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Climate Change Adaptation: Potential Contributions of Red Alder in Coastal British Columbia

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Craig Farnden, Louise de Montigny, and
Bruce C. Larson

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The red alder resource in British Columbia has the potential to support a future hardwood manufacturing sector over 10 times larger and considerably more diverse than the current condition. Three quarters of this increase is possible simply by managing the existing red alder resource to an intensity similar to that for conifers, with the remainder of the increase relying on climate change adaptation to take advantage of potentially improved future growing conditions. Increased harvest rates would provide the Province with commensurate social benefits in terms of jobs, taxes, and royalties. Additional benefits of increased management attention would be realized through improved ecosystem resiliency and the contributions that red alder makes to a wide variety of ecosystem services.

Benefits derived from improved red alder management in British Columbia

	Harvest (1000s m^3/yr)	No. of potential jobs	Carbon sequestration (1 000 000s tonnes)	Ecosystem services	Socio-economic stability
Mean 2008–2011	55	60	n/a		
Base case LRSY[a]	515	1300	3.5		
Climate change and no adaptation LRSY	470	1200	3.3	-[b]	-
Climate change with adaptation LRSY	595	1500	3.6	+[c]	++[d]

a LRSY: Long-run sustainable yield
b - small decrease
c + small increase
d ++ large increase

Ultimately, most of the benefits to society would come from the manufacturing of lumber and secondary products. In order to develop this sector, investors need confidence that they will have competitive access to a long-term supply of raw materials. Several initiatives are required to both build that capacity and to signal investors that Government fully recognizes the value in this sector. These initiatives include:

- commitments in management unit plans to manage red alder, including targets for long-term production,
- determination of alder harvest levels in the Timber Supply Review process,
- improvements in alder inventory information and data that affect industrial access to the alder resource,
- a program of genetic management to support facilitated migration and, if financially viable, traditional tree breeding, and
- development of a competitive log market.

In light of the uncertainty and potential instability introduced to the forest products industry by climate change, it seems prudent to aggressively pursue opportunities for diversifying and increasing the resilience of the forest resource as a critical economic engine for the Province wherever possible and practical. The hardwood sector, while currently a small component of the overall industry in British Columbia, offers just such a possibility.

ACKNOWLEDGEMENTS

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This document represents a summary outcome of FFESC Project B6: "Using red alder as an adaptation strategy to reduce environmental, social and economic risks of climate change in coastal BC."

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1 INTRODUCTION

A changing global climate brings uncertainty in many forms. For the British Columbia forest sector, there is uncertainty about timber supplies, the health and productivity of ecosystems, and the benefits that society can attain from the forest through its various goods and services. In addressing these uncertainties, the range of possible outcomes needs to be anticipated, action to mitigate the negative consequences must be taken, and opportunities for gain need to be embraced. Following on this philosophy, this document provides information on potential future management strategies for red alder with specific regard to the risks and opportunities presented by a changing global climate.

Markets for products from red alder and other hardwoods in western North America have increased dramatically over the last few decades, with a thriving and profitable industry just to the south in Washington and Oregon. Similar enterprises in British Columbia could make positive contributions to the Province's long-term economic stability through job creation, taxes, and royalties.

Implementing a climate change strategy for red alder in British Columbia will not simply be a process of evolutionary adaptation of current practices and policies. The current management context for red alder is largely missing, as are the domestic markets and industries necessary for the species to contribute anything close to its socio-economic potential. A large part of the strategy, then, is to identify what those contributions could be if we choose to fully develop the opportunities provided by the red alder resource. A strong case can be made for improved alder management in British Columbia even in the absence of climate change. Amelioration of stresses imposed on ecological and human systems by climate change simply makes the case stronger.

The primary goals of this document are to (1) demonstrate how improved alder management in an era of rapid climate change can provide substantial benefits to the Province of British Columbia, (2) summarize new and to some extent existing knowledge about how the red alder resource will be impacted by climate change, and (3) identify steps that need to be taken to adapt to climate change. In order to focus the discussion, this document uses the Campbell River Forest District (CRFD) as a case study and a surrogate for the coastal resource as a whole. While the benefits of alder management are generally discussed at the provincial level, their derivation occurs mainly at the district level, particularly where forest inventory and climate change scenarios are involved.

2 HARVEST LEVELS, THE MANUFACTURING SECTOR, AND JOBS

The red alder resource in British Columbia provides an opportunity to strengthen the forest-based economy. Compelling reasons to promote a stable and profitable hardwood sector in the province include the following:

- The commercial value of red alder has been increasing. In British Columbia it now commands considerably more per cubic metre than western hemlock, and in Washington State it competes favourably on a $/m³ basis with Douglas-fir.

- The market for hardwood lumber tends to be less cyclical than that for softwoods, and, in some cases, the cycles may be out of phase with those of softwoods. Such conditions can contribute to the industry, as a whole, being less susceptible to periodic fluctuations in market demand.
- Whereas softwood lumber is generally a commodity product, hardwoods are more commonly used to produce appearance-grade and other specialty items. High-quality hardwoods such as red alder have a higher capacity than most softwoods to generate incremental economic benefits to the Province for each cubic metre harvested. Much of this results from the hardwood industry being more labour intensive than the capital-intensive softwood sector. The non-commodity nature of hardwood products also suggests that they can be more effectively promoted through marketing efforts.
- The North American market for appearance grade products is very large (approximately $200 billion per year) and growing at a rate of 8–10% per year despite a sluggish economy. Whereas $4000–$5000 of commodity lumber is required in a new home, there could easily be a demand for $50 000–$60 000 in appearance-grade wood products.

From 1993 to 2008, a medium-sized hardwood sawmill was operated in Delta, B.C. that could produce 34 mmfbm/yr (million board-feet measure per year). The reasons for closure of this mill are not completely clear—despite having higher tax and labour rates than competing facilities south of the border, the mill appears to have been profitable. Other hardwood manufacturing facilities still operating in British Columbia could potentially produce approximately 15 mmfbm/yr. Most of this capacity is in three relatively small sawmills, a re-manufacturing plant that contracts out primary log breakdown, and a plywood plant. Several other small sawmills also use alder, mostly on a custom cut or ad hoc basis. Recent harvest (Figure 1) and export rates, along with assumptions about the proportion of billed waste, suggest that the currently operating sawmills are producing less than 4 mmfbm/yr. A commonly cited reason is limited access to an affordable log supply.

There are many possible futures for hardwood manufacturing industries in British Columbia. Assuming steady-state land use cover of alder and an appropriate climate change strategy, a Provincial long-run sustainable yield (LRSY) for alder of roughly 595 000 m³/yr could be developed (see Appendix 1). This would equate to production levels of approximately 101 mmfbm/yr. These values could easily be increased if there was sufficient will, simply by increasing the land area dedicated to alder management. For example, an increase in alder cover by only 0.8% of the total commercial harvest area, focussed on appropriate sites, could increase the alder LRSY and corresponding mill production levels by 65%.

The impacts of climate change and various management approaches for the red alder resource are presented in Table 1. With no change in land cover by species, the largest gains would arise simply from complete development of the resource, and planting to achieve full stocking of harvested sites and to take advantage of tree breeding opportunities. Assuming that these initial steps are taken, climate change adaptation is estimated to provide a further

