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17

Actinorhizal Plants in Pacific Northwest Forests

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I. Introduction

A. The Region

The forests of the Pacific Northwest are extensive and diverse. They contain representatives of most of the world's conifer genera. Geographically, they are constrained in a relatively narrow north–south trending belt between the Pacific Ocean and the high-elevation mountain ranges that occur 20 to 200 km inland. These forests extend from 42° to 60°N latitude. Climate ranges from cool maritime to cold alpine. Summers are dry, and annual precipitation decreases north to south. The geology includes sedimentary and volcanic rock, and the northern portions of the region have been heavily glaciated. Historically, extensive fire has been the major disturbance in the south while wind has been of primary importance in the north. For more detail about the region, see Franklin and Dyrness (1973) for an in-depth review of the climate, geology, vegetation types, and vegetation dynamics of Oregon and Washington. Much of their discussion of the *Picea sitchensis, Tsuga heterophylla, Abies amabilis,* and *Tsuga mertensiana* zones applies to the Canadian and southern Alaskan coast as well.

B. Actinorhizal Species

Three genera of actinorhizal plants occur in the region, *Purshia, Alnus,* and *Ceanothus. Purshia* species are found east of the Cascade Mountains

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and occasionally on dry sites in the Pacific Northwest. East of the Cascades, *P. tridentata* can fix a modest amount of nitrogen (Dalton and Zobel, 1977).

Red alder (*A. rubra*) is an early successional species found on mesic sites in the *Picea sitchensis* and *Tsuga heterophylla* zones (Franklin and Dyrness, 1973). North of about 50° latitude or above 800 m elevation, red alder is first mixed with and, with increasingly cooler climate, replaced by the shrubby Sitka alder (*A. viridis* ssp. *sinuata*). White alder (*A. rhombifolia*) occurs in riparian zones in the drier southern portions of the region (mixed-evergreen and interior valley zones). One other species of alder, the nonnative *A. glutinosa*, has been planted in a very limited set of research plots.

Species of the genus *Ceanothus* are restricted almost entirely to early successional sites in Oregon (Conard *et al.*, 1985), although they occur on drier sites as far north as Vancouver Island (Binkley, 1986). As a group, they are more stress tolerant than *Alnus*. They occur primarily as early successional shrubs on cold or drought-prone sites. Snowbrush (*C. velutinus*) regenerates from buried seed and inhabits middle-elevation sites in the Cascade Range and higher elevations in the Coast Range (*Tsuga heterophylla* and mixed-conifer zones). Redstem (*C. sanguineus*) overlaps snowbrush in range and habitat characteristics. However, it is more drought and cold tolerant and extends up the Cascade Range north of the Canadian border. Deerbrush (*C. integerrimus*) is the most drought tolerant of the three more common *Ceanothus* species. In the Pacific Northwest, deerbrush reaches its best development in the Siskiyou Mountains (mixed-evergreen and mixed-conifer zones). Deerbrush is an important wildlife browse species. Of minor importance in the region are *C. cuneatus*, *C. thyrsiflorus*, *C. cordulatus*, and *C. prostratus*.

Two genera of leguminous plants are also found in the forests of the region: *Lupinus* and *Cytisus*. The lupines are restricted to high elevation or dry sites. Scotch broom (*C. scoparius*) is a nonnative legume that is spreading northward as a roadside and forest plantation weed on mesic sites. It cannot be considered an important nitrogen fixer in the region (Helgerson *et al.*, 1979). Lupines are present but not common west of the Cascade crest, so they also are probably not important nitrogen fixers. East of the Cascade Mountains, lupines can fix 10 to 15 kg/ha/year (Cromack *et al.*, 1979).

C. Nitrogen Fixation Estimates

Estimates of nitrogen fixation rates vary greatly by species and region (Table I). Red alder shows the most consistently high levels of fixation, although snowbrush (*C. velutinus*) and Sitka alder can equal it on sites without temperature or moisture stress. The values in Table I need to be interpreted with caution because they comprise a diversity of estimation methods: ^{15}N, accretion, acetylene reduction, and chronosequences (sequences of similar sites of different successional ages).

