A Climate Change Strategy for Red Alder in British Columbia

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Executive Summary

The red alder resource in British Columbia has potential to support a future hardwood manufacturing sector at almost 10 times larger and considerably more diverse than the current condition. Most of this increase is possible simply by managing the existing red alder inventory to a similar intensity as for conifers, with a further 30% 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 would be realized through improved ecosystem resiliency and the contributions of red alder to a wide variety of ecosystem services.

Ultimately, most of the benefits to society would come from 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 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,
- improved alder inventories 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 this critical economic engine for the Province wherever possible and practical. While currently a small component of the overall industry, the hardwood sector in BC offers just such a possibility.

	Harvest (1000's m^3/yr)	Potential Jobs	Carbon Sequestration (1,000,000's tonnes)	Ecosystem Services	Socio-Economic Stabiliy
Mean 2008 to 2011	55	60	n/a		
Base Case LTHL	515	1300	3.5		
Climate Change and No Adaptation LTHL	470	1200	3.3	-	-
Climate Change With Adaptation LTHL	595	1500	3.6	+	++

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Introduction

A changing global climate brings uncertainty in many forms. For the British Columbia forest sector, there is uncertainty around the health and productivity of ecosystems, timber supplies, and the benefits society can attain from the forest through its various goods and services. In addressing these uncertainties, we need to anticipate the range of possible outcomes, take action to mitigate the negative consequences and embrace opportunities for gain. 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 from 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 BC 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 BC 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 take appropriate steps to fully develop opportunities that red alder provides. A strong case can be made for improved alder management in BC 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 i) demonstrate how improved alder management in an era of rapid climate change can provide substantial benefits to the Province of British Columbia, ii) summarize new and to some extent existing knowledge about how the red alder resource will be impacted by climate change and iii) identify steps that need to be taken to adapt to climate change. In order to focus discussion, this document uses the Campbell River Forest District 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.

The next two sections of this report summarize the benefits of implementing a climate change strategy for red alder in BC. Those wanting further descriptions, theory and rationale are encouraged to read further. In the case of timber supply calculations, the discussion of assumptions and other details is provided in Appendix 1.

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:

1. The commercial value of red alder has been increasing - in BC it now commands considerably more per cubic metre than western hemlock, and in Washington state it competes favourably on a $/m^3$ basis with Douglas-fir.
2. 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.

3. Where 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 meter 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.

4. The North American market for appearance grade products is very large (approximately $200 billion per year) and growing at 8-10% per year despite a sluggish economy. Where $4000 to $5000 of commodity lumber is required in a new home, there could easily be a demand for $50,000 to $60,000 in appearance grade wood products.

From 1993 to 2008, a medium-sized sawmill was operated in Delta BC that could produce 34 mmfbm/yr. The reasons for closure of this mill are not completely clear - despite higher tax and labour rates than for competing facilities south of the border, the mill appears to have been profitable. The remaining hardwood manufacturing capacity in BC is approximately

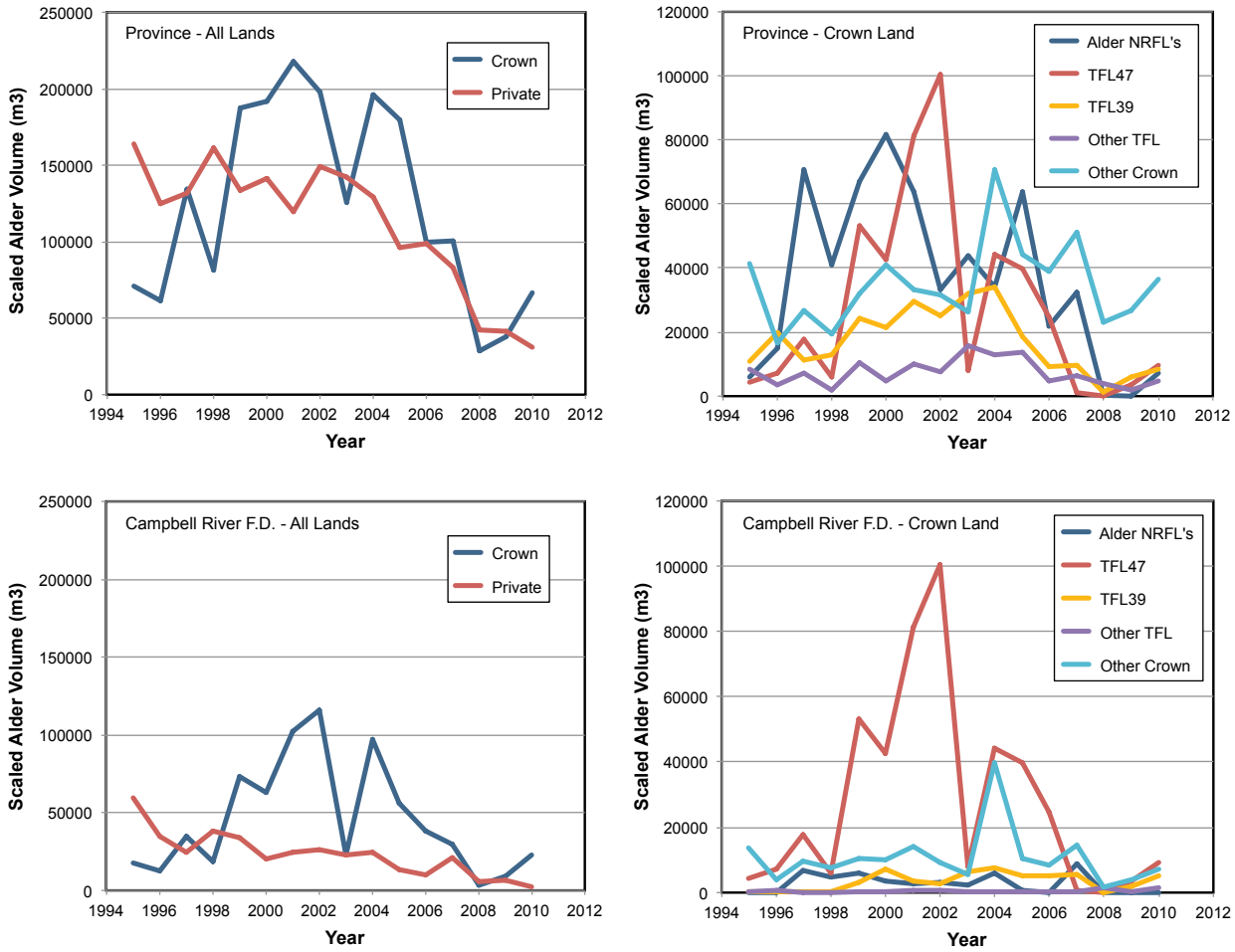


Figure 1. Sources and rates of red alder harvest within BC from 1995 through 2010, based on Government scaling and billing records. Just under half of all harvest has come from private land, primarily on Vancouver Island. On crown land, the primary sources have been non-replaceable forest licenses (NRFL's) focused on harvesting alder, 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 alder manufacturing sector, with future levels reflecting 4 cases with different climate change adaptation assumptions. Production figures assume a lumber recovery factor of 0.4. Employment values assume 0.25 forestry and harvesting jobs per 1000 m^3 harvested, 1 manufacturing job per 190 mfbm production and 1 additional spin-off job for every manufacturing job.

