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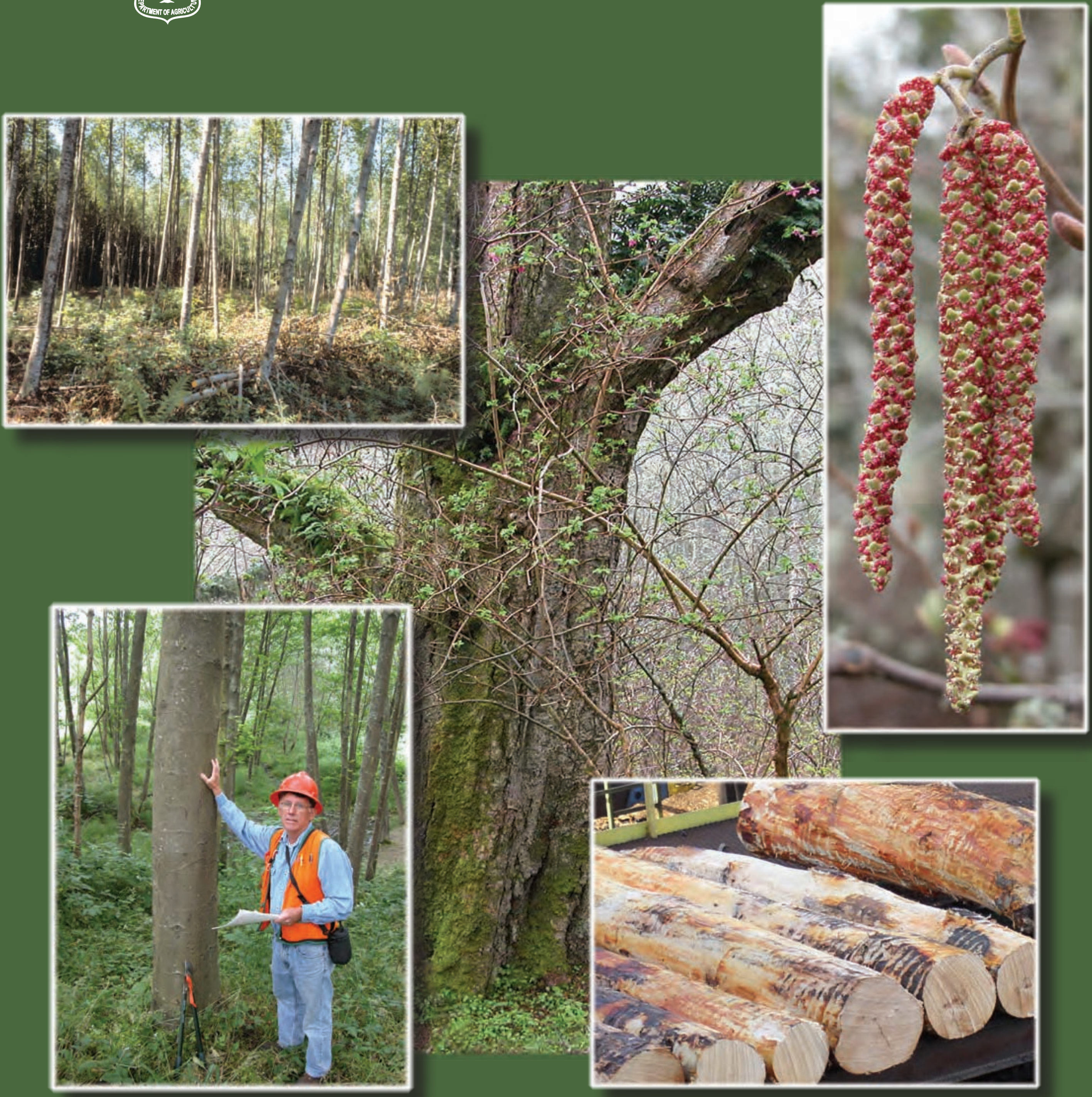
March 2006

Red Alder:
A State of Knowledge



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Red Alder:
A State of Knowledge

Robert L. Deal
and Constance A. Harrington
Technical Editors

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ABSTRACT

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In March 23-25, 2005, an international symposium on red alder was held at the University of Washington Center for Urban Horticulture in Seattle, WA. The symposium was entitled “Red alder: A State of Knowledge” and brought together regional experts to critically examine the economic, ecological and social values of red alder. The primary goal of the symposium was to discuss new advances in the understanding of red alder biology and silviculture, changing market and non-market values, and the current regulatory climate for management of alder. This proceedings includes 14 papers based on oral presentations given at the symposium. These papers highlight some of the key findings from the history, ecology, biology, silviculture and economics sessions presented at the red alder symposium.

KEYWORDS: Red alder, *Alnus rubra*, history, biology and ecology, mixed-species stands, silviculture, pruning, plantation establishment, economics, inventory, supply.

PREFACE

During March 23-25, 2005, an international symposium on red alder was held at the University of Washington Center for Urban Horticulture in Seattle, WA. The symposium was entitled "Red alder: A State of Knowledge" and was presented by the University of Washington College of Forest Resources Rural Technology Initiative and Stand Management Cooperative and Washington State University Extension. The primary goal of the symposium was to discuss new advances in the understanding of red alder biology and silviculture, changing market and non-market values, and the current regulatory climate for management of alder. This symposium brought together regional experts to critically examine the economic, ecological and social values of red alder. More than 180 people attended the meeting.

The primary members of the Symposium Scientific Committee included David Briggs (Chair) University of Washington; Glenn Ahrens, Oregon State University Extension; Norm Andersen, Washington State Department of Natural Resources; Andy Bluhm, Hardwood Silviculture Cooperative; Robert Deal, Pacific Northwest Research Station; Del Fisher, Washington Hardwoods Commission; Don Hanley, Washington State University Extension; Bari Hermann, Weyerhaeuser Company; David Hibbs, Hardwood Silviculture Cooperative, Oregon State University; Pete Holmberg, Washington State Department of Natural Resources; Paul Kriegel, Goodyear Nelson Hardwood Company; Larry Mason, University of Washington Rural Technology Initiative; George McFadden, Washington State Department of Natural Resources; Joe Monks, Weyerhaeuser NW Hardwoods; Megan O'Shea, University of Washington; and Dave Sweitzer, Western Hardwoods Association.

Red Alder: A State of Knowledge was sponsored by several companies, agencies, and universities in the region. Sponsors included: British Columbia Ministry of Forests, Carlwood Lumber; Cascade Forestry; College of Forest Resources, Olympic Natural Resource Center, Rural Technology Initiative, and Stand Management Cooperative, University of Washington; Goodyear Nelson/Mount Baker Products; Hardwood Silviculture Cooperative and Extension Service, Oregon State University; Northwest Hardwoods; USDA Forest Service, Pacific Northwest Research Station, Focused Science Delivery Program; Washington Alder LLC; Washington Department of Natural Resources; Washington Forest Protection Association; Washington Hardwoods Commission; Washington State University Extension; Western Forestry and Conservation Association; Western Hardwood Association; and Weyerhaeuser Company. Sponsors helped defray some of the costs of the meeting including funding attendance for several students.

This three-day symposium included a pre-conference field trip and two days of plenary and concurrent sessions on the history of alder, biology, ecology and silviculture of alder, and the economic and regulatory climate for alder. The field trip included a tour of the Washington Alder mill near Mt. Vernon, Washington and stops in the woods to visit a 14-year-old plantation planted at different densities (one of the installations of the Hardwood Silviculture Cooperative) and another stop to discuss the restrictions on management in riparian areas and how they differ in British Columbia, Washington, and Oregon. The 2-day indoor session included 44 formal presentations as well as poster sessions and several moderated discussion sessions. The oral presentations (including portions of the field trip) were videotaped and are available on line as streaming video presentations at: http://www.ruraltech.org/video/2005/alder_symposium/index.asp

Following the symposium, we invited the speakers to also submit a paper for publication; 14 authors responded. Although we were not able to include additional information from all the meeting presenters, the papers that are included capture many of the key findings from the history, ecology, biology, silviculture and economics sessions.

Red Alder: A State of Knowledge was a very successful conference with excellent interaction between researchers, practitioners, mill owners, students, consultants, planners, and extension agents. We thank all those involved in planning, presenting, or contributing in some way to the meeting. We hope that this printed proceedings will add to the overall value of the conference and that you will find this information to be useful and of interest.

This is a product of the Sustainable Wood Production Initiative from the Focused Science Delivery Program of the Pacific Northwest Research Station.

Robert L. Deal
Pacific Northwest Research Station

Constance A. Harrington
Pacific Northwest Research Station

— Red Alder: A State of Knowledge —

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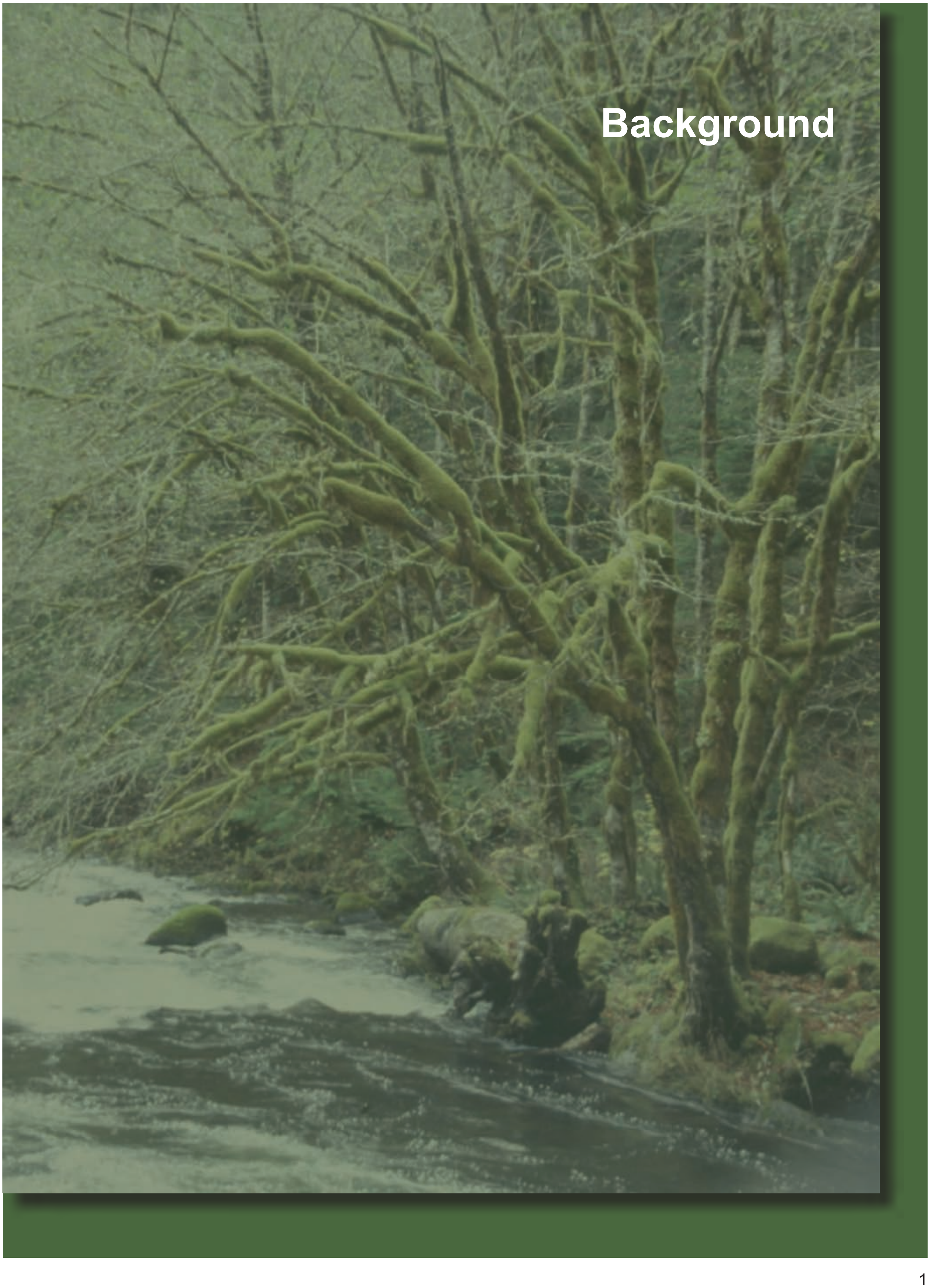

History of Research and Attitudes About the Biology and Management of Red Alder

Dean S. DeBell[1]

Abstract

Indigenous people of the coastal Northwest developed the earliest knowledge about red alder; next to western redcedar, they used the wood of alder more widely than any other tree species. Sea explorers from Russia and England were the first non-natives to observe and collect red alder specimens, but the first written descriptions of the species and its silvical traits were those in the published diaries of Lewis and Clark. Other pre-1900 references to red alder include journals and species descriptions by early botanists, and an 1882 book on "Forest Trees of California" by Kellogg that contained what may be the first mention of ecological amenities provided by alder, such as stream bank protection and trout habitat. Publications during the first two decades of the 20th century contained the diverse, contrasting opinions that remained through many decades: some foresters saw red alder as an undesirable species, to be removed and replaced with conifers as soon as practicable; others saw it as providing significant benefits to the forest; and some saw industrial possibilities in cabinetry and other uses. A comprehensive bulletin on utilization and management of red alder was published in 1926, but most of the silvicultural information then available was based on perceptive observations and measurements taken on temporary plots. In the 1930s, several long-term silvicultural projects were initiated by the Forest Service, and by the middle to late 1940's, interest and research in utilization and management of alder increased in other public organizations. The 1950s ushered in a long period of research and management interest in alder's soil-improving ability and growth rate, the competition it may create for conifers in plantations, and the use of herbicides to control or eliminate the species on conifer sites. In the 1960s, the long-term studies established earlier resulted in publications on several important topics: normal yield tables, growth and yield in pure and mixed stands, thinning, pruning, and soil improvement. Conversion of red alder stands to conifers increased, particularly on large industrial ownerships. Research on herbicides to control alder continued in the 1970s as new chemicals were developed. The expanding hardwood industry became concerned about future supplies, and began to question policies related to alder on public lands. National and international interest in short rotation culture of hardwoods (including bioenergy plantations) and use of nitrogen-fixing species as an alternative to chemical fertilizer stimulated further studies on red alder. Beginning in the 1980s, major changes in the status of alder began to occur in northwestern forestry. Oregon State University hired a hardwood silviculturist and formed a research cooperative focused on alder silviculture, industrial corporations began to establish alder plantations on high site quality forest land, the contributions of alder to wildlife habitat and riparian productivity were recognized, and prices for alder logs increased (and eventually equaled and at times surpassed) those paid for Douglas-fir. Today, red alder is acknowledged as a species with a significant role in the forest ecosystem and forest products economy and of the Pacific Northwest.

Keywords: *Alnus rubra*, early observations, management status, research history, red alder

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Introduction

Red alder (*Alnus rubra* Bong.) is an interesting and unusual species. Although lacking the impressive size of most trees in Pacific Northwestern forests, red alder now occupies a significant niche in the conifer-dominated ecosystem and wood products economy of the region. This was not always the case. During most of the past century, red alder was regarded as second rate, an undesirable, even threatening species. Even in those times, however, there were individuals and groups in forestry and other natural resource professions who saw value and possibilities in this hardwood species. Red alder is one of the first forest tree species to have had a symposium devoted exclusively to its biology. The first symposium held in 1967 at an annual meeting of the Northwest Scientific Association (Trappe et al. 1968) has been followed at 10- to 15-year intervals by three others. The second symposium dealt with utilization and management (Briggs et al. 1978), and the third with biology and management (Hibbs et al. 1994). The fourth symposium covered matters pertaining to markets and economics as well as biology, management and utilization, and many of the presentations are documented in this General Technical Report. A Hardwood Commission in Washington functions as an advocate and a Hardwood Silviculture Cooperative at Oregon State University is focused on alder research. Not a bad record for a tree regarded by many foresters as a third string species at best!

Organizers of this symposium asked me to provide a brief history of how the above situation developed, with particularly attention to research and attitudes concerning the biology and management of red alder. As I began to prepare this historical perspective, I identified more and more with a concern raised nearly two centuries ago by German forest scientist Heinrich Cotta (republished as Cotta 2000); that is, "the forester who practices much writes but little, and he who writes much practices but little." When tracing the history of alder over many decades, one is heavily dependent on published material. Unfortunately this written record represents only a small portion of both the experience and attitudes developing in any period, and the events and influences that shaped them. Despite such limitations, the history of red alder is an interesting one!

In the following pages, I shall relate first some information about the initial observations, collections and descriptions of red alder; then review some research reports and other literature that were published during the 20th century, particularly those items that reflected or influenced attitudes and management of the species; finally, I'll offer some thoughts about factors that contributed to the changing status of red alder in Pacific Northwestern forestry.

Early Observations, Collections, and Descriptions

The earliest knowledge about red alder obviously is that developed and passed on among the indigenous people that populated the Pacific Northwest. For many, many centuries, the wood of alder was, next to western redcedar (*Thuja plicata* Donn.), the most widely used of any tree species in Northwest Coast woodworking (Gunther 1973). Dishes, platters, spoons, cradles, and canoe bailers were made from alder. It was considered to be ideal firewood because it did not spark, and it was uniformly preferred for smoking salmon. Its value extended beyond the wood itself; the bark was used for dyes, and medicines were prepared from both bark and catkins (Turner et al. 1990).

The first observations and collections of red alder by non-native people appear to have been made in the mid- to late-1700s by Russian explorers in coastal Alaska. These collections were not described until the mid-1800s (Bongard 1833) and remained unknown to most of the western world until much later. In fact, it was not until the 1930s that red alder's scientific name was changed from *Alnus oregona* Nuttall to *Alnus rubra* Bongard to credit these earlier collections and descriptions.

Probably the next European to make an observation about red alder in the Pacific Northwest was Archibald Menzies, a botanist-naturalist with Captain George Vancouver's expedition. Menzies' personal diary refers to alder in several places, including a note about finding "American Aldar" at Discovery Bay on May 2, 1792 (Gorsline 1992).

The first written silvical (or ecological) observations appear to be those found in the original diaries (1804–1806) of Lewis and Clark (Thwaites 1905, reprinted 1959). Two hundred years ago (late October 1805), Lewis and Clark descended the Columbia River and near the mouth of Wind River observed a "timber resembling a beech in bark but different in its leaf which is smaller, and the tree smaller." This timber is believed to be red alder, and if so, the entry represents its first mention in their journal. The species was later referred to by Lewis and Clark as "black alder" or "beech." The smooth, beech-like bark of alder was no doubt the reason that both Lewis and Clark chose it to mark their presence at Cape Disappointment, the westernmost point of their journey (fig. 1). Lewis carved his name, and Clark later added not only his name but also the date and the line: "By Land from the U. States in 1804 and 1805." While at Fort Clatsop on the Oregon side of the river, Lewis and Clark observed that alder trees "grow separately from different roots and not in clusters or clumps as those of the Atlantic states." They also recorded phenological information—observing that alder "did not cast its foliage until about the first of December"; and they noted that "the black alder is in blume" on March 24, 1806, the day after they left Fort Clatsop for their return home.

Figure 1—The smooth, beech-like bark of red alder attracted personal inscriptions by both Lewis and Clark at Cape Disappointment.

Other early references to red alder in pre-1900 documents include the journals of James G. Swan (1852–1900) and David Douglas (1823–1827). Douglas collected alder near Cape Disappointment on April 8, 1825, and thought it might be *Alnus glutinosa* (European black alder) (Douglas 1959). In addition, original species descriptions of red alder (or Oregon alder) were prepared by H.G. Bongard (1833) and Thomas Nuttall (1842).

Kellogg (1882) wrote a particularly poetic account titled "The Great Red Alder" in his book, *Forest Trees of California*, and he may be the first writer to mention ecological amenities or values other than wood and plant products. His description of the species and its habitat included observations that trout seem to prefer those pools in which the mineral waters have been cooled and "toned" by alder's presence, and that their flesh there acquired an aldery-tinged color and quality (Kellogg 1882). He also indicated that the wood of red alder was highly esteemed as piles for foundations of bridges and other water structures because when kept constantly underwater, it is very durable. Such durability when immersed is probably the reason that another member of the *Alnus* genus was used along with oak and larch for piling in the marshes on which the city of Venice, Italy was built (Botkin, 1990).

Chronology of Research and Attitudes

The following chronology is intended to document briefly the evolution of knowledge and attitudes about red alder during the past century. To do so, a few items in each decade were selected to illustrate or reflect the status and development of information and thinking about red alder management during that period.

1900–1909

At the beginning of the last century, forestry in North America was in its infancy and was represented almost entirely by employees of the U.S. Forest Service.

In 1908, George Sudworth, a Forest Service dendrologist, included a description of red alder in his book, *Forest Trees of the Pacific Slope*. He recognized its "rapid growth" and referred to its "cherry-like, fine grain that was attractive when finished, and made the wood suitable for cabinet work" (Sudworth 1908).

1910–1919

This second decade of the 20th century brought forth contrasting views about alder that persisted throughout most of the century. Two publications—both from USDA Forest Service—illustrate this contrast:

The first view—and the dominant one for many years—was published in 1912 in U.S. Department of Agriculture, Forest Service Silvical Leaflet 53–*Red Alder* (Graves 1912). Referring to six species of tree-size alder, the author, presumably Henry S. Graves, second chief of Forest Service and founding Dean of the Yale School of Forestry, writes "The most important of these is red alder, a medium-sized tree of the Pacific coast region. Although it has no particularly excellent qualities, and is not abundant enough to be very important commercially, it is one of the conspicuous broadleaf trees of its range, where there are but few broadleafs of any species." This paper contains some information about growth patterns, site suitability, and utilization—including a number of observations that seem to contradict the idea that the species had no excellent qualities. These appear to have had little impact on the author's opinion, however, as the leaflet concludes with the following comments on management: "Red alder is not a tree which merits the forester's especial care, although it is one of the most abundant broadleaf trees of western Washington and Oregon. .... The forester's chief aim should not be to encourage this species, but to find a means of profitably disposing of what already exists. Stands of alder, wherever practicable, should be utilized before decadence sets in, and in cutting them an effort should be made to convert the forest of alder into a forest of more desirable species."

That view contrasts sharply with a view presented 5 years later in a Journal of Forestry article written by Herman M. Johnson, a forest examiner for the Forest Service. It was titled, *Alnus oregona: its value as a forest type on the Siuslaw National Forest* (Johnson 1917). After reviewing some of the silvical characteristics, he argued that "the value of this species has not been given proper recognition," and described several useful purposes, including its value for fire protection and soil rehabilitation (both particularly significant on the Siuslaw National Forest as it had experienced extensive fires in the 1800s). Johnson concluded his paper as follows: "Although the Oregon alder has been commonly considered a weed tree and in many respects undesirable, this study has shown that it has been and is yet of great value to the Siuslaw National Forest." He then added: "it may be expected that in the near future it will develop an industry of considerable extent."

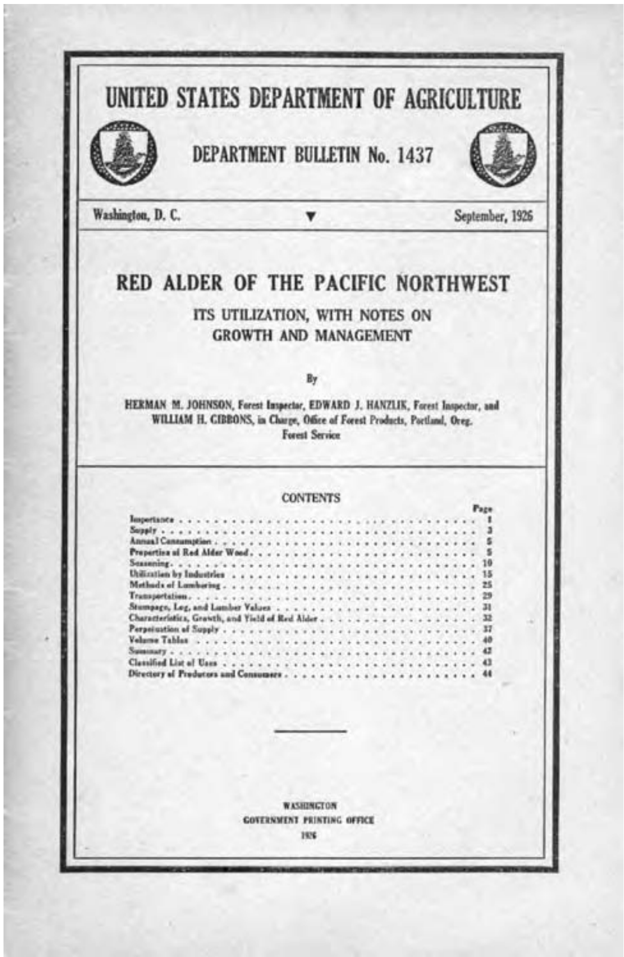
During this same period, Canadians were also beginning to examine the forests of British Columbia, and red alder receives brief mention. After describing some attractive growth and wood characteristics, the account ends with the statements: "The chief use, however, is as fuel, for which it is excellent. It is of local importance only and no estimate of the available supply has been secured." (Whitford et al. 1918).

About the same time, B. L. Grondal, a professor at the University of Washington College of Forestry, added his voice to those who saw a promising role for alder in the developing forestry economy of the Northwest. He wrote an article in the West Coast Lumberman titled *Seattle Shoe Factory Utilizes Red Alder* (Grondal 1918). Seasoned alder was used as sole material in shoes, and was "found by actual test to be superior to any other timber known."

Thus, early on in the development of forestry in the Northwest, the contrasting opinions that prevailed through many following decades were on the table: some saw red alder as an undesirable species, to be removed from the forest and replaced by conifers as soon as practicable; some saw it as providing significant ecological benefits to the forest; some recognized its superiority as a fuelwood; and some saw possibilities in cabinetry and actual use in a developing industry as sole material in a shoe factory!

1920–1929

Although there was not much research activity dealing with red alder in the twenties, the Forest Service published in 1926 the first comprehensive bulletin on its utilization, growth and management (fig. 2). The bulletin was co-authored by H.M. Johnson, who had foreseen the value of alder nearly a decade before on the Siuslaw National Forest, Edward Hanzlik, forest inspector, and W.H. Gibbons of the Office of Forest Products in Portland (Johnson et al. 1926). They addressed the species' importance in the first section of the bulletin stating "Red alder, although a wood of comparatively little importance outside of the region where it is found, is yet the leading hardwood of the Pacific Northwest…Its importance locally is due both to the intrinsic qualities of the wood and to the scant supply of other commercial hardwoods throughout its range." And after describing some of its wood characteristics, the authors wrote "The growth of the furniture industry and similar wood-using industries of the Pacific Northwest may indeed be said to depend in a large measure on the perpetuation of an adequate supply of alder." A section on *Characteristics, Growth and Yield* included the observation that alder is "exceptionally free from all sorts of diseases and injuries" up until the time of its maturity (about 50 years of age). They determined maximum size at about 120 feet in height and nearly 4 feet in diameter; and recognized that young alder trees grew "more rapidly even than Douglas-fir." Their yield data showed that stands as young as 30 to 40 years may average more than 90 feet tall, 12 inches plus in diameter, and contain more than 20,000 board feet per acre—this to a 6-inch top diameter and mininum breast-high diameter of 8 inches. Two-way volume tables were provided in both board feet and cubic feet. The management summary



UNITED STATES DEPARTMENT OF AGRICULTURE

DEPARTMENT BULLETIN No. 1437

Washington, D. C. ▼ September, 1926

RED ALDER OF THE PACIFIC NORTHWEST

ITS UTILIZATION, WITH NOTES ON
GROWTH AND MANAGEMENT

By

HERMAN M. JOHNSON, Forest Inspector, EDWARD J. HANZLIK, Forest Inspector, and
WILLIAM H. GIBBONS, in Charge, Office of Forest Products, Portland, Oreg.
Forest Service

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WASHINGTON
GOVERNMENT PRINTING OFFICE
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Figure 2—First technical bulletin on utilization and management of red alder was issued by the U.S. Department of Agriculture in 1926.

Figure 3—Stand of red alder at Cascade Head Experimental Forest thinned and released from overstory conifers at age 10.

concluded: "The facts indicate that for many reasons red alder is a desirable tree to perpetuate as a forest type in the Pacific Northwest."

1930–1939

Most of the information available on red alder before 1930 was based on perceptive observations and measurements taken on temporary plots. In the 1930s, additional labor became available on the National Forests, including the Experimental Forests, in the form of the Civilian Conservation Corps (CCC). Several long-term silvicultural projects were initiated during this period, perhaps aided directly or indirectly by the CCC program.

In 1932, red alder was planted in a strip, 70-90 feet wide and about one mile long, in the Yacolt Burn on the Wind River Experimental Forest. This planting was intended to serve as a firebreak, but through a serious of serendipitous events, it provided a classic example of benefits possible in a mixed stand of red alder and Douglas-fir (these will be described later in this paper). About the same time, some direct seeding of red alder was done on the Olympic National Forest. During the 1935 to 1937 period, several long-term studies on growth and silviculture of red alder were established at Cascade Head Experimental Forest. These studies included plots that compared pure and mixed stands of red alder and conifers, and thinned and unthinned stands of alder (fig. 3). A test of pruning was also established.

In 1938, Thornton Munger wrote a paper for the Hardwood Record titled *Red Alder Long Considered but a Weed Tree, Now an Important Raw Material for West Coast Woodworkers* (Munger 1938). And the next year, T. J. Starker, of Oregon State's College of Forestry, published in the Journal of Forestry what may be the first paper related to genetic variation of the species (Starker 1939). In *A New Alder*, he described a genetic variant, the cutleaf or *pinnatisecta* variety of the species.

