Utilization and management of red alder genetic resources in British Columbia

by Andreas Hamann[1]

During the last two decades, the value of red alder wood products has substantially increased and several initiatives have been launched in the United States to use red alder for reforestation. Nonetheless, red alder is a largely neglected resource in British Columbia. This review paper examines the reasons behind the under-utilization of red alder in British Columbia and investigates whether changes in red alder management practices could improve the value of the resource. Red alder's potential for plantation forestry and genetic tree improvement are discussed, and possible breeding objectives were evaluated with consideration for the species biology, growth, product value and market demand. Seed transfer rules and the possibility of gains from selection are summarized in the light of new research results in genecology and quantitative genetics for red alder populations in British Columbia.

Key words: red alder, *Alnus rubra*, tree improvement, quantitative genetics, genecology, resource management

Au cours des deux dernières décennies, la valeur des produits de bois d'aulne rouge a considérablement augmenté et plusieurs initiatives ont été entreprises aux États-Unis pour utiliser l'aulne rouge en reboisement. Néanmoins, l'aulne rouge demeure une ressource passablement négligée en Colombie-Britannique. Cet article synthèse passe en revue les raisons de cette sous-utilisation de l'aulne rouge en Colombie-Britannique et cherche à déterminer si des modifications aux pratiques d'aménagement de l'aulne rouge pourraient accroître la valeur de la ressource. Le potentiel de l'aulne rouge en plantation forestière et l'amélioration génétique sont abordés, ainsi que les objectifs potentiels d'amélioration qui ont été évalué selon la biologie de l'espèce, la croissance, la valeur des produits et la demande du marché. Les règles de transferts de semence et les possibilité de gains à partir de sélections sont résumées à la lumière des nouveaux résultats de recherche en génécologie et en génétique quantitative pour les populations d'aulne rouge de la Colombie-Britannique.

Mots-clés: aulne rouge, *Alnus rubra*, amélioration génétique, génétique quantitative, génécologie, aménagement de la ressource

Introduction

Red alder (*Alnus rubra* Bong.) is the most common and wide-ranging hardwood in the Pacific Northwest. Its natural range is usually confined to within 300 km of the ocean and to elevations below 1000 m (Harrington 1990). Ecologically, red alder is a pioneer species with low shade tolerance and rapid juvenile growth rates. After large-scale disturbance, it can form pure, even-aged stands. Widespread logging in the 1930s to 1950s created suitable habitat in southern British Columbia, Washington and Oregon for this originally infrequent species (confined to riparian areas). Today, naturally regenerated stands of red alder make up a significant proportion of commercially available timber in the Pacific Northwest (Plank and Willits 1994). In British Columbia, this resource is available predominantly in the Georgia Depression (GD), both on crown and private lands (Fig. 1).

During the last two decades, interest has increased to develop an intensive forestry management system for red alder. Its abundance and low timber price has made it one of the few hardwoods in the Pacific Northwest with major economic importance. Changes in forest management policy have taken place that support diversification of softwood plantation forestry and encourage the use of ecologically valuable species in reforestation programs. The potential of red alder for soil amelioration and wood production was described as early as the beginning of the century (Johnson 1917, Johnson *et al.* 1926) and its ecological values and suitability as a forestry species have been emphasized ever since (Trappe *et al.* 1968, Briggs *et al.* 1978, Hibbs *et al.* 1994a).

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Nonetheless, red alder is a largely neglected resource in British Columbia. Although volume in stands dominated by mature red alder in British Columbia is estimated at about 13 million m^3 (Massie 1990), and the theoretical annual allowable cut during the 1980s and 1990s was approximately 300 000 m^3, only about 10 000 m^3 were harvested per year (Peterson 1996). This accounts for less than 0.1% of the harvested volume of conifers (Nilsson 1985). This review paper examines the reasons behind the under-utilization of red alder in British Columbia and investigates whether changes in red alder management practices could improve the value of the resource. Particularly the possibility of genetic tree improvement is discussed in the light of new research results that are now available for this species.

