13: The Structure, Functioning and Management of Old-growth Cedar–Hemlock–Fir Forests on Vancouver Island, British Columbia

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13.1 INTRODUCTION

The coastal conifer forests of northern Vancouver Island, British Columbia, have developed over the last 10 000 years, since glaciation. The climate is wet and mild year-round and influenced by storms from the Pacific Ocean. Agriculture is not possible. At low elevation the dominant species are western red cedar (*Thuja plicata* Donn. Ex. D. Don), western hemlock (*Tsuga heterophylla* (Raf.) Sarg), amabilis fir (*Abies amabilis* (Dougl.) and Sitka spruce (*Picea sitchensis* (Bong.) Carr.). These forests grow to great ages and sizes due to the absence of fire or major insect or disease attacks. Windthrow is the primary disturbance agent. These forests are classified as Natural Disturbance Type 1 (NDT1), i.e. ecosystems with rare stand initiating events with gap regeneration and a disturbance interval of 250 years (British Columbia Ministry of Forests 1995, 1999; Voller & Harrison 1997). These are public forests owned by the Province of British Columbia. Large areas are managed by major forest companies who have rights to cut the timber with management obligations under long-term licences. These forests were not extensively cut until the mid 1900s; thus all stands cut today are naturally regenerated old stands. Today, most stands are clearcut in small irregularly shaped cut blocks. Clearcutting is used because of the great size of trees and problems of rot and windthrow in selectively harvested stands.

The forests are in the coastal western hemlock biogeoclimatic zone (CWH) as classified by Green and Klinka (1994). This system of classification, used throughout British Columbia for forestry purposes, uses a grid of soil moisture and nutrient regimes to identify individual forest sites. Silviculture and regeneration actions and productivity estimates are customized to each site. Licenses are required that specify regeneration of all cut blocks to prescribed stocking densities and species within a specified number of years following harvest.

Viewed from the air, the forests are in an obvious intermingled mosaic of two types:

1 very old, irregularly structured stands composed of cedar and hemlock (cedar–hemlock) that have not been blown down;

2 much younger, but mature even-aged stands composed of hemlock and Pacific silver fir (hemlock–amabilis) originating from a major windthrow event in 1906.

Regeneration problems on the cedar–hemlock cutovers became apparent in the 1970s when extensive areas of Sitka spruce plantations almost ceased growing and turned golden yellow in colour as salal (*Gaultheria shallon* Pursh), an ericaceous shrub, invaded the cutovers. Sitka spruce is not planted today due to attacks by spruce weevil (*Pissodes strobi*) which kills tree leaders.

These mature forests have a high commercial value. Western red cedar is especially valuable because it is decay resistant. Stands are logged by cable systems; the logs are trucked to the ocean where they are towed in rafts to sawmills for conversion into structural forest products. The chips from sawmills are barged to pulp mills. The rate of harvest is fixed by the provincial government (free of politics) on a sustainable basis, with due regard given for sustainable landscapes, landscape, stand, species and genetic biodiversity, and wildlife habitat. Under present management plans prepared by the licensees, and approved by the government, these natural, old stands will be cut for many more decades. Harvest rates are aligned to cutover productivity estimates, thus nutritional problems of regeneration are of concern.

Severe regeneration problems occur on cutovers of coastal old-growth cedar–hemlock forests in the very wet, maritime portions of the coastal western hemlock zone (CWHvm1). The problem appears as poor growth and chlorosis (yellowing) of regenerating western red cedar, western hemlock, amabilis fir and Sitka spruce (Fig. 13.1). These symptoms appear 5–8 years after clearcutting and slash burning, coincident with the expansions of the ericaceous shrub, salal, on the cutovers. This also coincides with the end of a period of high nutrient availability that follows harvesting on these sites. Some cutovers are nearly 50 years old and have still not achieved crown closure. The problem does not occur on adjacent cutovers that were formerly occupied by second-growth forests of hemlock and amabilis fir (Fig. 13.2), originating following a windstorm in 1906. Mean annual volume increment on hemlock–amabilis sites is 10–14 m^3 ha^{-1} $year^{-1}$ compared to 4–6 m^3 ha^{-1} $year^{-1}$ on cedar–hemlock sites. Lewis (1982) could not distinguish between the two forest types on the basis of topography or mineral soil characteristics, and included them

Fig. 13.1 Cedar–hemlock (CH) cutovers are characterized by dense salal cover and slow-growing conifers with chlorotic (yellow) foliage. These symptoms appear 5–8 years after clearcutting and result from low availability of nitrogen.

Fig. 13.2 Adjacent hemlock–amabilis fir (HA) cutovers (left) have abundant regeneration and rapid growth of hemlock compared with CH sites (right).

both in a 'salal–moss' ecosystem association. He further hypothesized that amabilis fir forests were a seral stage of cedar–hemlock forests, and that the superior regeneration and site growth conditions typical of hemlock–amabilis sites might be achieved on cedar–hemlock sites through silvicultural treatments. In the biogeoclimatic ecosystem classification scheme of Green and Klinka (1994), cedar–hemlock sites are classified as 10 '*HwBa—blueberry*' or 10 '*HwBa—deer fern*', with a modifier 's' that signifies the nutrient-poor to very poor 'salal phase' that occurs in subdued terrain of the west coast and north end of Vancouver Island.