1940–1949

During the early 1940s, there was relatively little new research on the biology and management of red alder, probably due in part to the war effort. A study of sprouting of alder at Cascade Head indicated that coppicing was not a feasible regeneration method for red alder, at least not for trees of saw timber size (Worthington et al. 1962).

In the middle to late 1940s, however, interest in utilization and management of alder increased in several public organizations. There were projects on kiln-drying of hardwoods (Voorhies 1944) and other aspects of hardwood utilization at the Oregon State University Forest Products Laboratory (Robinson 1948).

At the end of the decade, William Lloyd (1949) of the U.S. Department of Agriculture, Soil Conservation Service established thinning plots in northwest Washington, and George Warrack (1949) began researching red alder for the provincial government in British Columbia. The same year, Morrison published in the *British Columbia Lumberman* what may be the first report on use of herbicides to control alder (fig. 4)—"Keeping roads alder free by the use of chemical sprays" (Morrison 1949). And Philip Haddock, then a young assistant professor at University of Washington, wrote a paper for the *Forestry Club Quarterly* with the interesting title *A Problem Child Reforms—New Perspectives in the Management of Red Alder* (Haddock 1949). He pointed out that continuity and stability of production was one of the main obstacles to any permanent alder industry. After recognizing the problems of alder competing with or preventing establishment of conifers on some lands, he suggested the need for more exact knowledge of alder as a soil builder before attempting large-scale removals of the species by chemical control methods or otherwise. The most surprising aspect of this paper was that Haddock went on to discuss some of the genetic improvement work occurring in Europe, and advocated applying such techniques to intensive management of red alder in the Pacific Northwest. (Note that this recommendation was made 56 years ago!)

Figure 4—Roadside spraying in the late 1940s and 1950s was an early use of herbicides to control red alder.

1950–1959

The early 1950s ushered in a long period of interest in the soil-improving characteristics of alder. Bob Tarrant (fig. 5) and others compared nutrient content of litter of several tree species (Tarrant et al. 1951). They found that red alder leaf litter had extremely high nitrogen content (40 percent higher than the next highest species); and they suggested that alder had possible value as a soil conditioner. Elsewhere, scientists began to examine the nitrogen-fixing capacity of several *Alnus* species, and the role of alders in soil development after the recession of glaciers (Bond 1954, Crocker and Major 1955, Lawrence 1958).

Figure 5—Robert Tarrant pioneered research on soil improvement by red alder in the 1950s and 1960s, and later served as Director of the Pacific Northwest Forest and Range Experiment Station.

In the mid-1950s, Bob Ruth began to evaluate performance of young conifer plantations in coastal Oregon (Ruth 1956, 1957). He found that alder and various brush (or shrub) species hindered conifer development. Although red alder had been considered as inferior to Douglas-fir and other conifers in some respects (size, use as structural material), this research indicated that alder could actually threaten conifer establishment and early growth. As a result, work progressed on use of chemicals to control this threat. Basal spraying with 2,4,5-T in oil was found to be an effective way to kill alder (Ruth and Berntsen 1956).

The first volume tables (Johnson 1955, Skinner 1959), site curves (Bishop et al. 1958), and some preliminary yield tables (Lloyd 1956) became available in the late 1950s.

At the National Convention of the Society of American Foresters (SAF) in 1958, Carl Berntsen presented a paper titled *A Look at Red Alder–Pure, and in Mixture with Conifers*. He examined the results after 20 years of silvicultural manipulations starting in a 10-year-old mixed stand of red alder and Douglas-fir (Berntsen 1958). One area remained as a control; conifers were completely removed from two areas to leave pure stands of alder, one of which was also thinned to 8 ft by 8 ft; all alder was removed from the fourth area to leave a pure conifer stand at 6 ft by 6 ft spacing. From age 10 to age 20, alder grew much more rapidly than the conifers. At stand age 30, however, the conifers were growing at 400 cubic ft per acre per year and the pure alder only 260 cubic ft per acre. Thinning the pure alder stand made little difference. Growth in the mixed stand was least. Implications of this study were that pure stands of either conifers or alder were superior to mixed stands, at least to age 30, and that alder thins itself rather effectively.

1960–1969

The 1960s were rich in production of information on several topics about alder. Studies established in the 1930s had matured, and interest in both managing and controlling or converting red alder had increased over time. A number of significant publications on silviculture and management resulted.

One of the most important was a collaborative effort among several landowners and agencies to gather data and produce normal yield tables for red alder. These tables were authored by Norman Worthington (fig. 6) and Floyd Johnson (PNW Station) with George Staebler (formerly with PNW Station but by then of Weyerhaeuser Company) and William Lloyd (Soil Conservation Service) and were published as a PNW Station Research Paper (Worthington et al. 1960). They provided—for the first time—a broad-based estimate of levels of production that might be expected from fully-stocked stands of alder over a wide range of sites and ages.

Berntsen published three significant papers on the alder silviculture studies that had been established decades earlier at Cascade Head Experimental Forest. One was a detailed examination (Berntsen 1961) of the study that he discussed at the national SAF meeting three years before (Berntsen 1958). A second paper (Berntsen 1962) evaluated 20-year growth of alder stands that had three different treatments: scattered overstory Douglas-fir occurred in two stands and was girdled; one of these two stands was also thinned; the third stand was initially pure alder and was not thinned. The latter grew much more rapidly than the other two and differences between those were minimal, suggesting again that red alder may be rather effective at self-thinning. The third paper (Berntsen 1961) dealt with pruning and carried

Figure 6—Norman Worthington of the Pacific Northwest Forest and Range Experiment Station's Olympia Research Center led efforts in the late 1950s and early 1960s to produce normal yield tables and a comprehensive bulletin on management of red alder.

two main messages: (1) branch stubs were grown over very rapidly, and although decay was present in every stub, it did not extend beyond the knots; and (2) gains in clear wood were offset by development of epicormic branches. The upshot was that pruning of red alder was regarded as a questionable practice for many years. In hindsight, it appears that this pruning test was conducted in stands that were released from overtopping conifers and further thinned at the same time (Rapraeger 1949); it therefore seems likely that these other stand-opening treatments contributed to epicormic branching at least as much as the pruning itself.

Worthington, Ruth, and Matson (1962) combined efforts to publish a comprehensive bulletin on management and utilization of red alder. This was an update of the earlier bulletin by Johnson, Hanzlik, and Gibbons (1926) some 36 years before, but with considerably more information on silviculture and management.

Scientific understanding of the effects of alder on physical, chemical, and microbial properties of the soil was also advanced in the sixties. Tarrant (1961) published a significant paper on a study conducted in the mixed stand of red alder and Douglas-fir at Wind River—the one created serendipitously by the intended firebreak mentioned earlier. Tarrant compared soil properties and Douglas-fir growth in the mixed planting with soil properties and tree growth in the adjacent pure stand of Douglas-fir; in the mixed stand, soil nitrogen and foliar N of the Douglas-fir and current growth of dominant Douglas-fir trees were greater than in the pure Douglas-fir stand. Such evidence and the striking visual demonstration (fig. 7) at this site stimulated interest by other scientists and managers in the possibilities that alder may offer in the region's forest economy and ecosystem. A detailed follow-up study by Tarrant and Miller (1963) showed that organic matter content was also increased, bulk density was lower in surface soil, and on average an additional 36 pounds of N per acre per year had accumulated beneath the mixed stand. These studies at Wind River led to studies of soil properties in the mixed and pure stands at Cascade Head Experimental Forest (Bollen et al. 1967, Franklin et al. 1968).

In other microbiology and pathology studies, red alder was shown to be non-susceptible to *Phellinus (*then *Poria) weirii* root rot (Wallis 1968). Survival of *Phellinus* in infected cubes of Douglas-fir wood buried in soil was poorer beneath stands containing alder than under pure Douglas-fir stands (Nelson 1968). Research was also conducted on rhizophere microflora and mycorrhizal associations of red alder (Neal et al. 1968a, 1968b) and interactions between alder and various root rot fungi (Li 1969).

In the mid-sixties, Tarrant presented a paper on forest soil improvement by growing red alder at the International Soil Congress (Tarrant 1964); Warrack published some results on thinning of red alder in British Columbia (Warrack 1964); and the Extension Service of Washington State University issued a circular on *Growing Red Alder for Profit* (Washington State University Extension Service 1964).

Figure 7—A strip of red alder planted as a firebreak in the 1930s resulted in more productive soil and taller Douglas-fir trees with darker green foliage than occurred in the surrounding Douglas-fir plantation.

The first symposium on alder was held in 1967 at the Northwest Scientific Association Annual Meeting, and was geared primarily to forest scientists. The proceedings (fig. 8), *Biology of Alder*, were published by the Pacific Northwest Forest and Range Experiment Station the next year (Trappe et al. 1968) and contained three papers on taxonomy, eight on ecology, ten on soils and microbiology, five on physiology, and two on growth and yield.

In 1969, Bernard Douglass and Ralph Peters, foresters with the State and Private branch of the Forest Service, installed the first field study of red alder genetics at Cascade Head Experimental Forest (fig. 9). This provenance trial consisted of seedling sources collected from 10 locations ranging from Port Orford, Oregon to Juneau, Alaska.

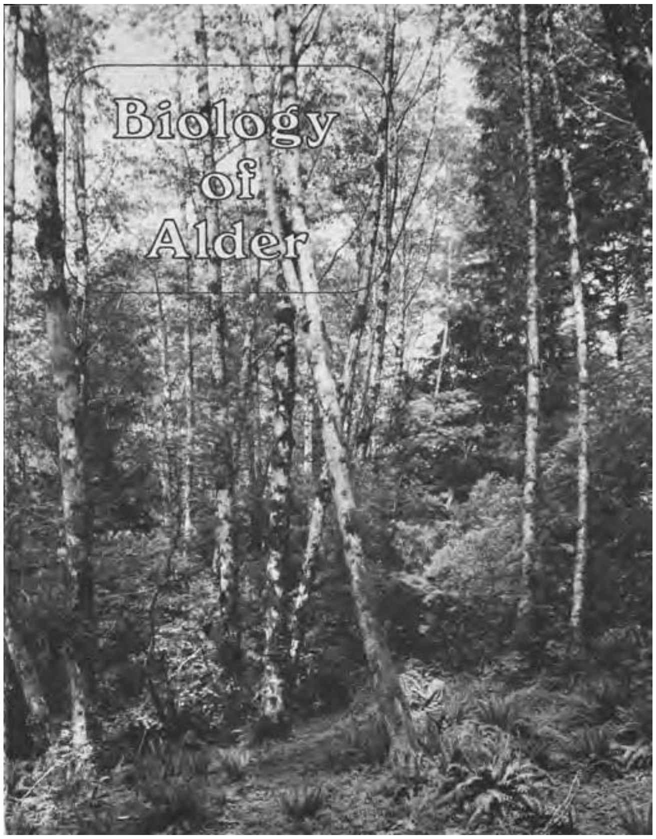
Biology
of
Alder

Figure 8—Proceedings of the first symposium on red alder were published in 1968 by the Pacific Northwest Forest and Range Experiment Station.

One might think the tide had turned during this decade regarding prevailing opinions about the usefulness for alder, but if it did, the change was minor. Forest managers were also looking more closely at stand conversion, and work on chemical release of plantations from alder and other brush was accelerating.

Staebler (1960) reported difficulties in killing red alder via a basal injection of 2,4,5-T. Many other studies were carried out using herbicides as basal sprays (Madison and Ruth 1962) or via injection or in frills to kill larger alder stems (Finnis 1964, Newton 1966). There was also work on application of foliar sprays to kill brush (one of the constituents being red alder) in conifer plantations (Hetherington 1964).

In 1969, James Yoho and other economists (1969a) published an economic analysis on converting red alder to Douglas-fir. They concluded that in most instances it was financially desirable convert red alder to Douglas-fir—and the sooner the better! They stated that forest managers were not rushing to respond to this profitable investment in conversion, and recognized that a large share of private owners do not respond at all—a good thing for the alder industry! Their paper stimulated a letter from the Chief Forester of Northwest Hardwoods, Inc. (Burns 1971) to the PNW Station Director. The letter began by suggesting that the paper was based upon "an inaccurate economic model, faulty data, and assumptions biased to give credence to the *one best species* myth peculiar to foresters in the Northwest." The letter then listed some reasons for such strong criticism, one of which was the assumption that "red alder stumpage rates would stay in the same ratio to Douglas-fir forever more!" The letter did, however, end on a conciliatory note; the chief forester offered to "cooperate in any way possible" in a new study to replace the "faulty" one.

Figure 9—A red alder provenance trial established in 1969 by State and Private Forestry at Cascade Head Experimental Forest was the first genetics field test and in 2005 is probably the oldest pure plantation of the species.

The same group of economists (Yoho et al. 1969b) also published a note at the same time that was probably somewhat better received by the alder industry. Although titled *Marketing of Red Alder Pulpwood and Saw Logs*, it was more than that. In it, the authors pointed out that quoted stumpage prices were not indicative of true market values because alder logs were usually a minor component of a timber sale and the concerns of buyers and sellers were usually centered on the conifer component. The economists foresaw a bright future for alder markets, however; the use of red alder in pulp mills was increasing at the time, and they thought the potential for market expansion and earnings in the lumber markets might be even greater.

1970–1979

The 1970s brought substantial increases in research on alder species throughout the northern temperate zone.

Studies on herbicides increased as many new chemical products were developed. Ron Stewart evaluated foliage sprays and budbreak sprays, and made recommendations for site preparation and release of conifer plantations from competition associated with red alder and other hardwood tree and shrub species (Stewart 1974a, 1974b). Further analyses were made on the matter of converting brush and hardwoods to conifers (Dimock et al. 1976).

The concept of short-rotation intensive culture of hardwoods, developed in the Southeast as "silage sycamore" in the mid-1960s (McAlpine et al. 1966), received some attention in the northwestern United States and Canada (Heilman et al. 1972, Smith and DeBell 1973). Red alder and black cottonwood were the species of choice (DeBell 1975, Harrington et al. 1979). When the oil crisis developed, an interest developed in using the concept for growing "energy plantations," and red alder (as well as poplars) figured prominently in early assessments (Evans 1974). The idea gained momentum and the U.S. Department of Energy was formed and initiated a long-term program of research on woody biomass production (Ranney et al. 1987); projects involving red alder (in addition to *Populus* and other hardwoods) were funded at several institutions in the Pacific Northwest (initially at University of Washington, Washington State University, and Seattle City Light, and later at the Pacific Northwest Research Station). The funds from this program fostered work on many aspects of red alder biology and silviculture.

Other work that had also started in the 1960s by soil microbiologists and forest pathologists at Corvallis led to the hypothesis that alder might serve as a biological control for laminated root rot of Douglas-fir (Trappe 1972). Several studies were undertaken in the 1970s to gather information on this possibility; these included additional exploratory studies and a long-term, large-scale test of effects of short rotations of alder or cottonwood on development of root rot in subsequent Douglas-fir crops on International Paper Company land in northwest Oregon (Nelson et al. 1978). Investigations of field survival of *Phellinus* in large Douglas-fir stumps did not confirm any special inhibitory effect of alder on the pathogen (e.g., Hansen 1979), but meaningful evaluation of the long-term empirical trial will not be possible for at least another decade. There is a general consensus, however, that on *Phellinus*-infested sites suitable for alder, a rotation of this non-host while the fungus exhausts its resources is a reasonable strategy for limiting losses from the root rot.

About this same time, the alder industry was expanding and became concerned about current and future log supplies. Public agencies began to be questioned about their policies related to alder management. There was a series of articles in the Portland *Oregonian* (Sorensen 1973a, 1973b). One investigated a so-called "mismanagement of the alder resource on the Siuslaw National Forest." The Corvallis *Gazette-Times* ran a feature on red alder that described the possible benefits derived from managing and utilizing red alder (Hall 1976). Washington Department of Natural Resources staff released several notes about alder management and the economics thereof during mid- to late-1970s (Prevette 1975, 1976; Koss and Scott 1977).

In 1977, a second symposium on alder was held; this one involved foresters and mill owners and managers as well as forest scientists and its focus was utilization and management of red alder. The proceedings, published by the Pacific Northwest Station (Briggs et al. 1978), contained many papers of practical as well as scientific interest. One of the papers (Miller and Murray 1978) examined growth and yield in the previously-mentioned stands of red alder and Douglas-fir at Wind River; at age 48, Douglas-fir in the mixed stand was taller by 16 ft and had a larger per acre volume despite having one-third fewer stems than in the pure Douglas-fir stand. Total volume of red alder and Douglas-fir in the mixed stand was about double that of the pure Douglas-fir stand. These substantial long-term growth benefits to Douglas-fir strengthened interest in the ecology and potential management of mixed species stands.

A great deal of interest developed during the decade in nitrogen fixation, stimulated in part by the high cost (in terms of money and energy) of nitrogen fertilizer. A workshop held at the Harvard Forest featured several papers on *Alnus*, two of which involved red alder in the Pacific Northwest—one a short-rotation intensive culture study of pure and mixed alder and cottonwood (DeBell and Radwan 1979), the other a conceptual paper on crop rotation of alder and Douglas-fir (Atkinson et al. 1979). Two years later, an international symposium on use of nitrogen fixation in management of temperate forests was held at Oregon State University (Gordon et al. 1979). Again, red alder and other *Alnus* species were prominent in the presentations.

1980 and Beyond

In the late 1970s and early 1980s, relative economic values began to change substantially—there were downturns in the forest products industry and values of Douglas-fir logs and stumpage declined for a time. During this same period, prices for red alder logs remained more or less stable. Gradually, prices for both Douglas-fir and alder increased. Trends were more erratic for Douglas-fir and there was a shift to smaller timber as public (primarily federal) timber sales declined. Red alder prices, however, increased steadily as both domestic and international (particularly Asian) markets expanded. In the past 5 years (i.e., since 2000), prices for alder sawlogs have commonly equaled or surpassed those for No. 2 and 3 Douglas-fir sawlogs.

In 1983, Bob Tarrant, Bernard Bormann, Bill Atkinson and I collaborated on a paper in the *Journal of Forestry* (Tarrant et al. 1983). We thought it timely to examine some options for managing red alder in the Douglas-fir region. We concluded that only small changes in then current costs, prices, and yields would make red alder management financially attractive. Crop rotation of alder and Douglas-fir and continuous rotations of sawlog alder appeared to be economically viable alternatives to continuous cropping of Douglas-fir.

A comprehensive bibliography of literature on red alder was issued by the Pacific Northwest Station (Heebner and Bergener 1983). It listed 661 documents, the vast majority with abstracts.

Throughout the eighties, the Department of Energy Short Rotation Woody Crops Program funded a great deal of research on biology and culture of red alder at the Pacific Northwest Station's Olympia Forestry Sciences Laboratory (fig. 10). Studies included tree nutrition and fertilization (DeBell et al. 1983, DeBell and Radwan 1984, Radwan et al. 1984, Radwan 1987, Radwan and DeBell 1994), initial spacing (DeBell and Giordano 1994, DeBell and Harrington 2002, Hurd and DeBell 2001), genetic variation (Ager 1987, Hook et al. 1987, 1991, Lester and DeBell 1989), stump sprouting (Harrington 1984, DeBell and Turpin 1989), seed germination (Radwan and DeBell 1981), vegetative propagation (Radwan et al. 1989), and seedling production (Radwan et al. 1992). Much of this work involved collaboration with other organizations, and it furthered the general state of scientific knowledge on the various topics.

Figure 10—A dense planting of red alder established as part of the U.S. Department of Energy's Short Rotation Woody Crops Program.

Findings from the research on stump sprouting indicated that red alder was not a good candidate for the coppice systems of management then advocated for energy plantations, but the basic understanding of factors affecting sprouting (Harrington 1984) led to development of effective guidelines for controlling alder by cutting in young conifer stands (DeBell and Turpin 1989). This approach was economically feasible and could be applied selectively within stands; it was also more socially acceptable than herbicide applications and became the routine practice for alder control on federal lands. The work of greatest immediate practical importance, however, provided methods to evaluate site quality for growing alder and was done by Connie Harrington (Harrington 1986). She and Bob Curtis also developed new height growth and site curves for red alder (Harrington and Curtis 1986); the index age used was 20 years total age (rather than 50 years as commonly used for most tree species) in recognition of the short rotations anticipated for the species.

In 1983, Oregon State University added a hardwood silviculturist to their faculty in the person of David Hibbs. A few years later, a research cooperative focused on alder silviculture was formed. This Hardwood Silviculture Cooperative (HSC) is led by Hibbs and involves cooperators from several industrial organizations, public agencies, and academic institutions. Decisions were made early on to concentrate on stand density management, and cooperators became involved in establishing plots in natural stands and also in establishing plantations at a range of densities (fig. 11). The HSC has installed 26 research plantations located from Coos Bay, Oregon to Vancouver, British Columbia, covering a wide range of site conditions. Each plantation contains blocks planted at four different spacings (100 to 1200 trees per acre), and each spacing block has several thinning and pruning treatments. Data from this endeavor will provide essential information for intensive management of red alder. Hibbs and his colleagues also studied some natural alder stands and existing plots to produce several publications on self-thinning guidelines, response to thinning, and stand development (Hibbs and Carlton 1989, Hibbs et al. 1989, 1995, Puettmann et al. 1992, 1993a). In addition, the cooperative published useful state-of-the-art publications on such matters as seed collection, handling and storage (Hibbs and Ager 1989), guidelines for regeneration (Ahrens et al. 1992), and stand density management (Puettmann et al. 1993b). More recent work of the cooperative is discussed in other papers contained in this volume.

In 1980, Weyerhaeuser Company acquired Northwest Hardwoods, Inc., a major producer of solid wood products from red alder. By the mid- to late-1980s, concerns about future log supply for these hardwood mills led to an interest in growing red alder on some of the company's land. Over the next decade, tens of thousands of acres of alder plantations were established on some of the highest site quality land for Douglas-fir in southwest Washington.

A third symposium on red alder was held in 1992 at Oregon State University on biology and management (Hibbs et al. 1994). The 1992 symposium brought together existing knowledge on many scientific and practical matters, and was attended by both scientists and managers. At that time, many shifts were developing in forestry and in the forest products economy throughout the Pacific Northwest.

Figure 11—A recently thinned stand density installation for red alder near Cascade Head on the Oregon coast.

In the years since, significant changes have occurred in land ownership (particularly industrial), mills, markets, and government and corporate policies. Issues related to riparian areas and various wildlife species have become more and more important and portend to be very influential in future alder management. On some sites, the influences are restrictive and may hamper harvest and subsequent investments in regeneration and management. In other situations, however, a recognition of the unique habitat provided for songbirds and other wildlife and beneficial effects on productivity and diversity of riparian sites may stimulate greater interest in managing red alder on some ownerships. These matters were addressed in the recent (fourth) symposium and are documented in other papers in this volume.

Concluding Thoughts

Over the past century, there has been a gradual but sustained effort to learn more about red alder and to develop an effective approach to its management and use. Much more so than we would expect for a species that early on was deemed undesirable and targeted for eradication. In recent years, a major turnabout in the status of alder in the forest management community and forest products industry has occurred (fig. 12).

I believe several factors have contributed significantly to this change:

1. Red alder possesses traits that are both valuable and uncommon. These include: rapid early growth, wood properties that are desirable and uniform, ability to fix nitrogen, and the provision of habitat features associated with hardwood trees in a region dominated by conifers.
2. Over the years, an adequate body of information to guide management was accumulated. This came about because several individual forest managers and scientists developed a personal interest in the species. These individuals carried out modest trials that were supported by their supervisors and employers, even though such work was a bit outside the main mission of their respective organizations. In the past two decades, research efforts on alder were accelerated through support from the Department of Energy's Short Rotation Woody Crops Program and formation of the Hardwood Silviculture Cooperative.
3. There has been a continual increase in value of red alder logs relative to logs of Douglas-fir and other conifer species.
4. The unique contribution of alder to the conifer-dominated forest ecosystem of the Pacific Northwest in terms of soil improvement, wildlife habitat and riparian productivity has been recognized and more fully appreciated.

Figure 12—Red alder plantations have been established on industrial land having high productivity for Douglas-fir.

Had it not been for the species' valuable intrinsic properties, the interest by—and encouragement and support of—individual foresters and scientists in its management, improvements in its relative economic value, and recognition of the other benefits it provides to the forest ecosystem, it seems unlikely that red alder would have achieved its present status in forest management and utilization.

The history of alder also provides us with a compelling example of the dynamic nature of forest resource management (including production forestry) and the extent to which attitudes and values can change—even within one rotation of a fast-growing timber species or within one professional career. This history challenges our natural tendency to think that certain components or processes in our forests are entirely good or entirely bad, or to focus on one way to manage them—whether choices and decisions involve tree species, silvicultural practices, or management policies.

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Biology / Ecology

— Red Alder: A State of Knowledge —

Biology and Ecology of Red Alder

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Abstract

Red alder is the most common hardwood in the Pacific Northwest with a range stretching from coastal southeast Alaska to southern California and east to isolated populations in Idaho. Soil moisture during the growing season influences where it grows and its growth rates; it can tolerate poor drainage but not droughty, hot sites. Due to its tolerance of wet soil conditions, alder is common in riparian areas. Alder can be injured by spring and fall frosts and is not found at elevations above 1100 m anywhere in its range. The species produces small, very light seeds that disperse over long distances; it is favored by disturbance and often increases in abundance after logging or burning. Alder establishment via seed is not assured, however, as drought and heat injury, pathogens, animals and other factors often destroy seedlings. Alder has nitrogen-fixing nodules on its roots that directly and indirectly increase nitrogen in forest ecosystems. Alder usually has a spreading fibrous root system when young and can root deeply if soil aeration is not limiting. When grown in dense stands, its shade intolerance results in rapid mortality of shaded stems and lower branches. It is a relatively short-lived, intolerant pioneer with rapid juvenile growth. This pattern of height growth—very rapid when young and slowing quickly at a relatively young age—means that if thinning is delayed, alder can not rapidly build crown and increase in diameter growth. Although alder wood stains and decays rapidly after death, live trees compartmentalize decay very efficiently, and pruning and thinning are feasible operations. Stem rots do not result in high volumes of damage overall but can be locally important; ring shake can also be a serious problem in some stands. Insects and diseases are not generally a problem in young stands although insect defoliators, Nectria cankers, and alder bark beetles can cause problems. Meadow mice, voles, and beaver can also hinder stand establishment in some areas. Deer or elk may rub small alder saplings during the fall with their antlers but do not usually browse its leaves and twigs. Sapsucker damage is sporadic, but if stems are repeatedly damaged, their future log value will be greatly reduced. Mortality and top damage have been observed after ice or early snowstorms. Red alder is now being managed for a wider range of objectives and on many more sites than in the past; this is due to recent increases in wood value of alder relative to other species as well as its ability to fill specialized niches (e.g., add nitrogen to forest ecosystems, immunity to laminated root rot) and produce sawlogs on relatively short rotations. Management experience with the species, however, is still limited to a fairly narrow range of sites and management scenarios. Thus, information on the biology and ecology of the species should help guide managers until more direct experience is available.

Keywords: *Alnus rubra*, biology, ecology, damaging agents, growth, red alder, regeneration

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Introduction

Red alder *(Alnus rubra),* also called Oregon alder, western alder, and Pacific coast alder, is the most common hardwood in the Pacific Northwest. It is a relatively short-lived, intolerant pioneer with rapid juvenile growth, the capability to fix atmospheric nitrogen, and tolerance of wet soil conditions (although best growth is not on poorly drained sites, see below). The species is favored by disturbance and often regenerates after harvesting and burning. Because the commercial value of alder has traditionally been lower than that of its associated conifers, many forest managers have tried to eliminate the species from conifer stands. On the other hand, red alder is the major commercial hardwood tree species in the region; its wood is used for furniture, cabinets, pallets, and to make paper (Harrington 1984b). Its value has increased substantially in recent years which has led to greater interest in the management of the species, and thus, to a need for more information on its biology. This chapter is a revised version of Harrington et al. 1994; it summarizes published information as well as unpublished data and observations on the biology and ecology of red alder with emphasis on topics not covered by other authors in this volume and on information that has become available since previous summaries were published (Trappe et al. 1968, Briggs et al. 1978, Heebner and Bergener 1983, Hibbs et al. 1994).

Taxonomy and Genetics

Red alder (genus *Alnus)* is a member of the family Betulaceae. The most conspicuous feature that the North American genera in this family have in common is the presence of male catkins (compact aggregates of staminate flowers) (Brayshaw 1976) that disintegrate after pollen shed. The seed-bearing catkins in alder remain intact and attached to the plant during seed dispersal and for a time after dispersal is completed. More detailed information on the taxonomy and evolution of red alder is presented in Ager and Stettler (1994).

Genetic Variation

No races of red alder have been described, though they may exist, especially in disjunct populations or in the extremes of the range. One researcher divided the species into three populations (northern, central, and southern) based on vegetative and reproductive features from herbarium specimens (Furlow 1974).

Geographic variation in growth rates, sensitivity to frost, and other characteristics has been reported (DeBell and Wilson 1978, Lester and DeBell 1989, Ager and Stettler 1994). In one study, provenances from areas with cold winters (i.e., Alaska, Idaho, high elevations in Washington and Oregon) had the poorest growth but the greatest resistance to frost damage. Specific gravity did not differ significantly among provenances, nor was it correlated with growth rate (Harrington and DeBell 1980). In another study that compared families from coastal sources, it was possible to identify families with high growth rates and low sensitivity to spring frosts (Peeler and DeBell 1987, DeBell et al. 1990); work on laboratory techniques to predict frost tolerance of alder families is ongoing (Johnson and Herman 1995). A 24-family progeny trial in western Washington also demonstrated family variation in height-growth response to water-table depth (Hook et al. 1987).

Phenotypic variation between trees is also high. Differences in form and in characteristics of branch, bark, and wood were assessed for eight stands in western Washington; only bark thickness, a branch diameter index, branch angle, and a crown-width index differed significantly among stands (DeBell and Wilson 1978). Variation among trees in seed production has also been reported (see discussion below).

