Red Alder Stand Development and Dynamics

Abstract

This paper synthesizes information on the development of natural pure red alder stands and dynamics of mixed alder-conifer stands. Early research on red alder growth and yield focused on developing stand volume and normal yield tables for alder in the Pacific Northwest. Recent site-index estimation and height-growth curves were developed on a 20-year site base age. These height-growth and site-index curves were a significant improvement over earlier work and are widely used today. Red alder exhibits rapid early height growth with much more rapid height growth than for conifer associates. On good sites, trees may be 9 m at age 5, 16 m at age 10 and 24 m at age 20. Height growth then quickly declines, and by age 15 alder will reach more than half its total height and nearly all of its mature height by the age of 40. Alder height growth essentially stops by age 50.

Long-term successional sequences of red alder stands are not well understood. Red alder frequently occurs in mixed stands with conifer associates including Douglas-fir, western hemlock, Sitka spruce and western redcedar. Mixed species dynamics is more complex and variable than for pure stands and depends on a number of factors including forest composition, establishment and survival of understory conifers, timing of alder mortality, abundance and composition of shrubs, and geographic location. Red alder is short lived (approximately 100 years) compared with its conifer associates. In some sites, alder may succeed to brush dominated communities with few if any conifers to replace the alder. In other sites, succession to more shade tolerant trees such as western hemlock and Sitka spruce is certain but the sequence of events is unknown. On some nitrogen deficient sites red alder has been shown to increase growth of conifer associates but in other cases red alder has been shown to suppress and even kill less shade tolerant conifers. Other conifer species such as western hemlock, Sitka spruce and western redcedar can survive as lower strata species and eventually grow above the alders but it may take several decades for this to occur. Height growth and long-term stand dynamics in mixed stands are highly variable and long-term succession is difficult to predict. More work is needed to understand the long-term successional sequence of events.

Keywords: *Alnus rubra*, red alder, stand development, stand dynamics, mixed alder-conifer stands, forest succession

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Introduction

Red alder (*Alnus rubra* Bong.) has become an increasingly important species both as a commercial forest product and for it's recognized ecological role in forests. However, many questions remain about the growth potential, stand development, and long-term succession of alder stands. Forest land owners and managers have only recently begun to manage alder plantations and preliminary results suggest that these plantations have different growth potential and possibly shorter rotations than natural stands. These alder plantations also appear to have different tree height and diameter growth patterns than natural alder stands. In natural stands, red alder frequently occurs in species mixtures and common conifer associates include Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco), western hemlock (*Tsuga heterophylla* (Raf.) Sarg.) and Sitka spruce (*Picea sitchensis* (Bong.) Carr.). These mixed stands are quite different than pure stands of either red alder or conifer species.

Red alder has often been considered as a weed species and in the past alder was commonly eliminated from conifer stands. However, the potential value of red alder as a commercial forest product has been recognized for decades. An article published in the 1930s (Munger 1938) discussed the increase of red alder in cut over and burned areas of the Pacific Northwest and the emergence of sawmills that were using the wood of red alder as a substitute for other hardwoods such as birch, mahogany or walnut. Munger described the wood of red alder as "among other desirable qualities it turns well, takes glue and paint satisfactorily, and does not incline to warp, check or shrink if properly handled." Other papers entitled "Alder comes of Age" (Clark 1955), and "Don't call red alder a weed!" (Morse 1967) highlight the struggle of alder to become recognized as an important commercial species in the Pacific Northwest. Despite this information on the potential of red alder, forest managers continued to discourage alder in managed forests for decades. However, the recent premium value for alder sawlogs has led to widespread interest in red alder as a commercial forest product. Current sawlog prices for red alder now equal or exceed those for Douglas-fir and red alder is now recognized as a premium value tree. In a region that has witnessed many saw mill closures and a major reorganization of the timber industry, new sawmills are being opened that are focusing almost exclusively on red alder. The commercial value of red alder now appears firmly established in the Pacific Northwest, with increasing demand for domestic lumber, furniture supply and a significant increase in lumber exports to countries such as China (Forestry Source 2005).