Incentives To Grow Red Alder

Ecological aspects

Red alder can be expected to be an unproblematic candidate for reforestation. Being a pioneer it survives open field conditions, naturally occurs in pure stands, and has few insect and disease problems (Harrington 1990). Red alder grows well on a wide variety of soil types ranging from well-drained gravel and sands to poorly drained clay and organic soils. It also is among the few temperate species capable of forming an endosymbiontic

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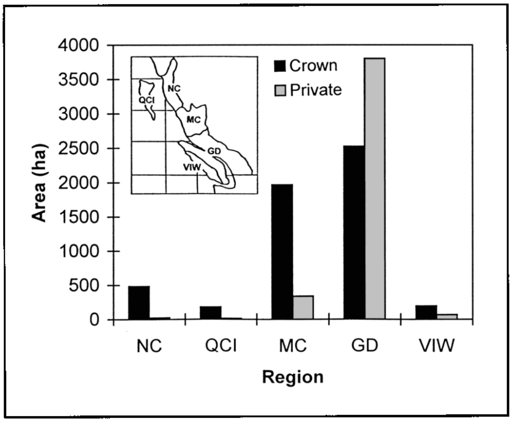

Fig. 1. Ownership of red alder stands. Data from Massie (1990) summarized by regions (NC, North Coast; QCI, Queen Charlotte Islands; MC, Mid Coast; GD, Georgia Depression; VIW, Vancouver Island West).

relationship with nitrogen-fixing bacteria. The nitrogen-rich litter of red alder can improve turnover rates of litter from other species, particularly conifers, resulting in increased availability of most macronutrients (Bormann *et al.* 1994, Giardina *et al.* 1995, Comeau *et al.* 1996, Compton *et al.* 1997). Red alder also tolerates occasional flooding and restricted drainage and has been proposed for reforestation on special sites where it regularly outperforms other candidate species (Dale 1989; Moffat *et al.* 1989; Heilman 1990a, 1990b). Since red alder is immune to laminated root rot fungus (*Phellinus weirii*), an important conifer disease in British Columbia, it has been suggested that red alder stands could be grown in alternate rotation with conifers to reduce the presence of the pathogen (Nelson *et al.* 1978).

Market for red alder products

Strong and consistent markets have developed for red alder saw timber in North America and overseas. The uniformity, color, and ease of processing have made red alder wood popular for furniture manufacturing, cabinetry, paneling, and musical instruments (Atterbury 1978, Leney *et al.* 1978, Resch 1988). In Oregon and Washington high grade logs in natural stands make up a significant proportion of harvests from natural stands (Plank and Willits 1994), and red alder's popularity today is mainly due to its abundance and low price on markets in the United States during the past 20 years. The most common log sizes (30 to 45 cm dbh) had half the value of softwood logs in the 1970s but have increased in value constantly since then (Fig. 2). Now, red alder logs of this size are second in value only to Douglas-fir. Since volume recovery at the sawmill is generally lower in red alder than in conifers, there is a dramatic increase in log value as the diameter increases. Red alder logs of 45 cm and above are comparable in value to similar-sized Douglas-fir logs (Plank *et al.* 1990). Warren (1994, cited in Daniels 1995) even reports prices of US$ 1600 per 1000 boardfeet for alder compared to US$ 1000 for Douglas-fir premium grade logs. These prices are partly due to over-utilization of good quality red alder stands and shortages in the supply of premium alder saw logs. As a result, several initiatives have been launched in the United States to use red alder for reforestation, the most prevalent arguably by Weyerhaeuser Corporation now growing 2.5 million trees per year (Tanaka *et al.* 1997).

Why Red Alder is a Neglected Resource in B. C.

Insufficient natural regeneration

Despite its reputation as a forest weed, natural regeneration of red alder is often inadequate. It has been pointed out that red alder often fails to establish under the most favorable site conditions (Harrington *et al.* 1994, Haeussler *et al.* 1995). The problem is that red alder seed are very small and susceptible to desiccation, competing vegetation, and other factors that impede successful development into a seedling (Elliott and Tailor 1981a, 1981b). Consequently regeneration success is erratic and stocking can be spotty. Natural regeneration has a second related disadvantage. Uneven spacing or mortality associated with close initial spacing results in lean and sweep of trees that grow into the free crown positions. Red alder is capable of considerable deformation to seek higher light environments, and this is one reason for reduced quality of red alder logs in nat-