A cut-leaf variety *(Alnus rubra* var. *pinnatisecta)* (fig. 1) was first reported near Portland, OR (Starker 1939); the cut-leaf variety has since been found in several other isolated areas in British Columbia, Washington, and Oregon. A single recessive gene causes the cut-leaf characteristic (Wilson and Stettler 1981); thus, this variety can be used as a marker in genetic breeding studies (Stettler 1978).

As forest managers plant red alder on increasing acreage, the need will increase for additional information on genetic variation in the species. Preliminary recommendations are available on seed zones for red alder (Hibbs and Ager 1989, Ager et al. 1994) and the major tree improvement options and long-term breeding prospects for the species have been discussed (Ager and Stettler 1994). Information, however, is lacking on the variation within the species in its tolerance of low nutrient or low soil moisture conditions and on the possible interactions among silvicultural practices, genotype, and wood quality characteristics.

Habitat

Native Range

Red alder occurs most commonly as a lowland species along the northern Pacific coast. Its range extends from southern California (lat. 34° N) to southeastern Alaska (60° N). Red alder is generally found within 200 km of the ocean and at elevations below 750 m. Tree development is best at elevations below 450 m in northern Oregon, Washington, and British Columbia. In Alaska, red alder generally occurs close to sea level. Farther south, scattered trees are found as high as 1100 m, but most stands are at much lower elevations. Red alder seldom grows east of the

Cascade Range in Oregon and Washington or the Sierra Nevada Mountains in California, although several isolated populations exist in northern Idaho (Johnson 1968a, 1968b).

Climate

Red alder grows in climates varying from humid to superhumid. Annual precipitation ranges from 400 to 5600 mm, most of it as rain in winter. Summers generally are warm and dry in the southern part of the range and cooler and wetter in the northern portion. Temperature extremes range from -30°C in Alaska and Idaho to 46°C in California. Low winter temperatures and lack of precipitation during the growing season appear to be the main limits to the range of red alder. For good development of trees, either annual precipitation should exceed 630 mm or tree roots should have access to ground water.

Soils and Topography

Red alder is found on a wide range of soils, from well-drained gravels or sands to poorly drained clays or organic soils. In Washington and Oregon it grows primarily on soils of the orders Inceptisols and Entisols but is also found on some Andisols, Alfisols, Ultisols, Spodosols, and Histosols (Harrington and Courtin 1994). In British Columbia, alder occurs on Brunisols, Gleysols, Organics, Podzols, and Regosols (Harrington and Courtin 1994). Best stands are found on deep alluvial soils in river and stream flood plains; however, some excellent stands are also found on upland sites on residual or colluvial soils derived from volcanic materials.

Soil moisture during the growing season appears to influence where the species grows. Alder can tolerate poor drainage conditions and some flooding during the growing season; consequently, it is common on soils where drainage is restricted—along stream bottoms or in swamps or marshes. It is not commonly found on droughty soils, however; and in areas of low precipitation, it seldom grows on steep south- or southwest-facing slopes. In Idaho and California, stands are usually limited to borders of streams or lakes.

Associated Forest Cover

Red alder grows in both pure- and mixed-species stands. Pure stands are typically confined to stream bottoms and lower slopes. Red alder is, however, much more widely distributed as a component of mixed stands. It is a major component of the Red Alder cover type (Society of American Foresters Type 221) and occurs as a minor component in most of the other North Pacific cover types (Eyre 1980).

Common tree associates are Douglas-fir *(Pseudotsuga menziesii),* western hemlock *(Tsuga heterophylla),* western redcedar *(Thuja plicata),* grand fir *(Abies grandis),* Sitka spruce *(Picea sitchensis),* black cottonwood *(Populus trichocarpa),* bigleaf maple *(Acer macrophyllum),* and willow *(Salix* spp.*).* Occasional tree associates include cascara buckthorn *(Fangula purshiana),* Pacific dogwood *(Cornus nuttallii),* Oregon ash *(Fraxinus latifolia)*, bitter cherry (*Prunus emarginata*), and Pacific silver fir (*Abies amabilis*). Western paper birch *(Betula papyrifera* var. *commutata)* is an occasional associate in the northern and eastern portions of the range of alder, and redwood *(Sequoia sempervirens)* in the southern portion.

In the western hemlock and Sitka spruce zones, alder is most vigorous in plant associations dominated in the understory by western swordfern (*Polystichum munitum*) or redwood sorrel (*Oxalis oregana*) (Henderson et al. 1989). Common associations in British Columbia are: alder-salmonberry (floodplain), alder-swordfern (more upland) and alder-sedge (*Carex*). Common species in these plant associations include salmonberry (*Rubus spectabilis*), red elderberry (*Sambucus racemosa*), thimbleberry (*Rubus parviflorus*), red-osier dogwood (*Cornus stolonifera*), false lily-of-the-valley (*Maianthemum dilatatum*), oval-leaf huckleberry (*Vaccinium ovalifolium*) (especially on decaying woody debris), youth-on-age (*Tolmiea menziesii*), Siberian miner's lettuce (*Claytonia sibirica*), lady fern (*Athyrium filix-femina*), foamflower (*Tiarella trifoliata*), devil's club (*Oplopanax horridum*), and coastal leafy moss (Plagiomnium insigne) (D. Peter, P. Courtin, pers. comm. 2005). Salal (*Gaultheria shallon*), especially on raised surfaces, logs or stumps, is common in these plant zones, but increasing amounts on mineral soil indicate progressively drier and poorer sites for red alder. Increasing amounts of devil's club, skunk cabbage (*Lysichiton americanum*), and sedge indicate progressively wetter sites with greater potential for windthrow and ultimately poorer growth. Windthrow is not common in alder stands but can occur on poorly drained sites or where the root system has been undercut.

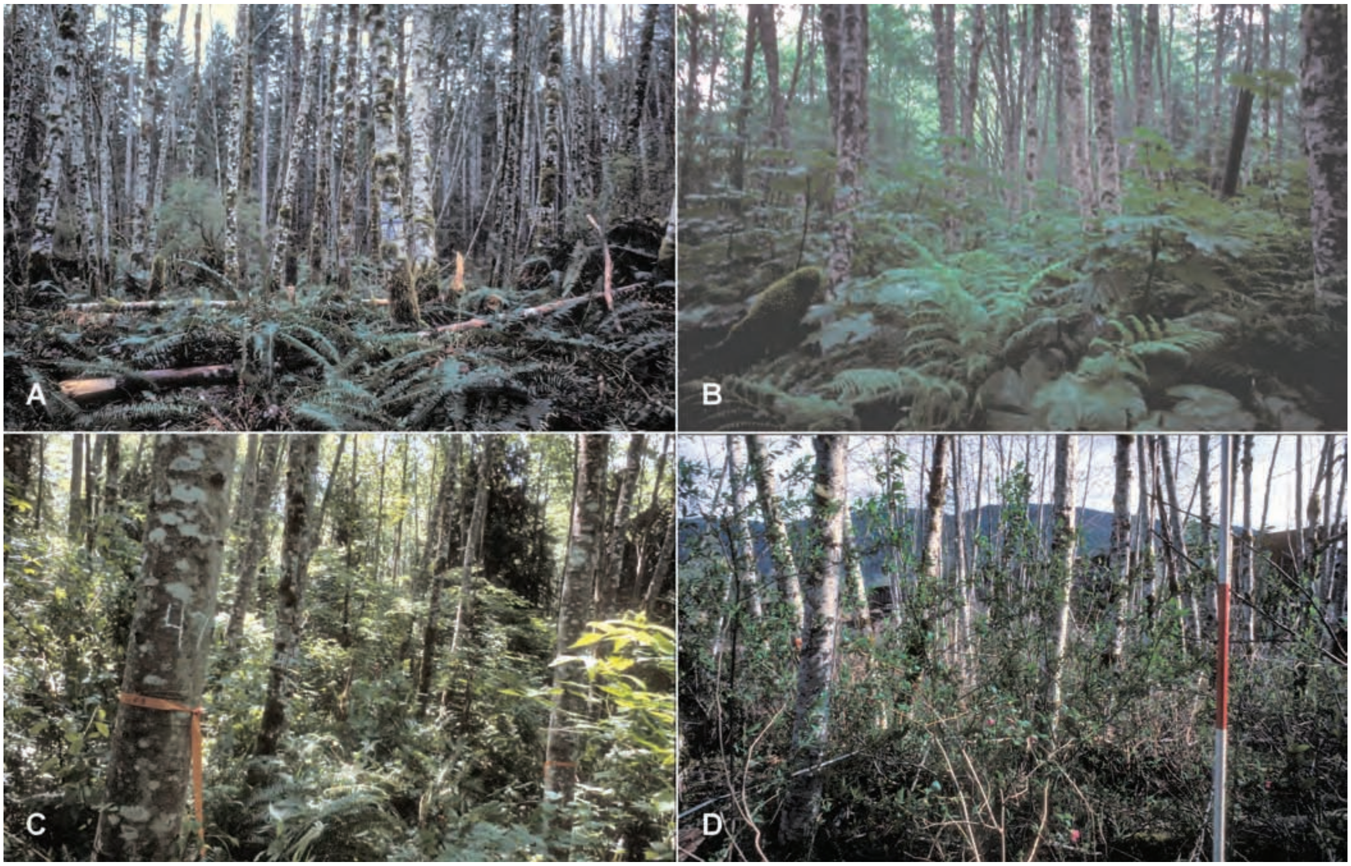
At higher elevations red alder is restricted by snow breakage. Increasing snow breakage potential is indicated by an increase in the occurrence of silver fir throughout much of the range of red alder with the notable exception of coastal rainforests in Washington and southern British Columbia. To the south, red alder is increasingly restricted to the Sitka spruce, redwood, and the wettest portions of the western hemlock zones, and especially to riparian areas. In these areas salmonberry is considered an especially good indicator of potential alder habitat (Atzet et al. 1996).

As is true in many plant communities worldwide, alder communities often contain non-native plants. This is particularly true in riparian areas as they are more open (many non-native plants that become problems are intolerant of shade) and water may serve as a transport path for seeds and other plant propagules. In addtion, riparian areas are often disturbed by flooding, animals accessing water, and in some areas by people recreating, so conditions may be favorable for non-native plant establishment. Japanese and giant knotweed (*Fallopia* (syn. *Polygonum*)) (fig. 3) and old man's beard (*Clematis vitalba*) are examples of three non-native species that can be very invasive in riparian areas. Disturbed or harvested alder sites are also favorable for rapid spread of nitrogen-loving species such as thistles (*Cirsium* spp.), grasses including bentgrass (*Agrostis* spp.) and velvet grass (*Holcus lanatus*), and groundsels (*Senecio* spp.). Other exotic plants that are common and vigorous on disturbed sites include cat's ear (*Hypochaeris radicata*), foxglove (*Digitalis purpurea*), evergreen blackberry (*Rubus laciniatus*) and Himalayan blackberry (*Rubus discolor*). Many exotic species are shade-intolerant and decline as the tree canopy closes, but particularly in riparian areas where flood disturbance may be chronic and the canopy more open, exotics such as the knotweeds may remain vigorous.

Alder is host to many epiphytes, especially lichens. Alder bark is brown, reddish brown, or greyish brown with white lenticels visible on the twigs; however, the bark often appears to be white or very light gray and patchy in color due to the presence of crustose lichens that can completely cover the bark and mask the underlying color (fig. 4). Common genera of crustose lichens on alder bark that give it a white or grey appearance are: *Arthothelium, Graphis, Lecanora, Lecidea*, *Ochrolechia, Rinodina,* and *Thelotrema* (T. Goward, F. Rhoades, pers. comm. 2005). Many other lichen genera are also present on alder trunks and branches; common species include: *Parmelia sulcata,*

Figure 1—(above) A cut-leaf alder growing in Capitol State Forest near Olympia, WA.

Figure 2—(below) Understory vegetation in alder stands can vary substantially. Shown are: A) swordfern understory with a red huckleberry just leafing out visible on a stump in the background; B) understory dominated by lady fern and devil's club on a fairly wet site; c) red elderberry and swordfern; and D) salmonberry in flower and indian plum on a riparian site.



Menegazzia terebrata, Ramalina farinacea, Usnea wirthii, Hypotrachyna sinuosa, Evernia prunastri, Hypogymnia enteromorpha, Peltigera collina, and *Usnea cornuta* (these were the 9 most common species out of 160 species of mostly foliose and fruticose species found on alder in western Washington, western Oregon, and northern California, L. Geiser and A. Ingersoll, pers. comm. 2005). Many lichen species are sensitive to air quality (Nash 1996, Stolte et al. 1993) and the bark of alder growing near pulp mills, coal-fired power plants or even in urban areas can be strikingly different in appearance from the bark of alders growing in areas of higher air quality (fig. 4).

Other Associates

General associations or interactions between red alder and wildlife species have been discussed previously (McComb 1994) and were discussed at this conference (McComb 2005). Interactions between red alder and animals, insects, and fungi that can result in tree damage are discussed later in this chapter.

Forest Succession

Red alder is a pioneer species favored by high light levels and exposed mineral soil. Its ability to fix atmospheric nitrogen permits establishment on geologically young or disturbed sites with low levels of soil nitrogen. It can form pure stands on alluvium, avalanche paths, and other disturbed sites. Harvesting and burning have favored alder; pollen records indicate that alder stands are more extensive in the twentieth century than they were for several centuries before that time (Heusser 1964, Davis 1973). Red alder pollen, however, was also abundant between 9000 and 4800 B.C.; the mix of species present in the pollen record for that time has been interpreted as indicating a somewhat warmer climate accompanied by an increase in fire frequency (Cwynar 1987).

Observations of mature forests in the Pacific Northwest suggest that alder stands are ultimately replaced by longer-lived, more tolerant conifers that have more sustained growth rates at older ages than does alder. This is undoubtedly true in most cases (see discussion below for exceptions), but the time required for this to occur in unmanaged forests is not well documented. Rapid growth and high stem densities of alder in younger stands make it difficult for conifers (especially shade-intolerant species) to regenerate and grow if they do not become established at the same time or shortly before alder invades a disturbed area. Douglas-fir can be easily eliminated in dense young alder stands while more tolerant species (western hemlock, western redcedar, and Sitka spruce) can survive and over time grow into the alder canopy and ultimately dominate the site.

Many alder stands in western Oregon have few associated conifers, leading some researchers to conclude that those alder stands will be replaced by shrubs and that without disturbance a shrub-dominated community may persist for an extended period of time (Newton et al. 1968, Carlton 1988, Tappeiner et al. 1991, O'Dea 1992). Clonal shrubs, particularly salmonberry, but also thimbleberry and vine maple, often form a dense shrub canopy which makes it difficult for conifers to invade and become established from seed. These shrub species can expand rapidly by vegetative reproduction as space becomes available due to death of the alder overstory (Tappeiner et al. 1991, O'Dea 1992, Zasada et al. 1992).

Experience suggests that alder replacement by conifers will have a high degree of spatial and temporal variation if the process is left to proceed naturally. The density of alder stems and the presence and abundance of shade-tolerant tree species are obviously important in influencing which successional trajectory will be followed; however, the specific ecological factors that determine the successional sequence in alder stands are not known. This topic is discussed in more detail in Deal (2006).

Life History

Reproduction and Early Growth

Flowering and fruiting. Red alder reaches sexual maturity at age 3 to 4 years for individual trees and at age 6 to 8 for most dominant trees in a stand (Stettler 1978). The species is generally monoecious, with separate male and female catkins developing on the previous year's twigs (Hitchcock et al. 1964). Staminate catkins, which occur in pendulous groups and are usually in a terminal position on a short shoot, elongate in late winter, changing from green to reddish brown and from 2 to 3 cm long to about 7 or 8 cm. Pollen grains are small (20 to 23 μM in diameter, Owens and Simpson, N.d.), lightweight, and produced in abundance. Several pistillate catkins are borne per floral bud and are commonly located on a bud proximal to the staminate catkins. They are 5 to 8 mm long and reddish green when receptive. Both male and female catkins usually occur in groups of three to six; variation in the ratio of male to female catkins in terms of numbers and weights has been described for three elevational transects (Brown 1986). Flowering occurs in late winter or early spring; peak shedding of pollen generally precedes peak receptivity by a few days but synchrony in pollen shed and receptivity have been observed in some trees (Brown 1985). Pistillate catkins are upright at the time of flowering but become pendulous as they mature. Most alder seed is probably the result of outcrossing, but some self-pollination occurs (Stettler 1978).

Limited information is available on the effects of cultural practices on flowering of red alder. In an experimental plantation on a well-drained site near Olympia, Washington, both male and female flower production were decreased by irrigation during the growing season

(Harrington and DeBell 1994); this is consistent with observations for other species that moisture stress increases flowering (Owens 1991). Within an irrigation regime, flower production was generally concentrated on the larger trees; thus, the percentage of trees flowering was greatest at the widest spacing, and within each spacing, the percentage of trees flowering increased as tree size increased.

Seed production and dispersal. Seeds are small, winged nutlets borne in pairs on the bracts of woody, cone-like strobili (Schopmeyer 1974). The seeds are without endosperm and contain only small cotyledons (Brown 1986). The strobili are 11 to 32 mm long and 8 to 15 mm wide.

Red alder is believed to be a prolific and consistent producer of seed; however, there are no long-term records of red alder seed production. Seed production in red alder varies substantially among trees; Brown (1985) reported production rates for 45 mature trees of similar size from 0 to 5.4 million seeds per tree. She reported within-stand variation to be much greater than variation among stands. Based on a two-year study of seedfall on two sites in British Columbia, McGee (1988) reported substantial variation between sites and years. Maximum total production was 1550 seeds/m^2; in the more productive year, production was four to seven times greater than in the less productive year. In the more productive year, one site produced 1.8 times more seed than the other, while in the less productive year seedfall was similar at both sites. Seed-crop quality (percent viable seeds) was similar between sites with 40 to 50 percent of the seeds viable in the good year and less than 10 percent in the poorer year. Worthington (1957) concluded that moderate seed crops are produced almost annually and bumper crops occur every three to five years; however, no specific studies were cited. Complete failure of a seed crop is rare, but after a severe freeze in 1955, almost no seed was produced in 1956 (Worthington 1957). Additional information on variation in red alder seed production is available (Ager et al. 1994). Information on seed production in other members of the Betulaceae (*Alnus* and *Betula*) is summarized in Harrington et al. 1994.

The annual pattern of red alder seed dispersal and how it varies over its range is not well documented. In general it is believed to begin in the middle of September in the center of its range and slightly earlier or later to the north and south respectively. McGee (1988), working in British Columbia, found that small amounts of seed were dispersed in September, but that the major dispersal events occurred from November to February. Lewis (1985) reported that major seedfall of red alder in Washington occurred during winter and spring, but that some seedfall was observed throughout the year. Major dispersal events occurred in consecutive months as well as in months separated by several months of low dispersal, a pattern similar to that in other members of the *Betulaceae* (McGee 1988, Zasada et al. 1991).

The nature of the catkin suggests that the timing of seed dispersal is regulated by factors similar to those regulating the release of seeds from the cones of conifers; that is, once catkins are mature, dispersal is determined by the occurrence of weather which dries them, thus opening the scales and allowing the seeds to be released. In general, wet weather keeps catkins closed and wet weather following dry weather closes catkins, thus terminating a dispersal event. Nonetheless, heavy seedfall can occur during wet weather under certain catkin conditions (Lewis 1985) and dispersal will not occur if ice freezes the seed in the catkin (Lewis 1985, Brown 1986). The dispersal patterns reported for red alder (Lewis 1985, McGee 1988) are consistent with the hypothesized mechanisms, but more frequent observations of seed dispersal in relation to weather and catkin condition need to be made. In coastal Alaska, drying trends brought by high-pressure weather systems are important to seed dispersal of Sitka spruce and western hemlock (Harris 1969), two common associates of alder. In addition, generally similar patterns of seed dispersal have been observed for alder and hemlock growing in the same stand in western British Columbia (McGee 1988).

Red alder seeds are very light, numbering 800 to 3000/g, and wind dissemination is effective over long distances. Lewis (1985) documented dispersal of red alder seeds for a two-year period and found amount of seed, seed weight, percentage of filled seed, and viability all to be inversely correlated with distance from the seed source. Amount of seedfall 100 m from the edge of an alder stand was 2 to 3 percent of the seedfall density inside the stand.

Although seeds are dispersed primarily by wind, some dispersal may occur by water (Brown 1986) and by birds or other animals. Birds are commonly seen around catkins, and alder seeds have been shown to be an important source of food for some species (White and West 1977). Birds play both passive and active roles in seed dispersal. Passive dispersal occurs simply by movement of the catkins as birds work in the crown of alders; active dispersal occurs as birds extract seeds from the catkins while feeding.

Germination, seedling survival and development. In normal germination of red alder seed, the radicle or root elongates first, followed by hypocotyl growth (hypogeal germination); this means that that the root emerges first from the seed coat (fig. 5). When seed has been stored for an extended period of time, this process can be reversed and hypocotyl elongation occurs first, the cotyledons emerge from the seed coat and then root elongation begins (epigeal germination) (pers. obs., J. Kraft).

Seed germination in clearcut environments in the central Oregon Coast Range began in late February and early March and was completed by mid-April (Haeussler 1988, Haeussler and Tappeiner 1993). Differences between north and south aspects were small compared to the forested environments where the onset of germination was delayed,

Figure 4—(above) The lichen community on alder bark can result in very different appearances from smooth brown bark to brown bark with shaggy spots to white or light gray bark. Many lichen species are sensitive to air pollution; the tree on the left with almost no lichens on its bark was growing in the vicinity of a coal-fired power plant near Centralia, WA.

Figure 5—(right) Alder seed germination is rapid and hypogeal; the radicle develops root hairs almost immediately. Photo by J. Kraft, PNW.

Figure 3—(below) Exotic species can be a particular problem in riparian areas where light levels are high and disturbance from flooding or animal access occurs. This view shows Japanese knotweed (yellow-brown foliage) overgrowing Himalayan blackberry (shrub with dark green foliage) in a black cottonwood and red alder stand on the Snoqualmie River in western Washington. Photo by S. Reutebuch, PNW.

relative to that in clearcuts, for a month and continued into June. On average, the number of germinants emerging was higher on disturbed than on undisturbed seedbeds. There was no clear difference in germinant appearance between forested and clearcut environments for either seed-bed type. A positive relationship between spring soil moisture conditions and germinant appearance was stronger in the clearcut environment than in the modified light and temperatures prevailing under forested conditions (Haeussler 1988).

Seedling establishment. The number of seeds required to produce a seedling one growing-season old differed dramatically between westside and eastside Coast Range environments (Haeussler and Tappeiner 1993). Under the drier conditions on the eastside of the Coast Range, no seedlings survived through the growing season in either of the years of study. On the north aspect of the westside coast site, 1 seedling was produced per 32 seeds sown; on an adjacent south aspect, 1 seedling was produced per 181 seeds (Haeussler 1988). In another study on a southwest-facing coastal site, sowings in each of two years on newly created mineral soil seedbeds at a rate of 1000 to 1500 seeds/m^2 failed to produce any surviving seedlings at the end of one growing season (J. Zasada, pers. comm. 1994). In a third study, sowing of alder seed on dry Coast Range sites similar to those studied by Haeussler (1988) resulted in germinants but no surviving seedlings after one growing season (J. Tappeiner and J. Zasada, pers. comm. 1994). These three studies suggest that alder establishment is not assured even when large quantities of seeds are sown on what are believed to be desirable seedbeds.

A number of environmental factors result in high mortality of seeds and seedlings between the time seeds arrive on the seedbeds and the end of the first growing season (Haeussler 1988), and these certainly contribute to the temporal and spatial variation in alder regeneration. In unprotected microsites, seedling emergence was 75 percent on disturbed seedbeds and 38 percent on undisturbed seedbeds on protected microsites. Loss of seeds to soil biota was greater under forest conditions than in clearcuts. On undisturbed and mineral soil microsites, 60 and 20 percent of the seed population were destroyed by soil organisms, respectively. Causes of seedling mortality included drought and heat injury, pathogens, animals, erosion, frost and smothering by organic debris. Drought and heat-related mortality were the major causes of mortality in clearcuts, whereas damping-off fungi and other pathogens were most important under forest conditions (Haeussler 1988).

Alder seeds are most commonly described as having little or no dormancy. This is based on studies which have shown that germination of stored seeds under optimum germination temperatures is not improved by stratification (Radwan and DeBell 1981, Berry and Torrey 1985); however, one provenance from British Columbia was reported as having a physiological dormancy that was released by stratification (Elliott and Taylor 1981a). Germination under sub-optimum temperatures, such as may prevail at the time of germination under field conditions, *is* enhanced by stratification (Tanaka et al. 1991). Based on germination of lots stored for several years, the need for stratification is not affected by storage but seed viability will decline over time.

Bormann (1983) and Haeussler (1988) demonstrated that alder seeds do not germinate in the dark and that the phytochrome system is very sensitive (i.e., germination is inhibited by exposure to far-red light). A field study by Haeussler (1988) strongly suggests that alder germination is controlled by light quality and that a type of light-enforced dormancy may prevent seeds from germinating when other conditions appear optimal; thus, a persistent alder seedbank may be present under some conditions. A buried seedbank is probably not important in alder because of the high seed mortality rate caused by soil organisms (Haeussler 1988); however, it can't be ruled out without study since seeds of some species of *Betula* remain viable in the soil for much longer than would be expected based on seedcoat structure and general seed germination characteristics (Granstrom 1982, Perala and Alm 1989).

Assuming that site conditions are suitable, red alder can initially be regenerated by any silvicultural system that provides moderate sunlight and exposed mineral soil. The species is an aggressive pioneer on avalanche paths, road cuts, log landings, skid trails, or other areas where mineral soil has been freshly exposed to seedfall. For example, shortly after a heavy thinning (removal of 50 percent of the basal area) in a 62-year-old Douglas-fir stand, an alder understory became established and grew rapidly (Berg and Doerksen 1975). Clearcutting and large-group selection are feasible regeneration systems. During harvesting or in a subsequent site preparation treatment, the site must be disturbed sufficiently to expose mineral soil. Fire probably can substitute for mechanical disturbance on most sites. To exclude red alder from the next rotation stand, some forest managers try to reduce the supply of alder seed by cutting possible alder seed trees in the vicinity before or at the time of final harvest; to avoid creating favorable seedbed conditions, they also disturb the site as little as possible during logging and, if feasible, do not burn the logging slash (Lousier and Bancroft 1990).

Artificial regeneration can be accomplished with either bare-root or containerized seedlings, and guidelines for producing planting stock are available (Berry and Torrey 1985, Radwan et al. 1992, Ahrens 1994). Survival and growth of planted seedlings are usually excellent (Radwan et al. 1992), but can vary significantly with slope, slope position, and aspect within a given clearcut. For example, Zasada (pers. comm. 1994) followed the fates of seedlings planted on different sites within a clearcut and observed nearly 100 percent survival on steep north aspects over a three-year period while immediately adjacent south-facing and stream bottom sites (with higher soil moisture stress and a higher probability of early season frosts, respectively) suffered as much as 60 percent mortality.

Height growth of red alder seedlings is generally rapid. 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) the second year (Smith 1968, Harrington and Curtis 1986). Maximum annual height growth of more than 3 m a year can be achieved by 2- to 5-year-old seedlings (Harrington and Curtis 1986).

Seasonal growth of red alder is under strong climatic control and consequently quite variable. The timing of radial growth is similar for red alder and its common associate Douglas-fir; in the Puget Sound area of Washington State, growth begins about mid-April and continues until mid-September (Reukema 1965). Substantial height growth (i.e., height growth other than that associated with initial bud break) begins slightly later in the season than radial growth. Red alder has indeterminate height growth; thus, height growth continues through the growing season until soil moisture, temperature, or light conditions become unfavorable (see DeBell and Giordano 1994). The specific environmental conditions that control root and shoot growth have not been determined.

Vegetative reproduction. Red alder sprouts vigorously from the stump when young. It can be repeatedly coppiced on short cycles but rootstock mortality increases with each harvest (Harrington and DeBell 1984). The likelihood of obtaining stump sprouts and the vigor of the sprouts are influenced by age, time of year, and cutting height (Harrington 1984a). Stumps sprout best when trees are cut in the winter and when stump height exceeds 10 cm. Older trees rarely sprout and coppice regeneration cannot be expected after pole-size or sawlog-size material is harvested (Harrington 1984a). Because of reduced vigor of sprouting, manual cutting of alder as a means of competition control in conifer plantations can be an effective vegetation management practice (DeBell and Turpin 1989); however, results from cuts at different times during the summer can be variable (Pendl and D'Anjou 1990).

Other vegetative methods of propagation that have been successfully used include: rooting greenwood cuttings from young trees (Monaco et al. 1980); rooting of cuttings of succulent new spring growth from shoots of young trees and epicormic sprouts from 30-year-old trees (Radwan et al. 1989), and rooting of sprouts propagated by mound layering (Wilson and Jewett, unpub. data, see Harrington et al. 1994 for a more complete description.).

Sapling and Pole Stages to Maturity

Growth and yield. Alder growth form is strongly excurrent during the period of rapid height growth. Crown form becomes moderately to strongly deliquescent as the trees mature. Growth of vegetative shoots is primarily monopodial (e.g., branching with the apical bud forming a persistent leader and new branches arising laterally below the apex, Swartz 1971); however, shoots producing flowers exhibit sympodial growth (e.g., the terminal bud withers and the main axis of branching is made up of a series of lateral branches, Swartz 1971).