Research has been conducted for a decade to determine the reasons for the poor nutrition of trees and the best silvicultural practices for alleviating the cedar–hemlock growth problem (summarized by Prescott & Weetman 1994 and Prescott 1996). The low availability of nitrogen (N) and phosphorus (P) in cedar–hemlock cutovers originates in forest floors of the old-growth forests prior to clearcutting. Nutrient availability is low in all layers of the forest floor in these forests. This is a result of three factors. First, cedar litter contains less N and more decay-resistant material than other species, and produces forest floors with low rates of N mineralization. Second, the forest floors in cedar–hemlock forests are wetter and have less soil than in forest floors of amabilis fir forests, leading to incomplete decomposition and mineralization of N. Third, the salal understorey in cedar–hemlock forests interferes with mineralization of N through the production of tannins. Processes involved in the development of low nutrient conditions on these sites are illustrated in Fig. 13.3.

13.2 CHARACTERISTICS OF FORESTS ON VANCOUVER ISLAND

Characteristics of these two forest types have been reviewed by Keenan (1993) and Fraser (1993). The natural landscape along the west coast of North America, from northern California to the top of the Alaskan panhandle, is dominated by coniferous forests of unsurpassed form and stature (as illustrated on the cover of this volume!). Most of the genera composing these forests differentiated from earlier gymnosperms during the Jurassic period from 140 to 160 million years ago (Scagel *et al.* 1965). Therefore, conifers

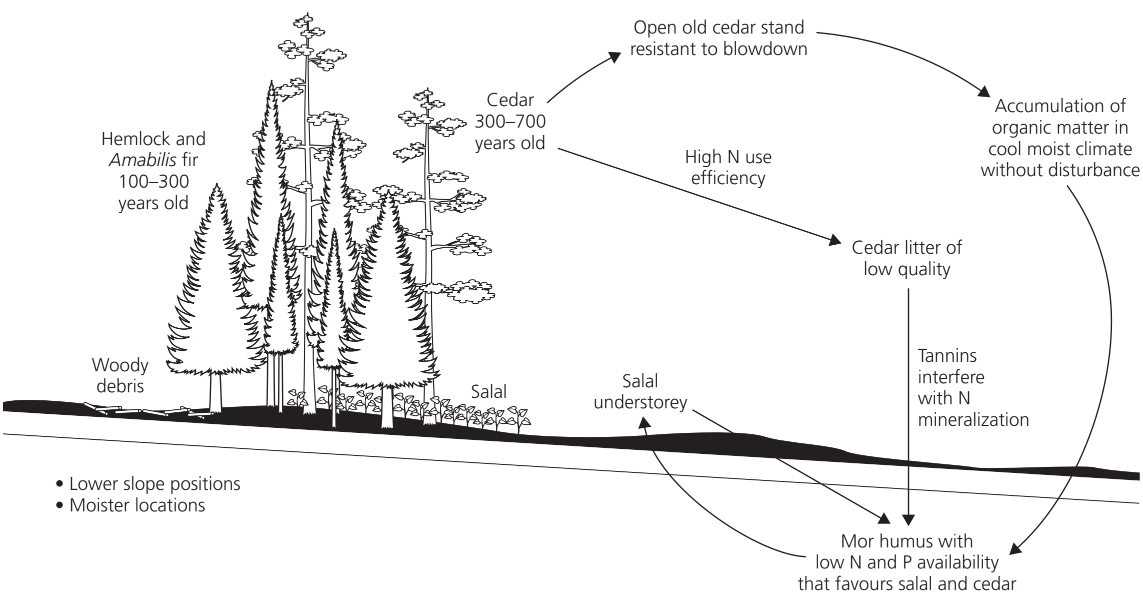

Fig. 13.3 In the absence of a major disturbance, nitrogen in cedar–hemlock forests is continually immobilized in humus, leading to poor N supply in old-growth forests.

have had a considerable period in which to adapt to a variety of environmental conditions and now occur in a wide range of climatic environments. However, Pacific coastal forests are thought to be remnants of vegetation types that once dominated the landmasses of the Northern Hemisphere. Their current range is now restricted to areas with a temperate, wet winter climate and mild to warm summers (Waring & Franklin 1979).

Northern Vancouver Island is located in the centre of this band of Pacific coastal forest, and its temperate climate has mild winters and cool wet summers. The distribution and forest vegetation across this area varies with topography, geological substrate, and the type and frequency of natural disturbance. On well-drained to somewhat imperfectly drained middle or upper slope situations, the forests form two distinct types: (i) old-growth type dominated by western red cedar with a smaller component of the western hemlock type, and (ii) a second-growth type dominated by western hemlock and amabilis fir, that appears even-aged and to have originated following a widespread windstorm in 1906 (the hemlock–amabilis type) (Fig. 13.3). The forest floors of both types are deep mor humus, generally of greater depth in the cedar–hemlock than the amabilis fir (Germain 1985). Mineral soils are duric or orthic Humo-Ferric Podzols.