Table I Examples of Estimates of Annual Nitrogen Fixation by Pacific Northwest Actinorhizal Plants[a]

Annual N fixation (kg/ha/year)	Location	Stand age (years)	Reference
Red alder			
23	Or. Coast Range	2	Kim *et al.* (1989)
320	Or. Coast Range	2–15	Newton *et al.* (1968)
70	NW. Oregon	5	Bormann and Gordon (1984)
80	W. Washington	1–4	DeBell and Radwan (1979)
62	W. Washington	2–4	Tripp *et al.* (1979)
85	W. Washington	1–38	Cole *et al.* (1978)
100	W. Washington	10–40	Bormann and DeBell (1981)
42	NW. Washington	1–23	Binkley (1982)
65	British Columbia	1–23	Binkley (1982)
130	British Columbia	20	Binkley (1981)
Sitka alder			
2	British Columbia	20	Binkley (1981)
Ceanothus velutinus			
8	SW. Oregon	5–6	Kim (1987)
69	SW. Oregon	11	Kim (1987)
32	NW. Oregon	11	McNabb *et al.* (1979)
70–108	Or. Cascades	1–10	Youngberg and Wollum (1976)
42–100	Or. Cascades	1–12	Binkley *et al.* (1982)
0–20	Or. Cascades	1–15	Zavitkovski and Newton (1968)
80	Or. Cascades	17	Cromack *et al.* (1979)
101	Or. Cascades	17	McNabb and Cromack (1983)
Ceanothus sanguineus			
24–50	British Columbia	1–12	Binkley and Husted (1983)
Ceanothus integerrimus			
<1	SW. Oregon	5–6	Kim (1987)

[a]This list is not exhaustive.

D. Importance of Actinorhizal Plants

The historic importance of actinorhizal plants to nitrogen budgets and forest productivity in the Pacific Northwest is uncertain. In recent history, logging activities with ground-based equipment and preparation of harvested land for replanting have increased the area occupied by *Alnus* and *Ceanothus*. This spread following disturbance has led to speculation that similar increases in abundance of these species would have occurred following the extensive fires or blowdowns that occurred throughout the presettlement history of the region. These nitrogen-fixing pioneer species would then have been succeeded by the mature forest conifers. If these nitrogen fixers were common following disturbances, they surely would have played an important role in maintaining or rebuilding nitrogen pools.

Two observations cause some uncertainty about this hypothesized importance in both the red alder- and snowbrush-dominated portions of the region (the *Picea sitchensis* and *Tsuga heterophylla* zones; Franklin and Dyrness, 1973). First, chronosequence studies of red alder succession in the Coast Range (Henderson, 1970; Carlton, 1988) show that conifer regeneration under alder is very rare. Instead, most alder stands appear to succeed to salmonberry (*Rubus spectabilis*)-dominated communities (Newton *et al.*, 1968; Hibbs, 1987b). How long these shrub communities would be stable is uncertain. This successional sequence, however, clearly delays conifer colonization by more than the 100-year life span of red alder and several decades or, perhaps, centuries of shrub dominance. Fire may be required to remove the shrubs and restart succession on another pathway.

The second observation comes from tree-age distribution studies in old growth Douglas-fir (*Pseudotsuga menziesii*) stands in the Oregon Cascade Mountains (Franklin and Hemstrom, 1981). There are at least two extensive fires that can be documented, about 250 years ago and 500 plus years ago. Stands resulting from the fire 500 plus years ago are uneven-aged. Conifer regeneration occurred over a period of 200 years. This could have resulted from the slow invasion of an already established plant community, perhaps including actinorhizal plants. It could also have resulted from a lack of seed source for Douglas-fir. The lack of signs of early growth suppression in dominant trees argues for the latter. Stands resulting from the fire 250 years ago are even-aged. Even-aged stands result from immediate colonization following a disturbance. Immediate conifer invasion precludes the possibility of a period of red alder domination. Because Douglas-fir can establish in and succeed snowbrush, this successional pathway is a possibility.