Red alder's important ecological role in both aquatic and terrestrial systems is also widely recognized. Red alder has been shown to increase the abundance of invertebrates for fish and other aquatic resources in its immediate vicinity and in downstream reaches (Wipfli 1997, Piccolo and Wipfli 2002). Within red alder stands, vegetation for both invertebrate and vertebrate herbivores was increased by the presence of red alder, an observation consistent with previous work in southeastern Alaska (Hanley 1996, Hanley and Barnard 1998, Deal 1997, Wipfli 1997, Piccolo and Wipfli 2002). Increased prey availability likely affects many more species, such as bats and other small mammals, birds, and other wildlife in these young forested ecosystems. Results suggest that red alder has an important ecological function in forested ecosystems (Pechanec and Franklin 1968, Tarrant et al. 1983, McComb et al. 1993, Deal 1997, Wipfli 1997, Hanley and Barnard 1998). Rather than viewing red alder as an undesirable, early-successional tree and managing it accordingly, managers are planting alder or manipulating existing vegetation to favor the maintenance of red alder.

Most available information on red alder growth and yield comes from natural unmanaged red alder stands (Worthington et al. 1960, Curtis et al. 1968, Harrington and Curtis 1986). New preliminary information from alder plantations suggest different stand and tree growth patterns in these plantations as compared with natural stands (Bluhm and Hibbs 2006). Little information is available on long-term stand development and forest succession of red alder, and most of the literature is from descriptive studies with speculation on successional sequences of red alder stands. Mixed alder-conifer stands are also very different than either pure red alder or conifer forests and show highly variable development patterns and differences among species compositions such as red alder – Douglas fir and red alder – Sitka spruce stands. This paper will briefly summarize some of the key findings and synthesize the state of knowledge about red alder stand development and dynamics of mixed alder-conifer stands. The major objectives of this paper include:

- Describe stand development and growth of natural pure red alder stands, and compare and contrast development with common conifer associates including Douglas-fir, western hemlock and Sitka spruce,
- Describe stand dynamics of mixed red alder-conifer forests focusing on red alder/Douglas-fir stands and red alder/Sitka spruce/western hemlock stands.

Finally, forest succession of red alder stands will be discussed and some specific future research needs for red alder management will be identified.

Development of Natural Pure Red Alder Stands

Some clarification of terms is necessary to define the scope and content of this section. Pure stands are those stands that are essentially composed of only red alder and are contrasted with mixed species stands which will be described in a later section. Natural stands are those stands that established following natural disturbances or harvesting without artificial aid and have never received any management practices including planting, vegetation control, thinning or pruning. These natural stands are contrasted with artificial plantations and/or stands that have received weeding, thinning or other density management or stand-tending practices.

Red alder growth and yield

Early research on red alder growth and yield focused on developing stand volume and normal yield tables for alder in the Pacific Northwest. Tree taper equations were developed (Curtis et al. 1968), site curves constructed (Johnson 1949, Bishop et al. 1958, Skinner 1959) and yield tables produced (Worthington et al. 1960, Chambers 1973). This research provided baseline information on red alder volume, growth and yield of natural unmanaged stands. Height growth models in the past were based on site-index equations (Bishop et al. 1958, Worthington et al. 1960). These equations were developed to predict site index from stand height, however, and were probably not the best means to predict stand height (Curtis et al. 1974). Another concern for using these equations was using a site index based on the top height at age 50 when alder rotations were becoming increasingly shorter in length. To address these concerns, Harrington and Curtis (1986) expanded the database to include younger stands and developed separate height growth equations for red alder. They sampled twenty three natural red alder stands in western Washington and Oregon across a range of geographic locations, site quality and soil conditions. They supplemented this data with red alder stem analysis data from earlier red alder height growth curves (Johnson and Worthington 1963). Harrington and Curtis (1986) developed site-index estimation curves for red alder and developed new height-growth curves based on a 20-year site-base age (fig. 1). The height growth and site index curves they developed were a significant improvement over earlier work and are still widely used today.