Old growth is a difficult term to define, but for these sites the oldest trees are over 500 years old and very large in diameter. These stands also have the diversity of height, diameter, age and understorey structure considered characteristic of old-growth stands of the Pacific North-west by Franklin and Waving (1981).

In classifying the ecosystems of this area, Lewis (1982) could not distinguish between the two types on the basis of topography or mineral soil characteristics, and included them in the same ecosystem association. He further hypothesized that they were different stages (or phases) of a successional sequence.

Since the 1960s, these forests have been extensively harvested for timber. Following clearcutting and slash burning, major differences in the productivity of planted and naturally regenerated seedlings have been observed in the two forest types (Weetman *et al.* 1989a,b). Seedlings regenerated after cutting in the cedar–hemlock type grow slowly and exhibit chlorosis which is symptomatic of nutrient (particularly N) deficiency. The regeneration on the amabilis fir type grows relatively rapidly and exhibits no signs of nutrient deficiencies. The slower seedling growth on the cedar–hemlock type is considered to be partly due to lower forest floor nutrient availability, and partly to competition for nutrients from the ericaceous shrub salal which re-sprouts rapidly from rhizomes following clearcutting and slash burning (Weetman *et al.* 1990; Messier 1991; Messier & Kimmins 1991). The differences between these types are summarized in Table 13.1.

13.3 THE HYPOTHESIS: EXPLANTATIONS WHY HEMLOCK–FIR AND CEDAR–HEMLOCK SITES DIFFER

To attempt to explain the differences four hypotheses were developed:

13.3.1 The 'disturbance hypothesis'

It was argued that areas frequently disturbed by catastrophic windstorms will regenerate to western hemlock and Pacific silver fir, as is observed on amabilis fir sites. Windstorms cause tree falls resulting in soil mixing which promotes a well-drained and aerated soil with active organic matter decomposition and nutrient cycling. Improved soils increase the growth rate of trees and help to produce dense stands which exclude salal by shading. In areas that are not affected by the windstorms, such as cedar–hemlock sites, western hemlock and Pacific silver fir stands thin, allowing the regeneration of western red cedar. This improves the stand's ability to withstand windstorms because wind can pass through rather than strike against the forest stand.

13.3.2 The 'salal hypothesis'

It was argued that salal, an ericaceous plant, is a major competitor with conifer seedlings. Two theories are relevant. One theory proposes that salal suppresses the growth of conifer seedlings through an allelopathic agent which inhibits either mycorrhizal development, root development, or both (deMontigny & Weetman 1990; deMontigny 1992). This theory is related to obser-

Table 13.1 Comparison of old-growth cedar–hemlock (CH) and second-growth hemlock–fir (HA) stands growing side by side on the same soils and topography on northern Vancouver Island, BC.

	CH (cedar–hemlock)	HA (hemlock–fir)
Before		
Dominant conifers	Western red cedar and western hemlock	Western hemlock and Pacific silver fir
Wind disturbance	Absent	Repeated catastrophic disturbance
Age of stand	'Old-growth' >200 years old	Young <100 years old
Productivity of conifers	Low	High
Canopy	Open	Dense
Salal abundance	Plentiful	Rare
After		
Natural regeneration of conifers	Slow	Prompt, dense, fast growing
Performance of planted conifers	Poor	Good
Non-crop vegetation regeneration	Plentiful salal, little fireweed	Little salal, plentiful fireweed

vations of other ericaceous species in eastern Canada (Meades 1983) and the heathlands of Europe (Malcolm 1975) which have been attributed to growth problems of planted conifer seedlings after deforestation. The second theory suggests that salal is simply a better competitor than the conifer seedlings for soil nutrients in the cedar–hemlock clearcuts. In either case, the reason for high productivity in amabilis fir sites following a major disturbance is that the dense regeneration of hemlock and fir excludes salal, thus eliminating either allelopathy, nutrient competition, or both. Because the cedar–hemlock stands are not dense, salal can maintain a dense understorey, and inhibit most conifer seedling growth. Therefore, little ecological succession occurs at those sites and the 'old-growth' cedar forests remain relatively stable

13.3.3 The 'western red cedar hypothesis'

Western red cedar, unlike western hemlock and Pacific silver fir, is highly resistant to decay due to the presence of a fungitoxic chemical (thujaplicin) and a chemical (thujic acid) which repels a variety of insects (Swan *et al.* 1987). Consequently, a forest floor dominated by decomposing western red cedar will have a low mineralization potential and will immobilize nitrogen in the decomposer community, thus lowering the rate of nutrient cycling and nutrient availability. It has also been postulated that western red cedar is not a climax species, but a long-lived pioneer species that requires exposed mineral soil, or decaying cedar logs, and moderate levels of light to regenerate. Therefore, the conditions in windthrown hemlock–amabilis sites are suitable for western hemlock and Pacific silver fir. Because western red cedar is better able to regenerate on decaying cedar logs than western hemlock and Pacific silver fir, it can regenerate slowly in the cedar–hemlock sites.