E. Defining the Bounds to Management

Two long-term studies have stimulated interest in actinorhizal plants and fueled the controversy that surrounds their use in forestry. Miller and Murray (1978) described a 4-year-old Douglas-fir pla... nitrogen-deficient soil in southwestern Washington (Wind River Experimental Forest) that was interplanted with red alder from a coastal seed source. By age 48, the mixed stand contained almost 7% more conifer wood volume than the pure conifer stand. Conifer diameter increased 23%; height increased by 24%. In addition, the mixed stand contained almost as much alder wood volume as conifer volume. The increase in forest productivity with mixed culture is clear. As the next example shows, however, the where and how of achieving such increases is not clear.

In 1935–1936, researchers established plots in an 8-year-old stand of mixed conifer/red alder at Cascade Head Experimental Forest (Berntsen, 1961). Soil nitrogen levels are high in this area. The four treatments were (1) control (mixed species, unthinned), (2) pure conifer, thinned, (3) pure alder, thinned, and (4) pure alder, unthinned (this plot originally

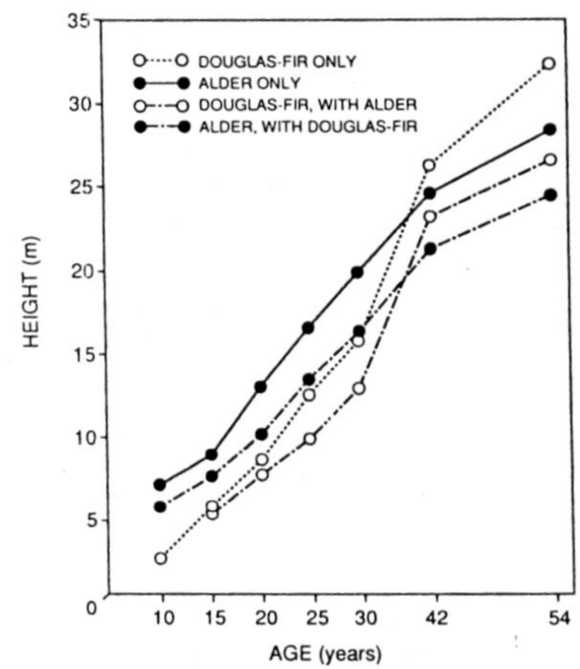

Figure 1 Height growth of red alder and Douglas-fir grown in mixture and in pure-species plots at Cascade Head Experimental Forest (S. Greene, unpublished observations). Note that there were some differences in height growth potential among plots at the beginning of the study.

had a low conifer complement). These treatments were unreplicated, and initial height measurements indicate that there were some site quality differences among the plots (Fig. 1). Table II documents the change in volume with time in these treatments. Berntsen (1961) and S. Greene (unpublished observations) do not separate these volumes by species. The early rapid growth of alder is clear. Through age 30, Douglas-fir was shorter than alder (Fig. 1) and the mixed stand underproduced relative to either species alone (Table II). By age 42, the Douglas-fir in the mixed plot grew through the alder canopy and then stand growth increased. In contrast, Miller and Murray (1978) found an almost immediate increase in Douglas-fir growth following alder planting at Wind River even though the Douglas-fir height did not surpass that of alder until age 30 (Douglas-fir). The ability of Douglas-fir to survive under and eventually grow through the dense alder canopy in both examples comes as a surprise to foresters.

The differences in stand development and productivity between Wind River and Cascade Head Experimental forests have made it clear that factors related to soil fertility and the spacing and timing of establishment may all be important to the production and outcome of pure-species stands and mixing species (see also Binkley, 1983). In the next sections, we will review the research in these areas. Then, we will discuss how these findings are or could be implemented in forest management.

II. Soil Building/Fertility

A. Increased Soil Nitrogen

In the Pacific Northwest, red alder clearly has the capacity to add significant amounts of N to soil (Table I) and also to increase soil organic matter

Table II Wood Volume (m^3/ha) in Cascade Head Mixed Alder/Conifer Study[a]

Treatment	Age at measurement (years) 15	20	25	30	42	54
Alder/conifer mix	48	121	206	278	434	518
Conifer, thinned	15	71	185	331	595	770
Alder, thinned	85	170	234	303	357	420
Alder, unthinned	174	240	294	361	420	406

[a]Minimum tree diameter measured was 4 cm. From Berntsen (1961) and S. Greene (unpublished observations).