	Harvest level (m^3/yr)	Mill Production (Mfbm)	Jobs
Mean domestic consumption, 1995-2008	255,000	43	635
Current domestic consumption (2008 - 2011)	55,000	9[1]	135[1]
Potential Provincal LTHL - Base Case	515,000	87	1280
Provincial LTHL - Climate Change with No Adaptation	470,000	80	1170
Provincial LTHL - Climate Change with Adaptation	595,000	101	1475
Provincial LTHL - Climate Change with Adaptation and Increased Alder Cover on 05 and 07 Sites	970,000	164	2390

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

15 mmfbm/yr. Most of this resides in three relatively small sawmills, a re-manufacturing plant that contracts out primary log breakdown, and a plywood plant. Several other small sawmills also utilize alder, mostly on a custom cut or ad hoc basis. Recent harvest (Fig. 1) and export rates, along with assumptions about proportion of billed waste, suggest the remaining 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 BC. Assuming steady state land use cover of alder and an appropriate climate change strategy, a Provincial long term harvest level (LTHL) for alder of roughly 595,000 m^3/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, focused on appropriate sites, could increase the alder LTHL and corresponding mill production levels by 65%.

The impacts of climate change and various management approaches to the red alder resource are presented in Table 1. With no change in land cover by species, the largest gains arise simply from complete development of the resource, and planting both to achieve full stocking of harvested sites and to take advantage of tree breeding opportunities. Assuming these initial steps are taken, climate change adaptation is estimated to provide a further 30% increase in economic indicators such as harvest levels, mill production and jobs.

Doubts may exist about whether markets exist to support the harvest and mill production levels presented here, but one needs look no further than just south of the 49th parallel for justification. Washington and Oregon have 5 active hardwood sawmills owned by Northwest Hardwoods plus several independents, with a collective capacity to produce almost 300 mmfbm/yr (Figure 2). There is general belief, however, that these mills already face serious log supply constraints that will worsen over the next two decades, a condition that would strengthen the case to enhance BC's milling capabilities to utilize domestic supplies.

Red Alder and Ecosystem Services

As with timber supply, decisions around 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 inclusion in conifer stands of a significant component of broadleaved 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,
- red alder can improve ecosystem productivity where nitrogen is limiting through symbiotic fixation of nitrogen from the atmosphere,
- red alder is resistant to the *Phellinus* root disease which affects conifers, and can be planted where this disease would be problematic otherwise, and
- broadleaved species in general are more resistant than conifers to the spread of wildfire, and can be used in planned firebreaks; this characteristic of broadleaved stands 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 N additions reaching 200 kg/yr. This characteristic of red alder can be used to improve productivity for other species such as Douglas-fir on nitrogen poor soils. Strategies for doing so include either 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 effects can have positive benefits on crop tree growth without the financial costs or the carbon costs related to manufacture and transport of artificial fertilizers.

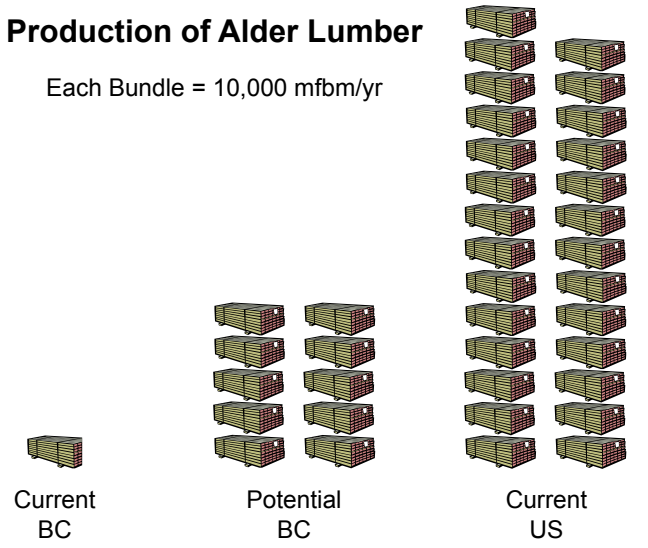


Figure 2. Comparison of alder lumber production capacities for current and potential future industries in BC, and the current US industry.

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 to 30 years). Other elements such as changes to soil carbon are weakly understood, with no strong evidence to suggest long term changes to carbon pools under a landscape level collection of pure and mixedwood stand regimes.

The Campbell River Forest District and its Red Alder Resource

As a surrogate for the entire coastal resource, the Campbell River Forest District (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, the CRFD has some portions with very good access typical in populated portions of the lower coast, and

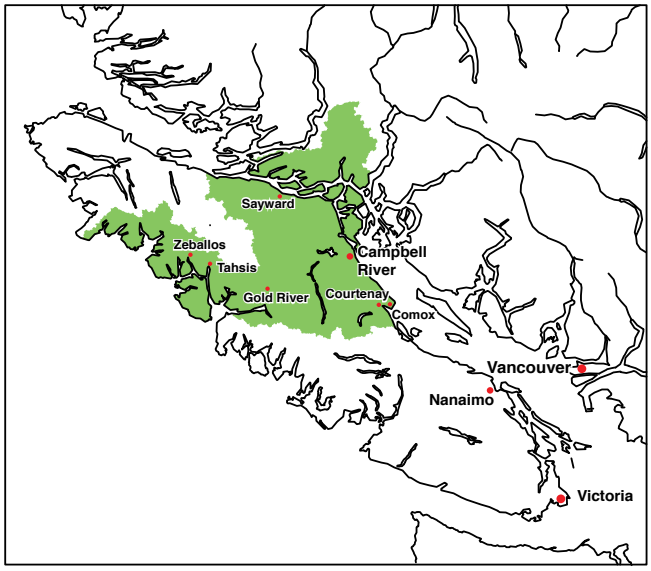


Figure 3. Location of the Campbell River Forest District and associated communities.