13.3.4 The 'site-difference hypothesis'

This hypothesis proposes that hemlock–amabilis and cedar–hemlock sites are not different seral stages in the same succession, but rather two different plant associations determined by topography. Hemlock–amabilis sites are situated on knolls and upper slopes and are therefore more exposed to wind and better drained than the cedar–hemlock sites which are situated in lower areas.

These hypotheses were examined in a series of studies on cedar–hemlock and hemlock–amabilis ecosystems.

13.4 STAND STRUCTURE

Age–diameter relationships, diameter and height class structure, spatial pattern and seedling establishment substrate were studied by Keenan (1993) in old-growth cedar–hemlock stands, and in windstorm-derived, second-growth amabilis fir stands. There was a strong positive relationship between diameter and age for both species in the cedar–hemlock stands. Cedar ranged in age up to

1000 years, while the maximum longevity for hemlock was 300–400 years. Hemlock dominated the cedar–hemlock stands in terms of numbers, but these were largely in the lower size and height classes and cedar made up 73–85% of the basal area. The second-growth amabilis fir stands exhibited a range in ages despite their catastrophic origin but the size class distributions were unimodal. Hemlock exhibited differential regeneration strategies depending on the disturbance regime. The reverse-J diameter distribution indicated continuous establishment and recruitment to larger size classes in cedar–hemlock stands, but the past rapid response to disturbance indicated by unimodal distributions in hemlock–amabilis stands were more characteristic of an early seral species. The diameter–class distributions for cedar were generally flat, with many gaps in the size class distribution. However, its presence in most size classes at each site and relatively high numbers of seedlings and saplings suggested that, because of its longevity, cedar does form stable populations despite relatively low levels of recruitment. Establishment of elevated surfaces, such as decaying stumps and boles, above the dense understorey of the shrub *Gaultheria shallon* appeared critical for the regenerative success of both species in the cedar–hemlock stands.

The two stand types predominate on middle- or upper-slope situations on northern Vancouver Island. Distribution of the two types was found to have no obvious relationship with geology, topography or mineral soil. However, seedlings regenerated following cutting on the two types exhibit large differences in growth. Seedlings on cutovers in the cedar–hemlock type grow slowly and have symptoms of nutrient deficiency; those in the amabilis fir type grow relatively rapidly with no sign of nutrient deficiency. This difference in productivity is partly due to lower nutrient availability in the forest floors of the cedar–hemlock type.

The diameter–class structure of the cedar–hemlock type suggested it was a self-replacing, climax community. The diameter–distribution of western hemlock indicated continuous recruitment, while that of western red cedar suggested more periodic recruitment, at a slower rate than hemlock. Although the diameter–class distribution of the amabilis fir type was unimodal, suggesting an even-aged stand, a sample of tree ages indicated that many trees established some time before, or after, the 1906 windstorm.

13.5 NUTRIENT CYCLING

Measurements of nutrient availability in cedar–hemlock and amabilis fir forest floors demonstrated that lower N and P availability in cedar–hemlock forest floors existed prior to clearcutting (Prescott *et al.* 1993). All layers of cedar–hemlock forest floors had lower concentrations of total and extractable N and mineralized less N during 40-day aerobic incubations in the laboratory (Fig. 13.4). Total and extractable P was lower only in the litter layer of cedar–hemlock forest floors. Seedlings of cedar, Sitka spruce, hemlock and amabilis fir grown from seed in forest floor material from cedar–hemlock forests grew more slowly and took up less N and P than did seedlings grown in hemlock–amabilis forest floor material during a 1-year greenhouse experiment. Analysis of P forms by ^{31}P solution nuclear mag-

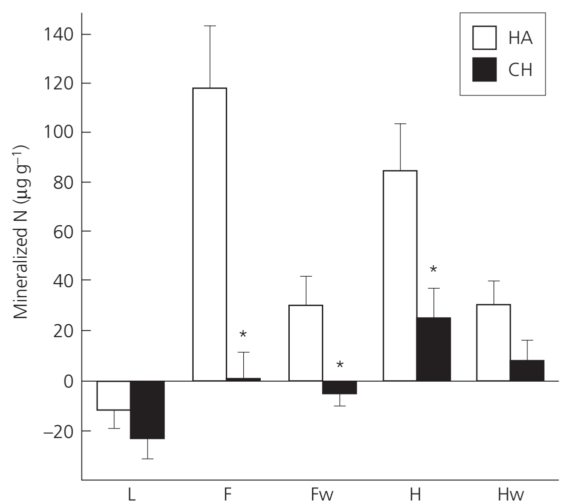

Fig. 13.4 Amounts of N mineralized during a 40-day aerobic incubation of each forest floor layer of adjacent hemlock–amabilis fir (HA) and cedar–hemlock (CH) forests. Each value represents the mean (+ 1 SE) of 15 samples; asterisks indicate significant differences ($P < 0.05$) between the two forest types based on two-factor ANOVA. L, litter; F, fermentation; H, humus; w, woody.

netic resonance (NMR) spectroscopy indicated that concentrations of total and available P were lower in cedar–hemlock forest floors, and there was less polyphosphate and more phosphate in cedar–hemlock forest floors (Cade-Menum 1995).

