mitigate the visual impacts of human-made alterations; the VLI is a tool that assists resource managers in this task.

Outdoor recreation management tools

All of the frameworks discussed in this section address the notion of *carrying capacity* and human uses of the natural environment that can cause stress in ecosystems. Although most of these frameworks were developed within the context of parks and protected areas management, the application of these methods can help to determine appropriate types, levels, and conditions of recreational use. The

Table 5: Visual sensitivity class (VSC) description.

Visual sensitivity class	Description
1	• Very high sensitivity to human-made visual alteration. • The area is extremely important to viewers. • Very high probability that the public would be concerned if the VSU was visually altered in any way or to any scale.
2	• High sensitivity to human-made visual alteration. • The area is very important to viewers. • High probability that the public would be concerned if the VSU was visually altered.
3	• Moderate sensitivity to human-made visual alteration. • The area is important to viewers. • The probability exists that the public would be concerned if the VSU was visually altered.
4	• Low sensitivity to human-made visual alteration. • The area is moderately important to viewers. • There is a risk that the public would be concerned if the VSU was visually altered.
5	• Very low sensitivity to human-made visual alteration. • The area may be somewhat important to viewers. • There is a small risk that the public would be concerned if the VSU was visually altered.

Adapted from BCMoF, 1997b.

methods to inventory and manage an appropriate mix of visitor opportunities that are presented here are the *Limits of Acceptable Change*, the *Visitor Impact Management* process, the *Visitor Experience and Resource Protection* framework, and the *Visitor Activity Management Process*. The *Recreation Opportunity Spectrum* that was discussed earlier is also considered to be an outdoor recreation management tool.

The outdoor recreation management tools that are described below are typically based on the application of a set of criteria and indicators. *Criteria* can be understood as broad categories of concern, such as trail condition. *Indicators* are derived from criteria and are specific variables that describe the status of the conditions of the criteria. Indicators can be applied and measured at different scales (i.e. from site to district), and might include campsite condition, trail conditions, social conditions (e.g. crowding, number of visitors), soil conditions (e.g. compaction, erosion), vegetation conditions, and management setting (Jackson and Leavers, 2000). A third level, *measures*, are applied to assess aspects of the indicators against a base, or desired, condition; measures judge the acceptability of the condition that is being examined (Nilsen and Tayler, 1997).

Carrying capacity and recreation

The question of how much human use can be accommodated in natural areas is often framed in terms of carrying capacity. The application of carrying capacity was first suggested for park management in the 1930s, although systematic application did not occur until the 1960s. The initial focus was on biological and ecological issues and was based on the hypothesis that increasing numbers of visitors caused greater environmental impact (measured through soil compaction, vegetation disturbance, etc.). Later, social aspects of carrying capacity emerged as a critical dimension, as environmental resources were not the only resource attributes that were affected by recreational use; the quality of the recreation experience was important too. These social aspects were based on the hypothesis that increasing numbers of people caused greater social impacts (measured by indicators like crowding or number of user conflicts). Thus, carrying capacity has two components: biological (environmental) capacity and social capacity (Manning, *et al*. 1996; Nash, 1990; Hendee, 1990; Stankey *et al*. 1990).

The concept of carrying capacity acknowledges that the natural environment has an ability to absorb some impacts of recreation use, as well as impacts that occur naturally in these environments; however, it also recognizes that there is a limit of impact or change that natural areas can sustain (Stankey *et al.* 1990). This limit is interpreted by recreation resource managers and used to develop range of carrying capacity, beyond which desired conditions are threatened; thus the carrying capacity of an area is best conceived of as a threshold that is set by resource managers based on fieldwork, research and experience. There has been increasing recognition among recreation researchers that carrying capacity is a "normative idea, derived from social judgments about appropriate conditions" (Stankey *et al.* 1990, p. 218). Carrying capacity *is not* an inherent quality of a landscape or ecosystem (Pigram, 1983). It cannot be emphasized enough that the determination of the carrying capacity of an area is not based on science alone: the establishment of an area's carrying capacity is also a product of value judgments. These value judgments are the result of legislative mandate, public input, management setting and philosophy, and the expectations of the people charged with managing the resources of an area; it becomes the resource managers job then, to facilitate consensus among competing value judgments (Stankey *et al.* 1990). A number of recreation management frame-works have been developed to guide resource managers through these decisions; some of these are presented later in this section.

The application of the carrying capacity concept to manage natural areas that receive recreation use should not attempt to preserve an ecosystem in any one state, as a certain amount of change occurs as a result of natural processes (e.g. succession). Natural change must be permitted to take place, but human impacts as a result of recreation must be checked and mitigated. Carrying capacity can be a useful tool to assist resource managers in achieving long term goals in backcountry recreation planning if accompanied by an effective monitoring program (Hendee, 1990).

It is the unknowns (e.g. use, quality, and sensitivity) that threaten recreation resources. Inventory and monitoring of recreation use and impacts are important first steps for managing recreation resources, but setting management thresholds cannot be overlooked. These thresholds are based on the criteria and indicators that have been adopted by the managers of an area; the definition and framing of these

criteria and indicators can determine what the carrying capacity for an area is and allow it to be managed, this concept is central to contemporary recreation planning frameworks like the *Limits of Acceptable Change* or the *Visitor Activity Management* process (Manning *et al.* 1996). The determination of thresholds for the capacity of a recreation feature or setting, beyond which that feature or setting ceases to sustain use and the resource begins to become degraded, allows resource managers to measure recreational use and the impacts that this use has. There are also intangible impacts that occur when these thresholds are exceeded that include social and economic benefits (Jackson and Leavers, 2000).

One of the problems of establishing carrying capacity is determining how much impact is too much; for example, how much crowding ought to be permitted in a particular backcountry area? Frameworks like the *Limits of Acceptable Change* can help to provide direction by emphasizing the definition of the visitor experience that is to be provided and maintained through monitoring. The *Visitor Experience and Resource Protection* process, discussed later in this section, is a framework that is used in park management. This process incorporates carrying capacity into its framework and recognizes the type and level of visitor use that can be accommodated while sustaining the desired resource and social conditions that compliment the purposes of the park units or zones and their management objectives. In this context, carry capacity is not a prescription for the number of visitors but a direction for desired ecological and social conditions: what level of visitor use is appropriate and where should visitor activity occur? (Manning *et al.* 1996).

Carrying capacity presents a paradox to resource managers: standards must be developed that are site specific, but they must be able to be adapted to various environmental settings at a variety of scales (Stankey *et al.* 1990). The indicators of change or capacity that are selected must be reliable, should be measurable using quantitative methods, and be able to demonstrate the impacts of recreation use. Jackson and Leavers (2000) have identified the following principles for the selection of indicators of recreation use and impacts: indicators should be: measurable (quantifiable), reliable (precise, accurate, and repeatable), cost effective, significant (relate to significant features of an area), relevant (relate to human impacts), sensitive (provide an 'early warning'), efficient, and be responsive to changes in human use patterns. Additionally, the indicators should be transparent so that the public and other interested parties can understand how the indicators were developed and applied.

A survey of recreation managers in the Squamish Forest District about carrying capacity models and elements found that there was support for carrying capacity methods in the management of recreation on Crown lands in BC. The managers that responded to the survey indicated that they required more baseline information, and that social and environmental elements were regularly included in carrying capacity measurements (other elements such as economics and access were also used, though not as consistently). There was also consensus among respondents that the monitoring of indicators should be the responsibility of all of the agencies that are involved in land use planning (e.g. BCMoF, BC Assets and Lands, BCMSRM, and BCMWLAP) as well as the users of the resource (i.e. the public and commercial recreation licensees). Coupled with monitoring is the responsibility to ensure that the thresholds that have been established are not exceeded; examples of enforcement

and regulation of recreation capacity thresholds include the adoption of reservation systems (e.g. the West Coast Trail, Bowron Lakes), licenses and permits (e.g. fishing and hunting), limits on group sizes or length of stay, and size limits on fish and game (Jackson and Leavers, 2000).

Some criticisms of carrying capacity are that the term itself implies that there is a single, fixed, amount of recreational use that can be determined through research and that there is an implication of an undue emphasis on limitations (alternative management strategies to limitations exist). A historical sense of carrying capacity tends to divert attention from social and experiential concerns that form an integral part of recreation management (Manning *et al.* 1996). It has also been suggested that the application of carrying capacity is inconsistent, although the *Limits of Acceptable Change* framework is the most common method that is used for assessing carrying capacity (Jackson and Leavers, 2000). The type of experience that people seek in their pursuit of a recreation activity differs widely – different people seek different experiences and have different expectations; thus the social component of carrying capacity is difficult to determine, what may be acceptable to one person may be restrictive to others. Another criticism of carrying capacity has been that there is an implicit cause-and-effect relationship between the level of use an area receives and the amount of impact it receives; there is evidence to suggest that other factors, such as season of use, are more important considerations in accounting for the impacts of recreation use (Stankey *et al.* 1990).

The tools

The frameworks discussed here have originated form collaborative efforts of government and non-government recreation researchers in response to various legislative and policy requirements as well as increases in recreation demands, impacts and conflicts. These frameworks recognize the origins and deficiencies of carrying capacity and attempt to move beyond it.

These outdoor recreation management tools represent two schools of thought: *rational planning* and *transactive planning*. Rational planning uses methodologies that are based on scientific methods, and aims to be value-free by imposing a separation between the investigator and society; rational planning is characterized as being fact-based, and uses approaches that evaluate correct, or best, choices (e.g. cost/benefit analysis).

Transactive planning views society as a complex network of intentional actions that cannot be understood through observation. Transactive planning typically has increased levels of public participation and stakeholder input, as it recognizes the merit of non-professionals; this is characterized by integrative bargaining, or principled negotiation, and is premised on the belief that optimal planning outcomes are a result of dialog between interested parties combined with technical information and government policy direction (Commission on Resources and Environment, 1996).

Most of these outdoor recreation management frameworks follow the standard rational planning approach, and follow a hierarchy of decisions that involve strategic and tactical decisions (Nilsen and Tayler, 1997). The general steps that these frameworks follow have been outlined by Nilsen and Tayler (1997) and Jackson and Leavers (2000):

1. Define terms of reference or goals (legal and policy mandates that govern or guide management).
2. Database development (identify the pertinent issues and concerns, as well as resource features and recreation activities).
3. Situation analysis (what is the context that recreation opportunities and settings are framed in?).
4. Synthesis.
5. Definition of management objectives.
6. Development of management alternatives (what other options exist?).
7. Development of a final plan.
8. Implementation of the management plan.

Limits of Acceptable Change

The *Limits of Acceptable Change* (LAC) approach was designed to manage designated and non-designated wilderness areas in the United States (Payne and Graham, 1993), and is an example of transactive planning. LAC, when applied to wilderness or natural areas settings can be viewed as an extension of the ROS (which is based on rational planning). The LAC framework is an attempt to apply the carrying capacity concept:

> The challenge is not one of how to prevent any human-induced change, but rather one of deciding how much change will be allowed to occur, where, and the actions needed to control it. (Stankey *et al.* 1985, p. 1).

LAC has four components: the specification of acceptable and achievable resource and social conditions; a comparison of acceptable and existing conditions; the identification of ways in which to balance acceptable and existing conditions; and the on-going monitoring and evaluation of the management plan (Stankey *et al.* 1990; Stankey *et al.* 1985). A recent modification of the LAC framework has incorporated defining management goals and desired conditions as the first step in the process. These steps help to develop a framework that identifies management strategies and the extent of change that may be appropriate for an area; LAC also can alert outdoor recreation and landscape managers of the need for action when changes to an area exceed standards that have been developed (Nilsen and Tayler, 1997).

LAC seeks to balance the needs and desires of outdoor recreation participants and other stakeholders with environmental considerations and the desire state of the area. The role that the public plays in LAC is large, and it is important to note that this process seeks consensus in order to advance. The involvement of the public in the planning process makes it more likely that the results of the exercise will be accepted and understood as the public had a role in their development; public input may also generate a broader range of ideas and solutions.

One of the key inputs to LAC is a landscape classification framework, usually the ROS; this makes the planning process two tiered, and may introduce complexity. A potential weakness of this approach is that a wilderness or backcountry area's classification may be threatened if user groups and/or other stakeholders suggest developments or management scenarios that are contrary to the sustainability of these wilderness or backcountry settings.

One of the first applications of LAC in BC was at Swan Lake (now Swan Lake Provincial Park), a BC Forest Service wilderness area; LAC was selected as the framework to assist forest managers in meeting the goals and objectives for this area. Parks Canada has used the LAC framework in Gwaii Haanas where the season of recreation use was an issue, and for the Chilkoot Trail where the impact of recreation use had become an issue due to an increase in the number of people using the trail (Jackson and Leavers, 2000).

Visitor Experience and Resource Protection

The *Visitor Experience and Resource Protection* framework (VERP) is a useful management tool for the management of outdoor recreation in national parks, as it can assist park planners and managers in addressing visitor carrying capacity, environmental and experiential (social) conditions, and allows managers to make sound decisions about visitor use (Nilsen and Tayler, 1997). As the name implies, VERP addresses the quality and impacts of visitor experience. Factors that may contribute to the quality of the visitor experience include: information or interpretation of the setting or area, facilities, crowding and visitor behaviour or activities (i.e. inappropriate actions of others), resource impacts, management actions, and natural features (Manning *et al.* 1996). VERP was developed by the US National Park Service to respond to its legislated responsibility to address carrying capacity in all of its national park units, and as an alternative to LAC. VERP was developed in the context of the US Parks Service's General Management Plans and represents a rational planning approach (Hof and Lime, 1997). VERP addresses carrying capacity through the adoption and meeting of goals instead of as a reactive tool.

VERP is an iterative planning framework that identifies current conditions and desired future conditions for management zones within parks and protected areas; VERP also considers the alternative allocation of these zones. VERP is a proactive approach to outdoor recreation planning, as it is goal-driven (Hof and Lime, 1997).

Visitor Impact Management

The *Visitor Impact Management* process (VIM) is a reactive management framework that is best suited for specific recreation site problems and is based on a rational planning approach. VIM addresses three basic issues of outdoor recreation impacts on the natural environment and on the quality of recreation visitor's experience: the identification of problem conditions; the identification of potential causal factors; and the identification of potential management strategies (Nilsen and Tayler, 1997; Payne and Graham, 1993).

VIM focuses on requirements for an enjoyable visitor experience by balancing an area's carrying capacity and visitor impacts, and was developed in the context of parks and protected areas. VIM was designed to deal with problems such as human waste and garbage disposal, and the destruction of habitat due to visitors straying from trails; it is the effects of the visitors themselves that is being managed – VIM places the park visitor within the context of a park's limitations, not *vice versa* (Payne and Graham, 1993).

VIM seeks to shape visitor use around the capabilities of the area (park); it is an

expert-driven process and does not incorporate public involvement. The results of the process are management policies that are fairly transparent.

Visitor Activity Management Process

The *Visitor Activity Management Process* (VAMP) is a Canadian-based framework that was developed in response to demands for increased nature interpretation in Canadian National Parks; it was hoped that VAMP would also increase the profile of National Parks in Canada, and help to increase the number of park visitors. VAMP works within the context of a park's management plan, and focuses on service planning by attempts to match appropriate recreation activities within the limitations (e.g. ecological, managerial); VAMP is a rational planning approach (Payne and Graham, 1993).

VAMP can be applied in a number of management contexts from large protected areas to site-specific facilities, and is useful for strategic and operational decisions such as deciding which education and recreation opportunities will be targeted, or the kind and quality of supporting services and facilities an area requires. VAMP combines a marketing approach to the management of public recreation opportunities with the constraints of managing heritage resources. This outdoor recreation management tool focuses on the requirements for creating an enjoyable visitor experience by identifying outdoor recreation user requirements and attempts to meet and plan for them (Nilsen and Tayler, 1997; Payne and Graham, 1993). However, Payne and Graham (1993) suggest that VAMP may be too service-oriented to be applicable to wilderness or backcountry areas.

Similarities and differences among the tools

VAMP and VERP are similar as they both emphasize criteria at a strategic level, and make suggestions about which indicators should be used. VERP describes resource and social indicators (e.g. crowding), while VAMP emphasizes social indicators and measures from the perspective of the visitor and is complemented by management practices that address resource criteria, indicators and measures (Nilsen and Tayler, 1997).

VIM and LAC identify criteria at the beginning of the planning process, and allow management objectives to follow. Both of these tools are reactive, or issues-driven, and attempt to narrow the range of criteria and place greater emphasis on the choice of indicators and measures and monitoring. VIM explicitly attempts to identify the cause of impacts, while LAC emphasizes the definition of opportunity classes and in the development of alternative class allocations (Nilsen and Tayler, 1997).

The application of these outdoor recreation planning tools depends greatly on setting. The ROS, VERP and VAMP are comprehensive and holistic approaches and address interpretation; these tools seek to establish a broad direction for managing human use in a variety of landscape settings. VIM and LAC are issues driven and due to their narrow focus, can help to interpret a management decision.

Lessons learned from the application of outdoor recreation management tools: Common themes

There are two important considerations in the successful adoption of any management framework or process. Public involvement is critical during the

implementation of planning to ensure that there is public acceptance of the conceptual plan. The second consideration is the necessity to foster an institutional setting that ensures that all levels of management are committed to, and held accountable for, the implementation of the planning process. This commitment includes the provision of adequate financial and human resources for the project, ensuring that the best quality data is made available, and that employees have the necessary training to successfully complete the task. (Hof and Lime, 1997). It cannot be emphasized strongly enough that the key to successful outdoor recreation management is monitoring; the tracking of visitor use trends and the state of recreation resources over time is critical for understanding the dynamic nature of this social use of forested landscapes.

Conclusions

The management of outdoor recreation in BC will become increasingly important and complex as resources (e.g. recreation opportunities and settings) become scarce and demand for recreation resources increases. If not carefully managed within the context of other forest resources, the number of conflicts between the public, resource companies, and the government ministries and agencies charged with the management of these resources can be expected to increase.

There are a number of tools that aid in the management of outdoor recreation in BC. But the full benefit of these tools will not be appreciated unless they are used and applied correctly and consistently. It is also important that resource managers adopt a set of principles for the management of outdoor recreation in BC. Some of these principles include:

1. **Manage forests to meet present needs without compromising the needs of future generations**
   This principle is the cornerstone of sustainability. As it is difficult to know what the needs of future generations might be, it is necessary to be cautious when considering management actions in forested landscapes.

2. **Manage for a diverse set of values, settings and opportunities**
   It is important to recognize the value of non-timber resources. Timber is not the only resource provided by forested landscapes, other forest values include recreation, visual resources, botanical products, and watersheds. With regard to outdoor recreation, it is important to recognize that people have different desires and needs for the pursuit of recreation activities; therefore it is important to provide a diversity of recreation settings from primitive backcountry areas to accessible recreation sites and trails. Managing for a diversity of outdoor recreation opportunities can also help to achieve principle #1 above.

3. **Manage for human-induced change**
   It is not the natural environment that needs to be managed; it is the public's use of, and behaviour in, forested landscapes that requires management attention. Recognize that recreation use of forested landscapes will have impacts on other resources and seek to mitigate those impacts.

4. **Outdoor recreation management should be efficient, economical, effective and transparent**

The management of outdoor recreation is no different than the management of other resources. The adoption of efficient, economical, and effective management strategies can help to ensure that management efforts are directed at the issues and concerns that matter. Efficient, economical, and effective management strategies can help to maintain the integrity of outdoor recreation resources. The implementation of transparent management strategies allows other forest resource users, government agencies, and the public to understand the management decisions that are made, and can facilitate broader acceptance of outdoor recreation goals and objectives.

5. **Identify and develop appropriate outdoor recreation management objectives**
   Recognize that outdoor recreation management objectives vary depending on location, availability of settings and opportunities, and the people who use the resources. These management objectives should also be realistic.

6. **Monitor the state of the outdoor recreation resources**
   Forested landscapes are dynamic – they change over time due to natural cycles and human activities. Outdoor recreation opportunities and settings also change as a result of recreation use and other resource uses. Many of the outdoor recreation management tools discussed in this chapter (e.g. LAC, VERP, VIM and VAMP) include monitoring as a key step in maintaining and understanding recreation resources. Changes in resource settings can affect outdoor recreation opportunities and experiences; these changes can also influence who uses the recreation resources. Understanding these changes is key to the management of outdoor recreation participants.

7. **Monitoring outdoor recreation participant behaviour and attitudes**
   People and populations are also dynamic. In order to keep abreast of changing public attitudes and recreation behaviour, it is important to consult the public on a regular basis through the use of solicitation tools like surveys, interviews, and round table discussions. The consultation of the public and other outdoor recreation stakeholders allows the opinions and preferences of the public to be incorporated into management decisions. Surveys and interviews of recreation participants can be employed to answer specific management questions: What do recreation participants think of current management? What recreation activities are important to them? What areas people using? Are there any conflicts that are arising that require management intervention? Surveys and interviews of recreation participants can also be used to determine public preferences: What do people want?

8. **Attempt to incorporate design into timber harvest layout and operations as well as outdoor recreation facilities**
   As the number of people engaging in outdoor recreation activities in forested landscapes increases, it becomes important to think about reducing the visual, environmental, and social impacts that these activities have, as well as the impacts on outdoor recreation that other forest resource use has. The incorporation of design can help to mitigate some of these conflicts by incorporating the concept of *care* discussed in this chapter. Not only do people prefer landscapes that appear cared for, but this evidence of care can also have a

positive influence on the behaviour and experiences of people participating in outdoor recreation activities.

9. **Limiting use is only one option for outdoor recreation management**
   Imposing limits on people's behaviour (e.g. where they can go, what they can do) is one strategy for the management of outdoor recreation, but it is not the only one. Resource managers should attempt to employ alternative strategies, such as the provision of other recreation opportunities that can help to distribute outdoor recreation use across a landscape, or the use of site hardening to reduce the direct impacts of concentrated recreation use at popular sites or facilities.

10. **Incorporate interpretation and education objectives into the management of outdoor recreation facilities**
    Encouraging awareness of the setting and landscape that outdoor recreation participants are in can assist the management of these areas. Providing people with information about the settings that they are in can enhance their experiences; as people gain an appreciation and understanding of the landscapes that they choose to be in, they start to develop affinities for these places – these affinities can be powerful influences for adopting behaviours that are consistent with reducing impacts on the natural environment. Outdoor recreation management is essentially the management of people – by giving people the tools to understand their surroundings, and the impacts that their actions and behaviours can have, the public can begin to manage themselves.

It is important to remember that people engage in outdoor recreation for enjoyment. This interaction with forested environments, and the experiences that these interactions bring, influence how people think about forested landscapes. By striving to provide positive outdoor recreation experiences on Crown land in BC, the public is served not only as consumers of recreation, but as the ultimate stewards of these landscapes.

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ECOSYSTEM MANAGEMENT AND CONSERVATION BIOLOGY

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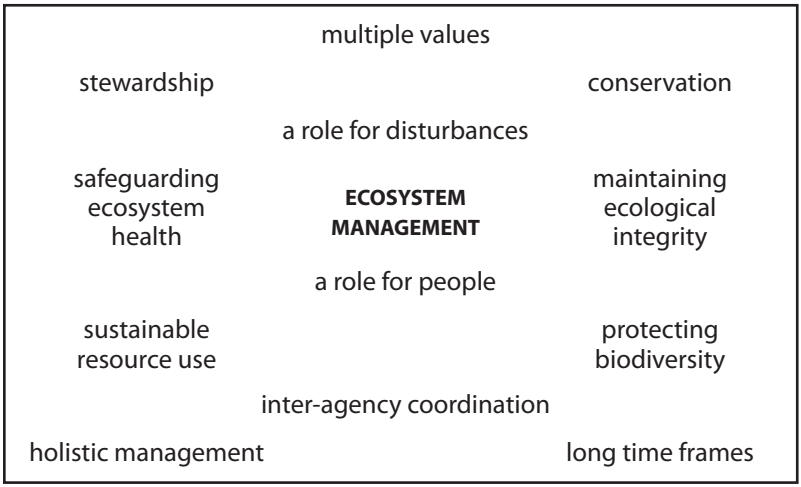
ECOSYSTEM MANAGEMENT AND CONSERVATION BIOLOGY

Principles of Ecosystem Management

Ecosystem management consists of all those policies and practices that effectively sustain ecosystem composition, structure, productivity and integrity (Grumbine, 1994; Galindo-Leal and Bunnell, 1995; Lackey, 1997). A holistic management approach, it is based on consideration for multiple ecosystem components rather than optimizing any one component. The concept embraces the traditions of good stewardship long practiced by progressive managers of natural resources. It is a legitimate descendent of the principles of managing public forests for multiple sustained use (Figure 1). Yet the current catch-phrase "ecosystem management" has rekindled recognition of the need to care for the land, the need for long-term conservation, the value of biological diversity, and the need to articulate a clear vision of what constitutes a healthy ecosystem.

Figure 1: The constellation of concepts contributing to ecosystem management.



Ecosystem management is a relatively new paradigm for land management, having been articulated in the United States in the early 1990s. Some people consider it synonymous with "ecosystem-based management" when this means that the needs of ecosystem integrity come before those of economic gain. The concept embraces much more than site-specific management guidelines for different site series or forest types, which are sometimes called "ecosystems" in British Columbia (BC). The principles of ecosystem management can be applied to the working forest,

huntable wildlife, range management, fisheries, parks or any renewable natural resource.

Ecosystem management differs from most traditional approaches to natural resource management in three important ways. First, it assumes that many (or even all) components of the ecosystem have equal value and must be managed accordingly, rather than trying to optimize production of a few species or a single product. Secondly, inter-generational sustainability of ecosystem functioning takes priority over other management goals. In this context, harvesting and use of natural resources can be allowed only when sustainable populations and ecosystem processes are first assured. Thirdly, humans are recognized as part of the system and have an active role to play in regulating disturbance and restoring ecosystem composition and function. Ecosystem management is an active process, not a passive one. Due partly to the global impact of human activity (in terms of atmospheric pollutants, climate change, widespread exotic species, and altered disturbance regimes), and trans-boundary influences of one land use on another, we can rarely expect an ecosystem to recover or remain healthy simply by excluding human use. Likewise, modern ecosystem management acknowledges the importance of disturbance in ecosystem renewal, the potential for restoration of ecological processes, and the tentative nature of our understanding of natural systems. Proponents argue that these principles must be integral to the management of both natural and highly altered ecosystems.

For practicing foresters and other land managers, ecosystem management means undertaking proactive landscape planning and design (see below), good coordination with fish, wildlife, and water managers, paying attention to sensitive populations of plants and animals, and being "good neighbours" with adjacent land owners. Maintaining ecosystem integrity may require more naturalistic management practices than are currently the norm under industrial forestry, including more emphasis on the retention of snags, logs, wildlife tree patches, and long rotations. Conversely, it may require less emphasis on "clean logging," full stocking, crop uniformity, and the meeting of free-growing timelines. But perhaps most fundamentally, the transition to ecosystem management requires that we don't harvest more than we grow in a given sustained yield unit, working circle or forest management area (see chapter on Modelling Stand and Forest Dynamics): sustainability of all ecosystem values within a geographically defined area becomes the bottom line.

Foresters should take note that there has been a parallel evolution of management philosophy in agriculture and fisheries management. Channelling resources into the short-term production of a few species has fallen into disrepute in many circles, because of the increased incidence of disease, waste build-up, collapsing yields, fossil fuel requirements, or general resource degradation. Yet there is a strong battle of philosophies, in which most corporate investment (e.g. in agriculture, aquaculture, and silviculture) is channelled into intensive, single-resource management. One solution to the conflicting demands between the need for high productivity and the need for resilient ecosystems is to develop appropriate zoning for intensive management, extensive management, and natural area protection, sometimes called the "triad" approach to land use planning (Seymour and Hunter, 1999).

The education of most foresters gives them a solid background in the elements of ecosystem management. In practice, however, there are often institutional barriers to implementing ecosystem management. Management policies in the forest industry understandably emphasize fibre production, often supported by the government agencies responsible for our public lands. But there is general agreement among all land managers that soils and streams must be protected, species should not go extinct, and that the production of all forest resources and forest values should be sustainable. When the need for ecosystem management is broken down into these components, it often wins a broader base of public support. Until its principles become widely adopted and a matter of policy, however, it could be argued that ecosystem management describes an ideal, not a management practice.

Principles of Conservation Biology

A fundamental component of ecosystem management consists of employing the principles of conservation biology. Conservation biology is the science of understanding and mitigating biological rarity and vulnerability. An applied discipline, conservation biology accepts as its mission the protection of biodiversity. Unlike the basic, curiosity-driven sciences, conservation biology has an underlying set of explicitly recognized values or beliefs (Primack, 2002), namely that:

- Biological diversity (including the range of species, genetic variation, biological communities and ecosystem interactions) should be preserved;
- The extinction of populations and species by human activities should be prevented;
- Ecological complexity should be maintained;
- Evolutionary change should continue; and
- Biological diversity has value in and of itself.

There are many different analytical tools and techniques employed in conservation biology at both the research and management levels. We know little about the causes of rarity, the population genetics of most species, the implications of human interference, and consequently, how best to manage species at risk. So a considerable amount of basic research is typically needed to support the rational management of any given wild species or protected area. Methods employed in both research and management include:

- Field surveys of organism abundance and its correlation with various habitat attributes, in order to identify necessary and sufficient habitat needs at different life stages and times of the year;
- Molecular genetic methods for determining relatedness and breeding systems in populations of plants or animals;
- Population viability analysis (PVA) to document the demographic parameters of a particular species or population, seeking to identify survival bottlenecks and risks to the population;
- Meta-population studies and modelling to consider the dynamics of organism dispersal and local extirpation across a landscape mosaic;
- Analysis of landscape patterns and metrics, typically using geographic information system (GIS) tools, to both assess and project habitat supply; and

- Gap analysis over large regions (often provincial, national, or global) to ascertain the degree to which ecosystem types are adequately represented and linked in protected areas, or adequately managed to sustain biodiversity in the jurisdiction of interest.

These methods may be focused on individual species, species groups, communities, or broader ecosystem types. They may be employed by academic researchers, by government agencies responsible for particular organisms of interest (e.g. fisheries, huntable wildlife, or rare species protected by legislation), by land managers, and increasingly by environmental non-governmental organizations (ENGOs).

A common challenge to conservation biologists studying the dynamics of threatened plant or animal species is determination of the degree to which fluctuations (particularly declines) in a population are natural or caused by man. Human influences can be so pervasive and are often indirect, making it tempting to attribute all population declines to human impact. But the natural world has always been dynamic too, characterized by disturbance, succession, dispersal and invasion, extinction and evolution of species. Management agencies may decide to intervene or not to intervene in the decline of a species, but it is important to understand the relative contribution of all threats to the maintenance of a species at a given place.

Two broad approaches to the research needs and application of conservation biology can be recognized: the "fine-filter" approach, and the "coarse-filter" approach. The fine-filter approach is primarily species centred; that is, it is concerned with the biology and protection of particular, identified species. Fine-filter management is expressed in the recovery plans prepared for species at risk of extinction (global disappearance) or extirpation (local disappearance). It utilizes many of the principles of wildlife biology and management, whether applied to game animals, furbearers, fish, or a rare species of butterfly or orchid. In contrast, coarse-filter management is an extension of habitat management, long a component of wildlife management. The difference is that coarse-filter management is also undertaken when we have not identified particular species at risk or of interest, but recognize that there are large suites of species (including many that have not been inventoried and even may not have been described by science) associated with different ecosystem types, successional stages, and habitat structures. Consequently, the protection of diverse ecosystems, successional communities, processes of natural disturbance, and general habitat diversity is seen as an important means of saving the world's biodiversity.

Both the fine-filter and coarse-filter approaches to conservation biology are important components of ecosystem management. It is an essential tenet of ecosystem management to assure that all species (identified and unidentified, common and rare) will be sustained in the area being managed. This commitment has led to formulation of a general principle of conservation biology, commonly known as the "precautionary principle." Simply put, the precautionary approach to management serves as a conservative test for all decisions, suggesting that it is always better to err on the side of caution when species, ecosystems, or ecological integrity are at risk. The rationale behind this principle is the fact that biodiversity is not a renewable resource: unless the science-fiction of the movie *Jurassic Park* becomes science-fact, extinction is forever, so we cannot undo mistakes that might be allowed to happen.

Landscape Planning and Design

Early efforts at multiple-use forest management often failed when all values were managed for in every stand, on every hectare. The compromises involved when trying to accommodate timber, wildlife, grazing cattle, watershed values, and recreation on a single piece of ground were often unworkable and unacceptable. It is also apparent that many animals (e.g. hunted ungulates such as deer [*Odocoileus* sp.] and moose [*Alces alces* L.]) require different habitats for foraging and cover. As a result, the more effective approach to ecosystem management is through the design of a portfolio of stands and habitats on the landscape to collectively provide for the full range of forest values and habitat needs. It is also only at larger spatial scales that numerous interactions between various habitats and ecosystem types can be considered: for example, the processes by which the riparian zone integrates terrestrial and aquatic influences. In practice, "ecosystem" management is usually carried out at the scale of the landscape, where the "landscape" refers to a mosaic of heterogeneous landforms, vegetation types, and land uses (Voller and Harrison, 1998).

A landscape often consists of a matrix or dominant land cover type in which patches (discrete units of less abundant land cover types) are imbedded. One example is a matrix of mature coniferous forest in which discrete patches of recent clear cuts or wetlands can be recognized; another example is a matrix of agricultural or urban land in which conifereous forest is only found in isolated pockets. Some landscape features or elements are linear (elongated and usually continuous), and serve as corridors within which materials or populations flow; examples include stream and road networks. Some corridors (e.g. large rivers, multi-lane highways) can also be serve as barriers to animal movement or to the propagation of disturbance.

The underlying importance of landscape ecology is that landscape patterns can influence the ecological processes of populations, communities, and ecosystems found in a region. Landscape analysis, when conducted as a prelude to land use planning or forest-level planning, may start out with the characterization of patch structure and corridor networks, but must also consider the flows (of water, animals, people, invasive plants, wildfires, logs) and edge effects (Figure 2) by which different landscape elements can affect each other. Landscape design can be readily incorporated into forest development planning because road building and timber harvesting are typically dominant agents of landscape change. Intelligent landscape design in support of sustainable forest management first requires that the landscape is mapped and adequately inventoried. Once biophysical resources and processes are documented, their desired arrangement over time and space need to be considered in the light of visual resource management and the various uses mandated for the forest (Diaz and Bell, 1997).

Much human use of forested ecosystems involves disturbance – the removal of biomass and the disruption of soils, vegetation or animal populations through road building, timber harvesting, berry and mushroom picking, hunting, or grazing by domestic livestock. So a fundamental component of resource management consists of understanding and managing disturbances. Disturbances can be described by their type or mode (e.g. wildfire, insect outbreak, flooding, or logging),

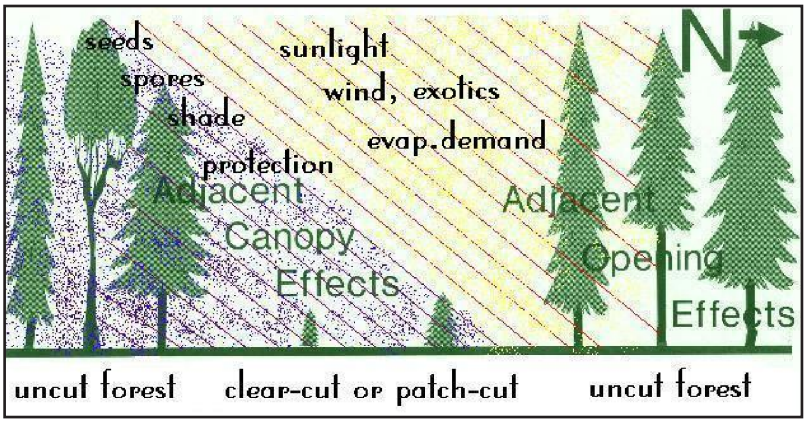


Figure 2:
Schematic representation of two kinds of edge effect, by which one landscape element can influence another: "adjacent canopy effects" from a forest stand into an opening; and "adjacent opening effects" from an open area into a nearby forest stand.

their frequency (or conversely, their return interval), the size (area) of individual disturbance events, and the intensity or selectivity of mortality or biomass removal. Collectively, the statistical frequency and spatial-temporal distribution of these attributes define the disturbance regime of a landscape. Every landscape's disturbance regime, overlaid on its natural variability in terrain and soils, is responsible for the generation of a unique set of landscape patterns, stand structures, successional trajectories, and habitat attributes important for the perpetuation of healthy populations and natural communities. Following the premises of coarse-filter conservation management, it is not enough, therefore, to protect representative habitats from human exploitation and degradation, but there also must be provision for continuation or emulation of the natural disturbance regime that is responsible for much of the landscape's ecological diversity. This means, for example, that few parks and wilderness reserves today are completely unmanaged, and may require wildlife culls or the use of prescribed fires to make up for simplistic (disturbance minimization) management policies of the past. It also means that considerable effort is now being made in controlling the impact of industrial forestry in such a manner that it better emulates the effects of wildfire and other natural disturbances (e.g. Kohm and Franklin, 1997; Burton *et al*. 2003). This is typically done by more closely designing the size, configuration, and residual structure of cutblocks to match that of natural disturbances (DeLong and Tanner, 1996). The emulation of natural disturbances will always be imperfect: e.g. natural disturbances never haul logs to town and leave roads behind! Scientists and managers are not yet sure which aspects of natural habitats and natural disturbances are critical to the survival of all indigenous species. For example, the size and shape of cutblocks may be more important to our aesthetic sensitivities than they are to landscape functioning, species preservation and ecological integrity.

Another useful concept in the sustainable management of forested landscapes (or any other ecological system) is that of the "historical" or "natural" range of variability, often abbreviated as HRV or NRV (Landres *et al.* 1999). The NRV for various attributes on a landscape (e.g. the density of cougars [*Felis concolor* L.], the fire return interval, or the area of land dominated by alder [*Alnus* sp.] thickets) describes the upper and lower limits previously experienced by the biota of that landscape, and to which it is presumably tolerant. These limits then provide some guidance as to the conditions beyond which selected attributes should not be allowed to drift. Of course, if species or communities are known to have not survived historical conditions, this is a good indication that past events or limits were not sustainable. Other problems arise when one tries to select a suitable historic period to serve as a benchmark (given that climatic and other pressures have changed over time), and when trying to assemble vague documentation or indirect evidence that may not lend itself to quantitative summarization. Nevertheless, the NRV concept provides some guidance to ecosystem management in the absence of specific information about the requirements of individual species and forest values.

It is a big step to take general principles of landscape ecology, conservation biology, land use planning, and forest harvest scheduling and apply them to a management program for a watershed or timber supply area. A variety of social and technical issues need to be addressed, both in setting objectives for the area as a whole (often done through public participation), and in getting a broad perspective on the opportunities and constraints affecting forest values within the area of interest (Pojar *et al.* 1994; Diaz and Bell, 1997). Those opportunities and constraints are often determined by the current degree of landscape modification, and can be strongly influenced by local community priorities and the overarching policy environment. From an ecological and resource sustainability perspective, however, some general guidelines can be offered:

- Prepare reliable map layers of all known forest values and resources.
- Establish an appropriate network of protected areas, and floating reserves that protect rare and representative species, communities, and habitats.
- Maintain a diversity of stand ages, patch sizes, and patch types (British Columbia, 1995).
- Pay particular attention to the protection of riparian (streamside) habitats, the intersection of roads and streams, and uncommon habitats.
- Maintain habitat connectivity between core reserves, especially where the landscape matrix is highly modified and unsuitable for many indigenous species, being cognisant of edge effects that may extend 100 to 200 m into a designated corridor or reserve.
- Remember the landscape is dynamic, that natural disturbance and succession will continue, and that human disturbances are usually spread out over time.
- Computer mapping and projection tools can be of great assistance in landscape design, helping planners identify potential conflicts and visualize the probable status of multiple forest values at different places and times in the future.

Maintaining Ecosystem Integrity at the Stand Level

As at the landscape level, the maintenance of ecological integrity during the course of stand management often means closely mimicking complex natural webs of structural, compositional and functional interactions. For example, the emulation of natural disturbances at the stand level generally requires a consciously diverse approach to logging and silviculture, retaining structural legacies of live and dead trees, bypassing clusters of diverse tree and shrub species, and ensuring that a good diversity of seedbeds and microsite types are available in the stand (Hansen *et al*. 1991). One solution is to use extended rotations on a portion of the managed forest land base, allowing some stands to achieve old growth structure and habitat value for at least several decades before being harvested (Curtis, 1997; Burton *et al*. 1999). Alternatively, the practice of variable retention harvesting (Franklin *et al*. 1997, Beese *et al*. 2001) has achieved widespread acceptance as a practical compromise between 100% clear-cutting and the adoption of regeneration systems based on partial cutting. If a stand is designated for harvest, but is still expected to maintain a role in the landscape as habitat for mature-forest or late-successional species, the key is to retain some level of internal stand structure, whether uniformly or in patches. Much work still needs to be done in secondary forests of different types in order to determine minimally acceptable thresholds for attributes (such as the density of canopy gaps, shrub thickets, standing snags, and large fallen logs) that will allow a stand to still function as mature or old growth forest habitat.

The maintenance of ecological integrity in forest stands and landscapes does not mean that forests should not be clear-cut, or that cutblocks should never be large. It is quite easy to find examples in nature where species and ecological processes are dependent on large-scale disturbances, and other examples where species are dependent on the absence of large-scale disturbance, while most species and processes probably have intermediate requirements. Consequently, almost every forest type can be managed by "great cycles" (of large stand-level disturbances, followed by even-aged stand development), or "small cycles" of gap dynamics that lead to an uneven-aged stand structure. For example, Coates and Burton (1997) document the creation of an array of harvesting gaps of different sizes, and illustrate how this diversity of opening sizes matches the natural distribution of forest canopy disturbances found in old Interior Cedar-Hemlock forests of northwestern BC. Neither "great cycle" nor "small cycle" management is universally applicable, and an appropriate balance between the two must be determined for each forest type and each set of forest management objectives. Furthermore, efforts to manage plantations for maximum primary productivity, or for interior-forest closed-canopy habitat, must still be cognisant of the edge effects (Figure 2) associated with cut-block boundaries, roads, wetlands, and breaks in topography. So even when trying to manage for stand-level ecosystem integrity, landscape context is important.