(Tarrant and Miller, 1963; Bormann and DeBell, 1981). Other alder species, including Sitka alder, can also increase soil N and organic matter (Van Cleve *et al.*, 1971; Binkley *et al.*, 1984). In Europe, *Alnus glutinosa* has been shown to have similar capacity (Wild, 1988), as has *A. incana* ssp. *rugosa* in the eastern United States (Voight and Steucek, 1969).

Red alder has the capability of fixing N over a wide range of stand densities and ages, ranging from 2-year-old stands having 10,000 stems/ha to a 58-year-old stand having 250 stems/ha (Kim *et al.*, 1990). Estimates of N fixation by red alder range from 22 kg/ha/year in 2-year-old alder (Kim *et al.*, 1990) to over 300 kg/ha/year in vigorous, mature stands (Zavitkovski and Newton, 1968). Bormann and Gordon (1984), for 5-year-old red alder, report fixation rates of 62 kg/ha/year with 2000 stems/ha ranging up to a maximum rate of 85 kg/ha/year with 10,000 stems/ha. Heilman and Ekuan (1982) recently demonstrated the ability of red and Sitka alders to fix large amounts of nitrogen on coal mine spoils in western Washington.

Alnus is quite versatile as a successional genus. Alders can occur as pioneer species in primary succession following deglaciation (Lawrence, 1958; Davis, 1981), landslides (Ugolini, 1968), and volcanic eruptions (J. Means, personal communication), and they can occur in secondary succession following a variety of forest disturbances (Franklin and Dyrness, 1973). Alder can occur as a dominant species early in succession. In other cases, it is an understory species in mature conifer stands (Van Cleve and Viereck, 1981; Simard, 1989). Substantial N fixation can occur when red alder is an understory species growing after heavy thinning of conifer stands, if light is adequate (Berg and Doerksen, 1975).

Addition of N to soil by alder species has been shown to increase significantly both total soil N and available soil N (Binkley *et al.*, 1984; Sollins *et al.*, 1984; Binkley, 1986). Increased available N is a key to increased growth of economically important conifers such as Douglas-fir (Shumway and Atkinson, 1978).

B. Soil Organic Matter

Increases in soil organic matter as high as 20% have been found under alder (Tarrant and Miller, 1963; Franklin *et al.*, 1968; Bormann and DeBell, 1981; Binkley *et al.*, 1982; Binkley, 1983). A chronosequence study documented that snowbrush can also increase soil organic matter (Binkley *et al.*, 1982). Soil organic matter is the primary storage medium for soil N, and the relatively decay-resistant nature of humified organic matter means that chemically bound organic N will be released fairly slowly (Stevenson, 1982; Wild, 1988). Soil organic matter has a high cation-exchange capacity and retains cations such as Ca^{2+}, K^+, Mg^{2+}, NH_4^+, and micronutrients. Retention of NH_4^+ is especially important since NH_4^+ is the dominant form of mineralized N in many forest soils (Binkley, 1986). Alder also has the capacity to acidify soil (Lawrence, 1958). Lowering soil pH can minimize volatilization losses of N as NH_4^+ from soils that normally have a high pH (Ledgard *et al*, 1984).

Addition of soil organic matter has been shown to increase aggregate formation and improve soil tilth (Oades, 1988; Wild, 1988). Soil aggregate structure is important to maintaining soil porosity and good aeration of the soil (Wild, 1988). Stable soil aggregates also protect soil organic matter from decomposition due to physical occlusion (Oades, 1988). In addition to contributing to improved soil structure, addition of soil organic matter to soil can decrease soil bulk density (Wild, 1988). Several studies have shown that both red and Sitka alder have decreased soil bulk density as well as increased soil N and organic matter (Tarrant and Miller, 1963; Binkley *et al.*, 1984; Binkley, 1986).

III. Use in Forest Production

This review of the interactions between actinorhizal plants and soil properties reflects the broad ecological interest that exists regarding these species. The interests in forest management are more narrow. Where they occur naturally in forest plantations, the various species of *Alnus* and *Ceanothus* are treated as undesirable weeds. They are removed from plantations to improve conifer survival and growth.