There was little evidence to support the hypothesis that more N and P were immobilized in detritus in cedar–hemlock forests, because the total amounts of N and P in coarse woody debris and forest floors were similar in the two forest types: 2.18 mg N ha^{-1} in cedar–hemlock, 2.05 in hemlock–amabilis; 142 kg P ha^{-1} in cedar–hemlock, 118.5 in hemlock–amabilis, respectively (Keenan *et al.* 1993). However, there was relatively more N in the humus (H) layer in cedar–hemlock forests and less in the F (fermentation) layer, so the N may be less available in cedar–hemlock forests. The greater mass of humus in cedar–hemlock forests may be the result of their greater age, or less complete decomposition, as discussed below.

Less N was returned in above-ground litter in cedar–hemlock forests (14.2 kg ha^{-1}) than in hemlock–amabilis forests (35.9 kg ha^{-1}), as a result of lower mass and N concentrations in foliar litter. There was greater internal recycling within the trees, which resulted from very efficient use of N by cedar, and from more efficient use of N by hemlock growing in cedar–hemlock forests. This is probably a response to low N availability and could also create a positive feedback that would exacerbate the low N availability in cedar–hemlock forest floors.

Decomposition rates of standard litter substrates were similar in the two forest types, and rates of CO_2 evolution from each forest floor layer during laboratory incubations were similar to or greater than those in hemlock–amabilis forests (Prescott *et al.* 1995a). These findings suggest that the decomposition potential of the two sites is similar. The lower N availability despite similar rates of litter decay may be attributable to the tannins, which bind proteins and immobilize N. There was evidence for tannins in the cedar–hemlock forest floor ^{13}C-NMR spectrum, as indicated by a peak at 145 p.p.m. (deMontigny *et al.* 1993). The dipolar-dephased cedar–hemlock spectrum also had higher intensity at 108 p.p.m., another feature diagnostic of tannins. This tannin may be associated with salal; ^{13}C-NMR spectra of salal components indicated high levels of tannin.

The presence of cedar in cedar–hemlock forests could also contribute to low N availability. In a modelling study (Keenan *et al.* 1995), there was lower N availability in forest floor in simulated cedar forests than in hemlock forests. In trials at the UBC Research Forest (Prescott & Preston 1994), and in Ireland (Prescott *et al.* 1995b), low rates of N mineralization were measured in forest floors in cedar plantations, compared with adjacent plantations of other species including hemlock and firs. The relatively low concentrations of N and high concentrations of waxes and lipids in cedar litter may be responsible for slower N mineralization in cedar forests.

There is also evidence that moisture levels in cedar–hemlock humus and soil are greater than in hemlock–amabilis forests, and this may result in conditions that inhibit decomposition and nutrient cycling in cedar–hemlock forests. For instance, in the study of Prescott and Preston (1994), moisture contents of samples of humus and mineral soils were usually greater in cedar–hemlock forests, and sensors placed in the humus recorded consistently higher moisture levels in cedar–hemlock forests. Mineral soil in many of the cedar–hemlock forests studied was more compacted and cemented layers were continuous and shallower than in hemlock–amabilis forests (deMontigny 1992). This could lead to poorer drainage of humus, as indicated by the occurrence of hydromors in cedar–hemlock forests. Lower biomass of fauna, and greater representation by aquatic animals such as copepods and brachiopods in cedar–hemlock humus, is also indicative of wetter conditions (Battigelli *et al.* 1994). High moisture content and lower faunal biomass could result in less complete decomposition in cedar–hemlock humus. This was suggested by the higher concentrations of lipids and carbohydrates in ^{13}C-NMR spectra of cedar–hemlock forest floors and the poorer lignin biodegradation (acid–aldehyde ratio) in cedar–hemlock forest floors (Prescott *et al.* 1995a). The poorer drainage in cedar–hemlock humus may be attributed to the lack of soil disturbance by windthrow, or the tendency for the cedar–hemlock forests to be on lower topographic positions.

Together, these studies indicated that the growth check of conifer regeneration observed in cutovers in cedar–hemlock forests is a consequence of inadequate supplies of N and P. The low nutrient supply originates in the forest floor of the old-growth cedar–hemlock forests, prior to cutting (Fig. 13.1). Several factors appear to contribute to low nutrient availability in cedar–hemlock forest floors, and their relative importance is not clear. Cedar litter, tannins associated with salal, and greater soil water lead to incomplete decomposition and low N availability in cedar–hemlock forest floors. Under these conditions, there is more efficient use of nutrients by trees, and less nutrients recycled in litter, which further reduces nutrient availability in the forest floor. These conditions develop over several centuries without severe disturbance, and may be most prevalent on lower slope positions.