Some requirements for maintaining ecological integrity on a forest site have long been known and well appreciated. For example, it is well understood that soil loss and degradation must be avoided during timber harvesting and site preparation, or the productivity of the subsequent rotation will be compromised. It is also understood that the more readily decomposable litter of northern hardwood trees can enrich a forest soil more rapidly than the litter of most conifers. But other

aspects by which complex structure and composition within forest stands can help maintain productivity and resilience are not so well known, and have only been documented recently. For example, non-crop hardwood and shrub species may hide western redcedar (*Thuja plicata* D. Don ex Lamb) seedlings from herbivory by black-tailed deer (*Odocoileus hemionus columbianus* Richardson) without an appreciable effect on conifer growth (Burton, 1996). Likewise, trembling aspen (*Populus tremuloides* Mich.) and willow (*Salix*) species can hide white spruce (*Picea glauca* (Moench) Voss) saplings from being attacked by spruce terminal weevil (*Pissodes strobi* (Peck)). Some unforeseen management impacts on complex ecosystem behaviour stem from the observation that forest openings greater than a certain size result in the disappearance of a suite of forest mushroom species (Durall *et al.* 1999). Some of those mushroom species form symbiotic relationships with trees and other vascular plants, and it has been demonstrated that different tree species can share photosynthate through these mycorrhizal intermediaries (Simard *et al.* 1997). It is safe to conclude that we still know very little about the complex modes and mechanisms of interaction found in any ecosystem, or the role of any particular species in ecosystem processes and integrity. Consequently, advice to maintain the presence and diversity of all native species in all layers and guilds would seem to be the most prudent guideline for responsible ecosystem management (Burton *et al.* 1992).

Ecological Restoration

Another component of ecosystem management and conservation biology is the repair of damaged ecosystems. When an ecosystem has been degraded, not just disturbed (see Figure 3), some active assistance may be needed for it to return to a natural successional trajectory or the natural range of variability (Gayton, 2001). The distinction between disturbance and degradation can be subtle but important. Natural disturbances are a vital agent of ecological diversity, habitat creation, and resource release. But if too much soil or biomass is removed, or too many species are lost, then the system can be said to have lost its integrity and to have become degraded. As illustrated schematically in Figure 3a, a healthy ecosystem can return to its pre-disturbance state with no significant loss of structure, composition or function in a reasonable length of time and with no outside assistance. But if the system passes some threshold, perhaps in terms of a loss of soil fertility or continuous forest cover, various ecosystem processes shift and the ecosystem is unlikely to recover on its own (Figure 3b). That is when active intervention in the form of ecological restoration is required (Figure 3c).

Perhaps more than most problems in resource management, ecological restoration requires an adaptive, experimental approach, with a careful analysis of factors that limit ecological integrity, the stating of clear hypotheses, and the monitoring of alternative treatments so as to improve future actions (Covington *et al.* 1999). Within this adaptive management framework, much ecological restoration involves some or all of the following steps:

1. Identification of the degrading process or processes, and halting further degradation of the site to be restored and similar ecosystems nearby; examples might include over-grazing by livestock, overly uniform silvicultural practices, sediment-

laden runoff from logging roads, fire exclusion in some ecosystems or excessive fire in others.

2. Review of the techniques and success of analogous restoration efforts in addressing similar problems in similar ecosystems; identification of suitable restoration strategies, and preferably selecting more than one for purposes of comparison.
3. Site preparation, sometimes involving the importation, reconstruction or decontamination of soil or substrate materials (e.g. in the restoration of gravel quarries and mine spoils, or after an oil spill); in other cases, site preparation may consist primarily of the removal of exotic vegetation (e.g. Scotch broom [*Cytisus scoparius* (L.) Link] to restore a Garry oak [*Quercus garryana* Dougl. ex Hook.] savannah on the Gulf Islands, or purple loosestrife [*Lythrum salicaria* L.] to restore a Fraser Valley marsh).
4. Re-introduction of key compositional or structural elements of a habitat; in a degraded grassland, this might mean sowing a mixture of native grass and forb species, while in a degraded (homogeneously managed) forest this might mean gap creation and the installation of artificial snags and fallen logs, and in a channelized stream it often involves the reintroduction of meanders, boulders and large woody debris.
5. Enrichment of the ecological community with transplants of nursery-grown or salvaged plants that might be rare or more commonly found in the mature or climax stages; assorted native animal species (both vertebrates and invertebrates) can be re-introduced once the habitat matrix is in place as well.
6. Active management may then be required for many years before the restored ecosystem is self-maintaining; this may consist of: ongoing exotic plant control (e.g. mowing annual weeds before they go to seed, organizing volunteer parties to manually cut or pull exotic perennials); repeated introductions of fish, amphibian, or insect eggs; prescribed burning; or coordination with neighbouring land managers to further limit degrading land management practices.
7. Systematic monitoring is then required to determine the effectiveness of the implemented treatments, as each intervention could be considered a hypothesis as to factors limiting ecosystem recovery and integrity; the installation of replicated and controlled treatments helps immeasurably in the evaluation of restoration options, but even repeated photographs of single treatments will help build a case file of effective techniques.
8. Documentation and communication of restoration successes and failures, so they can be applied and built upon in each new restoration endeavour.

Ecosystem restoration is typically undertaken on rare and threatened ecosystems, because common types of ecosystems are either ignored or can readily be protected in parks and reserves. Efforts to restore or reconstruct an ecosystem can never be as effective as protecting it from degradation in the first place, so the protection and responsible management of ecosystems, communities, and species is always preferred over their restoration. Restoration activities tend to be more concentrated near population centres for three reasons: first, urbanization and the concentration of industrial activities near towns and cities have resulted in wholesale ecosystem destruction and degradation, often in low-elevation and open habitats that were

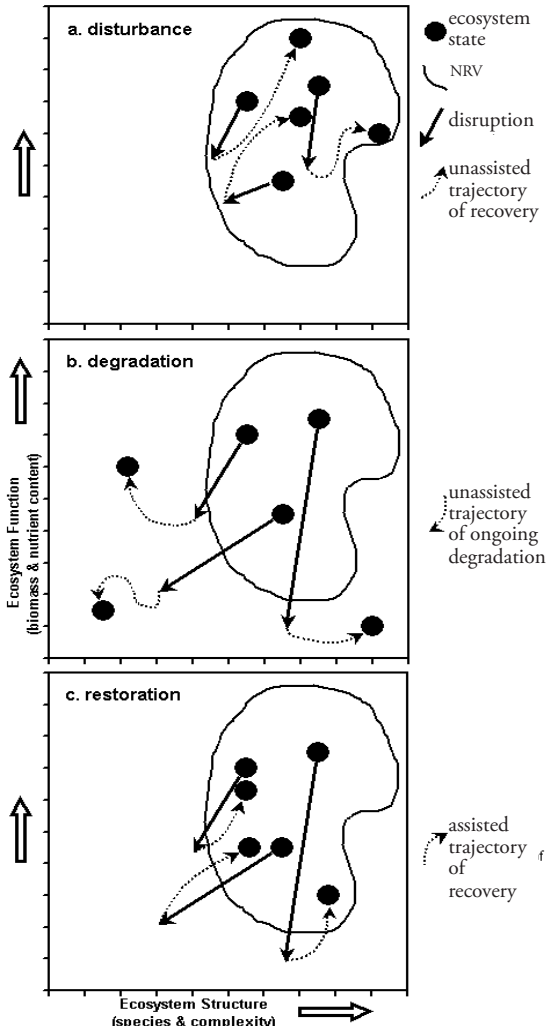


Figure 3: Conceptual models of disturbance, degradation, and restoration as related to the natural range of variability (NRV) and Bradshaw's (1984) model of ecosystem recovery of structure and function. (a) Disturbance of a healthy ecosystem, defined as disruptions within the historic NRV, will result in natural trajectories of ecosystem recovery, though not usually a return to conditions identical to those found immediately before disturbance. (b) In contrast, severe disruptions can cross the threshold of NRV (or other functionally important limits), causing ecosystem degradation and a loss of ecological integrity, as illustrated by the development of alternative successional trajectories and novel ecosystem states. (c) Careful intervention following the same disruptions shown in (b) can accelerate the recovery of mature structure and function, or conversion from a degraded state to one within the original bounds of natural ecosystem variability. Of course, many managed ecosystems are purposely maintained in an unnatural state, or in conditions this model would denote as degraded.

regionally rare in the first place; secondly, the need and incentive for restoration often comes from an urban population desperate for green space and nearby examples of "natural" ecosystems; and thirdly, effective restoration and the ongoing management of restored ecosystems typically requires involvement by a committed corps of volunteers.

With sufficient levels of public demand, political will and corporate responsibility, not all restoration work needs to be done on a small scale by volunteers. There are several examples of recent and ongoing large scale ecological restoration efforts undertaken in BC. The Watershed Restoration Program (1994-2002) of Forest Renewal BC identified upland sediment sources (primarily from logging roads, landings, and unstable slopes) and streamside management practices (logging and cattle access) as primary causes of fish stream degradation, and undertook a massive program of upland, riparian, and in-stream restoration work (Slaney and Martin, 1997). The Terrestrial Ecosystem Restoration Program (2000-2002, also funded by Forest Renewal BC) concentrated on the reintroduction of ground fires in fire-dependent ecosystems, primarily in the Interior Douglas-fir and Ponderosa Pine biogeoclimatic zones. Range managers in the southern third of the province have been battling the invasion of exotic plants such as cheatgrass (*Bromus tectorum* L.) and knapweeds (*Centaurea* spp.) for years (see Range Management chapter). A broad-based community of biologists, municipal leaders, and nature enthusiasts has been working to restore the Garry oak savannahs and associated wildflower meadows of southern Vancouver Island (Burton, 2002). Agencies such as Parks Canada and BC Parks regularly undertake ecosystem restoration in order to repair damage done by previous land uses and overuse by recreationists. Some mining companies, which have long been required to stabilize and revegetate their disturbed lands, are now seeing the value of more complete ecological restoration as well. With the enactment of the federal *Species at Risk Act* (2002), all recovery plans for threatened and endangered species essentially direct ecological restoration efforts in the form of species recovery plans. For very rare plants and animals, the maintenance and reintroduction of individuals and populations is usually done in the context of broader ecosystem restoration planning.

Effective ecological restoration work can generate a good deal of personal and professional satisfaction, as well as collective community pride and purpose. Consequently, this sub-discipline of ecosystem management attracts many people, both trained and untrained, who "want to make a difference" in combating ongoing environmental damage. However, it must always be remembered that restoration should only be the last resort of conservation biologists and ecosystem managers: restoration of degraded systems only takes place when the protection of ecological integrity has failed. Emphasis should first be placed on the protection, responsible stewardship and sustainable management of natural ecosystems.

Support, Resources and Prognosis

The fields of forest ecosystem management and conservation biology are so broad, and are evolving so rapidly, that little justice can be given to these topics in a few pages. The reader is strongly encouraged to use Boyce and Haney (1997), Kohm and Franklin (1997), Voller and Harrison (1998), Hunter (1999), Johnson *et al.* (1999),

Lindenmayer and Franklin. (2002), Burton *et al.* (2003) and Perera *et al.* (2004) as additional resources.

Professional associations and journals exist to assist practitioners of ecosystem management. Good sources for recent advancements in the field include the journal *Conservation Biology*, and the journals *Ecological Restoration* and *Restoration Ecology*. For an emphasis on forest ecosystem management, the reader is referred to the periodicals *Ecoforestry*, and the *BC Journal of Ecosystems & Management*.

The need to test, document and improve the effectiveness of many of the approaches outlined here provides an important opportunity for applied research, adaptive management, and further innovations in the theory and application of ecosystem management. Readers can expect to see an extensive literature on this topic developing in the near future, and those embarking on careers in renewable resource management will soon discover that their own creativity and experience will contribute much to our collective expertise in ecosystem management. There will often be objections to ecosystem management by those with vested interests in single resources. Nevertheless, considerable scientific evidence and public opinion now supports this well-reasoned, equitable and sustainable approach to resource stewardship. Furthermore, survival of much of the world's biodiversity will depend on it.

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Silvics and Silviculture

ECOLOGICAL AND SILVICAL CHARACTERISTICS OF MAJOR TREE SPECIES IN BRITISH COLUMBIA

by

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ECOLOGICAL AND SILVICAL CHARACTERISTICS OF MAJOR TREE SPECIES IN BRITISH COLUMBIA

Introduction

This chapter deals with the ecological and silvical characteristics of the important timber crop species of British Columbia (BC). Silvics, the study of the life history of forest trees, aims to describe how trees species establish, grow, and respond in relation to sites, each other, and other organisms. Silvics contributes to the knowledge foresters need to make the best possible decisions on how to manipulate forest stands for the certain and continuous production of goods and services desired from a forest. The application of silvics is governed by the following principles:

1. Trees grow and respond in ways that depend on ecosystems in which they grow; therefore, silviculture must be ecosystem-specific, i.e. tree species and site-specific.
2. Similar ecosystems will respond in similar ways to the same manipulation/treatment; therefore, ecosystem classification is a tool for recognizing different ecosystems and applying different treatments.
3. As forest growth cannot be fully controlled, a forester has to cooperate with nature; therefore, one must analyze and interpret each ecosystem subject to management.

Information included here is generalized and, except for native range, focuses on BC. Infrequent occurrence is indicated using square brackets for climatic amplitude and round brackets for edaphic amplitude. British Columbia. [Greater detail may be obtained from the literature resources cited at the end of the chapter.]

Abies amabilis (Dougl. ex Loud.) Forbes

Amabilis or Pacific silver fir

Native range

A Western North American, Pacific species, ranging from 52^{0}N latitude in BC to 42^{0}N in northern coastal California.

Climatic amplitude

Maritime subalpine boreal (MH zone) – wetter cool mesothermal (wetter CWH subzones).

Edaphic amplitude

Range of soil moisture conditions: slightly dry – fresh – moist – very moist.
Range of soil nutrient conditions: very poor – poor – medium – rich – very rich.

Tolerances

Tolerant of low light, nutrient-deficient soils (highly mycorrhizal species), and soil water surplus. Intolerant of high air temperature, soil water deficit, and severe winter frost.

Damaging agents

Resistant to high snowpack; medium resistance to wind. Low susceptibility to fire (minor concern in wet climates) and fungal attacks (minor concern in high elevations); susceptible to insect attacks.

Successional role and major associated tree species

Grows in all stages of secondary succession (a major component of old growth stands) in pure (less often) and mixed-species stands. Associates: mountain hemlock, yellow-cedar, and western hemlock.

Silvical Characteristics
(L – low, M – intermediate, H – high)

Reproduction capacity	M
Seed dissemination capacity	L
Potential for natural regeneration in low light	H
Potential for natural regeneration in the open	L
Potential initial growth rate (<5 yrs)	L
Response of advance regeneration to release	H
Self-pruning capacity in dense stands	H
Crown spatial requirements	L
Light conditions beneath closed-canopy mature stands	L
Productivity potential	L–H
Longevity	M
Suitability for clearcutting systems	H
Suitability for shelterwood systems	M
Suitability for selection systems	H

References: Crawford and Oliver (1990); Oliver and Kenady (1983); Klinka *et al.* (2000).

Abies grandis (Dougl. ex D. Don) Lindl.

Grand fir

Native Range

A Western North American, Pacific and Cordilleran species; ranging from 51^{0}N latitude in BC to 39^{0}N latitude in central coastal California.

Climatic amplitude

Cool temperate (IDF and ICH zones) – cool mesothermal (CDF and CWH zones).

Edaphic amplitude

Range of soil moisture conditions: (very dry –) moderately dry – slightly dry – fresh – moist – very moist (– wet).
Range of soil nutrient conditions: (poor –) medium – rich – very rich.

Tolerances

Moderately tolerant of low light, severe winter frost, high air temperature, nutrient-deficient soils, and soil water deficit. Tolerant of soil water surplus.

Damaging agents

Moderately resistant of high snowpack and wind. Susceptible to fire, and insect and fungal attacks.

Successional role and major associated tree species

Grows in all stages of secondary succession (a minor component of old growth stands) in pure (rarely) and mixed-species stands. Associates: Douglas-fir and western redcedar.

Silvical Characteristics
(L – low, M – intermediate, H – high)

Reproduction capacity	M
Seed dissemination capacity	L
Potential for natural regeneration in low light	M
Potential for natural regeneration in the open	L
Potential initial growth rate (<5 yrs)	M
Response of advance regeneration to release	M
Self-pruning capacity in dense stands	H
Crown spatial requirements	L
Light conditions beneath closed-canopy mature stands	L
Productivity potential	H
Longevity	M
Suitability for clearcutting systems	M-H
Suitability for shelterwood systems	M
Suitability for selection systems	M-H

References: Oliver and Kenady (1983); Foiles *et al.* (1990); Klinka *et al.* (2000).

Abies lasiocarpa (Hook.) Nutt.

Subalpine fir

Native Range

A Western North American species, mainly Cordilleran and less Pacific; ranging from 63^{0}N latitude in Yukon to BC to 32^{0}N latitude in southwestern United States.

Climatic amplitude

Subalpine boreal (MH, ESSF, and SWB zones) – montane boreal (BWBS and SBS zones) [– cool temperate (IDF and ICH zones)].

Edaphic amplitude

Range of soil moisture conditions: (moderately dry –) slightly dry – fresh – moist – very moist – wet.
Range of soil nutrient conditions: very poor – poor – medium – rich – very rich.

Tolerances

Tolerant of low light, severe winter frost, nutrient-deficient soils (highly mycorrhizal species), and soil water surplus. Moderately tolerant of high air temperature and soil water deficit.

Damaging agents

High resistance to snowpack; low resistance to wind. Susceptible to fire (a minor concern in wet climates) and insect and fungal attacks (a minor concern in high elevations).

Successional role and major associated tree species

Grows in primary succession and all stages of secondary succession (a major component of old growth stands) in pure (less often) and mixed-species stands.
Associates: Engelmann spruce, white spruce, hybrid spruce, and black spruce.

Silvical Characteristics
(L – low, M – intermediate, H – high)

Reproduction capacity	M
Seed dissemination capacity	L
Potential for natural regeneration in low light	H
Potential for natural regeneration in the open	L
Potential initial growth rate (<5 yrs)	L
Response of advance regeneration to release	H
Self-pruning capacity in dense stands	H
Crown spatial requirements	L
Light conditions beneath closed-canopy mature stands	L
Productivity potential	H
Longevity	M
Suitability for clearcutting systems	M-H
Suitability for shelterwood systems	M
Suitability for selection systems	H

References: Alexander *et al.* (1990); Oliver and Kenady (1983); Klinka *et al.* (2000).

Alnus rubra (Bong.) Carr.

Red alder

Native range

A Western North American, Pacific species, ranging from southeastern Alaska (59^{0}N latitude) to northern coastal California (36^{0}N latitude).

Climatic amplitude

Cool mesothermal (CDF and CWH zones).

Edaphic amplitude

Range of soil moisture conditions: (moderately dry –) slightly dry – fresh – moist – very moist – wet.
Range of soil nutrient conditions: (very poor –) poor – medium – rich – very rich.

Tolerances

Intolerant of low light, severe winter frost, high air temperature, and soil water deficit. Tolerant of soil water surplus and nitrogen-deficient soils.

Damaging agents

Low resistance to high snowpack; medium resistance to wind. Susceptible to fire and insect and fungal attacks (a minor concern).

Successional role and major associated tree species

Grows in primary succession and all stages of secondary succession (except in old growth stands) in pure (most often) and mixed-species stands (less often). Associates: black cottonwood, Sitka spruce, western hemlock, and western redcedar.

Silvical Characteristics
(L – low, M – intermediate, H – high)

Reproduction capacity	H
Seed dissemination capacity	H
Potential for natural regeneration in low light	L
Potential for natural regeneration in the open	H
Potential initial growth rate (<5 yrs)	H
Response of advance regeneration to release	na
Self-pruning capacity in dense stands	H
Crown spatial requirements	M
Light conditions beneath closed-canopy mature stands	H
Productivity potential	H
Longevity	L
Suitability for clearcutting systems	H
Suitability for shelterwood systems	M
Suitability for selection systems	L

References: Harrington (1990); Peterson *et al.* (1996); Klinka *et al.* (2000).

Chamaecyparis nootkatensis (Bong.) Carr.
Yellow-cedar or Alaska yellow-cedar

Native range

A Western North American, Pacific species; ranging from 61^{0}N latitude in south-eastern Alaska to 42^0 30'N latitude in southern coastal Oregon.

Climatic amplitude

Maritime subalpine boreal (MH zone) – and wetter cool mesothermal (wetter CWH subzones).

Edaphic amplitude

Range of soil moisture conditions: (moderately dry –) slightly dry – fresh – moist – very moist – wet.
Range of soil nutrient conditions: very poor – poor – medium – rich – very rich.

Tolerances

Tolerant of low light, nutrient-deficient soils, and soil water surplus. Moderately tolerant of soil water deficit. Intolerant of high air temperature and severe winter frost.

Damaging agents

Moderately resistant to high snowpack and wind. Susceptible to fire and insect attacks (not a major concern in high elevations); low susceptibility to fungal attacks.

Successional role and major associated tree species

Grows in primary succession and all stages of secondary succession (a major component of old growth stands) in pure (rarely) and mixed-species stands. Associates: Pacific silver fir, mountain hemlock, and western hemlock.

Silvical Characteristics
(L – low, M – intermediate, H – high)

Reproduction capacity	L
Seed dissemination capacity	M
Potential for natural regeneration in low light	M
Potential for natural regeneration in the open	H
Potential initial growth rate (<5 yrs)	L-M
Response of advance regeneration to release	H
Self-pruning capacity in dense stands at full site occupancy	H
Crown spatial requirements	L
Light conditions beneath closed-canopy mature stands	L
Productivity potential	L-M
Longevity	H
Suitability for clearcutting systems	M-H
Suitability for shelterwood systems	M
Suitability for selection systems	H

References: Harris (1990a); Lousier (1991); Klinka *et al.* (2000).

Larix occidentalis Nutt.

Western larch

Native range

A Western North American, Cordilleran species; ranging from 51^{0}N latitude in BC to 39^{0}N latitude in central Oregon and Idaho.

Climatic amplitude

[Cool semiarid (PP zone) – continental subalpine boreal (ESSF zone) –] cool temperate (IDF and ICH zones).

Edaphic amplitude

Range of soil moisture conditions: (very dry –) moderately dry – slightly dry – fresh – moist (– very moist).
Range of soil nutrient conditions: (very poor –) poor – medium – rich – very rich.

Tolerances

Intolerant of low light. Moderately tolerant of severe winter frost, high air temperature, and soil water deficit. Intolerant of soil water surplus and nutrient-deficient soils.

Damaging agents

Resistant to high snowpack and wind. Low susceptibility to fire and fungal attacks; intermediate susceptibility to insect attacks.

Successional role and associated tree species

Grows in all stages of secondary succession (except in true old growth stands) in pure (less often) and mixed-species stands. Associates: lodgepole pine and Douglas-fir.

Silvical Characteristics
(L – low, M – intermediate, H – high)

Reproduction capacity	M
Seed dissemination capacity	M
Potential for natural regeneration in low light	L
Potential for natural regeneration in the open	H
Potential initial growth rate (<5 yrs)	M
Response of advance regeneration to release	na
Self-pruning capacity in dense stands	H
Crown spatial requirements	H
Light conditions beneath closed-canopy mature stands	H
Productivity potential	H
Longevity	H
Suitability for clearcutting systems	H
Suitability for shelterwood systems	M
Suitability for selection systems	L

References: Schmidt and Shearer (1990); Schmidt and McDonald (1992; 1995); Klinka *et al.* (2000).

Picea engelmannii Parry ex Engelmann
Engelmann spruce

Native range

A Western North American species, mainly Cordilleran, marginally Pacific; ranging from northern BC (58^{0}N latitude) to southwestern United States (32^{0}N latitude).

Climatic amplitude

[Alpine tundra (AT zone) –] subalpine boreal (MH, ESSF, and MS zones) – [montane boreal (SBS zone) – cool temperate (IDF and ICH zones)].

Edaphic amplitude

Range of soil moisture conditions: (moderately dry –) slightly dry – fresh – moist – very moist – wet.
Range of soil nutrient conditions: (very poor –) poor – medium – rich – very rich.

Tolerances

Moderately tolerant of low light, high air temperature, soil water deficits; and nutrient-deficient soils. Tolerant of soil water surplus.

Damaging agents

Resistant to high snowpack, low resistance to wind. High susceptibility to fire; moderate susceptibility to insect and fungal attacks (a minor concern in high elevations).

Successional role and major associated tree species

Grows in all stages of secondary succession (a variable component of old growth stands) in pure (less often) and mixed-species stands. Associates most frequently with subalpine fir.

Silvical Characteristics

(L – low, M – intermediate, H – high)

Reproduction capacity	M
Seed dissemination capacity	M
Potential for natural regeneration in low light	L
Potential for natural regeneration in the open	H
Potential initial growth rate (<5 yrs)	L
Response of advance regeneration to release	M
Self-pruning capacity in dense stands	M
Crown spatial requirements	L
Light conditions beneath closed-canopy mature stands	M
Productivity potential	M-H
Longevity	H
Suitability for clearcutting systems	M-H
Suitability for shelterwood systems	M
Suitability for selection systems	M

References: Alexander and Shepperd (1990); Klinka *et al.* (2000).

Picea glauca (Moench) Voss and *P. engelmannii* x *glauca*
White spruce and interior (hybrid) spruce

Native range

A North American transcontinental species; a western North American Cordilleran species.

Climatic amplitude

Subarctic – subalpine boreal (SWB and MS zones) – montane boreal (BWBS, SBS, and SBPS zones) – cool temperate (IDF, ICH, and northern CHW zones).

Edaphic amplitude

Range of soil moisture conditions: (very dry –) moderately dry – slightly dry – fresh – moist – very moist – wet.
Range of soil nutrient conditions: (very poor –) poor – medium – rich – very rich.

Tolerances

Moderately tolerant of low light, high air temperature, soil water deficit, and soil nutrient deficiencies. Tolerant of severe winter frost and soil water surplus.

Damaging agents

Moderately resistant of high snowpack; low resistance to wind. Susceptible to fire and insect and fungal attacks.

Successional role and major associated tree species

Grows in all stages of secondary succession (a major component of old growth stands) in pure (less often) and mixed-species stands. Associates: subalpine fir, black spruce, lodgepole pine, and trembling aspen.

Silvical Characteristics
(L – low, M – intermediate, H – high)

Reproduction capacity	H
Seed dissemination capacity	H
Potential for natural regeneration in low light	L
Potential for natural regeneration in the open	H
Potential initial growth rate (<5 yrs)	L
Response of advance regeneration to release	H
Self-pruning capacity in dense stands	H
Crown spatial requirements	M
Light conditions beneath closed-canopy mature stands	L
Productivity potential	H
Longevity	H
Suitability for clearcutting systems	M-H
Suitability for shelterwood systems	M
Suitability for selection systems	M

References: Coates *et al.* (1994); Nienstaedt and Zasada (1990); Klinka *et al.* (2000).

Picea sitchensis (Bong.) Carr.

Sitka spruce

Native range

A Western North American, Pacific species, ranging from south central Alaska (61^{0}N latitude) to northern coastal California (39^{0}N latitude).

Climatic amplitude

Maritime subalpine boreal (MH zone) – wetter, cool mesothermal (wetter CWH subzones).

Edaphic amplitude

Range of soil moisture conditions: slightly dry – fresh – moist – very moist.
Range of soil nutrient conditions: very poor – poor – medium – rich – very rich.

Tolerances

Tolerant of soil water surplus; moderately tolerant of low light. Intolerant of severe winter frost, high air temperature, soil water deficit, and nutrient-deficient soils.

Damaging agents

Low resistance to high snowpack and wind. Susceptible to fire (a minor concern in wet climates) and fungal attacks; highly susceptible to white pine weevil and spruce beetle.

Successional role and major associated tree species

Grows in all stages of secondary succession (a variable component of old growth stands) in pure (less often) and mixed-species stands. Associates: western hemlock.

Silvical Characteristics
(L – low, M – intermediate, H – high)

Reproduction capacity	H
Seed dissemination capacity	H
Potential for natural regeneration in low light	L
Potential for natural regeneration in the open	H
Potential initial growth rate (<5 yrs)	M
Response of advance regeneration to release	na
Self-pruning capacity in dense stands	H
Crown spatial requirements	H
Light conditions beneath closed-canopy mature stands	M
Productivity potential	H
Longevity	H
Suitability for clearcutting systems	H
Suitability for shelterwood systems	M
Suitability for selection systems	L

References: Harris (1990b); Peterson *et al.* (1997); Klinka *et al.* (2000).

Pinus contorta Dougl. ex Loud.

Lodgepole pine

Native range

A Western North American species; Pacific, Cordilleran, and marginally Central; ranging from Yukon (64^0 N latitude) to Baja California (31^0 N latitude).

Climatic amplitude

Subalpine boreal (MH, SWB, ESSF, and MS zones) – montane boreal (BWBS, SBS, SBPS zones) – cool temperate (IDF and ICH zones) – cool mesothermal (CDF and CWH zones).

Edaphic amplitude

Range of soil moisture conditions: very dry – moderately dry – slightly dry – fresh – moist – very moist – wet.
Range of soil nutrient conditions: very poor – poor – medium – rich – very rich.

Tolerances

Intolerant of low light. Tolerant of severe winter frost, high air temperature, soil water deficit, soil water surplus, and nutrient-deficient soils.

Damaging agents

Low resistance to high snowpack; medium resistance to wind. Susceptible to fire, insect and fungal attacks, and dwarf mistletoe.

Successional role and major associated tree species

Grows in primary succession and in all stages of secondary succession, predominantly in pure, even-aged, fire-origin stands. Associates with many coniferous and broad-leaved tree species.

Silvical Characteristics
(L – low, M – intermediate, H – high)

Reproduction capacity	H
Seed dissemination capacity	L
Potential for natural regeneration in low light	L
Potential for natural regeneration in the open	H
Potential initial growth rate (<5 yrs)	H
Response of advance regeneration to release	L
Self-pruning capacity in dense stands	H
Crown spatial requirements	L
Light conditions beneath closed-canopy mature stands	H
Productivity potential	M
Longevity	M
Suitability for clearcutting systems	H
Suitability for shelterwood systems	M
Suitability for selection systems	L

References: Baumgartner *et al.* (1985); Lotan and Critchfield (1990); Klinka *et al.* (2000).

Pinus monticola Dougl. ex D. Don in Lamb.
Western white pine

Native range

A Western North American species, mainly Cordilleran, less Pacific; ranging from 51^0 30' N latitude in BC to 35^0 50' N latitude in southern California.

Climatic amplitude

Subalpine boreal (MH, ESSF, and MS zones) – cool temperate (IDF and ICH zones) – cool mesothermal (CDF and CWH zones).

Edaphic amplitude

Range of soil moisture conditions: (moderately dry) – slightly dry – fresh – moist – very moist – wet.
Range of soil nutrient conditions: (poor –) medium – rich – very rich.

Tolerances

Moderately tolerant of low light, severe winter frost, and high air temperature; tolerant of soil water surplus. Intolerant of soil water deficit and nutrient-deficient soils.

Damaging agents

High resistance to snowpack; medium resistance to wind. Susceptible to fire (not a major concern in wet climates) and insect attacks; highly susceptible to blister rust.

Successional role and major associated tree species

Grows in all stages of secondary succession (a minor component of old growth stands) in pure mixed-species stands. Associates with many coniferous species.

Silvical Characteristics
(L – low, M – intermediate, H – high)

Reproduction capacity	M
Seed dissemination capacity	L
Potential for natural regeneration in low light	H
Potential for natural regeneration in the open	L
Potential initial growth rate (<5 yrs)	L
Response of advance regeneration to release	H
Self-pruning capacity in dense stands at full site occupancy	H
Crown spatial requirements	L
Light conditions beneath closed-canopy mature stands	L
Productivity potential	L-H
Longevity	M
Suitability for clearcutting systems	H
Suitability for shelterwood systems	M
Suitability for selection systems	L-M

References: Graham (1990); Klinka *et al.* (2000).

Pinus ponderosa Dougl. ex P. & C. Lawson
Ponderosa pine

Native range

A North American species; Pacific, Cordilleran, and Central; ranging from 52^{0}N latitude in BC to 25^{0}N latitude in northern Mexico.

Climatic amplitude

[Continental subalpine boreal (ESSF and MS zones)] – cool temperate (PP, IDF, and ICH zones).

Edaphic amplitude

Range of soil moisture conditions: very dry – moderately dry – slightly dry – fresh (– moist).
Range of soil nutrient conditions: poor – medium – rich – very rich.

Tolerances

Intolerant of low light; moderately tolerant of severe winter frost and nutrient-deficient soils; tolerant of high air temperature, soil water deficit, and short-term inundation.

Damaging agents

Moderately resistant to high snowpack; highly resistant to wind. Moderate susceptibility to fire, insect and fungal attacks, and other damaging agents.

Successional role and associated tree species

Grows in all stages of secondary succession (a major component of old growth stands) in pure and mixed-species stands, associates most frequently with Douglas-fir.

Silvical Characteristics
(L – low, M – intermediate, H – high)

Reproduction capacity	H
Seed dissemination capacity	L
Potential for natural regeneration in low light	L
Potential for natural regeneration in the open	H
Potential initial growth rate (<5 yrs)	H
Response of advance regeneration to release	na
Self-pruning capacity in dense stands at full site occupancy	M
Crown spatial requirements	H
Light conditions beneath closed-canopy mature stands	H
Productivity potential	M-H
Longevity	M
Potential for clearcutting systems	L-H
Potential for shelterwood systems	M
Potential for selection systems	L-H

References: Oliver and Ryker (1990); Klinka *et al.* (2000).

Populus balsamifera L. and *P. trichocarpa* Torr. & Gray

Balsam poplar and black cottonwood

Native range

Balsam poplar: a North American transcontinental species; black cottonwood: a Western North American species, Pacific and Cordilleran, ranging from 62^{0}N latitude in southern central Alaska to 31^{0}N latitude in Baja California.

Climatic amplitude

Balsam poplar: [continental subalpine boreal (SWB zone)] – montane boreal (BWBS zone); black cotton wood: [subalpine boreal (MH, ESSF, and MS zones)] – montane boreal (BWBS, SBS, SBPS zones) – cool temperate (PP, IDF, and ICH zones) – cool mesothermal (CDF and CWH zones).

Edaphic amplitude

Range of soil moisture conditions: slightly dry – fresh – moist – very moist – wet. Range of soil nutrient conditions: (poor –) medium – rich – very rich.

Tolerances

Intolerant of low light, soil water deficit, and nutrient-deficient soils; moderately tolerant of high air temperature and severe winter frost (tolerance to frost is higher in balsam poplar); tolerant of soil water surplus and inundation.

Damaging agents

Moderately resistant to high snowpack, high resistance to wind. Low susceptibility to fire and insect and fungal attacks, and other damaging agents.

Successional role and major associated tree species

Grows in primary succession on alluvial floodplains, where is later replaced by shade-tolerant conifers, and in early and mid-stages of secondary succession in pure, less often in mixed-species stands. Associates: shade-tolerant conifers.

Silvical Characteristics
(L – low, M – intermediate, H – high)

Reproduction capacity	H
Seed dissemination capacity	H
Potential for natural regeneration in low light	L
Potential for natural regeneration in the open	H
Potential initial growth rate (<5 yrs)	H
Response of advance regeneration to release	na
Self-pruning capacity in dense stands	H
Crown spatial requirements	H
Light conditions beneath closed-canopy mature stands	H
Productivity potential	H
Longevity	L
Suitability for clearcutting systems	H
Suitability for shelterwood systems	L
Suitability for selection systems	L

References: Bell (1990); Zasada and Phipps (1990); Peterson and Peterson (1992); Klinka *et al.* (2000).

Populus tremuloides Michx.

Trembling aspen

Native range

A North American transcontinental species.

Climatic amplitude

Subarctic – [continental subalpine boreal (SWB, ESSF, and MS zones) –] montane boreal (BWBS, SBS, and SBPS zones) – cool temperate (PP, IDF, and ICH zones) [– cool mesothermal (CDF and CWH zones)].

Edaphic amplitude

Range of soil moisture conditions: (very dry –) moderately dry – slightly dry – fresh – moist (– very moist).

Range of soil nutrient conditions: (very poor –) poor – medium – rich – very rich.

Tolerances

Intolerant of low light and water deficit. Moderately tolerant of high air temperature and nutrient-deficient soils. Intolerant of severe winter frost and water surplus (strongly fluctuating water table).

Damaging agents

Moderately resistant high snowpack and wind. Low susceptibility to insects and other damaging agents; moderately susceptible to fire and fungal attacks.

Successional role and major associated tree species

Grows in all stages of secondary succession in pure, less often in mixed-species stands, most frequently with shade-tolerant conifers. In special situations (e.g. forest-grassland transition) it may be self-perpetuating without major disturbance.

Silvical Characteristics
(L – low, M – intermediate, H – high)

Reproduction capacity	H
Seed dissemination capacity	H
Potential for natural regeneration in low light	L
Potential for natural regeneration in the open	H
Potential initial growth rate (<5 yrs)	H
Response of advance regeneration to release	na
Self-pruning capacity in dense stands	H
Crown spatial requirements	M
Light conditions beneath closed-canopy mature stands	H
Productivity potential	H
Longevity	L
Suitability for clearcutting systems	H
Suitability for shelterwood systems	L
Suitability for selection systems	L

References: DeByle and Winokur (1985); Navratil and Chapman (1991); Perala (1990); Peterson and Peterson (1992; 1995); Klinka *et al.* (2000).

Pseudotsuga menziesii (Mirb.) Franco
Douglas-fir

Native range

A Western North American species, Pacific and Cordilleran; ranging from 50° 30'N latitude in BC to 23° 30'N latitude in west central Mexico.

Climatic amplitude

[Subalpine boreal (MH, ESSF, and MS zones) –] montane boreal (SBS and SBPS zones) – cool temperate (PP, IDF, and ICH zones) – cool mesothermal (CDF and CWH zones).

Edaphic amplitude

Range of soil moisture conditions: very dry – moderately dry – slightly dry – fresh – moist – very moist.
Range of soil nutrient conditions: (very poor –) poor – medium – rich – very rich.

Tolerances

Tolerant to intolerant of low light and severe winter frost. Intolerant of soil water surplus; moderately tolerant of high air temperature, soil water deficit, and nutrient-deficient soils.

Damaging agents

Low to moderate resistance to high snowpack; resistant to wind. Moderately susceptible to fire; susceptible to insect and fungal attacks.

Successional role and major associated tree species

Grows in all stages of secondary succession (a major component of old growth stands) in pure and a great variety of mixed-species stands.

Silvical Characteristics
(L – low, M – intermediate, H – high)

Reproduction capacity	H
Seed dissemination capacity	H
Potential for natural regeneration in low light	L-H
Potential for natural regeneration in the open	H
Potential initial growth rate (<5 yrs)	H
Response of advance regeneration to release	H
Self-pruning capacity in dense stands	H
Crown spatial requirements	M
Light conditions beneath closed-canopy mature stands	M
Productivity potential	H
Longevity	H
Suitability for clearcutting systems	L-H
Suitability for shelterwood systems	L-H
Suitability for selection systems	L-H

References: Oliver *et al.* (1986); Hermann and Lavender (1990); Klinka *et al.* (2000).

Thuja plicata (Donn ex D. Don) Spach
Western redcedar

Native range

A Western North American species, mainly Pacific less Cordilleran; ranging from 56^0 30'N latitude in southeastern Alaska to 40^0 10'N latitude in northern coastal California.

Climatic amplitude

[Subalpine boreal (MH, ESSF, and MS zones) –] cool temperate ([PP], IDF, and ICH zones) – cool mesothermal (CDF and CWH zones).

Edaphic amplitude

Range of soil moisture conditions: very dry – moderately dry –slightly dry – fresh – moist – very moist – wet.
Range of soil nutrient conditions: very poor – poor – medium – rich – very rich.

Tolerances

Tolerant of low light, soil water surplus, and nutrient-deficient soils. Moderately tolerant of severe winter frost, high air temperature, and soil water deficit.

Damaging agents

Moderately resistant to high snowpack and wind. Susceptible to fire, fungal (in trees that regenerated vegetatively) attacks, and browsing; low susceptibility to insect attacks.

Successional role and major associated tree species

Grows in all stages of secondary succession (a major component of old growth stands) in pure (less often) and mixed-species stands. Associates: western hemlock and Douglas-fir.

Silvical Characteristics
(L – low, M – intermediate, H – high)

Reproduction capacity	H
Seed dissemination capacity	M
Potential for natural regeneration in low light	M
Potential for natural regeneration in the open	H
Potential initial growth rate (<5 yrs)	H
Response of advance regeneration to release	H
Self-pruning capacity in dense stands	H
Crown spatial requirements	M
Light conditions beneath closed-canopy mature stands	L
Productivity potential	H
Longevity	H
Suitability for clearcutting systems	H
Suitability for shelterwood systems	M
Suitability for selection systems	H

References: Minore (1983; 1990); Smith (1988); Klinka *et al.* (2000).

Tsuga heterophylla (Raf.) Sarg.
Western hemlock

Native range

A Western North American species, mainly Pacific less Cordilleran; ranging from 60^0 30'N latitude in southern coastal Alaska to 33^0 30'N latitude in northern coastal California.

Climatic amplitude

[Subalpine boreal (MH and ESSF zones) –] cool temperate ([IDF] and ICH zones) – cool mesothermal ([CDF] and CWH zones).

Edaphic amplitude

Range of soil moisture conditions: (moderately dry –) slightly dry – fresh – moist – very moist (– wet).
Range of soil nutrient conditions: very poor – poor – medium – rich.

Tolerances

Tolerant of low light and nutrient-deficient soils (highly mycorrhizal species); moderately tolerant of soil water surplus. Intolerant of severe winter frost, high air temperature, and soil water deficit.

Damaging agents

Low resistance to wind; low to moderate resistance to high snowpack. Susceptible to fire and insect and fungal attacks; highly susceptible to dwarf mistletoe.

Successional role and major associated tree species

Grows in all stages of secondary succession (a major component of old growth stands) in pure and mixed-species stands. Associates: Douglas-fir, Pacific silver fir, and western redcedar.

Silvical Characteristics
(L – low, M – intermediate, H – high)

Reproduction capacity	H
Seed dissemination capacity	H
Potential for natural regeneration in low light	H
Potential for natural regeneration in the open	H
Potential initial growth rate (<5 yrs)	M
Response of advance regeneration to release	H
Self-pruning capacity in dense stands	H
Crown spatial requirements	M
Light conditions beneath closed-canopy mature stands	L
Productivity potential	H
Longevity	M
Suitability for clearcutting systems	H
Suitability for shelterwood systems	M
Suitability for selection systems	H

References: Ruth and Harris (1979); Packee (1990); Klinka *et al.* (2000).

Tsuga mertensiana (Bong.) Carr.

Mountain hemlock

Native range

A Western North American species, more Pacific than Cordilleran; ranging from ranging from 61° 25'N latitude in southern coastal Alaska to 36° 40'N latitude in northern coastal California.