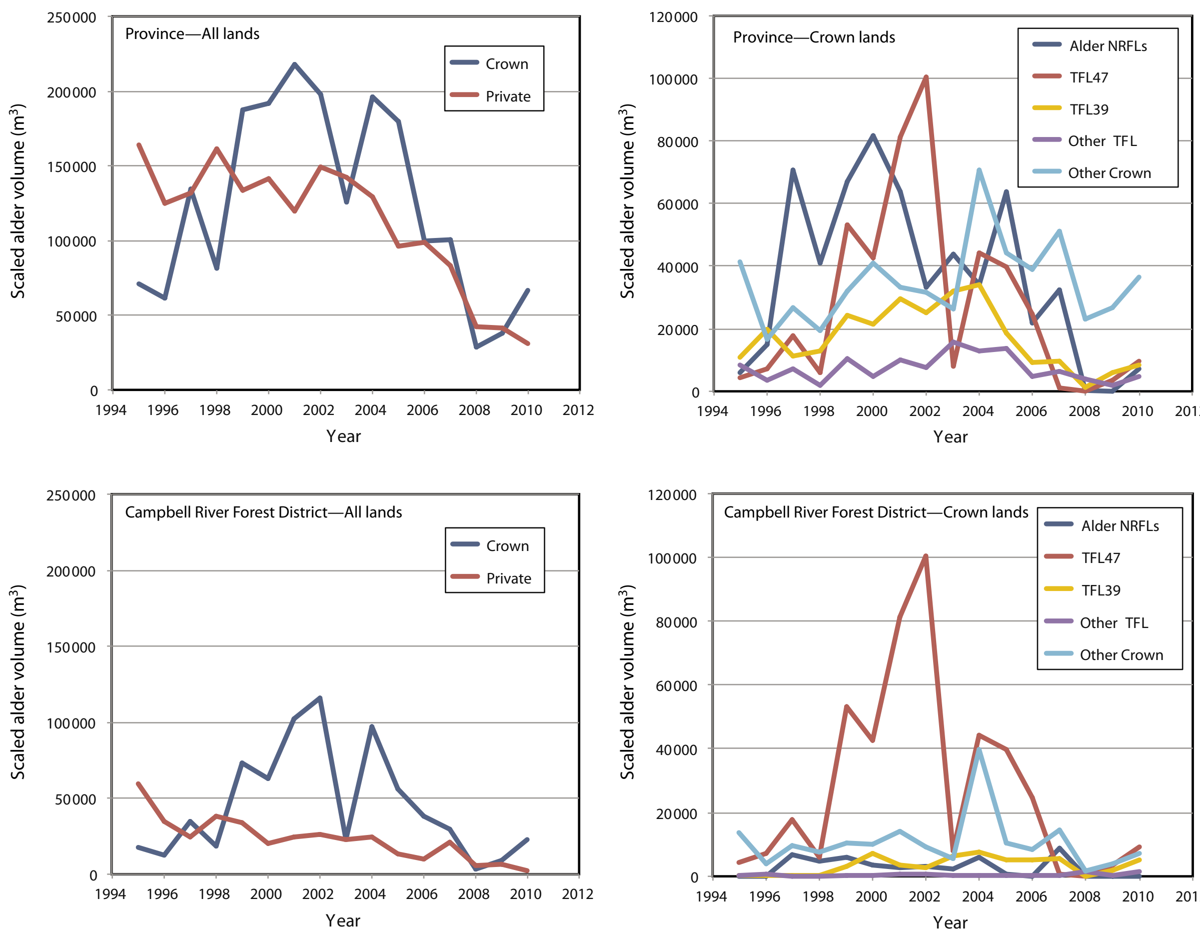

FIGURE 1 *Sources and rates of red alder harvest within British Columbia from 1995 through 2010, based on government scaling and billing records. Just under half of all harvest has come from private land, primarily on Vancouver Island. On Crown land, the primary sources have been non-replaceable forest licences (NRFLs) focussed on harvesting alder, Tree Farm Licence (TFL) 47 in the Campbell River Forest District, and the Sunshine Coast portion of TFL 39.*

TABLE 1 *Historic, current, and potential harvest levels, mill production, and jobs in the red alder manufacturing sector, with future levels reflecting four cases with different climate change adaptation assumptions. Production figures assume a lumber recovery factor of 170 bdft/m^3. Employment values assume 0.5 forestry and harvesting jobs per 1000 m^3 harvested, one manufacturing job per 170 mfbm production, and one additional spin-off job for every manufacturing job.*

	Harvest level (m^3/yr)	Mill Production (mmfbm)	No. of Jobs
Mean domestic consumption, 1995–2008	255 000	43	635
Current domestic consumption (2008–2011)	55 000	9[a]	135[a]
Potential Provincal LRSY[b]—base case	515 000	87	1285
Provincial LRSY—with climate change and no adaptation	470 000	80	1170
Provincial LRSY—with climate change and adaptation	595 000	101	1485
Provincial LTHL—with climate change, adaptation, and increased red alder cover on 05 and 07 Sites	970 000	164	2420

a These values are likely overestimates, as much of the recorded Crown land red alder harvest volume for 2008 through 2011 is believed to be billed waste.

b Long-run sustainable yield

30% increase in economic indicators such as harvest levels, mill production, and jobs.

There may be doubts about whether markets exist to support the harvest and mill production levels presented here, but one need look no further than just south of the 49th parallel for justification. Washington and Oregon have five active hardwood sawmills owned by Northwest Hardwoods, plus several independents, with a collective capacity to produce almost 300 mmfbm/yr (Figure 2). There is a general belief, however, that these mills already face serious log supply constraints. This situation is expected to worsen over the next two decades, a trend that strengthens the case to enhance British Columbia's milling capabilities to benefit from domestic supplies.

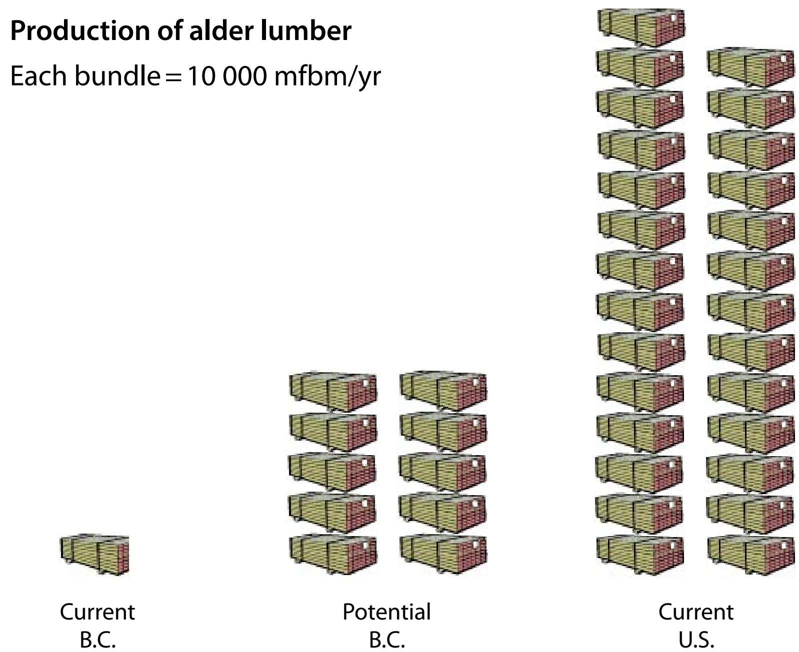

FIGURE 2 *Comparison of alder lumber production capacities for current and potential future industries in British Columbia, and the current U.S. industry.*

3 RED ALDER AND ECOSYSTEM SERVICES

As with timber supply, decisions about how much alder to promote on the landscape have at least as big an impact on ecosystem services as does climate change. Some effects that are frequently discussed but are (mostly) poorly quantified include the following:

- the inclusion in conifer stands of a significant component of broad-leaved species such as red alder helps provide a wide diversity of niches for organisms ranging from the smallest bacteria up to the largest terrestrial vertebrates and vascular plants,
- a wide diversity of organisms is generally accompanied by a wide diversity of energy pathways and other ecosystem linkages,

- where nitrogen is limiting, red alder can improve ecosystem productivity through symbiotic fixation of nitrogen from the atmosphere,
- red alder is resistant to the Phellinus root disease of conifers, and can be planted where the disease would otherwise be problematic, and
- broad-leaved species in general are more resistant than conifers to the spread of wildfire, and can be used in planned firebreaks. This characteristic could, on its own, justify considerable increases in red alder management on lands surrounding coastal communities.

Of these effects, fixation of nitrogen is the most studied and quantified, with soil nitrogen additions reaching 200 kg/yr. This characteristic can be used to improve productivity of other species, such as Douglas-fir, on nitrogen-poor soils. Strategies for taking advantage of this effect include establishment of intimate or patch mixedwoods, and alternating rotations of alder and conifers. In the former strategy, positive effects on soil nitrogen levels have been observed up to one tree length from an alder patch into adjacent conifer patches. With alternating crops, recent evidence has shown carry-over benefits from an earlier rotation of red alder to a later crop of Douglas- fir. Such benefits can include positive effects on crop tree growth without the financial costs or the carbon costs related to the manufacture and transport of artificial fertilizers.

Another ecosystem effect of concern is the impact of alder management on total ecosystem carbon. Based primarily on assessment of above-ground biomass, an increased emphasis on alder management is likely to have a small (< 5%) but positive impact (Appendix 1). While overall growth rates are likely to increase, suggesting a higher rate of carbon capture, the rate of turnover is also faster due to substantial use of short-rotation management (25–30 years). Other elements such as changes in soil carbon are weakly understood, and there is no strong evidence to suggest that long-term changes in carbon pools occur under a landscape-level collection of pure and mixedwood stand regimes.

4 THE CAMPBELL RIVER FOREST DISTRICT AND ITS RED ALDER RESOURCE

The Campbell River Forest District is located on the central portion of Vancouver Island and adjacent portions of the coastal mainland to the northeast (Figure 3). While the District is mostly mountainous, a rolling coastal plain runs along the eastern side of the Vancouver Island portion. There are several mid-sized drainages, including those of the Gold, Adam, Eve, Salmon, and Campbell Rivers. Major service centres within the District include the towns of Campbell River, Comox, and Courtenay; smaller communities exist at Gold River, Tahsis, Sayward, and Zeballos. These towns, which have a heavy economic dependence on the forest industry, have a combined population of 86 000. External service and manufacturing centres include Nanaimo, Victoria, and Vancouver.