After clearcutting there is an assart effect causing a temporary improvement in N and P availability for growth of regeneration (Fig. 13.2). During this period, salal re-sprouts from rhizomes, immobilizing nutrients in biomass and causing growth check in conifers through N and P competition, mycorrhizal antagonisms and release of tannins. The growth check of the conifers can be relieved by fertilization with additions of 250–300 kg N ha^{-1} and 100 kg P ha^{-1} fish silage or sewage sludge. With this treatment, it is hoped that crown closure will be reached after a few years, shading the salal and leading to sustained improvement in growth rates.

13.6 MANAGEMENT IMPLICATIONS

13.6.1 Site preparation

Cedar–salal sites can be broadcast burned to reduce slash and salal cover, thereby creating suitable seedbed and plantable spots. In addition to temporarily disrupting the salal, burning also temporarily increases nutrient availability, leading to higher foliar nutrient concentrations and improved early growth rates of conifers. Intense burns will increase the amount of N lost, so low-impact spring burns are recommended. Burning costs in 1996 ranged from US\$350 ha^{-1} to US\$650 ha^{-1}, depending on the guarding costs for the site. Burning may not be feasible in small blocks with convoluted edges.

Scarification and cultivation have been shown to increase early growth of western hemlock and western red cedar on cedar–hemlock sites. Responses are even greater when scarification is combined with fertilization (Fig. 13.5). The response to scarification appears to be largely due to the resulting disruption of salal, which reduces competition during the establishment of conifers. Cultivation or mixing of soil does not appear to increase nutrient availability on cedar–hemlock sites. Mounding may be successful on wetter sites such as cedar–spruce–skunk cabbage ecosystems and in the mid-coast. Mechanical site preparation can be used on sites that cannot be burned, such as those in the vicinity of riparian areas and wildlife corridors. Mechanical mulchers have caused unacceptable puddling; backhoes have been more successful on cedar–hemlock sites. Care must be taken with any equipment in wetter areas, to avoid interrupting water flow and creating unproductive wet depressions. The cost of mechanical site preparation on cedar–hemlock sites in 1996 is about US\$1.00 per planting spot.

13.6.2 Regeneration

Cedar–hemlock sites should be planted as soon as possible after burning or site preparation so that conifer seedlings can take advantage of the nutrient flush and disruption of salal. Large planting plug stock and genetically improved stock will improve the competitive ability of conifers on cedar–hemlock sites. Survival rates for conifers planted on cedar–hemlock sites are over 90% for cedar and 85% for hemlock. Direct seeding has proven unsuccessful on burned sites, due to seed predation by rodents. Planting at fairly high densities (1400–1800 stems ha^{-1}) will hasten crown closure, but broadcast burning may be necessary to create this many plantable spots. In a trial with western red cedar and western hemlock at 500, 1500 and 2500 stems ha^{-1}, growth of individual trees during the first 7 years was greatest at 1500 stems ha^{-1}. At 2500 stems ha^{-1} individual tree growth of both species was reduced. Stand volume of western hemlock was greatest at 2500 stems ha^{-1}, but western red cedar stand