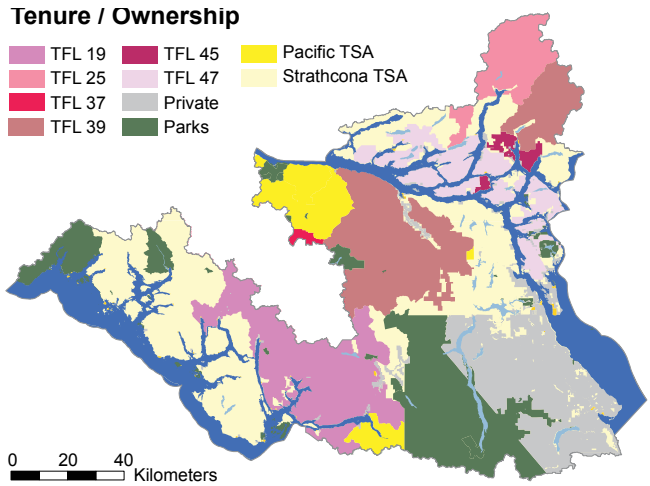


Figure 4. Distribution of land ownership, parks and crown forest management units within the Campbell River Forest District.

others with predominantly marine access such as prevails on central and north coast areas. All Districts have distinctly different community structures and access to markets.

The CRFD is located on the central portion of Vancouver Island and adjacent portions of the coastal mainland to the northeast (Fig. 3). While mostly mountainous, a rolling coastal plain runs along the eastern side of the Vancouver Island portion. Several mid-sized drainages include 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, with smaller communities 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 people. External service and manufacturing centres include Nanaimo, Victoria and Vancouver.

The total land area is approximately 1.5 million ha, of which about 1.3 million ha is forested. Within the District, 270,000 ha is devoted to Provincial Parks, 181,000 ha is privately owned, and 2366 ha is in Indian Reserves (Figure 4). The timber producing crown land is divided primarily into two Timber Supply Areas and six Tree Farm Licenses, with a small amount of area in woodlots.

Red alder is a minor species within the District, comprising only about 1.7% of the total forest cover (Fig. 5a). The species is concentrated at lower elevations (Figs. 5b and 6) and on better sites (Fig. 7). The prevalence of red alder along either side of the Johnstone Strait and Discovery Passage in the north eastern portion of the District is at least partially the result of good growing conditions on the low elevation sites and marine-clay soils that exist there. A second likely factor is the higher frequency of fire disturbance on the drier leeward side of Vancouver Island than on the windward side prior to the start of commercial timber harvesting. Where natural stand disturbance was infrequent, long lived conifer stands dominated the landscape, leaving little opportunity for shade intolerant species like red alder to regenerate. A third factor is the relatively high degree of soil disturbance that often occurred with early 1900's harvesting practices employed on easily accessible areas of the eastern Vancouver Island plain and coastal areas along the Johnstone Strait. Such practices created ideal conditions for alder to germinate and capture growing space.

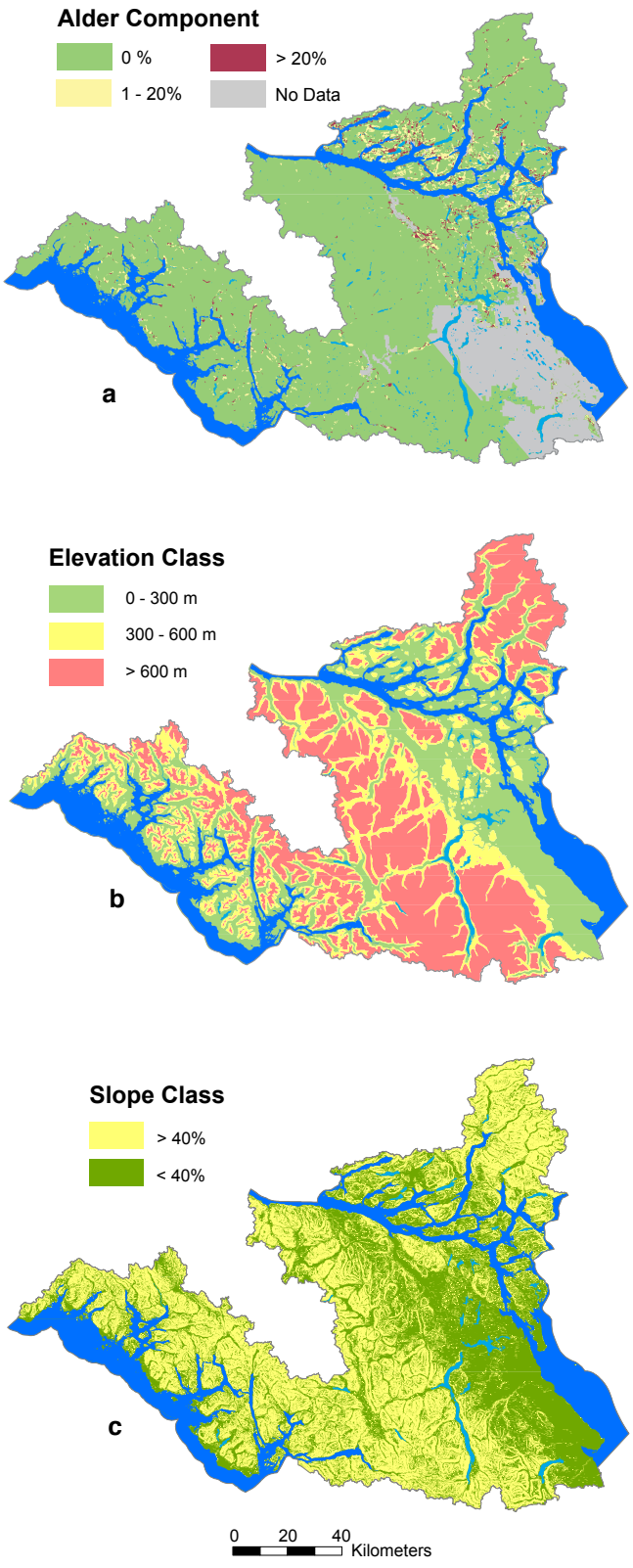


Figure 5. Thematic maps of the Campbell River Forest District. Red alder forest cover is primarily concentrated on either side of the Johnstone Strait and Discovery Passage (a) at low elevations (b) and on gentle slopes (c).

	Very Poor	Poor	Medium	Rich	Very Rich
Very Xeric	0.8%				
Xeric	1.9%			3.0%	
Subxeric					
Submesic	1.5%			6.8%	
Mesic					
Subhygric	1.5%			11.8%	
Hygric					
Subhydric	1.2%		8.0%		

All Subzones

	Very Poor	Poor	Medium	Rich	Very Rich
Very Xeric	1.1%				
Xeric	2.7%			5.2%	
Subxeric					
Submesic	2.8%			11.6%	
Mesic					
Subhygric	5.8%			17.5%	
Hygric					
Subhydric	2.2%		9.0%		

CWH xm Subzone

Figure 7. Area weighted coverage of red alder by edatope class within the Campbell River Forest District for the entire Coastal Western Hemlock (CWH) bio-geoclimatic zone (left) and the low elevation CWH xm (very dry maritime) subzone (right). Mean coverage for the CWH zone is 2.7%, and for the CWH xm subzone is 4.6%. Note that a substantial portion of alder cover in the Hygic-Subhydric, Rich-Very Rich class is associated with floodplain systems and riparian management zones .