Only in the last 10 years has interest begun to develop in the management of red alder, both in pure stands and in mixed culture with conifers. There is also a small interest in Sitka alder as an interplanted species in conifer plantations. The very limited interest that exists for *Ceanothus* species, as discussed earlier, has focused on its short-term nitrogen input as an early-successional shrub in plantations. Evidence for its effects on conifer regeneration is mixed. *Ceanothus* can be competitive with Douglas-fir (Peterson *et al.*, 1988); it also may provide protection from animal damage during seedling establishment (Youngberg *et al.*, 1979). Considering red alder's overwhelming economic importance, as a weed and as a crop, the rest of this discussion on forest management will focus on red alder. We will return at the end, however, to review interplanting actinorhizal shrubs in conifer plantations.

A. Reasons for Management

Red alder is planted and managed for three reasons. It is a disease-resistant crop in areas infected with conifer root diseases. It is a valuable pulp and timber species. As a nitrogen fixer, it can improve the growth of associated species.

Laminated root rot (*Phellinus weirii*) is a pathogenic fungus of Douglas-fir and many other conifers in the Pacific Northwest. An estimated 32 million cubic feet of Douglas-fir is lost each year in Oregon and Washington to the disease (Childs and Shea, 1967). Red alder, like all hardwoods, is immune. Thus, it can be an alternative crop in infected areas.

Nelson *et al.* (1978) review the research regarding the interactions between red alder and the fungus. First, it is well known that alder changes soil properties by adding nitrate, fatty acids, and phenolic compounds, by reducing pH, and by increasing the activity of microbial antagonists to *P. weirii*. Second, in the laboratory, some of these changes can inhibit fungal growth. In the field, however, it has been difficult to separate direct effects of alder from the indirect one of removing the host. Following harvest of an infected stand, fungal distribution becomes increasingly limited as first Douglas-fir roots and then stumps decay. In 50 years, the incidence of infected stumps can be reduced to 25% of the original number (Hansen, 1976). This reduction in fungal incidence has not been directly associated with the presence of alder.

Most debates about the alternatives of growing red alder or a conifer as a timber crop are abstract (Atkinson and Hamilton, 1978; Tarrant *et al.*, 1983). They involve comparisons of alder yield table estimates (Worthington *et al.*, 1961; Chambers, 1974) with Douglas-fir yield tables or growth models. For red alder, they also have involved estimates of growth response to thinning. The Cascade Head study (Table I) provides one side-by-side comparison. Here, it appears that alder can outproduce conifers only in short rotations. Atterbury (1978) came to a similar conclusion for high site quality land in the Coast Range.

B. Short Rotation Management

Two types of short rotation management systems have been proposed and explored in a limited way. DeBell (1975; DeBell *et al.*, 1978) has examined very short rotation (2 years) coppice systems and found yields on the order of 5.6 oven-dry tons per ha per year. DeBell and co-workers are continuing to explore the effects of spacing, fertilizer, and rotation length. Recent work has shown that resprouting after cutting is vigorous at this age (Harrington, 1984; Hoyer and Belz, 1984; DeBell and Turpin, 1989). The number of times alder can be recut is unknown. In one study, Harrington and DeBell (1984) found 54.8% of the plants dead after four 2-year cutting cycles. Technical questions remain regarding efficient planting and harvesting systems.

DeBell *et al.* (1978) also discuss a short pulpwood log management system. Mean annual increment in red alder stands peaks at age 10 to 15, depending on site quality and stocking (Worthington *et al.*, 1961; DeBell, 1972; Zavitkovski and Stevens, 1972). With short rotations, spacing control, and weed competition reduction, DeBell *et al.* (1978) estimate that yields almost double those given in normal yield tables can be obtained, thus, producing a 15-cm-dbh (diameter at 1.3 m) tree in 10 years on a site index 37 m at 50 years.