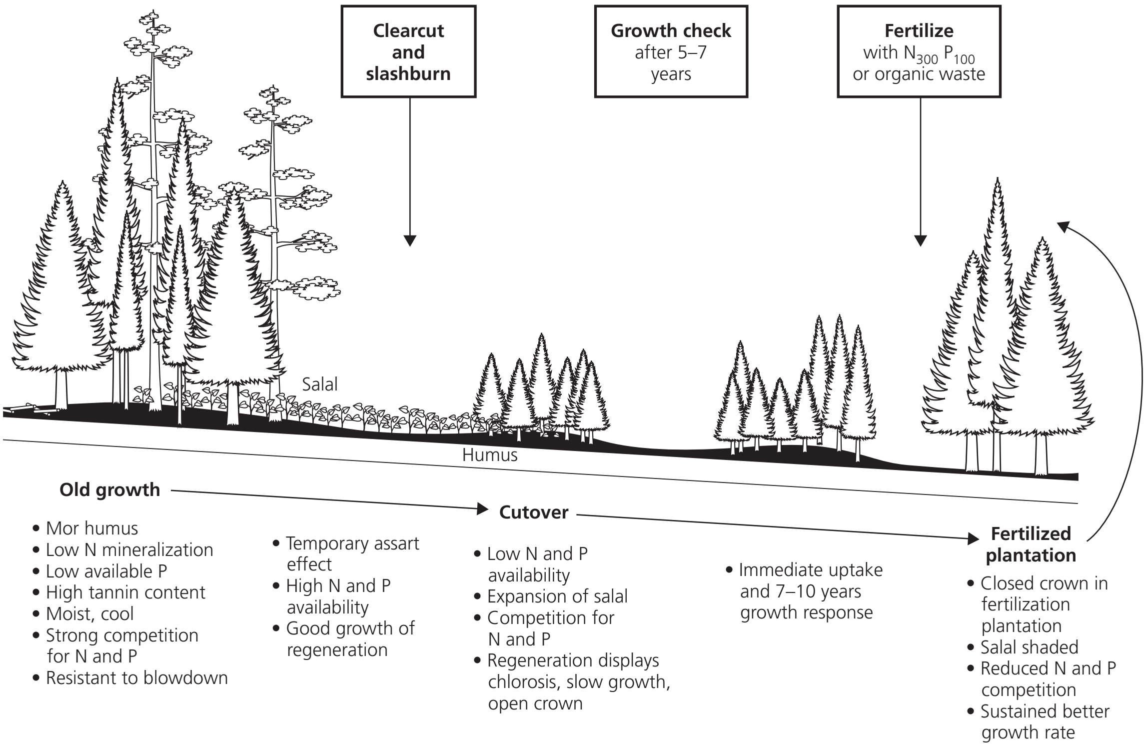

Fig. 13.5 Strategy for improving conifer growth on cedar–hemlock cutovers.

volume was greatest at 1500 stems ha^{-1}. Competition between trees is unlikely to be significant at this early stage of development. The reduced growth at higher densities is more likely related to the limited number of suitable microsites for seedlings on cedar–hemlock sites, which are characterized by uneven terrain and a prevalence of air pockets in humus.

Western red cedar is the preferred species on cedar–hemlock sites, because it will grow at acceptable rates without fertilization. However, the mean annual increment of unfertilized cedar is low. Yellow cedar (*Chamaecyparis nootkatensis* (D. Don) Spach) may be planted on cedar–hemlock sites because it grows as well as western red cedar and has a higher market value. However, some mortality due to *Armillaria* infection has been observed in yellow cedar plantations on hemlock–amabilis sites, so a maximum of 10–20% yellow cedar is recommended. Western hemlock grows poorly on cedar–hemlock sites, but responds well to fertilization, so it is a preferred species on sites for which fertilization is planned. Douglas fir grows well on drier and warmer microsites, but poorly on others. Because the cedar–hemlock ecosystem is off-site for Douglas fir, it often has poor form and low wood quality, although it can develop a dense canopy and large piece sizes. Sitka spruce and *Amabilis* fir grow poorly on cedar–hemlock sites, unless they are fertilized. Fertilization of Sitka spruce increases its susceptibility to terminal weevil (*Pissodes strobi*). The incidence of weevil is low in hypermaritime areas, but there is some evidence that it is increasing, particularly on the west coast of Vancouver Island. Both Sitka spruce and amabilis fir are better suited to sites richer than cedar–hemlock. Western white pine (*Pinus monticola* D. Don) grows well on cedar–hemlock sites, and outgrows other species on some sites. However, the prevalence of blister rust limits the use of this species, unless a scheduled pruning regime is followed to reduce the incidence of rust. Lodgepole pine (*Pinus contorta* var. *contorta*

Dougl. Ex Loud) is common on cedar–hemlock sites particularly in wetter locations, and may be useful as a nurse species for other conifers.

In summary, if the site is not to be fertilized, cedar (western red cedar and yellow cedar) should be planted, as these species will grow at acceptable rates under the nutrient-poor conditions. If fertilization is planned, hemlock could also be planted, and growth of naturally regenerated western hemlock will also be enhanced. Repeated fertilization may be necessary to maintain adequate hemlock growth, which may result in western hemlock overtopping the planted western red cedar.

13.6.3 Fertilization

Conifer growth on cedar–hemlock sites is limited by the extremely low availability of N, so fertilization is critical for improving productivity. Western hemlock, amabilis fir and Sitka spruce all respond well to N addition (Fig. 13.6); western red cedar is less responsive. Greater responses are achieved when P is added in addition to N. The response period is 5–10 years. One application significantly advances the stand towards crown closure. The recommended rate of addition is 250–300 kg N ha^{-1} and 100 kg P ha^{-1}. The cost of fertilization with N and P in 1996 was (Can.) \$550 to (Can.) \$650 ha^{-1}. Fertilizer blends in which the N and P granules are the same size ensures the even distribution of both nutrients across the cutover block. For this reason, forest-grade urea with diammonium phosphate is the preferred blend. Sites should not be broadcast fertilized until the trees are large enough to capture a significant portion of the nutrients added, i.e. at least 5 years after planting. Fertilization is most successful in immature stands on salal-invaded site series (Green & Klinka 1994) that have not reached crown closure (Weetman *et al.* 1989a,b).

Individual-tree fertilization at planting has been tested in two trials on cedar–hemlock sites. Spot application of granular NPK increased growth of newly planted cedar and western hemlock on cedar–hemlock sites. Hemlock response declined after 5 years, at which time fertilizer was reapplied in a broadcast application. Responses have also been observed in western red cedar and western hemlock seedlings that received either one Gromax teabag (24-4-7) or two Woodlace briquettes (14-3-3) at the time of planting. Additional trials are under way to compare broadcast fertilization at planting with spot application of granular fertilizer or teabags. Spot fertilization at planting may be particularly beneficial on sites which have not been burned, and may make it possible to use smaller seedlings. Some nurseries are experimenting with adding slow-release fertilizer to large-diameter plug-grown planting stock, which may provide an alternative to fertilization at planting.