Alder produces three types of branches: sylleptic (developed from a bud formed during the current year), proleptic (developed from a bud formed the previous year), and epicormic (developed from suppressed buds). Sylleptic branches are important in rapid development of leaf area but are short lived. Proleptic branches are persistent and form primarily from buds at the upper end of the height increment for the year; thus, the pattern of proleptic branches on the main stem can often serve as a rough method of determining past height increment. Epicormic branches are produced when suppressed buds are triggered to develop by injury or a change in plant environment. They are commonly seen after top breakage, a major increase in exposure (e.g., road construction, logging), or in response to injury (e.g., flooding, girdling). The physiological factors that determine the amount of apical control on branch growth and angle have not been studied for alder.

Growth of primary shoots of alder can be phototropic (i.e., differential elongation of cells resulting in growth toward light; Zimmerman and Brown 1971). Alder trees can exhibit substantial amounts of lean when grown in irregularly spaced stands or when located along roads, streams, stand boundaries, or other areas with unequal light distribution on all sides of the tree; the lean is probably caused primarily by greater crown development on the sunnier sides of the tree rather than by phototropism per se (DeBell and Giordano 1994). Other changes in stem form may occur as the result of heavy snow or if gravity causes all or part of the tree to shift abruptly (e.g., as a result of soil slumping or high winds when soils are saturated). If juvenile red alder is grown at wide and fairly even spacing, however, lean and sweep will be minimized (Bormann 1985, DeBell and Giordano 1994).

Red alder has rapid juvenile growth. Among its associates, only black cottonwood grows as much or more during the juvenile phase. On good sites, alder trees may be 9 m at age 5, 16 m at age 10, and 24 m at age 20. One tree was 9.8 m tall and 16.3 cm in dbh 5 years from seed (Smith 1968).

Growth slows after the juvenile stage, the decrease beginning much sooner on poor sites. Site index, as determined at base-age 20 years, ranges from 10 to 25 m (Harrington and Curtis 1986); at base age 50, it ranges from 18 to 37 m (Worthington et al. 1960). Associated conifers have much slower juvenile growth, but they sustain height growth years longer than alder. On an average upland site, both Douglas-fir and red alder can attain the same height at about age 45 (Williamson 1968). Beyond that age, Douglas-fir surpasses red alder in height. Because the two species have different site tolerances, their relative performances will be site-specific as well as age-specific (Deal 2005, Harrington and Courtin 1994).

Red alder is a relatively short-lived species, maturing at about 60 to 70 years; maximum age is usually about 100 years (Worthington et al. 1962). On favorable sites, trees can be 30 to 40 m tall and 55 to 75 cm in diameter. The American Forests Big Trees national champion red alder in Oregon measured 198 cm in dbh (www.odf.state.or.us; last updated Aug.25, 2004) and the largest red alder in Washington measured 158 cm in diameter (Van Pelt 1996), but trees over 90 cm in diameter are rare. In pure stands on good sites, it has been estimated that red alder can achieve mean annual cubic volume growth rates of 21 m^3/ha in pulpwood rotations of 10 to 12 years, and 14 m^3/ha in sawlog rotations of 30 to 32 years (DeBell et al. 1978). Most of the existing alder volume is in naturally regenerated mixed-species stands where growth and yield are variable. Several reports have indicated that maximum cubic volume in alder stands is about 500 m^3/ha at age 50 to 70 (DeBell et al. 1978, Worthington et al. 1960, Chambers 1983); however, volumes of 700 m^3/ha and even 1000 m^3/ha have been measured on small inventory plots in fully stocked natural stands 70 years or older in the Queen Charlotte Islands or islands in the Johnston Straits (N. Hughes, pers. comm. 2005). These extremely high volumes are very unusual and may not be possible on larger areas.

Rooting habit. Red alder forms extensive, fibrous root systems. Root system distribution is primarily controlled by soil drainage, soil structure, and compaction. In poorly drained soils, most rooting is surface-oriented, and rooting is often prolific in the boundary between the lower organic layer and the uppermost mineral horizon. In wet soils, the uppermost mineral horizon usually is rooted heavily, as is the lower part of the surface organic layer if it is thick enough. On well-drained sites, root distribution is strongly influenced by water availability; increased rooting is common at horizon boundaries where changes in soil texture slow downward water movement through the profile. Because rooting also follows the path of least resistance, it is greater in old root channels or, especially if the soil is compacted and soil structure well developed, between units of soil structure. Root system extent is a function of soil characteristics and tree size. Smith (1964) showed tree diameter and average root length to be significantly correlated; larger trees also tended to have deeper roots than smaller trees.

Red alder, especially when young, forms adventitious roots when flooded. In a greenhouse study, alder seedlings previously growing under well-drained conditions produced adventitious roots when the soil was saturated (Harrington 1987). These roots emerged at or near the root collar and grew on top of the saturated soil surface; when the soil was drained, the root exteriors suberized and many of the longer roots turned downward into the soil where they continued to grow. Minore (1968) also reported formation of adventitious roots when seedlings in pots were flooded, noting that seedlings that did not form adventitious roots did not survive. Although it has not been documented, formation of adventitious roots may be an important adaptive trait on floodplain sites.

The sensitivity of red alder root growth to environmental conditions is not well known, but recent studies provide some information (also see Shainsky et al. 1994). Under soil moisture stress, red alder saplings shifted carbon allocation from leaf and stem biomass to root biomass (Chan 1990). In a companion study, root biomass decreased with increasing density of alder stems (Shainsky et al. 1992). Ratios of root to shoot were significantly affected by stand density; however, most of the variation in root biomass was directly attributable to variation in shoot biomass. When grown in pots in a growth chamber, these ratios were decreased by fertilization and were lower in sandy soil than in loam or sandy loam (Elliott and Taylor 1981b).

Red alder roots are commonly ectomycorrhizal, although only a few species of fungi form ectomycorrhizal associations with alder. Fungal symbionts include alder-specific fungi and fungi capable of mycorrhizal associations with other hosts (Molina 1979, Molina et al. 1994).

Red alder also has root nodules that fix atmospheric nitrogen (fig. 6). The nodules are a symbiotic association between the tree and an actinomycete *(Frankia* spp.). In natural stands nodulation occurs soon after seed germination; root systems of seedlings a few months old commonly have dozens of visible nodules. Nodule sizes on young trees range from the size of a pinhead up to 25 mm in diameter. Mature trees have nodules on both the large woody roots and the smaller new roots. The large compound nodules found mature trees can be 80 or 90 mm in diameter. Rates of nitrogen fixation and the effects of these nitrogen additions on soil chemistry have been discussed by others (Binkley et al 1994, Bormann et al. 1994).

Reaction to competition. Red alder requires more light than any of its tree associates except black cottonwood and is classed as intolerant of shade (Minore 1979). Light quality has been shown to be important in germination (Bormann 1983, Haeussler 1988); however, its role in seedling development has not been documented. Young seedlings can withstand partial shade for a few years but will grow very little; if not released, they will die. The only trees that survive are those that maintain dominant or codominant crown positions. Self-thinning or mortality caused by competition is rapid in red alder stands; densities in natural stands may be as high as 124,000 seedlings/ha at age 5 (DeBell 1972) and fully stocked stands at age 20 averaged 1665 trees/ha (Worthington et al. 1960).

Red alder also self-prunes extremely well when grown in dense stands. Shaded lower branches rapidly die and fall off, resulting in clear and slightly tapered boles. Live crown ratios in crowded, pure stands are very low, and narrow, domelike crowns are characteristic. As would be expected for a shade-intolerant species, branch retention and crown shape are strongly related to light levels in the canopy. Trees grown at low densities develop large lower branches (c.f., fig. 7) that live longer and take much longer to decay after death than do branches that develop under higher stand densities.

Early control of spacing is necessary to keep live crown ratios high enough to maintain good growth beyond the juvenile phase. Sawlog yields might be maximized on short rotations by combining early spacing control with pulpwood thinnings (DeBell et al. 1978). Thinnings in previously unthinned stands are most effective in stimulating growth of residual trees if done before height growth slows—about age 15 to 20 (Warrack 1949, Olson et al. 1967, Smith 1978). Thinning in older stands can salvage mortality and help maintain the vigor of residual trees, but usually does not accelerate diameter growth (Lloyd 1955, Warrack 1964).

Epicormic branching has been reported after thinning, especially when thinning has been late or drastic (Warrack 1964, Smith 1978). If epicormic sprouting occurs after thinning, it is most common on the south or west side of stressed trees; however, trees drastically opened up (e.g., via clearcutting or construction activities) may have epicormic branches on any or all sides. Epicormic branches appearing after early thinning may be ephemeral, but this has not been documented and is likely to dependent on stand density. Epicormic branches were reported after pruning 21-year-old trees (Berntsen 1961), but those trees were heavily thinned and overstory conifers had been girdled at the same time as pruning (H. Rapraeger, 1949 report on thinning and pruning alder at Cascade Head Experimental Forest, on file at Olympia Forestry Sciences Laboratory) so it was not possible to separate the effects of pruning on epicormic branches from those of the other cultural practices. Very few epicormic branches developed after pruning of young trees (Brodie and Harrington 2006).

Red alder can be managed in pure stands or as part of a mixture with other intolerant species, such as Douglas-fir and black cottonwood (or *Populus* hybrids), or with more shade-tolerant species, such as western redcedar, western hemlock, or Sitka spruce. Knowledge of site-specific growth rates and relative shade tolerances of each component in a mixture is critical to achieving the potential benefits from mixed stands. Alder must be kept in the upper canopy to survive in mixed stands. Even if alder is shaded out in a mixed stand, however, it may make substantial contributions to soil nitrogen prior to that time (Berg and Doerksen 1975, Tarrant and Miller 1963). The benefit of alder to the other species is dependent on site conditions as well as the relative density of the tree species (Courtin and Brown 2001, Deal el al. 2004, Miller 2005, Miller and Murray 1978, Miller et al. 1993, Miller et al. 1999). The proportion of alder and Douglas-fir in mixed plantations has been shown to influence the stem quality of both species (Grotta et al. 2004). In addition, the richness of shrubs, ferns, herbs, and mosses in mixed-species stands is increased over that found in conifer stands (Deal 1997).

Reaction of alder to competition is influenced by many factors including the size, species composition, and density of the competing vegetation (other alder stems, non-alder stems in the upper canopy, and plants in the understory) as well as soil and site factors. For example, growth of closely spaced, dominant alder was decreased with increasing density of subordinate Douglas-fir (Shainsky and Radosevich 1991, Shainsky et al. 1994). Rectangularity of spacing also influences growth and development of alder (DeBell and Harrington 2002).

Damaging Agents

There are relatively few instances where damaging agents kill enough red alder trees to result in large openings in a natural stand. Frost pockets or unseasonable heavy frosts may be an exception. Forest managers may also be concerned, however, at lower levels of mortality, when growth rates are depressed, or tree form or wood quality is affected. In addition, problems will likely increase as management is intensified, particularly in nurseries and plantations.

Leaf and Stem Fungi. Red alder is fairly free from most disease problems, especially when young and uninjured (Worthington et al. 1962, Hepting 1971). Many species of fungi have been reported growing in association with alder (Lowe 1969, Shaw 1973, Farr et al. 1989), but few have been shown to cause ecologically or economically important levels of damage in natural stands. *Nectria distissima* can be a serious bark canker in young stands (Fig. 8) and *Cytospora* spp. can develop following sunscald or winter damage (W. Littke, pers. comm. 2005). Several other canker-causing stem diseases—*Didymosphaeria oregonensis, Hymenochaete agglutinans* and *Botytis cinerea*—cause some damage but overall their impact is slight. Nonetheless, the potential exists for more damaging levels of disease should conditions occur that favor their rapid development and spread. For example, naturally occurring weak pathogens have been used as biocontrol agents for juvenile red alder (i.e., to kill unwanted alder) (Dorworth 1995), thus, indicating their ability to cause mortality under certain conditions.

The primary disease of concern in nursery production is *Septoria alnifolia,* a disease that causes leaf spots and stem cankers (some experts believe that *Septoria alnifolia* only causes a leaf spot and another species or another stage of the same species with a separate name is responsible for the canker). Although some infected seedlings grow over stem cankers caused by *S. alnifolia* (see note above), on other seedlings the cankers result in top dieback, stem breakage, reduced growth, or mortality. Thus, infected nursery stock should be graded out as cull (i.e., discarded). This disease can be controlled with monthly applications of Benlate® (a fungicide) and by locating alder nursery beds in areas not adjacent to alder stands (W. Littke, pers. com. 1992).

Fungi diseases of alder catkins *(Taphrina occidentalis* and *T. alni)* cause enlargements of the bracts of female catkins (Mix 1949), which prevent or hinder normal fertilization and seed development. Although currently these fungi are not important economically, they could become so if alder seed orchards or seed production areas were established.

Compared with other hardwood species, living red alder trees have very little decay. In a study on Vancouver Island, Allen (1993a) examined 383 alder trees ranging from 20 to 120 years old. Decay losses of merchantable volume were less than 4 percent in all trees sampled. The incidence of decay (number of decay columns per tree) was not correlated with age in the Vancouver Island study and thus, susceptibility to decay in older trees does not appear to be as severe as suggested in previous reports (Johnson et al. 1926, Worthington 1957).

Much of the decay present in living alder results from injury to standing trees due to broken tops and branches, or scars from falling trees (Allen 1993a). Once trees are injured, decay organisms gain entry through the damaged tissue. Alder, however, is very efficient in its ability to compartmentalize decay, and most decay events do not spread much beyond the injured tissue. For example, the dead tissue of stubs formed from self-pruned branches was colonized by fungi and sometimes developed into a decay column in the main stem. Most branch stubs, however, were overgrown by healthy wood with no further decay development (see additional information on this topic in DeBell et al. 2006). In general, individual decay columns were not large, with a median volume of 0.0024 m^3.

The wood of red alder is a light, creamy-white color prior to exposure. Once trees are cut or the wood is exposed by breakage, the exposed wood develops a reddish orange or reddish brown stain. This stain is the basis for the species name (*rubra* meaning red). It is not known definitively what causes the color change but a compound, oregonin (a diarylheptanoid xyloside) was extracted from alder bark and demonstrated potential for stain development in the presence of peroxidase and hydrogen peroxide; i.e., the stain appears to be the result of oxidation but its exact mechanism is not known (Karchesy 1974). In addition, a more intense red stain can develop in response to fungal infection by *Ceratosystis picea* (a vascular wilt fungus) (Morrell 1987). Fungal spores land on freshly exposed surfaces of alder logs, germinate and grow into the wood, and the response of the living cells is an intense red stain (Allen 1993b). The rate of stain development is influenced by season of harvest and conditions after harvest (Allen 1993b). Wood producers use several techniques to reduce the stains due to both oxidation and those due to fungal infection; in addition, new techniques are being evaluated to determine their efficacy to reduce stain development in logs and sawn wood products.

A number of decay fungi have been isolated from living alder trees in British Columbia, including *Heterobasidion annosum, Sistrotrema brinkmannii, Pholiota adiposa, Trametes* sp., and *Meruliopsis corium*. From a log buyer's standpoint, "redheart" and "black knot" are common defects but multiple fungal species could be associated with these general terms; one species that causes red heart rot in alder is *Stereum sanguinolentum* (Omdal, pers comm. 2005). A previous report suggested that white heart rot, caused by *Phellinus* (syn. *Fomes) igniarius,* is the most destructive disease of living alder trees (Worthington 1957). This statement seems to have originated from Johnson et al. (1926), who made a similar claim that was unsupported by data or reference citation. *Phellinus igniarius* has been found only rarely on living alder in British Columbia, although the pathogen may be more common in other parts of the alder range. As indicated above, these decay fungi do not appear to result in serious losses in most living trees.

Wood stain and decay proceed rapidly in cut alder trees. Losses due to stain resulting from fungal infection that occurs during the time *between* harvesting and milling are much greater than losses from decay in living trees (Allen 1993a). For this reason, logs should be processed as soon as possible after harvest, particularly in warm summer months. The development of stain and decay is retarded in winter months and in logs stored in fresh water (Worthington 1957).

In the past, some foresters have suggested that red alder would have to be managed on short rotations due to increasing disease problems with age (so-called pathological rotations) or that thinning and pruning were risky due to the increased probability of inducing stem damage; based on our current information on alder's ability to compartmentalize decay, these suggestions appear unwarranted. During intermediate cuts, however, care should be taken to avoid injuring residual trees. There are good reasons for short rotations, such as the species' growth pattern with age and economics; however, sensitivity to decay does not appear to be a reason to suggest short rotations.

Root rots. The root rot pathogen *Heterobasidion annosum* has been observed growing on alder in mixed-species stands in which both alder and conifers were present (Allen 1993a). Since the fungus infects both hardwoods and softwoods, it is possible that alder could become infected when planted on sites previously occupied by infected conifers. In addition, infected alder could serve as an inoculum source for subsequently planted conifers. Thus, preharvest surveys for root-rot fungi should be considered for sites where alder is a possible species to manage as well as on sites where conversion from alder to other species is being considered.

Red alder is subject to root rot by *Armillaria mellea* but it is not considered to be a major disease (Hepting 1971).

All hardwoods are immune to *Phellinus weirii* (a widespread conifer root rot) and red alder occurs naturally and has been planted on sites where *P. weirii* infection levels are high. The absence of susceptible species will eventually "starve-out" the fungus as suitable substrates decay and are not replaced. It has been hypothesized that red alder alters the soil environment to the detriment of *P. weirii* by enhancing the growth of microbes (e.g., *Trichoderma)* antagonistic to the pathogen (Nelson et al. 1978) and/or by inhibiting the growth of the fungus (Li et al. 1969, 1972; Hansen 1979).

Many foresters, following the suggestion that alder may serve as a biological control agent for *Phellinus weirii* (Trappe 1972, Nelson et al. 1978), have recommended planting alder as a root-rot control measure. This may have contributed to increased planting of red alder on some lands, but the interactions between red alder and *P. weirii* are not fully understood and therefore caution should be exercised in making management decisions. For example, Hansen (1979) observed vigorous and extensive development of *P. weirii* ectotrophic mycelium on infected roots of very large, old-growth Douglas-fir stumps in a 20-year-old alder stand that established following logging of the Douglas-fir. He concluded that red alder apparently "does not shorten the time required to reduce the inoculum."

Long-term trials are underway to quantify the long-term effects of alder stands on *Phellinus weirii*. At this time all I can say is that alder should be considered as one of several immune species to plant on sites with high levels of *P. weirii*. Foresters planting red alder on sites with high levels of *P. weirii* inoculum that are considered poor or unsuitable sites for alder should expect alder growth to be poor and problems with damaging agents to increase.

Insects. Numerous insects have been reported feeding on or associated with red alder (Furniss and Carolin 1977, Gara and Jaeck 1978, Dolan 1984). Insect pests are not usually a major concern, but serious outbreaks of some defoliators can cause growth reductions. The forest tent caterpillar *(Malacosoma disstria),* western tent caterpillar *(M. californicum),* alder woolly sawfly *(Eriocampa ovata),* striped alder sawfly *(Hemichroa crocea),* the alder flea beetle *(Altica ambiens),* and a leaf beetle *(Pyrrhalta punctipennis)* have caused substantial damage, but reports of mortality are rare (Worthington et al. 1962, Furniss and Carolin 1977, Briggs et al. 1978). Mortality, however, has been observed when tent caterpillar outbreaks overlapped drought periods (Russell 1991, K. Ripley pers. com. 2005) and the mortality from the combined stresses was probably substantially greater than would have occurred if only one stress had been present.

A flatheaded wood borer *(Agrilus burkei)* can kill twigs and branches (Furniss and Carolin 1977, Briggs et al. 1978). The alder leaf miner, *Lithocolletis alnicolella,* can cause necrotic spots up to 30 mm in diameter on leaves but does not apparently affect growth (W. Littke, pers. com. 1992). An epidemic of grasshoppers was reported to only slow growth slightly (Russell 1986). The fall webworm *(Hyphantria cunea)* skeletonizes or consumes leaf blades, but its damage is usually minor (Furniss and Carolin 1977). The alder bark beetle *(Alniphagus aspericollis)* breeds primarily in slash and in young stressed trees; however, healthy trees can be attacked when bark beetle populations are high (Gara and Jaeck 1978).

The alder aphid *(Pterocaulis alni)* feeds on tender shoots (Furniss and Carolin 1977) and on foliage with high nitrogen content (Dolan 1984). Aphids are common associates in many young alder stands and generally are not considered to cause much damage, although severe aphid epidemics have been reported in young alder plantations planted on droughty soils (Dolan 1984, DeBell pers. comm. 2005).

Ambrosia beetles *(Gnathotrichus retusus, Trypodendron lineatum, Xyleborus saxeseni)* attack logs and slash left on the ground, thus, log quality can rapidly degrade. Insect holes can also serve as entry sites for fungi. Merchantable material should be removed rapidly, and large accumulations of slash should be avoided.

Animals. In general, animals cause only minor damage in alder stands; however, under some circumstances animal damage can be significant. Alder is not a highly preferred browse species for black-tailed deer *(Odocoileus hemionus columbianus)* or Roosevelt elk *(Cervus elaphus roosevelti)* during most of the year. Young trees are occasionally browsed by deer and elk, especially during the late summer and fall (Brown 1961), and browsing begins earlier in the summer when weather conditions are dry or when other food sources are not available.

Abscising or freshly abscised leaves were documented as being a major component of deer and elk diets in old-growth forests on the Olympic Peninsula (Leslie et al. 1984) and penned black-tailed deer have been observed eating freshly abscised alder leaves in the fall when other food sources were available (D. L. Campbell, pers. com. 1992). Seasonal changes in deer and elk browsing may be related to changes in foliar chemical composition; alder foliage in the fall is higher in crude fat content and lower in total phenols than during the summer (Radwan et al. 1978). Elk repeatedly browsed red alder planted on a debris flow associated with the 1981 eruption of Mt. St. Helens

(Russell 1986) when alternative food sources were limited. Most browsed trees resprouted vigorously and very little mortality was associated with the heavy browse damage; however, the repeated browsing resulted in trees with shrub-like forms.

Deer and elk can cause stem deformation, reduce growth, and provide entry sites for decay organisms when they rub their antlers against tree trunks; in localized pockets this type of damage can be common. In a young spacing trial near Centralia, Washington, the incidence of stem rubbing was greatest in the narrowest spacings, presumably because the closer spacings had higher rates of branch mortality that resulted in easier access to the main stems. Others, however, have observed greater damage in wide spacings (Newton and Cole 1994). The relationship between spacing and damage may change with age or other factors. Deer and elk occasionally strip and eat alder bark, especially during winter and spring.

Mountain beaver *(Aplodontia rufa)* clip small alder stems and branches; only the bark is eaten from stems 5 to 20 mm in diameter while smaller pieces are consumed whole (D. L. Campbell, pers. com. 1992). Although mountain beaver only clip small-diameter pieces, they climb trees and can continue to clip branches and terminals as trees increase in size. In an artificial feeding trial in which several plant species were made available at the same time, mountain beaver consistently selected alder stems all months of the year (data on file, USDA APHIS Animal Damage Research Unit, Olympia, Washington). Thus, alder appears to be a regular item in mountain beaver diets and problems in stand establishment should be anticipated on sites with established mountain beaver populations (D. L. Campbell, pers. com. 1992). Mountain beaver use of alder *foliage* for food is minor except when other food sources are not available or in late September when use is fairly heavy (Voth 1968).

Observations of other animals damaging red alder are limited. Beaver *(Castor canadensis)* will cut any species of tree near their ponds to support their construction activities. As a food source, beaver prefer red alder over Douglas-fir, but other plants are selected before alder if they are equally available (D. L. Campbell, pers. com. 1992). In years of high populations, meadow mice *(Microtus sp.)* girdle young stems; this type of damage has been most commonly observed in grassy or very wet areas. Deer mice *(Peromyscus maniculatus)* eat alder seed from the surface of snowpacks when other food is difficult to obtain (Moore 1949); however, alder seed is not usually a preferred food source. Individual trees can be heavily damaged (fig. 9) by red-breasted sapsuckers *(Sphyrapicus ruber);* if the damage encircles all or most of the stem, the top may break off during periods of wind or snow. Ring shake can create a serious problem of log quality in some stands. The causes of ring shake in alder are not known but it has been linked to sapsucker damage in eastern species (Baumgrass et al. 2000, Shigo 1963).

Extremes in physical factors. Extremes in temperature, wind, or fire can damage red alder. Mortality and top damage have been documented in natural stands after ice storms or unseasonable frosts (Duffield 1956, Worthington et al. 1962). Widespread cold damage (terminal dieback and mortality) has been observed in bare-root nurseries in several years after unseasonably cold frost events in October and early November. Frost protection in nursery beds via watering is effective in preventing damage and the stems that bend over with the ice resulting from watering usually recover well (N. Khadduri, pers. com. 2005). Recently planted trees are also susceptible to cold damage; late spring frosts and early fall frosts have caused top dieback and mortality (DeBell and Wilson 1978, Peeler and DeBell 1987). When grown at a common location, alder sources from northerly locations or higher elevations set bud and became cold tolerant earlier in the fall than sources from more southerly locations or lower elevations (Cannell et al. 1987, Ager and Stettler 1994); geographic variation in spring budbreak and frost hardiness were more complex. Variation in budbreak has been predicted from growing season thermal sums (Ager 1987, Ager and Stettler 1994). The winter dormancy requirement for red alder has not been studied, however, and the causal factors controlling timing of spring budbreak are not known. Presumably, once chilling requirements (if any exist) are met or day length is permissive, budbreak is temperature dependent. This assumption is consistent with the observation of Peeler and DeBell (1987) that cold damage occurred when late frosts followed a period of warmer-than-normal temperature.

Other temperature-related problems observed on alder are sunscald and frost cracks. As is generally true for other species, this type of damage is most common on the south and west side of exposed trees and both sunscald and frost cracks occur during the winter. As noted above, stem cankers may develop after this type of damage.

Fire is rarely a damaging agent because of the scarcity of flammable debris in alder stands; in fact, the species has been planted as a firebreak to protect adjacent conifers (Worthington et al. 1962). Alder bark is thin but sufficiently fire-resistant to prevent damage during light surface fires (Worthington 1957). Alder stands are also likely to be somewhat more fire resistant than most conifer stands because many alder stands are in riparian areas or on generally moister microsites.

Windthrow is not common in alder because of the intermingling of roots and branches, the absence of leaves during winter storms when soils can be waterlogged, and the relatively deep-rooting habit of the species on well-drained soils. Uprooted trees are most commonly observed along cutting boundaries or where flooding or erosion has undercut established root systems. High winds, heavy snow, and ice storms will break alder tops and branches, but these problems are generally less for alder than for associated species that are foliated during the winter. Exposed windy

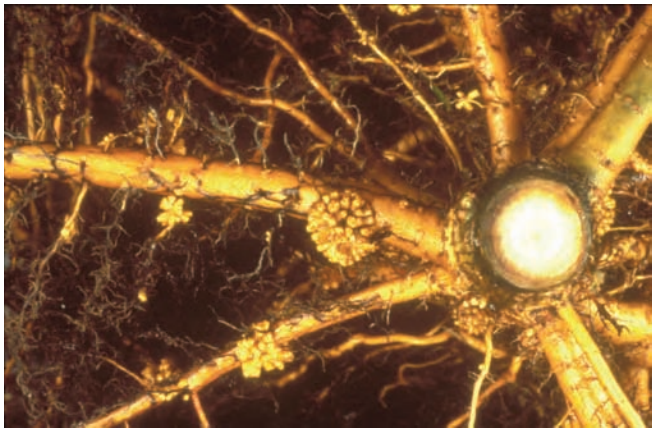


Figure 6—(above) Nitrogen-fixing nodules on the root system of a red alder seedling. Photo by J. Kraft, PNW.

Figure 8—(right–top) *Nectria distissima* can cause cankers on young alder. Photo by W. Littke, Weyerhaeuser Company.

Figure 9—(right–bottom) Red-breasted sapsuckers can cause substantial damage to individual alder stems. This tree near Olympia, WA was repeatedly damaged by sapsuckers several years after it was pruned.

Figure 7—(below) Alder trees grown at low density, such as this tree near Cape Disappointment, WA, will develop large-diameter branches that do not die or abscise quickly. Note the difference in stem form, branching and bark color between this tree and those shown in figs. 2 and 4.

sites, however, such as those near the ocean or mountain passes, have top breakage and reductions in height growth consistently enough to reduce site index (Harrington 1986). Top breakage due to snow, ice, or wind can be a serious problem under some conditions. For example, young trees re-spaced from high to lower densities can be very susceptible to breakage after thinning (P. Courtin, pers. comm. 2005). This occurs because the lower crown ratios that resulted from the higher density growing environment result in a small stem diameter at the base of the live crown and the thinning changes wind sway (or snow or ice loading) from a whole-stand phenomenon to one where individual trees primarily sway or flex with the base of the live crown as the pivot point. Damage is particularly severe if wet snow or ice occur in the late fall when the foliage is still on the branches.

Red alder has evolved to survive in climates with low summer rainfall. The greater stomatal control of red alder as compared to black cottonwood (Harrington 1987) is probably a key feature that allows the species to grow on upland sites. In general, however, red alder is probably not as drought tolerant as most of its coniferous associates (Shainsky et al. 1994).

During the summer of 1987, rainfall in the Puget Sound area of Washington was less than one-third of normal; for red alder this resulted in widespread leaf yellowing and premature abscission, terminal dieback, and, on droughty sites or new plantings, mortality (Russell 1991). Prior to 1987, the Puget Sound area experienced several decades without back-to-back dry summers and many years of above-normal rainfall. Combining these weather patterns with high levels of harvesting activity that created seedbed conditions favorable to alder establishment may have increased the percentage of alder stands growing on drought-sensitive sites (K. Russell, pers. com. 1992). Every summer (1 June to 30 September) from 1987 through 1992, the Puget Sound region had below-normal precipitation. Thus trees stressed by the extreme drought in 1987 may have been further stressed in subsequent years; presumably these back-to-back dry summers are one of the causes of the wide-spread instances of alder top dieback and mortality in the Puget Sound region in the late 1980s and early 1990s (K. Russell, pers. com. 1992).