C. Sawlog Management

Red alder has a long history of studies in density management for sawlog production (Warrack, 1949, 1964; Berntsen, 1961, 1962; Hibbs *et al.*, 1989). Although stocking guides do exist (Hibbs, 1987a; Hibbs and Carlton, 1989), these studies have not systematically addressed density and timing of spacing. Because of the high value of knot-free wood, questions about the effects of density and timing of thinning on wood quality are of great economic importance. Research being conducted by DeBell and Hibbs will provide most of the answers to these questions.

DeBell *et al.* (1978) estimated alder thinning response from the response of other species and predicted that 30-cm-dbh trees could be grown in 27–28 years in plantations (Atkinson *et al.*, 1979; Tarrant *et al.*, 1983). Hibbs *et al.* (1989) thinned a 14-year-old stand and found that diameter growth rate doubled to 1 cm per year for at least the first 5 years after thinning. This growth rate could result in a 30-cm-dbh tree at 29 years. In spite of this early rapid growth, the most recent economic comparison of red alder and Douglas-fir management shows alder trailing Douglas-fir (Tarrant *et al.*, 1983). Recent increases in alder value may have changed this comparison (R. F. Tarrant, personal communication).

D. Mixed-Species Plantations

To utilize the nitrogen-fixing capacity of red alder to increase the production of other tree species, management systems that either mix or alternate alder with another species have been considered.

Alternating alder and conifer crops has received the least experimental attention. A recent study of red alder and Douglas-fir at one location in Washington has shown that each species grows better following the other than following itself in sequential rotations (Cole, 1988).

In a theoretical analysis of alternating crops, Tarrant *et al.* (1983) estimated the fertilizer effect of several alder rotation lengths on subsequent Douglas-fir growth. They applied management costs and product values and compared alternate rotations of several lengths with conifer

culture, with and without chemical fertilizer. Among the tested alternatives, they found the greatest present net worth with 45-year, fertilized Douglas-fir rotations. A close second, however, was alternating 28-year alder and 45-year Douglas-fir rotations.

In mixed-culture systems, the Wind River (Miller and Murray, 1978) and Cascade Head (Berntsen, 1961) studies described earlier appear to delimit the extremes of results. Atkinson and Hamilton (1978) calculate the number of alder trees needed to supply all the nitrogen needs of a conifer crop. From this, they calculate the cost of fertilization by alder and compare this figure with the cost of application of chemical fertilizer. They conclude that mixing 500 alder per ha in the conifer plantation for 25 years will provide fertilizer at less than half the cost of chemical fertilization. Unfortunately, they do not include in this cost comparison any of the conifer growth loss that will occur as a result of shading.

Newton *et al.* (1968) have analyzed the height growth patterns of red alder and Douglas-fir over a range of site conditions and proposed a set of adjustment periods necessary to successful mixing of these two species. They divided site conditions into wet and dry, and into Coast, Valley, and Cascade. In comparing height growth curves, they show that delays in alder establishment of 4 to 8 years are necessary to prevent overtopping of the Douglas-fir. The longest delays are required on Coastal wet sites.

Mixing red alder and black cottonwood (*Populus trichocarpa*) in a 2-year coppice rotation has been tested (DeBell and Radwan, 1979). Yields of mixed plantings yielded 19,510 kg/ha (dry weight, minus leaves), 71% higher than pure cottonwood and 55% higher than alder. The yield increase was confined to the cottonwood component of the mix, indicating a nitrogen response. Alder growth was not reduced in mixture. In longer rotations, early-dominant alder is eventually overtopped by the cottonwood (Pezeshki and Oliver, 1985).

Mixing actinorhizal shrubs in conifer plantations has the short-term benefit of nitrogen input without the long-term hazard of conifer overtopping and suppression that can occur when red alder is used. Sitka alder, redstem (*C. sanguineus*), and snowbrush (*C. velutinus*) have been considered for mixed plantations. In all cases, high shrub density is expected to result in some crop tree growth reduction (Harrington and Deal, 1982; Conard *et al.*, 1985; Peterson *et al.*, 1988). Harrington and Deal (1982) examined height growth of Sitka alder over a range of site conditions and compared this growth with that of Douglas-fir. Their method of analysis (harmonized growth curves for each species by site quality) allows a land manager to compare the different competitive regimes created by using different conifer stock types or delays in Sitka alder establishment. They conclude that mixtures can increase conifer growth and that, on sites of poorer quality, Douglas-fir should be given a head start to reduce competitive growth loss. Binkley *et al.* (1984) examined one natural example of Sitka alder in a Douglas-fir plantation on Vancouver Island, B.C., and found that the presence of Sitka alder increased conifer biomass growth by 40%.