Re-fertilization may be necessary after 5–10 years to maintain the growth responses of conifers on cedar–hemlock sites. It is not known at this time if fertilization will be required after crown

Fig. 13.6 Fertilization with 250 kg N ha^{-1} and 100 kg P ha^{-1} results in denser crowns, greener foliage and doubling or tripling of height growth. Hw, Cw, Ss and Ba are all responsive to fertilization of CH sites. Pictured is a plot of Hw on a CH site 5 years after N + P fertilization.

closure. Studies of the fate of fertilizer N have shown that less than 10–15% of the N applied is taken up by the trees (Tamm 1991). Most of the added N becomes immobilized in the soil and in the salal and is not available to trees after the first year, necessitating re-fertilization with N. By contrast, higher concentrations of P have been found in foliage and humus 10 years after fertilization with triple superphosphate at 100 kg P ha^{-1}. The sustained improvement in P availability after fertilization may negate the need for re-fertilization with P. Such long-term response to P fertilization has been shown for many sites (Allen *et al.* 1990). When re-fertilization is being considered, concentrations of N and P in foliage should be measured and compared with levels considered to be adequate for each species: 1.45% N and 0.35% P in hemlock, and 1.65% N and 0.16% P in cedar (Ballard & Carter 1986).

Trials with a variety of organic fertilizers have shown them to be effective for increasing conifer growth on cedar–hemlock cutovers. Response to these fertilizers applied at a rate of 500 kg N ha^{-1} are generally similar in magnitude and duration to those achieved with chemical N + P fertilizer at 225 kg N ha^{-1}. The major drawback to using organic residues is the high application cost due to low nutrient content per unit weight. Municipal sewage sludge and fish silage both increased the height and diameter of cedar trees. Mixing with pulp sludge reduced the response to sewage sludge but increased the response to fish silage (McDonald *et al.* 1994). Wood ash alone suppressed tree growth. Composted fish and wood waste and wheat straw both increased height increments and foliar nutrient concentrations of cedar during the first year after application. During the second year, height increments in the plots treated with straw increased even more, and foliar concentrations of N, P, K and S remained high. This suggests that there may be a long-term improvement in nutrient supply following the addition of fresh residues such as straw.

Sewage sludge was tested experimentally because the forest area is close to the ocean for barge transport from Vancouver and the area is relatively flat and roaded. These are factors which would facilitate the type of sludge-disposal methods already in long-time use by Seattle in the USA (Bledsoe 1981). Fish silage is available from numerous salmon farms on the coast. Fish guts and dead fish cannot be dumped in the ocean. In a greenhouse bioassay, lime applied at a rate equivalent to 5000 kg ha^{-1} did not affect growth of seedlings of cedar, hemlock or Sitka spruce.

13.6.4 Vegetation control

Several studies have demonstrated that a reduction in salal competition will increase growth of conifers on cedar–hemlock sites. Eradication of salal through manual removal followed by a single application of triclopyr ester (Release) was effective at reducing salal cover for at least 9 years. Salal removal increased growth of cedar in particular, whereas Sitka spruce and cedar responded more to fertilization. However, the cost of manual salal removal is prohibitive (US$5000 ha^{-1}), and herbicides alone are not highly effective at controlling salal. Triclopyr ester is somewhat effective (Biring *et al.* 1996), especially foliar applications in the fall with a diesel carrier (D'Anjou 1990). However, conifers can also be killed when sprayed with triclopyr ester and diesel. Burning and mechanical treatments that temporarily disrupt salal appear to be the most viable means of vegetation control on cedar–hemlock sites.

There is some evidence that repeated fertilization with N alone, totalling more than 600 kg N ha^{-1}, will cause a reduction in salal cover. Nearly total kill of salal has been observed in field trials on northern and southern Vancouver Island following the heavy application of ammonium nitrate or urea. More research is needed on the effects of high N additions on conifer growth and drainage waters to determine if this may be a viable option for controlling salal and enhancing conifer growth on cedar–hemlock sites.

13.6.5 Recommendations for regenerating cedar–hemlock sites

- Clearcutting is the most viable silvicultural system because of the need for site preparation.
- Mechanical site preparation or slash burning are necessary to disrupt the salal prior to planting conifers.
- Sites should be promptly planted with large, genetically improved stock, at 1400–1800 stems ha^{-1}.
- Western red cedar should be planted; western

hemlock may also be planted if the site is to be fertilized.

- Fertilization with 250 kg N ha^{-1} and 100 kg P ha^{-1} will increase the growth of conifers for 5–10 years. Individual tree fertilization at planting is also effective, but refertilization with N 5 years later is likely to be required to reach crown closure.
- Organic materials such as fish silage, fishwood compost, sewage sludge or fresh residues are effective fertilizers for cedar–hemlock sites.
- Manual removal of salal is effective but the cost is prohibitive; herbicides are not highly effective at controlling salal.
- A combination of salal removal and fertilization will yield greater responses than either treatment applied separately.

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