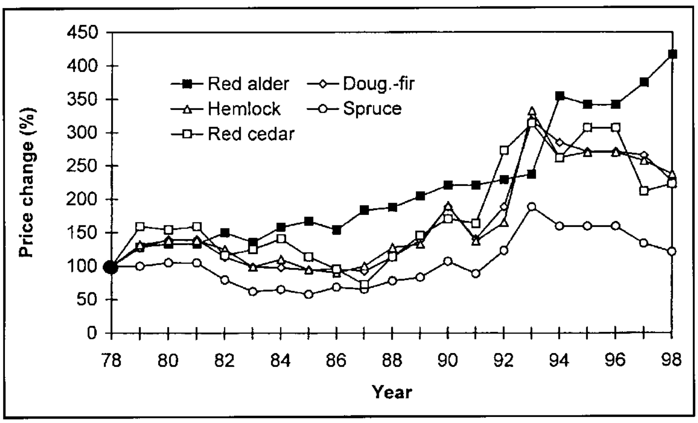

Fig. 2. Change of red alder log prices over the past two decades compared with softwood species (Data from Oregon Department of Forestry 1999).

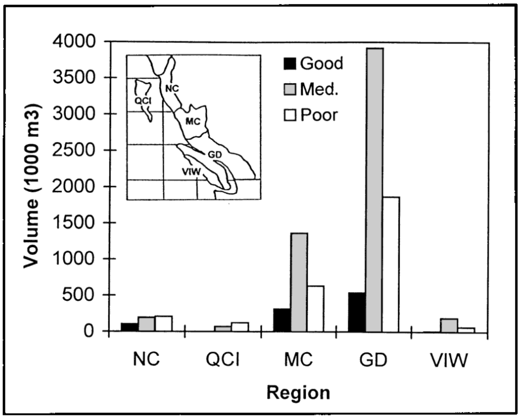

Fig. 3. Quality of red alder stands. Data from Massie (1990) summarized by regions (as in Fig. 1).

Table 1. Yield at peak mean annual increment (MAI) for median site indices for species in the Vancouver forest region (Peterson 1996)

Species	Yield [m^3ha^{-1}]	Age [yr]	MAI [$m^3ha^{-1}yr^{-1}$]	Height [m]	DBH [cm]
Red alder	210	25	8.5	20	19
Black cottonwood	260	25	10.4	26	27
Douglas-fir	594	70	8.5	28	30
Western hemlock	607	65	9.3	28	29
Sitka spruce	544	55	9.9	33	29
Western redcedar	519	100	5.2	28	25

Table 2. Yield of red alder at rotation at age for different site qualities in the Vancouver forest region (Peterson 1996)

Site	Objective	Yield [m^3ha^{-1}]	Age [yr]	MAI [$m^3ha^{-1}yr^{-1}$]	Height [m]	DBH [cm]
Poor	Max. MAI	204	40	5.1	18	19
Med.	Max. MAI	220	30	7.3	20	21
Fair	Max. MAI	211	20	10.6	19	20
Good	Max. MAI	228	15	15.2	21	22
Poor	Max. value	345	85	4.1	29	28
Med.	Max. value	350	60	5.9	30	29
Fair	Max. value	360	40	9.1	31	30
Good	Max. value	355	25	14.2	30	29

ural stands (Ahrens *et al.* 1992). High value stands can only be achieved through careful thinning or planting for better control over spacing and uniformity of establishment (Bormann 1985).

Inferior quality of stands

The low quality of natural stands in British Columbia may be the main reason that restricts their commercial harvest (Fig. 3). The low price of chips and pulp does not warrant investments necessary for harvesting medium and poor-quality stands. The value of alder wood chips is less than that of wood chips from most other hardwoods, because a smaller volume of pulp can be obtained from the same amount of solid wood equivalent (Massie *et al.* 1994). Average pulp prices of red alder, aspen and cottonwood chips for the period 1987 to 1991 were US$ 196, 203, and 228 for 1 m^3 solid wood equivalent, respectively (Massie *et al.* 1994). Alder wood chips and pulp are readily accepted in markets of the United States and Japan, but they have to compete with products from low-cost biomass production systems on the world market (Peterson 1996).

Poor yield on marginal sites

Compared to softwoods, rotations of alder in British Columbia are considerably shorter due to rapid juvenile growth. Peak mean annual increment (MAI) for volume at median site indices for the Vancouver Forest Region occur at less than half the age for red alder than for softwoods (Table 1). Rotation at maximum MAI for volume, however, is different from rotation at maximum value for sawtimber. A high log grade requires dimensions of approximately 30 cm dbh and 30 m tree height. These dimensions will be reached in natural stands at 40 to 60 years for median site conditions in British Columbia (Table 2). This is not much different from the time Douglas-fir, hemlock, or Sitka spruce requires to reach sawtimber dimensions (Table 1).