The total land area of the CRFD is approximately 1.5 million ha, of which about 1.3 million ha are forested. Within the District, 270 000 ha are devoted to provincial parks, 181 000 ha are privately owned, and 2366 ha are in Indian Reserves (Figure 4). The timber producing Crown land is divided primarily

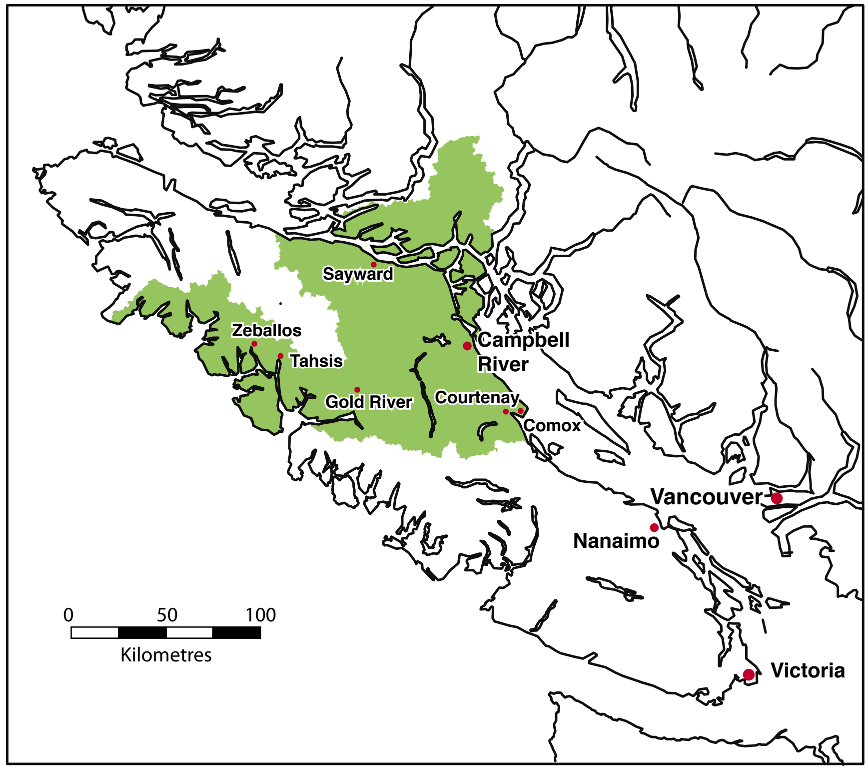

FIGURE 3 *Location of the Campbell River Forest District and associated communities.*

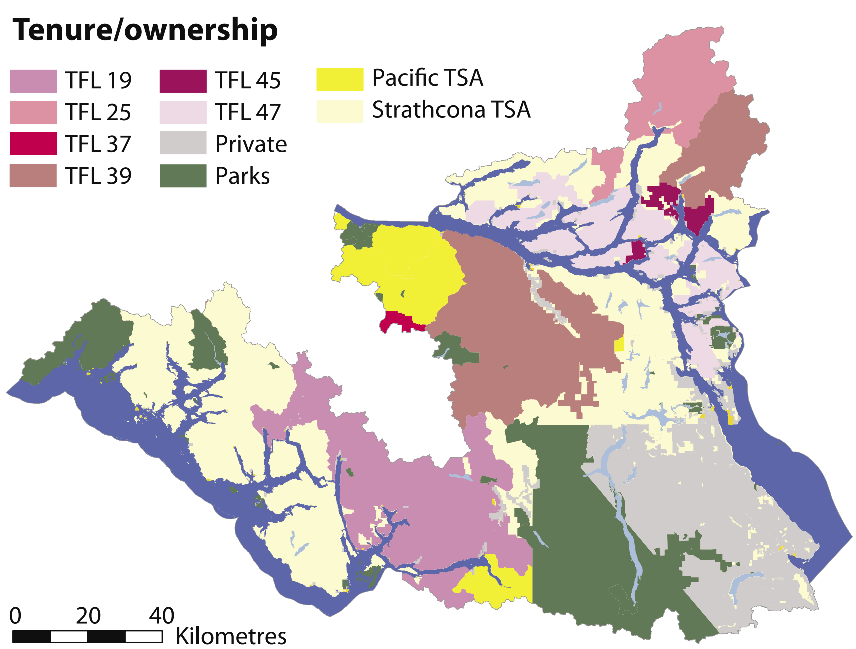

FIGURE 4 *Distribution of land ownership, parks, and Crown forest management units within the Campbell River Forest District (TFL: Tree Farm Licence; TSA: Timber Supply Area).*

into two Timber Supply Areas and six Tree Farm Licences but also includes a small area in woodlots.

As a surrogate for the entire coastal resource, the CRFD serves very well in some regards and less well in others. All coastal districts are mountainous, with red alder growing on similar sites regardless of location. From an access perspective, some portions of the CRFD have very good access, which is typical in populated portions of the south coast, and others have predominantly marine access, such as prevails on the central and north coast areas. All districts have distinctly different community structures and access to markets.

Red alder is a minor species within the District, comprising only about 1.7% of the total forest cover (Figure 5a). The species is concentrated at lower elevations, on gentle slopes (Figures 5b, 5c, and 6), and on better sites (Figure 7). The prevalence of red alder along either side of Johnstone Strait and Discovery Passage in the northeastern portion of the District coincides with a predominance of low-elevation sites with a favourable climate and rich marine-clay soils. A second factor that likely contributed to red alder's prevalence in this area is the higher frequency of fire disturbance that existed on the dry leeward side of Vancouver Island compared to the windward side prior to the start of commercial timber harvesting. Where natural stand disturbance was infrequent, long-lived conifer stands dominated the landscape and left little opportunity for shade-intolerant species such as red alder to regenerate. A third factor that likely contributed to the prevalence of red alder in this area is the relatively high degree of soil disturbance that often occurred as a result of harvesting practices employed on easily accessible areas of the eastern Vancouver Island plain and coastal areas along Johnstone Strait in the early 1900s. Such practices created ideal conditions for alder to germinate and capture growing space.

In the latter half of the 1900s, harvesting methods changed in order to create less ground disturbance, and the rate of alder establishment waned. It further diminished starting in the 1970s due to aggressive vegetation management practices that favoured conifers, particularly Douglas-fir. Such practices were taken to the extreme during the 1980s and 1990s, when alder stands were targeted for conversion to conifer plantations at great expense. The negative attitudes toward red alder that led to such practices continue to be pervasive throughout the forest management community today.

In the last two decades, alder has been heavily targeted for logging, and much of the easily accessible alder has already been harvested. This is particularly true on the east coast of Vancouver Island and adjacent small island and mainland areas along Johnstone Strait. Less harvesting has occurred on the west side of Vancouver Island.

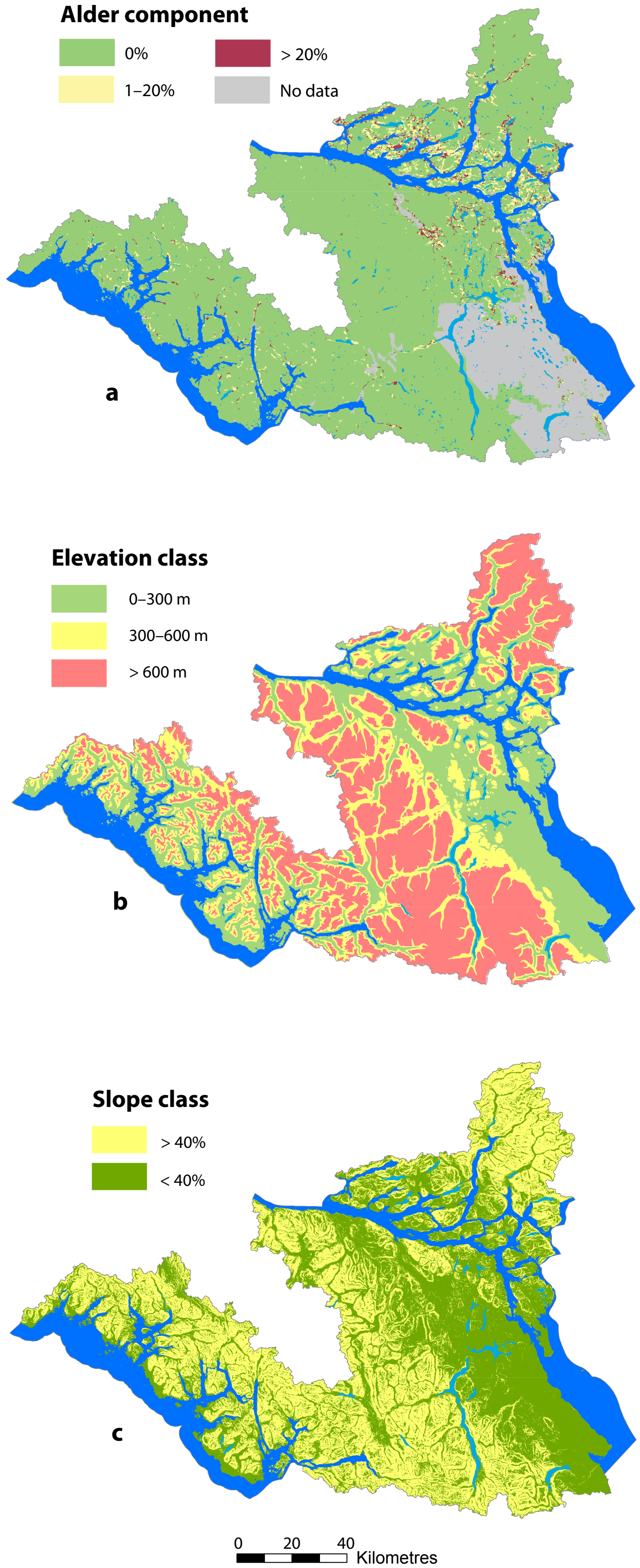

FIGURE 5 *Thematic maps of the Campbell River Forest District. Red alder forest cover is concentrated primarily (a) on either side of Johnstone Strait and Discovery Passage, (b) at low elevations, and (c) and on gentle slopes.*