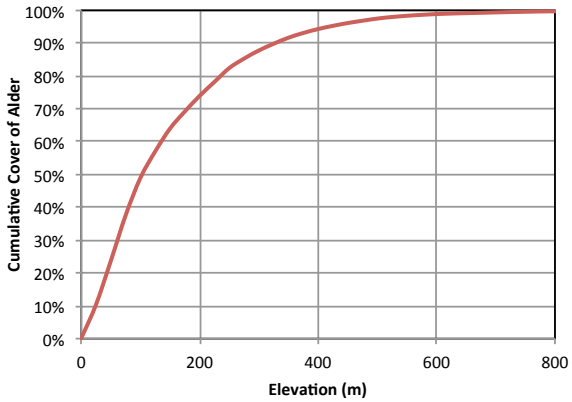


Figure 6. Cumulative percent of total red alder cover by elevation as recorded in inventory files compiled in early 2011. Seventy-three percent of the red alder on crown land in the Campbell River Forest District lies below an elevation of 200 m, and 94% is below 400 m. Field sampling on Vancouver Island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

In the latter half of the 1900's harvesting methods changed to create less ground disturbance, and the rate of alder establishment waned. It was further diminished starting in the 1970's by aggressive vegetation management practices that favoured conifers, and particularly Douglas-fir. Such practices were taken to the extreme during the 1980's and 90's, 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 even 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 the Johnstone Strait. Less harvesting has occurred on the west side of Vancouver Island.

Climate Change Scenarios and Productivity

Concern exists that the 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:

1. recent research projects conducted to support development of this red alder climate change adaptation strategy,
2. our extensive familiarity with biogeoclimatic ecosystem classification (BEC) and the associated mapping of biogeoclimatic zones and subzones, and
3. three climate change scenarios recommended as a minimum expression of the range of potential future climates for use in BC by the Pacific Climate Impacts Consortium [6].

Within the Campbell River Forest District, red alder is primarily associated with lower elevations in the Coastal Western Hemlock (CWH) biogeoclimatic zone. The nine CWH subzones within the District (Figs. 8 and 9) provide a convenient framework for describing patterns of relevant climate change over time, based on their associated climate envelopes [9].

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

1. The climate envelope currently associated with the Mountain Hemlock (MH) zone is predicted to become much smaller in extent, retreating to the highest elevations currently occupied by the Coastal Mountain Heather - Alpine (CMA) zone. This latter climate envelope largely disappears.
2. The climate envelope associated with the Coastal Western Hemlock submontane very wet maritime (CWH vm) subzone becomes increasingly prevalent on the windward side of Vancouver Island and mid-elevations on the mainland, but disappears from the leeward side of Vancouver Island.
3. 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 are 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 lies predominantly within the CWH xm1, CWH xm2 and CWH vm1 variants (Fig. 5a and current subzones in Fig. 8), the continued prevalence and/or expansion of climate envelopes associated with these subzones bodes well for future management of red alder.

For zonal sites that best reflect regional climates, recent models [3] have employed a balance of growing season temperatures and growing season moisture availability to predict climate-induced changes in red alder growth rates. For subzones in the Campbell River Forest District where alder is currently common, changes to climatic factors affecting productivity suggest 7 to 10% increases in alder growth rates