Shrubs can increase conifer seedling survival and growth on some sites through environmental amelioration. On an Oregon Cascades site, Youngberg *et al.* (1979) found that increased Douglas-fir survival and growth resulted from the reduced soil and air temperature, increased soil moisture in the top 15 cm, and reduced animal browsing, all in association with snowbrush. They did not discount the nitrogen fertilization effect. Rather, it could not be separated from the other environmental changes. At another location in the Oregon Cascades, Peterson *et al.* (1988) came to a different conclusion. They removed snowbrush cover in eight plantations and found that Douglas-fir seedling growth improved. One could suggest that the snowbrush had increased the soil N pool by this time, and its removal also removed its competitive effect on the Douglas-fir.

IV. Utilization of Red Alder

A. The Alder Resource

Information on the red alder resource (Bassett and Oswald, 1981a,b, 1982; Gedney *et al.*, 1986a,b, 1987; Chester, 1988) is at least 10 years old, has large sampling errors, and omits a critical part of the resource dynamics. Hence, this overview of the resource and its dynamics should be viewed with caution.

Forest stands classified as being primarily alder cover more than 1.2 million ha in the Pacific Northwest. Most of this land is held in private ownership. The alder volume is 238 million cubic meters, with almost half of this volume being found in stands that are less than 50% alder by volume. Growth of alder (NPP minus mortality) in Oregon and Washington averages 3.2%. Harvest removals (Fig. 2) for Oregon and Washington are estimated at 1.9 million cubic meters, about 25% of growth. However, this removal estimate does not include whole tree chipping, a serious omission (Beachy and McMahon, 1985). Harvest levels in British Columbia are low but growing.

There are two weaknesses in this picture. First, harvest rates have increased greatly since these figures were compiled. Second, the age-class distribution is not even. Most stands are in the 30- to 60-year-old

Figure 2 Red alder logs being delivered to a mill in the Oregon Coast Range.

age range. When these stands are harvested, they are replanted to conifers, not alder. As a result, the area of alder forest is decreasing. Both of these factors cause the harvest to represent an ever-increasing portion of growth.

B. Alder Products

The highest value use for red alder is found in the furniture and cabinet industry. Resch (1980) states that the manufacturing process adds $1,186 per thousand board feet to the value of the raw material. Alder lumber is prized for its even texture, moderate density, strength, and excellent working characteristics (turning, gluing, finishing, staining, bending).

Alder has found a ready place in the paper industry (Hrutfiord, 1978). Both the domestic and export markets currently compete strongly with the sawlog industry for the resource.

Probably the oldest use of red alder is for firewood. The demand is strong in urban areas, but competition with pulp chip and sawlog markets is reducing its availability. Alder could play a role in regional biomass energy programs (Smith, 1978).

... has occasionally been turned for veneer, both core stock in structural plywood and face veneer for interior paneling. Alder could be used in structural flake boards (Maloney, 1978).

V. Long-Term Productivity

Maintenance of long-term site productivity is a topic of considerable interest in both agriculture and forestry (Wild, 1988; Perry and Maghembe, 1989). Interest in long-term site productivity stems, in part, from the perspective of 150 years of experience in agriculture, where data exist for productivity of experimental plots under a variety of treatments (Wild, 1988). Changes in yield have occurred under fertilizer or manure treatments in contrast to unamended controls (Wild, 1988). Under the very long time perspective of millenia, there is evidence of productivity declines in some forest ecosystems. For example, on the deeply weathered soil occurring in Australian dune ecosystems, productivity may be limited by availability of essential nutrients such as phosphorus (Walker *et al.*, 1981). In this case, total ecosystem productivity declined by a factor of approximately 10 between the youngest and oldest dune ecosystems, paralleling a decline in soil phosphorus.