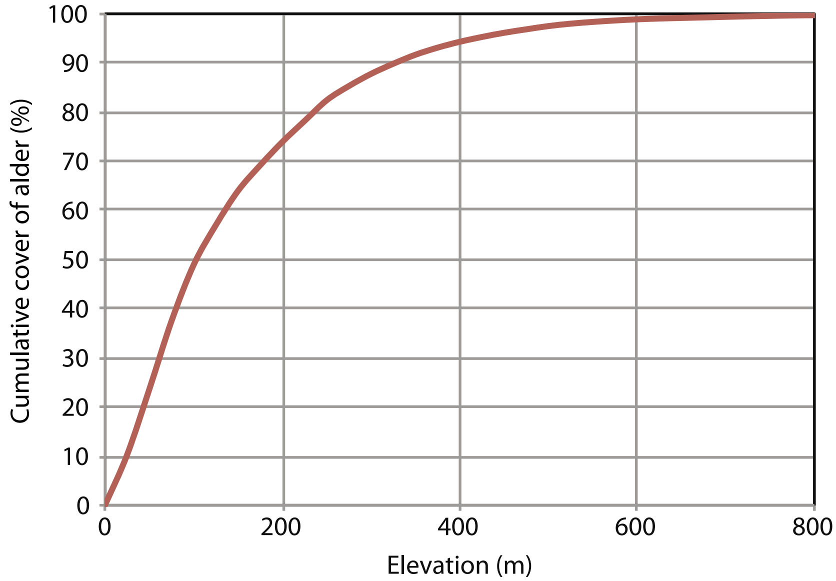

FIGURE 6 *Cumulative percent of total red alder cover by elevation as recorded in inventory files compiled in early 2011. Seventy-three percent of the red alder on Crown land in the Campbell River Forest District is below 200 m elevation, and 94% is below 400 m. Field sampling on Vancouver Island in summer 2011 indicated that alder occurrence at elevations above 400 m is likely overestimated.*

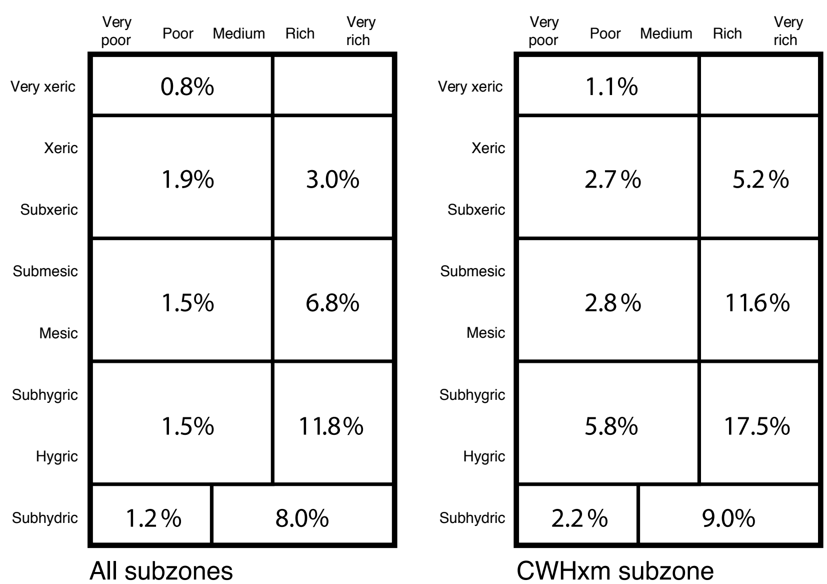

FIGURE 7 *Area-weighted coverage of red alder by edatope class within the Campbell River Forest District for the entire Coastal Western Hemlock (CWH) biogeoclimatic zone (left) and the low-elevation CWHxm (very dry maritime) subzone (right). Mean coverage for the CWH zone is 2.7%, and for the CWHxm subzone is 4.6%. Note that a substantial proportion of alder cover in the hygric–subhydric, rich–very rich class is associated with floodplain systems and riparian management zones.*

There is concern that long-term supplies of red alder as a timber-producing species will be heavily impacted by climate change. This concern is evaluated here by combining knowledge and theory from several sources:

- recent research projects conducted to support development of this red alder climate change adaptation strategy,
- extensive familiarity with biogeoclimatic ecosystem classification (BEC) and the associated mapping of biogeoclimatic zones and subzones, and
- three climate change scenarios recommended by the Pacific Climate Impacts Consortium as a minimum expression of the range of potential future climates for use in British Columbia (Murdock and Spittlehouse 2011).

Within the CRFD, red alder is associated primarily with lower elevations in the Coastal Western Hemlock (CWH) biogeoclimatic zone. The nine CWH subzones within the District provide a convenient framework for describing patterns of relevant climate change over time, based on their associated climate envelopes (Figures 8 and 9) (Wang et al. 2011).

While considerable variation in projected climates is evident under the three scenarios evaluated, there are several consistent trends within the District:

- The climate envelope currently associated with the Mountain Hemlock zone is predicted to become much smaller and to retreat to the highest elevations currently occupied by the Coastal Mountain Heather–Alpine zone. This latter climate envelope largely disappears.
- The climate envelope associated with the CWH Submontane Very Wet Maritime (CWHvm) subzone becomes increasingly prevalent on the windward side of Vancouver Island and at mid-elevations on the mainland but disappears from the leeward side of Vancouver Island.
- The climate envelope associated with the CWH Dry and Very Dry Maritime variants (xm1, xm2, and dm1) and/or closely associated but currently undefined subzones is predicted to become dominant on the leeward side of Vancouver Island across a very wide range of elevations.

Given that current alder cover in the District occurs predominantly within the CWHxm1, CWHxm2, and CWHvm1 variants (Figure 5a and current variants in Figure 8), the continued prevalence and/or expansion of climate envelopes associated with these units bodes well for future management of red alder.

For zonal sites that best reflect regional climates, recent models (Cortini et al. 2012) have employed a balance of growing-season temperatures and growing-season moisture availability to predict climate-induced changes in red alder growth rates. Application of these models within the CRFD for BEC units where alder is currently common suggests 7–10% increases in alder growth rates by the 2050s as an average effect of the three recommended pro-

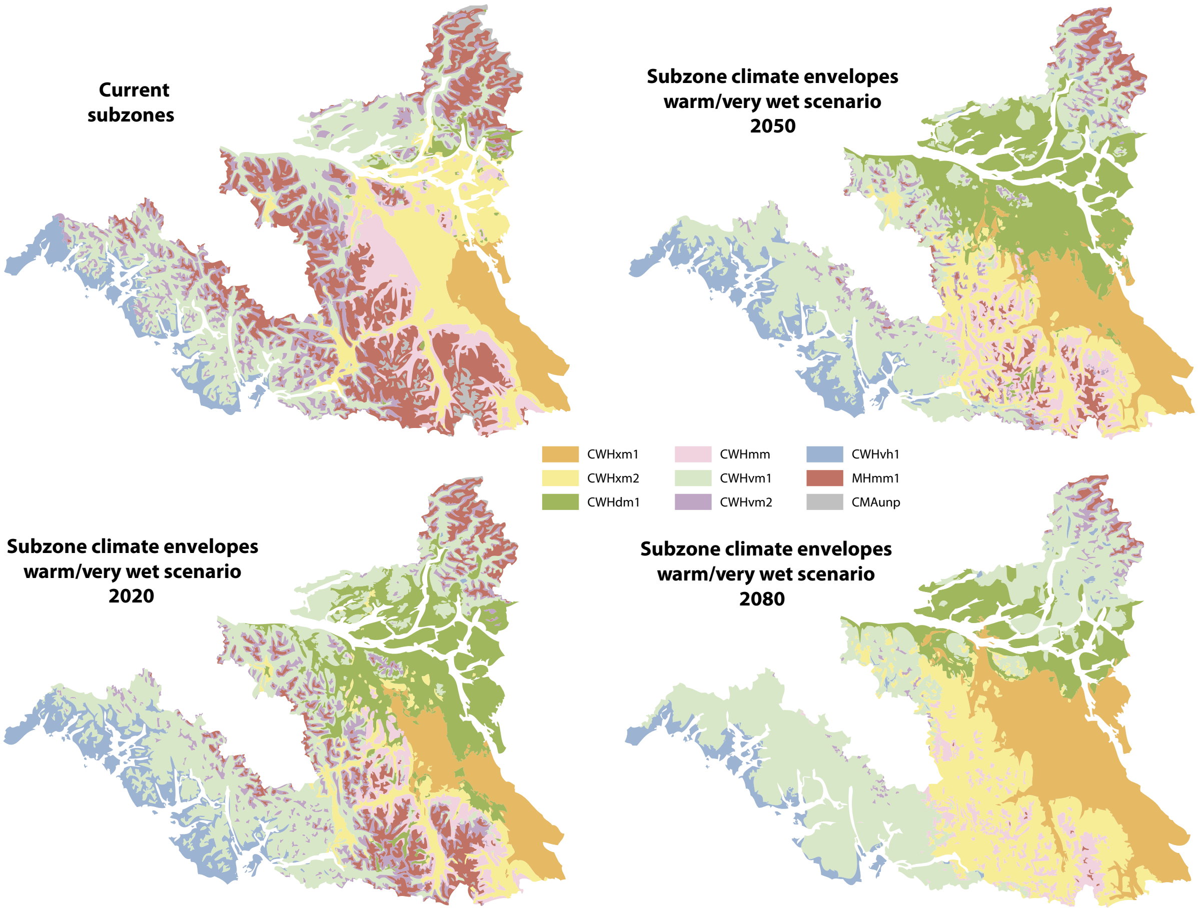

FIGURE 8 *Climate envelopes currently associated with biogeoclimatic subzones within the Campbell River Forest District (top left), and forecasts for three time periods (2020s, 2050s, and 2080s) for the provincial warm/very wet scenario. The extreme elevational range of the future CWHxm envelope likely results from the inclusion of predicted new climate envelopes for which there currently is no analogous subzone defined.*