Climatic amplitude

Subalpine boreal (MH and ESSF zones) – [cool mesothermal (hypermaritime CWH subzones)].

Edaphic amplitude

Range of soil moisture conditions: (moderately dry –) slightly dry – fresh – moist – very moist (– wet).
Range of soil nutrient conditions: very poor – poor – medium (– rich).

Tolerances

Moderately tolerant of low light, severe winter frost, and soil water surplus. Intolerant of high air temperature and soil water deficit. Tolerant of nutrient-deficient soils (highly mycorrhizal species).

Damaging agents

Moderately resistant to high snowpack, low resistance to wind. Susceptible to fire, insect and fungal attacks, and dwarf mistletoe.

Successional role and major associated tree species

Grows in all stages of secondary succession (a major component of old growth stands) in pure (less often) and mixed-species stands. Associates: Pacific silver fir and yellow-cedar.

Silvical Characteristics
(L – low, M – intermediate, H – high)

Reproduction capacity	M
Seed dissemination capacity	H
Potential for natural regeneration in low light	L
Potential for natural regeneration in the open	M
Potential initial growth rate (<5 yrs)	L
Response of advance regeneration to release	H
Self-pruning capacity in dense stands	H
Crown spatial requirements	M
Light conditions beneath closed-canopy mature stands	M
Productivity potential	L
Longevity	H
Suitability for clearcutting systems	L-M
Suitability for shelterwood systems	M
Suitability for selection systems	H

References: Means (1990); Klinka *et al.* (2000).

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TREE SPECIES IDENTIFICATION

Identification Key for the Trees of British Columbia

by

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TREE SPECIES IDENTIFICATION

Identification Key for British Columbia Tree Species

The key is dichotomous, i.e. either/or, the category described in A being opposite to that in AA for example. The main trait for keying out is given first, secondary traits are in square brackets. As an example, consider vine maple. The leaves are not as described in A, so go to AA [which is vertically below A, on page 349!], which describes the leaves as broad. B [within AA] describes leaves as being oppositely arranged on the twig [not alternately, as in BB] the leaves are simple [CC] and lobed [DD], and are small [EE] with 7-9 lobes (F).

Some species are so variable they occur in the key twice, e.g. Douglas maple, which may have simple or compound leaves. Throughout, dimensions are approximate. Round brackets enclose weasel-words and caveats.

A. Leaves needle-like or linear or scale-like [resinous, evergreen (except in larch); seed borne in woody or fleshy cones (hence "conifers", except in yew, whose seed is partially surrounded by a fleshy aril)]..... GYMNOSPERMS or SOFTWOODS

B. All leaves needle-like or linear (but not in whorls of 3).

C. Aril red, fleshy [leaves linear, spirally arranged, but appearing two- ranked; green on the underside; twigs green for several years; aril open at top, one seeded] (dioecious; seeds only on females!).....PACIFIC YEW ***Taxus brevifolia*** Nutt.

CC. Cone scales woody (except leathery in junipers).

D. Some or all leaves in clusters, or fascicles.

E. All leaves in clusters (but single and linear/acicular in seedlings) [cones pendant, bracts not visible; maturing in 2 years. .. PINES

F. Leaves in 5's [fascicle sheath early deciduous] .....SOFT PINES

G. Cone long-stalked [leaves 5-10 cm long, flexible; cones 13-38 cm long; seed winged] ..... WESTERN WHITE PINE ***Pinus monticola*** Dougl.

GG. Cones short-stalked [seed wing small or absent].

H. Cone scales recurved [cone 8-25 cm long, scales opening at maturity, seed wing very short] .....LIMBER PINE ***Pinus flexilis*** James.

HH. Cone scales not recurved [cone 7 cm long and almost as wide; scales never opening (without bird or rodent help), seed unwinged; cones point out radially from the twig in all directions] . ..... WHITEBARK PINE ***Pinus albicaulus*** Engelm.

FF. Leaves in 2's or 3s [sheath persistent] ..... HARD PINES

G. Leaves in 3's [cones 8 cm long, leaves 10 cm long; young bark scaly and dark, older bark orange, scaly and plated] ..... PONDEROSA PINE ***Pinus ponderosa*** Laws

GG. Leaves in 2s.

H. Leaves in bundle widely divergent, 2-4 cm long [slightly twisted; cones usually curved, smooth; cones point forward along the twig] ..... JACK PINE ***Pinus banksiana*** Lamb.

HH. Leaves less divergent [and longer and more twisted; cones prickly; pointing backwards along the twig].

I. Leaves slender, dark green [tree limby, of poor form, coastal] ..... SHORE PINE ***Pinus contorta*** var. ***contorta*** Dougl.

II. Leaves stouter, yellow green [stem straight, less limby; interior BC] ..... LODGEPOLE PINE ***Pinus contorta*** var. ***latifolia*** Engelm.

EE. Only growth older than one year with bundles of leaves (on short spur shoots) [cones usually erect] ..... LARCHES

F. Cone bracts not visible (leaves deciduous, as in all larches) ..... TAMARACK ***Larix laricina*** (Du Roi) K. Koch.

FF. Cone bracts visible.

G. First year twigs woolly [leaves four-angled, 30-40 per bundle] ..... SUBALPINE LARCH ***Larix lyallii*** Parl.

GG. First year twigs downy [i.e. less pubescent; leaves flat to triangular, 14-30 per cluster] (cones pendant) ..... WESTERN LARCH ***Larix occidentalis*** Nutt.

DD. Single leaves.

E. Leaves raised on short woody pegs (bare twigs therefore rough); [cones pendant] ..... HEMLOCKS and SPRUCES

F. Buds small [leaves flexible, not sharp-pointed, linear; bark furrowed] ..... HEMLOCKS

G. Cones 2 cm long, egg-shaped [leaves of varible length, buds rounded] ..... WESTERN HEMLOCK ***Tsuga heterophylla*** (Raf.) Sarg.

GG. Cones up to 7 cm, oblong [leaves of more uniform length, and rather 4 angled in cross-section; buds pointed] MOUNTAIN HEMLOCK ***Tsuga mertensiana*** (Bong.) Carr.

FF. Buds conspicuous [leaves stiff, sharp pointed, 3 or 4 angled; bark scaly] ..... SPRUCES

G. Cone scale's tip rounded, stiff.

H. Leaves 1 to 1½ cm long, blunt generally [twigs usually velvety pubescent; cone egg-shaped, 3 cm long; margin of scales smooth or ragged] ..... BLACK SPRUCE ***Picea mariana*** (Mill.) BSP

HH. Leaves longer, sharp [twigs smooth; cone to 6 cm long, scale margin smooth] ..... WHITE SPRUCE ***Picea glauca*** (Moench.) Voss.

GG. Cone scale wedge-shaped, flexible.

H. Leaves very sharp, flat, bluish below [not crowded towards upper side of twig; cone to 10 cm, scale margin ragged] .....SITKA SPRUCE ***Picea sitchensis*** (Bong.) Carr.

HH. Leaves 4-sided, less sharp [crowded towards upper side of twig; twigs sometimes pubescent; cone to 8 cm, scale margin ragged] ..... ENGELMANN SPRUCE ***Picea engelmannii*** (Parry) Engelm.

EE. Leaves not raised on woody pegs [naked twigs therefore fairly smooth; cones erect, or if pendant, with the bract clearly visible].

F. Terminal bud scaly, pointed [leaves not notched at tip; cones pendant, 3-pronged bract visible, cone falls intact] .....COMMON DOUGLAS ***Pseudotsuga menziesii*** (Mirb.) Franco. (There are about eight species of ***Pseudotsuga***, occurring in the north Pacific rim, two in North America. By giving the genus its very own richly deserved common name ... douglas, we can stop the nonsense of having to call ***Abies*** balsam (which only the not native in BC ***A. balsamea*** L. actually is!) and call it fir.)

FF. Terminal bud blunt, but obviously scaly [leaves often notched; cones erect, bracts not visible at maturity; cone disintegrates on tree].....FIRS

G. Stomatal bands on both surfaces [leaves twisted upwards on twig, tips rounded or pointed; cones 5-10 cm tall, purple]..... SUBALPINE FIR ***Abies lasiocarpa*** (Hook.) Nutt.

GG. Stomatal bands generally below only. Tips often notched.

H. Leaves, at least those on lower branches, 2-ranked [cones green, 8-13 cm tall, by 3 cm wide; bract tips short] ..... GRAND FIR ***Abies grandis*** (Dougl.) Lindl.

HH. Upper leaves pointing forward [cones purple, 10-15 cm tall by 7 cm wide; bract tips long] ....AMABILIS FIR ***Abies amabilis*** (Dougl.) Forbes.

BB. Leaves scale-like at least some of the time; attached in opposite pairs, the linear ones (in juveniles) in 2s, 3's or 4s. Or all linear, in 3's.

C. Leaves all scale-like [twigs flattened; a woody or berry-like cone, with protruding scale tips; seeds usually winged].

D. Cones egg-shaped [scale tips thin; leaves shiny, tips not divergent or prickly; aromatic] upright .....WESTERN REDCEDAR ***Thuja plicata*** Donn.

DD. Cone spherical [leathery; leaves dull, tips often divergent and prickly].....YELLOW CEDAR ***Chamecyparis nootkatensis*** (D. Don) Spach. (The genus ***Chamecyparis*** seems to be getting absorbed into ***Cupressus***, so the correct common name really is cypress.)

CC. Leaves scale-like or linear and sharp. Cone berry-like, scale tips not protruding (dioecious, so only half of mature plants will have cones).....JUNIPERS

D. Leaves always linear [cone light blue, plants shrubby] ..... COMMON JUNIPER ***Juniperus communis*** L.

DD. Leaves linear usually only on very young shoots, otherwise scale-like [cone dark blue; small tree or shrub with gloriously aromatic heartwood] ..... ROCKY MOUNTAIN JUNIPER ***Juniperus scopulorum*** Sarg.

AA. Leaves broad [not resinous; generally deciduous after one season; seeds not winged, fruits often winged] ..... ANGIOSPERMS or HARDWOODS

B. Leaves opposite on twig.

C. Leaves compound..... DOUGLAS MAPLE ***Acer glabrum*** Torr.

CC. Leaves simple.

D. Leaves unlobed [veins curve where they meet the leaf edge; 2 bud scales; flower heads surrounded by 4 or 6 white bracts] .... PACIFIC DOGWOOD ***Cornus nuttallii*** Audub.

DD. Leaves palmately lobed.

E. Leaf large [sparsely toothed; 5 lobes, deep sinuses, usually rounded; fruit is a bristly samara] ..... BIGLEAF MAPLE ***Acer macrophyllum*** Pursh.

EE. Leaves smaller [many teeth; sinuses not rounded; no bristles on fruit].

F. 7-9 shallow lobes ..... VINE MAPLE ***Acer circinatum*** Pursh.

FF. 3-5 deeper lobes ..... DOUGLAS MAPLE ***Acer glabrum*** Torr.

BB. Leaves alternate.

C. Leaves compound [fruit apple-like].

D. Leaflets toothed at apex only [fruit purplish] ..... WESTERN MOUNTAIN-ASH ***Sorbus occidentalis*** (S.Wats.) Greene

DD. Leaflets toothed nearly to base [fruit red] ..... SITKA MOUNTAIN-ASH ***Sorbus sitchensis*** Roem.

CC. Leaves simple.

D. Leaves lobed, though the sinuses may be rather shallow.

E. Lobes deep, pinnate [fruit an acorn] ..... GARRY OAK ***Quercus garryana*** Dougl.

EE. Shallow and/or no lobes [palmate, if anything; twigs thorny].

F. 5-9 lobes [fruit a black-purple apple] ..... HAWTHORNS ***Crataegus*** L. spp.

FF. 2 or 3 (or no!) lobes generally [the thorns are spur shoots] ..... PACIFIC CRAB APPLE ***Malus fusca*** (Bong.) Roem.

DD. Leaves not lobed.

E. Leaves elliptical to narrow oval [generally of symmetrical shape; bases acute to obtuse, tips acute to notched; toothing fine].

F. Glands at base of leaf blade.

G. Fruit in cylindrical clusters, dark red to black .....CHOKE CHERRY ***Prunus virginiana*** L.

GG. Fruit in rounded clusters, red [leaf tip sharp-pointed on new growth, may be notched on old] ..... BITTER CHERRY ***Prunus emarginata*** (Dougl.) D. Dietr. (Pin cherry, basically in eastern BC, is considered a variety of bitter cherry.)

FF. No glands at base of leaf blade.

G. Leaves shiny, tough, evergreen [fruit a red, roughened drupe; bark red, peeling] .....ARBUTUS ***Arbutus menziesii*** Pursh.

GG. Leaves thin, duller, deciduous [distinctly and regularly veined; naked buds] ..... CASCARA ***Rhamnus purshiana*** DC

EE. Leaves of various shapes, with generally deeper toothing. Leaves attached individually on long shoots, and usually in groups on short spur shoots.

F. Spur sharp [thorn-like] .....PACIFIC CRAB APPLE ***Malus fusca*** L.

FF. Spur not thorny.

G. Terminal buds present.

H. Minute, laterally winged fruit in woody "cones" (only conifers have cones!) .....ALDERS

I. Leaf margins bluntly toothed, margins rolled under [veins rusty below] ..... RED ALDER ***Alnus rubra*** Bong.

II. Leaf margins more sharply toothed.

J. Stalked buds ..... THINLEAF (or mountain).....ALDER ***Alnus tenuifolia*** Nutt.

JJ. Buds not stalked [teeth very sharp] ..... SITKA ALDER ***Alnus sinuata*** (Reg.) Rydb.

HH. Fruit a capsule releasing cottony seeds, hence ..... COTTONWOODS, ASPENS

I. Leaf stalks flattened [blade round; smooth white or pale grey bark, except grooved in very old trees] (meaning about 70 and up!).....TREMBLING ASPEN ***Populus tremuloides*** Michx.

II. Leaf stalks not flattened [blade egg-shaped; bark strongly ridged] (west of Rockies)

J. Capsule splits into 3 (west of Rockies) ..... BLACK COTTONWOOD ***Populus trichocarpa*** Torr. & Grey;

JJ. Capsule splits into 2 (east of the Rockies)..... BALSAM POPLAR ***Populus balsamifera*** L.

GG. No terminal buds.

H. Fruit a large woody nut, surrounded by a leafy bract .....BEAKED HAZEL ***Corylus cornuta*** Marsh.

HH. Fruit as in cottonwoods or as in alder

I. Fruit a capsule [leaves with a short stalk and a long narrow blade]. About 40 species of shrubs and small trees throughout BC..... WILLOWS

J. Leaf margins finely sharp-toothed [leaf tip very fine and long] ..... PEACHLEAF WILLOW ***Salix amygdaloides*** Anderss.

JJ. Leaf margin finely round-toothed [leaf tip shorter, twisted sideways] ..... PACIFIC WILLOW ***Salix lasiandra*** Benth.

II. Fruit as in alder, in "cones" with deciduous papery bracts [ovate bleaf blades, longer petiole].

J. Leaves roundish, small, mainly singly tooth [twig warty; "cone" stout, 2½ cm; bark brown, not usually peeling] .....WATER BIRCH ***Betula occidentalis*** Hook.

JJ. Leaf longer, oval, often doubly toothed [twig smooth, bark white, peeling in horizontal strips; "cone" longer, more slender]..... .....WESTERN PAPER BIRCH (and varieties) ***Betula papyrifera*** Marsh.

FOREST SOILS AND TREE NUTRITION

by

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FOREST SOILS AND TREE NUTRITION

"The first rule of intelligent forest management is to take care of the soil."

(Fisher and Binkley)

Soil is a dynamic natural body, composed of mineral and organic solids, gases, liquids and living organisms, which can serve as a medium for plant growth. In any ecosystem, soils have many roles to play. For example, soil supports the growth of higher plants by providing a medium for root growth and supplying nutrients. Soil also serves as nature's recycling system, habitat for various soil organisms, and filter for ground water. Soil is an important natural resource used by many industries and for many purposes. Throughout history, civilizations have risen and fallen based on how well they cared for their soil (Hillel, 1991).

In a broad sense **forest soil** can be defined as a soil that has developed under the influence of a forest ecosystem. Since not all of these soils are under forests today, a better definition of forest soils would be as "soils that are currently influenced by a forest ecosystem" (Fisher and Binkley, 2000). A good understanding of the nature and properties of soil is the foundation of sound, sustainable forest management.

Soil properties affect timber production, hydrology, forage, wildlife, and recreation on forest land, and have important implications for harvest engineering, and road construction and maintenance. Foresters must be able to make appropriate evaluations of soil conditions and problems in the field. Major soil considerations that foresters commonly encounter include shortage or excess of water, restrictive soil depth, trafficability, soil temperature, and nutrient status. This chapter emphasizes the importance of thorough site assessments and provides some management interpretations. The following must be treated as a supplement to, rather than a substitute for, more complete, specialized soil management references.

Soil Description and Classification

Generally, soil description and classification provides the framework for making management interpretations and communicating experience with soils. The following brief overview may assist the forester in interpreting horizon symbols found in soil survey reports. For a complete treatment of the subject, refer to "The Canadian System of Soil Classification" (1998) prepared by the Soil Classification Working Group.

Several field guides have been produced by the Provincial Government to help with site data collection including soils (BC Ministry of Environments, Lands, and Parks and the BC Ministry of Forests, 1998 and Curran *et al.* 2000).

Soil horizons

Soils are classified according to the kinds and degrees of development of soil horizons, which also have some value for inferring nutrient status, moisture regime, and probable management constraints. A **soil horizon** is a layer of mineral or organic soil material, approximately parallel to the land surface, with distinctive characteristics (e.g. colour, texture, structure, consistence, chemical, biological, and mineralogical composition). The two-dimensional vertical section down through all the horizons in a soil is called the **soil profile**. Horizons commonly encountered in forest soils include organic horizons (containing more than 17% organic C or 30% organic matter, by weight) and mineral horizons (containing less than 17% organic C or 30% organic matter, by weight).

Relatively well-drained organic layers are designated L, F, or H. Poorly drained organic horizons are designated O, and mineral horizons are designated A, B, or C, with various descriptive lower case suffixes, several of which are discussed below.

Organic horizons

L horizon is characterized by an accumulation of undecomposed organic matter, derived mainly from leaves and woody materials, in which the original structures are easily discernible. This is the surface litter layer.

F horizon is characterized by an accumulation of partly decomposed organic matter, derived mainly from leaves and woody materials. Some of the original structures are difficult to recognize.

H horizon is characterized by an accumulation of highly decomposed organic matter in which the original structures are indiscernible. This material differs from the F horizon by its greatest decomposition due chiefly to the action of soil organisms. It is frequently intermixed with mineral particles, especially near the junction with a mineral layer.

O horizon is an organic horizon developed mainly under vegetation characteristic of poorly-drained sites (e.g. mosses and rushes). It is divided into three groups.

- **Of** (**fibric**) consists dominantly of well-preserved fibres that are readily identifiable as to botanical origin.
- **Om** (**mesic**) is at a stage of decomposition intermediate between fibric and humic horizons. The material is partly altered both physically and biochemically.
- **Oh** (**humic**) is at an advanced stage of decomposition. It has the lowest amount of fiber, the highest bulk density, and the lowest saturated water-holding capacity of the O horizons. It is very stable and changes very little physically and biochemically with time unless it is drained.

Mineral horizons

A horizon is a mineral horizon formed at or near the soil surface, in the zone of washing out (eluviation) of clay, iron, aluminium, and organic matter. It may not always be present. Common horizon descriptors for the A horizons in British Columbia (BC) forest soils include the following:

- **Ah**: a surface mineral horizon containing a net accumulation of organic matter. Usually darker coloured than the underlying horizons; often looks like garden/potting soil but has < 30% organic matter; sometimes called "topsoil." The Ah horizon will usually dominate the nutrient pool of the site and determines the humus form classification.
- **Ae**: a surface or near-surface mineral horizon in which most of the organic material, clays, and soluble materials have been eluviated due to leaching in solution or washing out in suspension. Usually lighter coloured than the underlying horizons; appearing "bleached " or "ashy."

The A horizon can also be characterized by disturbance due to mechanical site preparation, plowing, etc. (**Ap**), or by properties transitional to the B horizon (**AB**).

B horizon is a mineral horizon demonstrating soil development, due to (i) enrichment or illuviation (precipated from solution or deposited from suspension) of organic matter, sesquioxides (Fe and Al oxides), or clay, (ii) development of soil structure, and/or (iii) a change of colour denoting hydrolysis, reduction or oxidation. Common horizon descriptors for the B horizons in BC forest soils include the following:

- **Bf**: iron and aluminum oxides enriched; reddish brown to reddish colour.
- **Bh**: enriched in organic matter formed in very wet climates; Bhf if a mineral horizon high in both iron and aluminium oxides and organic matter.
- **Bt**: clay accumulation; a finer textured horizon underlying a coarser-textured horizon (e.g. Ae); often blocky structure; clay coatings may be visible.
- **Bg**: fluctuating water table or restricted drainage; often a bluish grey (gleyed) matrix with reddish mottles and granular structure. Mottles indicate depth of fluctuating water table.
- **Bm**: weakly modified layer not showing the distinct characteristics of the above-mentioned B horizons; yellowish brown to slightly reddish brown, some structure developed.
- **BC**: transitional between B and C horizons.

C horizon is a mineral horizon that is relatively unaffected by the soil forming processes operative in A and B, with an exception of the processes of gleying (**Cg**), or the accumulation of calcium and magnesium carbonates (**Cca**), and accumulation of soluble salts (**Cs**, **Csa**). Typically a C horizon is found below the B horizon.

R layer is a consolidated bedrock layer that is too hard to break with hands or to dig with a spade when moist, and that does not meet the requirements of a C horizon.

W layer is a layer of water that may be present in Gleysolic, Organic or Cryosolic soils.

Horizon modifiers – For any of the mineral soil horizons described above, the following modifiers are used to indicate the conditions specified:

- **b**: used with any horizon to indicate it is a burried horizon, which may suggest active fluvial or slope processes, or windthrow.
- **k**: used with any horizon to indicate presence of carbonates (fizz with acid); most often used with B and m (e.g. Bmk) or C.

- **g**: used with any horizon to indicate a fluctuating water table; usually bluish grey soil matrix with prominent reddish mottles.
- **j***:* used with any horizon to denote a weak expression of the suffix it modifies.

Forest humus forms

On a number of forested sites, the physical activity of worms and/or arthropods near the bottom of the organic layers leads to mixing of organic and mineral material. This results in the formation of an Ah horizon and may prevent formation of H (or in some cases both F and H) horizons. Factors such as abundance and activity of soil organisms tend to produce characteristic organic profile morphology or "**forest humus form**". The condition and configuration of the LFH layers is described by humus form.

Historically, several systems of forest humus classification have been used in BC. Currently at least two systems of classification may be encountered in infomation about soils in BC: that of Bernier (1968), and one proposed by Green *et al*. (1993). The principal humus forms (taxa) are **mor, moder**, and **mull** and approximate criteria for their identification are as follows:

Bernier's System

- MOR – Ah is absent; or, if it is present, there is an abrupt transition from the Ah to the overlying organic layer, and there is no evidence that the Ah originated through vertical mixing by soil animals.
- MULL – H is absent; Ah is present, and contains some clay, and is characterized by presence of a "clay-humus complex" (a mechanically inseparable association of clay and colloidal organic matter), and the Ah originated through vertical mixing by soil animals. F, if present, is thin.
- MODER – Ah is present; transition from the Ah to the overlying organic layer is gradual; no "clay-humus complex" is found; the Ah originated through vertical mixing by soil animals.

Green et al. System

The "new BC system" of forest humus form classification was proposed by Green *et al*. (1993) as a modification of the system of Klinka *et al*. (1981). In the taxonomic hierarchy of the new system, two levels are recognized: orders (mull, moder, and mor are differentiated by the type of F horizon and the relative prominence of Ah horizon) and groups (16 groups of this system reflect differences in the nature and rate of decomposition processes).

- MOR – F and H horizons are more than 2 cm thick or they may be less than 2 cm if Ah is less than 2 cm thick.
- MULL – Combined thickness of F and H is equal to or less than 2 cm with Ah being thicker than 2 cm.
- MODER – F principally developed through animal activity or fungal decomposition. A greater variety of soil animals may be seen than in mor.

Despite some differences in definition, a forest humus form would usually fall into the same broad category in either system. Some general interpretations are:

MOR – This forest form develops under conditions, which favour dominance of fungi over bacteria and soil animals. Such conditions may be cold, rainy, acid, and/or nutrient-deficient. Decomposition is slow, allowing thick layers of organic matter to accumulate over time. Factors favouring mor formation may limit tree growth. Most mors can be strongly acidic (pH 3 to 4.5 in water). In clearcuts, surface soil temperature fluctuations on exposed, undisturbed mor may be large, but subsurface temperatures will not fluctuate much since the forest floor acts as an insulating layer. Water retention by thick mor may be of hydrologic significance, especially on shallow, weakly developed soils. Mechanical site preparation to expose or incorporate mineral soil may be necessary for successful regeneration of some tree species. Severe burning (e.g. burning of a substantial amount of the F horizon) should be avoided.

MULL – This humus form develops under conditions, which favour rapid decomposition of organic matter and usually a high diversity of soil animals. Organic matter decomposes too rapidly to accumulate in large amounts on the soil surface, so that nutrient cycling is rapid. These conditions are likely to be favourable for tree growth. Most mulls are not strongly acidic and their pH range is usually between 5 to 7 (sometimes higher in soils developed on calcareous (high pH) parent materials). In clearcuts, surface temperature fluctuation on exposed, undisturbed mull is unlikely to be large. Sub-surface temperature typically rises quickly in the spring, extending the growing season for root systems. Mechanical site preparation is seldom necessary, but it might be needed for vegetation control. Burning is unlikely to result in serious depletion of soil nutrients.

MODER – Intermediate between mull and mor.

Canadian system of soil classification

Knowledge of soil classification is helpful in making management interpretations and may be needed for herbicide permit application. The following is a brief description of 10 Soil Orders (Order being the highest classification category followed by great group, subgroup, family, and series) of the Canadian System of Soil Classification (Soil Classification Working Group, 1998), with some management interpretations.

Regosolic order: These soils have insufficient A or B horizon development to meet the requirements of other orders. They may have developed on young parent materials that have recently been deposited or exposed (floodplains or land slides). When Regosols form on a steep slope they may be experiencing slope stability problems, hence it is important to check neighbouring slopes for soil development stage.

Brunisolic order: Soils of this order lack the horizon development specified for soils of other orders, but have developed sufficiently to be excluded from the Regosolic order. These soils, which occur under a wide variety of climatic and vegetative conditions, have brownish Bm or Btj horizons. More alkaline Brunisols (e.g. Melanic or Eutric Brunisols) are often calcareous at depth. If Brunisols are found on steep slopes they may be experiencing slope stability problems if surrounding slopes have more developed soils.

Luvisolic order: Soils of this order may have eluvial Ae horizons, and must have clay-rich Bt horizons. These soils develop under deciduous or mixed forest or

forest-grassland transition zone in a moderate to cool climate. Luvisols are often characterized by a presence of a dense "clay pan" that may result in presence of suspended water table and associated windthrow problems. In addition, these soils are also prone to slope stability problems and may be calcareous at depth. These soils often have a very high compaction hazard.

Podzolic order: Soils of coniferous forests having podzolic B horizons (Bf, Bhf, or Bh) in which combinations of amorphous aluminum, iron, and organic matter have accumulated. When a thicker Ae is present (e.g. > 5 cm), these soils can be very acidic and nutrient-poor.

Gleysolic order: These soils develop under wet conditions with fluctuating water table and permanent or periodic anaerobic conditions. They often have shallow rooting depth, which is commonly associated with windthrow problems.

Organic order: These are soils that have developed in organic deposits. The majority of Organic soils are saturated for most of the year. They contain more than 17% organic carbon or 30% organic matter by weight. These soils are normally very cold and wet, and very sensitive to disturbance such as rutting or drainage alteration. **Folisols** are upland Organic soils that occur in very humid climates. Sometimes Folisols is the only soil present on a site and protection of their forest floor is very important.

Chernozemic order: Soils that have developed under relatively dry grass-land, forb, or grassland-forest transition vegetation, in cool to cold, subarid to sub-humid regions. These soils have a dark-coloured surface (Ah, Ahe, Ap) horizon and a base rich B or C horizon. Chernozems typically develop in areas that are usually droughty and may have summer frosts, often calcereous at depth.

Solonetzic order: Soils developed mainly under grass or grass-forest vegetative cover in semiarid to subhumid regions. The soils have a stained brownish solonetzic B (Bn or Bnt) horizon and a saline C horizon. The surface horizon may be an Ap, Ah, Ahe, and/or Ae horizon. Solonetzic soils can be saline and consequently restrictive for growth of many plant species. These soils are not common in BC forests.

Cryosolic order: These are mineral or organic soils of the sub-arctic and arctic regions that have permafrost within 1 m of the surface (or 2 m of the surface if more than one-third of the pedon has been strongly cryoturbated, as indicated by disrupted, mixed, or broken horizons). Cryosols are very sensitive to disturbance. These soils are not common in BC forests.

Vertisolic order: A new classification that is usually not indicated on older soil surveys, these are clay-rich soils that lack the degree of development necessary for other orders. They are characterized by deep, wide cracks (present at some time during the year) and a high bulk density between the cracks. These soils have marked shrink-swell tendencies with changes in soil water content resulting in wedge-shaped aggregates and/or evidence of severe disruption of horizons. Vertisols are not particularly common in BC and they occur as pockets throughout central and northeastern BC. On slopes, Vertisols commonly experience stability problems.

Table 1: Summary properties of parent materials and landforms (from Curran *et al.* 2000)

Parent material	Mode of deposition	Texture	Internal arrangement	Topography	Management implications
Fluvial	Water; streams and rivers	Variable, depending on mode of deposition	Stratified beds, coarse fragments, well rounded; loose material not compacted	Fans, floodplains	Active fans and floodplains are potentially subject to flooding and erosion
Glacio-fluvial	Glacial meltwater	Boulders, gravels, and sands with minor silt and rarely clay	May or may not be well sorted; coarse fragments can vary from sub-angular to well rounded	Flat surface to steep terrace slopes; level or sloping terraces; floodplains	Gravel source: often nutrient poor unless seepage water is close to the surface (forest floor probably very important); droughty; poor cohesion can lead to dry ravel on slopes; rapidly drained; low water retention; scarp face unstable (ravels like gravel pit face)
Lacustrine	Deposited in still lakewater	Fine sand, silt, clay; rarely any coarse fragments	Layered, particularly at depth	Old deltas and lakebeds	For both lacustrine and marine: unstable when wet; poor trafficability when wet; easily eroded; high water- and nutrient-holding capacity; poor road foundation
Marine	Deposited by ocean/ sea water	Same as lacustrine; may contain shells	Layered	Previously sub-merged coastal areas	
Morainal (Till)	Laid down from the base, ends, sides, or melting surface of glacial ice sheets	Heterogeneous mixture of sand, silt, and at least some clay; various amounts of coarse fragments (usually do not touch each other)	Non-sorted; generally sub-rounded to sub-angular coarse fragments; may be compacted at depth	Extensive	Properties are variable and depend on texture and coarse fragment content; generally provides a good foundation and can have stable cuts if compact (dense) till; can make good road sub-grade and surface grade

Parent material	Mode of deposition	Texture	Internal arrangement	Topography	Management Implications
Colluvial	Moved by gravity (e.g. talus, avalanche deposits)	Variable: coarse fragments usually very angular and often touch each other	Loose, randomly sorted; often only one rock type	Steep slopes and lower slopes/toe	Steep slopes may be unstable; forest floor probably very important; often nutrient poor and droughty
Eolian	Deposited by wind or by volcanic eruptions in local areas	Sands and silts; coarse fragments covered by veneer, unless volcanic pumic	Loose; may be cross-bedded, well sorted	Variable: valley bottoms to steep slopes	If denuded, is subject to wind and water erosion; properties of underlying parent material important if shallow deposit
Organic	Decomposing vegetation on saturated sites	Fibric, Mesic, and Humic	—	Saturated depressions; bogs, swamps, fens	Poor trafficability; poor road foundation, even when drained; poor aeration; cold, wet
Bedrock	—	See bedrock key, in Curran *et al.* (2000)	—	—	—

Parent material

Parent material is the unconsolidated and more or less weathered mineral and organic matter from which a soil is developed by soil forming processes. Table 1 outlines key properties of common parent materials in BC and provides some management interpretations. Parent material is normally determined once a soil pit is dug to adequate depth, and also from road cuts and windthrown trees. Experience gained with specific parent materials can be transferred to other sites with similar materials and climate. Various other references (e.g. Curran *et al*. 2000 and regional ecological field guides) will help you further identify and classify parent materials and landforms.

Sources of soil information

British Columbia's forests are very diverse due to wide variations in climate, soil, and topography. This diversity makes the management of the province's forest resources, including soils, challenging. To successfully manage forest soils, practitioners must have a broad understanding of ecosystem functions and the interactions among climate, soil, vegetation, and topography. Various tools such as soil surveys, maps, and the associated soil classification are available for forest managers to integrate this understanding and apply it to forest soil management.

The spatial distribution of different soils is of fundamental importance to foresters. The soil surveys consist of a soil map accompanied by a report containing analytical laboratory data, field measurements of physical and site properties, background information of the area, and soil interpretations. Soils, or soils and landforms mapping are available at reconnaissance scales (1:50,000 to 1:125,000) for approximately one-third of the forested areas of BC.

This reconnaissance soil mapping "paints a picture" for the user of the common landforms, soil parent materials, textures, and soil development in a given area. However, because of mapping scale, and level of field checking, the actual soil on a given cutblock is often different than described on the reconnaissance map. Hence, these maps are useful for general planning (e.g. locating potential gravel sources, or soils and parent materials less prone to compaction during wet season harvesting).

Regardless of whether soil mapping is available or not, one needs to thoroughly assess a proposed development area to check and describe the soil variability. It is essential that this information is as accurate as possible because it directly influences the economic and environmental success of a chosen harvesting strategy. For example, not recognizing a "Very High Compaction Hazard" site as defined under the *Forest Practices Code/Forest and Range Practices Act* can be very troublesome and lead to costly, unplanned shutdowns or penalties. Conversely, categorizing a site as "Very High Compaction Hazard" when it does not belong to that category will lead to selection of a much costlier and more restrictive harvesting strategy. Site assessment and data collection includes the following three general steps:

- collecting and reviewing all available information,
- looking at the site in stereo using air-photos, to make initial strata based on landforms, and vegetation features, and,
- walking along transects through the area to describe the soil variability.

Refer to Curran *et al.* (2000) for more information on how to perform a detailed site assessment.

Soil Physical Properties

Coarse fragments and bedrock type

Coarse fragments refer to soil mineral particles larger than 2 mm in diameter, and include:

- gravels (2-75 mm),
- cobbles (75-250 mm), and
- stones (> 250 mm).

When describing soil horizons, the coarse fragments size and percent are reported to enable interpretations of soil compactibility, erodibility, available rooting volume, etc.

In some areas, it is important to note the general rock type(s) of the coarse fragments or bedrock (e.g. granite). A keys for rock identification that is based on rock properties such as crystal size, hardness, and colour (from a fresh face on the rock) is available in the handbook by Curran *et al.* (2000). If available, local bedrock keys and geology information should be used.

Some bedrock types can indicate potential problems. For example, serpentine and phyllites, as well as some shales and schists, are often unstable; phyllites weather readily to clays, and areas of limestone and calcareous siltstone are difficult to revegetate.

Bedrock properties are also important in considering slope stability. Important lithological or bedrock features that may affect forest management activities include bedding planes that are similar to the general slope angle, or extensive fracturing and weathering. These features can potentially affect the stability of the slope, or the stability of road cuts and fills.

Texture

Texture refers to the relative proportions of the sand, silt, and clay particles within a mineral soil. Clay particles are smaller than 0.002 mm (2 μm) in diameter, silt particles range from 0.002 to 0.05 mm, sand is between 0.05 to 2 mm, while coarse fragments (e.g. gravel, cobbles, stones) are larger than 2 mm. When describing soils in the field, the texture is often the first and most commonly determined soil property. The knowledge of soil texture is critical for understanding of soil behaviour and management. By knowing soil texture land managers can draw conclusions regarding soil trafficabilily and other properties.

Soil texture can be determined in a laboratory by hydrometer or pipette methods (Gee and Bauder, 1986) or in a field by hand texturing (or feel) method.
To perform the hand texturing method take some soil in the hand, discard coarse mineral and organic fragments, moisten the soil uniformly (not quite enough to glisten), and work the soil between the fingers, attempting to bring the soil to the consistence of moist, workable putty. Determine the graininess (indicates sand content) of the soil putty by rubbing it between thumb and forefinger. Then determine the stickiness (indicates clay content) of the soil putty by pressing it between the thumb and forefinger and observe how strongly soil adheres to the fingers when pressure is released. It is also useful to determine how a “worm” or ribbon can be rolled with the sample. Performing a soapiness test helps determine silt content; silt feels smooth (slick) and not too sticky (like clay) or grainy (like sand). For more information on how to perform a complete hand texturing test refer

to BC Ministry of Environments, Lands, and Parks and the BC Ministry of Forests (1998).

Textural names are given to soils based on the relative proportions of each of the three fine-earth soil particles – sand, silt, and clay. After the percentages of sand, silt, and clay are determined the **textural triangle** (Figure 1) is used to determine the soil textural name. Soils of different texture exhibit different behaviour and pose different management challenges. Hence, it is useful to group soils of similar texture into textural classes. General implications of soil texture for forest management are summarized in Table 2.

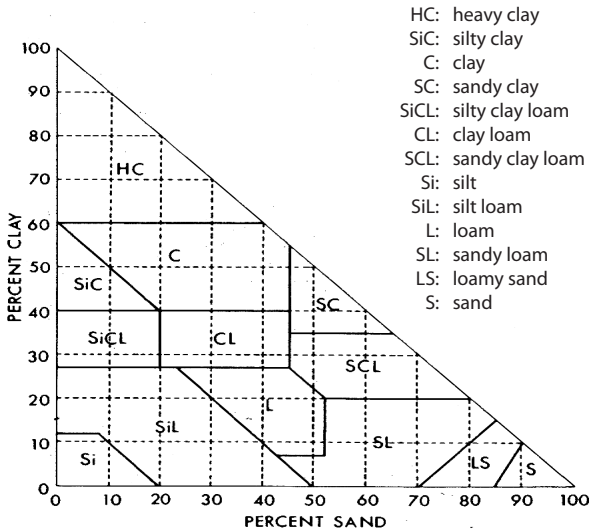

Figure 1: Textural triangle

Retention of water, including water available to plants, is the poorest for coarse-textured soils (particularly for sand, loamy sand, and sandy loam). On the other hand, coarse-textured soils tend to be better drained, because of higher permeability, than fine-textured soils. In addition, coarse-textured soils normally have better trafficability when wet. Soils with most particle size classes well represented, but with relatively little silt and clay (e.g. sandy loam and loam), tend to be mechanically stable, especially if coarse fragments are angular. Retention of positively charged ions or cations (including several nutrients) tends to be high in soils with a high clay content (e.g. clay, clay loam, silty clay, silty clay loam).

Plasticity

Soil consistency refers to the resistance of soil material to deformation, and tendency of the soil mass to cohere (stick together) and adhere (stick to other materials). Soil consistency is described in terms of stickiness (wet consistence), plasticity (moist consistence), and resistance to deformation (dry consistence). It is strongly affected by the inter-particle forces, clay content (or soil texture), type of clay present, and soil water content. Soil consistency can also be characterized by Atterberg limits (shrink-

Table 2: General implications of soil texture for forest management (from Curran *et al.* 2000)

Texture	Surface erosion (soil detachability)	Compaction/ rutting	Available nutrients	Slope stability	Available water
LS or S	■ severe on steep slopes	❍	■ (◆or ●)[a]	■ dry ravelling can be severe on steep slopes	■ very poor
SL	◆ very steep slopes	●	◆ or ●	● dry ravelling on steep slopes	■ poor
Fine SL	■ severe on all slopes	◆	●	◆ can flow	●
L	◆ moderately steep	●	●	●	●
SiL or Si	■ all slopes	◆	❍	◆ can flow/slump	❍
SCL	●	■ very high	❍	■ can flow/slump	●
CL	●	■ very high	❍	■ can flow/slump	●
SiCL	● (◆)[a]	■ very high	❍	■ can flow/slump	●
SC	❍	■ very high	❍	■ can flow/slump	◆
C	❍	■ very y high	❍	■ can flow/slump	■
SiC	❍ (●)[a]	■ very high	❍	■ can flow/slump	●

Other important site factors to consider in addition to texture (vegetation can influence as well):

Surface erosion	Compaction	Available nutrients	Slope stability	Available water
Climate	Climate	Coarse fragments	Climate	Climate
Slope %	Coarse fragments	Organic matter	Slope %	Slope %
Slope length/uniformity	Soil structure	Soil depth	Slope length/continuity	Slope position
Coarse fragments	Soil moisture	Seepage	Soil layers	Coarse fragments
Soil moisture	Forest floor depth	Climate (leaching)	Soil depth	Organic matter
Soil layers/depth		Unfavourable substrate	Soil moisture	Soil moisture
Soil structure			Bedrock features	Soil depth/layers
Seepage			Seepage	Seepage

[a] Depending on site condition. ■ = major problems, ◆ = concern, ● = may be a concern, ❍ = no concern.

age, plastic, and liquid limits). For forest soil management, moist soil consistence (plasticity) is recommended.

Plasticity represents the ability of soil to change shape under influence of an applied stress, and to retain the new shape after removal of the stress. It is a better measure of soil mechanical behaviour at different water contents, than soil textural classes. The latter do not take into account type of clay minerals present (that behave differently when submitted to mechanical forces), presence of organic matter and/or calcareous material (that also contribute to soil consistency), and finally some textural classes have a very large range of clay content (e.g. 0-28% clay for silt loam). For more information on how to determine plasticity and classify soils based on their plasticity refer to Curran *et al.* (2000) or visit www.for.gov.bc.ca/hfd/pubs/Docs/Lmh/Lmh47.htm. Management interpretations based on soil plasticity are provided in Curran 1999 and Curran *et al.* 2000.

Porosity

Soil structure represents the arrangement of primary soil particles (sand, silt, and clay) into secondary units called aggregates or peds. Soil structure affects pore size distribution and consequently influences many important soil properties such as the rate of water infiltration, water retention, aeration, and drainage. Size of soil pores and overall **porosity** (defined as the volume percentage of the total soil bulk not occupied by solid particles) are important for tree growth and normal soil biological function. Sometimes **aeration porosity** (the fraction of total volume of soil that is filled with air at a specific soil-water content such as field capacity) is used as an index to characterize soil aeration. Soil structure, porosity, and aeration porosity are not routinely described for forest soil management interpretations, but aeration porosity is important enough to warrant some discussion here.