The sensitivity of red alder to stress factors other than those discussed above is not documented. Alder is found on sites close to the ocean and presumably is fairly tolerant of salt spray. Alder has also been observed adjacent to pulp mills and other industrial plants and thus exhibits tolerance for at least some components of air pollution.

Future Research Needs

More than 25 years ago Minore (1979) commented on the surprising lack of information on autecological characteristics of red alder. Although available information has increased since then, much of our knowledge of the biology of red alder is still based on casual or short-term observations and not on detailed life histories or controlled experiments. Additional research on the biology and ecology of red alder is warranted to provide a firm knowledge base from which to make management recommendations. Specific topics of interest include the physiological or ecological factors that control: (1) forest succession, (2) alder seed production, dispersal and germination, (3) spatial distribution, timing of, and interrelationships between root and shoot growth, (4) tree responses to changes in light, nutrients, moisture, or temperature regimes, and (5) the occurrence and significance of biotic damaging agents.

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Red Alder Stand Development and Dynamics

Robert L. Deal[1]

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 difficulty for 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 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.

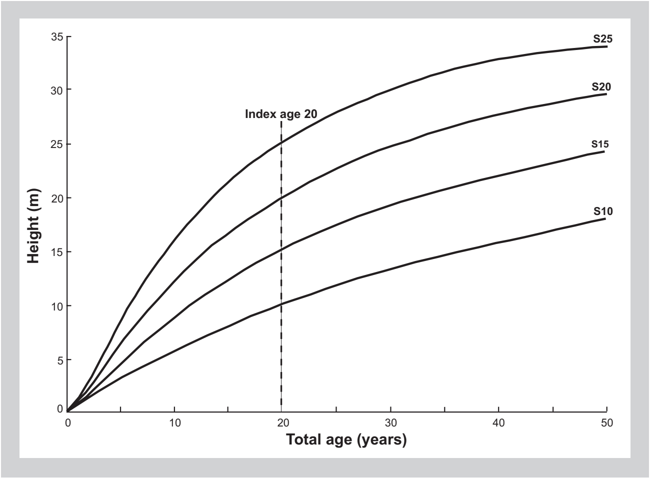

Figure 1—Red alder height-growth curves based on a 20-year site base age (Figure modified from Harrington and Curtis, 1986).

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 from 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-

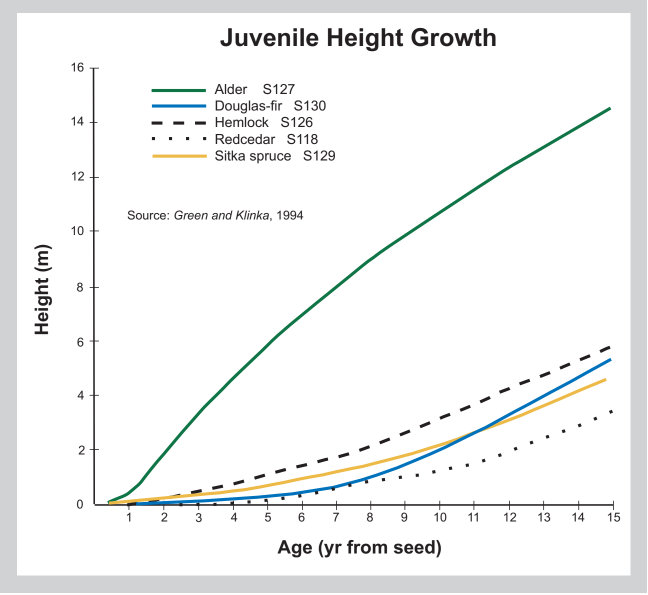

Figure 4—Comparison of juvenile height growth of red alder and associated conifers to age 15. Height curves are based on median values for conifers on Site Class II (King 1966). (Figure modified from Green and Klinka 1994).

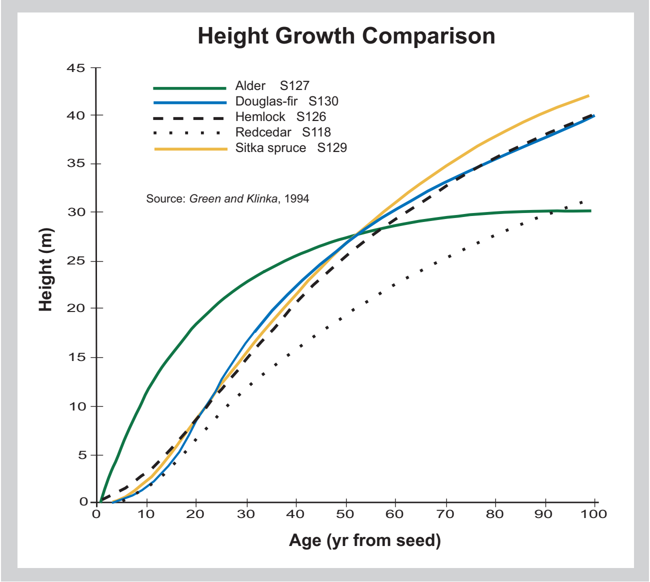

Figure 5—Comparison of height growth of red alder and associated conifers to age 100. Height curves are based on median values for conifers on Site Class II (King 1966). (Figure modified from Green and Klinka 1994).

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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The Value of Red Alder as an Integrated Pest Management Tool For Controlling Weevil Damage to Sitka Spruce

Lyle Almond[2]

Abstract

Among the numerous benefits they provide, mixed-species forests are often extolled for their greater resilience than monocultures to disease and insect outbreaks. Evidence of this resistance mechanism was investigated by observing variation in the intensity of leader damage inflicted by spruce weevils (*Pissodes strobi* [Peck] [Coleoptera: Curculionidae]) on Sitka spruce (*Picea sitchensis* [Bong.] Carr.) terminals under a broad gradient of canopy closure densities in stratified mixtures of red alder (*Alnus rubra* Bong.) and Sitka spruce. Analysis using all tree species failed to reveal a substantial correlation between weevil damage and canopy closure, but a very high level of association emerged when all tree species except red alder were removed from the regression model. Further analysis of the whiplash damage that upper stratum red alder imposes on Sitka spruce terminals attempting to emerge into the upper canopy resulted in predictably greater incidence of terminal damage at higher densities of red alder crown closure. As an attempt to address these two inextricably linked concerns, the hypothesis of this research analysis is that, at some ideal spacing of overstory red alder, a balance can be achieved whereby minimally acceptable levels of weevil damage occur without drastically suppressing leader growth. Superimposed linear trends of increasing whiplash damage and decreasing weevil infestation intersected at a red alder canopy closure value of 88% closure. This observational study of pest-host interactions under a broad range of canopy densities establishes an optimal range of threshold values for managing canopy closure that could be useful in managing mixed stands of red alder and Sitka spruce for better commodity production and ecosystem diversity.

Keywords: integrated pest management, Sitka spruce, *Alnus rubra,* red alder, spruce weevil, mixed-species silviculture.

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Introduction

Sitka spruce (*Picea sitchensis* [Bong.] Carr.) is a vital component of the Pacific Northwest's temperate rain forest, set in a unique coastal maritime zone with growing conditions which maintain such high rates of productivity by Sitka spruce that it reaches the largest size of any spruce on Earth, making it the fourth tallest tree in the world (Van Pelt 2001).

Sitka spruce and its primary pest, the spruce-tip weevil (*Pissodes strobi* [Peck] [Coleoptera: Curculionidae]), have successfully coexisted over millennia. Since the advent of single-species plantation management in the 20th century, the spruce-tip weevil population has exploded to epidemic proportions, reaching such levels of infestation that regeneration commitments have begun shifting away from Sitka spruce production altogether. However, avoidance cannot be considered an integrated pest management approach, especially when the tree species in question is as densely distributed and as ecologically and economically valuable as Sitka spruce.

An integrated pest management (IPM) approach is necessary to allow the continued use of Sitka spruce for reforestation and to protect those stands already established, but prone to continued damage from weevil attack. With the possible exception of avoidance, the range of available control options has met with limited success and lacks sufficient coordination. At present, few, if any, practical options are available to minimize weevil damage in susceptible stands. Avoidance of planting spruce obviously works, but at the expense of encouraging lesser valued trees on prime spruce sites. While a successful IPM system should be predicated on studying the biology, population dynamics, genetics, and impacts of the weevil and its host, the overall objective of all lines of research should be to develop forest management practices that will produce and maintain productive forest stands on the riparian floodplain and terrace sites that have proven to be most ecologically suited for Sitka spruce.

The resurgence of heightened research interest in the ecology and silviculture of mixed-species forest communities has recognized, among numerous benefits they provide, that forest mixtures often exhibit greater resistance than monocultures to disease and insect outbreaks (Kelty 1992, Perry 1994, Smith et al. 1997). Evidence of this resistance mechanism is exemplified by natural stands of even-aged red alder (*Alnus rubra* Bong.) and Sitka spruce, a stratified mixture commonly found growing in the riparian floodplains of coastal river systems in the Pacific Northwest. Under the expansive canopies of mature red alder growing along river bottoms and streambanks, shade-tolerant Sitka spruce trees are generally observed to be virtually free of weevil damage. The use of deciduous overstory trees, principally red alder, in mixture with Sitka spruce in the understory could have great value in an integrated pest management program to deter spruce-tip weevil invasion. Initial research trials in British Columbia in a shade versus no-shade study design have shown encouraging evidence that the shade provided by red alders overtopping spruce trees in a nurse-tree shelterwood system can significantly reduce weevil damage. (McLean 1989). This research analysis elaborates upon those findings by investigating the response in spruce-tip weevil damage intensity to a wide range of red alder overstory shade levels.

Dense overstory canopies of red alder may substantially reduce levels of weevil infestation, yet those same canopies may also impose barriers impeding the growth rate of terminal development as spruce trees attempt to emerge through the red alder canopy. Whiplash damage to Sitka spruce terminals abraded by red alder branches breaks down epinastic control, causing primary meristem development of the terminal bud to produce several small shoots that each attempt to assume apical dominance. This results in arrested height growth, unduly extending the rotation period or allowing other tree species to outcompete spruce trees. Whiplashed spruce trees that do emerge above the red alder canopy expose this cluster of terminal shoots to the risk of multiple weevil attacks.

This research investigation was partially intended to construct a predictive tool as a means to assist forest managers in selectively cultivating a red alder canopy as an integrated pest management approach in protecting Sitka spruce from weevil attacks.

The primary research goal in this research study was to determine what optimal level of red alder canopy closure will produce the greatest reduction in weevil attack without overly suppressing growth of Sitka spruce due to whiplash damage. By using a regression model approach, this research investigation also provided a look at the sensitivity with which changes in the level of spruce weevil activity might correspond with differences in the level of overstory canopy closure.

Weevils respond directly to changes in the level of ambient air temperature, not to canopy closure *per se*, preferring to oviposit at high temperatures. Although weevils will oviposit after emerging from hibernation and before consistently warm weather, they do not do so readily until temperatures above 60°F become common in British Columbia (Silver 1968). In southwestern Washington, egg-laying activity commenced at approximately 75°F and peaked at 90° F (Gara et al. 1971). The air temperature for maximum oviposition in the field was 84.9°F (Overhulser 1973). Maximum rates of oviposition have also been recorded to occur between 50.5° to 79.3°F (Holsten 1977). McMullen (1976) demonstrated that the accumulated heat required for brood development on Vancouver Island, from egg to emergence, is at least 888-degree days above 45°F (Holsten 1977). Oviposition most commonly occurs only at bark temperatures between 77°F and 84°F associated with

20% to 35% relative humidity (Beleyea and Sullivan 1956, Gara et al. 1980).

In conditions where heat accumulation is insufficient for completion of larval development, a Sitka spruce stand cannot sustain viable weevil populations (Holsten 1977). Regulation of understory microclimate temperature is clearly a determining factor in the success of any silvicultural approach to arrest spruce weevil damage.

Methodology and Research Models

Do increasing levels of red alder canopy closure influence the level of spruce weevil damage to Sitka spruce growing in the understory? If so, is red alder the only tree capable of producing this nurse-tree function? Is there some ideal level of canopy closure that can optimize reductions in the hazard of weevil damage as well as the whiplash damage that these canopies may also inflict on developing spruce terminals? To answer these questions, a set of hypotheses was formulated:

Research hypothesis 1: Sitka spruce weevil damage diminishes under canopies of red alder and continues to decrease along a gradient sensitive to the increasing density of canopy closure.

Research hypothesis 2: reductions in spruce weevil damage are uniquely associated with the presence of a red alder canopy in the overstory; the overstory presence of other coniferous canopies has no significant effect on the intensity of spruce weevil damage.

Research hypothesis 3: at some ideal spacing of overstory red alder, a balance can be achieved whereby minimally acceptable levels of weevil damage occur without drastically suppressing leader growth.

Field data collection

Twenty circular quarter-acre plots were established in a 59-acre stand at Merrill and Ring's Pysht Tree Farm located on the north coast of the Olympic Peninsula in western Washington. The stand was planted in 1986 with Sitka spruce. During the intervening years, red alder seeded naturally and became a vigorous component in the stand.

Canopy closure was calculated by measuring and, in many cases, estimating with Schumacher equations, the diameters, heights, and crown lengths of all trees in each plot. This data was then entered into least crown width (LCW) equations developed for each tree species (Hann 1997). The radius of this width was then squared and multiplied by *pi* to calculate each tree's horizontal crown area. Summation of tree crown areas was compiled individually for each species (reduced model) and for all species (full model) in each plot. Percent canopy closure was calculated as the ratio of square-foot canopy closure within the total square footage of the quarter-acre plot (10,890 ft^2).

With the assistance of binoculars, each Sitka spruce tree was evaluated for leader deformities caused by weevil damage. A four-point damage rating system was developed to identify the morphological characteristics of the damaged terminal. This rating system simulates a chronological sequence of weevil damage over time, whereby a shepherd's crook indicates most recent damage (one year), a broken top indicates two to three years since weeviling, one or more upturned laterals suggest three to four years since weeviling, and a forked top represents the longest time since weeviling, approximately four or more years.

Data analysis

To compare the relative benefits of red alder to other tree species canopies in weevil protection, a full regression model and a partial model were both constructed. Included in the full model were the combined canopy closure values of red alder, western hemlock, Douglas-fir, and Sitka spruce itself (weeviled and unweeviled) that were measured in each plot. All species except red alder were eliminated to formulate the partial model.

The response variable of spruce weevil damage was determined by comparing the ratio of weeviled spruce trees to all spruce trees, resulting in a percentage of spruce weevil damage for each plot.

Polynomial equations, based on a method of curve fitting (Sit and Poulin-Costello 1994), were calculated using SPSS$_©$ for constructing a set of linear regression models to best explain the change in weevil damage under various levels of canopy closure, one for total canopy closure (full model), the other for red alder alone (reduced model).

Results

Weevil damage

Polynomial regression analysis comparing percent canopy closure with percent of Sitka spruce damaged by spruce-tip weevils resulted in the graphs and equations displayed in figures 1 and 2.

Preliminary analysis of total canopy closure by all tree species within each quarter-acre research plots, including mixtures of red alder, western hemlock, Douglas-fir, and Sitka spruce itself (weeviled and unweeviled), revealed a very poor relationship (r^2=0.0626) to the percentage of weevil damage.

When all other tree species were removed from the model except red alder, a conspicuous well-defined relationship emerged between levels of red alder canopy closure and the intensity of weevil damage, indicating that

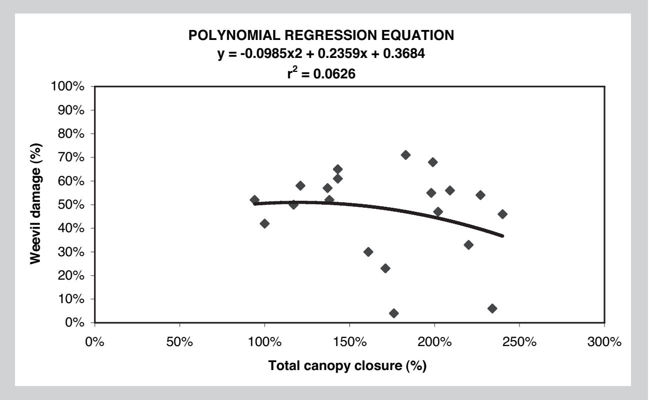

Figure 1—Comparison of weevil damage to the amount of total canopy closure.

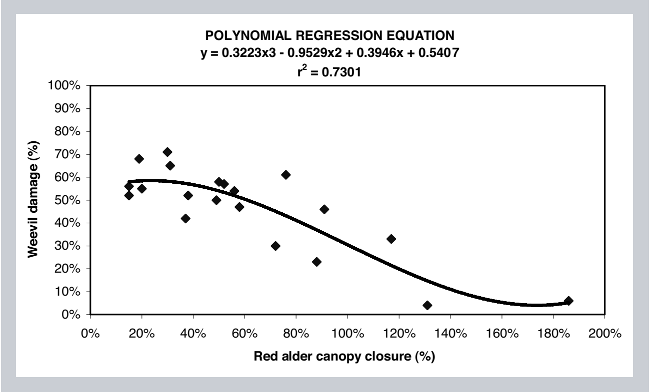

Figure 2—Comparison of weevil damage to changing levels of red alder canopy closure.

73% of the change in weevil infestation could be explained solely by the amount of red alder canopy shade present in the overstory (r^2=0.7301). ANOVA testing confirmed a very high level of significance to red alder canopy closure as a predictor of weevil damage ($p<0.001$).

Whiplash damage

The percent of spruce trees whiplashed in each plot was compared to the density of red alder canopy. The slope of this linear trend conforms to the expectation that the incidence of whiplash damage rises with an increasing density of red alder canopy closure (fig. 3).

Balancing levels of weevil damage vs. whiplash damage

Is there a balance that can be achieved between minimally acceptable levels of weevil damage and spruce leader whiplash damage in a nurse-tree shelterwood system? As an attempt to address these two inextricably linked concerns, the linear trend of the impacts made by various levels of red alder canopy closure on weevil damage reduction was superimposed with the linear trend of height growth suppression measured as a function of whiplash damage. The intersection of these two lines in the resulting model indicated that a threshold target of 88% red alder canopy closure would best optimize control of both weevil attack and whiplash damage (fig. 4).

Relative density of unweeviled Sitka spruce

Another finding was revealed by graphical comparison of the relative stem density by various species in each plot. Under a broad range of different species mixtures, including Douglas-fir, red alder, western hemlock, and weeviled spruce, the stocking level of unweeviled spruce trees consistently remained at around 25% of the plot stem density.

Figure 5 shows three representative distributions of plot species composition; in all three, unweeviled Sitka spruce comprised about 25% of the plot's stem density. In Plot MR13 (fig. 5A), red alder comprised half of the stem density; the remaining plot area was shared equally between weeviled and unweeviled spruce. Plot MR07 (fig. 5B) was comprised of red alder, weeviled and unweeviled spruce, as well as western hemlock and Douglas-fir. Even with the introduction of a more diverse tree species mixture, unweeviled spruce maintained a relative density of 25%. Under ideal conditions for managing an unweeviled Sitka spruce stand, red alder comprised 75% of Plot MR19 (fig. 5C), leaving only 25% of the growing space for unweeviled spruce.

Conclusion

The high coefficient of determination produced by the linear regression model constructed for this research analysis illustrates the sensitivity with which spruce weevil activity changes with corresponding shifts in the level of red alder canopy closure. By analyzing this phenomenon under a broad continuum of canopy closure levels, compelling evidence revealed the enormous—and unique—impact that red alder canopy shade exerts on the reduction in spruce weevil damage. As a natural resistance mechanism to facilitate healthy spruce leader development, red alder creates a thermal barrier that significantly reduces spruce-tip weevil infestation levels on young Sitka spruce by lowering the high ambient temperatures required by the spruce weevil to complete larval development and carry out much of its subsequent life history.

To optimize reductions in spruce terminal damage by maintaining a threshold range of 88% canopy closure, a carefully executed red alder management plan must be pursued, both in initial stem density and in intermediate density management, particularly during that period in stand development when Sitka spruce is most susceptible to weeviling, approximately between seven and twenty-

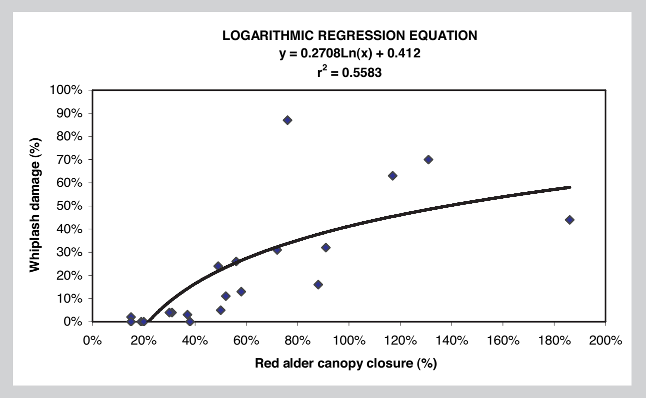

Figure 3—Comparison of whiplash damage to the amount of red alder canopy closure.

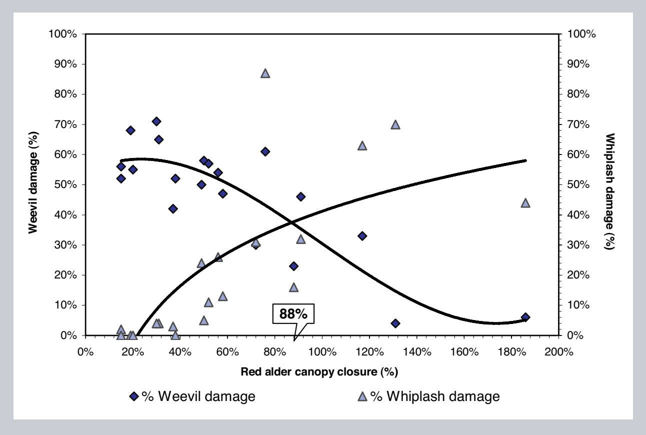

Figure 4—Superimposed trends of weevil and whiplash damage indicating best practices in managing red alder canopies to protect spruce leader development.

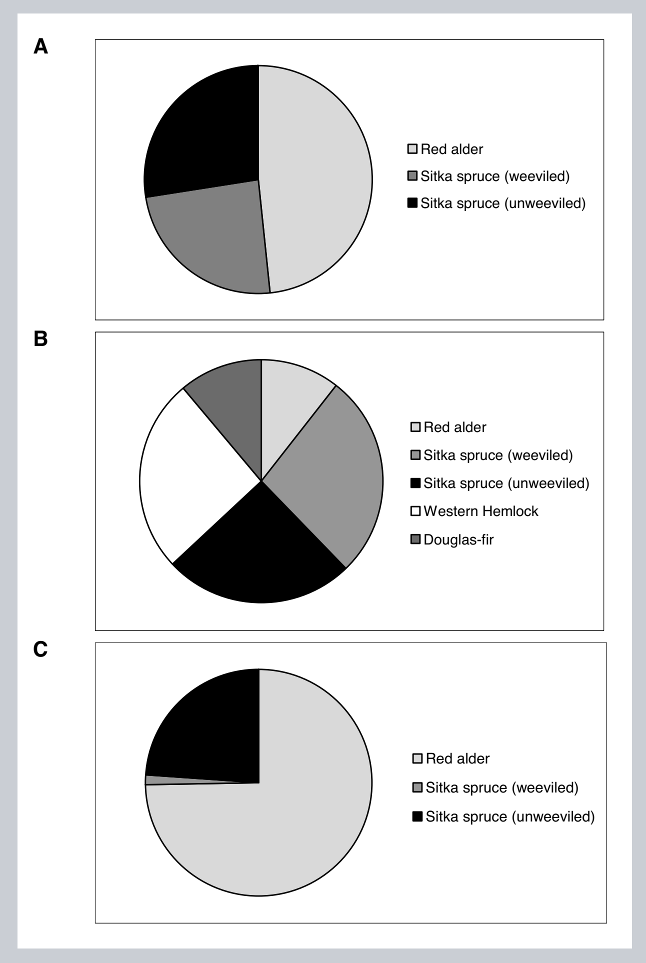

Figure 5—Relative density of component species in a weeviled spruce stand.

five years of age. The 88% threshold recommended by this research analysis should be thought of as a range, not a fixed point, to provide direction for continued investigation of interspecies interactions between Sitka spruce, the spruce weevil, and red alder within the complex dynamics of mixed-species forest stand development.

Results from this retrospective, primarily descriptive, case study of spruce-tip weevil damage occurring in a single Sitka spruce stand leave many questions to be answered. A controlled and more sophisticated research effort must be undertaken to measure the effects of managing various red alder canopy closure levels to achieve crown characteristics that are most effective in facilitating healthy Sitka spruce leader development.

Mixtures of red alder planted at, and thinned to, various densities in a range of proportions with Sitka spruce would provide the ideal opportunity to analyze variations in stand development patterns that maximize overall production by Sitka spruce and red alder. Empirical analysis or theoretical modeling could be carried out to establish what initial spacing of red alder seedlings will produce a canopy at 88% closure at a given age of fifteen years. A review of the red alder data gathered for this research indicates that dominant 17-year old red alders have a largest crown width of approximately 25 feet, based on LCW equations devised by Hann (1997). Red alder seedlings could be interplanted with Sitka spruce at a relative density of 1:1 on a 12’ x 12’ spacing. As alders mature and overtop the spruce seedlings, their crowns may close at age 15.

However, graphical comparison of the relative stem density by various species in each plot suggests that healthy, unweeviled Sitka spruce will consistently comprise no more than 25% of the stocking density in any mixture. The significance of this finding indicates that initial and intermediate density management of a spruce-alder forest stand should maintain a 1:3 balance of spruce-to-alder. Greater red alder density will accelerate height growth competition, promote better self-pruning, and force alder branching to assume a more acute upright angle, all of which are important canopy design features for reducing the hazard of whiplash damage to understory spruce.

Successful innovation in mixed-species stand management is a critical requirement to meet increasing multiple resource demands for improved wood utilization and greater biodiversity on a shrinking land base. Developing silvicultural methods that are congruent with the ecological compatibility of red alder and Sitka spruce, such as the nurse-tree two-cropping system of management recommended by this study, will lead to increased commodity production in an environmentally acceptable manner.

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Experimental Studies of Red Alder Growth and Nutrition on Vancouver Island

Kevin R. Brown[1] and Paul J. Courtin[2]

Abstract

Correlative field studies suggest that productivity in red alder stands on Vancouver Island increases with P availability. We have examined this in glasshouse and field experiments.

In the glasshouse, triple superphosphate (TSP) and dolomite were added to seedlings potted in soil from alluvial alder stands. Growth increased with P additions, less so in soils with high Bray-P levels and in higher-pH soils. Dolomite additions did not affect growth. We then added P and a blend of other elements to 10 young plantations on eastern Vancouver Island. P, as TSP, was added with or without other elements. The initial experiments applied 0, 20, or 40 g P per tree to plantations ranging from 2-4 years old. The second set applied 0, 10, 20 or 30 g P per tree within one year of planting. Additions of P increased growth in two of five older and in all five younger plantations through three years. Adding other elements did not increase growth.

We are now assessing the effects of P additions on stand development and carbon and nitrogen accretion at a slightly dry site. Seedlings were planted in fall 1999, with additional seedlings fill-planted in spring 2001. P (0, 15, 30 g per tree as TSP) was added in 2001; additional P has been added subsequently (cumulative additions of 0, 41, 88 g per tree through 2004) in order to maintain differences in foliar P concentrations. Through fall 2004, individual stem volumes have increased by 52 % (1999 cohort) or 164 % (2001 cohort). Mortality increased in 2003, but is not yet related to P treatment.

Growth of very young red alder on eastern Vancouver Island appears often limited by P deficiencies. How long effects of P additions persist and how responses vary with stand development remain unknown.

Keywords: Growth, nutrition, phosphorus, *Alnus rubra,* red alder, Vancouver Island.

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Introduction

Red alder (*Alnus rubra* Bong.) is the most widespread deciduous broadleaved tree species in low-elevation forests of coastal British Columbia. In B.C., as in Oregon and Washington, red alder was long considered an undesirable competitor with its coniferous associates. More recently, management *for* alder growth has been encouraged, in view of its rapid juvenile growth rates (Harrington 1990), ability to fix atmospheric nitrogen (N_2) (Binkley et al. 1994), immunity to laminated root rot, *Phellinus weirii* (Thies and Sturrock 1995), suitability for a variety of valuable products (Tarrant et al. 1994) and contribution to habitat diversity in a conifer-dominated forest landscape. In B.C., low-elevation sites on eastern Vancouver Island and the Sunshine Coast have the greatest potential for intensive management of red alder (Massie et al. 1994).

Increased harvest of mature alder has led to concerns that the current inventory of red alder will not meet projected demands (Rural Technology Initiative, Tarrant et al. 1994, Weyerhaeuser BC Coastal Group 2005). In B.C., the reliability of inventory data for red alder is questionable, but there is insufficient alder in the 1-20 year age class to supply projected demands without plantation establishment and intensified management. In anticipation of these needs, studies have been conducted in B.C. to assess the effects of site characteristics (Courtin 1992; Harrington and Courtin 1994), proportions of conifers (Comeau et al. 1997, Courtin and Brown 2001), and spacing, thinning and pruning on tree growth and log quality (Courtin et al. 2002).