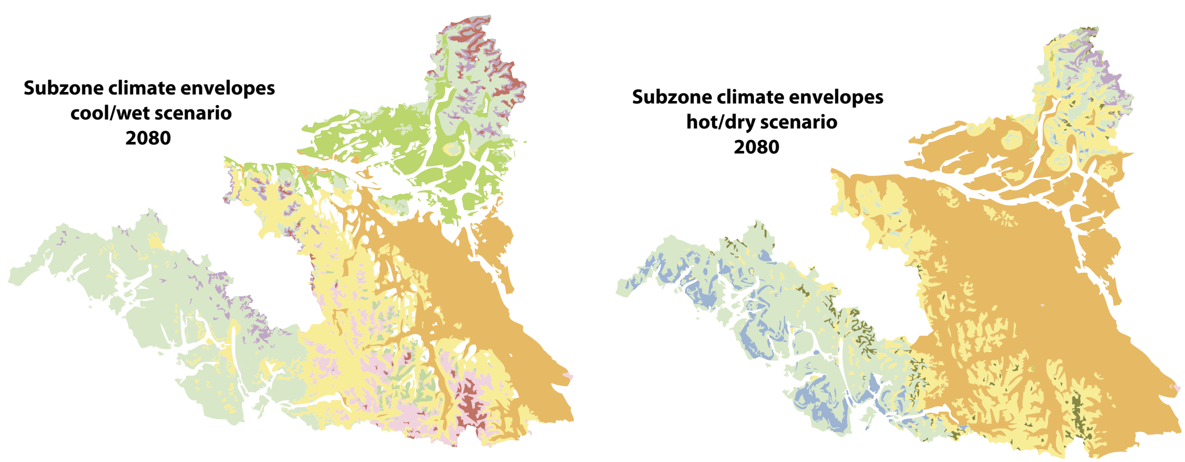

FIGURE 9 *Forecasts for the extent of future climate envelopes within the Campbell River Forest District in the 2080s for the provincial cool/wet and hot/dry scenarios. For this District, the hot/dry scenario appears to result in the greatest degree of change when compared to the warm/very wet scenario in the bottom right portion of Figure 8.*

vincial climate scenarios. Variations between the scenarios were in the order of 1–3 percentage points.

While these trends are useful, it is also important to recognize that a large proportion of alder cover is currently found on wetter than zonal sites (Figure 7), where potential increases in photosynthetic activity supported by increased temperatures are less likely to be restricted by drought stress than on zonal and drier sites. As a result, subhygric and moister sites are the most likely to experience increases in alder growth rates with climate warming.

6 VULNERABILITIES AND GENETIC MANAGEMENT OF RED ALDER

An important vulnerability of red alder relates to its genetic adaptation to climate. Recent research in common garden studies (Porter 2011) suggests that red alder is highly adapted to regional climates and will not acclimate physiologically to significant changes in climate. This may limit the ability of both in situ alder and new trees of natural seed origin to take full advantage of climatically improved growing conditions that could be experienced on the best growing sites.

Two factors important in red alder's genetic adaptation to climate are localized patterns of tolerance to frost and drought, factors that are believed to have large impacts on site-specific productivity. Overall growth can be impacted by both overwinter and growing-season tissue damage related to cold temperatures, and by the pattern of leaf senescence through the growing season and into autumn.

Caution regarding the planting of alder on frost-susceptible sites is a common missive in management guides for the species, and is based on frequent observations of tissue damage following growing-season frost events. Whereas dehardening and bud break in spring appear to have minimal variation across provenances, the onset of frost hardiness in autumn is variable based on latitude and/or continentality of genetic source material. Such patterns are important in the deployment of genetic sources under a changing climate, particularly given that there is little or no evidence thus far of a change to the frost-free period despite overall spring and fall warming.

Many of the climate sensitivities of red alder relate to its propensity to break cold dormancy early and to continue growing late in the season. For example, leader extension has been observed into October, and full leaf senescence can be delayed until well into December. These factors likely contribute to a competitive advantage for the species under favourable climatic conditions, but such conditions in the past have been limited to the lowest elevations in British Columbia and the Pacific Northwest in the U.S.

Red alder is generally viewed as a drought-susceptible species. A common response to drought is the closure of leaf stomata, which saves water but reduces photosynthesis and overall productivity. However, trees can quickly reopen stomata once drought conditions subside. An alternative strategy to avoid drought is early leaf senescence, which has potentially greater productivity implications. The prevalence of both strategies appears to be genetically controlled, although the pattern of variation geographically is poorly quantified. While drought tolerance may be a factor to consider in managing deployment of genetic sources, it may not be as important as cold hardiness.

Genetic selection of appropriate families will likely be influenced by these and other factors. Estimates of the breeding potential of red alder suggest that yield gains of well over 20% are possible. It seems likely that a breeding program could be coupled with work to choose physiologically suited families for facilitated migration. On its own, appropriate facilitated migration would help ensure that managed alder plantations use genetic sources best suited to improved growing conditions related to climate change.

7 APPROACHES TO GROWING RED ALDER

The implementation of climate change strategies is at least partly dependent on basic stand management tactics. Three general approaches are commonly recognized for growing red alder (Silviculture Working Group 2007). The first, dubbed the mixedwood option, continues to be adopted by most coastal licensees in British Columbia, particularly where alder is not being harvested as the primary crop species. This approach relies primarily on natural regeneration, often accepted on an ad hoc basis within areas otherwise managed for conifers. Whether naturally regenerated or occasionally planted, these stands are allowed to self-thin naturally and are expected to be harvested on rotations of 50–70 years, depending on site quality. A target tree size of at least 30 cm dbh is often considered ideal. The perceived advantage of this option is its low thresholds for establishment costs and risk.

A second approach is extensive plantations, where alder is planted to ensure high stocking levels to maximize production. With carefully selected plantation densities, improved tree form and desirable rates of diameter growth can also be achieved. In comparison to naturally regenerated alder, plantations generally achieve greater estate-level yields on rotations of 30–40 years.

The extensive plantation establishment approach has significant advantages over mixedwood management for generating and maintaining climate change adaptation options. These include the following:

- Plantations allow for control of the genetic source of the trees, thereby strengthening opportunities for both facilitated migration and use of improved seed from (not yet existing) tree improvement programs.
- Plantations allow for alder expansion to new growing sites as they become suitable under a warming climate, such as mid-elevational areas within the CRFD. Note that the feasibility of such expansion may be limited by slope steepness because cable harvesting of alder is not generally considered to be a financially viable operation.
- Shorter rotations from plantation management of alder allow for maximum flexibility to adapt to changing climates as they occur. A shorter lag in response to climates should allow for improved deployment of genetic resources.
- Plantations intended to utilize the nitrogen-fixing abilities of red alder can be interspersed with rotations of other species such as Douglas-fir to maintain higher levels of overall site productivity.

A third approach, intensive plantations, has recently received considerable attention and debate on both sides of the Canada–U.S. border, although there has been somewhat greater application in the U.S. Under this approach, stands are planted at moderate to high densities to promote straight stems with small branches, and then are thinned at a height of 10 m to promote rapid diameter growth (Figure 10). In some cases, trees may also be pruned (Figure 11). With these management scenarios, similar-sized sawlogs with an overall improvement in grade recovery can be produced in 25–35 years. Such shortened rotations can be very important for managing timber supplies, and

FIGURE 10 *Red alder in Oregon, SI50 = 31 m, planted to 1600 trees/ha, and thinned to 630 trees/ha at age 17.*

FIGURE 11 *Red alder in Oregon, SI50 = 31 m, age = 17 yrs, planted to 700 trees/ha, and pruned.*

in particular for helping fill projected supply deficits that are still one to three decades away. In the U.S., revenue generated with good-quality alder logs is now similar to that of second-growth Douglas-fir, thus making returns on this type of investment attractive. However, there is a trade-off. Results of research trials and simulations with both the Tree and Stand Simulator (TASS) model in British Columbia and the ORGANON model at Oregon State University indicate stand level yield losses of up to 10% or more as a result of thinning for accelerated diameter growth.