Coarse textured, less plastic soils tend to have high aeration porosity (e.g, 25%), whereas fine textured, very plastic soils tend to have very low aeration porosity (e.g. 12% on undisturbed sites). Reported critical values for aeration porosity that are limiting for root respiration and hence plant growth range from 5 to 20% (averaging around 10%). Aeration porosity values obtained on several common soil disturbance types on a typical southern Interior soil (fine sandy loam) are given below:

- Undisturbed soil 22%
- Main skid trail 8%
- Rut meeting Forest Practice Code criteria 12%
- Other traffic not meeting Forest Practice Code criteria 16%

As demonstrated by the above data, soil disturbance types targeted by the Forest Practice Code guidelines typically have lower soil aeration porosity affected by compaction and/or puddling. Also of interest is the fact that lighter machine traffic can affect soil aeration. This is cause for consideration when planning machine operations, as discussed in section on "Soil Management."

Soils abundant in clay and silt particles tend to be poorly aerated unless they possess good, stable structure. If mechanically disturbed when wet, these soils may lose their stable aggregates. This process is called "**puddling**". Timber harvesting or mechanical site preparation on wet, fine-textured soils often results in puddling,

which impairs seedling establishment and growth. To avoid puddling, harvesting should be done either when there is adequate snowpack, or when the soil is frozen. On soils abundant in clay, mechanical site preparation should be done during the driest season, or completely omitted. Special attention should be given to selection of appropriate site-preparation equipment.

Depth

Shallow soils restrict rooting and limit the amount of material from which the tree can obtain nutrients and water. In addition, shallow soils may cause engineering problems. Depth to bedrock, or to some other impermeable layer, or to the water table should be noted. Windthrow susceptibility is often extreme where depth to the water table is shallow. In addition, windthrow susceptibility on shallow soils (so called lithic soils) may be high if the bedrock is smooth, but low if the rock is fractured, which allows certain degree of root penetration and growth. Dense basal tills (morainal parent material) can also increase windthrow susceptibility.

Depth to unfavourable substrates is an important property to describe in forest soils, along with other soil properties (texture, coarse fragments, forest floor type). These data provide a basis for interpreting the sensitivity of a forest site to soil degrading processes, and the suitability of the site for mechanical treatments to alleviate seedling growth-limiting factors. Types of unfavourable substrates include seepage, unfavourable subsoils, and root-restricting layers.

Seepage is a condition indicative of excess soil water and therefore reduced soil aeration. A gleyed soil matrix (dull yellowish, blue, or olive colour) indicates a permanent water table, while orange-coloured mottling indicates a fluctuating water table.

Unfavourable subsoils refer to conditions that produce adverse growing conditions when exposed by displacement. Unfavourable subsoils include:

- ***Carbonates*** that can be present in arid and semi-arid areas (e.g. Ponderosa Pine, Interior Douglas-fir biogeoclimatic zones) where limited precipitation results in accumulation of salts (including lime) that cannot be leached out of the soil profile. Even in humid areas with limestone-derived parent materials, calcium carbonate (lime) has often not been weathered and leached out of the profile. The resulting "calcareous horizons" have alkaline pH and are unfavourable for conifer nutrition. Often, these calcareous soils exhibit a white coating on coarse fragments or contain powdery white deposits (i.e. free lime). The presence of free lime is demonstrated by a fizz (low foam formation) when fine soil particles are brought in contact with 10% hydrochloric acid (also known as muriatic acid).
- ***Water-restricting layer*** is a substrate that restricts the downward flow of water, but not necessarily root growth. A water-restricting layer may indicate the presence of certain soil hazards. This substrate includes impermeable, dense, very compact or cemented layers (i.e. soils that are hard to dig with a shovel), bedrock, or a permanent water table.
- ***Bt horizon or dense parent material.*** Bt horizon refers to a B horizon enriched with clay. To restrict root growth, a Bt horizon must be at least 5 cm thick. Dense parent materials may include soils that are hard to dig with a shovel such as compact glacial till (or moraine), and compact silty- or

clay-textured glaciolacustrine deposits.

- ***Sands/gravels.*** Any soils with a sand or loamy sand texture have very little silt and clay, and consequently little nutrient or water-holding capability (that are less of a concern in wettest biogeoclimatic subzones). These unfavourable substrates commonly occur in glaciofluvial or recent fluvial deposits, but may also be derived from other parent materials.
- ***Fragmental soils*** include any soils with more than 70% of coarse fragment content (i.e. fragments >2 mm diameter). These soils can restrict rooting volume, and water and nutrient availability to plants.

Root-restricting layer refers to a substrate that restricts the downward growth of roots. It may include a layer of bedrock, impermeable, very compact or cemented layers, or a permanent water table. Normally the specific type of restrictive layer is described, such as bedrock, compact glacial till, compact silty-or clayey-glacio-lacustrine deposits, compact marine deposits, dense clay-enriched horizons, cemented horizons, etc.

For further descriptions of unfavourable substrates refer to the guidebook produced by the BC Ministries of Forests and Environment (1998).

Soil Chemical Properties and Nutrients Required by Trees

One of the fundamental roles of a soil is to supply plants with **nutrients** (or **essential elements**) in quantities and proportions appropriate for plant growth. Nutrients are the elements needed by plants to complete their vegetative and reproductive cycles since these elements are constituents of necessary metabolites. Nutrients such as carbon (C), hydrogen (H), oxygen (O), nitrogen (N), sulphur (S), phosphorus (P), potassium (K), calcium (Ca), and magnesium (Mg) are used in relatively large amounts (>0.1% of dry plant tissue) and called **macronutrients**. Nutrients needed in relatively small amounts (<0.1% of dry tissue), i.e. **micro-nutrients,** include iron (Fe), manganese (Mn), zinc (Zn), boron (B), copper (Cu), and molybdenum (Mo).

Carbon, H, and O are supplied as CO_2, H_2O, and O_2 by either atmosphere or soil water. All other nutrients are provided by soil. As nutrients are absorbed from the soil solution they are replenished from several sources. For example, organic matter is the primary source of soil N and N-fixing soil organisms add N to the soil from the atmosphere. For nutrients, other than N, the major sources are weathering minerals in the soil and parent materials.

Trees require the same nutrients as agronomic plants, however because trees are perennial they differ in how they secure and process nutrients and have a number of mechanisms that allow them to reduce nutritional requirements. These mechanisms, which include cycling and internal translocation of nutrients, provide for better nutrient use efficiency relative to annual, agronomic plants. Even though trees are efficient in the use of nutrients, when they experience nutrient deficiency levels they grow more slowly. Forest management practices that aggravate nutrient deficiency will result in further decline of soil productivity.

Nutrient deficiencies in BC forests

Severe N deficiency is common in all forest regions of BC (Cole and Gessel, 1992). The most common factor that leads to N deficiency is low rate of mineralization, which is a result of either very low pH, anaerobic conditions, cold soil temperatures, or too much or too little water present in the soil. Other nutrient deficiencies appear to be less common and usually less severe. Sometimes other deficiencies are induced by N fertilization, i.e. they appear only when the N deficiency has been relieved. For example, S and P deficiencies may be found occasionally, but more often may be induced by N fertilization.

A few cases of low (and possibly deficient) K have been found, mostly in soils developed on alluvial, glacio-fluvial, and aeolian (wind-blown sand) parent materials in the central interior of BC. Potassium deficiency is most likely to occur on acidic soils that are low in organic matter and cation exchange capacity. Possible K deficiencies in Douglas-fir and lodgepole pine stands observed on calcareous soils in southeastern BC were induced by high soil solution concentrations of Ca (Smith and Wass, 1994). Low (but not necessarily deficient) Ca occurs in some coastal Douglas-fir stands. These soils are coarse-textured, acidic, and developed on quartzite and granodiorites. Deep-rooted trees are able to grow normally even on soils that have very low Ca contents since they are able to permeate a larger volume of soil (Baule and Fricker, 1970). Low (but probably not deficient) Mg is observed somewhat more widely.

Iron deficiency is the most common micronutrient deficiency encountered in BC and it often occurs on well-drained sandy soils of low pH or high pH (calcareous soils). Low Fe availability of calcareous soils results either from low concentrations of dissolved inorganic Fe or the reaction of Fe with carbonates forming insoluble Fe-oxides (Loeppert *et al.* 1984).

Low Mn levels are seldom encountered in soils, but some have been observed on calcareous (high-pH) soils. Manganese deficiency is very uncommon in BC's forests, although low Mn was observed in lodgepole pine foliage on a rehabilitated, calcareous skidroad in the southern Rocky Mountains (Curran, unpublished data). Iron and Mn deficiencies are aggravated by summer droughts, because roots cannot exploit the more acidic organic surface layers (Stone, 1968). Low (probably deficient) Zn has been found in some western hemlock, notably in the Prince George Forest Region, but also in some other areas; other species occupying the same stands typically have clearly adequate Zn levels (Ballard and Carter, 1986). Low Cu status has been found in some Interior stands and there is some evidence that repeated N fertilization has induced Cu deficiencies on coarse-textured glacial outwash soils (Thompson *et al.* 2001).

Boron deficiency appears to be rare, however; in some areas, B deficiency might be induced by N fertilization. Low foliar levels and B deficiency symptoms can be encountered on morrainal soils derived from igneous rock and subjected to periods of soil water deficit during the growing season (Stone, 1990). Brockley (1996) also reported severe B deficiency symptoms (top dieback) on coarse-textured soils developed on glacial outwash in the BC interior where high rainfall may depleted available soil B. On both soil types mentioned above, B deficiency was induced by N fertilization. Soils that have experienced losses of organic matter through burning, scalping, or erosion may be deficient in Zn, Cu, and B. Insufficient data exist to infer the importance of Mo deficiencies in BC; however, they might exist in some

situations (e.g. N-fixing or nitrate-using tree species growing on strongly acidic soils developed on low-Mo parent materials).

Diagnosing nutrient deficiencies

Three principal methods for operationally diagnosing nutrient deficiencies are visual symptoms, foliar analysis, and soil chemical analysis.

Diagnosis of nutrient deficiency through visual symptoms relies on field observations of anatomical and morphological abnormalities of plants. Table 3 summarizes some visual symptoms of nutrient deficiencies in conifers, while detailed description of visual deficiency symptoms in lodgepole pine are given by Thompson *et al.* (2001).

Table 3:
Visual symptoms of nutrient deficiencies in conifers (condensed mostly from literature review table of Morrison, 1974)

Nutrient	Visual Symptoms
N	General chlorosis and stunting of needles, increasing with severity of deficiency
P	Older foliage more affected than young foliage: some chlorosis with mild deficiency, purplish colour with severe deficiency
K	Variable symptoms: chlorosis, especially at branch tips or needle tips. With more severe deficiency, purpling and necrosis with top dieback; or purpling or browning or necrosis, sometimes with oldest needles most affected.
Ca	Chlorosis followed by necrosis of foliage, especially at branch tips; terminal bud death or top dieback in severe cases
Mg	Yellow tipping or banding of needles, needle tip necrosis in severe cases
S	General chlorosis of foliage
Fe	General chlorosis (in mild cases, more evident in young foliage); little or no bud development
Mn	General chlorosis, some necrosis of needles
Zn	Chlorosis (sometimes with bronzed needle tips), general stunting of growth, premature needle fall; in severe cases top-dieback and resetting
Cu	Chlorotic or bronzed foliage, twisting of needles and/or shoots
Mo	Chlorosis followed by necrosis of foliage, beginning at needle tips
B	Chlorosis and/or necrosis of foliage, tip dieback late in growing season, twisting of leader(s)

The problems associated with the visual deficiency method of diagnosis include

the following:

1. Symptoms may differ among tree species.
2. Mild deficiencies may not be expressed by visual symptoms.
3. Certain symptoms may result from any of several different nutrient deficiencies, or from certain non-nutritional factors, e.g. water stress, disease, or insect attack.

These disadvantages often tend to outweigh the principal advantages (speed and low cost), so that alternative methods may be preferred. Visual symptoms may be useful for initial indication of nutritional disorders and should be confirmed by means of foliar nutrient analysis.

Foliar analysis enables all 12 nutrients to be assessed and it can be used to infer directly the nutrient status of the stand. However, it may be insufficient to identify the reasons for a nutritional problem, and is seldom a sufficient basis for prescribing fertilizers. It is likely to be cost-effective on sites where diagnosis is clearly required, but cannot be justified for all stands. Interpretive criteria are unavailable for some species (and for some elements in several species), so it is important to ensure that diagnostic criteria exist before sampling.

Many factors (time of year, foliage age, crown position, sample size and handling) can affect nutrient concentrations in conifer foliage. Consequently, only foliar samples collected by following standardized sampling guidelines can be used for a reliable comparison with published interpretive criteria. Ballard and Carter (1986) provided the primary source of information on collecting foliage samples and interpreting analytical data. Subsequently, Carter (1992) modified the interpretive criteria for macro- and micronutrients (see Table 4), while Brockley (2001b) updated guidelines for collection and handling of foliage samples. The foliage sampling guidelines for conifers (other than larch) in BC can be summarized as follows:

1. Collect foliage during dormant season, between mid-September and mid-December.
2. Confine sampling to dominant and co-dominant trees (of each species to be evaluated) in the stand.
3. Collect current-year shoots from at least two (preferably five or more) branches, located between the top 1/4 and the bottom 1/2 of the live crown.
4. Avoid trees likely to yield poor samples because of heavy cone production, insect, or disease attack.
5. Do not collect foliage from trees near unpaved roads or in other situations where foliage may be contaminated by dust.

Keep the samples cool and sealed in labelled plastic bags. Samples collected under dry conditions can be put into labelled paper bags (as long as the samples are packaged in a plastic bag to keep dust out). Dirty samples should be discarded and replaced.

Strip needles from the twigs and dry them (at 60-70°C for 8-12 hours) within 48 hours after collection. If samples cannot be dried within 48 hours, they should be refrigerated, (at 1-5°C) ideally for no more than a week, before drying.

Samples from individual trees may be analyzed separately enabling assessment

Table 4: Interpretation of macronutrient concentrations in current year's foliage of five commercial conifer species of the Pacific Northwest (from Carter, 1992).

		Foliar concentration (% dry mass basis)				
Element	**Interpretation**	**Douglas-fir**	**Lodgepole pine**	**Western hemlock**	**White spruce**	**Western redcedar**
Nitrogen	Very severely deficient	<1.00	<l.00	<1.00	<1.05	<1.10
	Moderate to severe deficiency	1.00–1.20	1.00–1.15	1.00–1.20	1.05–1.25	1.10–1.30
	Slight to moderate deficiency	1.20–1.35	1.1 5–1.35	1.20–1.35	1.25–1.45	1.30–1.45
	Adequate	>1.35	>1.35	>1.35	>1.45	>1.45
Phosphorus	Severely deficient	<0.08	<0.09	<0.11	<0.10	<0.10
	Moderately deficient	0.08–0.10	0.09–0.12	0.11–0.15	0.10–0.14	0.10–0.13
	Slightly deficient	0.10–0.15	0.12–0.15	0.1 5–0.25	0.14–0.16	0.13–0.16
	Adequate	>0.15	>0.l5	>0.25	>0.16	>0.16
Potassium	Very severely deficient	<0.35	<0.35	<0.40	<0. 25	<0.35
	Moderate to severe deficiency	0.35–0.45	0.35–0.40	0.40–0.45	0.25–0.30	0.35–0.40
	Slight to moderate deficiency	0.45–0.65	0.40–0.55	0.45–0.65	0.30–0.50	0.40–0.80
	Adequate	>0.65	>0.55	>0.65	>0.50	>0.80
Calcium	Severely deficient	<0.1 5	<0.06	<0.06	<0.10	<0.10
	Moderate to severe deficiency	0.1 5–0.20	0.06–0.08	0.06–0.08	0.10–0.15	0.10–0.20
	Slight to moderate deficiency	0.20–0.25	0.08-0.10	0.08–0.10	0.1 5–0.20	0.20–0.25
	Adequate	> 0.25	>0.10	>0.10	>0.20	>0.25
Magnesium	Severely deficient	< 0.06	<0.06	<0.06	<0.05	<0.05
	Moderate to severe deficiency	0.06–0.09	0.06–0.08	0.06–0.08	0.05–0.08	0.05–0.09
	Slight to moderate deficiency	0.09–0.12	0.08–0.10	0.08–0.10	0.08–0.12	0.09–0.14
	Adequate	> 0.12	> 0.10	>0.10	>0.12	>0.14

of withinstand variability. However, for routine diagnosis of a whole stand, it is less expensive to analyze a composite sample, representing all the sampled trees of a particular species. All individual trees should contribute the same foliage dry mass to the composite sample. Collecting foliage samples from 15 to 20 trees per stand should provide adequate levels of precision and confidence for most macro- and micronutrients (Ballard and Carter, 1986).

Further information regarding sample storage and preparation can be viewed at www.for.gov.bc.ca/tasb/legsregs/fpc/fpcguide/fert/ferttoc.htm, entitled Forest Fertilization Guidebook (1995).

Interpretation of foliar analysis data involves a comparison of the foliar concentration of particular nutrients to published "critical levels" in addition to an evaluation of overall foliar nutrient balance. Interpretations of data may make use of published criteria such as those proposed by Ballard and Carter (1986) and consequently modified by Carter (1992). Revised interpretive criteria for lodgepole pine are summarized by Brockley (2001a). The only way to confirm actual nutrient deficiency is to undertake a screening trial. Data from local research or trials are normally consulted before embarking on operational fertilization.

Soil chemical analysis has some value for diagnosing site nutrient status. On sites where foliage sampling is impractical, soil sampling may be the best available alternative. Strong relationships between production and specific soil nutrient levels have not been successfully applied to forestry as to agriculture, for several reasons:

1. The root zone of forest soils is very heterogeneous, often containing dissimilar horizons yielding very different analytical values. Integration of these disparate results to evaluate nutrient status of the whole soil is problematic.
2. The high variability of some forest soils may require a large number of samples and creation of composite samples for cost-effective analysis.
3. Nutrient uptake by tree roots is more efficient than agricultural plants since trees commonly form mycorrhizal associations.
4. Fewer interpretive criteria exist for forestry than for agriculture, and extrapolation of such criteria from one soil or species to another may be problematic.

Forest soils are normally sampled to keep the forest floor separate from the mineral soil, which is sampled by depth, not horizon. More detailed work may involve horizon sampling. Common depths used vary by interpretation, hence make sure you know what is appropriate for your interpretation. Because of soil variability, it is useful to make composite soil samples (this is done in a similar manner as for composite foliage samples, i.e. 15 to 20 samples taken on the same site are combined to form one composite sample).

The most useful routine soil chemical analysis for forest soil fertility interpretations in BC include soil reaction (pH), organic C concentration, and total N concentration. The absolute values of soil analysis are not always meaningful, but the comparative values can be useful. In addition, soil analysis may also indicate a presence of toxic concentrations of elements that may be detrimental to plant growth.

Soil reaction is described in terms of pH values. Soil pH is a measurement of the hydrogen ion concentration within the soil. A pH of 7 is neutral, pH lower than 7 is acidic, and pH above 7 is alkaline (basic). The amount of hydrogen ions present in the soil solution represents **active acidity,** which is determined by measuring soil pH in water. The **exchangeable acidity** is represented by the

quantity of hydrogen and aluminum ions easily replaced by a salt solution (such as 0.01 *M* $CaCl_2$). A third category, **residual acidity**, reflects the amount of hydrogen and aluminum ions not replaced by a salt solution. Soil pH is commonly determined in water and $CaCl_2$, but since these two tests determined two different types of soil reaction it is important to indicate how was the soil pH determined.

High soil pH (up to about 8.2) is commonly associated with limestone parent materials and some forest soils of semi-arid regions. Relatively low pH (high acidity) is often associated with quartz- or silicate-rich parent materials, particularly in cool, humid regions. Even where parent materials and B horizons are not very acidic, it is common to find organic and A horizons which are moderately to strongly acidic. Optimum soil pH for most conifers is about pH 5.0 to 5.5, while for most deciduous trees, optimum pH is about 5.5 to 6.5. Some species may have optima outside these ranges, and species differ in tolerance to pH deviation from the optimum. Availability of nutrients such as Fe, B, Zn, Mn, and Cu tends to be low at high pH. On the other hand, at low pH, Mo availability is low. Phosphate solubility usually is highest when pH is between about 5.5 and 6.5. Consequently, at lower pH, P deficiency may occur in trees which lack mycorrhizae. Deficiencies of Ca, Mg, and K are not common in soils of near-neutral or alkaline pH. If deficiencies of Ca, Mg, and K do occur in soil, it is likely to be because that element was not very abundant in the parent material. Soil pH may be raised by adding lime, or lowered by adding materials such as aluminum sulfate, in appropriate amounts. However, such treatments are very large undertakings and they are seldom justified except for intensively managed high-value crops (e.g. in forest nurseries or seed orchards).

Organic C concentration of more than 17% (or 30% organic matter, by weight) in the soil fraction finer than 2 mm is the criterion for recognition of an organic horizon (vs. a mineral horizon). Organic C concentration is also used for calculation of the C/N ratio, which is an indicator of organic matter decomposition rate and N availability. The C concentration in soil organic matter is fairly constant, often assumed to average 58% (mass basis). Thus, the organic matter content of soil can be estimated by multiplying organic C content by the reciprocal of 0.58 (= 1.724). Usually methods used for determining soil organic matter are based on determination of organic C. These methods are described by Nelson and Sommers (1982) and can be classified in the following groups (a) weight loss on ignition at 350 to 600°C, (b) dry combustion and conversion of C to CO_2, and (c) wet combustion. Weight loss on ignition and dry combustion methods are not appropriate for clay-rich soils and calcareous soils, where significant losses of hygroscopic water or carbonates may lead to overestimation of soil organic matter content.

Total N concentration (in the soil fraction finer than 2 mm) is, at best, a crude index of available N soil supply capability. Generally, one can expect that the soil will supply adequate available N for good tree growth if the N concentration in the surface 15 cm of the mineral soil exceeds 0.1%. It is much more important to know how much N will be mineralized into available (inorganic) N forms during the growing season than what is the overall total N. Hence, the C/N ratio is usually a better index of N availability. A low C/N ratio (near or below 15) suggests that soil N is rapidly being made available (by mineralization). A high C/N ratio (more than about 25) suggests low N availability (because of predominant immobilization). The

C/N ratio of mull Ah horizons often lies within the range 12 to 18; in mor, the C/N ratio of most H horizons is above 25, and that of F horizons usually exceeds 40.

Another useful index of available soil N (in addition to the C/N ratio) is **mineralizable N**. It represents a portion of total soil N that can easily be transformed into available forms by soil microorganisms over time. Several studies have shown good relationships between mineralizable N and foliar N concentration, response to N fertilization, N uptake, and site index (Shumway and Atkinson, 1978; Powers, 1980).

For more information on methods of soil N determination (including both total and mineralizable N forms) refer to Bremner (1996).

Soil nitrogen

Soil nitrogen deserves more thorough discussion because many forest soils in BC are seriously deficient in nitrogen. The nitrogen cycle involves many chemical forms such as organic nitrogen, molecular nitrogen (N_2), ammonium (NH_4^+), ammonia (NH_3), nitrite (NO_2^-), nitrate (NO_3^-), and various oxidized forms, e.g. N_2O. The N cycle consists of several biochemical conversions: fixation (N_2 to NH_4^+), nitrification (NH_4^+ to NO_2^- and to NO_3^-), immobilization (NH_4^+ to organic nitrogen), mineralization or decay (organic nitrogen to NH_4^+), and denitrification (NO_3^- to N_2O and N_2).

Nitrogen fixation can be carried out by several soil micro-organisms (bacteria, cyanobacteria, actinomycetes) that can be either symbiotic or nonsymbiotic, but latter group is seldom considered important. Symbiotic fixation in significant amounts occurs in root nodules of the following plants of western Canada: *Alnus* spp., *Shepherdia* spp., *Elaeagnus* sp., *Ceanothus* spp., *Myrica* sp., *Purshia* sp., *Dryas* sp., and most native and introduced members of the *Leguminosae* (e.g. lupines, vetches, clovers). Nitrogen is also fixed in certain lichens. For example, lichen *Lobaria oregona* fixed 2-10 kg N/ha per year in Douglas-fir stands in Oregon (Denison, 1973).

Annual rates of fixation in young red alder stands have been estimated to range from 50 to 300 kg N/ha. This compares favourably with normal forest fertilization rates of about 200 kg N/ha. Cole *et al.* (1978) reported that a 35-year-old red alder stand of moderate productivity increased the soil N from 3,000 to 5,600 kg/ha within the 35-year period. Under certain conditions excessive N accumulation under red alder may lead to various problems. Van Miegroet *et al.* (1990) reported that nitrification under red alder resulted in high rates of nitrate leaching, exceeding environmental drinking water standards for nitrate concentrations. In addition, nitrate leaching can also result in acidification of the soil and reduced phosphorus availability.

Mineralization – Immobilization. The majority of soil N is present in organic compounds (e.g. proteins, humic compounds) that are not available to trees, though some N is indirectly available via mycorrhizal fungi. The release of inorganic ions (ammonium and nitrate), in which form N is available to plants, is accomplished through microbial activity in a process called mineralization. The rate of mineralization usually supplies sufficient inorganic N for normal growth of natural vegetation, with an exception of soils with low organic matter (e.g. sites where surficial organic matter was removed through burning or scalping). The

opposite process to mineralization is called immobilization and it is the conversion of inorganic nitrogen ions into organic nitrogen forms. Immobilization can be done through both biological processes (microbial incorporation of inorganic N forms into their cellular components) and nonbiological processes (chemical reaction with the soil organic matter). The latter is of a considerable importance in forest soils. Mineralization and immobilization occur simultaneously in the soil and the rate of available nitrogen is considered to depend primarily on the C/N ratio of organic residues undergoing decomposition. In the Pacific Northwest, the rate of mineralization ranges from 1 to 2% of the total N per year (Cole and Gessel, 1992). Since many forest soils in the Pacific Northwest may have 2,000 to 4,000 kg/ha of total N, mineralization could result in 20 to 80 kg/ha of N available annually for uptake by the higher plants. The mineralization rate of 80 kg/ha of N is most likely adequate for good growth of conifers, but 20 kg/ha of N would result in a N deficiency.

Nitrification is biochemical process in which ammonium is oxidized by certain soil bacteria into nitrites and then nitrates. Under conditions favourable for nitrification (good aeration, near neutral pH, abundance of nutrients) nitrite levels are seldom high, since they are quickly oxidized into nitrates. This is fortunate, because nitrite toxicity to most plants and mammals occurs even at low concentrations of a few ppm. Both ammonium and nitrate ions may be used as N source for protein formation. Nitrate ions are readily leached out of the soils in temperate regions (that are dominated by negatively charged colloids). Most undisturbed forests are very tight with respect to N cycling, and leaching removes less than 10% of the N cycled annually. Exceptions occur only on sites with very high rates of N mineralization (such as some hardwood forests), some areas receiving very high atmospheric deposition of N, and some ecosystems with N-fixing trees such as red alder (Fisher and Binkley, 2000). Timber harvesting increases nitrate leaching relative to undisturbed forest stands. Annual leaching losses of up to 25-30 kg N/ha were observed in forest ecosystems after timber harvest (Brady and Weil, 2002).

Denitrification is a biochemical process carried out by heterotrophic bacteria which use oxidized N as a source of oxygen. During denitrification nitrate ions are converted to gaseous nitrogen compounds by a series of biochemical reduction reactions. Denitrification losses are usually small in non-wetland forests (i.e. well-aerated soils) and range from 0 to 4 kg N/ha/yr (Davidson *et al.* 1990). Some studies found that denitrification can be a major mechanism of N loss from forests following disturbance. For example, Ineson *et al.* (1991) found annual gaseous losses of N by denitrification of 3.2 kg N/ha in a study of Sitka spruce forest in Scotland. This loss was increased following clearcutting and an estimated 9 to 40 kg N/ha was lost annually over the first two years after harvesting, declining to the pre-harvesting rates after four years.

Forest fertilization (particularly with nitrogen fertilizers) is a routine practice in all commercial forests that are managed intensively for high production. Guidelines for forest fertilization, including selection of candidate stands for fertilization, are presented in Forest Fertilization Guidebook prepared by the BC Ministries of Forests and Environment (1995).

Soil Management

Regardless of the management operation being considered, forest managers need to be aware of the inherent site sensitivity to soil disturbance, the need to maintain natural drainage patterns, within site variability, and site growth-limiting factors. These issues are discussed in this section with accompanying examples.

Site sensitivity to soil disturbance

Soil disturbance can be defined as any disturbance that changes the physical, chemical, or biological properties of the soil (Lewis *et al.* 1991). Not all types of soil disturbance are bad. Foresters commonly prescribe purposeful soil disturbance as site preparation for seedling planting and establishment.

Management strategies need to strike a balance between "favourable" and "detrimental" disturbances by limiting the latter. Within a harvested area, potentially detrimental disturbance is defined by specific categories under the *Forest Practices Code/Forest and Range Practices Act* (FPC/FRPA). The FPC/FRPA recognizes that some level of disturbance is necessary to permit access to timber. Counted disturbance is defined in terms of visually recognizable disturbance that include machine traffic (compaction and rutting) and displacement types. Machine traffic is defined in terms of main trails and ruts/impressions of certain dimensions. Displacement is defined in terms of wide (1.8 m x 1.8 m) or deep (30 cm) gouges into the soil, and very wide scalps (3.0 x 3.0 m wide). Refer to the latest version of the FPC/FRPA for details at www.gov.bc.ca/for/.

Soil disturbance hazards

To develop site-specific guidelines and prescriptions for mechanical operations such as harvesting and site preparation, soil disturbance hazards are used to describe specific soil conditions in relation to potential for the corresponding soil degrading processes. Hazards officially recognized in the FPC/FRPA include: compaction and puddling; soil displacement; and surface soil erosion. In addition, forest floor displacement and mass wasting are locally important considerations during planning and operations.

In practice, soil disturbance guidelines in the FPC permit up to 5 or 10% net disturbance within a cutblock area (excluding permanent access). The trigger for 5% is the site having one of the key hazards rated as High on the Coast, or Very High in the Interior". On more sensitive sites (High or Very High depending on hazard) additional disturbance types are also counted.

A High rating for any hazard is primarily intended to alert the prescription developer, and the operational staff, of a hazard that may require special treatment to prevent problems (manage and mitigate the hazard). High compaction hazard also results in more equipment traffic disturbance types being counted under FPC/FRPA criteria. The soil disturbance hazards are also helpful for identification of site conditions that are suitable for construction of excavated and bladed trails (skid roads or backspar trails), and/or temporarily exceeding soil disturbance levels and rehabilitating slope hydrology and forest site productivity. The hazards and degrading processes are defined below, including brief discussions of why they are of concern. Keys for giving specific soil ratings for these hazards are provided in Curran *et al.* (2000).

Soil compaction and puddling hazard

Soil compaction is the increase in soil bulk density that results from the rearrangement of soil particles in response to applied external forces. "Soil puddling" is the destruction of soil structure and the associated loss of macroporosity that results from working the soil when wet. The rationale for establishement of the key is provided in Carr *et al.* (1991).

Compaction hazard is determined based on texture (finer textured soils are most compactible), coarse fragments (if > 70%), and the presence of deep forest floor H horizons (prone to rutting). Concerns that coarse fragments do not typically provide "bridging" support for equipment until they are 70% by volume resulted in modifications to the final key currently in use by the FPC/FRPA. In BC, the soil compaction hazard key ranks are formed by grouping soil textures based on their susceptability to structural degradation from compaction and puddling, and likelihood that they will hold water and remain wet for longer periods.

Soil compaction and puddling are of concern in timber harvesting operations because of effects on roots and soil-water relations. Compacted soils have higher penetration resistance that can impede root growth. Compacted and puddled soils both have lower aeration porosity, hydraulic conductivity, and infiltration rates. However, compaction may actually increase water holding capacity in some coarser textured soils (these soils typically have lower compaction hazard ratings).

Lower aeration porosity results in reduced gas exchange that can adversely affect oxygen levels in the soil air; this reduces physiologic function of roots which in turn can lead to root die off under wetter conditions. Some data was provided in section on "porosity". Lower hydraulic conductivity and infiltration rates of the compacted or puddled soil can result in increased runoff during rainfall and snowmelt events. This can lead to increased net export of water from a cutblock, which can affect down-slope sites, natural drainage features, and other resource values due to erosion and sedimentation. Increased water export also means less water may be stored on site to support tree growth during summer drought. Compacted soils can also remain wetter longer, thereby further affecting seedlings because the soil may be colder and has poorer aeration. One major installation where effects of compaction are being studied involves the "Long-term Soil Productivity Study" a cooperative study carried out by the US Department of Agriculture, Forest Services, Canadian Forest Service, BC Ministry of Forests, various universities and industry groups in North America. This study addresses two areas where more knowledge is needed – soil compaction and organic matter removal.

Soil displacement hazard

Soil displacement is the mechanical movement of soil materials by equipment and movement of logs. It involves excavation, scalping, exposure of underlying materials, and burial of fertile surface soils. Three aspects of displacement can produce soil degradation:

- exposure of unfavorable subsoils, such as dense parent material, gravelly subsoil, and calcareous (high pH) soils
- redistribution and loss of nutrients
- alteration of slope hydrology, which can lead to adverse hydrologic effects (discussed under compaction, above).

Throughout the BC Interior, soil development is often shallow and many of the nutrients that are limiting to tree growth are often "biocycled" and concentrated in the upper soil horizons. As shown in Table 5, the top 20 cm of mineral soil and the forest floor are often where most of the nutrients are concentrated. Therefore, we do not want to displace this fertile topsoil away from seedlings, or reduce the rooting volume of these vital topsoil layers.

Table 5: Typical nutrient distribution in BC Interior soils (from Curran, 1999)

	Nutrients in kg/ha (% of total)		
Soil layer	**Nitrogen**	**Phosphorus**	**Potassium**
Forest floor	~~1,450 (44%)~~	~~112 (82%)~~	~~224 (73%)~~
0-20 cm	1050	13	56
20-40 cm	820	8	25
Total	3,320	133	305

Another example of the relevance of soil displacement hazard can be found on calcareous soils of the Rocky Mountains and adjacent areas. Exposure of calcareous subsoils by mechanical operations creates unfavourable growth conditions for coniferous species.

Surface soil erosion hazard

Surface soil erosion is the wearing away of the earth's surface by water and includes splash, rill, and gully erosion. It has on-site impacts (soil loss, nutrient loss, lower productivity) and off-site impacts (water quality, sedimentation, habitat impacts). The surface soil erosion hazard key focuses on on-site erosion and conservation of the fertile topsoil layers near developing seedlings. The rationale for soil erosion key was described by Carr *et al.* (1991), and tested in the former Nelson Forest Region by Commandeur (1994), resulting in modifications to the final key currently in use by the FPC/FRPA. In application, this hazard also reflects concerns about increased channelling and redirecting of water because rehabilitation of excavated and bladed trails is required once the erosion hazard is High.

Haul roads and landings are also of concern because erosion and drainage diversions can lead to sedimentation and stability problems – these are addressed under other assessments and provisions outlined in the FPC/FRPA.

Forest floor displacement hazard

Forest floor displacement is the mechanical movement of the upper organic materials by equipment and movement of logs. It involves scalping, mineral soil exposure, and burial of the forest floor. The effects of forest floor displacement range from beneficial to detrimental, depending on site factors (e.g. humus form and mineral soil characteristics) and how far the forest floor is displaced from the seedlings. Foest floors typically represent a major component of the nutrient capital on a forest site. In the BC Interior, it is not uncommon for the forest floor to contain over 50% of the soil nitrogen and 80% of the phosphorus. Given that many

Interior sites are considered nitrogen deficient, conservation of the forest floor is important.

Two aspects of forest floor displacement can produce soil degradation:

- redistribution and loss of nutrients (e.g. chemically bound and unavailable in the mineral soil, and accelerated decomposition of organic matter)
- exposure of unfavourable rooting medium

A review of forest floor displacement and implications for tree growth was done in southern BC by Hickling (1997). BC Ministry of Forests reviews indicated that most forest operations were well below the forest floor displacement limits originally set in the FPC/FRPA. Hence, determining the forest floor displacement hazard is no longer officially required for harvest planning and permitting. However, use of this hazard interpretation is supported and recommended for planning dispersed skidding on slopes, rehabilitation of soil disturbance, and root rot treatments. Forest floor displacement is also of a concern on calcareous soils.

The conservation of forest floor and other organic matter forms is very important in maintaining biodiversity and soil fertility. Guidelines exist for the retention of coarse woody debris, and the Canadian Council of Forest Ministers recently considered the existence of site-specific standards for slash and coarse woody debris as indicators of sustainable forest management. The rationale is that whole-tree harvesting on nutrient-poor sites has been forecast to result in long-term depletion of some nutrients (e.g. micronutrients). More information is needed on these topics and, in the interim, consideration to modifying whole-tree harvesting should be given on sites with very high forest floor displacement hazard.

Mass wasting hazard

The mass wasting hazard assesses susceptibility to small, disturbance-related slope failures and it is not the same as landslide likelihood. Landslide likelihood is determined through terrain stability mapping and detailed terrain stability field assessments, described in the Forest Practice Code of BC, Managing and Assessing Terrain Stability Guidebook (see www.gov.bc.ca/for/).

Mass wasting hazard refers primarily to small-scale failures which mainly cause on-site degradation, while landslide hazard primarily refers to larger events. The small-scale mass wasting is of concern because it impacts tree growing site and may have off-site effects. The two hazards are correlated: a very high mass wasting hazard may indicate a possible landslide hazard, and such sites should be checked by a qualified slope stability specialist. In addition, small, disturbance-related slope failures can lead to larger landslides through drainage diversion or failure of "stacked" excavations up a hillside, such as in switchbacks or contour skid roads.

Mass wasting hazard is no longer officially required for harvesting planning and permitting under the FPC/FRPA; however, determination of indicators of slope instability is still required (available in Curran *et al.* 2000). Common indicators of potential slope instability include presence of wet areas on slopes, jack-strawed trees, curved trees, tension cracks in slopes, stepped slope profiles, burried soil horizons and poor soil development due to removal of topsoil by slope processes. Determination of mass wasting hazard is important in planning for any excavation, or root rot treatments, and is supported and encouraged for these uses.

Natural drainage

Alteration or diversion of natural slope drainage is a concern with any soil disturbance, particularly with excavation (roads, trails, landings) or continous rutting. Drainage problems can lead to erosion, sedimentation, and in the worst case scenario, landslides. In the BC, the most common cause of these problems are forest roads, landings, and excavated and bladed trails. The FPC/FRPA contains a number of provisions regarding protection of natural streams and wetlands, and maintaining adequate drainage control at all times.

In practice, due diligence is needed regarding waterbarring and cross-ditching for seasonal deactivation. Care is also required in cases of seepage areas that may be too small to be recognized during ecosystem site mapping for a harvest prescription. In some regions, the regional ecology guide contains general interpretations regarding "road drainage control needs" for each ecological site series, to help remind data collectors and prescription developers that some sites are wetter during spring run-off than may be apparent during data collection in drier periods (Braumandl and Curran, 1992).

Drainage control is the number one priority when planning any soil disturbance and needs to be planned for in layout and construction. Major runoff events can and do occur at any time of the year. In the case of excavated and bladed trails, the use of grade relief dips and outsloping sections is important in preventing drainage concentrating on landings or haul roads which can affect operations, stability, and downslope resource values. Timely waterbarring, cross ditching and/or rehabilitation is important and drainage control must be in place before spring or other runoff events. Winter constructed trails and landings must be rehabilitated before spring thaw because these structures are often constructed with snow in addition to soil.

Within-site variability

In the few instances when soil disturbance limits are exceeded it is often because either the site was inadequately described, or a more sensitive treatment unit ended up being treated the same as a less sensitive one. High quality data collection, and due diligence to record keeping is essential in ensuring that a prescription matches a site and protects other resource values. Collected data is used with aerial photo interpretation to determine final treatment units by grouping soils of common sensitivity (for more information refer to Curran *et al.* 2000).

Growth-limiting factors

The actual effect of a given soil disturbance on tree growth will depend on which factors are the most growth-limiting on a given site and how these factors change over the course of a rotation. The net effect on growth will also depend on whether soil disturbance has introduced a new limitation, such as reduced soil aeration from compaction. Long-term effects could also include increased susceptibility to blow-down because of poor rooting in detrimentally disturbed soil.

In BC, common growth-limiting factors include: competing vegetation, excess or lack of soil water, soil temperature, summer frost, rooting substrate (volume), soil nutritional problems (e.g. calcareous soils), and root rot. Regional ecology guides often summarize common growth-limiting factors for various ecosystems (Braumandl and Curran, 1992), and a model has been developed for comparing

disturbance effects on growth-limiting factors when deciding on site preparation prescriptions (Curran and Johnston, 1992).

Regardless of the actual tree growth effects, a number of soil disturbance types are also of concern because of potential for effects on site and slope hydrology, and potential for downslope impacts. On-site changes in site hydrology are difficult to study but we need to err on the conservative side considering that much of BC is not flat and summer drought is often one of the most growth-limiting factors on many sites. Effects on hydrology may confound tree growth on apparently "undisturbed" microsites in tree growth studies. Similar hydrologic concerns have been voiced by other researchers, like Kuennen *et al.* (1979), which has been updated with more detailed vegetation information for the southern Interior, from the work of Drs. Suzanne Simard, Don Sachs, and others, and can be accessed at: www.myacquire.com/spvegman/expertsystem/ (full authorship listed on the website).

Specific soil management considerations

The principles discussed above apply to all management operations, and are discussed below along with some specific observations regarding permanent access network, timber harvesting, rehabilitation, and mechanical site preparation.

Permanent access network (roads and permanent landings)

Since roads and landings create the deepest disturbance into the soil they need to be carefully planned and their area minimized to reduce potential for impact on other resources. Landslides and erosion events are often associated with roads, or drainage diversions from roads. In the interior of BC, almost all landslides attributed to forest harvesting are related to this. On the Coast, roughly half of landslides attributed to forest harvesting are related to permanent access or its drainage. If a spur road or landing is not going to be used until the next rotation, it should be rehabilitated to restore site productivity and minimize risk to other resources. In very steep or otherwise sensitive terrain, rehabilitation may be prescribed on all roads and landings in the affected area as well. Rehabilitation of roads follows the same principles for logging trails, described below, except that large, deep water drainage structures are not normally used, instead swales in draws or full pull backs in actual drainage courses and gullies. In very sensitive areas an engineering prescription is often followed, similar to construction in such areas. In all cases, rehabilitated soil disturbance should be replanted to encourage tree growth.