Most available information on growth and yield comes from natural unmanaged stands. A number of variables including initial stand density, mortality, site factors such as soils, moisture and nutrients, and management regimes such as planting density, thinning, and vegetation control can significantly affect stand growth. Some important considerations for growth and yield are summarized by Puettmann (1994) and include information on height and diameter growth, mortality, site-index and height-growth

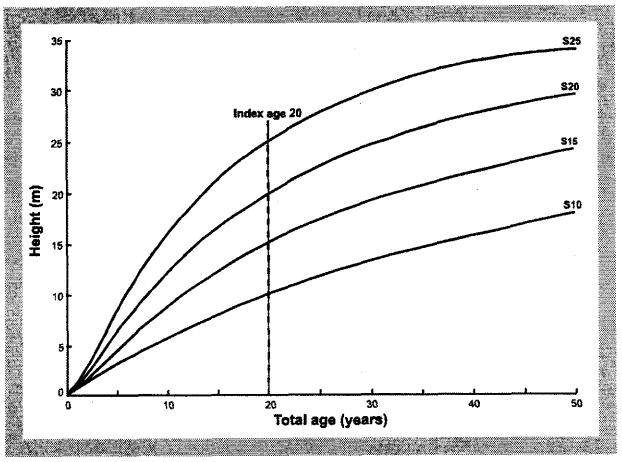

Figure 1—Red alder height-growth curves based on a 20-year site base age (Figure modified from Harrington and Curtis, 1986).

equations, yield tables, growth models and stand density guides. Red alder plantations appear to have different tree height, diameter and stand growth than natural stands (Bluhm and Hibbs 2006) and the need for further investigation of plantations led to the establishment of the Hardwood Silviculture Cooperative (HSC). The first plantations from the HSC were established in 1989 and efforts are underway to use this information to develop new stand growth models for red alder. In particular, there is a need to use new tree taper data from plantations to develop volume equations and growth models more appropriate for red alder plantations.

Height growth of red alder stands

Red alder exhibits rapid early height growth and then growth slows considerably after age 15-20 (fig. 1). Height growth of seedlings is exceptionally rapid and on favorable sites seedlings can grow 1 m or more the first year, and on all but the poorest sites, seedlings surpass breast height (1.3 m) by the second year (Harrington 1990). Maximum annual height growth of more than 3 m per year can be achieved by 2- to 5- year-old seedlings. On good sites, trees may be 9 m at age 5, 16 m at age 10 and 24 m at age 20 (Harrington and Curtis 1986, Harrington 1990). Height growth rate decreases substantially beyond age 20. Dominant tree heights range from 10-25 m at age 20 and at age 50 range from 18-37 m (Worthington et al. 1960). By age 15, red alder has reached more than half of its total height and height growth attains nearly all of its mature height before age 40 (Newton and Cole 1994).

Total height and total age possible for red alder is unknown. Red alder height can reach 25-30 m on many sites and the tallest red alder is listed as 32 m (http://en.wikipedia.org/wiki/Alnus_rubra). As previously mentioned, alder height growth essentially stops by age 40 or 50. Red alder is a short lived tree but individuals can

Figure 2—Four-year-old red alder plantation planted at about 2950 trees ha^{-1}.

Figure 3—Nine-year-old red alder plantation planted and thinned later to about 246 trees ha^{-1}.

live to be more than 100 years old, however, pure red alder stands frequently begin to "break up" at around age 80 (Newton and Cole 1994, Smith 1968). Red alder is shade intolerant and highly susceptible to suppression. When slower growing but longer lived conifers eventually overtop alders, these alders can die, and alders are not reestablished without new disturbances. Long-term succession for alder stands is not clearly understood and depends on the establishment of conifer associates, shrub development, geographic location and specific site factors. More discussion on succession is presented below in the section on mixed species stand dynamics.