The extent to which elemental deficiencies limit the growth of red alder is relatively unknown and unstudied (previously reviewed by Radwan and DeBell 1994), perhaps because alder fixes atmospheric N_2 and deficiencies of N most often limit the growth of Pacific Northwest coastal forests (e.g., Weetman et al. 1992). Indeed, a significant amount of research has examined how much N is added to soil at the scale of stands (reviewed by Binkley et al. 1994) and watersheds (Compton et al. 2003). Growth responses to supply of phosphorus (P) have been of interest because P is required in relatively high quantities in all plants and requirements may be greater in N_2-fixing species in association with nodulation and N_2-fixation (Marschner 1995). In earlier research, conducted in western Washington, additions of P to potted seedlings increased growth (Radwan and DeBell 1994) and either increased (Radwan and DeBell 1994) or did not affect growth (Harrington and DeBell 1995, Hurd and DeBell 2001) of young plantations. Alder planted on a site previously containing alder grew less and had lower tissue concentrations of P, calcium (Ca), and magnesium (Mg) than did alder planted on a site previously containing Douglas-fir (Cole et al. 1990, Compton et al. 1997), possibly as a consequence of N_2-fixation.

The purpose of this paper is to review recent and ongoing experiments examining the effects of nutrient supply on growth of red alder on Vancouver Island. Our reasons for initiating these studies in the mid-1990s were: (1) site index of red alder on Vancouver Island and the adjacent mainland increased with foliar and available soil P concentrations on low-pH soils, even on sites classified as rich or very rich (Courtin 1992; Harrington and Courtin 1994); (2) experimental confirmation of nutrient deficiencies on such sites was lacking, except for a single study with potted seedlings (Binkley 1986) which inferred deficiencies of P and S in a single soil; (3) red alder was increasingly being replanted on sites from which mature alder stands had been harvested, raising the question of whether nutrient supply might limit the growth of a second consecutive rotation of red alder (e.g., Compton et al. 1997); (4) there was increasing experimental evidence of P deficiencies in other tree species (Brown 2004; Brown and van den Driessche 2005, Zabek and Prescott 2001) on sites considered suitable for red alder.

The long-term objectives of our studies have been to determine: (1) what mineral nutrients are deficient for red alder; (2) on what sites deficiencies are most likely and, presumably, correctable, and (3) long-term effects of additions of limiting nutrients on stand growth and site characteristics, particularly carbon and nitrogen accumulation. Such information should assist in site selection and refine the use of fertilization for red alder management.

Throughout the paper, we refer to soil moisture regimes (SMR) and soil nutrient regimes (SNR) in discussing variation of response to nutrient additions on different sites. SMR and SNR are integral parts of the B.C. biogeoclimatic ecosystem classification system and are identified through presence and abundance of indicator plant species, topographic (e.g., slope position) and soil (e.g., humus form, soil depth, soil texture and coarse fragment content, type of A horizon, and soil color) characteristics (Green and Klinka 1994). SNR is linked to measures of nutrient availability, particularly for N (Kabzems and Klinka 1987); SMR has been related to soil water balance (Giles et al. 1985). Combined, SMR and SNR indicate the site series (site classification), which is linked to site index for different species (Anonymous 1997), including alder (Courtin, 1992) and is used to guide silvicultural decision-making (Green and Klinka 1994).

The initial nutrition experiments were conducted with potted seedlings in glasshouses, followed by short-term field experiments employing single-tree plots, and currently, long-term field experiments with multi-tree plots. The experimental approach varied with the question asked and the availability of appropriate sites and plantations. Studies employing potted seedlings were used first because appropriate plantations were unavailable and because they allowed assessment of which essential nutrients were limiting when other factors (e.g., light, moisture, competition, herbivory) were not. Subsequently, single-tree plot experiments were conducted because available young plantations were small and of variable size and tree spacing; this approach allowed for experimental confirmation of elemental deficiencies. As larger plantations became available, we initiated multi-tree plot experiments. The primary objective in the latter studies is to assess growth responses of young red alder to a restricted (and manageable) number of nutritional treatments over time at a stand level.

Nutrient analyses were conducted on all foliage (potted seedlings) or on recently-matured leaves from the upper crown (field studies). Collected leaves were oven-dried at 70°C for 48 hours, and ground using a coffee grinder. Total N and C were determined by micro-Dumas combustion using an automated NCS analyzer. For other elements, samples were digested in a microwave digestor with a mixture of 30% H_2O_2 and concentrated HCl and HNO_3 (Kalra and Maynard 1991), then analyzed by inductively coupled argon plasma emission spectrometry (ICAP). Soil extractable P was determined colorimetrically by autoanalyzer following extraction with Bray P1 extractant (Kalra and Maynard 1991).

Experiments

Glasshouse: Effects of phosphorus fertilization and liming on red alder seedlings grown in soils from mature alluvial alder stands

The impetus for this experiment (Brown and Courtin 2003a) came from field data relating alder site index to foliar and soil available P concentrations in low pH soils (Courtin 1992), data indicating that growth of alder, soil pH and availability of P and other elements all decreased when alder was grown in consecutive rotations (Compton et al. 1997), and recognition that alder might be preferred for reforesting recently-harvested and potentially brushy alluvial sites. The objectives were to determine if: (1) seedling growth was limited by elemental deficiencies in soil from alluvial alder stands; (2) seedling growth response to growth of alder seedlings to P additions differed in higher and lower pH alluvial soils; and (3) liming could alleviate deficiencies of P (or other elements) by increasing soil pH.

Soils were collected from 0-15 cm depth (mainly Ah horizon) in six mature alluvial red alder stands on Vancouver Island, screened and potted into 3 L capacity pots in the glasshouse. Soils from four stands were classified as low pH (mean = 4.4) and two were classified as high pH (mean = 5.3); soil nutrient regimes (SNR) were classified as "very rich" at all sites. Three levels (0, 0.4, or 0.8 g P pot^{-1}, equivalent to 0, 225, or 450 kg P ha^{-1}) of triple super phosphate (0-45-0) and two levels of dolomitic lime (0 or 8.8 g pot^{-1}, equivalent to 5 t ha^{-1}) were applied in factorial combination. Seedlings were grown for 54 days, dried and weighed, and analyzed for tissue nutrient concentrations.

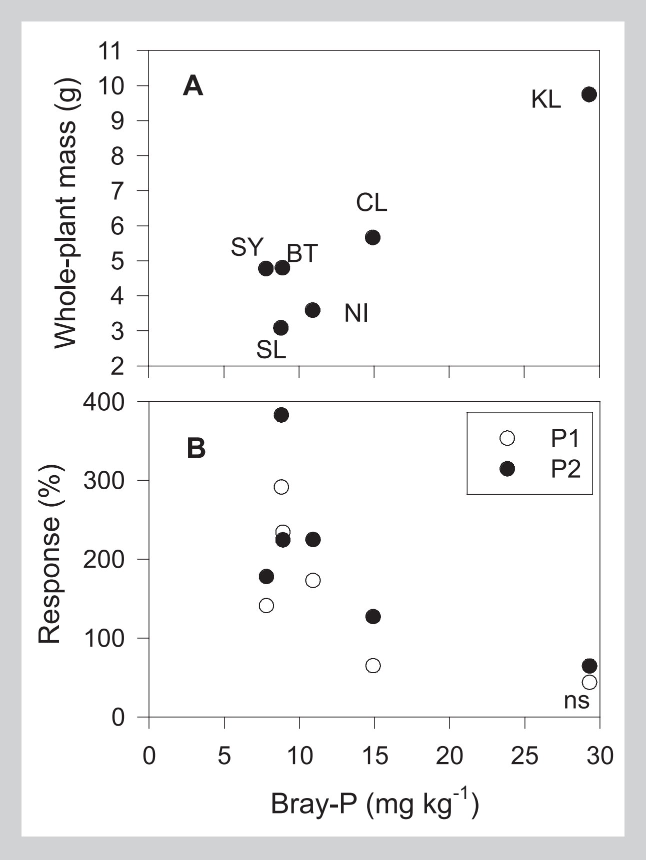


Figure 1—Effects of soil Bray-1 P concentrations on (A) whole-plant dry mass of unfertilized red alder seedlings (B) response (%) of whole-plant mass to P additions, potted seedling experiment (adapted from Brown and Courtin 2003).

Growth in unfertilized soils increased with P availability (fig. 1). Additions of P increased growth, but the response decreased with increased P availability (fig. 1) and was greater in low-pH soils. Liming did not increase growth, but increased pH and whole-plant and foliar concentrations of Mg. The increases in growth with P additions were accompanied by increases in whole-plant and foliar concentrations of P, but also of N, Ca, and S. Growth increases were probably due mainly to increased uptake of P, because: (1) concentrations of P were lower than those previously suggested as deficient (Brown 2002) and (2) the correlations of growth and P concentrations were consistent across soils. Conversely, Ca concentrations were high compared with concentrations previously reported (Radwan and DeBell 1994) and increases in N, Ca, and S concentrations with P additions or liming were not always associated with increased growth. P additions increased masses of all plant parts, but increased root mass the least and branch mass the most. Consequently, P additions resulted in decreased root weight ratios and increased branch weight ratios, without affecting allocation to stems or leaves.

Table 1—Selected site and plantation characteristics, alder single-tree plot fertilization experiments.

Site	Age	Bray-P (mg kg^{-1})	CEC (cmol kg^{-1})	Previous Stand
Malaspina (M)	4	37.8	5.6	*P. menziesii*
Bowser (B)	4	11.4	4.3	*P. menziesii*
French Creek (FC)	4	48.5	3.5	*P. menziesii*
Quinsam River (QR)	3	91.6	2.8	*P. menziesii*
Hillcrest (Hill)	2	118.5	4.1	*P. menziesii*
Fanny Bay Dry (FBD)	1	3.0	7.5	*A. rubra*
Fanny Bay-Wet (FBW)	1	6.8	10.8	*A. rubra*
Campbell River Lower (CRL)	1	3.5	5.7	*A. rubra / P. trichocarpa*
Campbell River Upper (CRU)	1	124.9	2.3	*P. menziesii*
Harry Road (HR)	0	6.8	9.1	*A. rubra*

Note: age represents years since planting. Previous stand refers to dominant tree species on site prior to plantation establishment.

The data suggested that P deficiencies might limit the growth of alder in "very rich" soil from mature alluvial alder stands. Interpretation of such bioassay results is problematic. Glasshouse conditions should maximize uptake of added nutrients and expression of potential growth responses to nutrient additions (i.e., elemental deficiencies should be more obvious). Conversely, soil processing might increase nutrient availability and lessen growth response to nutrient additions. In short, field experiments are required to confirm whether deficiencies exist and to assess magnitude of response to nutrient additions.

Field: Responses of young red alder plantations on southeastern Vancouver Island to additions of P and other elements using a single tree plot design

This study was initiated in 1997 (Brown 1999); ultimately, ten experiments were established from 1997–1999 (table 1), mainly in the coastal western hemlock very dry maritime subzone (CWHxm) of eastern Vancouver Island between Duncan and Campbell River. Soil moisture regimes (SMR) ranged from moderately dry to very moist (preferred, Courtin et al. 2002); soil nutrient regimes (SNR) ranged from poor – very rich (fig. 2). Site series ranged from 03 - 07 where 07 is considered optimal for red alder (Courtin et al. 2002) and 03 and 05 are drier than optimal.

Plantation age at time of fertilization ranged from 0 (within one month of planting) – 4 years. Older plantations (> 2 years old) were fertilized in 1997 or 1998; younger plantations (fertilized within one year of planting) were fertilized in 1998 or 1999. The types of plantations available necessitated use of single-tree plot designs, for reasons discussed previously. Only healthy trees were selected for treatment and a minimum distance of 8 m (> one tree height) was maintained between treatment trees. The basic treatments consisted of three levels of P (P0, P1, P2), added as triple super phosphate (TSP, 0-45-0), with or without the "C" fertilizer (C0, C1), a blend of potassium magnesium sulphate (0-0-22K-11Mg-22S) and fritted micronutrients (table 2). Treatments were either randomly assigned across the plantation or within blocks. The number of trees per treatment ranged from 14 to 25.

Experiments differed between older and younger plantations as follows:

(1) Older plantations were located on sites generally classified as less fertile and drier than were younger plantations (fig. 2).

(2) Of five older plantations, four were established in infection centers of laminated root rot (*Phellinus weirii*) requiring the removal of infected Douglas-fir; the fifth also previously contained Douglas-fir. In contrast, four of five younger plantations were planted following the harvest of an alder stand. Hence, previous stand history and plantation age at the time of treatments were confounded.

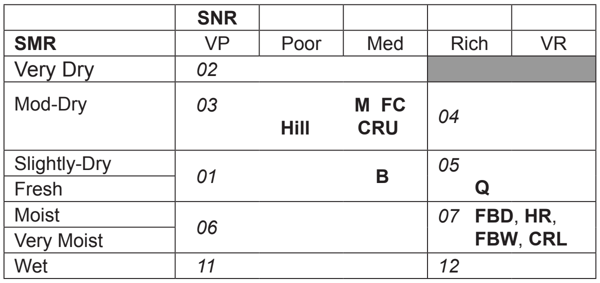
(3) Older plantations were generally smaller in area and numbers of potential treatment trees; consequently, only three treatments (P0C0, i.e., control; P1C1 and P2C1) were applied in two experiments. Conversely, three younger plantations were large enough to allow adding four levels of P, with or without C.

(4) All plantations received the same balance of nutrients in a given treatment; however, the maximum mass of nutrients added per tree was less in younger plantations (table 2) because trees were smaller.

Table 2—Nutrient additions by treatment (Trt) for fertilized plots. P0 and C0 treatments did not receive P or the C blend, respectively.

							Element Added (g tree^{-1})					
Site	**Trt**	**P**	**K**	**Ca**	**Mg**	**S**	**Fe**	**Mn**	**Zn**	**B**	**Cu**	**Mo**
M, B, QR, FC	P1	20		12								
	P2	40		24								
	C1		11		7	13	6.3	2.6	2.4	1.1	1.1	0.03
Hill, FBD,FBW,	P1	10		6								
CRL,CRU,HR	P2	20		12								
	P3	30		18								
	C1		5.5		3.5	6.5	3.2	1.3	1.2	0.6	0.6	0.015

Note: Site abbreviations are as shown in Table 1.



	SNR				
SMR	VP	Poor	Med	Rich	VR
Very Dry	*02*			▨	▨
Mod-Dry	*03*	**Hill**	**M FC** **CRU**	*04*	
Slightly-Dry Fresh	*01*		**B**	*05*	**Q**
Moist Very Moist	*06*			*07* **FBD**, **HR**, **FBW**, **CRL**	
Wet	*11*			*12*	

Figure 2—Site series (italics), soil moisture regime (SMR) and soil nutrient regime (SNR) of alder plantations in the single-tree plot fertilization study. A site series of 07 (CWHxm subzone) is considered optimal for red alder (Courtin et al. 2002).

(5) In older plantations, vegetation was removed to 1 m from the base of each tree and fertilizers applied in a band 0.6 – 0.8 m from the tree base. In younger (0-2 year old) plantations, vegetation was removed to ca. 0.3 m distance from the seedling. Fertilizer was applied in 2 (P1), 4 (P2), or 6 (P3) dibble holes 0.2 – 0.3 m from (and spaced equidistant around) the seedling. The objective in both was to ensure that added fertilizer was available for uptake by the target tree.

Height and basal diameters were measured in the spring at the time experiments were established, in the fall after one and two growing seasons and, in younger plantations, after three years. Individual tree stem volume was estimated assuming the stem was a cone and using basal diameter (bd) to estimate basal area of the cone. An earlier study (Brown 2002) indicated that this approach reasonably estimated stem volumes of red alder to the sizes seen in younger plantations, in the two years of measurement at two older plantations, and in the first year of treatment at two other older plantations.

Growth responses to P additions were significant (α=0.05) in the five youngest plantations (fig. 3). Averaged across the five plantations, P additions increased foliar concentrations of P from 1.3 (unfertilized) to 2.0 g kg^{-1}, within the range considered deficient (Brown 2002). P additions also increased foliar N and decreased foliar Zn in four of five young plantations and increased (Ca, Mg, S) or decreased (K, B, Cu, Mn) in one to three plantations, depending on the element. The "C" fertilizer increased foliar concentrations of K, S, and B in all five plantations and N Mg, and Zn in three of five plantations without increasing growth; increases in S and Mg were of the same or greater magnitude as those resulting from P additions (Brown and Courtin, submitted). The data indicate that, on eastern Vancouver Island, low availability of P limits growth of young (within one year of planting) alder plantations on sites classified as rich – very rich and suitable for alder management. This is consistent with results of the potted seedling trial discussed above and with correlative data presented for mature alder stands (Courtin 1992).

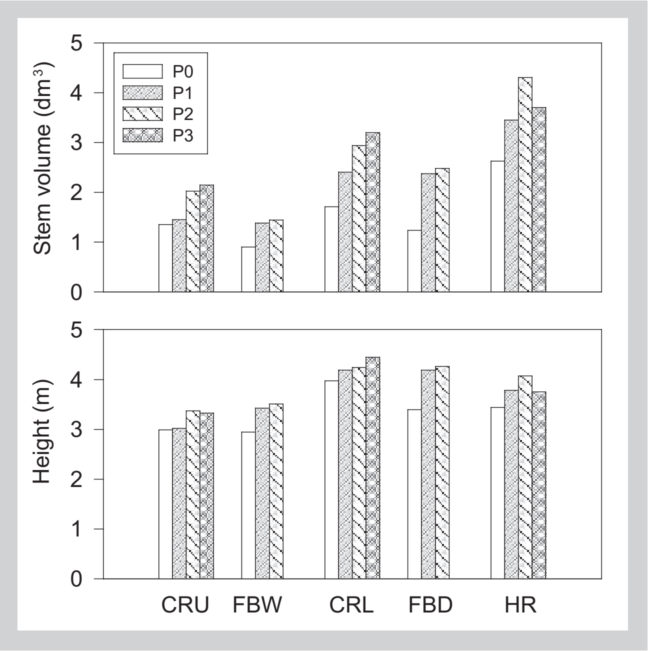


Figure 3—Effect of P addition on stem volumes and heights of young red alder (< 2 year old at time of fertilization) after 3 years, single-tree plot P fertilization experiment.

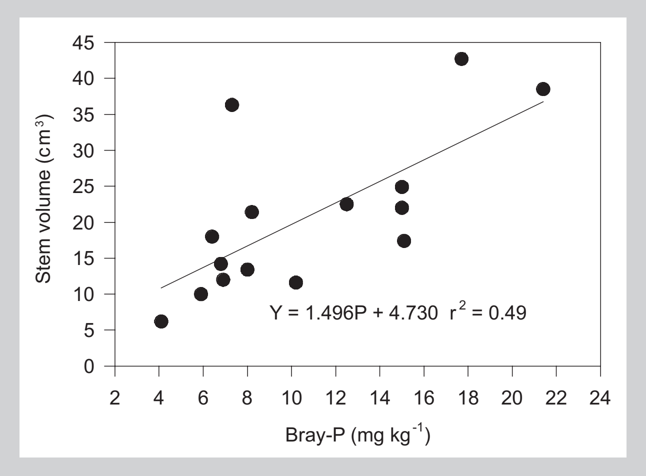


Figure 4—Stem volume prior to fertilization in relation to soil Bray-P concentrations, multi-tree plot fertilization experiment.

Table 3—Foliar concentrations of N, P, and Zn of red alder over time in relation to P treatment (Trt) at the McColl Road experiment. Trees were planted in fall 1999 and initially fertilized in spring 2001.

		Year			
Element	**Trt**	**2000**	**2001**	**2003**	**2004**
P (g kg^{-1})	P0	1.41	1.53	1.44	1.44
	P1	----	1.95	1.44	1.52
	P2	----	1.99	1.48	1.60
N (g kg^{-1})	P0	29.3	29.7	28.8	28.0
	P1	----	32.1	30.5	29.2
	P2	----	32.7	30.0	29.6
Zn (mg kg^{-1})	P0	62.0	37.0	28.0	24.0
	P1	---	32.0	22.0	20.0
	P2	---	31.0	20.0	21.0

In the older plantations, growth increased with addition of combined P and C fertilizers at Bowser and French Creek, the latter only when in combination with understory vegetation removal around the tree base (Brown 1999). Volume responses at both sites were significant through two growing seasons following fertilization (Brown and Courtin, submitted). The Bowser plantation had relatively low soil Bray-P concentrations, compared with other plantations > two years old at the time of fertilization.

Several factors might explain the more frequent growth response of younger plantations to P additions. Foliar P concentrations in unfertilized trees were much less in younger than in older plantations (mean of 1.3 and 2.1 g kg^{-1}, respectively) and much more likely deficient (Brown 2002). With the exception of the CRU site, soil Bray-P concentrations were also less in younger plantations (table 1). The greater soil and foliar P concentrations in older plantations may have been due to differences in site characteristics (e.g., parent materials, climate) or stand history (e.g., Compton et al. 1997), as most older alder plantations in the study were established after harvest of a Douglas-fir stand, rather than after harvest of an alder stand. If P was deficient in the older plantations, insufficient amounts of P may have been added to the older and larger trees to elicit any detectable increase in P uptake and growth. Tree volumes in plantations four years old at the time of fertilization were 75 times greater, on average, than in plantations fertilized one year after planting. However, trees in older plantations received only two times as much P as did the corresponding trees in younger plantations and foliar P concentrations did not increase with P additions.

Multi-tree plot experiments: Stand-level responses of young plantations to P additions

In 2001, we established a multi-tree plot field experiment in a young alder plantation on eastern Vancouver Island (Brown and Courtin 2003b). The long-term objectives are to assess effects of P additions on stand growth and ecosystem properties (specifically, carbon and nitrogen accumulation). The site is relatively dry; SNR was classified as medium-rich and soils were relatively low in Bray-1 extractable P (mean = 10.7 mg kg^{-1}), suggesting that P might be deficient. The site previously contained a *Phellinus*-infected Douglas-fir stand. Although the greatest growth potential for red alder is on moist and nutrient-rich sites, its immunity to *Phellinus* may make alder appropriate to plant on sites that are less moist and fertile than considered optimal. Such sites are common on eastern Vancouver Island. We felt P additions might be beneficial to red alder under such conditions because growth responses of alder to P additions were greater when moisture supply was suboptimal than when optimal (Radwan and DeBell 1994) and P additions increased instantaneous water use efficiency on a unit leaf area basis (Brown 2002; Brown and Courtin 2003a).

Following harvest of the existing Douglas-fir stand, the site was stumped and a portion of the site planted with alder seedlings in fall 1999. Survival was patchy and the site was fill-planted in March 2001 to a target density of 1300 seedlings ha^{-1}. Fifteen plots, each 45 x 45 m, were established in March 2001. Each plot consisted of a 25 x 25 m inner plot surrounded by a 10 m wide buffer and was separated from adjacent plots by an untreated buffer.

Soil was sampled at the beginning of the experiment from 0-30 cm depth at two points randomly selected along each of four lines extending from the plot center to a corner and analyzed for Bray-P, exchangeable cations, total N and P. Coarse fragment contents were estimated in each plot near the plot center and pits were excavated for description of soil profiles.

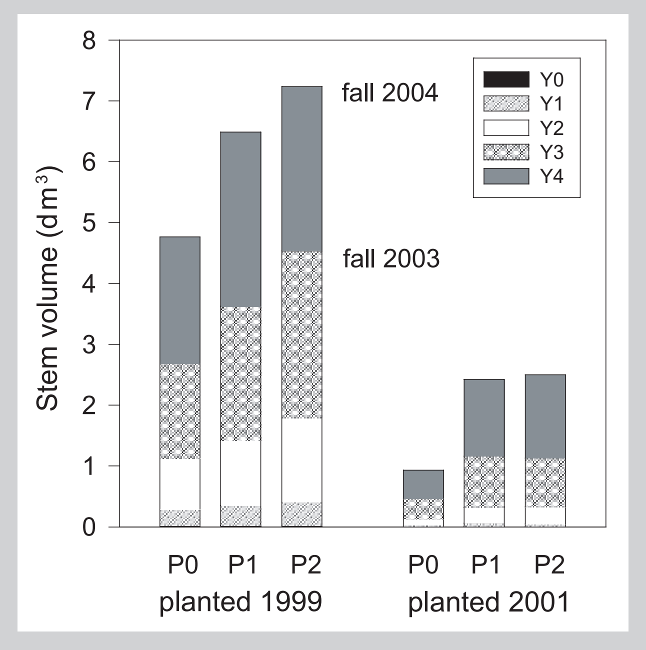


Figure 5—Four-year stem volume growth of red alder in relation to P treatment and cohort, multi-tree plot fertilization experiment.

An objective of the treatments is to maintain differing foliar concentrations of P, while maintaining adequate concentrations of other elements. In May 2001, P was added at rates of 0, 15, or 30 g P tree^{-1} as triple superphosphate and placed in dibble holes 15-30 cm from the tree. P has been added in subsequent years, based on projected rates of growth from year to year (determined from annual measurements), measured allocation of P to foliage (Brown 2002), and conservative assumptions of uptake of added P and rates of resorption of internal P prior to leaf senescence. Cumulative additions of P through 2004 (start of experiment year 4) in the P0, P1 and P2 treatments total 0, 41, and 88 g P tree^{-1} (0, 58, 124 kg P ha^{-1}), respectively.

Heights and diameters (basal in years one, two, and three; dbh in years three and four) were measured at the start of the experiment (spring of 2001, year one) and again in the fall of years one, two, three, and four. Foliage has been analyzed yearly as described above.

Similar to the relationship demonstrated earlier across sites, stem volumes of unfertilized seedlings one growing season after planting increased with soil Bray-P levels (fig. 4). Through four growing seasons, P additions have increased individual stem volumes by 56 % in the 1999 cohort and 156 % in the 2001 cohort (fig. 5); absolute increases due to P additions have been greater in the 1999 cohort. To-date, absolute effects of P addition have also increased each year since fertilization (fig. 5). Effects of P additions have been greater for dbh than for height in both the 1999 (24 vs. 16%) and 2001 (60 vs. 31%) cohorts.

Over the experiment, P additions have most consistently increased foliar concentrations of P and decreased concentrations of Zn (table 3). Nonetheless, foliar P concentrations have decreased over time despite our refertilizing treatment plots. The foliar P concentrations are within the range of P concentrations felt to be deficient in both cohorts of seedlings. Concentrations of elements other than P and Zn have generally been unaffected by P additions during the study period and have been within ranges observed in the single-tree plot experiments.

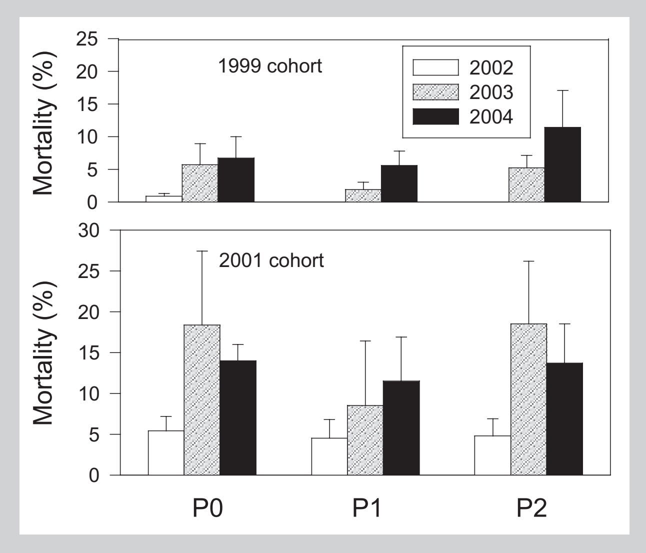


Figure 6—Mortality (% of initial number of seedlings per plot) of red alder in relation to cohort, P treatment, and year, multi-tree fertilization experiment. Vertical bars represent standard errors about the mean.

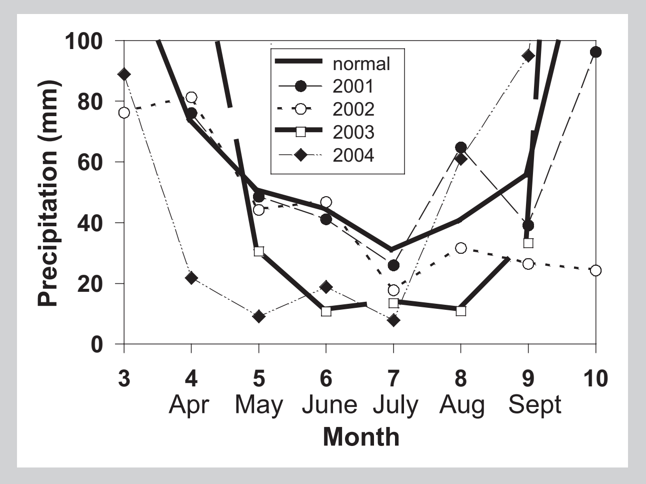


Figure 7—Precipitation, 2001–2004 growing seasons, multi-tree plot fertilization experiment.

Mortality in this relatively dry site has been significant through four years (fig. 6). Mortality has been greater in the fill-planted 2001 seedlings, possibly because of increased competition at the time of establishment, or because fill planting occurred mainly on poorer microsites. There is no clear evidence that P treatments have affected mortality rates. Mortality was greater in 2003 and 2004 than 2002 and may have been associated with drought during those growing seasons (fig. 7). A simple estimate of stand level volume, based on individual stem volume responses and mortality rates suggests that P additions have increased volume by 2.1 (46%) and 2.5 m^3 ha^{-1} (56%) in the P1 and P2 treatments, respectively, through 4 years of treatments.

Discussion

Our studies suggest that the early growth of red alder on eastern Vancouver Island is limited by insufficient P supply. Deficiencies of other elements have not been clearly demonstrated, which might indicate that supplies of those elements are sufficient or additions of those elements were insufficient to increase growth.

The effects of P additions have been most pronounced at low soil Bray-1 P levels (< 12 mg kg^{-1}) and low foliar P concentrations (< 2 g kg^{-1}) and in plantations fertilized within one year of planting. Responses have been measured for up to three years following fertilization, but it is unknown how long growth responses might persist. In the sites studied, soil nutrient regimes classified as rich or very rich had low Bray-P concentrations. At this point, the relative effects of plantation age, stand history, and site characteristics on growth response to P additions are difficult to untangle, because the less-responsive older plantations were on drier sites with higher Bray-P concentrations and were planted on sites previously occupied by Douglas-fir, not red alder.