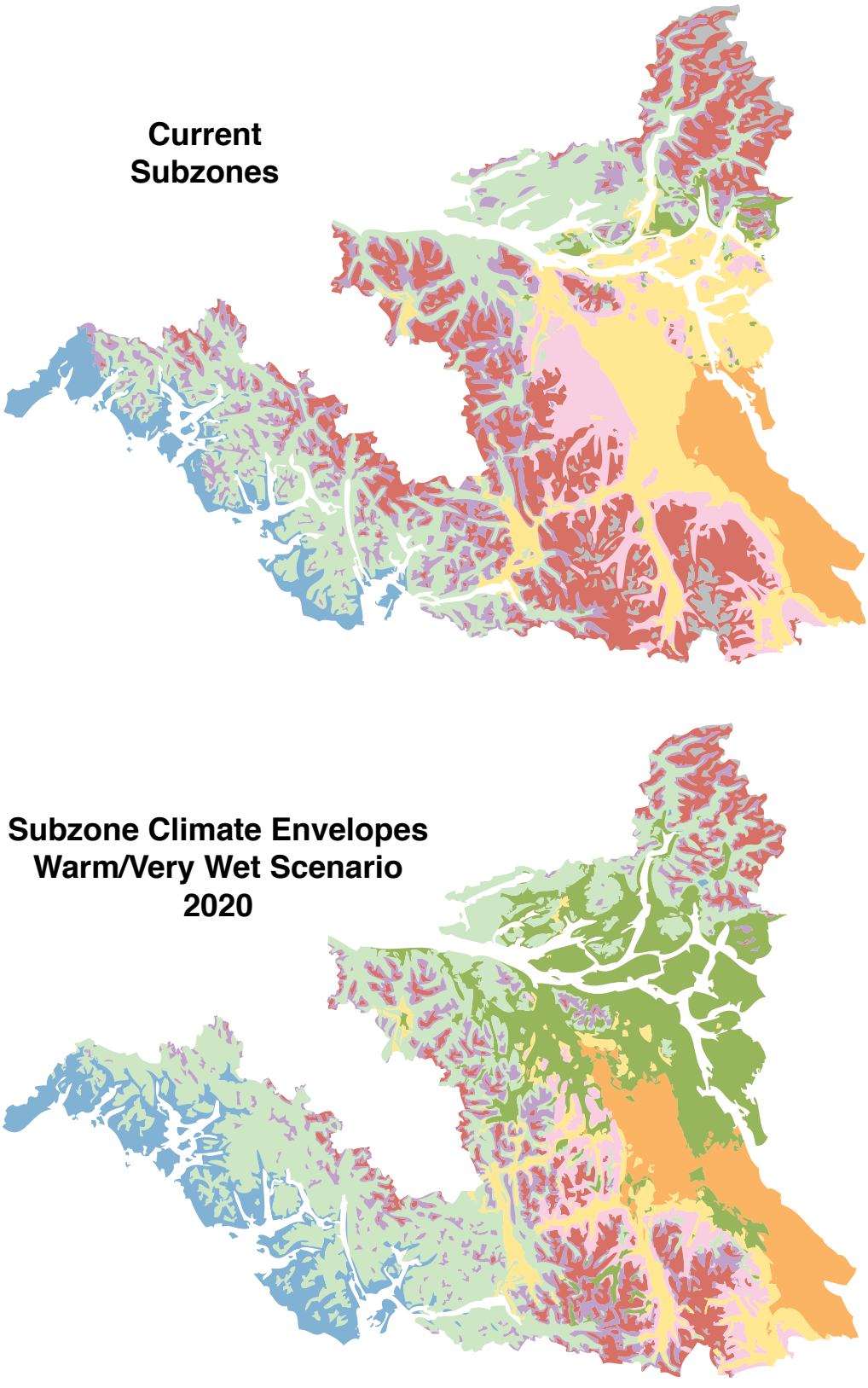
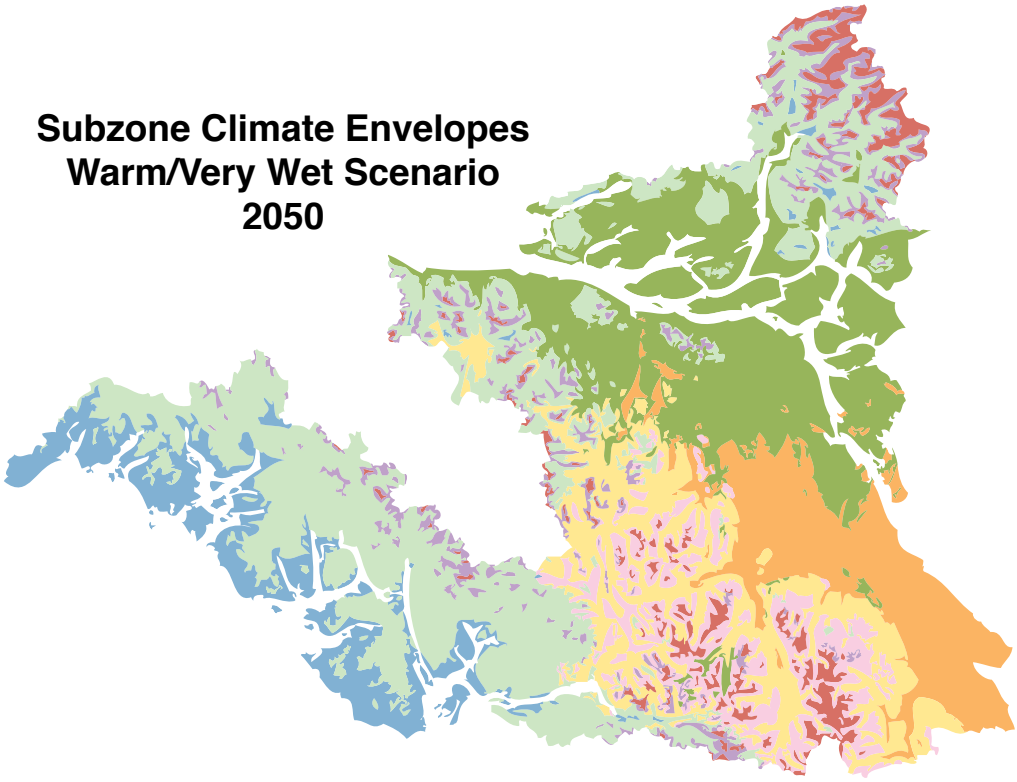
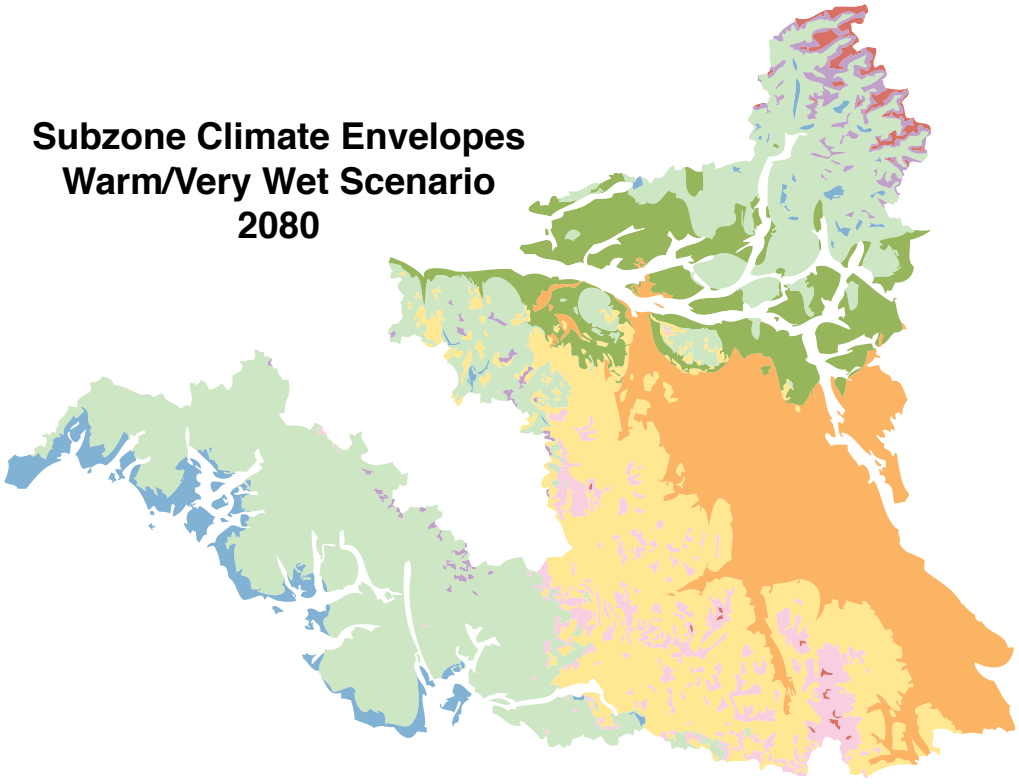


Figure 8 (with facing page). Climate envelopes currently associated with biogeoclimatic subzones within the Campbell River Forest District (top left) and forecasts for three time periods (2020's, 2050's and 2080's) for the Provincial warm/very wet scenario. The extreme elevational range of the future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