Potential site productivity or site quality for alder is indicated by height-growth and site-index curves. Site index or height at a specified age is the most commonly used index of site quality. Site index estimates will be most reliable when stand age is within 10 years of the index age and estimates are unreliable for stands less than 5 years of age or at stands much older than 50 years. Site-index curves were developed by Harrington and Curtis (1986) and later adapted to a 50 year base to compare with conifer associates (Mitchell and Polsson 1988, Thrower and Nussbaum 1991). Site quality is also closely associated with other measures of productivity other than tree height. Site quality was related to several environmental factors and published by Harrington (1986) and summarized later by Harrington and Courtin (1994). Harrington found that elevation, physiographic position, and other soil site characteristics could be used to predict potential site index. This information has been useful to predict potential site index for red alder from soil data and other environmental factors when reliable tree height data was not available.

Management activities also can influence apparent site quality as measured by tree height. Spacing experiments have indicated that alder height growth is influenced by initial density and maximum height growth occurs at intermediate spacings (DeBell and Giordano 1994, Knowe and Hibbs 1996). Recent findings by the Hardwood Silviculture Cooperative indicate that plantations established at high densities appear to be growing faster than natural plantations with more rapid height, diameter and volume growth than expected (Bluhm and Hibbs 2006, figs. 2 and 3). Density appears to have an important effect on early height growth with most rapid height growth in stands of moderate to moderately high densities. The site index and height growth curves developed from natural stands (Harrington and Curtis 1986) may underestimate potential height and volume growth of plantations at moderate to moderately high densities.

Height growth and stand development of conifer associates

This section compares early and later height growth of pure conifer stands with pure red alder stands. It is important to make the distinction between height growth of pure conifer and pure alder stands, and the development of mixed species stands. Competition between tree species with different growth development patterns produces more variable and complex mixed species stands and will be described in the last section on dynamics of mixed alder-conifer stands. This section will describe juvenile and mature height growth of common conifer associates of red alder including Douglas-Fir, Sitka spruce, western hemlock and western redcedar (*Thuja plicata* Donn ex D. Don).

Young red alder height growth is more rapid than all other tree associates with the exception of black cottonwood (*Populus trichocarpa* Torr. and Gray) (Harrington 1990). The available height growth information for conifers is much better than for red alder and the data for Douglas-

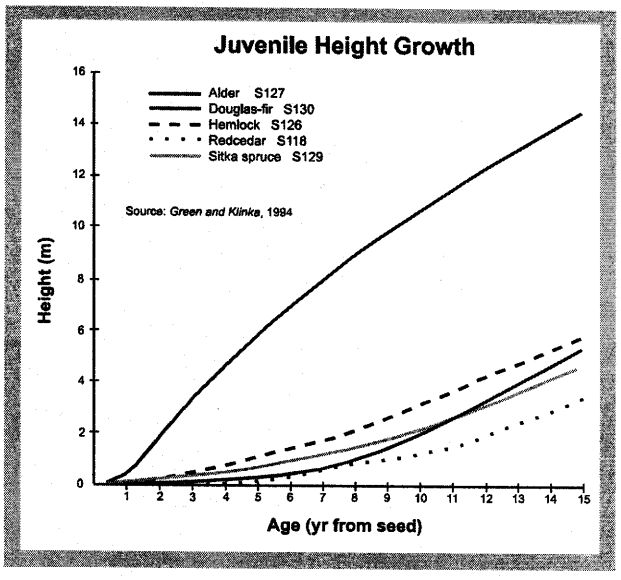

Figure 4—Comparison of juvenile height growth of red alder and associated conifers to age 15. Height curves are based on median values for conifers on Site Class II (King 1966). (Figure modified from Green and Klinka 1994).

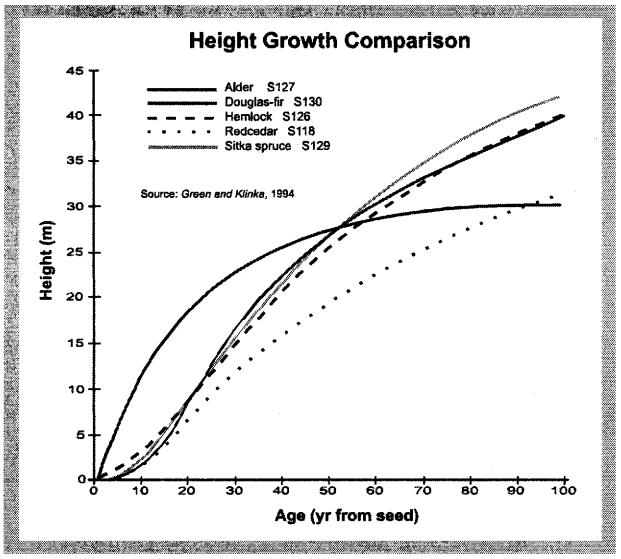

Figure 5—Comparison of height growth of red alder and associated conifers to age 100. Height curves are based on median values for conifers on Site Class II (King 1966). (Figure modified from Green and Klinka 1994).