Assuming that site quality factors for red alder and conifers are largely the same as indicated by the work of Harrington (1986) and Harrington and Courtin (1994), site index curves for

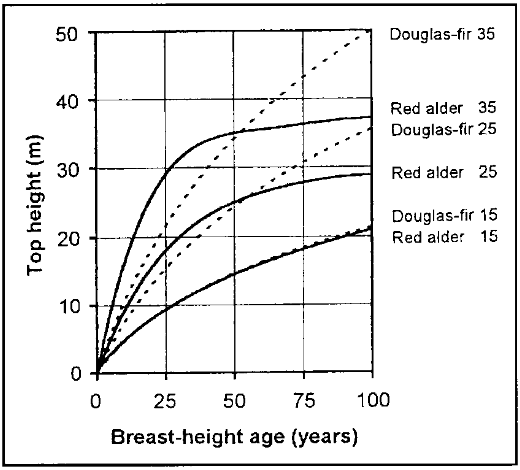

Fig. 4. Site index curves (age 50) for red alder and Douglas-fir, the latter representative of most conifers in B. C. (Data from Thrower and Nussbaum 1991).

British Columbia (Mitchell 1988, Thrower and Nussbaum 1991) imply that growth on poor sites is comparable to conifers. Rotation length for alder sawtimber is only reduced due to rapid juvenile growth under above-average site conditions (Fig. 4). These findings go contrary to the notion that red alder should be grown on marginal sites because of its nitrogen-fixing capabilities and capacity to survive under extreme site conditions. There has been a reluctance to grow red alder on prime sites, traditionally reserved for planting only the most valuable conifer species. This, however, is where alder has the greatest potential to generate superior revenue.

Recommendations for Reforestation

Plantation establishment and tending

If red alder is to become a significant forestry species in British Columbia, there is an obvious need to develop a forestry system that produces better quality stands. Reliable reforestation on sites determined optimal for red alder can best be achieved through the use of nursery grown planting stock. This will allow successful regeneration on a much wider range of site conditions than natural regeneration, decrease the susceptibility to environmental stress, and permit escape from competing vegetation and damage from browsing by rapid growth (Newton and Cole 1994). Techniques for mass production of seedlings and plantation establishment are well researched, including guidelines for seed collection, storage, germination, and inoculation with the symbiotic bacterium *Frankia* (Kenady 1978, Berry and Torrey 1985, Sheppard *et al.* 1988, Hibbs and Ager 1989, Wheeler *et al.* 1991, Radwan *et al.* 1992, Haeussler and Tappeiner 1993, Ager *et al.* 1994, Ahrens 1994, Crannell *et al.* 1994). Artificial regeneration alone can be expected to improve the quality of red alder stands in British Columbia through even spacing and avoidance of early mortality. Control of spacing should be maintained throughout the rotation to optimize form, to increase growth rates, and to shorten rotation age (DeBell *et al.* 1978; Hibbs *et al.* 1989, 1995; Puettmann *et al.* 1993; Knowe and Hibbs 1996; Knowe *et al.* 1997).

Seed transfer guidelines

Regeneration of a forestry species by planting usually makes some level of genetic resource management necessary. The choice of seed sources for reforestation is a critical decision, and using inappropriate seed sources can result in maladapted tree populations low in vigor and prone to pests and injury due to unusually severe climatic conditions. Substantial genetic variation in growth and adaptive traits of red alder has been found throughout its range (Ager 1987, Cannell *et al.* 1987, Lester and DeBell 1989, Hook *et al.* 1990, Ager *et al.* 1993, Hibbs *et al.* 1994b, Xie and Ying 1994, Hamann *et al.* 1998). A responsible reforestation program must take this genetic differentiation into account. Seed zones and seed transfer guidelines are essential tools to minimize the risks of maladaptation due to movement of seed or vegetative material from its source to another location.