CWH xm1
CWH xm2
CWH dm1
CWH mm
CWH vm1
CWH vm2
CWH vh1
MH mm1
CMA unp

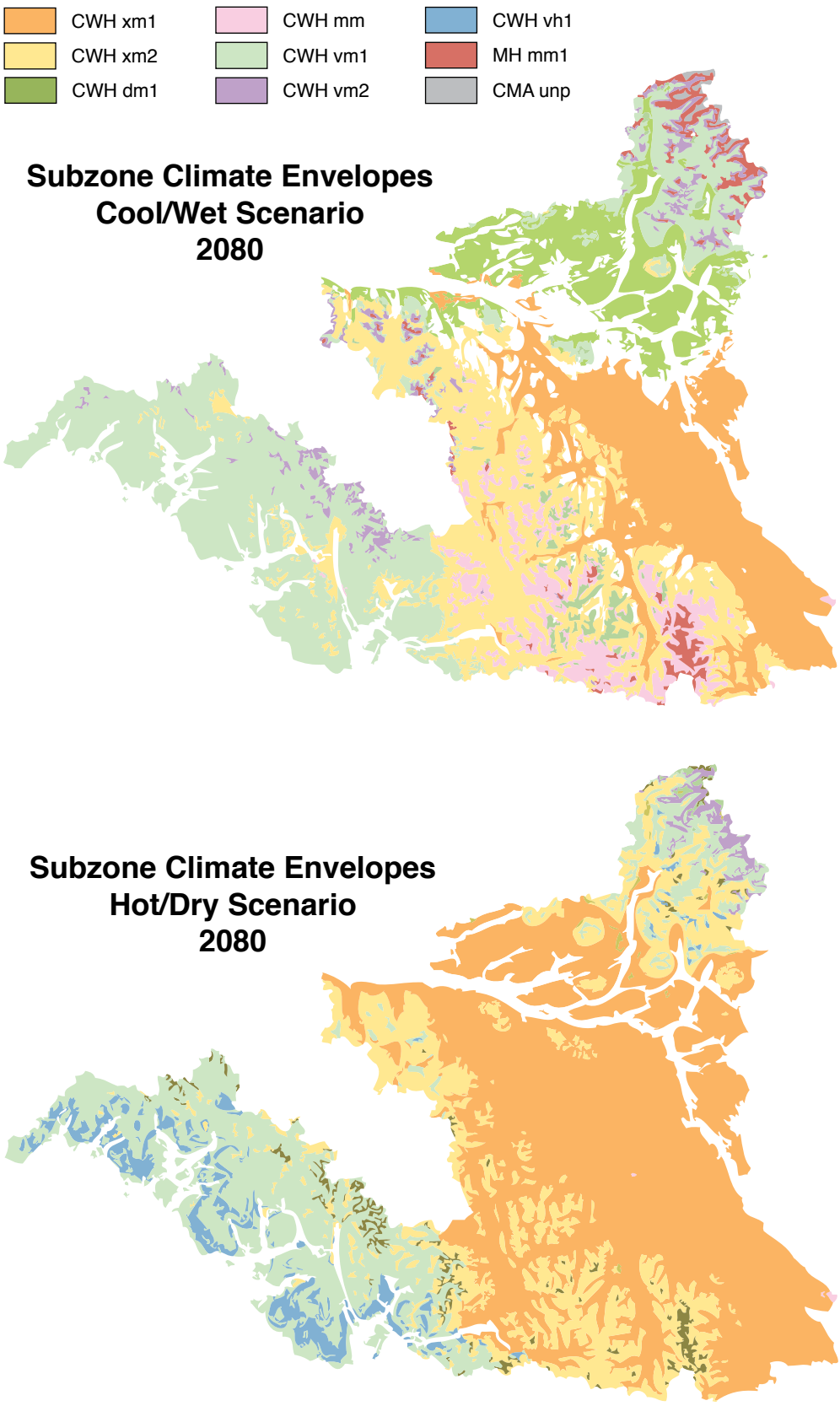


Figure 9. Forecasts for the extent of future climate envelopes in the 2080's for the Provincial cool/wet and hot/dry scenarios. For this District, the Provincial hot/dry scenario appears to result in the greatest degree of change, when contraste with the warm-very wet scenario in the botton right portion of Fig. 8.

by the 2050's as an average effect of the three recommended Provincial climate scenarios. Variations between the scenarios were of the order of 1 to 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 (Fig. 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.

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 [7] suggests that red alder is highly adapted to regional climates, and will not acclimate physiologically to significant changes in climate. This factor 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, based on frequent observations of tissue damage following growing season frost events. Where 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 it 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 BC and the Pacific Northwest in the US.

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 the drought conditions are relieved. An alternate strategy employed by red alder 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 for the breeding potential of red alder by BC government scientists 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 managed alder plantations use genetic sources best suited to improved growing conditions where they are realized through climate change.

Approaches to Growing Red Alder

The implementation of climate change strategies is at least partially dependent on basic stand management tactics. Three general approaches are commonly recognized for growing red alder [8]. The first of these, dubbed the mixedwood option, continues to be adopted by most coastal licensees in BC, particularly where alder is not being harvested as the primary crop species. It 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 to 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 option 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 to 40 years.

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

1. Plantations allow for control of the genetic source of the trees, strengthening opportunities for both facilitated migration and use of improved seed from (not yet existing) tree improvement programs.

Figure 10. Red alder in Oregon, SI_{50} = 31m, planted to 1600 trees/ha and thinned to 630 trees/ha at age 17.

2. Plantations allow for alder expansion to new growing sites as they become suitable under a warming climate, such as mid-elevational areas within the Campbell River Forest District. Note that feasibility of such expansion may be limited by slope steepness, as cable harvesting of alder is not generally considered as a financially viable operation.

3. Shorter rotations from plantation management of alder allow for maximum flexibility to adapt to changing climates as they are realized. A shorter lag in response to climates should allow for improved deployment of genetic resources.

4. The nitrogen fixing abilities of red alder can be used in interspersed rotations with species such as Douglas-fir to maintain higher levels of overall site productivity.

A third option of *intensive* plantations has recently received considerable attention and debate on both sides of the US-Canada border, with somewhat greater application stateside. Under this *intensive* approach (Fig. 10), stands are planted at moderate to high densities to promote straight stems with small branches, then thinned at a height of 10 m to promote rapid diameter growth. In some cases, trees may also be pruned (Fig. 11). With these management scenarios, similar sized sawlogs with an overall improvement in grade recovery can be produced in 25 to 35 years. Such shortened rotations can be very important for managing timber supplies, and in particular for helping to fill projected supply deficits that are still 1 to 3 decades away. In the US, revenue generated with good quality alder logs is now similar to that of second growth Douglas-fir, making returns on this type of investment attractive. However, there is a trade-off. Results of research trials and modeling with both the TASS model in BC and ORGANON 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 management of alder in pure stands, there are also options for intimate and patch mixedwoods. The former of these methods makes most sense on nitrogen poor soils, where admixtures of alder can improve overall growth of Douglas-fir [2]. On richer sites, intimate mixtures of alder within fir stands make less sense as the nitrogen fixation capabilities of red alder

Figure 11. Red alder in Oregon, SI_{50} = 31m, age = 17 yrs, planted to 700 trees/ha and pruned.

offer lesser benefit. Wood quality of the alder in such stands will also likely be degraded, as 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 such 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 N 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 BC.

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

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:

- collection of accurate inventory data for hardwoods has not been a priority and needs to be improved; of particular concern is accurate aging of stands along with information on age-related decline (stand break-up),
- associated with the inventory, 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 Campbell River Forest District) and other management zones with management restrictions,
- there is some evidence of higher than average numbers of species at risk being associated with broadleaved stands; work is needed to identify hazards associated with further damaging sensitive populations and delineating appropriate conservation strategies,
- further work is needed in identifying 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, and
- further work is needed to understand how climate, site and other factors influence interactions between alder and conifers in mixed stands.