Growth responses in the multi-tree plot experiment discussed here have been largely consistent with results observed in the single-tree plot studies, as are first-year responses to 0, 30, and 60 g P $tree^{-1}$ in a moist, very rich site near Powell River. Continued growth and soil measurements in these and similar newly-initiated multi-tree plot P fertilization experiments should provide insight into long-term effects of P availability on stand growth and soil development.

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Management/Silviculture

Red Alder:
Its Management and Potential

Andrew A. Bluhm and David E. Hibbs[1]

Abstract

Red alder is now recognized as a valuable tree species in the Pacific Northwest because of recent increases in wood value, its fast growth and therefore its ability to produce sawlogs on short rotations. As compared to conifers, red alder has extremely fast juvenile growth rates but good growth is limited to a narrower range of site conditions. Red alder is also resistant to many of the diseases afflicting conifers, improves site productivity due to its nitrogen-fixing ability, and enhances wildlife and plant diversity across the landscape. Diameter and height growth of trees in managed plantations of red alder are greater than that of naturally regenerated stands. This apparent increase in growth is primarily due to the control of competing vegetation and planting density, and intermediate silvicultural activities (i.e. thinning). This faster growth results in a shorter time required to achieve trees of any given size. Tree form is also improved with management due to more uniform stocking. Results are presented here on the effect of initial planting density and various thinning treatments on twelve-year-old variable-density red alder plantations. Initial planting density influenced early diameter and height growth. Up through age 6, diameter growth increased with increasing density until a crossover occurred between ages 7 through 11. Diameter increment ranged from 1.4 cm/year to 1.8 cm/year. Height growth also increased with stand density except at extremely high densities. Height increment ranged from 1.1 m/year to 1.4 m/year. Optimal alder height and diameter growth was maximized around 1400-1500 tph until about age 10, at which time optimal diameter growth shifted to lower densities. Early stand volumes of close to 80 m^3/ha were achieved in the intermediate planting densities mainly as a function of absolute tree number and minimum merchantability limits. Thinning increased diameter growth response as compared to the control plots and thinning at age five resulted in greater diameters than thinning at age eight. By age 12, diameters were 21% and a 14% greater than the control for the early thinned and later thinned plots, respectively. Post thinning annual diameter increments were 25% and 38% greater for the early thin and the late thin, respectively. Thinning had no effect on tree height. Thinning increased individual tree volume 14% and 4% over the control plots for the early thin and the late thin, respectively. Thinning reduced the number of merchantable trees per hectare. Volume per hectare was greatest in the early thin plots (89.0 m^3/ha), followed by the control plots (81.2 m^3/ha) and the late thinned plots (68.0 m^3/ha). These results illustrate that the careful control of planting density and thinning regimes provide opportunities to achieve higher yields of better quality logs in a relatively short time.

Keywords: red alder, *Alnus rubra*, management, silviculture, planting density, precommercial thinning, tree growth, stand yield

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Introduction

> "What is a weed? A plant whose virtues have not been discovered."
>
> – Ralph Waldo Emerson (1803-1882)

Red alder (*Alnus rubra*; hereafter referred to simply as alder) is the major hardwood tree in the Pacific Northwest (PNW), comprising approximately two-thirds of the hardwood growing stock in the region. Although always present in the landscape, alder has historically been a low-value and under-utilized timber resource. The origin of most stands was accidental (natural regeneration after fire, logging or failed conifer plantations) and management efforts focused on eradication or conversion. This is changing rapidly due to the increased commercial value and recognition of its ecological benefits across the landscape.

Alder's easy regeneration, rapid growth rates and log price trends make it an attractive species to manage in the Pacific Northwest. However, this has not always been the case. Until recently, alder has been considered a "weed" by most foresters in the region. In fact, even recently, debate still surrounds the desirability of managing alder. For instance, the OSU Extension Service released, in the same year, two publications, "Managing Red Alder" (Hibbs 1996) and "Converting Western Oregon Red Alder Stands to Productive Conifer Forests" (Bondi and Emmingham 1996). While some were trying to grow alder, others were trying to get rid of it.

Alder is not without its merits. It has always been a small component of the PNW conifer-based timber industry and has long been recognized as a desirable component in riparian systems. But as much as people used alder, the scientific understanding of this species lagged far behind that of its associated conifers. Recognizing the virtues of alder and the serious lack of silvicultural understanding, the Hardwood Silviculture Cooperative (HSC) was formed to improve the understanding, management, and production of alder. Due to the efforts of the HSC and other research organizations, the acceptance of alder is increasing along with (or due to) the growing knowledge base. This chapter describes the state of knowledge of managing alder plantations. Focus is primarily on four topics:

1) Characteristics of alder compared to conifers and other hardwoods
2) Reasons to manage alder
3) Differences between alder plantations and natural stands
4) Responses of alder to stand density management activities (initial spacing and thinning).

The HSC in brief

The Hardwood Silviculture Cooperative (HSC), begun in 1988, is a multi-faceted research and education program focused on the silviculture of alder and mixtures of alder and Douglas-fir (*Pseutotsuga menzeisii*). The goal of the HSC to improve the understanding, management, and production of alder. The activities of the HSC have already resulted in significant gains in understanding regeneration and stand management, and have highlighted the potential of alder to contribute to both economic and ecological forest management objectives.

To understand the response of alder to intensive management, the HSC has installed 26 variable-density plantations from Coos Bay, Oregon to Vancouver Island, British Columbia. The plantation distribution covers a wide range of geographic conditions and site qualities. At each site, cooperators planted large blocks of alder at four specific densities. Each block is subdivided into several treatment plots covering a range of thinning and pruning options.

Since the HSC was established, they (and many others) have learned a great deal about seed zone transfer, seedling propagation, stocking guidelines, identification of sites appropriate for alder, and the effects of spacing on early tree growth. Much of this information is available to the public and found on the HSC web-page http://www.cof.orst.edu/coops/hsc. Furthermore, the data set is now complete enough to begin analyzing the growth response of alder after thinning and/or pruning. However, much still needs to be accomplished. The ultimate goal is a better understanding of the effects of stand density on alder growth and yield and wood quality, and to develop a robust alder growth model.

How does alder stack up against conifers and other hardwoods?

There are obvious physical differences between alder and other conifers in the region, but perhaps the most important to managers is that there is relatively little knowledge about alder management as compared to conifers. This lack of information is a result of a combination of many factors, including inconsistent markets and the region-wide conifer-forestry mindset. Some of the important differences, with management implications, between alder and conifers are discussed below.

Alder is not what usually comes to mind when imaging the forests of the PNW. Conifers dominate the landscape, in abundance, size and stature. Hardwoods comprise only 12% of the growing stock in the region (Raettig et al. 1995) and pale in comparison to conifers in tree size and lifespan. However, alder has impressive juvenile height growth rates, accumulating more than two-thirds of its mature height by age 30 (Harrington and Curtis 1986, Worthington et al. 1960). This rapid growth is attractive to foresters. However, this fast growth dictates that management activities must

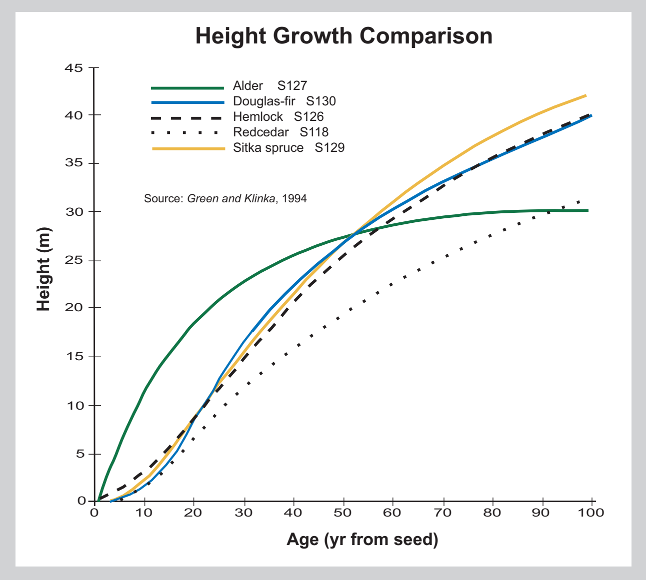

Figure 1—Comparison of height growth from seed to age 100 for red alder and associated coniferous species. Height curves and site index values are based on median values for conifers on Site productivity class II (from "Red Alder manager's Handbook for British Columbia," Peterson et. al. 1996).

be performed in a narrower time window and much earlier than in conifer stands for at least two reasons. One, stand characteristics are determined primarily by early stand conditions (i.e. diameter and height increment, live crown ratio). Two, vertical crown expansion is the primary means of crown response following thinning. Therefore early thinning is needed whereas thinning older stands (with minimal live crown) may not be beneficial.

Good performance of alder is limited to a narrower range of site conditions than most of its associated conifers. Despite the fact that alder is (incorrectly) perceived as a wet site species, it grows across a wide variety of sites. However, what is a good site for conifers may not be a good site for alder, and vice versa. For consistent, risk-minimizing management, species requirements (Harrington 1990) and proper site identification (Harrington 1986) is critical. Alder survival and growth is also more sensitive than conifers to small-scale, within-stand site variations.

At full stocking, alder usually has lower basal area than conifers (Puettman 1994), ranging from 20-30 m^2/ha. Volume is likewise lower than conifer stands, ranging from 300-500m^3/ha at 50-70 years. However, alder has similar rates of annual wood production as many conifers, with annual cubic volume growth rates of 21 m^3/ha in pulpwood rotations of 10 to 12 years, and 14 m^3/ha in saw-log rotations of 30 to 32 years (DeBell et al. 1978).

Today, alder is managed primarily for high-grade lumber/veneer. This fact means the quality of the resource (i.e. the log) is as important (or more so) than the quantity of the resource. Furthermore, unlike conifers, alder is a diffuse porous species. This trait allows uniform wood properties and wood quality regardless of growth rate (Lei et al. 1997). These two traits have far-reaching impacts on management strategies.

Although alder is a minor component of the total timber volume in the PNW, it is, by far the most abundant hardwood in the region and comprises approximately 60% of the total hardwood resource (Raettig et al. 1995). It has a wide geographic range (1.9 million hectares) and a large volume of approximately 30 billion board feet (Glenn Aherns, personal communication). So while other hardwood species may be locally important, alder is the most important region-wide hardwood species.

A few factors other than the limited availability of other hardwoods favor the management of alder. Except for black cottonwood (*Populus trichocarpa*), alder growth rates far exceed other hardwoods of the region. Fast growth means short rotations. The only other region-wide hardwood species, bigleaf maple (*Acer macrophyllum*) has been found to be notoriously hard to grow. Alder seedlings are less susceptible to browsing than those of bigleaf maple. Furthermore, compared to many other hardwood species, living alder has surprisingly little decay. Allen (1993) indicates that merchantable volume losses to decay average 4% in alder 60-80 years old.

Why manage alder?

First and foremost, alder exhibits very rapid juvenile growth rates (Harrington and Curtis 1986, Nigh and Courtin 1998, Peterson et al. 1996) making it an appealing species to manage in short rotations. Through about age 25, alder height growth exceeds that of all associated conifers (fig. 1). Therefore, a primary management objective is to capture this difference. Although height growth rates decline rapidly after 20 years, a short-rotation, high-value crop can be achieved. With today's quick-return emphasis on plantation management, this short rotation length is economically appealing.

Although volume yields for alder are lower than those for conifers at typical conifer final rotation ages, alder volume is greater than the associated conifers at these short rotations (25-35 years). For instance, empirical data from natural stands in British Columbia indicate that for the first 25 years, the rapid volume growth of alder surpasses all other conifers. After age 25, well-stocked, undamaged (i.e. no weevil) Sitka spruce (*Picea sitchensis*) stands may surpass the alder. Western hemlock (*Tsuga heterophylla*) may catch up to alder by age 35, Douglas-fir by age 40, and western red cedar (*Thuja plicata*) not until age 75 (Peterson et al. 1996).

The resistance of alder to many diseases afflicting conifers offers another reason for interest. Although alder has diseases of its own, it is immune to two widespread diseases in the region. The high incidence of laminated root rot (*Phellinus weirii*) in the region causes untold amounts of conifer growth losses. Conifer species show various levels of resistance, but all hardwoods are immune. On appropriate sites, alder is the species of choice in reforesting lands infected with laminated root rot (Nelson et al. 1978). Swiss needle cast, first observed in the Oregon Coast Range in the 1990's, affects approximately 50,000 hectares. In some heavily infected areas, it may cause up to 50% volume loss in Douglas-fir stands. Alder and western hemlock are alternative species to manage on lands heavily infected with this disease.

Alder produces more aboveground litterfall than do associated conifers. This litterfall has higher nutrient concentrations and decomposes more rapidly, resulting in improved nutrient cycling rates and leading to enhanced nutrient availability on a site. Furthermore, alder is a partner in a three-way symbiosis among roots, nitrogen-fixing actinomycetes in root nodules (*Frankia* spp.), and mycorrhizal fungi. This contributes to alder's rapid growth and positively influences soil structure and fertility. Rates of nitrogen fixation vary, but can range between 10-150kg/ha/yr (see table 1 in Bormann et al. 1994). Because nitrogen is the commonly limiting nutrient in the PNW, alder is likely to be important in the ecosystem productivity. Clearly, alder has the ability to improve soils not only for the next rotation, but long-term as well.

Studies in Alaska have shown that understory vegetation abundance, wildlife browse, songbird and aquatic invertebrate abundance, terrestrial arthropod abundance (Wipfli et al. 2002), and plant species richness (Deal 1997) increased with increasing proportion of alder in the stand. Furthermore, mixed alder-conifer stands provided greater complexity than stands dominated by either conifer or alder (Deal et al. 2004), enhancing the productivity and biological function of headwater streams (Wipfli et al. 2002).

Plantations vs. natural stands

The activities of the HSC have shown that managed plantations of alder can dramatically out-produce natural stands, resulting in a short-rotation, high-value crop. This apparent increase in productivity can be attributed primarily to three management activities: 1) proper selection of planting sites, 2) control of competing vegetation and initial planting density, and 3) intermediate stand treatments (i.e. thinning and/or pruning). Proper site selection and competition control are covered in other chapters. Planting density and thinning will be covered later in this chapter.

Perhaps the greatest advantage of managed stands of alder as compared to natural stands is the improvement in tree form. Most of the stems in older, natural alder stands have considerable lean and sweep, usually the result of uneven stocking, alder's high degree of phototropism, and differential growth rates (Wilson 1984). Such traits are considered defects and result in lower log value. Observations of planted stands indicate that the stems are much straighter than in unmanaged natural stands (Bormann 1985). Because the greatest value is in high-quality sawlogs, increases in log quality will result in direct increases in returns.

Alder plantations exhibit improved diameter and height growth rates across all site qualities and greater height growth across most planting densities except for extremely low densities. Research results indicate that the growth and yield of managed alder plantations will exceed that of natural stands (fig. 2). According to Worthington et al. (1960), 17 year old trees growing on site with a site index of 35 m would have a mean diameter of 15.3 cm. The mean diameter from one 17-year-old managed alder plantation of the same site quality was 23.3 cm, a 66% increase.

Height growth is also improved in plantations as compared to natural stands both across site quality classes and planting densities. Taking height growth data from 13 alder plantations, dividing into site quality class, and then overlaying these height growth curves on the site index curves from natural stands (Harrington and Curtis 1986) indicated that observed alder height growth in plantations was greater than predicted height growth across all site quality classes. Observed total height at age 12 was improved 1.4 m (9.3%) and 1.1 m (8.9%) for the high and low site quality classes, respectively (data not shown).

Alder growth is affected by stand density, and by controlling stand density it is possible to affect long-term stand trajectory. Figure 3 shows that observed tree height at year 12 was dramatically improved in all densities except of the extremely wide spacing (290 trees per hectare [tph]). Using the same data as the previous comparisons, observed height was improved 1.4 m (10.4%), 3.0 m (22.4%), and 2.0 m (14.9%) for the 680 tph, 1480 tph, and the 2800 tph densities, respectively, with the 1480 tph density approximating desired operational planting densities. However, tree height started to decline at extremely high densities (2800 tph). One would expect to see even greater declines in height growth with increasing density until it reached the levels of natural stands (which usually establish at very high densities).

So what are reasonable yield targets for managed alder plantations? Since no plantations have yet reached harvest age, one cannot say with absolute certainty. However, management of any species will increase yield. This pattern of increasing yield with management for Douglas-fir show that yields of intensively managed plantations can be double that of unmanaged natural stands. There is no reason to believe alder is any different.

Research results so far clearly indicate an increase in yield with alder management. Estimates of increased volume yield due to management range from 10-40% (Peterson et al. 1996, Puettman 1994) and increases in basal area of 14% (DeBell and Harrington 2002). Thinning can maintain diameter growth rates as much as 30-80%

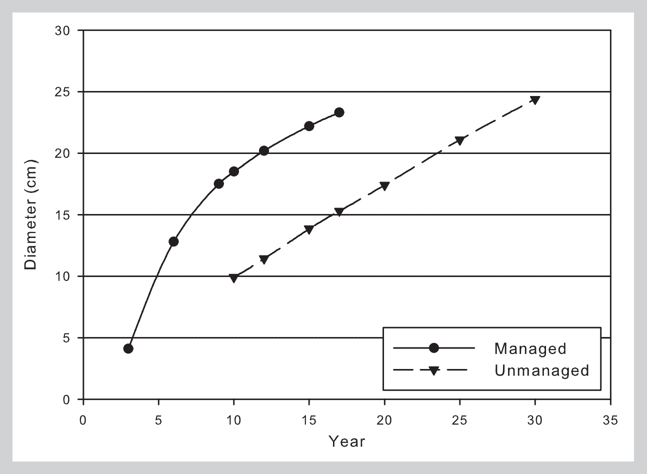

Figure 2—Comparison of diameter growth between an alder plantation (HSC Site #4201), planted at 1300 trees/hectare (tph) and thinned to 565 tph at age 4 with natural alder stands of the same site index (base age 50 years) of 35 m (from Worthington et. al. [1960]).

higher than those in unmanaged stands, at least until age 25. Thinning can maintain diameter growth rates of 0.75-1.0 cm/year for at least 10-15 years (Peterson et al. 1996). In another study, thinning increased the diameter growth of crop trees by 54% and net basal area growth was 60% greater, compared to unthinned stands (Hibbs et al. 1989).

Plantations would also have shorter rotations than natural stands. Managed stands are expected to attain an average diameter by 30 cm by age 30 years or earlier; an average natural stand would take 45 years (Peterson et al. 1996). Using the data from fig. 2 and assuming a constant diameter increment of 1.37 cm/year, the time required to produce a stand with mean diameter of 30 cm would be 22 years. DeBell and Harrington (2002) concluded that 20-year-old managed stands reached an equivalent basal area as that of a fully-stocked unmanaged stand of 27 years old. Other research (Barri Hermann, personal communication) has shown a halving of the time it takes managed plantations to reach the same yield (approximately 300 m^3/ha) as unmanaged stands (25 years vs. 50 years, respectively).

A serious concern for foresters is the lack of control one has over both density and stocking of natural stands. Of all the tools a silviculturist has, the manipulation of stand density holds the most promise; for density management provides opportunities to influence stand yield and tree size, form, and quality (Puettmann et al. 1993). Sawtimber yields and economic return can be greatly improved with management of most tree species—both alder and conifer—but the return for alder may be greater. With alder, management is needed to make the difference between good and poor results. The next section will describe experimental results of density management activities in alder plantations. Specifically, it will address the effect of initial planting density and thinning on individual tree and stand growth.

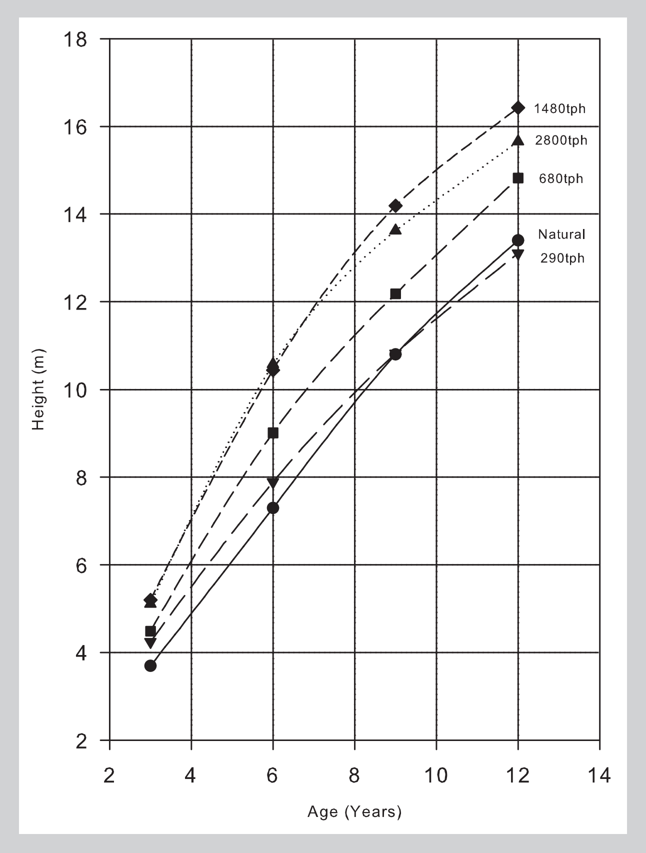

Figure 3—Comparison of height growth curves between managed plantations and natural stands of red alder. Plantation data is from 13 sites with a mean site index (base age 50 years) of 27.0 m (calculated from Harrington 1986). Height was calculated by planting density and was derived from the largest 247 trees per hectare. Natural stand data is from Harrington and Curtis (1986).

Density Management in Alder Stands

Methods

Site Description

The data in this analysis are from the 13 variable-density plantations of pure stands of alder in western Oregon and Washington that have reached 12 years old. The majority of plantations are in the Coast Range, with the remainder on the Olympic Peninsula, the Puget Trough, and the Western slopes of the Cascade Range (fig. 4). The climate is maritime and characterized by mild temperatures, wet, mild winters, cool, dry summers, and heavy precipitation (Franklin and Dyrness 1973). Soil types are silty loams, clay loams, gravelly loams, and cobbly loams. Elevation ranged from 46 m to 548 m, slopes ranged from 5% to 60%, and annual precipitation ranged from 115 cm to 330 cm.

Plantations were established on previously harvested sites of at least 6 ha and reasonably uniform ground

Figure 4—Location of Hardwood Silviculture Cooperative (HSC) pure alder plantations at least 12 years old.

conditions. Climatic (annual and growing season precipitation, length of growing season), and soils information was determined and site index was determined using the soil-site method of Harrington (1986). Mean site index (base age 50 years) was 30.9 m and ranged from 26-35 m. Treatment activities and data collection are administered by the Hardwood Silviculture Cooperative, Forest Science Department, Oregon State University, Corvallis, OR.

Measurements

At each site, blocks of inoculated, local alder nursery stock were planted with target spacings of 5.8 x 5.8 m, 3.8 x 3.8 m, 2.5 x 2.5 m, and 1.7 x 1.7 m (247, 568, 1297, 2967 tph). Site preparation methods used were the standard operating methods for the region and included normal competition reduction practices. Sites were planted using operational planting crews. Each treatment plot is 0.50 ha containing a 0.13 ha measurement plot. In addition to the four control plots, thinning and pruning treatments are present at each site. Seedling survival was evaluated in year one and year two and plots were interplanted if mortality exceeded 30 percent. All invading trees and any overtopping shrubs were controlled

Two thinning treatments were performed on the two highest planting densities (1297 and 2967 tph). The first treatment was thinning when the tree crowns closed and lower branch mortality commenced (hereafter referred to as the “early thin”). The second thinning treatment was thinning when the average height to the live crown was between 4.5 and 6.0 m (hereafter referred to as the “late thin”). Residual target density for all thinning treatments was 568 tph. Leave trees were selected based on spacing, form, and dominance and marked with flagging. DBH was measured on all trees (both trees to be “cut” and “saved”) and height and height to live crown was measured on all “save” trees. Measurements and thinning were done in the dormant season. Thinning was done with a chainsaw.

At age 3, 6, and 9, data on permanently tagged individual trees was collected in the dormant season. For every tree, stem diameter at 1.37 m (DBH), stem defect (fork, lean, sweep) and presence or absence of damage (animal, weather, etc) was recorded. Height was measured on a subsample of 40 trees spatially well-distributed over the plot that included the 10 trees of smallest diameter,10 of largest diameter, and 20 mid-range trees (based on diameter). Mean tree diameter was calculated as quadratic mean diameter. Plot means were calculated for diameter, height, and height to live crown for 1) the sample of trees on the plot that would represent the 247 trees per hectare with the largest diameter (used for initial planting density comparisons), or 2) all the trees on the plot (used for thinned versus unthinned comparisons). Actual density differed from target density and was calculated as the number of trees alive at age three, averaged across all sites. Individual tree volume was estimated from Skinner (1959) and volume per hectare was calculated by multiplying mean individual tree volume by the number of merchantable trees per acre (diameter greater than 15 cm).

Results

Planting Density

Early in stand development (through age 6), diameter increased with increasing density (fig. 5). After age 6, reduction of diameter with increasing density was observed primarily for the highest density. By age 9, DBH for the 2800 tph plots was 2.9 cm less (16% less) than the DBH in the lowest density (290 tph). DBH in the two intermediate densities was practically equal to the lowest density at age 9. Annual increment peaked at age 6 for all densities and then declined. At age 12, annual DBH increment ranged from 1.4 cm/yr to 1.8 cm/yr across all densities. By age 12, the typical reduction in DBH with increasing density was observed.

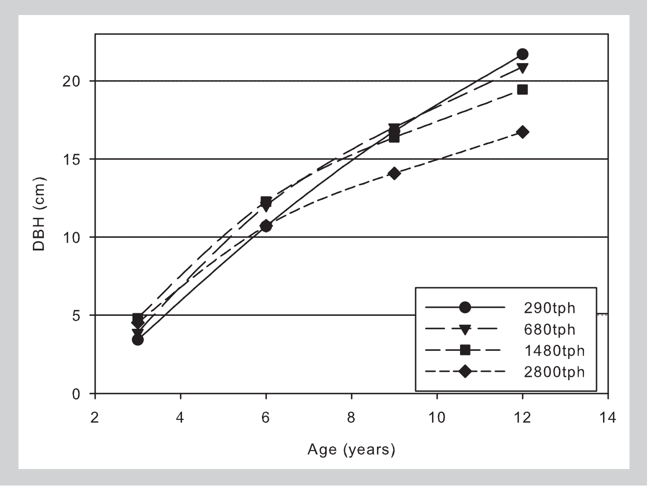

Figure 5—Comparison of diameter at breast height (DBH) by initial planting density for the 247 largest trees per hectare (crop trees). Data is derived from 13 red alder plantations throughout the Pacific Northwest with an average site index of 30.9 m (base age 50 years) calculated from Harrington (1986).

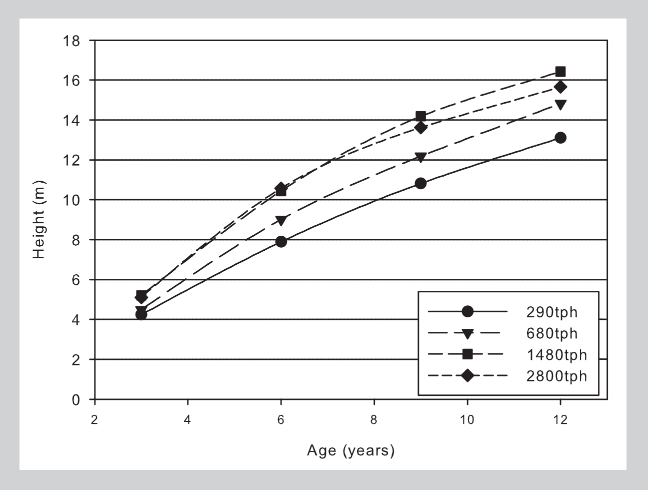

Figure 6—Comparison of total tree height by initial planting density for the 247 largest trees per hectare (crop trees). Data is derived from 13 red alder plantations throughout the Pacific Northwest with an average site index of 30.9 m (base age 50 years) calculated from Harrington (1986).

The influence of planting density on height was similar to that of DBH. Generally, height increased with density (fig. 6). This positive relationship was observed through age 6, after which height growth reductions were greater for the 2800 tph plots as compared to the 1480 tph plots. From age 6 through 12 the relative rankings did not change. As compared to the lowest density, total tree height increased 13%, 25%, and 19% for trees planted at 680 tph, 1480 tph and 2800 tph, respectively. For every measurement date, the lowest density (290 tph) had the shortest trees. By age 12, tree height in this density was at least 1.7 m less than the next closest planting density. At age 12, annual height increment ranged from 1.1 m/yr to 1.4 m/yr across all densities.

Across all densities, individual tree volume averaged 0.16 m^3 and ranged slightly from 0.14 m^3 to 0.18 m^3 (data not shown). A pattern of decreased individual tree volume with increasing density was observed. The number of merchantable trees varied substantially by planting density (data not shown). The intermediate densities, 680 tph and 1480 tph, had two to three times (432 tph and 494 tph, respectively) the number of merchantable trees per acre than that of both the high (202 tph) and low (158 tph) extremes. The proportion of merchantable trees to total trees was 0.56 and 0.63 for the 290 tph and the 680 tph densities, respectively, then declined to 0.33 for the 1480 tph and dropped sharply to 0.07 for the 2800 tph density.

The sharp differences in the number of merchantable trees per acre accounted for large differences in volume per hectare. Volume per hectare for the 680 tph and the 1480 tph was 73.3 m^3/ha and 81.2 m^3/ha, respectively. These volumes were almost three times that of the two density extremes. Volume per hectare for the 290 tph and the 2800 tph was 28.5 m^3/ha and 29.6 m^3/ha, respectively The 290 tph density had the largest individual trees; there were just not that many of them. The 2800 tph density had a lot of trees, just not many yet of merchantable size.