Beyond plantation management of alder in pure stands, there are also options for intimate and patch mixedwoods. The former makes most sense on nitrogen-poor soils, where admixtures of alder can improve overall growth of Douglas-fir (Comeau et al., in prep.). On richer sites, intimate mixtures of alder within fir stands make less sense because the nitrogen fixation capabilities of red alder offer a lesser benefit. Wood quality of the alder in such stands will also likely be degraded because the alder will outgrow the fir early in the rotation and will have insufficient crowding to promote good stem form and minimal branchiness.

On good growing sites, mixedwoods are likely best managed with the alder in patches. These need to be large enough that a large percentage of the trees are interior to the patch and not experiencing edge effects.

Where desired, patches of alder can still improve soil nitrogen for up to one tree length into adjacent conifer stands. With climate warming, the separation of alder and Douglas-fir into distinct patches may become even more important, as there is some evidence that the competitive interactions between the species will become more severe. For example, it appears that alder has stronger competitive effects on Douglas-fir and other conifers in Oregon than in British Columbia.

Overall, the silvicultural management of red alder requires an amended toolbox from that currently employed for conifer management. As a start, several compendia on the technical aspects of managing red alder are listed in Appendix 2.

8 KEY INFORMATION GAPS

Throughout the development of this document and its associated studies, several important deficiencies in the knowledge base concerning red alder management became apparent. In no particular order, these include the following:

- Collection of accurate inventory data for hardwoods has not been a priority and needs to be improved. Of particular concern is the accurate aging of stands and the collection of information on age-related decline (stand break-up).
- There appears to be significant locational variation in form and grade of logs. Information is needed to quantify this variation, and ideally its causal effects, such as genetics and/or local climate.
- There is considerable uncertainty surrounding the hardwood timber harvesting land base, particularly given that a significant portion of the

coastal hardwood resource is associated with riparian areas (20% or more in the CRFD) and other management zones with management restrictions.

- There is some evidence that higher than average numbers of species at risk are associated with broad-leaved stands. Work is needed to identify hazards associated with further damaging sensitive populations and to delineate appropriate conservation strategies.
- Additional work is needed to identify genetic family characteristics related to stress tolerance and growth, with a particular emphasis on frost and drought.
- Further work is needed to identify cost-effective options for genetic management of red alder.
- Additional work is needed to understand how climate, site, and other factors influence interactions between alder and conifers in mixed stands.

9 IMPEDIMENTS TO CLIMATE CHANGE ADAPTATION FOR RED ALDER

Two main hurdles need to be overcome in order to initiate a climate change adaptation strategy for red alder. The first is a pervasive conifer bias that exists throughout all forestry sectors, including government, licensees, consulting, and academia. In all of these, there is still a common reaction of incredulity when the concept of active management of red alder is raised. The perceptions that alder is a weed species, is good only for firewood, or is a small niche market species are difficult to overcome based on many decades of exposure to such beliefs.

The second major hurdle is for all levels of government and the forest industry to accept the need for climate change action in general and for adaptation plans specifically. It is clear, particularly for government, that this process is at least partly under way. The Government of British Columbia has made substantial financial commitments to forest-sector climate change research, which is a positive step. However, there has been little to date on changes to management policy and direction. For the most part, current government policy is focussed on forest management by licensees, with minimal direction from government, and licensees have demonstrated little appetite for management options beyond the status quo. Substantive change under this set of conditions is unlikely to occur.

A clear example of the difficulty in implementing change under the current regulatory framework is the lack of reaction to the report "Hardwood Management in the Coast Forest Region" (Silviculture Working Group 2007). This document provides clear guidance on adopting progressive hardwood management but has had very little uptake. Harvest targets set for each Forest District are sufficient to achieve a future sustainable harvest of 300 000 m^3/yr on Crown land, but current rates are falling far short. Volumes for 2008 through 2011 averaged 44 000 m^3/yr, including incidental harvest and billed waste from conifer blocks. While this can be at least partly attributed to the closure of the Northwest Hardwoods mill in Delta, it coincides with claims by existing mill operators that lack of affordable access to alder sawlogs is hurting their businesses.

Other possible reasons for the current lack of enthusiasm for alder management and manufacturing include the following:

- Conifer licensees are short staffed under the current economic climate and are sticking to practices with which they are familiar, thus minimizing costs for learning new practices and maintaining low levels of risk.
- Operational staff employed by many of the conifer licensees recognize the land base benefits of growing alder, but upper levels of management appear focussed primarily on supplying fibre to their own sawmills and/or traditional customers.
- The big-picture benefits of alder management, such as diversification of the wood processing sector, accrue mainly to new start-ups, government, and society. It is often difficult for existing conifer licensees to justify the uncertainty of new management approaches unless they are direct beneficiaries.
- Conifer licensees are concerned about the impact of widespread alder management on allowable cut levels for conifers and perceptions of higher costs for alder management compared to traditional conifer management.
- There are uncertainties about access to appropriate seed and/or planting stock.
- On the investment side, there is uncertainty about long-term access to raw materials because (1) much of the alder harvest is occurring under non-replaceable forest licences, all held by a single company, (2) there is a general lack of interest by most tree farm licence (TFL) holders in harvesting alder for the domestic market, (3) there are strong memories of the alder eradication and conversion programs of the 1980s and 1990s, and (4) there is inconsistent access to alder logs through log markets.
- There is a lack of commitment to alder management in higher-level plans, Forest Stewardship Plans, and management practice, as reflected in Timber Supply Review evaluations and allowable annual cut determinations.

In addition, the processes of harvesting and transporting red alder logs, and the final manufacturing of alder products, have some unique attributes that distinguish them from comparable processes for conifer products. In some cases, inadequate understanding of these differences leads to poor integration of efficient alder utilization within the larger conifer-dominated forest industry. Some of these factors are as follows:

- Time from stump to kiln (net of rafting/booming time) is critical to avoid fungal staining, particularly in summer.
- Minor components of alder in conifer stands need to be processed first in order to capture value. The onset of value degrade for red alder logs can be rapid if left sitting in log decks, particularly in summer months.
- Saltwater rafting of logs can extend storage times somewhat, but it may introduce the need for special dry kiln regimes to avoid appearance degrade.
- Wood-based manufacturing industries that rely heavily on appearance products are most successful with tight integration of primary breakdown and follow-up processing. Unlike commodity lumber, specifications for appearance-grade lumber can vary considerably, and knowledge of end use in the last manufacturing step can influence all previous steps.
- As reflected in hardwood markets elsewhere, there is a need for a wider range of log grades than for softwoods; this need is not currently reflected in the Vancouver Log Market.

In policy to date, the hardwood sector in general, and the red alder sector in particular, have been treated as smaller versions of the conifer sector, with no distinction between raw material inputs. This is inaccurate and potentially damaging. The hardwood processing sector is a distinctly different entity from the softwood processing sector, and raw materials are not generally interchangeable. As a result, the hardwood sector may be particularly vulnerable to large fluctuations in harvest rates (as shown in Figure 1), especially when dictated by non-market forces such as imbalanced age class distributions and varying transport costs where past harvesting has concentrated on the cheapest access.

Government action is key to the successful implementation of a red alder adaptation strategy. Solutions to documented impediments require government support through planning and policy incentives designed to address key uncertainties.

10 RECOMMENDED ACTIONS

A climate change adaptation strategy for red alder would take advantage of both market opportunities and the likelihood that improved growth of the species can be achieved through appropriate deployment of genetic family traits. In moving forward, there are several strategic issues that need to be addressed, some that involve considerable investment and some that are purely signals from government to industry that a favourable investment climate is likely to develop. The following is a list of such strategic issues and recommended courses of action:

1. As a result of climate change, growth losses may be experienced for in situ populations of red alder. Conversely, selection of appropriate families for facilitated migration and a red alder breeding program offer considerable promise for growth gains.

   Breeding programs are expensive and the alder resource is relatively small; therefore, it is recommended that the Province undertake a benefit/cost analysis to determine an appropriate strategy to deal with genetic management of the species. Given that the ability to select appropriate parentage for tree seedlings is needed immediately, such an analysis is considered to be an immediate priority.

2. A reliable inventory and timber supply analysis for the red alder resource is needed to inform current investors about potential log supplies in the 0- to 30-year term.

   When Coast Mountain Hardwoods (later the Northwest Hardwoods Division of Weyerhaeuser) originally established the Delta sawmill, it did its own survey of the alder resource to ensure that an adequate short- to mid-term supply existed to justify their investment. Two decades later, that information is not generally available, and the resource has experienced considerable depletion, with many of the harvested stands being regenerated to conifers.

In order to better inform itself and potential investors for strategic planning, the Province, at the minimum, should require that (a) attention be paid equally to hardwoods and softwoods in all future inventories, and (b) hardwood cut levels be determined in all future timber supply analyses. In the short term, an analysis of current inventories should be undertaken to determine short- and mid-term supply constraints, including effects of age-related decline in the current growing stock, economic accessibility, regional variation in log quality, and land base net downs for factors such as visually sensitive landscapes and rare or endangered species and ecosystems.

3. The economic contributions to society from a hardwood industry on the coast of British Columbia will be dictated by the industry's size and relative stability. These in turn are dictated largely by the magnitude of, and temporal fluctuations in, the hardwood (primarily red alder) resource.