Impediments to Climate Change Adaptation for Red Alder

There are two main hurdles that need to be overcome in order to initiate a climate change adaptation strategy for red alder. The first of these 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 red alder management is raised. The perceptions that alder is a weed species, good only for firewood, or a small niche market species are difficult to

overcome, based on many decades of people's 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 partially underway. The government of BC 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 focused 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 can be observed in the lack of reaction to the report *Hardwood Management in the Coast Forest Region* [8]. This document provides clear guidance for progress in adopting active hardwood management, but has experienced very little uptake. Harvest targets are set for each Forest District 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 partially attributed to the closure of the NW Hardwoods mill in Delta, it coincides with claims by existing mill operators that lack of affordable access to alder sawlogs is hurting their businesses.

Beyond those already cited above, possible reasons for the current lack of enthusiasm for alder management and manufacturing include:

- 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 landbase benefits of growing alder, but upper levels of management appear primarily focused 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 impact of widespread alder management on allowable cut levels for conifers and perceptions of higher costs for alder management as compared to traditional conifer management,
- there are uncertainties around access to appropriate seed and/or planting stock,
- on the investment side, there is uncertainty around long term access to raw materials, with reasons including i) much of the alder harvest is occurring under non-replaceable forest licenses, all held by a single company, ii) a general lack of interest by most TFL holders in harvesting alder for the domestic market, iii) strong memories of the alder eradication and conversion programs of the 1980's and 1990's, and iv) inconsistent access to alder logs through log markets, and
- there is a lack of commitment to alder management in higher level plans and Forest Stewardship Plans, and management practice as reflected in TSR evaluations and AAC 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 include:

- 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 can be rapid if left sitting in log decks, particularly in summer months,
- salt water rafting of logs can somewhat lengthen storage times, but introduces 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, and
- 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 red alder in particular have been treated as a 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 than for softwoods, and raw materials are not generally interchangeable. As a result, this sector may be particularly vulnerable to the large fluctuation in harvest rates observed in Figure 1, particularly 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.

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. A listing of such issues and recommended courses of action are provided below.

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.**

   It is recognized that breeding programs are expensive, and that the alder resource is relatively small. It is therefor recommended that the Province undertake a benefit/cost analysis to determine an appropriate strategy to deal with genetic management of the species. Given that ability to select appropriate parentage for tree seedlings is needed immediately, such an analysis is considered to be a high 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, they did their 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 along with potential investors for strategic planning, the Province at the minimum should require a) equivalent attention to hardwoods as to softwoods in all future inventories and b) a determination of hardwood cut levels 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 issues such as the effects of age-related decline in the current inventory, 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 its size and relative stability. These in turn are largely dictated 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, it 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 area dedicated to 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 landbase, but be open to expansion should that be in the interests of society.

4. **The ecosystem services provided by red alder and other hardwoods are considerable, and their relative value for these services is magnified as a result of their low abundance on coastal forested landscapes.**

   Management targets are needed for cover and spatial patterns of red alder based on its contributions to overall ecosystem resilience, 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 water courses or other geographic features, and the need for fire breaks being associated with communities or other important infrastructure.

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 coporate benefit in managing for alder. One potential policy solution could be to establish landscape level targets that are apportioned to licensees based on the suitability of their operating areas to growing the species.

6. **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 you separate Timberwest's private and crown holdings). 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 heavily dominated by the Delta sawmill while in operation, and the current situation is considerably muddied by a disproportionately large export demand. An open and transparent alder log market is desperately needed to support development of a thriving domestic hardwood manufacturing sector in BC.

7. **Knowledge gaps need to be filled**

   Where items identified in the *supply chain* and *knowledge gaps* sections of this document have not already been addressed in these recommendations, they should be flagged as information needs to be addressed by Provincial forest research and inventory programs.

The issue of climate change adaptation strategies for forest management on public lands is one where the primary focus is on net benefits to society through both 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 BC offers just such a possibility.

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Appendix 1: Alder Log Supply and Carbon Storage Scenarios

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 term harvest level 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. 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 for 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 examining the long term potential yield of alder logs from the Campbell River Forest District are outlined in Tables 1-1 through 1-3. This analysis evaluates how yields might respond both 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 2050's under averaged conditions from the three Provincial climate change scenarios illustrated in Figure 6 in the main body of this document.

The first example (A) in Table 1-2 is presented as a base case for comparison and assumes:

- the current proportion of alder on the landbase stays constant,
- site index values by BEC subzones and site series as determined from field sampling (4),
- no thinning
- mean annual increment (MAI) is as predicted using the 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 Campbell River Forest District has been harvested much more heavily than others.

Case B builds upon case 1 by adding climate change with no management response. Here there are two multipliers applied to yield. The first of these (first row in Table 1-1) 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 BC, and appropriate trees genetically adapted to that climate were to move with it? The second multiplier (row 2 in Table 1-1) recognizes that the second condition in the previously stated assumption is not necessarily true. For this case, there is no management action, and the genetically programmed trees for the new climate are not immediately present. This leads to a condition where the *in situ* populations of alder are somewhat maladapted to the new climate, resulting in growth reductions. The assumed multipliers in this case are partially offsetting, with a small overall decline in productivity.

Subzone	Site Series	Total Area (ha)	% Alder Cover	Current Site Index	TASS MAI (planted)	TASS MAI (Natural)
CWH dm1	01	15600	5.9	25	6.0	4.6
	05	7400	15.4	30	9.9	8.5
	06	2300	5.4	25	6.0	4.6
	07	5300	20.8	31	10.8	9.4
CWH mm1	01	15400	1.2	22	4.2	2.7
	05	1400	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
CWH vm1	01	285300	1.6	25	6.0	4.6
	05	47000	4.3	30	9.9	8.5
	06	23700	1.6	25	6.0	4.6
	07	27600	7.8	31	10.8	9.4
CWH xm1	01	6300	2.6	26	6.3	4.9
	05	6200	9.5	31	10.8	9.4
	06	100	3.0	26	6.3	4.9
	07	2700	23.6	32	11.7	10.3
CWH xm2	01	94500	2.8	24	5.3	3.9
	05	15500	12.4	29	8.6	7.1
	06	3200	5.9	24	5.3	3.9
	07	10800	14.7	30	9.9	8.5

Table 1-1. 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. TASS potential yields have been adjusted assuming operational adjustment factors (OAF's): 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 & breakage (DWB).