fir is particularly robust. Red alder juvenile height growth is much more rapid than any of its conifer associates. On the best sites, Douglas-fir may be 12 m at age 10, 18 m at age 15, and 24 m at age 20 (King 1966). Even on the best Douglas-fir sites, juvenile height growth of red alder is more rapid than for Douglas-fir, and total height of dominant alder are greater than dominant Douglas-fir until about age 20.

It is probably more useful to compare height growth of alder and conifers on average sites. Alder has significantly greater early height growth than any of the common conifer associates. On average sites, Douglas-fir height is only 1 m at age 5, 2 m at age 10 and 4 m at age 15 compared with 5 m at ate 5, 11 m at age 10 and 15 m at age 15 for red alder (fig. 4). Green and Klinka (1994) report that early height growth is slightly higher for western hemlock followed by Douglas-fir and Sitka spruce, with the slowest height growth for western redcedar. Other researchers (Omule 1987) report Douglas-fir with the most rapid early height growth, with redcedar height growth significantly slower than these other conifers. However, differences in early height growth are small among the four most common conifer associates with each species lagging behind red alder (Omule 1987, Green and Klinka 1994).

Longer-term height growth and stand development shows very different height growth patterns for alder and conifers. As previously reported, alder height growth rapidly declines after age 20 whereas height growth increases and is sustained for Douglas-fir, hemlock and spruce. Coastal Douglas-fir attains the largest height increments between ages 20-30, and has the ability to maintain a fairly rapid rate of height growth over a long period (Hermann and Lavender 1990). On average sites, Douglas-fir, Sitka spruce and western hemlock all surpass red alder at about age 50 (fig. 5, Green and Klinka 1994). Another study (Williamson 1968) reports that Douglas-fir and red alder attain the same height at about age 45. Western redcedar height growth is somewhat slower and may take as long as 80 years to achieve the same height as red alder (Green and Klinka 1994). Again, it is worth noting that these projections are for pure stands and not for mixed alder-conifer stands where tree species interact. Mixed stands can be quite different and have extremely variable growth patterns.

Dynamics of mixed red alder – conifer stands

Growth and development of mixed red alder-conifer stands is different than patterns observed in either pure alder or pure conifer stands. Mixed species stand development is more complex and variable than for pure stands and depends on a number of factors including establishment and species composition, early height growth, species shade tolerance, initial species dominance and the spatial distribution of species. This section will discuss dynamics of mixed alder-conifer stands using some examples of mixed red alder/ Douglas-fir stands and mixed red alder/Sitka spruce/western hemlock stands. Discussions of stand dynamics will focus on stand growth and development and some of the effects of mixed stand structure on other forest resources including understory plants.

Mixed red alder – Douglas-fir stands

A well-documented study of mixed red alder-conifer stands at Wind River in southwestern Washington compared a nitrogen-deficient stand of mixed Douglas-fir and red alder with adjacent pure stands of Douglas-fir (Tarrant 1961, Tarrant and Miller 1963, Miller and Murray 1978). After 48 years, mixed alder-conifer stands had significantly greater stand growth with overall wood production nearly double that of adjacent pure Douglas-fir stands. Douglas-fir site index was increased by an average of 6.4 meters. Improved soil fertility was suggested to be largely responsible for the improved growth of these stands (Bormann et al. 1994). Other authors have indicated that on poor sites alder may increase growth and production in Douglas-fir plantations (Atkinson et al. 1979, Tarrant et al. 1983).