For coastal British Columbia, the Ministry of Forests delineates three general seed planning zones for all species: Maritime, Georgia Lowland, and Submaritime, which are based on biogeoclimatic subzones and variants (Lester *et al.* 1990). Red alder's natural range is confined to these coastal seed planning zones. Within a seed planning zone, seed transfer is usually further restricted to 3° latitude or 300m elevation in the Maritime zone and to 1.5° latitude or 200m elevation for the Submaritime zone, but may differ for particular species (Ministry of Forests 1995). Similar guidelines for red alder have been proposed for Washington and Oregon (Hibbs and Ager 1989, Randall 1996). These guidelines assume that populations are adapted to local environments, which has been confirmed for red alder populations in British Columbia (Hamann *et al.* 2000). This study found that within the Maritime seed zone a 10% reduction in growth and survival compared to local sources can be expected for a transfer of approximately 3° latitude. Geographic patterns of variation also suggested that transfer across the boundaries of the Georgia Lowland and the Maritime zones should be avoided. As an alternative to the general Ministry of Forests guidelines, three seed zones/breeding zones have been suggested based on genetic differentiation in growth and adaptive traits: British Columbia north of 51°N, Georgia Depression, and Vancouver Island West as shown in Fig. 1 (Hamann *et al.* 1999, 2000).

Recommendations for Tree Improvement

Breeding objectives

Regeneration of a forestry species by planting opens up the opportunity to improve a forestry program by planting selected genotypes. Where intensive plantation forestry is warranted, genetic improvement should usually be complementary to silvicultural prescriptions. Growth and yield of red alder implies that a product equal or greater in value compared to conifers can be produced in considerably shorter time. In order to exploit the full early growth potential of red alder, it must be grown on fair to good sites (site index 25/50 or better) and genotypes should be selected for these environments. Saw timber production appears to be the economically most desirable option for a tree improvement program, since quality saw logs of red alder are highly valued and in short supply in both U.S. and overseas markets. Selection should, therefore, include growth traits as well as quality-related traits such as stem form, sweep and lean, branch number and size, epicormic branching, and wood properties. A biomass production system for red alder would have to compete with other short-fiber species on world markets, where strong competition exists through low-cost silvicultural systems with fast growing species. Furthermore, local competition for biomass production exists through efficient coppice systems with black cottonwood (Massie *et al.* 1994, Daniels 1995).

Genetic gains from selection

The translation of breeding objectives into selection criteria depends largely on the genetic control of traits. Daniels (1995) suggests there may be little opportunity for genetic improvement for growth and form traits because of limited within-population variability found by Ager and Stettler (1994). He suspected that in red alder, being an aggressive colonizer, intensive selection for height growth and biomass partitioning could have resulted in reduced variability in growth traits. It has also been observed that red alder is morphologically remarkably uniform throughout its range (DeBell and Wilson 1978, Stettler 1978). Presumably, intense natural selection in dense even-aged stands has reduced the genetic variability. In order to assess the potential benefits from selection and evaluate different options for tree improvement, estimates of genetic parameters are needed for traits of importance.

In British Columbia, substantial within family variation has been found in most traits (Hamann 1999, Hamann *et al.* 2001). Estimated individual heritabilities for various traits were moderate to high, with values between 0.30 and 1.0 depending on the method of calculation (Fig. 5). The lower heritability value in Fig. 5 is based on the additive variance calculated as four times the family variance component and would apply for selection within a provenance. When several provenances are combined into a breeding zone, the provenance variance component will contribute, and the additive variance was calculated as four times the provenance plus family variance component. The higher value can be considered as an upper bound