Timber harvesting

Timber harvesting practices make different levels of impact on soil, ranging from minimum impact by helicopter and skyline systems, over high-lead system with somewhat greater impact, to ground-based harvesting with severe impacts such as scalping, compaction, and puddling. Fully mechanized systems, and rubber-tired vehicles generally have a more severe impact than tracked vehicles. Hoe-forwarding of wood with an excavator, or cut-to-length harvest systems typically have the least ground-based disturbance.

On steep slopes, and on moderate slopes in wetter climatic zones, cable

harvesting is usually used. If ground based-harvesting is considered appropriate for a given site (and compatible with downslope risks), a strategy is normally developed to match equipment and harvest pattern to the site constraints. This harvesting strategy should address the following considerations:

- it must be site specific and responsive to the soil sensitivities on site (and downslope),
- it needs to offer a reasonable amount of independence from climatic interruptions,
- it must incorporate rehabilitation, if necessary, to lower disturbance below guidelines, and
- it must instill enough confidence at all levels of approval and operations.

Based on industry innovation, practical experience, and research trials on a number of sites in Interior BC and some Coastal sites, four general ground-based harvesting strategies meet the above criteria:

- close trail spacing with rehabilitation,
- closely spaced temporary spur (haul) roads with rehabilitation,
- combined, designated and dispersed (random) skidding, and
- hoe-forwarding.

These strategies may or may not include fully mechanized harvesting with feller-bunchers and grapple skidders and may offer the opportunity to reduce site preparation costs by creating disturbance during the harvesting or rehabiliation phases.

For "combined designated and dispersed (random) skidding" to be a successful harvesting strategy, seasonal soil conditions often need to be employed. Seasonal conditions refer to when the soil is "wet", "dry", "frozen", and "snowpack" and defining these conditions has been problematic. Local experience is very important and further discussion occurs in Curran (1999). Once it has been determined at the prescription stage that seasonal soil conditions are a viable part of the harvesting strategy, operational staff need to determine when these conditions occur. In practice, it is often best to plan for designated trails and then take advantage of the weather when it is stable, and use the trails when it is not favourable. It is much easier to go from designated to dispersed than the reverse.

Hoe-forwarding on the coast of BC normally involves handling the same piece of timber several times, forwarding it to the landing area. In the Interior, often due to smaller piece size and value, hoe-forwarding normally involves handling the piece of timber once, forwarding it to a skidtrail or cable-yarding corridor.

Rehabilitation of harvesting disturbance

Rehabilitation may be approved as part of a harvesting strategy that allows some higher disturbance during harvest (e.g. 5% main trails), or it may be required in the few cases of non-compliance with disturbance guidelines. The primary objective in rehabilitation is to restore the natural hill slope drainage, thereby preventing erosion and/or drainage diversion. When subsurface drainage hits an excavated cut, such as a skid road, it will usually surface and run down the trail until it is directed off by a waterbar, dip, or outsloping section of trail. Intact skid roads increase the risk for

erosion and when waterbarred, they concentrate the snowmelt that should be stored on-site for summer drought, downslope (off-site), away from hill slope seedlings. Screening of sites for the appropriatness of rehabilitation is discussed by Curran (1999). Timely and thorough drainage control is important – winter constructed, temporary trails and roads almost always need to be rehabilitated before snowmelt.

Soil productivity can be conserved by carefully handling the topsoil and minimizing mixing with unfavourable subsoils. Rehabilitation techniques are the subject of a video and field cards available from the BC Ministry of Forests (Curran, 1997). The technique, briefly summarized below, applies to haul roads, some landings, and winter excavated trails as well. On coarser textured soils, some landings may be successfully rehabilitated with simple ripping (Bulmer and Curran, 1999a). Trails on gentler ground and old trails that have been re-used may just require simple ripping and drainage control.

Construction phase usually involves use of excavatiors and consists of the following steps:

- branches and woody debris are removed and placed on the downhill side,
- forest floor and topsoil (to 30 cm) are stripped and placed on top of the branches, and
- running surface is constructed out of subsoil.

Rehabilitation phase should be done under appropriate soil water content to avoid soil clod formation. It consists of the following steps:

- woody debris is removed from the running surface because this may act as a wooden culvert and pipe subsurface water,
- decompact running surface in an outsloping manner (do not rip lengthwise),
- replace soil materials in reverse order, subsoil first,
- slash and other woody debris are placed back on top of the rehabilitated trail, to a similar level as the surrounding cutblock, and
- regenerate the disturbance as per the surrounding cutblock, unless weeds or erosion are a concern in which case grass seeding and/or mulch are used.

Mechanical site preparation

Mechanical site preparation needs to follow the same principles laid out for harvesting, and some strategies to deal with these are presented in Curran *et al.* (1993). Site preparation (mechanical or burning) is normally carried out to address seedling growth-limiting factors, fire hazard abatement, or sometimes planting costs in heavy slash or grass turf. On wet, fine-textured soils, compaction and puddling may occur, limiting regeneration establishment. Removal of relatively nutrient-rich surface layers (scalping) may be detrimental for early growth of seedlings, if the underlying soil is nutrient-poor. Exposed mineral soil warms up more and faster at depth than does soil with organic horizons at the surface. Thus on cold sites mounding or scarification may lead to better early-season root growth of young seedlings. Also in comparison with exposed organic horizons exposed mineral soil is less subject to high surface temperatures on warm sites.

Burning

Sixty percent or more of the nitrogen and sulfur in forest fuels may be lost by volatilization during burning. Most of the ash consists of basic oxides, which can raise the soil pH by as much as 3 pH units. Other things being equal, the magnitude of the pH rise is least but the duration of the high pH is greatest in soils with high clay and organic matter content. Of the nutrient elements in the ash, potassium is especially susceptible to leaching loss. Available nutrient levels may be higher after burning than before, i.e. soil fertility may be enhanced in the short run. However, because of the nutrient losses caused by fire, and the subsequent immobilization of nutrients in accumulating organic matter, long-term soil fertility might be impaired. Sites with thin forest floors may be considered sensitive for slashburning (Curran *et al.* 1993), although those in grassland areas might have an ecological history of repeated burning. Evidence of some long-term impairment of tree growth by burning in Norway (Braathe, 1974) may be of significance for some sites in BC. However, Curran (1994) could not find long-term negative effects of burning on soil or Douglas-fir growth in Coastal BC.

Forest soil conservation in BC

Throughout BC, all agencies affecting forest soil management need to work cooperatively in an overall adaptive management framework to harness new knowledge. Consequently this knowledge should be applied to provide the continual improvement of our soil conservation policy and our best management practices, aimed at maintaining soil productivity and health. Long-term research and operational trials are a key component of this framework. Principles behind implementing operational trials are discussed by Bulmer and Curran (1999b). The "Long-term soil productivity study" is an example of ongoing long-term research study carried out in collaboration among various government organizations, universities, and industry.

Summary

Forest management practices should protect and improve forest resources such as vegetation, soil, water, and wildlife, while improving the output of products as wood and fibre. Successful forest management requires a broad understanding of ecosystem functions and the interactions among climate, soil, vegetation, and topography. To integrate this understanding foresters should rely on various tools such as soil surveys and maps, and soil description and classification.

Soil description and on-site mapping of treatment units allows foresters and other land managers to infer soil properties and management limitations and implications. Canadian soils have been grouped according to the Canadian System of Soil Classification into 10 orders (and subsequently into great groups, subgroups, families, and series). A brief description of the soil orders and common limitations for timber production associated with each of the orders are provided in this chapter.

A good understanding of the nature and properties of soil is a key for an efficient soil management. Foresters must be capable to make appropriate evaluation of soil problems in the field. The nature and properties of individual soil particles (sand, silt, and clay), their size distribution (texture), and their arrangement (structure), accompanied with the soil organic matter content, have profound effects on

plant growth and on all kinds of soil manipulations and use. Soil texture and structure influence pore size and total soil porosity, thereby imparting water and air relationships and the level of soil compaction.

Nitrogen is the most commonly deficient macronutrient, while iron is the most commonly lacking micronutrient in BC's forests. Deficiencies of other nutrients occur in various regions of the province depending on a combination of climate, soil, and tree species. Examples of various environmental conditions that lead to nutrient deficiencies in BC forests are given in this chapter. The principal methods for operationally diagnosing nutrient deficiencies include visual symptoms, soil chemical analysis, and foliar analysis. The most useful routine soil chemical analysis for forest soil fertility interpretations in BC are soil reaction (pH), organic carbon concentration, total nitrogen concentration, and mineralizable nitrogen.

When planning management operations, forest managers need to be aware of the inherent site sensitivity to soil disturbance, the need to maintain natural drainage patterns, within site variability, and site growth-limiting factors. These issues are discussed in this chapter and some specific observations regarding permanent access network, timber harvesting, rehabilitation, and mechanical site preparation are provided.

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SILVICULTURE

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SILVICULTURE

The Organization and Development of Silviculture in BC

What is silviculture?

A forest is a landscape with tree cover. Administratively, forests are a collection of stands managed as an integrated unit. A stand is a contiguous group of trees distinguishable from adjacent groups because of its particular species composition, age class or structure. Silviculture consists of actions in individual stands to regenerate them after harvesting and then tend the stand to produce a desired future stand condition. A planned series of actions can be combined into a silviculture system, which regulates the way in which the stands are harvested, renewed and tended.

The objective of the silviculture actions is to produce the type of stands required by the forest owner. The objectives may be timber, wildlife habitat, range or special biological diversity attributes. Silviculture in BC is mainly focused on the harvesting, renewal and tending of natural old forest stands in publicly owned forests.

Silviculture is just one component of forest management. The other management actions are: protection and the planning of harvest size, location and timing. All these actions are combined in time and space in long term plans to produce the future forest condition wanted by the owners of the forest. The amount of silviculture activity and the practices used, are not necessarily a measure of the sustainability of the values in a forest. Natural forest ecosystems in BC are resilient and have been self renewing after natural disturbances since the last Ice Age about 10,000 years ago. The degree to which logging parallels historic disturbance, and the resilience and renewal of forest ecosystems has been well studied. Emulation of natural disturbance is presently in vogue as a paradigm for planning harvests and silviculture actions. The degree of emulation is proposed as one measure of sustainability.

Recent developments in BC silviculture and forest management (see Table 1)

1980s

- Use of ecosystem specific silviculture recommendations for species selection, silvicultural systems and stocking goals using the biogeoclimatic ecosystem classification (BEC) system with edatopic grids (soil nutrient regime × soil moisture regime) to identify site series; published in site manuals for each region.

- Silviculture funded under Section 88 of the Forest Act. Annual funding frequently insufficient to cover all necessary regeneration silviculture activities.
- Integrated resource management is the prevailing paradigm for forest planning.
- Required use of Pre-Harvest Silviculture Prescriptions (PHSPs) signed and sealed by Registered Professional Foresters (RPFs) for all cutblocks on Crown Land (95%).
- Establishment of a Silviculture Institute of BC (SIBC) to educate silviculturalists with five years of experience and RPF status. SIBC requires attendance at 6, 2-week modules to receive a University of BC Diploma in Advanced Silviculture. In the first 10 years 150 graduates were produced. Crop planning teaching is developed.
- Joint Provincial-Federal Forest Resource Development Agreements (FRDA) fund backlog reforestation and stand tending activities.

The 1984 Forest and Range Resource Analysis estimated that there were 738,000 hectares of good and medium site Crown land that had been harvested, burned by wildfire, destroyed by pests or other damage and were classified as backlog (pre-1982) not satisfactorily restocked (NSR). These areas were considered economically viable for timber production and given a high priority for silviculture activities.

1987

- Corporate licensees required to assume full funding responsibilities for basic (regeneration) silviculture, i.e. all costs to achieve free-growing status of adequately stocking acceptable species on all cutovers. The silviculture contracting industry, including nearly all nursery stock production, site preparation, planting and tending is privatized. Each year about 200,000 ha were cut, 200 million trees were planted and about $400 million were spent on basic silviculture. The Silviculture Contractors Associations is formed and the 'Canadian Silviculture' magazine is published.

1990s

- The idea of New Silviculture – a New Perspectives Silviculture is introduced in the Pacific Northwest; the objective is to develop or maintain old growth forest attributes in silviculture practices. Increased interest in partial cutting in BC. Silviculture systems integrated research experiments are established together with re-invigoration of early research installations.
- The idea of ecosystem management is adopted by the US Forest Service and is introduced into BC. Four fundamental principles of ecosystem management are: first, the necessity of interagency cooperation and public involvement; second the foundation of management on sound scientific principles supported by research findings; third, a focus on preservation and restoration of biological diversity; and fourth, the importance of aesthetic values and amenities expected by visitors to the region.

1990+

- Years of work on biometrics and modelling had led to the development of the tree and stand simulator (TASS) – a computer model which grows individual trees and predicts their exterior attributes (diameter, branch size, etc.). TASS was calibrated for major BC tree species. TASS output was put into the Windows version tabular output (WINTIPSY) for use by forest managers. TASS output was also built into stand density management diagrams (SDMDs), which allow graphical, visual crop planning based on mean stand attributes and self-thinning theory.
- Crop planning using SDMDs is widely taught in SIBC, UBC, UNBC and in workshops. TASS is adopted by the BC Ministry of Forests as the official model for production of managed yields for 'perfect' stands, Operating Adjustment Factors (OAFs). OAFs are used to reduce the output to realistic yield values for forestry.

1991

- The decline in old growth reserves, plus strategic consultant reviews of future timber prices and grades and the 'quality' of second growth timber and a rise in 'timber' prices especially for better log grades all focused more attention on second growth timber quality.
- The age class gap in most TFLs and TSAs had previously led to expanded use of pre-commercial thinning (PCT) to accelerate second growth operability but at a sacrifice in stem quality, branchiness and stand growth rate. These circumstances led logically to the 1995 Forest Practice code requirements for Stand Management Prescriptions when stand tending work, over basic silviculture, is foreseen. A clear stand management objective and a crop plan became mandatory.

1992

- Public concerns locally, nationally and internationally about cutting natural old forests in BC, plus pressure from environmental groups led to demonstrations, much negative publicity for major forest companies and boycotts of BC timber in Europe.
- After failed corporate attempts to alleviate the situation by public relations, the provincial and federal governments acted. The BC government adopted a regulatory approach through the Forest Practice Code (1995) with 70 guide-books. The code was required to be observed legally – thus making RPFs very concerned about their legal exposure, "due diligence" and ethical position in carrying out silviculture planning and actions.
- The Association of Professional Foresters (ABCPF) tightened its procedures for dealing with disciplining ethics, continuing education, entrance standards and professional inspections. Many foresters take Code training workshops.
- The Federal Government put up $50 million for Model Forests across Canada, ten are chosen, two in BC. The MacGregor Model Forest (Northwood TFL at Prince George) pioneers software for GIS based forest estate planning with support field studies for input data on inventory and ecosystem process. The Long Beach Model Forest attempts to develop land use consensus among many stakeholders at the Clayoquot area on the west coast.

- The BC Government adopts the findings from the Clayoquot Sound Scientific Panel, which attempted to find on-the-ground solutions to revised cutting methods and harvest schedules in a forest dominated by very old cedar and hemlock. A symposium is held to develop feasible silviculture prescriptions. Residual structures are recommended to be left as cutblocks.

1992+

- Since TASS "grows" stands based on height (not age) accurate site index values are required for each stand for inventory program. This situation led to re-appraisal of the underestimated site indexes in old growth and repressed lodgepole pine. Use of the intercept technique for early cutover SI_{50} determination expanded. Allowable cut increases developed as a consequence of revised site index determinations.

1993

- As the constraints imposed on harvest schedules, locations and rates by landscape and biodiversity issues became of greater concern, computer models were developed which grow the forest in a spatially explicit way (Complan, Atlas, etc.). Spatially based forest estate modeling became more widely adopted as the basis for allowable cut determination by government and industry. Allowable harvests are the schedules produced from long simulation of the forest after all the landscape and stand level constraints are put into the model.
- Silviculture actions which enhance and accelerate projected second growth stand yields can help offset annual allowable cut (AAC) declines due to spatial constraints and can concentrate intensive forest management on a smaller portion of the land base, thus leaving more old growth unlogged.
- Corporate concerns over effective on-the-ground performance in silviculture led to corporate audits and attempts to link silviculture to forest level plans.
- "Green-up" and "adjacency" requirements which delay logging of adjacent uncut blocks focuses attention on rapid development of "green-up" in basic silviculture.

1995

- The Federal Government funds a national centre of excellence (NCE) in sustainable forestry, based at the University of Alberta, but with studies across Canada of ecosystem process, planning and manufacturing processes.
- The Province of BC establishes Forest Renewal BC (FRBC) based on a "super tax" on top of stumpage and starts funding incremental silviculture (over and above basic silviculture) at about $200 million per year. A shortage develops of foresters and silviculturists to fill all the available jobs.
- The Canadian forest industry, via the Canadian Pulp and Paper Association, sponsors a national effort using the Canadian Standards Association to develop a national mechanism for certification of forest management. Consensus has been very difficult on the criteria for forest sustainability.
- The Alberta Forest industry develops its own 'Forest Care Code' for certification using its own audit procedures.

1996

- In August 1996 government offloaded funding of the backlog reforestation program to FRBC. FRBC agreed to fund a ten year, $250 million backlog reforestation program.

1997

- The Chief Forester completes his revision of allowable cuts in BC; many TFL and TSAs have substantial reductions, mainly due to spatial constraints on harvesting. The amount of cutover not yet reaching "free-growing" under licensee obligation, is estimated to stabilize at over one million hectares.
- "Just the facts: A review of forestry and silviculture statistics" is first published by the Ministry of Forests.

1998

- 1998 Results Based Silviculture Prescriptions: With amendments to the Act in 1998 the requirement for specifying silviculture treatments in the SP was discontinued. Licensees were required to retain an RPF to prepare a regime of treatments such that there was a reasonable likelihood of achieving target stocking and then follow that regime.

1999

- Market forces against the use of 'clearcutting' in coastal forests result in the adoption of "variable retention" by coastal BC companies with licenses in Natural Disturbance Type 1 forests characterized by gap dynamics.
- Emulation of the historical natural disturbance is adopted as a model for silviculture. In Crown fire dominated interior forests (NDT3) cut block sizes, shapes and residual structures emulate natural forest fires.

2002

- A new Liberal government suggests assigning more managerial responsibilities to licensees on defined forest areas and a "results based Forest Practice Code". Silviculture prescriptions for each cut block will become part of a five-year Sustainable Forest Management Plan and no longer approved individually on a 'stand alone' basis.
- The new *Forest and Range Practices Act* no longer mandates silviculture prescriptions for each harvest block but requires site plans to implement short-term forest stewardship plans. These plans must specify intended results or strategies and conform to prescribed requirements. This Act should be enacted in Fall 2003.
- Stand tending practices, and backlog reforestation, now funded under the Forest Investment Account (FIA) mechanism which assigns funding for land base investments in proportion to a licensee's allowable cut.
- On December 17, 2002 streamlining amendments to the FPC Act and regulations came into effect. These amendments give licensees immediate relief from regulatory burden, which licensees can enjoy through the two-year transition period until the new *Forest and Range Practices Act* is fully implemented in December 2005. This included replacement of the silviculture prescription with the requirement for a site plan with reduced content and no

Table 1: The development of British Columbia Crown land silviculture.

Date	Problem silviculture	Policy	Application strategic	Application tactical	Research
1910-1960	Inventory of forest cover types	Seedling and planting trials	"Get the wood out"	Forest inventory	Silviculture as logging
1931-1970	Unknown silvics of species	Unassisted natural regeneration	Replace old growth by vigorous young stands	Regeneration surveys	Silviculture as logging • stand development • plantation trials
1950-1970	Inadequate regeneration following unregulated logging	Assisted natural regeneration	Cut modification	Scarification, large scale planting	Silviculture as regeneration: • stocking standards • ecology based regen. prescriptions
1971-1978	"NSR" plus accumulating "backlog"	Expanded government planting	Site and stand specific prescriptions	Quality planting, site classification	Silviculture as plantations: • cutover response • forest tree improvement • site/species matching
1978-1988	Unknown falldown and ACE benefits and risks	All site "basic silviculture" by industry plus optional tending	Designing crop planning	Biological and economic efficiency of regeneration and tending	Silviculture as biological basis for sustained yield: • managed yield curves • modelling benefits • efficiency of technique • risk assessment
1988-present	Reduce clearcutting; biodiversity and old growth conservation	Basic silviculture based on natural precedents, limited intensive silviculture	Cut modification and adaptive ecosystem management to achieve desired stand and landscape goals	Use natural regeneration and innovative silviculture systems	Silviculture as a substitute for natural disturbance: • stand structure biodiversity • silviculture system trials • retrospective studies • geriatric silviculture
2000+	Emulate historic natural disturbance while maintaining or increasing allowable cut	Silviculture actions as part of a sustainable forest management plan	Avoidance of "clearcutting" if possible and meeting non-timber values	Use of stand level biodiversity oriented cutting	Analyses of stand and landscape structures, habits and dynamics following natural disturbance

requirement for government approval. The government also deregulated backlog and current fire and pest silviculture obligations classifying these as discretionary silviculture eligible for FIA funding. There was also a significant reduction in government funded silviculture.

Professional Accountablity in Silviculture

Silviculture prescriptions (SPs)

It is good professional practice to prepare a silviculture prescription (SP) when harvesting is proposed or when silvicultural treatments are proposed for timber that has been damaged or destroyed by natural causes

An SP contains stand level management objectives and strategies that must be consistent with forest-level plans. It outlines the conditions required to accommodate known forest resource values. It also summarizes site and stand conditions and provides standards for environmental protection and target stand conditions. It should describe the silviculture system to be used and a regime of silvicultural treatments to achieve the target conditions within the period specified in the SP.

Essential information required in an SP includes (see Figure 1):

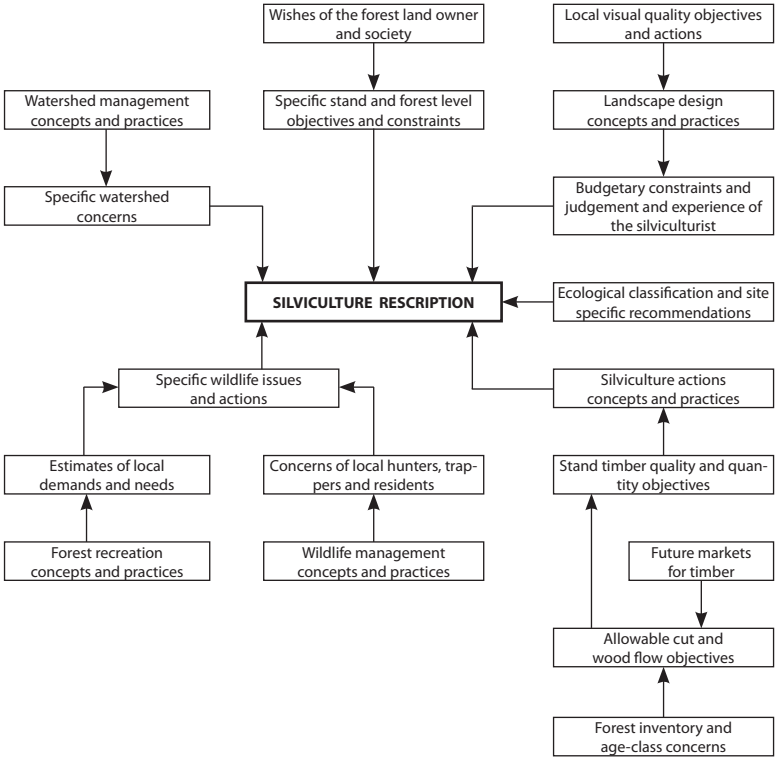


Figure 1: The interaction of areas associated with the silviculture prescription.

- management objectives consistent with higher-level plans;
- ecological information and site characteristics (including limitations);
- specific management strategies;
- soil conservation requirements;
- proposed silvicultural system(s), and
- stocking requirements.

As a matter of professional accountability and due diligence, the field data collected must be adequate to support any management decisions made in the SP. (see Silviculture Prescription Data Collection Field Handbook. Land Management Handbook No 47 BC Ministry of Forests). The handbook provides helpful suggestions regarding data collection methods, including stratification, soil sensitivity evaluation, and initial prescription development.

Suggestions from the Association of BC Forest Professionals about preparation of silviculture prescriptions

When professional foresters sign a silviculture prescription, they are expressing a professional opinion. They are accountable for all of the content of that document, or any other documents that represent professional opinion, work, or practice. Accountability attaches whether or not the professional forester has performed all the work underlying the documents themselves, or as is more typical in the case of complex planning documents signed by a professional forester, they have relied on input (or adopted wording) from technical staff allied professionals, and even other professional foresters for part of the content.

In signing documents, professional foresters are assuring the public (among other things) that:

- all the conditions represented in the document and on which opinion is based exist;
- necessary data have been gathered appropriately;
- experts and interest-holders have been consulted;
- all of these data and values have been considered and incorporated into the documents;
- in the opinion of the professional, the document represents an expression of "good stewardship of forest land based on sound ecological principles to sustain its ability to provide those values that have been assigned by society" (Bylaw 14.3.1), and
- the document meets all other requirements/expectations of the profession and the law.

Professional foresters are also accountable for the results of plans, prescriptions, and/or opinions when implemented or acted upon as directed in the documents.

The term accountability means that professionals must be able to answer any challenge made to their work such that the public, profession, and client is satisfied that the professional is qualified to undertake the work and that the work was done in a competent manner. Accountability also means that when professional foresters rely on the work of others, the reliance was appropriately placed given all the circumstances of the case. In other words, was appropriate due diligence exercised?

Reliance

Professional foresters routinely rely on the assistance and advice of others in the discharge of their duties. The question is not whether they can, or ought to rely on others, but under what circumstances that reliance is exercised appropriately?

When professional foresters rely on technical staff or experts (including other professional foresters) they must take the necessary steps to satisfy themselves that the persons upon whom they are relying are competent and qualified to do the work assigned. Professional foresters must also satisfy themselves that the work has been carried out appropriately and to acceptable standards.

When professional foresters receive work products from others, they must review them to ensure they make sense given their own knowledge of, for example, the area and site conditions, and that the data and/or recommendations/opinions are incorporated appropriately into their own work product.

The necessary considerations when relying on the work of others will vary with the circumstances of each individual case. The following list represents but a few of the more pertinent considerations when considering professional due diligence:

- How well does the forester know the physical area or the area of practice/expertise?
- Does/do the individual(s) upon whom the forester is relying have the necessary degree of education, skill, training, and knowledge to carry out the task(s) assigned?
- What steps are in place to ensure adequate instruction and supervision of individuals(s) upon whom reliance is placed?

The Ecological Basis for Silviculture in BC

Natural forests

The forests of BC are 95% publicly owned. They are also natural in origin with about 40% in "late successional stage" or with "old growth" attributes. This is due to the absence of frequent historical disturbance in regions that have wet climates or are at high elevation, and in last 50 years is due to the suppression of wildfires. In BC the historical natural relationship between the forest cover and the climate and land forms has been little affected by human influence. This has allowed the use of the BEC system for characterizing ecological conditions at the zone, sub-zone and site level. Sites within the same classification (e.g. site series) are considered to be ecologically equivalent.

There are about 300 different major forested ecosystems in BC. Each has a different species composition, stand structure and successional trends following disturbance. Silviculture treatments are prescribed for "treatment units" on cutovers, which recognize the underlying pattern of ecological units (BEC site series). Silviculture "systems" are custom fitted to the particular ecosystem characteristics and dynamics. With many management units in BC dominated by old natural forest, each prescription requires a customized set of silviculture treatments regarding type of harvesting, protection of habitat, biodiversity, landscape beauty, regeneration and tending.

The universal use of the BEC system both in practice and research publications allows knowledge on successes and failures in silviculture to be made portable across

the landscape: BC is still in a learning mode on what silviculture works and what silviculture does not in the many ecosystems. The adaptive management aspect of silviculture is built around the common use of the BEC system and a silviculture record keeping system. There are few formal "silviculture guides" in BC and none are required to be used by regulation.

Natural disturbance regimes

Following the precedent of the historical natural disturbance is the current paradigm for silviculture in BC. This is a default position based on the assumption that the current natural forests have kept their "ecological integrity" over the past 10,000 years, thus human intervention should parallel the natural disturbance.

While the ecosystems are well classified in BEC and, the structure and dynamics are less well documented, particularly for "old growth" stands. At the landscape level four Natural Disturbance Types (NDT) are recognized. The proportions of age classes maintained in landscape units within each NDT is intended to reflect the age class structure of unmanaged forests in these types.

For NDT1 forests (maritime coastal, interior wet belt, high elevation) with small scale gap dynamics and little disturbance, clear cuts do not 'emulate' natural disturbance; thus the retention system is increasingly being used as a silviculture system.

NDT2 forests occur in coastal and cooler continental zones and experience infrequent stand-initiating events. Historically, these forest ecosystems were usually even-aged, but extended post-fire regeneration periods (200 years) produce stands with uneven-aged tendencies. Many larger fires occurred after periods of extended drought, but the landscape was dominated by extensive areas of mature forest surrounding patches of younger forest. Clearcutting has been the dominant system in these forests but the retention system is increasingly used.

In NDT3 forests (interior montane, sub-boreal, boreal) the ecological parallel between use of modified clear cuts and large-scale fires in natural forests is much debated. Cutblock patterns, sizes, and residual structures currently try to emulate those of large-scale fire disturbances (in BC mountain pine beetle is a factor).

In NDT4 forests (interior dry belt) with historically frequent surface fires, 50 years of fire exclusion has resulted in overstocked stands, fuel accumulation and major forest health problems and catastrophic crown fires. This human-caused ecological crisis, common in western North America, has resulted in strong pressures to restore fire into the ecosystems by prescribed burns and reducing fuel by thinning.

While silviculture in BC is "ecosystem specific", this should not be confused with "ecosystem based management" (EBM). EBM calls for ecologically based protection, harvesting and renewal actions in a forest. "Ecosystem management" is a land use management philosophy that originated in the US which calls for a balance of ecological, social and economic values in managing a forested landscape.

Natural regeneration limitation

In most BC forests, the trees here today regenerated naturally following natural disturbances. Each species has its own successful reproduction and survival strategy or else they would not be there. The distribution of a tree species across the

climates and sites reflects its tolerance to a range of ecological conditions (ecological amplitude) and its competitive abilities. Stocking standards require that the choice of species to regenerate on a cutblock follow this fit or a natural precedent, since history has proven them to be successful survivors. BC does not permit the use of exotic species or use of species outside their range except under special circumstances.

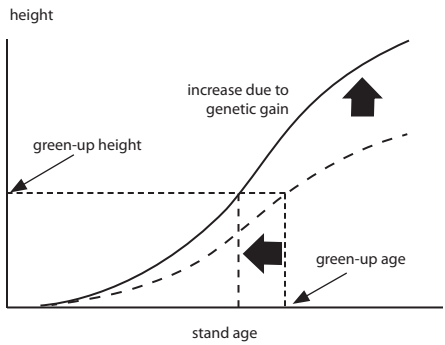
The history of both anthropogenic and natural disturbances has shown that nearly all BC forests are resilient, i.e. they will reproduce naturally back to trees given enough time. On severe sites, at high elevation, the ingress of natural regeneration may be slow, but is nevertheless inevitable if the sites are not repeatedly disturbed. The natural regeneration of the large 1860 clearcuts from the gold mining days at Barkerville in the high elevation, cold forests in the ESSF is an example. In the dry interior valleys, the absence of natural surface fires due to fire suppression has lead to the expansion of interior Douglas-fir and ponderosa pine into the grasslands.

"Waiting for naturals" as a deliberate silviculture strategy has some advantages in terms of habitat for some species, i.e. a longer time in a seral condition. From a timber supply viewpoint the natural succession may be to less valuable species (classically aspen in boreal mixedwoods or red alder on the coast) or excessive stand densities (classically western hemlock or lodgepole pine). At the time of writing, the policy on both Crown lands and on private forest lands managed under the *Assessment Act* is to require observance of stocking standards which specify species, density and tree growing under a Forest Practice Code. Historically, the low level of regeneration activity prior to 1975 on cutblocks gave rise to millions of hectares of NSR (not satisfactorily restocked) land. Non-crop vegetation dominated cutovers that were obviously not going to produce equivalent yields to the natural mature stands that were cut. Under a sustained timber yield policy, regenerating stands should have yield curves at least as good as the natural yield curves (volume over age curves VAC or Variable Density Yield Plan VDYP) for the stands that occupied the sites prior to harvest. In a landscape dominated by old forest it has been very difficult to quantify the speed and nature of natural regeneration in hundreds of different ecosystems. The historical natural "regeneration delay" in the natural yield curves is often not known well. Nevertheless, in the provincial stocking standards there is a specified "regeneration delay" (normally 3-6 years) and a specified number of years to meet "free growing" (normally 8-20 years). These requirements are in place because long delays in regeneration impact allowable harvest levels in wood supply models. The Chief Forester sets the AAC on Crown lands and does a sensitivity analysis for it. The FS-SIM timber supply model used by the Chief Forester is sensitive to uncertainty over regeneration. For partially cut stands using the selection system the stocking standard is not related to free growing but the number of trees of advanced growth needed to maintain the reverse-J frequency curve under repeated stand cutovers.

To ensure each stand is renewed to a reasonably predictable condition, BC has chosen to set stocking standards for every site association in the province. The forest licensees are required to meet the standard on all cut blocks within the regeneration delay periods. Wood supply models often show improved harvest flexibility when rapid regeneration is achieved. In turn, green-up is influenced by genetic gain. In

TIPSY the specified amount of gain is applied at the index age.

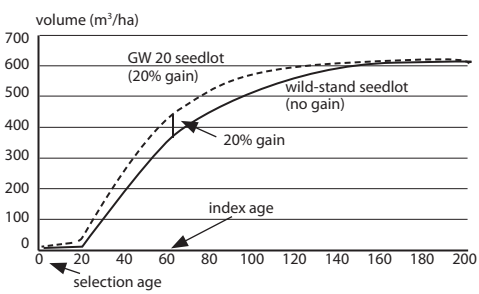
Due to pressure from the United States about "subsidies" in the countervailing tariff issue over lumber exports, the BC forest industry, starting in 1988, has accepted full fiscal responsibility for "basic silviculture" – i.e. meeting the provincial stocking standards. The combined effect of stocking standards and industry paying the silviculture on about 180,000 ha of annual cutover, gave the forest industry a huge incentive to not rely on natural regeneration, unless past experience indicates that it will be prompt and assured. Natural regeneration is used only in: aspen in the boreal to regenerate some cutblocks, western hemlock, lodgepole pine and partial cut systems in dry coastal Douglas-fir, interior Douglas-fir, some boreal spruce and



Genetic gain can lower the age at which green-up height is reached.

Species	Selection age	Index age
Coastal Douglas-fir	12	60
Western hemlock	15	60
Western redcedar	10	60
Sitka spruce	8	60
Interior lodgepole pine	10	60
White spruce	15	80
Interior Douglas-fir	10	60

Selection ages and index ages used to model genetic gain in TIPSY, by species.



Modelling genetic gain in TIPSY.

Figure 2: Incorporating genetic gain in timber supply analysis (Tanz, 2001).

ponderosa pine ecosystems where established advance growth may be used. In other ecosystems, cutovers are usually planted to meet basic silviculture obligations as quickly as possible. The replacement of natural regeneration by planting has been possible in BC by the high economic value of the virgin mature conifer forest being cut.

In essence the government has 'privatized' the regeneration silviculture in BC. Today there is a large silviculture contracting industry of container stock growers, planters and stand tenders. Regeneration silviculture has been more professional with RPFs signing all the silviculture prescriptions and being held accountable and required to display due diligence. Since 1975 there have been many improvements in planting stock quality and species availability, and the customization of site preparation and vegetation management on the many ecosystems being cut. Survival rates exceed 90% in the first year after planting. These circumstances have eliminated much of the historical "backlog" of understocked cutover; most companies are 'caught up'. At any one time, with about 180,000 ha of annual cutover at present, and up to 15 years allowed to reach free growing, forest licensees have a combined liability for two to three million ha of cutover in BC.

A review of stand level silviculture tactics

Recent analyses of the long-term supply of wood available to the forest products industry have shown that wood supply deficits for certain products are likely in the foreseeable future. For some forest management units, these deficits could occur very shortly or in the next two to four decades. The sensitivity of allowable annual harvest (AAC) is provided in the Chief Forester's statements when the BC Ministry of Forests approves the AAC. Many units have gaps in age classes and often have a preponderance of mature and over-mature age classes.

An attempt is being made to achieve a more favorable balanced supply of maturing age classes with due allowance for landscape level habitat and biodiversity requirements in landscape units.

To offset forecast deficits in magnitude of supply, in species, or in quality, attention is focused on the two courses of action available:

1. Closer utilization of presently used species, and utilization of inferior species and grades of timber.
2. Large-scale implementation of silviculture practices.

The forest industry is still based largely on the harvesting of natural-origin coniferous forests composed of large, old trees. Historical lack of attention to forest regeneration resulted in changes in many cutover areas to "inferior" forest types following unregulated logging and unassisted natural regeneration. The sheer magnitude of these changes was recognized to have potentially grave, long-term consequences for the viability of the forest industry. As a consequence, achievement of a satisfactory stocking standard on all cut blocks became a requirement for forest industry licensees ("basic silviculture obligation").

Appropriate silviculture treatment can prevent the invasion by inferior species, and can give yields considerably higher than those obtained with unregulated natural succession following logging. Silviculturally treated stands of the same species composition can produce two to three times the merchantable yield in the same time

period. In other cases, although the yield per hectare at rotation may be unchanged, the time to reach rotation age is reduced. In either case, the sustained harvesting rate, or annual allowable cut (AAC) may be increased. Thus, silviculture treatment will become an indispensable tool in maintaining the industry's viability in the future.

The task of much silviculture research is to determine the probable magnitude of yield curve shifts resulting from specific stand level silviculture options under even-aged and uneven-aged management. These data are used by planners to prepare forest level harvesting scenarios and to plan other management activities.

The annual allowable cut depends on age class structure, operability of forest types, and yield curves for wild and managed stands. The AAC calculations assure a certain allowance for loss of growing stock due to fire, insects and disease. In other words, a certain rate of decline in the yield curve is allowed for. If the AAC calculation is to be valid, the actual losses from fire, insects, and disease must be within this allowance.

Prompt and satisfactory regeneration of cut and burned lands

The effects of improved reforestation are felt in the AAC calculation by:

a. A shift of the yield curves for unregulated natural succession following logging,
b. An increase in the magnitude of the yield over that expected from unregulated natural regeneration.

Having provided the conditions for a more favorable yield curve (Figure 3) by establishing a plantation for example, it is essential to protect the future crop against fire, insects, disease, animals, or as frequently happens on the most productive sites, invasion by less desirable species.

Depending on the age class structure of the sustained yield unit a massive reforestation program can have no effect on the AAC position if the plantations do not become operable in time to cover an age class gap. However, such a program can result in an immediate major increase in AAC if the requirements for the allowable cut effect (ACE) are met, i.e. old growth is available, age classes are balanced, risk of loss is low, and the anticipated benefits from the plantations are real and reliable.

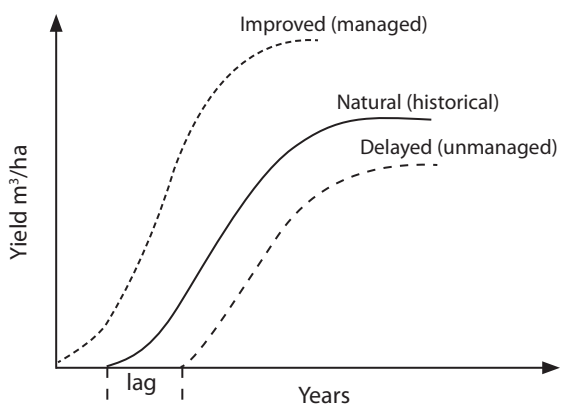


Figure 3: Shifts in yield curves from the historical natural yields due to management, or its absence.

A landowner has a public responsibility to ensure a minimum stock level on all denuded lands, at least in reasonably accessible areas. This is the concept of "basic" silviculture. Thus, BC will always be concerned about reforestation research. This is particularly so in "backlog" areas not satisfactorily regenerated (NSR), i.e. with insufficient stems per hectare or stocked with undesirable species.

Precommercial thinning

Precommercial thinning (PCT, cleaning juvenile spacings) acts like planting on the AAC by causing a shift in the yield curve – in this case to the left. (Figure 4).

Being fixed, the growth capacity of the site is shifted to fewer trees which reach operable size sooner. The benefits are:

a. drop in rotation age
b. regulation of species composition
c. control of diameter growth to "custom grow" trees for industrial plants
d. provision of opportunities for commercial thinning and fertilization
e. reduction of irregular mortality losses

Unlike planting, precommercial thinning produces faster benefits – i.e. stands become operable in 25 to 45 years versus 45 to 90 years for planting, depending on species and site quality. Like planting, a massive PCT program can have little or no effect on AAC, or can lead to a massive increase, again depending on age class structure and ACE assumptions.

For the pulp industry the benefits of PCT are largely those of faster operability and lower harvesting costs, since no real fibre increase is involved. However, as multi-product logging becomes more prevalent, the attractiveness of PCT increases. For the sawmill industry PCT is almost an essential operation to produce sawlogs quickly.

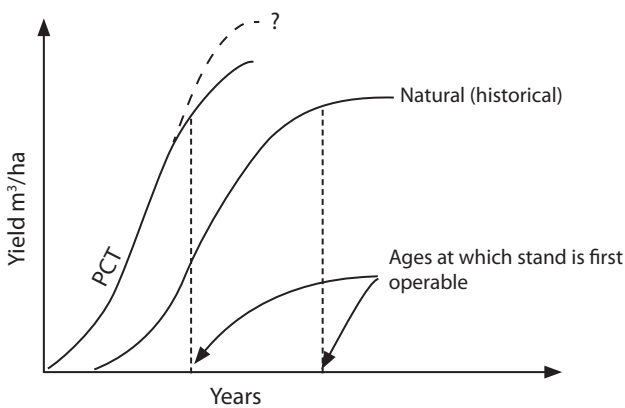


Figure 4: Effect of precommercial thinning on AAC.

Commercial thinning

Up to one-third of the total production on a site can be lost due to mortality; in theory, thinning can recover this. For some corporations thinning represents about 30% of their projected cut (Figure 5).