   The Province should take the view that red alder is a strategic resource that can help provide economic and social stability. As such, the Province should implement policies that will ensure that a stable supply of red alder logs of sufficient quality and quantity is available to sustain future hardwood industries. The Province should also ensure that alder is deployed on the landscape in a manner that best takes advantage of its environmental benefits. At a minimum, this should include reforestation policies to ensure a non-declining cumulative commitment of land area for growing alder. Ideally, the Province would set targets for the desired size of a future hardwood industry, and implement policies to ensure an adequate supply of raw materials for that industry. Considerations should not be restricted by the current extent of the alder land base but should be open to expansion if that is in the best interests of society.

4. Management targets are needed for cover and spatial patterns of red alder based on its contributions to overall ecosystem resilience and habitat diversity, and its ability to provide effective fire breaks. Location dependence is of particular concern for the latter two factors, with habitat value often being associated with proximity to watercourses or other geographic features, and the need for fire breaks being associated with communities or other important infrastructure. Overall, the ecosystem services provided by red alder and other hardwoods are considerable, and the relative value of these services is magnified as a result of their low abundance on coastal forested landscapes.

5. The Province needs to implement effective policies that will promote appropriate management actions to shape the future alder resource.

   Recent licensee performance clearly indicates that management policies need to go well beyond the current non-binding guidelines established in the "Hardwood Management in the Coast Forest Region" document. Forest management is all about setting objectives for the resource and ensuring that appropriate goals are met. One of the primary reasons that the current guidelines are not working is that targets are set at the District level, with no single individual or licensee responsible or accountable for implementation. At the same time, most licensees appear to see little corporate benefit in managing for alder. For effective management to work in an administratively fragmented forest, it is important that all parties recognize and accept their individual responsibilities for achieving the collective goals.

6. An open and transparent domestic alder log market is greatly needed to support development of a thriving domestic hardwood manufacturing sector in British Columbia. Markets work best when there are multiple sources of supply and demand.

   Over the last two decades there have been only three primary sources of alder sawlogs (four if Timberwest's private and Crown holdings are considerd separate). Markets could be influenced considerably by one player choosing not to harvest in any given year or attempting to focus on export markets. The demand side was previously dominated by the Delta sawmill while it was in operation, and the current situation is considerably muddied by a disproportionately large export demand.

7. Information gaps need to be filled.

   Items identified in sections 2 and 8 of this document that have not been addressed in these recommendations should be flagged as information needs to be addressed by provincial forest research and inventory programs.

   Climate change adaptation strategies for forest management on public lands focus primarily on net benefits to society through accessing economic opportunities and enhancing ecosystem resilience. In moving forward on a climate change strategy for red alder, there is a strong need for a single entity to provide leadership: most individual licensees and corporations will voluntarily do only what they perceive to be best for their own interests. Government leadership is required.

This document inherently assumes that manufacturing of products from red alder in British Columbia is a worthwhile commercial venture. Such enterprises can make positive contributions to the province's long-term economic stability through job creation, taxes, and royalties. In light of the uncertainty and potential instability introduced to the forest products industry by climate change, it seems prudent to aggressively pursue opportunities for diversifying and increasing the resilience of the forest products sector wherever possible and practical. While it is a small component of the overall industry, the hardwood sector in British Columbia offers just such a possibility.

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Silviculture Working Group. 2007. Hardwood management in the Coast Forest Region. Coast Region Implementation Team. www.for.gov.bc.ca/rco/stewardship/CRIT/docs/ Hardwood Management in the Coast Forest Region (final July11V2).pdf

Wang, T., E.M. Campbell, G.A. O'Neill, and S.N. Aitken. 2011. Projecting future distributions of ecosystem climate niches: uncertainties and management applications. For. Ecol. Manag. 279: 128–140.

Estimates of potential supplies of alder logs and carbon storage as impacted by management assumptions and climate change are derived here using a modification of Hanzlik's formula, wherein the mean annual increment (MAI) for a particular stratum of stands is multiplied by the total area available in those stands. The long-run sustained yield (LRSY) is then summed from the collection of results for each stratum. Due to time and budgetary constraints, the current analysis has been completed only for the Campbell River Forest District (CRFD). Estimates for the remainder of the coast are then derived using a simple multiplier.

The relatively simple methods employed here are not intended to replace a thorough timber supply analysis using modern forest estate models. However, they will suffice to provide initial estimates of the potential size of an alder processing industry that could be supported. The major drawback to this method is its insensitivity to the current condition of the inventory, and in particular its ability to support a steady state supply of timber over the short term in the absence of a normalized forest, where all desired age classes are equally present. Other limitations include a gross generalization of factors such as area net downs for riparian and other sensitive sites, and the impacts of access limitations in remote areas.

Log supplies—Campbell River Forest District

Four case studies on the long-term potential yield of alder logs from the CRFD are outlined in Tables A1–A3. This analysis evaluates how yields might respond to different growing conditions under a changing climate and to variations in adaptation in the form of management actions. The degree of climate change in these cases reflects conditions in the 2050s under averaged conditions from the three provincial climate change scenarios illustrated in Figure 8 in the main body of this document.

The first example (A) in Table A2 is presented as a base case for comparison, and assumes:

- the current proportion of alder on the land base stays constant,
- site index values by BEC subzones/variants and site series are as determined from field sampling (C. Farnden, unpublished data),
- there is no thinning,
- MAI is as predicted using the Tree and Stand Simulator (TASS) II growth model, and
- harvest occurs at culmination age where MAI is maximized.

The outcome for this base case is similar in magnitude to the average volume harvested from the District (90 000 m^3/yr) from 1995 through 2008, although in relation to standing volumes, the CRFD has been harvested much more heavily than other Districts.

Case B builds on Case A by adding climate change with no management response. Here there are two multipliers applied to yield. The first (row one in Table A3) represents improved growing conditions: better alder growth is expected primarily as a result of increased growing-season temperatures, although moisture and its interaction with temperature is also a factor. This multiplier essentially deals with the question, What if a climate from further south were to occur in British Columbia, and appropriate trees genetically adapted to that climate were to move with it? The second multiplier (row 2 in Table A3) recognizes that the second condition in the previously stated assumption is not necessarily true. This leads to a condition where the in situ populations of alder are somewhat maladapted to the new climate, thereby resulting in growth reductions. The assumed multipliers in this case are partly offsetting, with a small overall decline in productivity.

TABLE A1 *Area summary and productivity assumptions for ecosystem units with significant coverage of alder and good suitability for alder management on Crown land within the Campbell River Forest District. Tree and Stand Simulator mean annual increment (TASS MAI) potential yields have been adjusted assuming operational adjustment factors 0.85 and 0.75, respectively, for unstocked area in planted and natural stands, and 0.9 for age-dependent factors, such as pest losses, and decay, waste, and breakage.*

Variant	Site series	Total area (ha)	% alder cover	Current site index	TASS MAI (planted)	TASS MAI (natural)
CWHdm1	01	15 600	5.9	25	6.0	4.6
	05	7 400	15.4	30	9.9	8.5
	06	2 300	5.4	25	6.0	4.6
	07	5 300	20.8	31	10.8	9.4
CWHmm1	01	15 400	1.2	22	4.2	2.7
	05	1 400	1.1	27	6.9	5.6
	06	900	4.2	23	4.7	3.3
	07	900	2.9	28	7.8	6.3
CWHvm1	01	285 300	1.6	25	6.0	4.6
	05	47 000	4.3	30	9.9	8.5
	06	23 700	1.6	25	6.0	4.6
	07	27 600	7.8	31	10.8	9.4
CWHxm1	01	6 300	2.6	26	6.3	4.9
	05	6 200	9.5	31	10.8	9.4
	06	100	3.0	26	6.3	4.9
	07	2 700	23.6	32	11.7	10.3
CWHxm2	01	94 500	2.8	24	5.3	3.9
	05	15 500	12.4	29	8.6	7.1
	06	3 200	5.9	24	5.3	3.9
	07	10 800	14.7	30	9.9	8.5

TABLE A2 *Hanzlik-type calculation of long-run sustainable yield (LRSY) for four case studies assuming different responses to climate change. The net area managed is a function of percent alder cover and total area, adjusted downward by 20% on all sites to reflect areas unavailable for management, and a further 20% on 07 sites to reflect areas within riparian zones. Mean annual increment (MAI) values have been adjusted to reflect growth impacts of climate change and adaptive measures as presented in Table A3.*

A. Current

Site series	Net managed alder area (ha)	MAI (planted)	MAI (natural)	% planted	LRSY (m^3/yr)
01	6700	5.8	4.4	5	30 000
05	4600	9.6	8.3	15	39 000
06	600	5.9	4.5	5	3 000
07	3300	9.9	8.5	15	29 000
				Sum:	101 000

B. Climate change—no adaptation

Site series	Net managed alder area (ha)	MAI (planted)	MAI (natural)	% planted	LRSY (m^3/yr)
01	6700	5.4	4.1	5	28 000
05	4600	9.0	7.7	15	36 000
06	600	5.6	4.3	5	3 000
07	3300	9.4	8.1	15	27 000
				Sum:	94 000