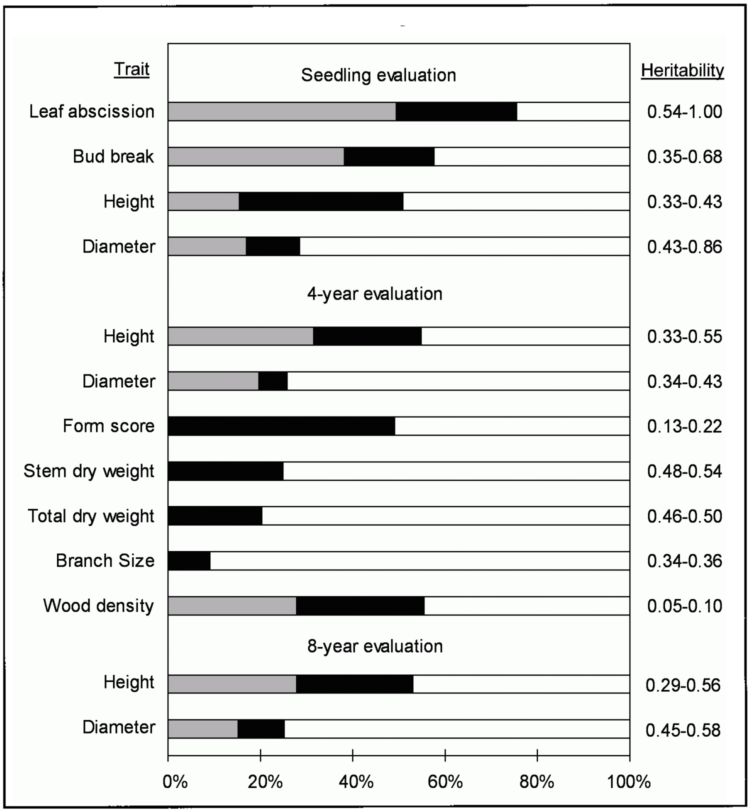

Fig. 5. Proportion of total genetic variation due to region (▦) as in Fig. 1, provenance (■), and family (□). Heritabilities are based on family variance components (lower value) and family plus provenance variance components (higher value).

for heritabilities that can be expected for breeding populations in British Columbia (Hamann *et al.* 2001). Standard errors of heritabilities were estimated according to the delta-method (Lynch and Walsh 1998, Appendix 1). Standard errors of either heritability estimate were 0.09 for traits evaluated at 8 years, 0.16 for the traits wood density, branch size, and dry weight, and 0.05 for all other traits. Branch size and form score showed lower individual heritability estimates than did growth traits, although quality-related traits are usually under stronger genetic control (Cornelius 1994). The form score does not appear to have sufficient genetic variability to allow substantial improvement from selection. It is, however, positively correlated with growth traits (Table 3) and form will, therefore, not be adversely influenced by selection for better growth. Breeding for trees with many small rather than a few large branches may not be easily accomplished due to substantial positive genetic correlations with other growth traits. High frequency of multiple leaders and retention of low branches was observed in only a few families in test plantations. Their exclusion from a breeding program would probably eliminate these undesirable characteristics.

Heritability for wood density is close to zero, which is in accordance with results of other studies for this species (Harrington and DeBell 1980, Ager and Stettler 1994). There is apparently little potential to improve wood properties in red alder. In general, wood properties are under relatively strong genetic control in most tree species (Zobel and van Buijtenen 1989), and Daniels (1995) warned that ignoring wood properties in red alder could be risky since the studies cited were based on juvenile material with limited sample size. However, non-genetic publications suggest that alder wood is indeed very uniform among individuals as well as within the tree. Lei *et al.* (1997) did not encounter correlations between growth rates and wood properties of economic importance for either timber or pulp production. Lowell and Krahmer (1993) revealed that tension or compression wood due to lean in red alder has no effect on wood

Table 3. Genetic correlations (upper right) and phenotypic correlations (lower left) for traits evaluated at age four

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Height (1)		0.92	0.75	0.72	0.15	0.62	0.05
Diameter (2)	0.82		0.88	0.85	0.32	0.70	0.01
Stem dry weight (3)	0.80	0.92		0.99	0.35	0.81	0.00
Total dry weight (4)	0.78	0.91	0.99		0.36	0.84	0.08
Form Score (5)	0.37	0.40	0.22	0.23		0.20	0.00
Branch Size (6)	0.57	0.79	0.82	0.84	0.26		0.02
Wood density (7)	0.09	0.07	0.07	0.01	0.01	0.06	

density. Gartner *et al.* (1997) found that reaction wood from lean was not significantly different in a number of measures, and that most wood properties were remarkably uniform throughout stems. Hence, breeding for improved wood properties in red alder is unlikely to succeed. On the other hand, growth rates of red alder may be increased through breeding or silvicultural practices without negative effects on wood and fiber quality.

Conclusions

Red alder can be expected to be a relatively unproblematic candidate for plantation forestry regarding survival, growth, and resistance to pests and diseases. The use of larger seedlings will allow stand establishment under a wide range of environmental conditions and avoid patchy distribution of alder usually found in natural stands. Cultural measures, such as control of spacing at plantation establishment and thinning, will enhance growth rates and quality of stands. Three seed zones/breeding zones are necessary for British Columbia to ensure adaptation of planting stock to local climatic conditions. Previous studies suggested that there is little opportunity for genetic improvement in growth and form traits within populations. Substantial within-population variance observed in recent investigations is an important finding and shows that genetic improvement through selection and breeding is possible. Growth traits had moderate individual-tree heritabilities on the order of 0.40. Small improvements would indirectly be achieved in the form score, and exclusion of a few families with high frequency of multiple leaders and insufficient self pruning would probably eliminate these undesirable characteristics. Results of current trials suggest that wood density has little genetic variation and cannot be improved via selective breeding.

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