A. Current

Site Series	Net Managed Alder Area (ha)	MAI (Planted)	MAI (Natural)	% Planted	LRSY (m3/yr)
01	6700	5.8	4.4	5	30000
05	4600	9.6	8.3	15	39000
06	600	5.9	4.5	5	3000
07	3300	9.9	8.5	15	29000
				Sum:	101000

B. Climate Change - No Adaptation

Site Series	Net Managed Alder Area (ha)	MAI (Planted)	MAI (Natural)	% Planted	LRSY (m3/yr)
01	6700	5.4	4.1	5	28000
05	4600	9.0	7.7	15	36000
06	600	5.6	4.3	5	3000
07	3300	9.4	8.1	15	27000
				Sum:	94000

C. Climate Change - With Adaptation

Site Series	Net Managed Alder Area (ha)	MAI (Planted)	MAI (Natural)	% Planted	LRSY (m3/yr)
01	6700	7.1	4.1	10	30000
05	4600	11.8	7.7	70	49000
06	600	7.3	4.3	10	3000
07	3300	12.4	8.1	70	37000
				Sum:	119000

D. Adaptation & 5% Cover Increase on 05 and 07 Sites

Site Series	Net Managed Alder Area (ha)	MAI (Planted)	MAI (Natural)	% Planted	LRSY (m3/yr)
01	6700	7.1	4.1	10	30000
05	8500	11.8	7.7	85	95000
06	600	7.3	4.3	10	3000
07	5700	12.4	8.1	80	66000
				Sum:	194000

Table 1-2. Hanzlik-type calculation of long term harvest lavel (LTHL) 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. MAI values have been adjusted to reflect growth impacts of climate change and adaptive measures as presented in Table 1-3.

	CWH dm1				CWH mm1				CWH vm1				CWH xm1				CWH xm2			
	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																			

Table 1-3. Multipliers for yield based on a) anticipated changes to growing conditions resulting from a warming climate, b) maladaptation or the 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 1-2, the first set of multipliers is applied to all yield values under climate change (cases 2, 3 and 4). The second set is applied to all stands under climate change with no adaptation (case 2), but only to natural stands in cases 3 and 4 where genetic management is assumed to negate maladaptation. The genetic gain multiplier is applied to all planted stands with adaptation (scenarios 3 & 4).

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 nonexistent) 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 1-3). 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 BC is desired to provide greater socioeconomic 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 is increased 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 LTHL. 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 above is only 0.8% of the total commercial crown forest area.

Other sources of uncertainty in the LTHL projections include:

1. 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 LTHL values. However, the contrasts between cases will remain unchanged
2. 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 LTHL levels, but again the contrasts between cases will largely be unaffected.
3. The area stated for the 07 site series may be overestimated. Many areas labeled as this site series were found to be flood plain sites around small streams during field sampling. As such, a larger riparian area net down factor may be warranted. As with points 1 and 2 above, this would affect the absolute LTHL levels, but not the relative comparison between cases.
4. 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 partially to naturally seeded alder. Given that over 80% of red alder harvested in BC over the last 15 years 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 underway.
5. There is uncertainty in all of the growth multipliers used to assess the impacts of climate related growth potential, maladaptation and the benefits of a tree breeding program (genetic gain). The potential impacts of this uncertainty are illustrated in Table 1-4 for Cases 1, 2 and 3. Over all of the variations in growth multipliers tested, climate change with no adaptation (Case 2) resulted in a 3 to 15% decline in productivity relative to the base case (no climate change), while adapta-

tion to climate resulted in 20 to 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 BC Coast

In the absence of a comprehensive timber supply analysis, evidence for crude multipliers that can be applied to the Campbell River LTHL values to get Provincial level values can be derived from several sources:

1. Given that approximately one third of the historic harvest from 1995 to 2008 came from the Campbell River Forest District, we can assume a multiplier of 3 to get an estimate of the long term *economically* available Provincial timber supply. This LTHL multiplier is likely low, as the historic harvest levels from this District have been skewed by disproportionately high harvest levels in TFL 47.
2. Given that the total standing inventory of alder in the Campbell River Forest District has been estimated as 11% of the Provincial total (1), a multiplier of 9 could also be assumed. Such a value would likely be a considerable overestimate, as the Campbell River District 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 flood plains.

A compromise multiplier of 5 would result in the values for LTHL of 505,000, 470,000, 595,000 and 970,000 m^3/yr for the four case studies in Table 2. For the base case, the result is slightly higher than a 1994 estimate (5) of 448,000 m^3/yr. In the short term, maintaining harvest levels at the 1995 to 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 (1). 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 1-1 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 1-4 are based on the average cumulative content of three carbon pools over the long term. These are 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 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.

1. The treatment of broadleaved species in the Timber Supply Review (TSR) process in BC 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 broadleaves. A newly released (Jabuary 2012) TSR for the Sunshine Coast TSA is the first to provide an alder partition to the allowable cut where there is also an assumption for long term red alder management.

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	1394000
05	4600	240.4	250.8	15	1147000
06	600	169.8	209.8	5	125000
07	3300	240.2	250.6	15	822000
				Sum:	3488000

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	1296000
05	4600	223.2	232.8	15	1064000
06	600	161.1	199.1	5	118000
07	3300	227.8	237.6	15	779000
				Sum:	3257000

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	1317000
05	4600	295.3	232.8	70	1272000
06	600	212.1	199.1	10	120000
07	3300	299.8	237.6	70	928000
				Sum:	3637000

Table 1-4. Comparison of carbon sequestration by live and dead trees for three of the timber yield case studies of climate change adaptation presented in Tables 1-1 to 1-3.

Appendix 2: List of Compendia on Alder Management

Briggs, D.G., DeBell. D.S. and Atkinson, W.A. (eds.) 1978. **Utilization and management of alder**. Proceedings of a symposium held at Ocean Shores WA, April 25-27 1977. USDA For. Serv. Gen. Tech. Rep. PNW-GTR-070. 379 p. http://www.treesearch.fs.fed.us/pubs/25142

Comeau, P.G., Harper, G.J., Blache, M.E., Boateng, J.O. and Thomas, K.D. (eds.) 1996. **Ecology and management of B.C. hardwoods**. Proceedings of a workshop held Dec. 1-2, 1993, Richmond BC. FRDA Rep. 255. BC Min. For., Victoria BC. http://www.for.gov.bc.ca/hfd/pubs/Docs/Frr/Frr255.htm

Deal, R.L., Harrington, C.A. (eds.) 2006. **Red alder: a state of knowledge.** PNW-GTR-669. Proceedings of a symposium held March 23-25, 2005, Seattle WA. USDA For, Serv, PNW Res. Stn., Portland OR. 150 p. http://www.treesearch.fs.fed.us/pubs/22325 (9 MB in 4 parts).

Heebner, C. F., and Bergener, M.F.. 1983. **Red alder: a bibliography with abstracts**. USDA Forest Service, General Technical Report PNW-161. Pacific Northwest Forest and Range Experiment Station, Portland, OR. 186 p. http://www.treesearch.fs.fed.us/pubs/7704

Hibbs, D.E., DeBell, D.S. and Tarrant, R.F. (eds.) 1994. **The biology and management of red alder**. Oregon State University Press, Corvallis OR. 256 p. hardback.

Massie, M.R.C, E.B. Peterson, N.M. Peterson and K.A. Enns. 1994. **An assessment of the strategic importance of the hardwood resource in British Columbia.** FRDA Report 221. Canadian Forest Service and BC Ministry of Forests, Victoria BC. 206 p. http://www.for.gov.bc.ca/hfd/pubs/docs/Frr/frr221.pdf

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