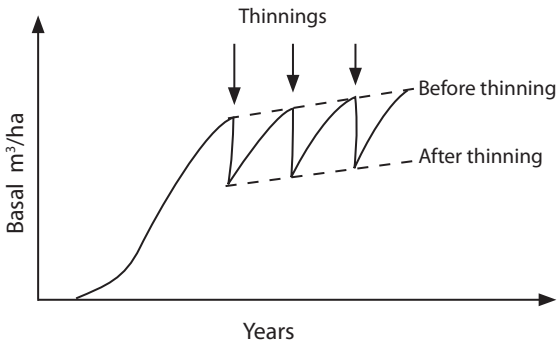


Figure 5: Idealized representation of three thinnings designed to recover mortality and maintain high standard growth rates.

The effect on AAC is positive only if it can be demonstrated that volume loss due to mortality is being harvested, rather than taking a final cut in two or three steps. The extent to which the mortality loss is harvested is a bonus to AAC, since all AAC calculations are based on net, unmanaged yield curves.

Thinning theory suggests that to capture the entire loss due to mortality, several thinnings are required. In order not to lose increment, high basal areas and well-distributed trees should be maintained. In practice, this is almost impossible with high logging costs and low timber values.

Fertilization

By adding nitrogen (N) to forests periodically (5 to 10 years), increases in mean annual increment of 30% are possible. The effect on AAC is through a real increase in the magnitude of the yield curve with repeated nitrogen applications.

The general problem for research is to determine the likely response from a given application of fertilizer, to a given stand of trees, on a given site. Depending on age class and species, the effects on AAC can be minimal or considerable. For example, fertilization is particularly effective for companies with a shortage of trees in an intermediate age class which can be harvested for pole-sized timber.

Strategic analysis of wood supply and silviculture needs

Since silvicultural benefits work through AAC and ACE, the criteria for establishing practices for budgeting of operations and for research must be developed by analysis of the wood supply. In addition, the Crown must also consider the broader based social and economic benefits, the multiple use implications.

British Columbia is divided into management units with a policy of sustained timber yield within their boundaries. The corporations must fit into this framework. For forest company licensees, the opportunity exists for the companies to do their own analyses of its wood supply and develop their own criteria for silvicultural

operations and research. These can then be proposed to the Crown's strategic planners for approval and funding. If the calculations are valid, increased cuts can be justified by either improved utilization practices or by more intensive forest management.

Silviculture Systems and Reproduction Methods

Species selection (refer to management guides by species)

Species selection is one of the most critical decisions made in regeneration silviculture. The timber and non-timber objectives for the site must be considered along with the site and stand condition and the silvics of the species of interest, including tolerance where partial cutting is planned. Candidate species are ranked in terms of their productivity, reliability (freedom from pests), silvicultural feasibility (ease and efficiency of establishment and growth to rotation), and contribution to non-timber objectives. Based on this ranking, preferred and acceptable species are chosen. Preferred species are promoted by management practices. Acceptable species may contribute up to 20% of stocking.

At the stand level there are published species selection and stocking guides for all the recognized forest site associations. The guides assume even-aged management with timber production as the primary goal. They specify the choice of acceptable species, stand densities at "free-growing" and the times allowed to reach free growing.

It is common to prescribe more than one preferred species. This increases diversity and reduces risk of failure due to disease or insect outbreaks. Be sure, however, to consider the relative growth rates of each species. Mixes of fast and slow growing species will produce stratified stands and delay culmination for the slower growing species.

Natural *versus* artificial regeneration

If target stocking with preferred species can be met within a reasonable period by use of advance regeneration, regeneration from seed or vegetative reproduction, then there is no need to use artificial regeneration (planting or seeding).

Prescribing natural regeneration

A silviculture prescription to use natural regeneration must be based on evidence for a reasonable chance of success in meeting a stocking standard. Natural regeneration from seed requires coincidence in space and time of an adequate seed source, favorable seed bed (microsite) and suitable environment (site). These components of the 'regeneration triangle' (Figure 6) must be considered together with problems associated with:

- regeneration risks
- species mix
- root form
- density control
- delayed regeneration and irregular stocking
- acceptability of advance regeneration

Careful observation of natural regeneration and successional trends can help a forester to build a great deal of local knowledge about regenerating stands. The following points may help others to follow suit:

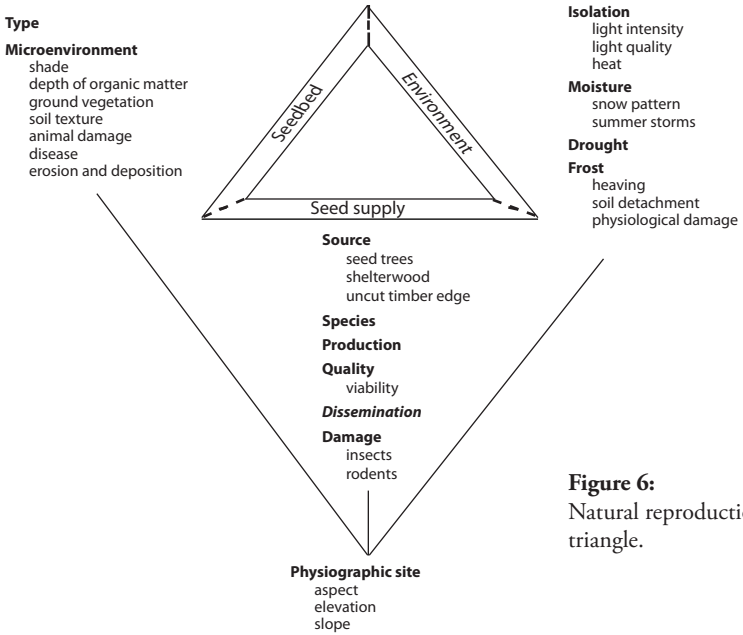


Figure 6: Natural reproduction triangle.

- Use the ecosystem approach to classify forest sites. This provides a framework for assessing the effects of climate and site on the success of alternative reproductive methods.
- Examine old cutblocks and natural disturbance for the quality and quantity of natural regeneration, the rate of ingress, and the development of advance growth.
- Note the occurrence, type, and distribution of natural regeneration in routine regeneration surveys.
- Note the influence of cutblock aspect, orientation, size, and shape on regeneration success.
- Note the occurrence and nature of regeneration on roadsides and landings. Estimate the timing following disturbance and investigate the nature and distance of the seed source. For serotinous lodgepole pine, remember that limbing of trees often occurs at roadside leading to local accumulations of cones.
- Obtain local information on the periodicity of seed crops and the relationship between the abundance of seed produced and the resultant number of seedlings (seed:seedling ratios).
- Observe how long favorable seedbed conditions last following disturbance.
- Examine old records, photos, and files and talk to people who know the history of cutting and other disturbance in the local forests. The forest survey reports produced in the 1920s and 1930s are a possible source of information and photographs.
- Compare growth and yield of natural stands and planted stands.
- Document your findings. Permanent regeneration sample plots in well-defined forest types can be invaluable and could lead to the development of a scheme for predicting regeneration.

The most efficient way to regenerate a stand is to have the regeneration already established as advanced growth before the native stand is cut. Use of advanced growth gives assurance of species composition, is cost effective, saves time by telescoping the location, and produces trees with small juvenile cores. Advanced growth of tolerant species is often present in maturing and overmature stands where canopy openings have developed. It is "natural" and thus avoids any association with an "unnatural" agricultural model of silviculture. Most stands cut today are of natural regeneration origin and have not been tended. In deciding on the acceptability of advanced growth foresters should consider whether the preferred species are present, the health, vigour and size of the advance regeneration. Smaller trees typically release better than larger trees. Trees that are growing faster in height before harvest typically show better release than slower growing trees. Regional guidelines on acceptability for free growing are available (Table 2).

If advanced regeneration is to be used in the prescription then it must be protected in the logging operation. In boreal forests, with low net revenues per hectare, long rotations and minimal silviculture budgets, the extra logging costs for advanced growth protection become a cost of silviculture. Several BC hardwoods aggressively sprout from stem bases (big leaf maple, cottonwood, birch), while aspen regenerates from root suckers. Leaving parent trees standing, or girdling them suppresses sprouting and suckering. These responses can be promoted where regeneration of these species is desired, or suppressed where these species compete with the target species.

Reproduction methods

Reproduction methods include any cultural treatments used to ensure the harvested trees are replaced rapidly by adequately stocked stands of desirable tree species. Reproduction methods are one component in a silvicultural system. A silvicultural system is a long-term program of treatments including reproduction, controlling non-crop vegetation, thinning, and harvesting.

Numerous reproduction methods have been applied to regenerate forest stands from seed, stumps sprouts, root suckers, or layering. Any given method can usually be classified under one of the six standard methods, each of which reflects distinctly different principles. The following classification is after that provided by Smith (1986). An earlier and more detailed classification can be found in Troup (1952).

Selection method: The removal of mature trees, usually the oldest and largest trees, either single or scattered individuals (single tree selection) or in small groups (group selection) from areas rarely exceeding 0.1 ha in size at relatively short intervals, repeated indefinitely. The selection method is the regeneration phase of the selection system. The selection system is applied to uneven-aged forests or even-aged forests being converted to an uneven-aged condition. Reproduction is by natural regeneration in the openings created by mature tree or group removal. Stocking in other layers is managed though thinning and spacing operations. This method can and has been misused as a rationale for "high grading" a forest for low investment, extensive silviculture.

Shelterwood method: the removal of all trees on an area to be regenerated in a series of cuttings extended over a period of years. Removal usually occurs over less than one-quarter to one-tenth of the rotation. Establishment of natural regeneration

Table 2:
Summary of current silvicultural acceptance of advanced regeneration by ecological zone.

	Advanced regeneration acceptability		
Ecological zone	**Usually acceptable**	**Sometimes acceptable**	**Rarely acceptable**
CDF		***Fdc, Bg***	
CWH		Ba, Cw	
MH		Ba, Cy, Hm	
PP	***Py, Fdi***		
IDF	Fdi	Sw	***Pl, At***
ICH		Cw, Sw, Fdi	Hw, Bl, At, Ac, Ep
MS		Sw, Fdi	Pl, At, Bl
SBS		Sw	Bl, Pl, At, Ac
ESSF		Se	Bl
SBPS		Sw	***Pl***
BWBS		At	

Species codes:

Ac – Poplar	Cy – Yellow-cedar	Hw – Western hemlock
At – Trembling aspen	Ep – Paper birch	Pl – Lodgepole pine
Ba – Amabilis fir	Fdc – Coastal Douglas-fir	Py – Yellow pine
Bg – Grand fir	Fdi – Interior Douglas-fir	Se – Engelmann spruce
Bl – Subalpine fir	Hm – Mountain hemlock	Sw – White spruce
Cw – Western redcedar		

of desirable tree species is obtained under the partial shelter of the trees remaining after each cutting. Regeneration of a mature forest stand by the shelter-wood method may involve a series of different cuts applied in sequence: preparatory cuttings that remove unwanted trees and improve the condition of the remainder; seed cuttings that create canopy openings and suitable forest floor conditions; and removal cuttings which remove the remainder of the stand when regeneration is established.

The number of cuttings required to regenerate a forest stand by the shelter-wood method depends on the species composition, abundance, and distribution of advance regeneration present beneath the stand. For example, regeneration of a dense mature stand with no advance regeneration may require a preparatory cutting, a seed cutting, and several removal cuttings. At the other extreme, regeneration of an open stand with an abundance of well-distributed advance regeneration may require only one removal cutting to complete the regeneration process. The latter type of cutting is not clearcutting. The regeneration has become established under the partial shelter and protection of the parent stand, and so is properly classified as being the final removal cutting of the shelterwood method.

Seed-tree method: the removal in a single cut of all trees on an area to be regenerated except for a small number of seed-bearing trees, usually less than 25 trees per hectare. Trees are retained either singly (single seed-tree method) or in small groups (group seed-tree method) to provide seed for the subsequent natural

regeneration of the area. Following establishment of adequate regeneration, the seed-bearing trees may be removed in a second cutting or left indefinitely.

Clearcutting method: the removal of all trees on an area in one cutting. The majority of the opening is greater than one tree length from the stand edge. Regeneration of desirable species is subsequently obtained naturally from seed disseminated over the cutting area from adjacent forest stands, from trees removed in the harvesting operation, from advanced regeneration, or artificially from planted tree seedlings or sown seed.

Coppice method: any type of cutting wherein reproduction relies primarily on vegetative regeneration (stump sprouts, root suckers).

Coppice-with-standards method: the combination of coppice method with a method that reserves a few better trees to be grown through one or more cycles of coppicing.

Retention: this is a recognized silviculture system in BC. Individual trees or groups of trees are maintained to provide structural diversity over the area of the cutblock for one rotation, and leave more than half the harvested area within one tree height from the stand edge or from reserved trees. Trees are selected for retention for their contribution to structure and habitat rather than growth potential or seed production. The biological legacy retained includes very old poorly formed trees, dead standing trees, coarse woody debris, and patches of distinctive vegetation (Mitchell and Beese, 2002). It is recognised that this system may reduce timber yields.

Choosing a reproduction method

As in the selection of species, in choosing a reproduction method, foresters should consider management objectives, site and stand conditions and the silvics of the species of interest. Candidate methods are ranked on the basis of productivity, reliability, silvicultural feasibility and contribution to non-timber objectives.

Each of the reproduction methods has potential for application in BC. Table 3 provides a summary of the methods with rankings based on these considerations under average operability where it is desirable to regenerate the same forest type. If the management objective is to alter the forest type, the appropriate regeneration method will change. If the method is unacceptable for reasons other than meeting the regeneration objective (for example, for aesthetic considerations), then the forester must accept the consequent changes in forest type. These rankings should be moderated based on operability and local experience with such factors as root disease, windthrow and snow damage.

The reproduction methods are ranked in the table as:

- R Recommended. Should regenerate productive stands similar to the pre-harvest type, silviculturally feasible, with low risk of failure.
- F Worth Considering. Will regenerate the same forest type but with lower productivity, lower reliability or greater costs than alternate methods.
- n Not Recommended. Will not regenerate same forest types, or has low productivity, reliability or very high costs compared to other methods.

In addition, Table 3 lists methods of regenerating stands that do not have old growth characteristics. Typically, this includes young natural stands that have developed after fire, or second-growth stands that have developed after clearcutting.

Table 3: Recommended regeneration methods for reestablishing forest types.

Region	Forest type	Old growth							Young natural					
		CCP	CCN	ST	SW	SE	CO	VR	CCP	CCN	ST	SW	SE	CO
Coast	Cottonwood	R	F	F	n	n	F	F	R	n	n	n	n	R
	Red alder	n	R	F	n	n	n	F	n	R	F	n	n	n
	Douglas-fir dry	R	F	F	F	F	n	F	R	F	F	F	F	n
	Douglas-fir wet	R	n	F	n	n	n	F	R	n	F	n	n	n
	Western hemlock	R	R	F	F	F	n	F	F	R	F	R	F	n
	Western redcedar/Western hemlock	R	F	F	F	F	n	F	F	R	F	F	F	n
	Sitka spruce	R	F	F	F	n	n	F	R	R	F	F	n	n
	Mountain hemlock	F	R	F	F	n	n	F	F	R	R	R	F	n
	Yellow cedar	R	F	F	n	F	n	F	R	F	F	F	F	n
	Pacific silver fir	R	F	n	F	F	n	F	R	F	n	R	F	n
S. Interior	Engelmann spruce/subalpine fir	R	F	n	F	F	n	F	F	F	n	R	F	n
	Lodgepole pine	F	R	n	n	n	n	F	F	R	n	n	n	n
	Western larch	F	F	F	F	n	n	F	F	F	F	F	n	n
	Douglas-fir – dry	n	n	n	R	F	n	F	n	n	n	R	F	n
	Douglas-fir – wet	R	F	F	n	n	n	F	R	F	F	n	n	n
	Ponderosa pine	F	F	R	F	F	n	F	F	F	R	F	F	n
	Western redcedar/western hemlock	R	F	n	n	n	n	F	F	R	n	F	F	n
N. Interior	Spruce	R	n	n	F	n	n	F	R	n	n	F	n	n
	Aspen	n	R	n	n	n	R	F	n	R	n	n	n	R
	Mixed wood	R	n	n	F	n	F	F	R	n	n	F	n	F
	Black spruce	R	n	n	n	n	n	F	R	n	n	n	n	n
	White birch	n	R	F	n	n	F	F	n	R	F	n	n	F
	Lodgepole pine	R	F	n	n	n	n	F	R	F	n	n	n	n

See key page 418

Key for Table 3

CCP	=	Clearcut method with planting	Co	=	Coppice
CCN	=	Clearcut method with natural regeneration	VR	=	Variable retention
ST	=	Seed tree method	R	=	Recommended
SW	=	Shelterwood method	n	=	Not feasible
SE	=	Selection method	F	=	Feasible

In such stands, the lack of deadwood accumulations, reduced volume of standing unmerchantable materials, and lower insect and disease risks allow the forester more choice in selecting prescriptions for developing the future stand.

Prescribing artificial regeneration

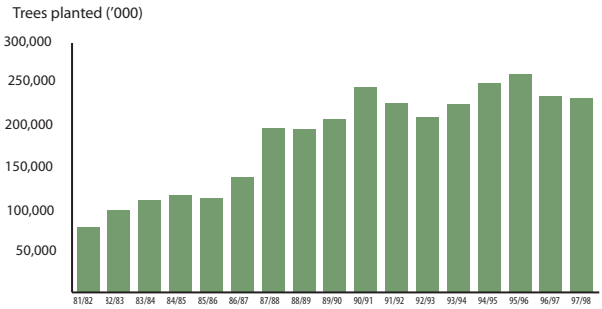
If it is unlikely that target stocking with preferred species can be met within a reasonable period by use of advanced regeneration, regeneration from seed or vegetative reproduction, then artificial regeneration (planting or seeding) should be used.

Direct seeding has been little used in BC due to low establishment rates and lack of available cheap seed in quantity. It has been used in other provinces with jack pine and black spruce.

Most cutblocks are prescribed for planting due to the need for prompt restocking with controlled densities and species compaction. Not only are the liabilities for reaching free-growing or green-up reduced, but also rapid achievement of green up may increase allowable cuts in spruce management units. In the 1990s the number of trees planted was about 200 million per year (Figure 7). The total area planted annually is about 200,000 ha on crown and private land. The history of planting in BC goes back to the 1930s (Figure 8). The first major plantation (7,000 ha) was on the Sayward fire at Campbell River. In the early 1970s nurseries began producing container stock grown in cavities in styrofoam blocks. Experimentation with cavity size and density, sowing and lifting dates, and temperature, light, irrigation, fertilization, regimes has enabled container nurseries to produce very large vigorous stock in a single growing season. This, in combination with better stock handling and quality control during planting has lead to steady increases in first year plantation survival throughout the 1980s. Current first year survival rates exceed 90%. The species planted in 1996/97 are given in Table 4.

In BC stock types are named in a standardized format (BC Ministry of Forests, 1998). While the general trend for the past 20 years has been towards larger stock, there are a wide variety of stock types available. In deciding which stock to prescribe, foresters should choose seedlings with a morphology (height, root:shoot ratio, height:diameter ratio, lateral branch development, succulence) that will enable the seedlings to rapidly acclimate to growth limiting conditions on the site. It is also important to schedule planting for a season (spring, summer, fall) during which the stock will be in a condition to best tolerate stresses and rapidly establish.

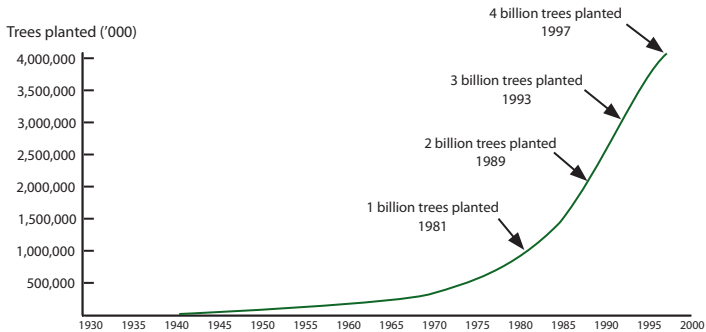
Because of the slash loadings and generally rough ground conditions, and the need for careful microsite selection, planting has not been mechanized in BC. It is all done by hand by silviculture contractors with a seasonal work force working on piece rate. Foresters must work with the contractors to ensure correct stock handling and planting procedures. Stresses to stock during the 'handling chain' from the nursery to the planting hole are cumulative. For spring planting windows, stock is dormant



Data source: MoF annual reports.

Trees planted yearly reached an all-time high in 1995 with 250 million trees. Planting is anticipated to continue to decline as the backlog of not satisfactorily restocked (NSR) land is regenerated.

Figure 7: Number of seedlings planted on BC Crown land (1981-1998).



Data source: Forest Practices Branch.

Figure 8: Cumulative number of trees planted on BC Crown lands (1930-2000).

and has been frozen-stored. Stock is rapidly thawed and shipped to the planting site in sealed boxes. If interim storage is necessary, the stock should be kept cool in sealed boxes until planting. For summer and fall planting windows, the stock has set bud but is still actively photosynthesizing, adding radial increment and growing roots. This stock is hot-lifted in the nursery and shipped directly to the planting site for immediate planting. If a short period of interim storage is necessary, the boxes should be opened under suspended tarps in a cool location, as the seedlings require light and may need watering. Target spacing, spacing tolerances and acceptable microsites are prescribed by the forester to reflect site and target stand conditions. Typical planting faults include incorrect spacing, poor microsite selection, and poor root placement. Site preparation can improve plantability and make it easier for inexperienced planters to maintain quality and production. On some sites, the reduction in planting cost covers the cost of mechanical site preparation.

Details of nursery stock and a directory of nurseries can be seen at www.for.gov.bc.ca/nursery.

Table 4: Trees planted yearly ('000 seedlings) on Crown land by species.

Species	Year 96/97
Alder, red or Sitka	
Birch, paper	5
Cedar, western red	10,397
Cedar, yellow	2,078
Cottonwood, black	84
Douglas-fir	14,017
Fir, subalpine	2,525
Fir, amabilis	4,147
Fir, grand	122
Fir, noble	40
Hardwoods	33
Hemlock, mountain	245
Hemlock, western	7,877
Larch, Siberian	49
Larch, western	3,883
Pine, lodgepole	97,513
Pine, western white	220
Pine, yellow	995
Spruce, Engelmann	8
Spruce, Engelmann and white	
Spruce, Norway	11
Spruce, Sitka	1581
Spruce, hybrid	92,431
Spruce, white	189
Tamarack	
Yew, western	
Willow	
Other	30
Totals	**238,480**

Acquisition of seed

Seed crop production in BC conifers varies from year to year depending on species, weather, site quality and tree vigor, with 3-10 years between medium or better seed crops. Seeds mature in late summer. For most BC conifers, the seeds are immediately released on maturity and are viable only for the first year after release. In locations where wildfires were frequent, lodgepole pine is serotinous, meaning that the cones remain closed and the seed viable until the cone is exposed to high temperatures (60°C). The variation in serotiny observed in lodgepole pine from different locations is a good example of how local populations of trees (provenances) have adapted to local climate and disturbance processes. It is very important for foresters to use seed

that is well adapted to local site conditions. For this reason there has been extensive provenance testing and seed transfer guidelines limit the latitudinal, longitudinal and elevational distances that seed can be planted from site of origin.

The BC government is concerned that seed used for reforestation is locally adapted, comes from high quality parents and is genetically diverse. Seed orchards have been established in BC for commercially important conifer species to produce quantities of seed from parents selected through breeding for desired qualities such as enhanced growth potential, frost tolerance, insect or disease resistance, or better wood quality. Procedures are in place to ensure that local adaptations are maintained and that genetic diversity is maintained. At the time of writing, approximately 40% of seed for reforestation in BC is obtained from seed orchards.

Licensees are required to use seed orchard seed (Class A) in preference to seed collected from wild stands (Class B) if it is available and is suitable for the reforestation site. Prior to planning a collection of seed from wild stands, foresters should do a 'seed need calculation'. They should consider: the hectares planned for harvest over the next 10 years within a given seed planning zone and range; the planned stocking (stems/ha); the seedlings potentially available from seed in storage; and the seedlings that can be produced per hectoliter of cones for the species of interest.

Cone crop assessment, monitoring and collection is a specialized task and one increasingly done by experienced contractors. Collectable crops are typically identified during early-summer and a cone collection permit from the BCMOF is applied for in preparation for a late summer collection, just prior to maturity. The choice of collection method depends on the species (size of cone, location of cones in the crown, number of cones per tree), the size of the cone crop, the size of the collection, and access. Cones for most species are collected from standing trees using helicopter borne cone rakes or clippers. Serotinous lodgepole pine cones are often collected from felled trees during winter logging operations. Information on cone collection methods and procedures can be found in Portlock (1996).

During cone collection, cones are sampled and checked for maturity and for disease or insect infestations. Cones are separated from branches and other debris and placed in partially-filled burlap sacks. It is critically important to know the origin of seed, so the sacks are labeled inside and out with the seedlot number. For most species, seed is stored for several weeks on racks in a cool, dry, well-ventilated location with rodent screens prior to shipping to the Tree Seed Centre for processing. This interim storage allows seed maturation to continue and enables the Tree Seed Centre to prioritize seedlots for processing.

Cone and seed processing is the operation of removing seed from the cones and obtaining viable seed. It usually includes removing seed wings, eliminating debris, and separating empty non-viable seeds from those that have developed, are mature, and have potential to grow. A representative sample of each new seedlot is tested to determine purity, moisture content, seed weight, and germination rate and potential. To monitor viability – the number of seeds that will grow – germination tests for each seedlot are repeated periodically. This information is used to predict how much seed will be needed to produce the number of seedlings required for a planting project.

Tree seed is stored in secure vaults at –18° C until it is required for the reforestation

program. Processed seed can be stored for up to 30 years or more. Seed is withdrawn from storage in time to meet the sowing (seeding) dates of each nursery that will provide the seedlings requested by foresters. In most cases, the seeds are soaked in water, surface-dried and then stratified (exposed to cold temperatures to overcome dormancy and induce rapid germination) prior to shipment.

Through ongoing experimentation, the Tree Seed Centre has customized processing and seed treatment regimes for different species and provenances. Cone-processing reports are distributed to all seed collection agencies. These reports provide cone collection staff in the field with detailed extraction and test results and recommendations for improving seed quality.

Seedlot tracking

Tree seed is tracked from its collection site to its planting sites. A cone collection permit, issued by a district office, is required to collect cones, seed and cuttings from provincial forests. Tree seed orchards and stoolbeds, designed to produce seed or cuttings for a specified seed planning zone and elevation band, are licensed by the Tree Improvement Branch (TIB). Seed and vegetative lot information (source, genetic quality, etc.) is verified at registration and entered into the Seed Planning and Registry System (SPAR). All registered seedlots, are identified by a unique number and are tested and stored at the Ministry's Tree Seed Centre. Foresters use SPAR to select appropriate seed for sowing and subsequent planting. Regulatory requirements, such as seed transfer guidelines and use of the best genetic quality, are automatically applied to each sowing request. The Tree Seed Centre prepared and ships requested seed to nurseries for seedling production. Planting information, including seedlot numbers and their planting locations, must be recorded and submitted to the ministry. Similar requirements exist for vegetative materials used in reforestation (Figure 9).

Site preparation and vegetation management

Site preparation is the modification of vegetation, slash, forest floor, or mineral soils in order to improve microsites for tree establishment, to reduce fuel loading, or to reduce pest incidence. In vegetation management, competitive relationships between crop and non-crop vegetation are modified to promote establishment of the crop. Non-crop vegetation has both positive and negative effects. Positive effects include food by wildlife and humans, improved visual quality, improved soil fertility, reduced erosion, and moderated temperatures. Negative effects include competition for light, moisture, nutrients and seedbed, snow press and whipping, and cover for browsers. In making vegetation management decisions it is important to consider both the positive and negative effects of non-crop vegetation, and to identify the maximum level of non-crop cover at which crop tree survival and growth will be satisfactory. It is important to understand the autecology (silvics) of both the crop and non-crop species and predict the response of each species to disturbance. There are three broad approaches to vegetation management: avoidance (harvesting or site-preparation), out-competition (site preparation and planting) and removal (brushing).

Site preparation and vegetation management decisions are naturally complex as they relate to processes that involve interaction of a multitude of ecological, economic and social factors. In addition to being capable of producing the desired outcome,

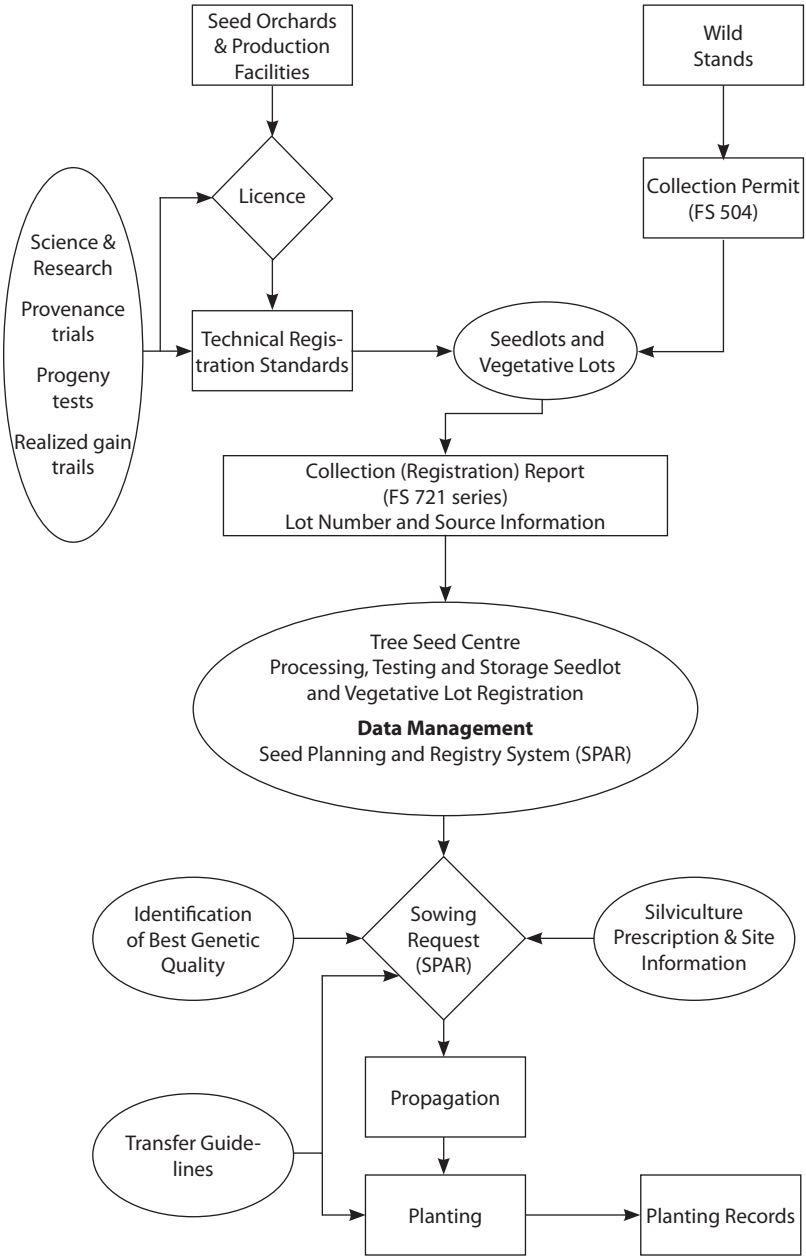


Figure 9: BC's tree seed management system.

prescribed treatments must be operationally efficient, safe, and consistent with social expectations and legal requirements. There are many aids to decision making, several of which are listed below, but there is no substitute for local observation of crop and non-crop vegetation development on a range of microsite and site conditions under differing levels of canopy removal. Systematic experimentation and observation of outcomes is at the core of good silvicultural practice.

There are three broad classes of site preparation – chemical, mechanical, and prescribed burning. Chemical treatments will be considered below under brushing.

Since the late 1980s use of prescribed fire has declined in favor of mechanical site preparation. There are a number of reasons for this including public concerns about air quality, reduction in opening sizes and increased overstory retention, and improvement in mechanical site preparation technology. There are now prime movers (skidders, crawler tractors, excavators) that can work on all but the steepest ground, and a wide variety of implements (disk trenchers, drag scarifiers, buckets, rakes, mixing heads) that can create raised, lowered or level microsites composed of mineral or mixed soil. The aim with mechanical site preparation is to improve microsite quality, but avoid damaging soil fertility through excessive removal of forest floor or compaction. This can be achieved through discontinuous or spot treatments, stratification of treatment units with different ecological or operational conditions, and careful selection of prime-movers and implements within treatment units (Coates and Haeussler, 1987).

Avoiding excessive competition through site preparation, or out-competing it through prompt planting of large, vigorous stock are the preferred vegetation management approaches. However, some vegetation communities are tenacious or establish very rapidly after disturbance. In these situations it may be necessary to use chemical, mechanical or biological techniques to reduce competition with natural or planted crop trees. While the public is generally supportive of the need for brushing, use of chemicals in forestry is very contentious, especially in broadcast applications. Chemicals or biological agents used for pest control are regulated by the Federal government. Qualities tested for include toxicity to the target organism, toxicity to non-target organisms, effects on reproduction and offspring, and breakdown in the environment. There are very few herbicides registered for use in forestry. Glyphosate (Vision) accounts for over 90% of forest herbicide use. Triclopyr and hexazinone are also used. Use of herbicides is regulated by the Provincial government. On public and private forest lands in BC, users must prepare a pest management plan and submit this for government approval. There is an opportunity for public input and appeal. Vendors and users must take training courses and obtain the appropriate provincial certification. The objective of herbicide prescriptions is to ensure delivery of the target rate to the target plants while minimizing movement of herbicide off-site. Prescriptions for herbicide use must ensure that 10 m pesticide free zones are maintained on all water bodies.

While use of chemical brushing has declined in the past decade, use of mechanical treatments has increased. Mechanical brushing treatments control competing vegetation for a shorter period, are typically more costly, cause greater damage to crop trees, and have higher rates of worker injury than chemical treatments. They are more acceptable to the general public and carry less risk of impacting water quality or non-target organisms. Girdling suppresses basal

sprouting or suckering. Cutting perennial plants just after full leaf expansion when root reserves are at their lowest reduces resprouting. However, crop tree damage is lower and worker productivity is higher after leaf drop. Equipment should be matched to the type and size of non-crop vegetation, treatment intensity and ground conditions (Haeussler and Coates, 1986; Hart and Comeau, 1992).

Stand tending

Stand tending includes stand density management, juvenile spacing (pre-commercial thinning), fertilization, commercial thinning, pruning, wood quality and stand level wildlife habitat and biodiversity needs. Objectives and decisions are incorporated into a stand management prescription that identifies all the actions needed to guide a stand from its current condition towards a future desired stand condition. On crown lands all the stand tending costs beyond achievement of free-growing status (industry cost responsibility) are currently funded by various government mechanisms. Licensees, without equity in crown timber, are traditionally reluctant to pay for stand tending unless an improvement in annual allowable cut (AAC) is foreseen. The case for increases in AAC depends on good growth and data and the ability to accurately forecast stand development.

When prompt reforestation with seed from tree improvement programs (class A seed) is used together with appropriate stand tending actions, large increases in stand timber yield and accelerated operability are possible. A further source of increase has been found in applying the correct site index to each regenerated stand. The original natural forest inventory site class designations have tended to be greatly underestimated.

Rational use of crop planning requires the ability to plan the next crop of trees, either using a computer program (e.g. TASS, TIPSY or PROGNOSIS) or stand density management diagrams (SDMDs) (usually derived from TIPSY). TASS/TIPSY and SDMDs are widely used in BC for forecasting stand development and crop plans in single species even-aged stands. These tools have been reliably back calibrated against real second stands. Mixed species and irregular and uneven-aged stands currently do not have good forestry tools.

Many management units in BC have age class structures dominated by old natural stands, with age class gaps. Harvest rates of old stands are linked to: 1) the need to continuously supply old growth into the future (in landscape units with seral stage requirements), and 2) acceleration where second growth stands can be harvested in order to better balance age classes. This latter requirement can be achieved by juvenile spacing (pre-commercial thinning, PCT) which thins out dense young stands and concentrates growth on fewer stems. In addition PCT allows for earlier commercial thinning (CT) opportunities since individual trees are larger in the stand.

Also PCT by reducing stand density, allows the use of pruning of crop trees (usually at about 10 cm dbh) to grow clearwood and thus higher timber values. Fertilization of PCT treated stands in coastal Douglas-fir and lodgepole pine stands is used to further increase stand growth rates and operability. These stand tending actions can be crop planned visually in stand density management diagrams (SDMDs).

SDMDs, based on self-thinning theory, were first used extensively in the 1990s. The rate of stand development depends on height growth. By using SDMDs in conjunction with Site Index curves, stand development trajectories can be predicted,

tending actions planned and yields forecast. The classic options for crop planning are given in Figure 10.

Application of the SDMD to determine post-thinning densities with the objective of reaching a minimum operability standard (20 cm average stand diameter) at a given age (50 years) with three different stands of SL_{50} 13, 16 and 19 (Figure 11). The high site will be thinned to 1250 stems/ha, and the medium site to 850 stems/ha. The low site cannot reach the stated objective in the given time.

Stand tending work in BC expanded in the 1990s due to better government funding, and an improved understanding of its technical effects and influence on AAC. For 97/98 49,000 ha were PCT'd, but only 6,000 ha were fertilized and 8,500 ha pruned. Fertilization of Douglas-fir uses urea at about 200 to 300 kg N/ha. Fertilization of lodgepole uses nitrogen plus sulphur plus boron at about the same N rate. Foliar analysis is used to prepare the appropriate fertilization prescriptions.

Pruning is restricted to high site index, thinned stands, mainly in Douglas-fir. Its economic viability is much debated. BC has decades of cut left in high quality conifers that originated from dense natural regeneration which have grown well beyond technical rotation ages.

Monitoring and adaptive management

Silviculture treatments are complex to apply and feedback on success and failure is

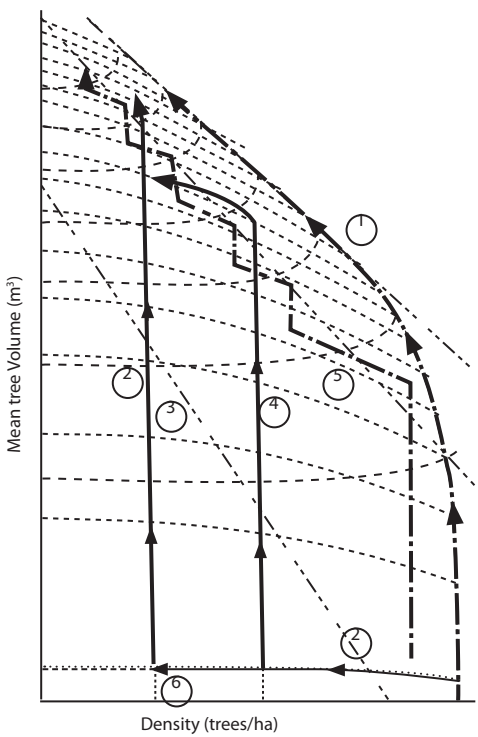


Figure 10: Classic options for forest crops that can be planned and compared on a SDMD include dense natural regeneration carried through to rotation for high total volume production at low cost (1); pre-commercial thinning of dense natural regeneration to a final crop density (2); thinning to final crop density coupled with pruning to increase product values (3); pre-commercial thinning to a density which allows for a single commercial thinning (4); and establishing moderately dense stands followed by frequent light commercial thinnings to maximize volume production (5). Establishment can also be by planting to the desired density rather than through pre-commercial thinning natural stands (6) (Farnden, 1996).

an essential part of successful implementation. Monitoring can be in the form of walkthroughs, interpretation of aerial or satellite imagery, surveys using temporary plots, or re-measurement of permanent plots. Time limits for establishment are set out in the Forest Development Plan or the Forest Stewardship Plan.

A silviculture survey is an examination of an opening for the purpose of providing information to the forest manager on how the site and stand are progressing relative to the prescribed management objectives.

The survey information may be used for prescription creation, auditing, or monitoring. It can also be used to update long-term history files for the opening and forest cover maps. Accuracy and consistency in conducting the surveys are therefore

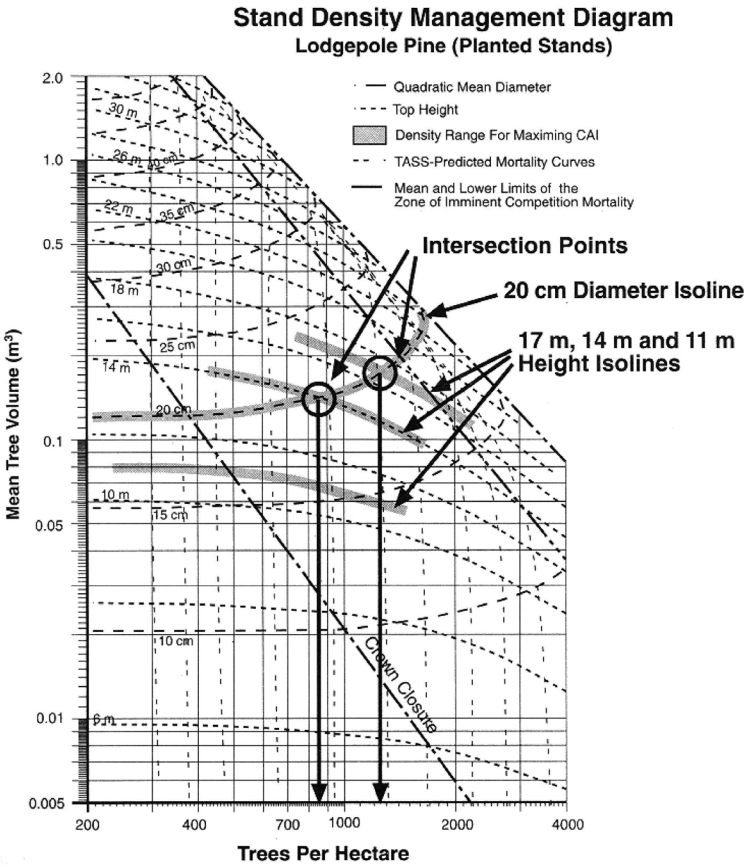


Figure 11:
Application of the SDMD to determine post-thinning densities with the objective of reaching a minimum operability standard (20 cm average stand diameter) at a given age (50 years) with three different stands of SL_{50} 13, 16 and 19. The high site will be thinned to 1250 stems/ha, and the medium site to 850 stems/ha. The low site cannot reach the stated objective in the fiven time (Farnden, 1996).

important if the information collected is to be of value. Surveys are a formal, legal requirement on Crown land.