Research from a mixed alder-conifer stand at Cascade Head in coastal Oregon reported different results in productivity. At Cascade Head, researchers found no appreciable difference in productivity between the mixed alder-conifer stand and an adjacent pure conifer stand. Both biomass and net primary productivity were higher in the pure conifer stand than in the mixed stand (Binkley et al. 1992). On fertile sites such as this stand, where growth was less limited by nitrogen, availability of nitrogen also increased, but with no corresponding increase in productivity (Binkley et al. 1992). The mixed alder-conifer site at Cascade Head has also been used to investigate effects of alder on stand structure and understory vegetation (Franklin and Pechanec 1969, Pechanec and Franklin 1968). Franklin and Pechanec found that the species richness and cover of herbaceous plants was greatest under pure alder and least under pure conifer, with mixed stands intermediate.

Several studies suggest that red alder can inhibit Douglas-fir growth (Newton et al. 1968, Miller and Murray 1978, Miller et al. 1999). In a reconstruction study of red alder and Douglas-fir in the Pacific Northwest, Newton et al. (1968) assessed height growth of red alder and Douglas-fir in 39 nearly pure red alder stands in western Oregon. They determined that red alder remained dominant for 25 to 35 years on most sites, and 40 years or more on wetter sites. Emergence of Douglas-fir from beneath red alder depends on its ability to grow while being suppressed and the intensity of suppression. Newton et al. (1968) reported that under all environmental conditions the initial growth of red alder was substantially better than for Douglas-fir. On some sites they suggested that Douglas-fir could not be expected to reach the overstory unless it was established 3 to 8 years before the alder. Newton concluded that Douglas-fir would be unable to maintain height growth while being suppressed, but more shade-tolerant species might be able to do so. In another study, Miller and Murray (1978) assessed growth in four mixed red alder — Douglas-fir stands. Conifers showed reduced growth in heavily stocked mixed alder — Douglas-fir stands on higher quality sites. Douglas-fir generally emerged from the alder canopy and attained dominance in mixed stands by 25 to 35 years on drier sites and about 10 years later on wetter sites. They suggested that to attain full stocking of Douglas-fir, the stocking and distribution of red alder would need to be controlled either by thinning the alder and recommended uniformly stocking the stand with 50 to 100 alder trees ha^{-1}.

Mixed red alder – Sitka spruce – western hemlock stands

A series of studies was established in 45-year-old mixed red alder/Sitka spruce/western hemlock stands on Prince of Wales Island, Alaska (Wipfli et al. 2002, Deal et al. 2004, Orlikowska et al. 2004). Nine stands were sampled across a compositional range from 0-86% alder. Alder height growth was initially rapid then slowed considerably, whereas, conifer height growth was initially slow then rapidly increased. Dominant conifers emerged from the alder overstory in 18-25 years after logging, and at age 45, conifers were 4-9 m taller than the associated alders (Deal et al. 2004). Red alders were relatively evenly distributed with most trees in a narrow diameter and height range. Conifers were more variable in size than the alders and included numerous small trees and a few of the tallest trees in the stand. Stands containing both red alders and conifers provided a broader and more even tree-size distribution than is typically found in pure conifer stands. These mixed alder-conifer stands created a multi-layered forest canopy with a few tall overstory conifers, a mid-canopy level of red alder and a lower canopy level of small diameter conifers. This pattern of development has also been reported in other mixed red alder/Sitka spruce/western hemlock stands in Alaska (Hanley and Hoel 1996, Deal 1997). Overall, these mixed alder-conifer stands provided more heterogeneous structures than is typically found in pure conifer stands of the same age.

Stand development in these mixed alder-conifer stands is highly dynamic and tree height and stand structure is different then it was at earlier stages. In mixed alder-conifer stands in Alaska (Deal et al. 2004), dominant spruces and hemlocks emerged from the slower growing alder overstory at about 18-25 years after logging. This species change in overstory canopy position has been reported by other authors (Newton et al. 1968, Miller and Murray 1978, Stubblefield and Oliver 1978) in mixed red alder and Douglas-fir stands in the Pacific Northwest. Increased Sitka spruce height growth, however, occurred earlier and appeared to release more quickly then for Douglas-fir. Other conifer species such as western hemlock and western redcedar survived as lower strata trees and eventually grew above the alders, however, it took several decades for these conifers to release (Stubblefield and Oliver 1978).