Although actinorhizal species are important as a source of nitrogen, their presence would not prevent long-term limitations of other nutrients. These secondary limits can result in productivity declines and retrogressive succession in ecosystems like the Australian dune example (Walker *et al.*, 1981). Although phosphorus is generally not limiting in the Pacific Northwest, there is evidence that nitrogen-fixing understory plants can recycle greater amounts of phosphorus in litter and thus influence phosphorus cycling on phosphorus in litter and thus influence phosphorus cycling on phosphorus-limited sites. This has been seen in eucalypt forests of Australia (O'Connell, 1986). Thus, actinorhizal plants may be able to mitigate some of the effects of limitations on nutrients other than nitrogen.

In the Pacific Northwest, greater retention of anions such as PO_4^- and SO_4^- can occur in soils colonized by red alder (Johnson *et al.*, 1986). This greater retention is apparently due to a greater soil content of amorphous iron and aluminum and less of the crystalline forms of these elements. This results in greater retention of phosphorus and sulfur from organic ligand formation (Johnson *et al.*, 1986). Therefore, these elements would be more available when alder is or has recently been present on a site.

In long-term studies, there is an opportunity to confuse anthropogenic and autogenic changes. The current levels of industrial emissions of nitrogen and sulfur in many parts of the world can result in nutrient imbalance or other soil effects such as increased soil acidity. This ultimately would decrease forest productivity (Waring and Schlesinger, 1985). However, such results from cases of environmental pollution will have to be distinguished from cases of natural soil acidification such as found under nitrogen-fixing species like alder (Crocker and Major, 1955; Franklin *et al.*, 1968), including effects of acidification on nutrient cycling and production.

VI. Nontimber Values

A. Riparian Areas

Red alder is a frequent dominant in riparian areas because of its tolerance of moister sites (Minore, 1970; Minore and Smith, 1971) and the seedbeds created by stream erosional and depositional processes. Most streambanks today are composed of intermixed patches or trees of alder and conifers. This forest cover provides shade and large woody debris to the stream.

Both natural succession and riparian area buffer strip practices tend to increase understory shrub density and decrease tree regeneration (Hibbs, 1987b), particularly in alder-dominated reaches. This has led to a growing social concern that the very regulations that were intended to preserve riparian area values for fish, wildlife, and water quality through limiting human impact may be accelerating its degeneration.

B. Wildlife

The seeds, twigs, and foliage of *Ceanothus* species are an important food source for domestic stock and wildlife (Hickey and Leege, 1970; Leege, 1979; Conard *et al.*, 1985). Redstem (*C. sanguineus*) and deerbrush (*C. integerrimus*) are the most important food sources. Up to 80% of the annual growth of deerbrush may be consumed in a year by elk and deer (McCulloch, 1955; Thilenius and Hungerford, 1967). Snowbrush is a poor browse species.

The foliage, buds, and twigs of *Alnus* are eaten by deer and elk (Dayton, 1931; Cowan, 1945), although other common species rank as high or higher in preference. Alder in riparian zones is collected by beaver for food and structural purposes (Maser *et al.*, 1981). Mountain beaver (*Aplodontia rufa*) show little preference for alder (Crouch, 1968; Voth and Black, 1973).

VII. Summary

Actinorhizal plants play an important role in the nitrogen budgets of the Pacific Northwest. All the actinorhizal species are pioneer species that colonize newly disturbed sites. They are commonly found in riparian areas, avalanche tracks, and dry, fire-prone slopes and ridges. Recent forest management activity has increased their occurrence greatly. Where they occur, they can improve soil fertility by increasing soil nitrogen, organic matter, and cation-exchange capacity. They can also be an important wildlife food source.

In forestry, red alder is harvested as a timber crop. Some deliberate regeneration of red alder is now being practiced. Red alder and other of the region's actinorhizal plants have been considered for mixed culture with conifers. Such mixtures are theoretically possible but are currently not practiced. Mixed culture with shrubs is clearly easier than mixed culture with red alder. However, red alder offers the double benefit of nitrogen fixation and a timber crop.

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