The *Ministry of Forests Act* requires that the Ministry of Forests manage, protect, and conserve the forest resources of the Crown. The *Forest Act* and *Forest Practices Code of British Columbia Act* oblige major licensees, woodlot licensees, and the Small Business Forest Enterprise Program (SBFEP) to establish a crop of commercially valuable species on harvested areas. Standards describing what must be regenerated and the time limits for establishment of the crop are set in silviculture prescriptions. The Silviculture Surveys Guidebook provides a description of the methods used to measure the achievement of these standards.

On a per hectare basis, silviculture surveys are one of the lowest cost silviculture activities. This, however, does not mean that they are of little value. The value of the survey relates to the silviculture decisions made, which often involve species selection and treatment recommendations. Surveys costing $2 to $50 per hectare provide the information necessary to prescribe silviculture treatments costing $100 to $2,000 per hectare. Silviculture surveys assemble the baseline information required to develop and implement effective silviculture programs. They are also an essential element in the confirmation of a completed silviculture obligation.

Data collected during silviculture surveys are used to make important management decisions. The quality of the data collected can only be assured if proper procedures are followed during the organization, implementation and summarization of the survey. Following proven procedures ensures consistency between those who would assess the opening.

Assessment procedures for formal periodic surveys have been standardized in order to:

- avoid subjectivity;
- allow for comparison of performance between licensees, districts and regions;
- ensure that the survey methodology is not more onerous on one licensee, district, or region than another;
- resolve differences in interpretation of stand status.

Types of silviculture monitoring:

1. **Site preparation surveys:**
   - *Cone and seedbed survey:* to determine whether an adequate seedbed and seed source is available to achieve satisfactory regeneration.

     Cone and seedbed survey for lodgepole pine.

     A cone and seedbed survey is used to collect data to determine the need for site preparation and the best method of site preparation.

     Seedbed survey for species other than lodgepole pie: a seedbed survey is used to collect data to determine the need for, and the best method of site preparation.
   - *Site preparation survey:* there are two general types of site preparation surveys: a pre-site preparation survey and a post-site preparation survey.

Pre-site preparation survey – used to collect the information needed to determine the need for site preparation an the best method of site preparation.

Post-site preparation survey – used to assess the results of site preparation.

2. **Plantability survey** is used to determine number of plantable spots per hectare on an opening and to gather sufficient data to complete a planting description.
3. **Stocking survey** is used to determine the stocking status of an opening by describing both the preferred and acceptable well-spaced and total trees and to generate an inventory label for updating the forest cover map.
4. **Multi-story survey** is a survey method that separates a stand into components by dbh, height category, or layer. It is used to determine the stocking status of an opening by describing both the preferred and acceptable well-spaced and total trees and to generate an inventory label for updating the forest cover map.
5. **Visual assessment** is a more subjective assessment of an opening than a formal survey.
6. **Vegetation management surveys** are used to assess vegetative competition and tree condition. They are used to determine the need for, and the most appropriate type of treatment.
7. **Pest damage surveys** are used to collect data on stand damage and the agents causing it, and to allow a determination of incidence. These should be carried out as an integral part of all other survey types.
8. **Free growing surveys** are used to determine the number of preferred and acceptable, free growing trees per hectare present on an opening.
9. **Pre-stand tending surveys** are used to gather data that will aid in assessing openings for stand tending treatments.
10. **Combining surveys.** While doing the walkthrough, you may determine that another survey is required in addition to the survey being conducted to meet the original objective. For example, the surveyor was instructed to do a stocking survey yet the opening had a brush component that needed to be addressed. A stocking survey and a vegetation assessment survey should be combined.

Examples of survey combinations would be a stocking/plantability survey, site preparation/plantability survey, and multi-story stocking seedbed survey. When combining surveys, such as a stocking and a free growing survey, the objectives of each must be kept in mind as the tally procedure for each may be quite different. Combining surveys may be more cost effective and/or efficient than doing two separate surveys.

Adaptive management

Learning by doing and learning from mistakes and successes is essential in BC silviculture, when much of it is pioneering work.

Forest ecosystems are complex and dynamic. As a result, our understanding of ecosystems and our ability to predict how they will respond to management actions is limited. Together with changing social values, these knowledge gaps lead

to uncertainty over how best to manage British Columbia's forests. Despite these uncertainties, forest managers must make decisions and implement plans. Adaptive management is a way for forest managers to proceed responsibly in the face of such uncertainty. It provides a sound alternative to either "charging ahead blindly" or "being paralyzed by indecision", both of which can foreclose management options, and have social, economic and ecological impacts.

Adaptive management is a systematic process for continually improving management policies and practices by learning from the outcomes of operational programs. Its most effective form – "active" adaptive management – employs management programs that are designed to experimentally compare selected policies or practices, by evaluating alternative hypotheses about the system being managed.

We often portray the adaptive management process as a six-step cycle, and emphasize that successful adaptive management requires managers to complete all six steps. Assess problem, design, implement, monitor, evaluate and adjust. Some of the differentiating characteristics of adaptive management are:

1. Acknowledgement of uncertainty about what policy or practice is "best" for the particular management issue.
2. Thoughtful selection of the policies or practices to be applied (the assessment and design stages of the cycle).
3. Careful implementation of a plan of action designed to reveal the critical knowledge that is currently lacking.
4. Monitoring of key response indicators.
5. Analysis of the management outcomes in consideration of the original objectives, and
6. Incorporation of the results into future decisions.

Silviculture Research

Well designed replicated experiments enable testing of hypotheses about treatment outcomes and provide the data necessary for forecasting future forest conditions. The BCMOF and licensees have established protocols for plot establishment, documentation and re-measurement. For further information on PROBE and EXPLORE refer to Simard *et al.* (2001).

Learning about silviculture

Besides the web based information there is the need for networking, seeing how silviculture is practiced and keeping up-to-date. British Columbia has three regional silviculture committees: the Coastal, Northern and Southern Interior. Each has indoor winter meetings and summer 2-day field tours, each with its own web page. In addition, FORREX, the BC forest extension network produces mainly publications on silviculture and links research and practice. The Forest Management Institute of BC (FMIBC) started in 1995 offered six 2-week Modules of Advanced Silviculture Education for RPFs, leading to a UBC Diploma. There are many other additional short courses. In addition the 300 BC silviculture contractors are represented by the Western Silviculture Contractors Association. "Canadian Silviculture" is a trade magazine for silviculture.

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FOREST ECOLOGY
The Ecological Stage, the Ecological Play, and the Ecological Actors in Forest Ecosystems

by

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FOREST ECOLOGY

Introduction

Forest ecology is the study of forest ecosystems at both the stand and landscape scale – ecosystems in which ecological processes are dominated by trees. But forests are much more more than just trees. Tree dominated landscapes include aquatic as well as terrestrial ecosystems, both of which are complex systems of linked and interacting physical and biological components and processes. It is these systems that are the focus of forest ecology.

The world's population doubled between 1960 and 2000 – an increase of three billion. Fortunately, the rate of human population growth is slowing, but it is still expected that this century will see another three to four billion people adding to the pressure that our species is putting on the planet's forests and other resources (Lutz *et al.* 2001; UN, 2001a,b; IIASA, 2002). Even after the population has peaked and possibly declined somewhat, pressure on the world's forests and forest resources is expected to continue to increase for a considerable period of time as per capita standard of living rises. It is therefore imperative that humans establish a more sustainable relationship to their environment and its resources now, before more damage is done to the forests and the supply of forest-related values in areas where the population increase continues.

The biophysical issues of ecosystem sustainability, productivity, biodiversity, carbon budgets, and the overarching issue of climate change have dominated the discussion about the environment for the past decade. However, resolution of the present conflict between the human species and the global environment is fundamentally a political and social rather than a natural science issue. While it is unlikely that we will find a sustainable solution without a sound ecological foundation for the evolution of policy and practice, as much or more work is needed on the social, cultural, economic and political aspects of our environmental problems, without which all the natural science in the world will not achieve our objectives (e.g. Lugo, 1995). The review of some of the key concepts of forest ecology in this chapter is made in the context of contributing to this ecological foundation.

This chapter examines forest ecology in terms of the metaphor of ecological theatre. This enables one to consider the three key dimensions of forest ecosystems that are important from both a conservation and a management (stewardship) perspective: ecological diversity (the ecological stage, set by the climate, topography, geology, soil and physical disturbance factors), temporal diversity (the ecological play, representing ecosystem disturbance and the ecosystem process of post-disturbance recovery and development), and biological diversity (the ecological actors, determined by the ecological stage and the ecological play – ecosystem disturbance and recovery). The full detail of forest ecology cannot be addressed in a single chapter, and the reader interested in pursuing the topic could see Kimmins (1997a; 2004).

Philosophical Foundations

Henry David Thoreau, widely considered the progenitor of the modern wilderness and nature conservation movement, was fascinated by nature's wildness (Botkin 2001). While he was a great admirer of civilization and its cultural, scientific and technological achievements, he recognized the important spiritual counterbalance of unmanaged nature: "*In wildness is the preservation of the world*."

However, he was also fascinated by the discrepancy between the romantic, mystical and unrealistic view of nature held by the society of his time, and the reality that he experienced when he penetrated into unmanaged and unroaded forest and mountain landscapes. He asserted an abiding truth: *that the best way to understand nature is first hand field experience*. The debate over forests, forestry and other environmental issues has been conducted far too much by individuals lacking field experience and knowledge of the ecosystems and organisms in question, and at locations physically remote from these ecosystems – lecture halls, the courts and the media at urban locations far removed from the objects of debate.

Aldo Leopold provided the key philosophical underpinnings for developing an ethical foundation for conservation and forest management. A forester, farmer, hunter and fisherman, but foremost a conservationist and philosopher, Leopold's Land Ethic and other essays published with his Sand County Almanac should be required reading for all those working in resource management and conservation (Leopold, 1966).

"*To keep every cog and wheel is the first precaution of intelligent tinkering*."

Widely interpreted in the environmental debate as implying constant species lists and no-change forestry at a stand level, Leopold was in fact referring to metapopulations: a landscape-level concept not yet developed in his time that recognizes the role of temporary, local extirpation of species as an important component of the long-term stability of regional populations of some species, rather than to stand level species richness and structure. Elsewhere in his writing in the late 1940s he rejects the fallacious "balance of nature" interpretation of Victorian times that implies that nature is stable and, therefore, that change is anti-nature (Leopold, 1966).

"*The image commonly employed in conservation education is 'the balance of nature.' For reasons too lengthy to detail here, this figure of speech fails to describe accurately what little we know of the land mechanism*."

He understood that ecosystems contain certain levels of functional redundancy (Perry and Amaranthus, 1997; Walker, 1992), that nature is constantly undergoing stand level changes in structure and species composition, and that this change is part of, and necessary for, "healthy" ecosystem functioning (Pickett and White, 1985; Attiwill, 1994a;b; Rogers, 1996; Bengston *et al.* 2000).

Leopold's quote: "*A thing is right when it tends to preserve the integrity, stability and beauty of the biotic community. It is wrong when it tends otherwise*." has been wrongly interpreted in terms of "balance of nature" and human aesthetic beauty. Elsewhere in his writing is the explicit reference to change as part of stability, integrity as being the maintenance of a natural range of variation in ecological processes, and beauty as being the functional beauty – the interactions and interdependence between the different components – of the ecosystem. He

supported this interpretation of the above sentence on the very next page of Land Ethic (Leopold, 1966) where he says: "*The evolution of a land ethic is an intellectual as well as emotional process. Conservation is paved with good intentions which prove to be futile, or even dangerous, because they are devoid of critical understanding either of the land, or of economic land use.*"

Daniel Botkin, a contemporary thinker and writer on the subject of conservation, and a student of Thoreau's writings (Botkin, 2001), noted the ineffectiveness of all paradigms of nature that do not directly respect nature's spatial and temporal diversity. The "perfect Swiss watch" analogy, in which it is assumed that the system will fail and collapse if a single "cog" is removed, is simply not an accurate reflection of the way ecosystems function (Botkin, 1990). Echoing the ideas of Thoreau and Leopold, he noted that the only way to understand nature is to study it directly in the field, and not theorize about it from some remote location.

Successful management must be based on a respect for nature as it is, not as we romantically might wish it to be (Kimmins, 2000). "Respect" has two groups of meanings:

1. to honor, revere and be deferential towards, and
2. to notice with attention; to pay due regard to, the object of respect.

The first interpretation provides a basis for developing the objectives of management – what are the values that are to be sustained in the ecosystem. The second asserts that in order to be successful in sustaining these values, we must understand ecosystems and their spatial and temporal diversity, and develop site-specific and value-specific management strategies based on this understanding.

Sustainable forest management must start with a set of management objectives for a defined forest area. These objectives must reflect a balance between what society would like, what is ecologically possible and sustainable, and maintenance of ecosystems within the socially acceptable portion of the historical natural range of variation. Humans are unique amongst the mammals in the degree to which we depend on our visual senses, the degree to which we make decisions from our heart rather than our head (decisions based as much on our emotions, values and ethics as on our logical analysis or instincts), and our dislike of environmental and aesthetic change, although we do not really know whether other species dislike change as much as we seem to, other than when it denies them security, thermal protection and resources. Because of these attributes, many in society equate aesthetically pleasing forestry that produces little short-term visual change and satisfies our emotions with "good stewardship", "ethical forestry" and sustainability (Kimmins, 1999; 2000b).

Unfortunately, visual evidence and lack of change are not always a reliable guide to the sustainability and ecological consequences of forestry. As a result, forestry should be based on a balance between aesthetics and emotion-based judgments, and an objective analysis of the ecology and sociology of the values that are to be sustained (papers in Sheppard and Harshaw, 2001).

Definitions: Forest and ecosystem

Forest ecology is about forest ecosystems. Confusion sometimes arises in discussions about forests because of the lack of a common understanding of terminology. It is therefore useful to commence such discussions with a clarification of how particular

technical terms are being used.

A *forest* is a terrestrial ecosystem in which the ecological processes, the physical and chemical conditions, and the availability of plant, microbial and animal habitats are determined by the dominance of the system by trees. A forest may refer to a stand-level ecosystem (e.g. 1 – 100 ha), or to a local (e.g. 100 – 1,000 ha) or regional landscape (e.g. 1,000 – 100,000 ha or more). Forested landscapes can, and generally do, contain aquatic and terrestrial areas that are not occupied by trees, but the overall ecological, hydrological and biological character of the landscape still reflects the dominant role of trees.

A *terrestrial ecosystem* is any land dominated system of biological and physical components and processes of energy and material exchange that exhibits the following five attributes:

1. *Structure* – plants, animals and microbes organized in particular horizontal and vertical patterns, and associated with particular substrate (soil) and atmospheric (climatic) conditions.
2. *Function* – plant biomass creation and storage based on photosynthesis; energy transfers through food webs in the form of high energy organic molecules; nutrient circulation from soil to plants and back to soil, either directly or associated with animal and microbial energy transfers; and control of micro-climate and of hydrological cycles, regimens and water quality
3. *Interconnectedness* – the components of ecosystems are highly interconnected through a wide variety of ecosystem, population and community processes.
4. *Complexity* – the variety of structures, functions and interactions creates characteristic levels of ecological and biological diversity. This complexity includes characteristic levels of functional redundancy that enables ecosystems to function normally while undergoing change that periodically removes or adds individual species and structures. The high degree of structural and functional complexity and the complexity of the interactions make accurate prediction of the change in ecosystems over time, and their response to disturbance, difficulty in the absence of an adequate understanding of ecosystem-level ecology.
5. *Change over time* – ecosystems are not static entities and they are not analogous to human-created engineering systems such as mechanical watches or moon rockets. These engineering systems may fail if individual pieces are removed and their structure and component parts change, unless functional redundancy has been designed into the system. Ecosystems are continually changing as a result of "natural" (non-human[1]) and human-caused disturbance (allogenic and biogenic processes) and the processes of post-disturbance ecosystem recovery (autogenic processes).

Aquatic ecosystems share similar attributes, but have structural, functional and temporal differences from terrestrial ecosystems, depending on the type of aquatic ecosystem involved. Large lake ecosystems have considerable differences from forest ecosystems, whereas first order forest streams share more in common with their terrestrial counterparts.

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[1] Humans are part of nature, but I have followed the convention here of "natural change" being a reference to non- human processes (see Peterken 1996 for a useful discussion of "natural").

Important Diversities in Forest Ecosystems: The Metaphor of Ecological Theatre

"Diversity" has become a scientifically important and politically correct concept in forestry and conservation, as well as in other aspects of society. But what is it? Use of the "ecological theatre" metaphor can provide a useful conceptual framework for considering diversity in forest ecosystems.

Ecological diversity – the ecological stage

A particular theatrical stage with its lighting and sets will determine which play, and therefore which actors, can be expected. The ecological stage is determined by the regional and local climate, by the geology, soil and topography, and by the characteristic regimes of physical disturbance such as wind, fire, snow, flood and landslide or avalanche. These physical factors determine both the frequency and severity of physical ecosystem disturbance and change (allogenic succession), and contribute to the determination of the rate of ecosystem recovery from disturbance (autogenic succession). They determine which species (ecological actors) can "perform" on the stage and thus which "ecological play" (disturbance – recovery successional sequences) will occur.

Ecological diversity determines to a great extent the spatial (especially landscape-level) diversity of forests – how they vary from place to place.

Biological diversity – the ecological actors in the ecological play

Within the ecological framework set by ecological diversity, the various measures of biological diversity are determined in part by the type, severity, frequency and scale of physical and/or biological disturbance to the ecosystem. Disturbance is defined here as: *any allogenic or biogenic factor or event that alters the rate, pattern and pathway of ecosystem change that is expected to result from the autogenic succession processes operating in the ecosystem in question.*

Disturbance removes or alters population levels of individual species depending on their genetically controlled tolerances and requirements. It affects the population and community processes that collectively determine which species arrive and colonize a disturbed area, which species subsequently invade and displace these early biotic communities, and which species will be able to resist further invasion and create at least temporarily self-replacing communities. It is the post-disturbance sequence of biotic communities that constitutes the "ecological play", which in ecological terminology is called autogenic succession.

There are many measures of biological diversity, and each of these can be evaluated at several (traditionally, three) different spatial scales: local stand level (alpha), local landscape level (beta), and regional landscape level (gamma) (Table 1). Beta diversity is the variation in alpha diversity measures between stands in the local landscape due to differences in soil and disturbance history. Gamma diversity is the variation in alpha and beta diversity measures along climatic gradients across a region.

Table 1: Temporal diversity: diversity in the measures of biodiversity over time at three spatial scales alpha (α), beta (β), gamma (γ).

	TIME											
	t 1			t 2			t 3			t 4.....>		
	Spatial Scale											
	α	β	γ	α	β	γ	α	β	γ	α	β	γ
Measures												
Genetic	*	*	*	*	*	*	*	*	*	*	*	*……>
Taxonomic	*	*	*	*	*	*	*	*	*	*	*	* ……>
Species	*	*	*	*	*	*	*	*	*	*	*	* ……>
Structural	*	*	*	*	*	*	*	*	*	*	*	* ……>
Functional	*	*	*	*	*	*	*	*	*	*	*	* ……>
Temporal	*	*	*	*	*	*	*	*	*	*	*	* ……>

Genetic diversity is within-population and within-species variation in genetic make up.

Taxonomic diversity is the diversity of species, genera, families and other taxonomic levels

Species diversity includes both species richness – the number of species – and species evenness – the relative abundance of the different species in the ecosystem in question.

Structural diversity includes plant life forms, canopy layers, snags (standing dead trees), and decaying logs on the ground.

Functional diversity includes plant adaptations to light, temperature, moisture, seasonality, soil fertility, fire and wind; animal and microbial adaptations to food (energy), nutrition, and the factors of the physical environment. Diversity in energy and carbon capture, storage and release. Diversity in nutrient cycling and biogeochemistry, in water balance and hydrology.

Temporal diversity is the change in all the other measures of diversity over time as a consequence of ecosystem disturbance and post-disturbance ecosystem development due to autogenic successional processes.

All these and other measures can be assessed at the three spatial scales: stand (alpha - α), local landscape (beta - β), and regional landscape (gamma - γ).

Temporal diversity – changes in the ecological actors (the species list), the community structure, and the physical/chemical conditions in the ecosystem over the course of the ecological play

The levels of all the measures of biodiversity change over time. This temporal diversity is most obvious at the stand or alpha level, but can also be seen as a shifting mosaic of changing ecosystem conditions and characteristics at the local (beta level) and regional (gamma level) landscape scales. Temporal diversity is linked to the concept of stability. Stability at the stand level is non-declining patterns of change, which involves a balance between the frequency and severity of ecosystem change

and the resilience of the ecosystem – its rate of recovery. At the beta and gamma levels stability is a shifting mosaic of changing stand level conditions. At the gamma level the overall character of the mosaic may be relatively constant, whereas at the beta level it may change over time if the forest is subject to periodic large-scale disturbance. Accompanying the change in the structure and function of the biotic community over time there is change in the soil and microclimatic conditions.

Temporal diversity is the inevitable consequence of "natural" and human-caused disturbance that changes ecosystem processes, structure and composition, and the return of these attributes towards pre-disturbance conditions or some new condition due to the ecosystem (autogenic) process of succession. At the stand (alpha) level, temporal diversity following disturbance is driven by autogenic succession (see discussion of succession below); it is the series of seral stages following disturbance. At the beta and gamma levels it reflects the regime of ecosystem disturbance (the frequency, type, severity, spatial scale and landscape pattern) interacting with rates of autogenic succession.

Accompanying the changes in biodiversity measures over time, there are changes in soil, microclimate and hydrological attributes and processes. The complexity of biodiversity is explored in Bunnell and Huggard (1999) and Bunnell (2002).

Ecosystem Attributes

Structure

Forest ecosystems exhibit a variety of structural characteristics of which the mass and spatial arrangement of live and dead plant biomass are the most important. They determine habitat for forest animals and microbes, and affect soil and hydrological processes. The vertical and horizontal variability in plant structure is a major component and determinant of biological diversity. Multiple plant canopy levels (trees, shrubs, herbs, bryophytes, epiphytes and climbers), the diversity of sizes of standing dead trees (snags) and decomposing logs on the ground (coarse woody debris or CWD), and the horizontal variation (the spatial variability) in vertical live plant structure, snags and CWD are the major components of forest community structure.

Other components of structure are the soil and the animal and microbial communities. While not strictly speaking "structure", microclimate has traditionally been considered to be part of the structural ecosystem attribute. However, the creation of microclimate can be considered a functional aspect of forest ecosystems.

Function

The creation of biomass by plants is the single most important functional process in terrestrial ecosystems. It creates the energy (food) supply that drives most animal and microbial populations, and is the dominant foundation for biotic community food webs. Plant biomass also creates habitat for animals and microbes, and produces acids and other chemicals that are important in geological weathering and soil development, and thus in nutrient cycling.

Because the creation of plant biomass requires nutrients, a major function of ecosystems is regulation of the inputs of nutrient chemicals into ecosystems, the mobilization of unavailable nutrient and other elements from inorganic and organic

sources within the ecosystem, and the circulation, concentration and retention of nutrients within the ecosystem.

A third important function of terrestrial ecosystems is the regulation of the hydrological cycle. Precipitation inputs to forests are largely determined by air mass movements and seasonal variations in temperature interacting with topographic features, and by systems of variation in atmospheric pressure. Plant biomass generally plays a modest role, although effects such as fog drip and snow accumulation can be significant in some forests. In contrast, trees play a major role in regulating the loss of water back to the atmosphere (canopy interception loss, evaporation, transpiration), in the regulation of snowmelt, surface runoff, infiltration into soil, water storage in and movement through the soil, and the quantity, quality and regimen of water moving out of the terrestrial ecosystem into aquatic ecosystems.

In forest ecosystems the creation of an organic forest floor, the maintenance of mineral soil organic matter and mineral soil structure, and the creation of root channels that allow for rapid conduction of water from the soil surface to groundwater are important contributions to forest hydrology and the character of associated water bodies. The production of CWD that limits surface runoff on slopes and creates and sustains stream habitat diversity is another important role of the forest.

Closely associated with the role of plant biomass in hydrological regulation, the creation of microclimates as a plant-mediated modification of local climate is a major functional role of ecosystems.

Interactions between ecosystem components

A key attribute of any system is the interactions between its structural components and functional processes. An assemblage of soil, plants, animals and microbes that are not interacting, if this were possible, is not an ecosystem. Only when these structural components are arranged in a way that they interact to function in biomass creation, energy flow, material exchanges, hydrological control and microclimatic regulation do they constitute an ecosystem. There is a wide range of interactions, from the association of soil fungi with the tree roots that is critical in tree nutrition and access to soil water, to interactions between minor vegetation and trees, and the action of pathogens that result in the death of individual trees and create snags and CWD.

Complexity

It is an inevitable feature of a system that has many structural components, many functional processes and a wide range of interactions, that it is difficult to predict with acceptable accuracy the characteristics and change over time of such a system unless one has a sound knowledge of system structure, function and interactions (Kimmins, 2004, Chapter 3). The close (but not always linear) and negative correlation between unaccounted for complexity and the ability to predict future states of a system gives to complex forest ecosystems an apparent stochasticity (randomness) and unpredictability when knowledge of the system is incomplete, which it generally is. This contributes to the belief by some that forest ecosystems behave chaotically, cannot be predicted and therefore cannot be managed, a

belief that reflects the lack of knowledge of ecosystems and their structures and processes on the part of such believers more than any fundamental characteristic of a forest ecosystem. However, complexity in the face of incomplete knowledge and understanding certainly renders the management of forest ecosystems to achieve particular objectives difficult.

Change over time

Ecosystems are living systems. While they include important physical, inanimate structural components and processes, they are dominated by living components and biotic processes. Implicit in all living systems is change over time, and this biotic change engenders change in the physical components and processes of the ecosystem, complementing the purely abiotically induced changes.

Change in ecosystems, which is broadly referred to as ***succession***, is the result of many processes:

1. Physical processes, which produce ***allogenic*** succession, such as fire, wind, snowstorm, flood, landslide, or changes induced by climate change. These processes are controlled by forces external to the ecosystem in question and they cause ecosystem disturbance (see definition above).
2. Biotic processes, which disturb ecosystems to initiate new sequences of biotic communities and physical conditions. Such ***biogenic*** successional processes include insect and disease epidemics of native species, invasions of non-native species, and human disturbance of the forest. Biogenic succession is differentiated from autogenic succession (below) in that biogenic factors cause ecosystem disturbance (as defined above) whereas autogenic processes do not.
3. Internal ecosystem processes, referred to as ***autogenic*** succession. These are the population and community ecological processes of invasion and colonization by new species, the environmental alteration and the species exclusion (by competition or other processes) that result in a sequence of biotic communities that successively occupy and are replaced over time in a particular ecosystem. This sequence of communities is accompanied by alterations of the physical environmental conditions.

Change in ecosystems is frequently a necessary component of long-term ecosystem stability and "healthy" functioning (Pickett *et al.* 1992; Attiwill, 1994a;b; Rogers, 1996; Kimmins, 1996; 2000; 2004b; Perry and Amaranthus, 1997). Change occurs as plants establish, mature, die and are replaced by new individuals of the same or different species. As this predictable and inevitable change in plant populations and communities occurs, there is change in soils, microclimates and hydrology; in animal and microbial habitats and communities; and in the rates of ecosystem processes. The change in soils that occurs both as a result of ecosystem disturbance and during the course of autogenic succession is frequently necessary for, or beneficial to, the subsequent plant community, and therefore to the associated animals and microbes. In the absence of biotic change, parasites, predators and diseases of particular plant or animal species may build up to epidemic levels. Successions of plant, animal and microbial communities (temporal diversity) prevent this and help to maintain these relationships at levels that do not disrupt ecosystem function. As noted above, local species extirpations are often part

of the long-term stability and health of regional metapopulations.

By periodically replacing whole biotic communities, succession increases biological diversity. If the "ecological play" had only one act (i.e. seral stage), one would see few actors; with many acts, the play incorporates many actors (see Figure 2 and the discussion below). Disturbance is positively related to many measures of biodiversity if it acts to initiate new successional sequences.

Disturbance, whether allogenic or biogenic, is a key process in maintaining the productivity of many forest ecosystems, and in some types of forest is essential for their long-term persistence. The accumulation of woody material (CWD) in the forest floor and soil of a forest certainly has some habitat and hydrological benefits, but over time it can reduce the availability of nitrogen and the rate of nutrient cycling (e.g. Pastor and Post, 1986; Keenan, 1993). This is because the higher levels of lignins, tannins and other complex organic chemicals that are present in woody material, and which soil microbes are unable to decompose rapidly, reduce the rate of forest floor mineralization and nutrient circulation. This impairs tree nutrition, which reduces tree leaf area and consequently reduces tree photosynthesis and biomass creation. The lower tree leaf area allows more light to penetrate the forest canopy, increasing the growth of the understory. While this may benefit wildlife species that are dependent on herbs and shrubs, it increases competition for soil water and nutrients between trees and these other plant life forms, further reducing tree growth. Sometimes this increased competition renders the trees more susceptible to diseases, parasites and insects.

It is commonly thought that trees are the most competitive and evolutionary successful plant life form in forests. After all, trees dominate all other types of plant in closed canopy forests. However, in many cool, humid climates, shrub species belonging to the Heather family (the *Ericaceae*) or comparable southern taxa (e.g. *Ipacridaceae*) are competitively superior to trees in the long-term absence of disturbance. Because these shrubs can reproduce vegetatively by rhizomes, can tolerate low levels of nutrients, have very dense fine root systems, and may be able to reduce nitrogen availability to trees (by both competition and a process known as allelopathy), they are well adapted to rapidly colonize gaps in the forest that are created when individual trees die, and to restrict tree regeneration in these gaps. In the long-term absence of disturbance, this can gradually convert some types of closed forest into shrub-dominated woodland or even shrub heathland (Dammann, 1971; Malcolm; 1975, Messier and Kimmins, 1990; Fraser, 1993; Prescott and Weetman, 1994; Titus *et al.* 1995). Sphagnum moss may similarly take over northern forests by reducing soil temperatures and access to essential soil nutrients by the trees and/or by altering soil moisture conditions (Heilman, 1966; 1968; Banner *et al.* 1983). It is severe, stand replacing disturbance, such as fire, landslides, insect epidemics or human-induced ecosystem disturbance events that periodically tip the competition balance back in favor of trees in such ecosystems. Where such processes are operating, closed forest conditions may require periodic disturbance at some particular spatial scale, severity and frequency. The critical combination of these disturbance characteristics that will sustain particular forest conditions and attributes, including biological diversity and ecosystem function, can be identified through the concept of *ecological rotations.*[2]

[2] It should be noted that excessive frequency, severity and scale of disturbance can also result in treeless shrub or herb communities.

Forests and Sustainability: The Concept of Ecological Rotation

The concepts of sustainability and ecosystem change initially appear to be incompatible. How can a system be sustainable if it is constantly changing? The answer lies in the widely accepted concept that forest ecosystems are dynamic, and that "stability" at the stand level means a non-declining pattern of change. But how can one assess whether a particular forest ecosystem disturbance is part of a non-declining pattern, and therefore, sustainable, or is part of a directional and non-sustainable change? An answer can be found in the concept of ecological rotations (Kimmins, 1974).

An ecological rotation is the time taken for a particular ecosystem condition, structure, composition or attribute – its structure, function, interactions and complexity – to return to predisturbance levels following disturbance, or for recovery to some new, socially desired condition. Ecological rotations are defined by the severity (degree of ecosystem change) and extent (spatial scale, which influences the processes of recovery) of the disturbance, interacting with the rate of recovery of ecosystem conditions – the rate of autogenic succession. Where the recovery rate is slow, ecological rotations will be longer than where the rate is fast, for any particular severity of disturbance. Where the degree of disturbance-induced ecosystem change is high, the ecological rotation will be longer than where the change is less, for any particular rate of ecosystem recovery. If the severity of disturbance is high, stability must involve less frequent disturbance; where the severity is low, the ecosystem can be sustained in the face of frequent disturbance (Figure 1).

Ecosystem sustainability at the stand level cannot be judged by any one of: disturbance severity, disturbance scale, disturbance frequency or ecosystem resilience (rate of autogenic succession). It is only when all of these factors are considered as an interacting system of determinants that sustainability of local forest ecosystems, and thus concepts such as stewardship and ethical forestry, can be assessed. Simple visual observation of stand level ecosystem change following a disturbance provides a very unreliable basis for evaluating sustainability, biodiversity and stewardship questions. Yet most of the debate about forest stewardship is currently based on such "snapshot" (i.e. short term visual) evaluations of local (stand-level) ecosystem change, to the exclusion of a dynamic evaluation of ecosystem recovery and frequency of future disturbance events over ecologically meaningful time (multiple decades or centuries) and spatial scales (landscape as well as stand).

Definition of what severity and scale of disturbance is consistent with ecosystem function, biodiversity, social and other considerations will depend on what ecosystem conditions, functions and values are to be sustained, what type of ecosystem one is dealing with, and what the historical relationship has been between disturbance and the desired functions and values (i.e. the historical 'natural' disturbance regime) in the ecosystem in question.

In some coniferous-dominated forest ecosystems, shade intolerant, disturbance adapted, early successional deciduous hardwood tree species play a very important, though temporary, ecological role. Their deciduous nature can result in warmer soils in cold forest climates. Their litterfall is often more decomposable than coniferous litterfall, resulting in increased soil animal and bacterial activity, and greater rates

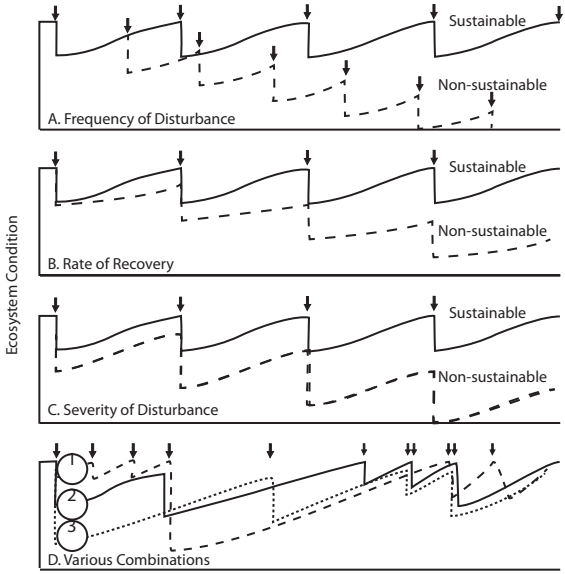

Figure 1:
The concept of ecological rotation. **A**. Effect of frequency of disturbance for a given severity of disturbance and rate of recovery. **B**. Effect of rate of recovery, for a given frequency and severity of disturbance. **C**. Effect of severity of disturbance, for a given frequency of disturbance and rate of recovery. **D**. Different combinations of severity and frequency for a given rate of recovery: 1, Three partial harvests at short intervals, followed by a very severe disturbance, a long recovery period, and two medium severity disturbances. 2, A medium severity disturbance repeated more frequency than the ecological rotation, followed by a long recovery rotation, two low severity disturbances and a final medium disturbance. 3, An initial severe disturbance, followed by two disturbances of declining severity, followed by a final moderate severity disturbance. All three combinations have returned to the same ecosystem condition. Not all ecosystem characteristics will follow the same temporal pattern, so this example is not generalizable.

of decomposition and nutrient cycling. This can improve soil structure and soil fertility, resulting in higher organic production in subsequent, conifer-dominated seral stages. Some such trees (e.g. alder and birch) establish relationships with microorganisms that can convert inert atmospheric nitrogen gas into organic nitrogen, and thus increase nitrogen availability. This acidifies the soil, causing accelerated weathering of primary soil minerals which releases other essential plant nutrients (e.g. potassium, magnesium, phosphorus, sulphur, micro-nutrients) and other chemicals (e.g. calcium) that play important roles in soil development, and nutritional roles that are either complex or not yet completely understood.

Many of these early seral deciduous species are fast growing, relatively short lived, and subject to stem decay, which creates an early supply of snags and stem cavities for cavity nesting birds and mammals. These early hardwoods may be resistant to soil fungi that decay the roots of, and kill, conifer trees, or render the conifers susceptible to wind or snow-induced mortality. Periods of ecosystem occupancy by such hardwoods induced by stand-replacing disturbance can maintain lower levels of these conifer root and stem diseases. Except during epidemics of coniferous insects, the hardwoods are often associated with higher sustained populations of insects than adjacent conifer stands, providing food for birds and for aquatic organisms as the insect larvae fall from streamside trees. Mixtures of disturbance-dependent, early seral deciduous hardwoods and later successional evergreen conifers often result in higher levels of ecosystem productivity than either group of trees alone because of ecological niche diversification. Clearly, these disturbance-related hardwoods are an important component of the landscapes where they occur, suggesting the need for appropriate severities and frequencies of management-induced ecosystem disturbance if natural disturbance events are not sustaining desired abundance of such hardwoods in the landscape.

High severities and frequencies and high spatial scales of ecosystem disturbance will maintain landscapes in early seral biotic communities to the exclusion of ecosystem structures, functions and values that are associated with late seral forests. Conversely, low severity, small-scale disturbance regimes will sustain late seral conditions and values to the exclusion of the early seral stages (Figure 2). Depending on the desired values and the relationship between ecosystem sustainability and disturbance, either of these successional extremes may be consistent with management objectives. Generally this will not be the case for reasons given above. More commonly, a shifting landscape pattern of different seral stages and ecological conditions will be needed to maintain desired diversities of values and conditions, and will permit the temporal sequences of seral stages within particular ecosystems that constitute the true "balance of nature". For many, but not all, forest ecosystems, attempts to hold the ecosystem in any one successional stage through repeated management cycles will fail to sustain desired measures of ecosystem productivity, "health", biological diversity and ecosystem function, and will fail to emulate past natural disturbance regimes and the resultant natural range of variation in ecosystem conditions. However, some unmanaged forest ecosystems exist naturally in a narrow range of seral conditions as a result of the disturbance regimes to which nature subjects them.

As a consequence, all the different silvicultural systems of forest stand management will have relevance somewhere in the diversity of forest types that exist in most forest regions (Figure 3). None of the classical silvicultural systems mimic natural disturbance precisely, largely because they *all* take tree stems away, whereas many "natural" disturbances leave much of the stem mass on site. However, 20 to 30% of the biomass of a mature tree is typically left on site following clearcutting in the form of stumps, roots, bark, branches, treetops and broken or decayed pieces of stem, and the importance of decaying root systems for the growth of the next tree crop has been demonstrated (Van Lear *et al.* 2001). Within the range of available tree management systems it is possible to identify one that will emulate a particular disturbance most closely (Figure 4). Although we have little empirical evidence on

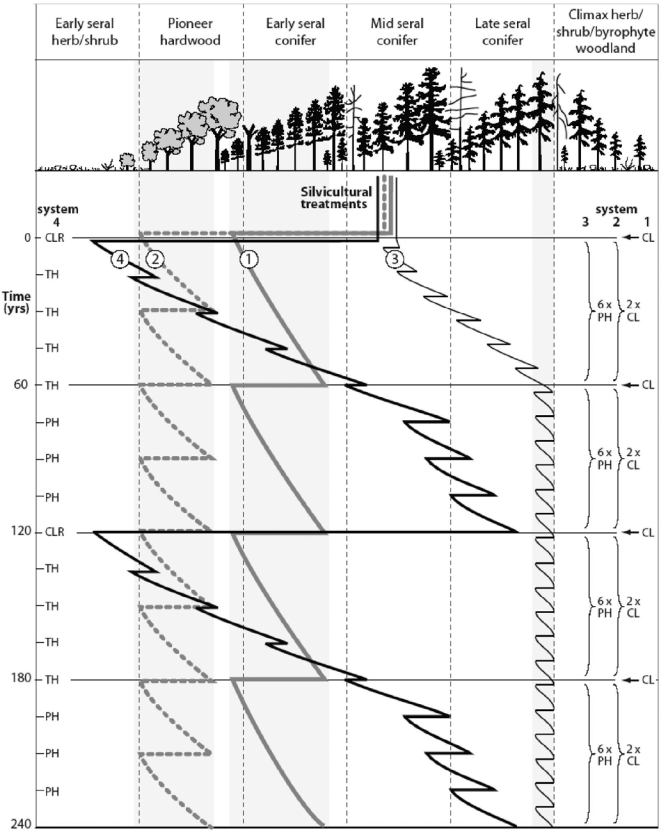

Figure 2:
Different disturbance regimes will result in different ranges of seral stages occurring in stands and across landscapes. This figure shows how different management-induced disturbance regimes affect the seral stage of the managed ecosystem. Commencing in the mid-seral stage of a hypothetical sere, the effects of four disturbance regimes are presented. Medium severities and frequencies of disturbance (line 1, representing industrial silviculture to maintain an early seral conifer stage by clearcutting and planting on a fixed 60 year rotation) will sustain a relatively narrow range of mid seral conditions. Frequently repeated small-scale disturbance (line 2, representing selection harvesting on a 10 year entry cycle) will sustain a narrow range of late seral conditions. An initial severe disturbance followed by relatively frequent disturbance (line 3, representing an initial clearcutting and slashburning or mechanical site disturbance, followed by short 30 year rotations with clearcutting) will sustain early seral communities and conditions. A temporally variable severity and frequency of disturbance (line 4, representing an initial clearcut and site disturbance, followed by pre-commercial spacing at 15 years and commercial thinning at 30, 45 and 60 years, then three selection or small patch harvests at 15 year intervals and a second clearcut at 120 years) will sustain the widest range of ecosystem conditions.

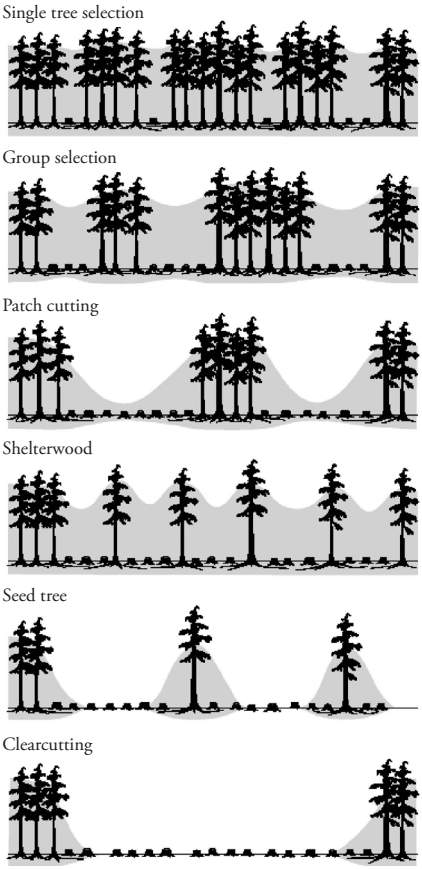

Figure 3:
Diagramatic representation of the degree of removal of "forest influence" (different severities of disturbance) associated with different classical silvicultural systems. In single tree selection there is essentially no loss of forest influence (grey shading). Clearcutting is where forest influence is lost over more than 50% of the harvested area. Variable retention (VR) silviculture (not shown, but see Figure 5) is similar to the seed tree system except there may be aggregations of retained trees as well as dispersed trees as shown for the seed tree system, and in VR the retention may be permanent. These different systems represent a gradient of removal of forest influence.

which to base the following, it would appear that employing different management-induced disturbance severities at different frequencies over time would sustain the greatest range of seral stages and the associated biological diversity (Figure 2) (Kimmins, 2004b).