Forest succession of red alder stands

Red alder is relatively short-lived compared to its associated conifers (Smith 1968, Harrington 1990). Worthington et al. (1962) suggested a maximum age for red alder of about 100 years. Smith (1968) notes that by 50 years of age, pure alder stands on highly productive Douglas-fir sites in British Columbia were "breaking up." Individual trees showed dieback as early as 40 years of age. On less productive sites, mortality occurred at stand age 60 to 70, with few red alder stands remaining intact beyond 100 years. In Washington, Oregon, and British Columbia, mortality of red alder increases rapidly in stands over 90 years old, and little alder remains by the age of 130 years (Newton and Cole 1994).

Successional sequences of alder stands are not well understood. Observation of mature forests in the Pacific Northwest suggests that where seed sources are present, alder is replaced by longer-lived, more shade-tolerant conifers that sustain growth rates for longer periods. Alder's rapid early growth and high stem densities make it difficult for other shade-intolerant species to regenerate and grow if they do not become established at the same time alder invades a disturbed area. Douglas-fir can be eliminated in dense, young alder stands while more shade-tolerant species such as western hemlock, Sitka spruce and western redcedar can survive, grow into the canopy, and ultimately dominate the site (Harrington et al. 1994). Other scenarios have been reported where following initial dominance by alder, understory shrub cover increases after about age 20, and in the absence of understory conifers, shrubs may completely dominate the site after senescence of alder at age 80-100 (Peterson et al. 1996, Hibbs and Bower 2001).

Long term stand dynamics of mixed alder-conifer forests are uncertain. Red alder is expected to die out of these stands but it is unclear how long this will take. The mechanism of alder mortality is also unknown but it is likely due competition with conifers and/or tree disease. Red alder is short lived and some researchers have reported that by 50 years most alder stands were breaking up and few stands remain intact beyond 100 years (Smith 1968). Newton and Cole (1994) report for stands in Oregon that the last alder will succumb in less than 130 years. It is unlikely that any of the alder stands in southeast Alaska will be replaced by shrubs as has been observed in some sites in the Oregon Coast Range (Newton et al. 1968, Hibbs and Bower 2001). The abundance of shade tolerant conifers such as Sitka spruce and western hemlock suggests that a treeless shrub succession is highly unlikely. Also, when alders die out they may create more gaps in the canopy and lead to a later stage of stand development that is either more open or invaded by a new cohort of conifers. Where alder forms a more continuous canopy with few conifers, alder trees compete with one another, often forming a continuous canopy height, and they may persist for much longer. In summary, the successional sequences of alder depend on a combination of factors including forest composition, establishment and survival of understory conifers, timing of alder mortality, abundance and composition of shrubs and geographic location.

Future Research Needs

Most of the available information for red alder on stand development, growth and yield comes from natural unmanaged stands. Red alder plantations, however, appear to have different tree height and diameter and stand growth than natural stands. As new information becomes available from red alder plantations it will be essential to use these data to construct new tree taper and volume equations and develop growth models based on plantations. A number of factors including initial planting density, mortality, thinning, vegetation control and other management practices significantly affect stand growth. Preliminary results suggest that early height growth of alder plantations is closely related to initial stand density. Longer term data is needed to determine if this reported early height growth in red alder plantations results in shorter rotations and/or increases in overall stand growth. If so, then new growth models will need to be developed that reflect these changes in stand growth projections. Growth and development of mixed red alder-conifer stands is quite different than patterns observed in pure stands and successional sequences of alder stands are not well understood. Stand development of mixed-species stands is highly variable and depends on a number of factors including species composition, establishment, initial species dominance, shade tolerance, disturbance frequency, geographic location and other factors that influence long-term successional sequences. Although it would be difficult to control experimentally, better information is needed on the relative importance of these factors and their role for successional sequences of different alder-conifer compositional mixtures.

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