C. Climate change—with adaptation

Site series	Net managed alder area (ha)	MAI (planted)	MAI (natural)	% planted	LRSY (m^3/yr)
01	6700	7.1	4.1	10	30 000
05	4600	11.8	7.7	70	49 000
06	600	7.3	4.3	10	3 000
07	3300	12.4	8.1	70	37 000
				Sum:	119 000

D. Adaptation and 5% cover increase on 05 and 07 sites

Site series	Net managed alder area (ha)	MAI (planted)	MAI (natural)	% planted	LRSY (m^3/yr)
01	6700	7.1	4.1	10	30 000
05	8500	11.8	7.7	85	95 000
06	600	7.3	4.3	10	3 000
07	5700	12.4	8.1	80	66 000
				Sum:	194 000

TABLE A3 *Multipliers for yield based on (a) anticipated changes in growing conditions due to a warming climate, (b) maladaptation or unsuitability of existing genetic resources to a newly experienced climate, and (c) improved growth resulting from a tree breeding program. For the cases in Table A2, the first set of multipliers is applied to all yield values under climate change (Cases B, C, and D). The second set is applied to all stands under climate change with no adaptation (Case B) but only to natural stands in Cases C and D where genetic management is assumed to negate maladaptation. The genetic gain multiplier is applied to all planted stands with adaptation (Cases C and D).*

	CWHdm1				CWHmm1				CWHvm1				CWHxm1				CWHxm2			
	01	05	06	07	01	05	06	07	01	05	06	07	01	05	06	07	01	05	06	07
Multiplier for climate	1.10	1.10	1.15	1.15	1.05	1.05	1.15	1.15	1.10	1.10	1.15	1.15	1.00	1.00	1.15	1.15	1.10	1.00	1.15	1.15
Multiplier for maladaptation	0.85																			
Multiplier for genetic gain	1.15																			

In comparison to Case B, Case C adds active management to adapt to the changing climate. It is assumed that appropriate alder families can be identified to take advantage of the new growing climate in the District, and that an expanded planting program can take advantage of both the climatically adapted families and a complementary (but currently non-existent) alder breeding program. In this case, the planted trees lose the maladaptation penalty and gain the benefits resulting from the breeding program—a 15% gain in stand level yield (Table A3). In comparison to the case with no adaptation, there is a considerable gain in landscape-level productivity.

In the fourth case (D), it is assumed that an expanded alder industry in coastal British Columbia is desired to provide greater socio-economic resilience through industrial diversification. An expansion of total alder cover by 5% on the best growing sites is assumed, and that cover is concentrated on sites available for commercial timber management. By adding 3900 ha in alder plantations on 05 sites, and 2400 ha on 07 sites, predicted overall alder production in the District increases by 65%. This comes, of course, at the expense of conifer production on those same sites.

By far the largest alder log supply effect in these cases results from changes to the area on which alder is grown. The reasons for this are reasonably transparent: assuming an MAI of 8.0 m^3/ha/yr, each 1000 ha increase in the net managed area results in an 8000 m^3/yr increase in long-run sustainable yield (LRSY). Given that total alder cover in the District is less than 2%, a large increase in the alder cover is still a very small change for the District as a whole—the 6300 ha increase assumed in Case D is only 0.8% of the total commercial Crown forest area.

Other sources of uncertainty in the LRSY projections include the following:

- Estimates of the area available for management are relatively crude. Errors of +/-10 percentage points in these values will have a similar magnitude of impact on the predicted LRSY values. However, the contrasts between cases will remain unchanged.
- Current inventory values for alder cover may be considerably overestimated, particularly in mixed species stands, based on field observations in the summer of 2011. This may simply result from a natural process of ecological succession, whereby early dominance of alder is gradually replaced by increasing proportions of conifers. Overestimation of the alder land base will result in overestimation of LRSY values, but again, the contrasts between cases will be largely unaffected.
- The area stated for the 07 site series may be overestimated. Many areas labelled as this site series were found during field sampling to be floodplain sites around small streams. As such, a larger riparian area net down factor may be warranted. As with the previous two points, this would affect the absolute LTHL values but not the relative comparison between cases.
- The area coverage of alder in the District may not be static. After harvest, many mixed stands tend to be converted to pure conifer or pure broadleaved stands. In other cases, stands that were previously pure conifer are starting to be allowed to regenerate partly to naturally seeded alder. Given that more than 80% of red alder harvested in British Columbia from 1997 to 2012 came from stands where it was not the leading species, and that most of these stands will be aggressively regenerated to conifers, it seems likely that a long-term decline in alder cover is well under way.
- There is uncertainty in all of the growth multipliers used to assess the impacts of climate-related growth potential, maladaptation, and benefits of a tree breeding program (genetic gain). The potential impacts of this uncertainty are illustrated in Table A4 for Cases A, B, and C. Over all of the variations in growth multipliers tested, climate change with no adaptation

(Case B) resulted in a 3–15% decline in productivity relative to the base case (no climate change), while adaptation to climate resulted in 20–31% gains in productivity over the no adaptation case.

As stated previously, this analysis is relatively simplistic. A thorough hardwood analysis for the entire coast would be invaluable for assessing options for future hardwood industries and setting corresponding targets for alder timber production.

Log supplies—entire British Columbia coast

In the absence of a comprehensive timber supply analysis,[1] several sources can be used to derive crude multipliers that can be applied to the Campbell River LRSY values to get provincial level values:

1. Given that approximately one-third of the historic harvest from 1995 to 2008 came from the CRFD, a multiplier of 3 can be used to derive an estimate of the long-term economically available provincial timber supply. This LTHL multiplier is likely low, as the historic harvest levels from the CRFD have been skewed by disproportionately high harvest levels in TFL 47.
2. Given that the total standing inventory of alder in the CRFD has been estimated as 11% of the provincial total (Buss and Brown 2008), a multiplier of 9 could also be assumed. Such a value would likely be a considerable overestimate, as the CRFD has some of the best accessibility and relatively low land base net downs, particularly in comparison to the mid-coast, where much of the resource is located on floodplains.

A compromise multiplier of 5 would result in LRSY values of 505 000, 470 000, 595 000, and 970 000 m^3/yr for the four case studies in Table A2. For the base case, the result is slightly higher than a 1994 estimate (Massie et al. 1994) of 448 000 m^3/yr. In the short term, maintaining harvest levels at the 1995–2008 mean level of 255 000 m^3/yr may be difficult given constraints of age class distributions, poor stocking of remaining stands, economic accessibility, and other factors (Buss and Brown 2008). However, there is currently no credible analysis to provide a clearer picture.

Estimates of carbon sequestration

Similar to the Hanzlik-based analysis of timber supply, a simple comparison of adaptation strategies can be made for effects on long-term ecosystem and wood products carbon storage. In this analysis, Cases A, B, and C from Table A2 are compared using the same assumptions for magnitude of climate effects on growth and a static land base allocation to alder cover. The intent here is to assess relative impacts of climate adaptation on sequestration on a static land base, so Case D is excluded.

Results provided in Table A4 are based on the average cumulative content of three carbon pools over the long term: (1) live tree biomass (tree stems, branches, bark, foliage, and roots), (2) dead tree biomass (dead trees, litter, and roots), and (3) persistent wood products (35% of stem wood carbon at

1 The treatment of broad-leaved species in the Timber Supply Review (TSR) process in British Columbia has been inconsistent, and no provincial summary can be constructed. As is the case for many management units, the 2004 TSR for the Campbell River Forest District makes no projections for broad-leaves. A newly released (January 2012) TSR for the Sunshine Coast Timber Supply Area is the first to provide an alder partition to the allowable cut where there is also an assumption for long-term red alder management.

time of harvest, with a life span of 30 years). Missing and necessary for a thorough assessment of absolute carbon accounting are factors such as energy usage in silviculture, harvest, and manufacturing. A small drop in energy consumption might be expected between Cases A and B, with an increase by a slightly larger margin between Cases B and C.

TABLE A4 *Comparison of carbon (C) sequestration by live and dead trees for three of the timber yield case studies of climate change adaptation presented in Tables A1–A3.*

A. Current

Site series	Net managed alder area (ha)	Mean C (tonnes/ha) planted	Mean C (tonnes/ha) natural	% planted	Total C (tonnes)
01	6700	169.9	210.1	5	1 394 000
05	4600	240.4	250.8	15	1 147 000
06	600	169.8	209.8	5	125 000
07	3300	240.2	250.6	15	822 000
				Sum:	3 488 000

B. Climate change—no adaptation

Site series	Net managed alder area (ha)	Mean C (tonnes/ha) planted	Mean C (tonnes/ha) natural	% planted	Total C (tonnes)
01	6700	157.9	195.3	5	1 296 000
05	4600	223.2	232.8	15	1 064 000
06	600	161.1	199.1	5	118 000
07	3300	227.8	237.6	15	779 000
				Sum:	3 257 000

C. Climate change—with adaptation

Site series	Net managed alder area (ha)	Mean C (tonnes/ha) planted	Mean C (tonnes/ha) natural	% planted	Total C (tonnes)
01	6700	208.9	195.3	10	1 317 000
05	4600	295.3	232.8	70	1 272 000
06	600	212.1	199.1	10	120 000
07	3300	299.8	237.6	70	928 000
				Sum:	3 637 000

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