Application of Forest Ecology Knowledge in Sustainable Forest Management

Ecological site classification and ecological inventories

The first step in designing forest management strategies (policies) and selecting appropriate tactics (practices) is to identify the types of forest ecosystem in the management area in question (the "ecological stages", using the ecological theatre analogy) through the process of ecosystem and site classification (e.g. the biogeoclimatic or BEC classification of British Columbia; Pojar *et al.* 1987; Meidinger and Pojar, 1991; Kimmins, 2004a, Chapter 6). Climates, soils, geology, topography and physical disturbance regimes should be identified, followed

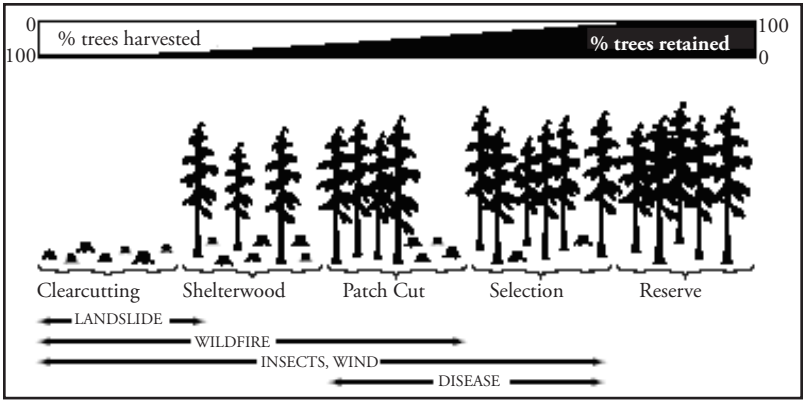

Figure 4:
Comparison between the degree of tree removal in classical silvicultural systems and the range of tree removal associated with natural disturbance. Note that most natural disturbances produce a much wider range of tree removal and ecosystem disturbance than individual silvicultural systems, suggesting the need to have temporal sequences of different silvicultural systems in any particular stand or landscape to produce the range of ecosystem conditions that result from natural disturbances. Alternatively, this diversity of disturbance can be provided in a variable retention system.

by an inventory of the biotic communities that are occupying this diversity of ecological conditions. The biotic inventory should then be understood in terms of its relationship to the physical environment, its temporal patterns of change (the successional relationships in the area in question), and the ecosystem disturbance regimes that have historically affected the area.

Having established this ecological inventory and understanding, the next step is to identify the range in values and ecosystem conditions that are ecologically possible, and which portion of this range is desired and socially acceptable. This leads to a statement of the management objectives in terms of spatial patterns and temporal sequences of change in the desired conditions and values. Having defined the objectives, combinations of management-induced and anticipated "natural" disturbance regimes are defined that are consistent with the ecology and sociology of the desired spatial and temporal forest patterns (e.g. Bergeron *et al.* 1999; Lieffers *et al.* 1996).

Determination of appropriate management-induced disturbance regime: Stand dynamics vs. succession

Where historical disturbance has occurred with a frequency that is similar to the time scale of timber production, and a spatial scale that is socially acceptable, emulation of natural disturbance may be an appropriate management paradigm (c.f. Lugo, 1995; Denslow, 1995). Where past disturbance was infrequent but large scale and severe, natural events may not be a socially acceptable template for management.

Discussions of emulation of natural disturbance have sometimes assumed that the different natural disturbance types are unique, quantifiable events that produce a characteristic and limited range of ecosystem impacts. In reality, most types of natural disturbance can result in a wide range of severity and spatial scale. Fire, wind and insects can kill virtually every tree on hundreds of thousands of hectares, from ridge tops to valley bottoms, including riparian areas. Alternatively, they may produce scattered, small-scale mortality that merely reduces stand density and within-stand competition. Any intermediate level of tree mortality is possible. Landslides tend to produce a narrower range of severity (generally high) and scale
of disturbance (generally quite small to medium). Similarly, diseases may produce only scattered patch disturbance rather than replacing entire forest stands over extensive areas, and the severity of disturbance is often quite low, unless it predisposes the area to an increased risk of fire and wind disturbance (Figure 4). This suggests that in emulating natural disturbance the full range of traditional silvicultural systems (Figure 3), modified where appropriate to retain individual trees or groups of trees (variable retention silviculture – Franklin *et al.* 1997; 2002) (Figure 5), should be employed as appropriate for the values and ecosystem types concerned, from clearcutting to individual tree selection harvesting.

Stand replacing natural or management-induced disturbance results in essentially even-aged forests. These may be single tree species (monoculture) stands because of one or more of availability of seeds, suitability of seedbeds, tolerance of the disturbance-induced microclimate, seed predation, herbivory, seedling diseases or other factors. Alternatively, they can be multi species stands. Low severity, small-scale disturbance can result in uneven-age, multi canopy

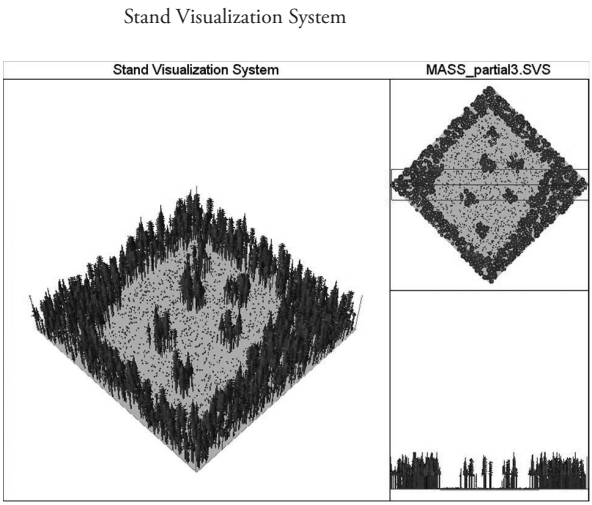

Figure 5:
Simulated variable retention silvicultural system produced by the FORECAST ecosystem management simulation model (Kimmins *et al.* 1999, Seely *et al.* 1999; Messier *et al.* 2003) and presented using the SVS stand visualization software.

layer monoculture stands of shade tolerant tree species, or mixed communities of intermediate to high shade tolerance if seed sources of this diversity of tree species are available. Post-disturbance planting can result in mixed or single species stands depending on what is planted and the natural regeneration that augments the planted trees. Planting generally results in even aged stands, but can result in uneven age stand structures if there is continuous recruitment of shade tolerant natural regeneration.

Even-aged stands, whether "natural" or produced through forest management by clearcutting, patch cutting, seed tree or shelterwood systems (Figure 3), are generally dense at early ages (a large number of trees per ha), and this density declines as the stand gets older due to competition-related stand self-thinning. This process takes the stand through four recognizable phases (Figure 6):

1. *Stand initiation,* in which populations of trees of one or more species establish following the period of competition reduction (and, frequently, soil disturbance) produced by stand replacing disturbance.
2. *Stem exclusion*, the phase following crown closure (when the canopies of individual small trees, touch, overlap, and intercept most of the incoming light) when light competition kills less competitive trees, stand density declines and the remaining trees increase in stem and canopy size.
3. *Understory re-initiation,* the phase when dying trees are large enough to leave rather persistent gaps in the canopy and the wind-induced swaying of taller trees causes branch breakage, both of which increase light penetration to the ground and permit the development of understory vegetation. This phase also facilitates the establishment of seedlings of the more shade-tolerant tree species of the next seral stage if there is a source of their seed. Thus, the understory reinitiation phase of one seral stage is also the stand initiation phase of the subsequent seral stage.

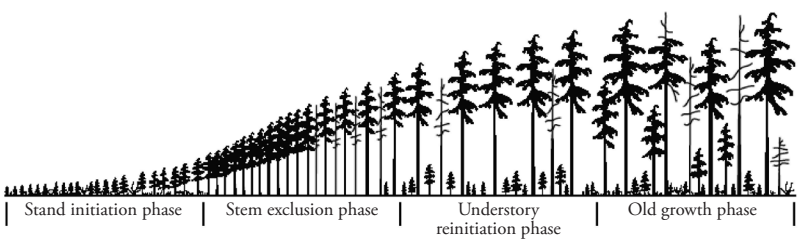

Figure 6:
The four phases of stand development (Oliver and Larson, 1990): stand initiation, stem exclusion, understory reinitiation and old growth. These four phases occur in each forest seral stage during succession. As a result, "old growth" can occur at several times during a succession, and can, therefore, vary greatly in its characteristics and persistence.

4. *Old growth*. This is the phase during which the individuals of the initial population/community of trees are approaching maximum size and longevity, experiencing physiological weakening and increased disease and/or insect damage, and exhibiting other symptoms of old age. The abundance of large snags and large CWD produced by the survivors of the initial cohort reaches its maximum for that seral stage. At this phase of the first cohort, the population of the next seral stage is developing through its stem exclusion and possibly also its understory reinitiation stages, depending on the longevity of the earlier seral species. Thus, there is a continuing overlap of the various stand development phases of the different seral stages as autogenic succession proceeds.

These four phases of stand development occur in each seral stage of ecosystem development (i.e. succession). Stand development and succession are related but different phenomena. If there is no invasion of more shade tolerant species during the understory reinitiation and old growth phases of a particular seral stage, there is no succession – only stand development. If the loss of canopy cover in the old growth phase is sufficient, and no new species invade, seedlings of the present overstory cohort may establish to produce a self-replacing seral stage, which is referred to as a climax. A useful review of both stand development and succession in Vancouver Island forests of British Columbia can be found in Trofymow and MacKinnon (1998).

One of the most interesting aspects of stand development from a wildlife, stream and fisheries perspective is the production of snags and CWD. Because the stem exclusion phase produces relatively small dead stems, it is not as useful for wildlife habitat and the development of stream diversity as the understory reinitiation and old growth phases that produce larger diameter snags and CWD. Similarly, the important role of shrubs and tree regeneration for stream bank stability and fish habitat of low order streams is poorly developed in the dark, stem exclusion phase, which is also of reduced value for foraging species of terrestrial wildlife. Forests that do not develop beyond the stem exclusion phase because of high frequency of natural disturbance, or relatively short rotation timber management, thus tend to have lower wildlife and fish habitat values. This is why it is important to maintain streamside (riparian) buffers on much longer rotations or to exclude tree harvesting from these areas to ensure that features of understory reinitiation and old growth phases of stand development are sustained either continuously or periodically over an appropriate proportion of the stream length. Alternatively, dense young riparian stands can be thinned to promote understory development and shorten the time to produce large snags and CWD. Such thinning accelerates stand development.

Timber management, whether it involves clearcutting or low disturbance partial harvesting, has typically truncated both the sequence of seral stages and the series of stand developmental phases within a seral stage (Figure 2). Where this occurs, biological diversity of the managed forest can be expected to decline (see papers in Gillam and Roberts, 1995). Variation in silvicultural systems, types and severities of ecosystem disturbance over time within a particular stand and in different ecosystem types across the landscape can prevent this problem.

Partial harvesting and uneven-age stands are currently politically correct and publicly popular. However, such harvesting can eliminate or greatly reduce the abundance of early seral stages and deciduous hardwoods and promote late seral,

shade tolerant conifer forests in areas where conifers form the climax ecosystem community, or eliminate/reduce early seral conifers or shade intolerant hardwoods from climax, shade tolerant hardwood forests. Partial harvesting typically eliminates or reduces competition-related tree mortality because the frequently repeated harvesting reduces stand density and competition. Thus, while partially harvested stands may look nice, they can be starved of snags and CWD. In contrast, even-age stands that are not thinned (no intermediate harvests) and are allowed to go through stem exclusion and understory reinitiation phases of stand development can be a rich source of small and medium sized snags and CWD. It is obviously necessary to consider both stand dynamics and successional relationships in deciding on the silvicultural system that is needed to sustain desired values and functions. Sullivan and Sullivan (2001) and Sullivan *et al.* (2001) review the effects of variable retention harvests on diversity of stand structure and small mammals.

Because diversity in everything (spatial and temporal) seems to be a good idea, a mosaic of different severities, scales, types and frequencies of disturbance across a landscape, and a diversity of disturbance over time in any one stand may be the optimum strategy for sustainable forest management. Such a strategy will result in increased diversity in stream habitats, from stream exposure, to early seral conditions, to various later seral stages and different stages of stand development within each stage. The universal application of one system (e.g. even age, monoculture with clearcutting) everywhere is unlikely to result in the desired diversity. But the banning of clearcutting, suggested by some, and its replacement by one other system everywhere (e.g. low severity, small scale, frequent disturbance produced by partial harvesting that produces fewer snags and CWD) constitutes the same error and will also fail to sustain habitat and ecosystem diversity. Neither approach respects the diversity we observe in most unmanaged forests. However, the previous statement notwithstanding, some unmanaged forests do approximate these two ends of the disturbance spectrum. Consequently, both large scale clearcutting and large scale, low disturbance, partial harvesting may be appropriate in some types of forest, at least from an ecological and sustainability perspective. Either may be socially unacceptable under specific circumstances.

A recent variation on natural disturbance emulation is Variable Retention silviculture (Franklin *et al.* 1997; 2002; Mitchell and Beese, 2002). Reflecting the fact that larger scale and more severe "natural" disturbance events frequently leave undisturbed patches and living individual trees scattered within the disturbance area, harvesting systems are now being designed to create such retention patches. These have aesthetic value, and may have short-term wildlife habitat values depending on how they are designed. They also have the merit of space-for-time substitution. By retaining ecosystem elements that have longer ecological rotations within a matrix of forest managed for values that have shorter ecological rotations, one can sustain within a given management unit ecological conditions and functions that require either short or long term successional sequences for their renewal.

Variable Retention systems have many merits and are used to address both the social values of aesthetics and economic timber production, and the environmental values of certain measures of biodiversity and wildlife habitat. However, there can be conflicts between these two sets of values. Patterns of retention that are optimal for wildlife may not be optimal for aesthetics or timber production, and vice versa.

Careful analysis at both stand and landscape spatial scales over one or more timber production rotation time scales is needed to establish the desired balance of values and identify the tradeoffs between the different values. The best option may be to adopt a wide spectrum of VR intensities, designs and patterns across the landscape to ensure that all values are represented. One single way of doing things everywhere is generally to be avoided.

In comparing different silvicultural systems and harvest systems, one often finds that the public interpretations of management-induced disturbance are inaccurate. Clearcutting has been widely condemned as destructive of ecosystems and not comparable to the effects of stand-replacing wildfire or insect epidemics. It is certainly true that there are fundamental differences between clearcutting and these "natural" events, because clearcutting removes stems, but there are other differences. Because clearcutting frequently disturbs only a small percentage of the soil and minor vegetation and regeneration, it is often a much less severe ecosystem disturbance than wildfire. Clearcutting that only removes commercialsized stems leaves 20 to 30% of the tree biomass as stumps, roots, stem tops and branches, and causes much less loss of nutrients than a severe fire. Clearcutting generally leaves the most nutrient-rich biomass components, only removing the stem which has the lowest concentrations of the limiting nutrients – usually nitrogen and phosphorus. Fire has the opposite nutrient loss effect, removing the foliage and branches and the upper forest floor that account for the majority of the circulating nitrogen. Clearcutting that includes removal of branches and foliage as well as stems (whole tree harvesting) causes nutrient losses more comparable to, but still lower than those caused by severe fire because it does not remove the forest floor, whereas fire generally does to some degree.

Because clearcutting frequently leaves significant shrub and herb cover and seedlings/saplings of more shade tolerant tree species, it may fail to produce the level of ecosystem disturbance needed to ensure new successional sequences and facilitate the natural regeneration of early seral, disturbance-dependent species. In fact, it can, and sometimes does, accelerate successional development rather than being "destructive" and retarding it (Figure 7). In some ecosystems it can result in poorly stocked, shrub-dominated woodland unless the area is promptly planted and the seedlings released from shrub and/or herb competition. Evaluations of the ecological impacts of clearcutting can be found in Keenan and Kimmins (1993) and McRae *et al*. (2001).

This great diversity in the successional effects of clearcutting reflects the different phases of stand development and the different seral stages at which the clearcutting takes place, as well as different harvesting techniques, time of year and various other factors. Traditionally, the inadequate severity of disturbance to soil or minor vegetation by some clearcutting has been rectified by burning, mechanically scarifying the site, or the use of sheep or herbicides to manage plant competition, and by the planting of desired tree species. These disturbances resynchronize the microclimate, soil conditions and competition components of the ecosystem so that they are suitable for desired tree species (Figure 8).

Clearly, there is need to undertake careful analysis of the successional consequences of different silvicultural and harvesting systems and ensure that the level of ecosystem disturbance matches the ecology of the desired values. This

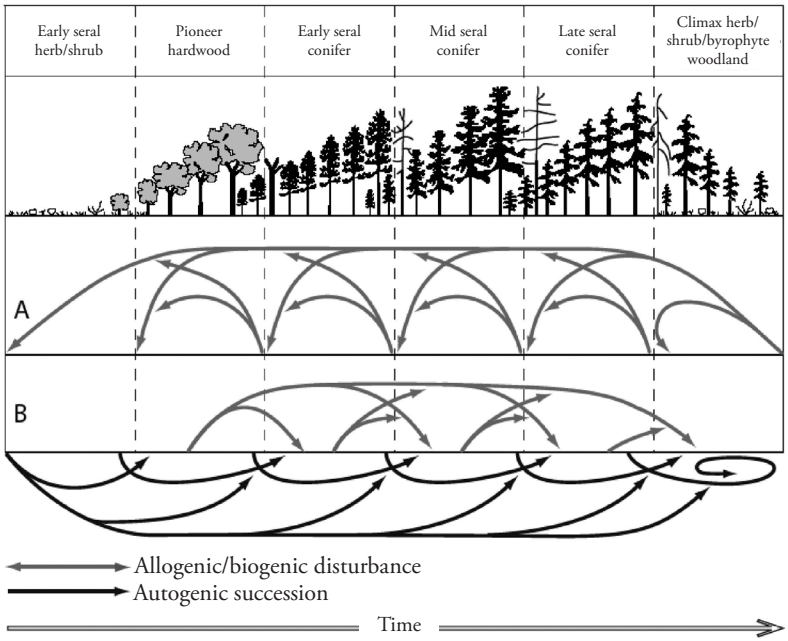

Figure 7:

A: Moderate to severe allogenic or biogenic disturbance can result in successional retrogression (the grey lines), the degree depending on the type of disturbance, the seral stage and stand development phase when it occurs, and the soil and climatic conditions. This is the popular conception of ecosystem disturbance. **B:** However, allogenic and biogenic disturbances can accelerate succession if the severity is moderate to low. This diagram also shows the variable pathways that can be followed through autogenic succession (dark lines) in a hypothetical mesosere, starting from a severely disturbed, early seral condition. Depending on the climate and soil conditions, and the availability of seeds of the different seral species, autogenic succession could take the ecosystem back to almost any of the seral stages directly, or via a successional sequence of stages, over widely varying periods of time. Low to moderate severity allogenic or biogenic disturbance (grey lines) can accelerate this autogenic sequence by speeding the removal of the existing community without retarding the ecosystem condition. Management can be used to manipulate autogenic successional sequences and rates.

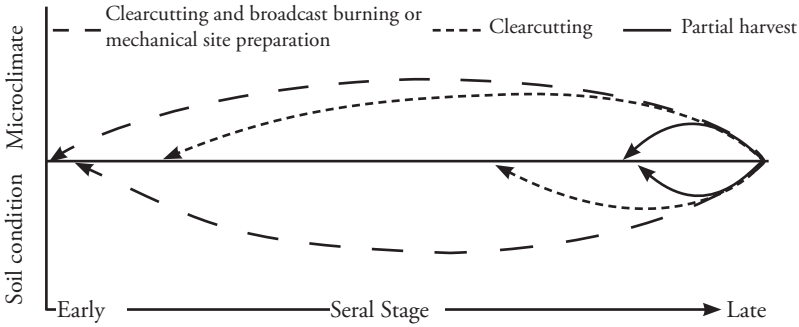

Figure 8:
Successional retrogression involves two major physical components – the soil condition and the microclimate. Some allogenic or biogenic disturbances regress the microclimate to an earlier seral condition without regressing the soil condition to the same extent. This can lead to a de-synchronization of these two physical components of the ecosystem, making it difficult for vegetation to re-establish. Where this is the case, fire or mechanical disturbance may be used in forest management to re-synchronize the soil and microclimate. If such soil disturbance is not acceptable and microclimate/soil de-synchronization is a problem, clearcutting should be replaced by a harvest system that does not regress the microclimate to such an extent (see Figure 3).

includes applying disturbance regimes that ensure the variety of seral conditions required to produce desired ecosystem conditions (Figures 2 and 7). For example, frequent low severity harvesting or natural disturbance in riparian environments can result in closed late seral forest or open shrub/herb woodland, to the exclusion of earlier seral species. In coastal British Columbia, this may reduce the abundance of deciduous hardwood species, and the production of snags and CWD – all of which are important to stream function and diversity. Where natural disturbance provides sufficiently frequent and severe disturbance, these possibly undesirable outcomes will not occur.

Synthesis of knowledge and understanding of forest ecosystems into ecologically-based decision support tools

Forestry is defined as the skill (art), practice, science and business of managing forest stands and landscapes to sustain an ecologically possible and socially desirable balance of values. It is first and formost people-centered; the values people derive from forests define what they are managed for. However, unless science is involved in designing policies and practices it is unlikely that forestry will satisfy this definition.

Science has three essential components: knowing, understanding and predicting. **Knowing** involves description and classification of the object of interest – in this case forests. **Understanding** involves the reduction of explanations and theories (derived from our description and classification activities) into relatively simple

and testable hypotheses, followed by experimental studies to test them. **Prediction** involves a synthesis of the results of reductionist, disciplinary science (undertaken to provide understanding) up to the level of complexity of the forest ecosystem or management unit.

Science is strongly influenced by the principle of parsimony (known as Occam's Razor: when choosing between two explanations or hypotheses, always choose the simplest), which was advanced by an English theologian in the late 12th – early 13th Century. However, Occam's Razor has two "edges": as simple as possible but as complex as necessary. This was echoed by Albert Einstein: "as simple as possible, but no simpler". Forest ecosystems and the issues in forestry are complex. A problem is an issue that has not yet been solved. Issues that are solved quickly are not problems. Problem issues often persist because they are complex, but only simple solutions are offered. The science component of forestry must be soundly based on knowledge and understanding, but unless this is synthesized to the level of complexity of the problem in question, the issue is unlikely to be solved.

Synthesis of diverse experience and knowledge is now possible through the medium of computer-based ecosystem management models. Multi value, stand-level models that include representations of key ecosystem structure and processes are used to drive landscape models that become important decision support tools. They facilitate the incorporation of knowledge and understanding of individual forest ecosystems into the management of forested landscapes. Examples of such systems can be found in Messier *et al.* (2003) and Seely *et al.* (2004) (Figure 9).

Issues in Forestry Related to Forest Ecology

There are several issues in forestry today that require an understanding of forest ecology if correct solutions are to be reached.

Old growth

The term *old growth* is highly emotive, with connotations of "ancient" forests, "virgin" forests, "first growth", the "last remaining" and "primeval" forest (Kneeshaw and Burton, 1998; Peterken, 1996). These connotations arouse strong feelings, fundamental belief systems and address important spiritual, aesthetic and emotional values. However, before one can inventory how much "old growth" there is or develop policies to conserve or manage it, one must define what it is.

Much of the discussion of "old growth" assumes that there is a dichotomy between "old growth" and "not old growth", and that there is a fixed definition that enables one to categorize all forests into one of these two states. Forest ecologists studying this issue have rejected such a simple classification in favor of an "old growth index" (OGI: Spies and Franklin, 1988; 1991).

Studies of forests that have been considered good examples of "old growth" have found a wide variation in structural, functional and species attributes. This has led to the concept that "old growth" is a multi-characteristic ecosystem state. By identifying a set of "old growth" characteristics (e.g. number and size of snags, number and size of large decaying logs, diversity of canopy levels, size of largest live trees relative to the maximum size for that species, all relative to expected values for the site in question), scoring individual stands for each of these characteristics, and

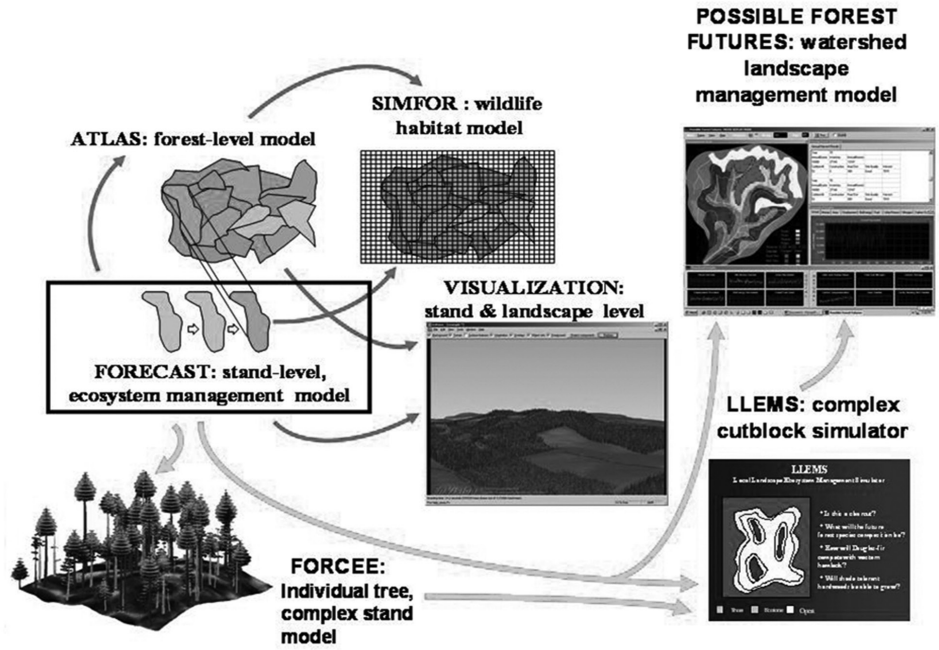

Figure 9: Models developed at various scales can be combined into meta-model decision support tools for scenario and value tradeoff analysis. In this example, the hybrid simulation, stand level, ecosystem management model FORECAST is used to drive a variety of other models – landscape timber and wildlife habitat supply; an individual tree spatial model, a complex cutblock (VR) model, and a small watershed model.

expressing the sum of the scores as a proportion of the maximum possible score, an index of oldgrowthness (OGI) is arrived at.

The importance of using OGI rather than an "OG/not OG" dichotomy is that many stands that satisfy a qualitative assessment of OG may fail to satisfy a simple quantitative dichotomous definition, and therefore are ineligible for OG status and conservation under the dichotomous definition. Under the OGI approach one can set threshold levels of "oldgrowthness" that render a stand eligible for both classification as "old growth" and conservation. In fact, the definitions of "classical" OG in the Pacific Northwest were arrived at by identifying what OG ecologists felt were OG stands and then modifying the definition to include these stands. For purposes of inventory, conservation and management of OG, the OGI is more flexible, operational and effective than a simple dichotomous classification.

OG has often been considered to be synonymous with "ancient" forest, late successional or climax forest. However, as noted above, each seral stage passes through an "old growth" phase of stand development. There are old growth red alder, birch, aspen and pine forests (shade intolerant, early seral species), as well as old growth beech, maple, redcedar and hemlock (shade tolerant, late seral or climax species; but note that western redcedar does not fit the classical concept of "shade tolerant"). These different types of "old growth" vary in their characteristics and persistence, but all of them can have significant numerical values of OGI.

Because "old growth" can exist over a wide variety of seral stages, the significance of high OGI stands for riparian areas and streams varies considerably. Litterfall quantity and quality; rain of canopy insects; light quality, quantity and seasonality; size, persistence and substrate quality of CWD; riparian vegetation, groundwater chemistry, and other attributes of significance to streams and aquatic organisms all vary between different types of "old growth". Caution is therefore needed in attributing stream characteristics to an undefined "old growth" condition.

For a review of "old growth" forests in Canada, see Environmental Reviews, Vol. 11, 2003 and Trofymow and McKinnon, 1998.

Carbon storage

The role of forests in the global carbon cycle has been identified as one of the important "environmental services" performed by forests (Houghton *et al.* 1983; 1990; Kurz *et al*. 1995a;b; IPCC, 2002). By acting as a sink and/or store of carbon, forests play an important role in the regulation of atmospheric carbon, the greenhouse effect of the atmosphere, and global climate. It has been widely asserted that the carbon storage of forests is so significant that the high carbon, old forests that exist in humid climates should not be harvested; that they should be left unharvested and protected from natural disturbance to conserve their stores of carbon (Harmon *et al.* 1990).

There is little doubt that high carbon forests represent an important global store of carbon, and that harvesting and managing them reduces this storage. However, the issue of the role of forests in global carbon budgets is more complex than this. While old forests may have high carbon stores, they generally have low rates of net carbon accumulation (however, some old forests can sequester atmospheric carbon when they are not increasing their carbon store because of exports of dissolved

(DOC) and particulate organic matter in stream water; this can be significant in some types of old forest, but has not been adequately researched). In contrast, younger forests have lower storage but much higher rates of net carbon removal from the atmosphere. The question of whether to set aside old forests as a carbon store, or harvest them to increase their role as a carbon sink, can only be evaluated in the context of the fate of harvested carbon and the degree to which the use of wood reduces the release of carbon from fossil fuels. This reduction will occur if wood fibre is ultimately used to produce ethanol or burned directly as a fuel to replace fossil fuel, or if wood is used to replace metals and cement-based products the use of which releases more fossil fuel carbon than does the use of wood.

The issue of the carbon role of forests is important because it is one of the several values that must be considered in deciding how they should be managed. Recent discussion of the growth response of forests to higher atmospheric CO_2 levels can be found in Oren *et al.* (2001), Davidson and Hirsch (2001), Schlesinger and Lichter (2001). The role of soils in the carbon cycle is discussed in Hendrickson (2003).

Biodiversity

The diversity of measures of biodiversity, and of the spatial scales over which these measures can be evaluated, were introduced earlier. Biodiversity is considered to be important for many reasons. It represents the product of millions of years of evolution, and constitutes nature's insurance policy against environmental change and disturbance (Bengston *et al.* 1997). It provides functional redundancy within ecosystems that buffers ecosystem function in the face of changes in species composition and environmental conditions (Perry and Amaranthus, 1997; Bengston *et al.* 2000).

Protection of biodiversity is one of the most consistently asserted principles of sustainable forestry and forest stewardship. However, rarely is this principle elaborated into a set of specific objectives that identifies desired levels of specific measures at particular spatial scales, and how these levels should vary over time, because vary they will in both managed and unmanaged forests (Bunnell and Huggard, 1999). In the absence of specific biodiversity goals, the statement "protect biodiversity" is not actionable; it remains a qualitative statement of overall intent that lacks the linkage to actions that will fulfill our biodiversity obligations.

Aldo Leopold asserted that the first rule of "intelligent tinkering" is to keep all the parts (Leopold, 1966). This has been interpreted by many to mean that biodiversity is protected by maintaining a constant species list in the forest in question. Leopold and most ecologists since his time have recognized that not only will species lists at the stand and local landscape change over time, but that such change is an essential component of maintaining high values for the sum of individual biodiversity measures over the long term, or for targeted individual measures. Ecologists recognize the importance of temporal diversity in maintaining over the long-term all the other measures of biodiversity. The importance of biodiversity and its relationship to ecosystem disturbance and autogenic succession requires that we balance the management for other values against the timber management practices needed to achieve broadly defined biodiversity objectives.

There are three key relationships that have long attracted attention with respect to biodiversity:

1. The relationship between biodiversity and disturbance. Does disturbance threaten or reduce measures of biological diversity?
2. The relationship between biodiversity and ecosystem stability. Do high values of various measures of biodiversity ensure ecosystem resistance to change in the face of disturbance (resistance stability), and do diverse ecosystems recover more rapidly (resilience stability) from disturbance-induced change than low diversity ecosystems?
3. The relationship of diversity to ecosystem productivity. Are more diverse forest ecosystems more productive than low diversity systems?

There is only one reliable answer to these questions. It is the answer that is true for most questions about forestry and forest ecosystems: ***IT DEPENDS***.

1. Disturbance and biodiversity

There has been an extensive and prolonged debate in the scientific literature on the relationship between disturbance and biodiversity. The cause of the longevity of this debate appears to be related to differences in the ecological systems in which researchers have considered this relationship and tested hypotheses related thereto. Many high latitude and high elevation forests have relatively low alpha diversity but can have quite high beta diversity, whereas many low elevation tropical forests have high alpha diversity but relatively low beta diversity (Turner, 2001). The temporal diversity of different forest types also varies considerably. Unless the debate focuses on specific measures of diversity at specific spatial scales and accounts for differences in temporal diversity, there is little hope of finding reliable generalizations and relationships. However, one theory – the intermediate disturbance/maximum biodiversity hypothesis (Connell, 1978; Huston, 1979) – has enjoyed considerable support, although it is clearly not universally applicable (e.g. Schwilk *et al.* 1997).

Forest ecosystems that are disturbed frequently and severely often have low values of taxonomic, tree species, structural, functional and other measures of biodiversity. Disturbance-related alder, aspen and eucalyptus forests are examples of forest ecosystems with low tree species and structural diversity. One reason for this is that because of the high frequency of disturbance, these forests exist for much of the time in the stem exclusion phase of stand development of a single seral stage. The low diversity is thus a predictable outcome of the interaction between disturbance and stand development. However, depending on the soil and climate conditions, the diversity of other plants and of animal and microbial species in these forests may or may not reflect the disturbance-induced, low tree species and structural diversity.

Forests that rarely experience stand-replacing disturbance are frequently dominated by shade tolerant tree species. Many low-disturbance, high latitude forests are structurally diverse in the tree canopy layers, but low in tree species diversity. They may also be low in understory vascular plant species diversity because of lack of light penetration, but this is not always the case. Old temperate rainforests in coastal western Canada in which nitrogen availability has declined frequently have open canopies and a well-developed but low species diversity shrub or herb understory. They can have a very diverse canopy structure with diverse bryophyte and insect communities, something that is lacking or less well-developed in less structurally diverse low disturbance forests in somewhat drier climates in this region

(papers in Trofymow and MacKinnon, 1998).

Maximum vascular plant diversity and associated faunal diversity at medium and high latitudes is often found in forests with intermediate frequencies and severities of disturbance (Parminter, 1998; Hunter, 1999; Boyce and Haney, 1997; Voller and Harrison, 1998; Attiwill, 1994a;b). In contrast to these diversity-disturbance relationships at medium and high latitudes, maximum structural and vascular plant species diversity in tropical humid forests is reported in low disturbance forests (Turner, 2001).

The only reliable conclusion appears to be that diversity-disturbance relationships vary by climate and, therefore, by type of forest; by type, severity and spatial scale of disturbance; and by which taxonomic group, plant life form or other measure of biodiversity one is examining. There may be reliable generalizations about the diversity-disturbance relationship within a particular forest type or disturbance regime, and for a particular measure of biodiversity, but none that apply equally to all forest/disturbance/biodiversity measure combinations. In other words, ***it depends***. And the more the different measures of biodiversity are examined, the more we will probably find diversity in the relationship to disturbance.

2. Diversity-stability relationships

In the 1960s and early 1970s, many ecologists subscribed to the idea that the more diverse the biotic community, the more stable and productive it was (Bengston *et al.* 2000; Pimm, 1991). This conclusion was based on a combination of theoretical models and empirical data from particular forest types. The supremacy of this view was short-lived as different studies revealed very variable relationships between stability and diversity, and between diversity and ecosystem productivity. One of the reasons for the lack of agreement is there are several different measures of stability as well as many different measures of biological diversity, and it is unlikely that a single relationship would apply to all combinations of these measures. Another problem is that the issue has been examined for widely varying ecosystem types, seral stages and plant life forms, often under experimental conditions that differ from real ecosystem situations (e.g. Huston *et al.* 2000; Loreau *et al.* 2001).

If stability is measured by the degree of ecosystem change caused by disturbance, low species and structural diversity, early seral stage pine, aspen, birch and eucalyptus forests would be considered very stable in the face of stand replacing wind, fire, insect or because they regenerate reliably and promptly to exactly the same or very similar type of forest. In contrast, higher diversity mid or late seral forests would be less stable by this definition in the face of stand replacing disturbance because these forests are much more changed by such disturbance than the simpler early seral forests. It takes less time for early seral, low diversity forests to return to predisturbance conditions than disturbed late seral, high diversity forests, which therefore have lower resilience stability than the simpler early seral forests. The late seral forests require a substantial period of post-disturbance autogenic succession to return the ecosystem to the predisturbance level of diversity. Low species and structural diversity Douglas-fir forests in interior western Canada may be less susceptible to stand replacement by insect herbivore epidemics than high structural diversity and mixed species stands in this area because the latter have higher survival of the insect larvae (Wickman, 1992).

Low diversity, fire-maintained forests in eastern Oregon and Washington are less moisture stressed than low-disturbance complex forests on similar sites, which are less stable because the stress renders the latter forest type more susceptible to insects and disease and their diverse stand structure renders them more susceptible to severe fire (Everett, 1994; Johnson *et al.* 1994). Different types and severities of disturbance would affect these early and late seral types differently than severe disturbance and lead to different conclusions. Thus, outbreaks of a tree-species specific bark beetle cause much more forest change in low structural and species diversity forests of susceptible species than in mixed tree species forests in which several of the tree species are not affected. Species-specific diseases and epidemics may similarly have less impact on high tree species diversity than on low diversity forests. Some forest fires will burn less intensely through mixed species forests than monocultures where the former includes low flammability and the latter high flammability trees. However, monocultures of low-flammability species will be as resistant to fires as the multi-species forests, at least for low and medium intensity fires. Preston (1969) suggests that resilience (rate of recovery) is a better measure of stability than resistance to change.

As with disturbance-diversity, the stability-diversity relationship depends on many things: the type of forest, the type, severity and scale of disturbance, the type of climate and soil, the type of species, the measure of stability being considered, and the biodiversity measures and spatial scales at which they are being evaluated. Diversity and stability are not inevitably related, and therefore diversity is not always critical for any particular ecosystem function or attribute (Simberloff, 1998). In short, ***it depends***, as is usual in ecology. For entry into a vigorous debate on these issues, see Hooper and Vitousek (1997), Hector (1998), Naeem (1998, 1999), Schlapfer and Schmidt (1999), Grime (2001), Chapin *et al.* (1998), Tilman *et al.* (1996, 1997), Doak *et al.* (1998), Tilman (1996), van der Heijden *et al.* (1998), Pahl-Wostl (1995), McCann (2000), Kimmins (2004a,b) and Perera *et al.* (2004).

3. Diversity-productivity relationships

Where the different species in a forest occupy different ecological niches, one could expect that higher diversity forests could be more productive than lower diversity forests. Differences in rooting depth, shade tolerance and nutritional demands should result in more complete utilization of a site's resources, and greater net primary production. In contrast, where different species occupy similar niches, there will probably be little relationship between diversity and productivity. Many of the world's most productive unmanaged forests are early seral, even age monocultures with low values for many measures of biodiversity, maintained by stand replacing disturbance. Some old forests in which nitrogen cycling has slowed down have greatly reduced levels of productivity but relatively high levels of some measures of biodiversity. Where mixtures involve nitrogen-fixing species or promote rapid nutrient cycling, productivity can be expected to be higher than in monocultures of the constituent species. As a result, some mixed species, mid seral forests are more productive than either early seral or late seral forests. This mid seral condition may or may not be related to higher measures of biodiversity, depending on what phase of stand development is examined, and the forest type.

As with the other diversity relationships, the diversity-productivity debate has

suffered from lack of recognition of varying relationships in different physical environments, different seral stages, different phases of stand dynamics within a seral stage and different vegetation types. Much of the research on these relationships has examined herbaceous plant communities in grasslands or old fields, and the portability of the conclusions to forests is often questionable. Entry into the discussion of this topic can be found in Hooper and Vitousek (1997), Hector (1998), Schlepfer and Schmidt (1999), Tilman *et al.* (1996) and Loreau *et al.* (2001).

Forest Diversity and Forest Management

What are the implications of the apparent universality of diversity for the management of forests? The single most important conclusion is that regulation-based management of diverse forests is unlikely to be successful unless the regulations are specific to the ecological (climate, soil, geology, topography, physical disturbance regimes) and biological measures of diversity, and are applied flexibly enough to account for this diversity.

To be sustainable of desired values, forest management must be based on a classification of the multiple dimensions of forest diversity, both spatial and temporal, and a linkage between this classification and forest management policies and practices. Regulation-based forestry applied without the ability to recognize and interpret different ecosystem situations is very unlikely to be successful. This emphasizes the importance of adequate experience and education of forest policy makers, planners and managers, and of experience and training of forest workers. This education and training must be strongly biased towards field instruction and experience. Theoretical knowledge is important to prepare an individual to "read" the forest, just as learning the vocabulary and grammatical rules is important preparation for communicating and reading the literature of a foreign language. However, there is no substitute for the actual speaking and reading. As David Henry Thoreau, Aldo Leopold, Daniel Botkin and most forest ecologists have asserted, there is no substitute in learning to understand and respect forests to actually being in and observing the forest itself. Forestry education and the education of biologists and environmental and conservation scientists must have a heavy emphasis on fieldwork. Lecture room theory is only a preparation for the more important activity of learning in the field.

Concluding Statement

This chapter has not attempted to provide a rigorous review of forest ecology. This is not possible even in a lengthy textbook because forest ecology spans botany, zoology, microbiology, geology, pedology, hydrology and climatology, and then adds ecological layers as the interactions of these components of the ecosystem are considered – ecosystem structure, function, interactions, complexity (diversity) and change over time (disturbance and autogenic succession). What I have attempted to do is to illustrate the critical importance of basing forest management and conservation on an ecosystem concept at a range of spatial and temporal scales, and encompassing both ecological (physical) and biological diversity. Management and conservation must respect nature as it is and not as we might wish it to be for one or more of convenience, simplicity or emotion-based reasons.

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