Live crown ratio, an important indicator of tree vigor, differed predictably by density. Figure 7 illustrates the decrease in crown ratio through time and with increasing density. Reductions in crown ratio commenced immediately and were of greatest magnitude in the highest density. Reductions occurred later and were of less magnitude as density decreased. No appreciable drop in crown ratio occurred in the lowest density through age 12. Although reductions in crown ratio are seemingly severe, it is important to note that even in the highest density, crown ratios of the crop trees are still greater than 50%. These results imply that although interspecific competition is undoubtedly occurring, dominant tree vigor remains high.

Thinning

Table 1 describes the tree and stand characteristics, both pre-and post-thinning, for all four treatments. In the 1480 tph density (both the early thin and the late thin treatments), thinning removed about half of the basal area and for the 2800 tph density, approximately two-thirds of the basal area. There were similar reductions in relative density.

Tree and stand responses to thinning are presented only for the 1480 tph densities with some comparisons to the 2800 tph densities. Two main factors affect tree and stand response to thinning; the timing and the intensity of thinning. Therefore, the similar response patterns observed between the two densities reveals a notable result, intensity (i.e. proportion of trees or basal area removed) has little effect on tree and stand growth following thinning at least within these timings and intensities. However, the timing of thinning noticeably affects tree and stand growth responses.

Table 1—Stand characteristics of thinned HSC plots.

	Early Thin		Late Thin	
Treatment	**1480 tph**	**2800 tph**	**1480 tph**	**2800 tph**
Age at thinning	5.09	5.27	8.73	8.20
Pre DBH (cm)	6.15	6.20	11.62	9.15
Post DBH (cm)	6.79	6.99	12.70	10.81
Post Live Crown Ratio	0.87	0.78	0.63	0.52
Pre Density (tph)	1332	2474	1371	2646
Post Density (tph)	555	573	584	624
% Density Removed	57%	72%	57%	76%
Pre Basal Area (m2/ha)	4.07	7.36	14.34	17.22
Post Basal Area (m2/ha)	2.09	2.26	7.43	5.78
% Basal Area Removed	48%	65%	48%	67%
Pre Relative Density	0.14	0.25	0.37	0.49
Post Relative Density	0.07	0.07	0.18	0.15
Relative Density Removed	0.07	0.18	0.19	0.34

Thinning increased diameter growth response as compared to the control plots; however, thinning at age five resulted in greater diameters than thinning at age eight (fig. 8). At age 12, diameters in the early thinned plots were 3.8 cm greater than the control while diameters in the late thinned plots were 2.3 cm greater. This corresponds to a 21% and a 14% increase, respectively. Annual diameter increments since thinning were 2.0 cm/yr and 1.5 cm/yr for the early thin and control, respectively and 1.3 cm/yr and 0.8 cm/yr for the late thin and control, respectively.

Thinning had virtually no effect on tree height (data not shown). At age 12, tree height ranged between 14.1 m and 15.0 m. Control trees were the tallest. There was only a 3% and a 6% reduction in tree height for the early thin and late thin, respectively.

Thinning increased individual tree volume. Individual tree volume at age 12 in plots thinned at age five was 0.19 m^3, a 14% increase compared to unthinned plots (0.16 m^3). The volume of trees thinned at age eight was only 4% greater (0.17 m^3) than unthinned trees (data not shown). Thinning reduced the number of merchantable trees per hectare. There were 494 tph of merchantable size in the unthinned plots as compared to 469 tph in the early thin and 400 in the late thin (data not shown). The minor differences in individual tree volume and merchantable trees per hectare resulted in slight differences in volume per hectare. The greatest volume occurred in the early thin plots (89.0 m^3/ha), followed by the unthinned plots (81.2 m^3/ha) and finally the late thinned plots (68.0 m^3/ha). This corresponded to a 9% increase in volume for the early thin and a 16% reduction in volume for the late thin compared to the controls.

Discussion

Planting Density

Contrary to conventional wisdom and much experience, the results presented here show that early diameter and height increase with stand density. Up through age 6, diameter growth increases with density until a crossover effect occurs between ages 7 through 11. Up through age 9, no penalty occurs with increasing density except at extremely high densities. Optimal diameter growth was maximized in the intermediate densities through about 10 years of age, after which optimal diameter growth shifted to the lowest density (290 tph). Only by age 12 was the pattern of decreasing diameter with increasing density observed. It could be argued that these results are not unique at all since the typical relationship of diameter and density did occur and (most likely) will continue and intensify as the stands age. Also, this crossover effect could be due to a combination of factors since early tree growth is a result of many factors in addition to density (Puettman 1994).

As discussed earlier in this chapter, one goal of managing alder is to capture the difference in early growth between alder and conifers. Therefore it follows that a manager should then continue to capture the difference in early growth between alder densities. These early differences are important for at least three reasons. First, due to the short rotation ages predicted, 10 years old is about half to a third of a rotation. It would be unwise to ignore this phase of growth. Second, since thinning can maintain diameter growth rates and current research indicates the possible need to thin alder plantations before age 10, one could not only take advantage of the positive relationship

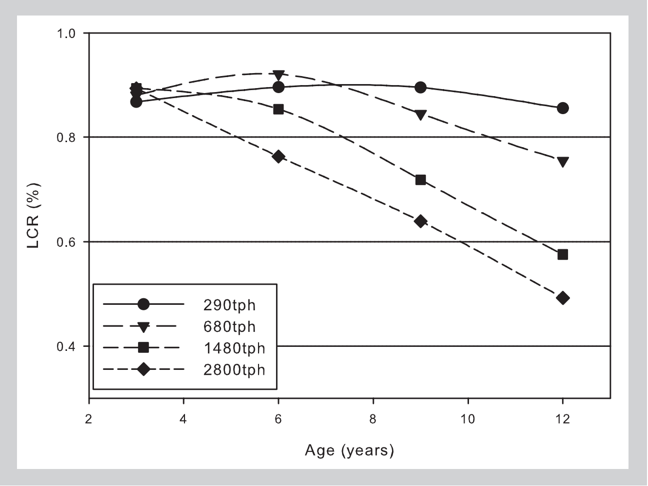

Figure 7—Comparison of live crown ratio (LCR) by initial planting density for the 247 largest trees per hectare (crop trees). Data is derived from 13 red alder plantations throughout the Pacific Northwest with an average site index of 30.9 m (base age 50 years) calculated from Harrington (1986).

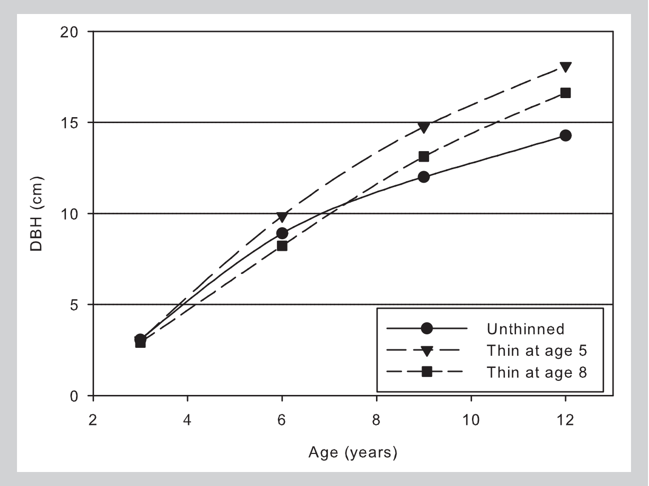

Figure 8—Comparison of diameter at breast height (DBH) for unthinned (control) trees, trees thinned at age 4 and trees thinned at age 8. All plots were planted at approximately 1480 trees per hectare (tph) and thinned to approximately 570 tph. Data is derived from 13 red alder plantations throughout the Pacific Northwest with an average site index of 30.9 m (base age 50 years) calculated from Harrington (1986).

between diameter and initial density, but possibly continue to build off of these increased growth rates. Third, since no penalty is incurred with increasing density but a huge improvement in tree form occurs with increasing density, log quality and thus value is maximized.

Mean annual diameter growth rates reported here (1.64 cm/yr, averaged across all densities) compare favorably to those reported in DeBell and Harrington (2002). They report annual diameter growth rates of 1.2 and 1.0 cm/yr for 20-year-old trees grown in a plantation on a comparable site. Across their lowest density plots (within the range of densities presented here and potential operational planting densities), the similar pattern of decreasing diameter increment with increasing density was detected.

Comparisons of the results presented here with other spacing trials are difficult due to the natural regeneration origin of previous spacing studies as well as the extremely high (outside the range of operational forestry) densities used. However, in a review of density management studies, Puettman (1994) reported annual diameter growth rates between 0.6 and 1.2 cm/yr. He then extrapolates that under optimal management regimes “good” sites could average trees 38 cm in diameter in approximately 27 years. Using these same assumptions and the mean diameter increment across all densities (1.64 cm/yr) reported here, it would take only 23 years to attain trees of comparable size.

Contrary to conventional wisdom, dominant height growth was not independent of stand density. Generally, height increased with stand density except at extremely high densities. Trees were consistently shorter in the lowest density plots. Will the crossover effect occur for height as it did for diameter? It did for the highest density but looking at the height growth curves of the three lower densities, it remains unclear. All curves seem to have parallel trajectories at age 12 and since height growth for alder decreases dramatically around age 20, one could conclude that early differences in tree height due to planting density may maintain themselves through an entire rotation.

The rapid decline in height growth for only the densest plots raises an interesting question about potential differences in height growth patterns between plantations and natural stands. All published height growth curves are based on natural stands and natural stands usually establish at densities equal to, or more often, much higher, than 2800 tph. Height growth reductions of the lower plantation densities were less than the highest density and seem to remain fairly constant. These results further indicate tree growth in plantations is distinct from that of natural stands and elucidates the need to draw new height growth curves for plantation-grown trees.

The negative effect of density on diameter combined with the positive effect on height resulted in similar mean individual, merchantable tree volume across all planting densities. However, the number of merchantable trees per acre varied considerably, mainly as a function of the absolute number of trees per acre and minimum merchantability limits. Trees in the lowest densities were generally larger in diameter than the other densities and therefore had a very large percentage (but not number) of merchantable trees. Conversely, the densest plots had lots of trees but few above the merchantable diameter limit. At this time, the best balance between tree size and number is found in the intermediate densities. Stand volume was considerably greater at intermediate densities as compared to the two density extremes.

Individual crop tree volumes reported here (0.16 m^3) were comparable but slightly greater than that reported by Hibbs et al. (1989) for 14-year-old individual crop tree volumes found in a natural stand (0.15 m^3). Per hectare volumes of the two intermediate densities in this study (approx. 77.3 m^3/ha) was much greater than what Worthington et al. (1960) predicted for 15 year-old unmanaged alder of equivalent site productivity (31.4 m^3/ha).

These volume estimates are only a snapshot during stand development. Using these values at age 12 to predict volume at final rotation age is unwise for multiple reasons. First, as the stands age, growth rates change in different patterns for the different planting densities. These differential diameter and height growth rates are not accounted for and will result in major errors in extrapolation. Second, these are merchantable volume estimates (trees greater than 15 cm DBH). Not accounted for are the trees just below this limit that would become merchantable in the future. Third, stand growth (and thus volume) will be affected by any changes in site or stand growing conditions. Precipitation, storm events, insects, etc. all affect final stand volume.

The growth patterns observed here are unexpected results according to current theory (Grey 1989, Smith et al. 1997). Density-dependent height growth has been observed for southern pines (MacFarlane et al. 2000, Quicke et al. 1999) and for Douglas-fir (Scott et al. 1998). For alder, this effect has either not been observed (Bormann 1985, Smith and DeBell 1974) or observed for alder planted at extremely high densities (DeBell and Harrington 2002, Hurd and DeBell 2001), well outside the range of operational planting levels.

This research agrees with previous research (Bormann and Gordon 1984, Cole and Newton 1987, DeBell and Giordano 1994, Hibbs et al. 1989, and Knowe and Hibbs 1996) that optimum height growth is maintained at intermediate levels of density and reduced at either extreme. But a word of caution is needed when attempting to compare natural stand growth with plantation growth. Puettman (1994) recognized that site index curves are based on natural stands and natural stands come in at very high initial densities. This would result in reductions in potential height growth and an overestimation of productivity when applied to plantations. Furthermore, will this enhanced height growth continue to final rotation? Regardless, it is apparent that just the simple act of planting trees at lower densities than those found in natural stands can increase diameter and height growth through at least age 12.

Log quality is extremely important in determining value for alder since clear wood has much greater value than unclear wood. Perhaps what is more important than the differential effect of density on growth is the effect of density on tree form. Figure 9 illustrates the stem form differences found across planting densities. Increasing planting density reduces multiple stems, tree lean and sweep and increases the length of the branch-free bole; resulting in increased log quality. This research and others has found that long-term diameter growth will be reduced somewhat at these higher densities. Wide spacings, however, lead to large branches on the lower bole that reduces log grade and value of lumber recovered. Such branching can be reduced by growing the trees at denser spacing to facilitate natural pruning (Hibbs and DeBell 1994), and then thinning once a desired branch-free bole is obtained. This research indicates planting at intermediate densities maximizes tree form with minimal deductions in growth. Furthermore, a clear understanding of the effect of live crown ratio on tree growth and log quality is absolutely essential in choosing and timing silvicultural treatments.

Thinning

The crossover effect observed in diameter due to planting density begs the question of whether or not to thin alder plantations (and if one should, then when and to what residual density). Clearly, diameter growth rates are optimized in intermediate densities through age ten, then they start to decline. This leads to the question; can these declines in diameter (and by extension, volume) growth be prevented with thinning? This question will be discussed in the framework of four issues: intensity of the thin, timing of the thin, tree vigor, and stem form.

Although not specifically tested in this project, it seemed that the intensity or magnitude of removal with thinning had little effect on tree growth response. As mentioned earlier, thinning 2800 tph plots to the same residual density as the 1480 tph plots (i.e. a much heavier thin, see table 1) resulted in the same patterns of individual tree response. However, stand responses would differ in that the leave trees in these denser plots would be smaller than the intermediate plots, would have reduced diameter increments, and would thus take longer to reach equivalent size. Secondly, it has been observed that alder is susceptible to weather damage following thinning, especially with drastic reductions from very high densities. The experimental design here had all thinning treatments to one residual density (approximately 570 tph). Therefore, until more research is done testing specific residual densities, specific recommendations on the intensity of precommercial thinning cannot be accurately made. However, within the range of the densities used in this project, thinning resulted in increased diameter response, had no effect on tree height, and thus increased individual tree volume regardless of pre- or post-thinning densities.

Results presented here indicate that thinning elevated diameter increment levels as compared to not thinning. Furthermore, thinning early offset or prevented the gradual decline in diameter increment with age and thus resulted in greater diameter increment when compared to thinning later. At age 12, the mean diameter of plots thinned at age five (on average) was 1.5 cm greater than plots thinned at age eight. This increase would likely be maintained throughout the

Figure 9—Comparison of tree form between trees planted at planted at 1480 trees per hectare (left) and planted at 290 trees per hectare (right). Both photos taken on the same day, from the same plantation, from the same location.

rotation as seen by the apparent parallel diameter trajectories of the thinned plots illustrated in fig. 8.

The question of when to thin can also be addressed by using this data and placing it into the context of relative density. Relative density was calculated for each of the four planting densities and plotted in relation to the density management guide (Puettman et al. 1993) in fig. 10. Line B (relative density of 0.65) is the average maximum or the "self-thinning" line that stands approach as trees grow and mortality reduces their numbers. Line C (relative density of 0.45) is the operating maximum which is the line above which considerable mortality occurs. Line D (relative density of 0.25) is the competition threshold which is the line below which the site resources are not fully utilized. The zone between lines D and C is considered the recommended management zone because 1) below line D individual tree diameter growth is maximized but stand productivity is reduced and 2) above line C substantial mortality and reduction in tree growth occurs. This management zone compromises individual tree growth and stand yield.

Therefore, according to the diagram, trees in the 1480 tph density would start suffering growth losses (i.e. competition) at age six and significant mortality at age ten. This timeframe of the management zone underlies the importance of early management and illustrates the narrow "window" of management activities of alder stands as compared to conifers. However, the data used here implies that diameter growth reductions may occur even before age 6 (i.e. Line D) and waiting until age ten (i.e. Line C) would result in not only mortality but significant losses in diameter growth.

According to Puettman et al. (1993), the location of the competition threshold (Line D) was determined not only by diameter growth reductions due to competition but also by the observation that some stands thinned below this line showed reductions in height growth (also see Hibbs et al. 1989) and that trees growing in stands with densities below this line had poor height growth and stem form. Therefore, the recommendation is not to thin below a relative density of 0.25. The results presented here are contrary to this recommendation. First, as stated above, it seemed that substantial diameter growth losses in plantations occurred near or even below Line D. Second, no reductions in height growth after thinning occurred in any of the four thinning treatments, all of which reduced relative density far below Line D. Third, trees in these stands had already achieved desirable stem form and form did not deteriorate after thinning. The discrepancies between what was observed here and the recommendations from the stand density diagram (thin earlier and heavier) emphasize the need for more research on tree growth in plantations versus natural

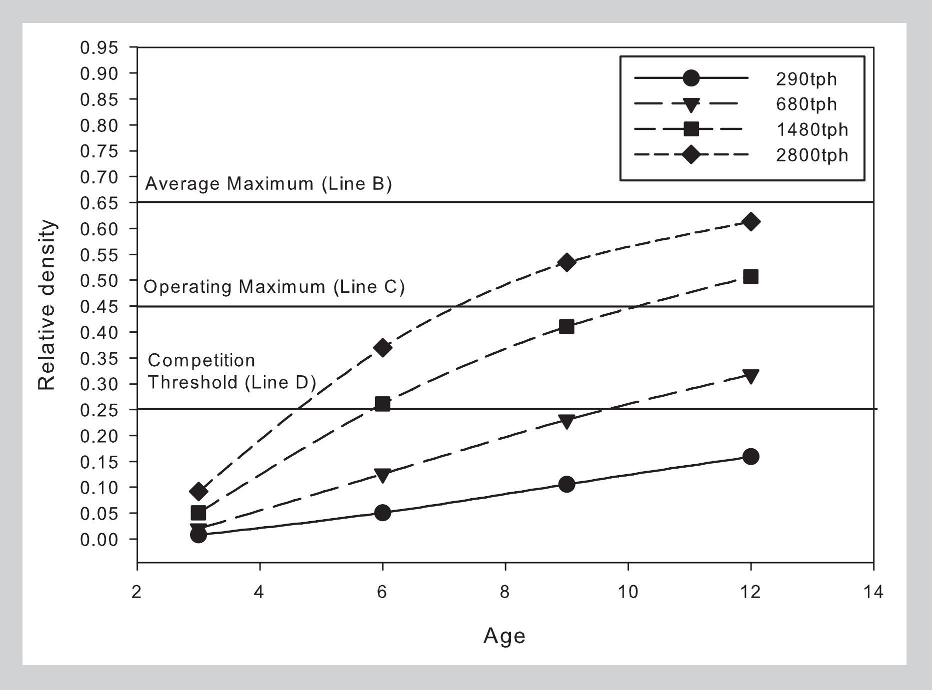

Figure 10—Relative density by initial planting density. Data is derived from 13 red alder plantations throughout the Pacific Northwest with an average site index of 30.9 m (base age 50 years) calculated from Harrington (1986). Lines B, C, and D are taken from the density management guide developed by Puettman et al. (1993).

stands, underscore the benefits of stand management and illustrate the importance of tree vigor and stem form in determining when to thin.

When alder is planted at densities high enough to rapidly occupy the site and (as shown earlier) to maximize early tree growth, crown recession occurs rapidly. Thus, it would seem that thinning early is crucial since thinning must favor trees with good growth potential (i.e. large crown size). Thinning early will capture the early rapid growth phase and maintain a good live crown ratio but reduce stem quality because of the presence of branches on the lower stem. Trees thinned late would have better wood quality but reduced vigor (as indicated by reduced crown ratios) and thus, less growth response following thinning. Therefore, as with all species, the goal of thinning is to balance the maintenance of vigorous individual tree growth with overall stand growth and, more exclusively with alder, optimal stem quality.

Thinning in alder plantations increased individual tree diameter with minimal effect on height growth. Volume data at age 12 indicated that the reduction in stand density through thinning is offset or will be overcome by the increased diameter growth rates associated with thinning. Furthermore, the accelerated diameter growth rates would result in shorter rotations because the remaining trees would reach commercial size sooner. However, the long-term effects of the time and intensity of thinning on plantation yield and wood quality are still unknown.

Conclusion

Red alder (*Alnus rubra*) is the major hardwood tree in the Pacific Northwest yet, until recently, management efforts have been practically non-existent. However, the rapid growth rates and the recent increase in alder prices have resulted in increased interest in managing alder.

Due to a number of biological factors, managing alder is different from managing conifers. First, alder has impressive juvenile growth rates. It is not until about age 40 that the associated conifers surpass alder in height. This not only reduces rotation lengths but creates a narrower window in which to perform management activities. Second, good performance of alder is limited to a narrower range of sites than most conifers. For instance, alder is very susceptible to summer drought stress as well as unseasonable frosts. This makes site selection and site preparation an extremely important first step in alder plantation establishment. Third, alder is resistant to many diseases that afflict conifers such as laminated root rot and Swiss needle cast. Fourth, alder is an important element of healthy forests and biodiversity. Alder fixes nitrogen (improving site productivity), furnishes wildlife habitat and is an important component in aquatic food webs. Fifth, alder is not a commodity product; it occupies a special niche due to its uniform wood properties. This places special emphasis on log quality as well as overall yield.

Previous research has indicated that managed stands of alder can out-perform natural stands. Not only are growth rates increased, but tree/stem form are improved as well. This improvement is mainly due to proper site selection, control of competing vegetation and planting density, and silvicultural treatments.

When deciding on whether, when, and how much to thin, a manager must weigh individual tree growth and vigor, stand yield, and log quality. Regardless of specific ownership objectives, it is recommended that precommercial thinning should be done early in stand development. Thinning too early negates the growth benefits associated with higher densities and would reduce stem quality due to branches. Thinning too late results in improved wood quality (due to self-pruning) but the trees are smaller with reduced vigor and thus do not respond well to the thinning.

More research into the long-term effects of initial plantation density and the timing and intensity of thinning treatments on alder tree growth, wood quality, and stand yield is needed. Once this is achieved and an alder growth and yield model is developed, alder can contribute to both economic and ecological forest management objectives.

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Red Alder Plantation Establishment: Site Selection, Site Preparation, Planting Stock, and Regeneration

Alex Dobkowski[1]

Abstract

The information to be presented is based on research results from experimentation done on red alder (*Alnus rubra* Bong.) from 1987 to 2001 by Weyerhaeuser Company, and anecdotal evidence from almost 20-years of experience growing red alder at an operational-scale on Weyerhaeuser lands in western Washington.

As with any tree species, the keys to successful red alder plantations establishment are: (1) site selection; (2) quality planting stock; (3) site preparation; (4) out plant timing; and (5) planting quality. However, red alder is generally less forgiving of sub-optimums for these factors than other commercial tree species grown in the Pacific Northwest.

Frost, very poor soil drainage, drought stress and exposure can negatively affect establishment success, site productivity and wood quality (from top-breakage and sun-scald) of red alder plantations. Sites with these characteristics are not suitable for growing of red alder commercially. Frost/cold is the number one killer of planted red alder—avoid frost prone sites and within-site frost pockets. Generally, the best sites biologically for growing red alder are also some of the best sites for growing Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco).

All stock types have been used to establish red alder plantations successfully. Seedling morphological characteristics and physiological readiness at time of planting, and site conditions over the first 3-years, determine field performance success. Seedling survival and early growth is predicted by the following factors: (1) stem basal caliper (measured 25-mm above the root-collar); (2) height; (3) height on the stem to the lowest healthy bud; (4) percent of the stem with healthy buds; (5) total vegetation ground cover in years 1 and 2; and (6) root system fullness. Basal caliper appears to be the most significant factor for seedling survival and growth—presumably because more stored carbohydrates are available for new root growth early in the growing season. This allows the tree to develop an active root system before the demands from rapid leaf growth begins. Seedlings with a basal caliper of 6-10 mm, height of 60-90 cm, a root mass that is dense enough to indicate a good balance with the shoot, and with abundant *Frankia* nodules throughout the root system will survive, grow fast and capture the site quickly.

Weed competition > 30% cover decreases growth and > 90% decreases survival. Currently there are few selective herbicides for release of planted red alder from weed competition—most broadcast vegetation control must be done prior to planting.

The spring planting period begins when the probability of a killing frost is low and ends before there is an appreciable seasonal drying of the soil. The recommended planting window for western Washington, at elevations less than 300 meters, is mid-March to mid-April.

Red alder plantation establishment can be very successful on "the right sites," when the "correct" silviculture is practiced. Establishment success and subsequent tree growth can be highly variable on "sub-optimal" sites, or when sub-optimal silviculture is practiced.

Keywords: Red alder (*Alnus rubra* Bong.), site selection, planting stock, site preparation and planting.

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Introduction

Red alder (*Alnus rubra* Bong.) is a valuable hardwood tree species that competes with many other hardwoods in the marketplace (Western Hardwood Association 2005). Red alder is used principally for the production of lumber and veneer—high-grade lumber for fine furniture, cabinets, and turnings; lower-grade lumber for furniture frames/interior parts and pallets; face veneer for cabinets; and core veneer for high-quality paneling. When red alder is compared to other important North American hardwoods—yellow birch (*Betula alleghaniensis* Britton), black cherry (*Prunus serotina* Ehrh.), sugar maple (*Acer saccharum* Marshall)—its workability index reflects that it is very competitive for finishing, machining, sanding, polishing, color uniformity and gluing, and it has the lowest specific gravity/strength. A very important characteristic of red alder is that the wood readily accepts stain enabling red alder to mimic more expensive woods very convincingly. Lower grade alder logs have value as a desirable pulpwood species.

Because of the expectation of a continuing strong hardwood industry in the Pacific Northwest, some landowners are investing in growing red alder saw-logs to provide future raw material for that industry. This paper will focus on what we know about the requisites for successful red alder plantation establishment. The information presented is based on results from experimentation, and anecdotal evidence from almost 20-years of research and operational experience in red alder tree growing. The intent is to provide a practical guide to assist landowners in growing red alder plantations successfully.

As with any tree species, the factors to successful red alder plantations are: (1) site selection; (2) quality planting stock; (3) correct site preparation; (4) proper out plant timing; and (5) planting quality. The exception for red alder is that the species is generally less forgiving of sub-optimums for these factors than other commercial tree species grown in the Pacific Northwest.

Site Selection

Site selection for red alder requires evaluation of site characteristics relative to the risk of plantation failure from environmental factors, red alder productivity potential, and the need for herbaceous weed control. The objective is to exclude from consideration planting units that will have obviously low red alder productivity potential and/or obviously high risk of plantation failure due to poor soil drainage, frost, drought or inability to control weed competition.

Risk of Plantation Failure

Some characteristics of the better sites for red alder management are (Harrington 1986, Harrington et al. 1994):

Elevation – Less than 300 m;

Physiographic position – Flood plain, terrace, bench, lower slopes;

Aspect – West to east slopes;

Slope – 10-30%;

Soil drainage –Well drained;

Soil texture – Silt loam, silty clay loam, clay loam, silty, clay;

Soil depth – Greater than 75 cm;

Depth to summer water table – 2- to 3-meters; and

Parent material – Sedimentary, sedimentary/volcanic, and volcanic.

Planting units with a combination of the following site characteristics are probably undesirable candidates for red alder production (site productivity will be low and the risk of plantation failure will be high):

- Bog or marsh areas;
- Upper slope positions;
- Ridge tops;
- S to SW exposures;
- Frost pockets (within site & “macro” cold air drainage);
- Exposed and windy sites;
- Droughty sites - sandy, excessively drained, soils;
- Poorly drained soils;
- Depth to summer water table less than 1-meter or greater than 4-meters.
- Highly weathered/leached soils.
- Elevation greater than 450 meters.
- Sites with expected very high levels of weed competition that can not be adequately controlled to low levels—i.e. salal (*Gaultheria shallon*).

Foresters need to use their judgment when determining the suitability of a site for growing red alder. Any single characteristic that would result in a high risk of plantation failure may be sufficient to exclude a unit from consideration for red alder production (e.g., a severe frost pocket). If a unit has an “undesirable” characteristic that does not increase the risk of mortality, it may still be acceptable for red alder production depending on the combination of other factors (e.g., S to SW Exposure). A site with multiple “undesirable” characteristics is probably unacceptable as a red alder management unit (e.g., S to SW exposure and excessively drained soils).

Select sites with a low risk of regeneration failure. Poor soil drainage, frost, drought and difficult to control weed communities can hinder successful plantation establishment considerably.

Although naturally occurring red alder can tolerate poorly drained soils, careful examination shows that it occupies only the better drained micro-sites within the irregular topography of a wet site. The establishment of a well-stocked plantation is significantly hindered on wet sites because suitable micro-sites occur infrequently and are poorly distributed.

Newly planted seedlings are adversely affected by poor drainage. Where saturated soils persist into the growing season, poor drainage induces seedling mortality and also severely restricts root growth of those seedlings that survive periodic soil saturation. The diminished root system can predispose newly planted seedlings to later summer drought stress. Given the heavy herbaceous weed communities that can develop on these sites and limited site preparation options, drought stress effects can be compounded, resulting in considerable seedling mortality. Red alder is a riparian and upland site species—not a wet-site species.

Areas of high frost hazard should not be regenerated to red alder. These sites are associated with topographic features having a high probability of cold air drainage from higher elevations in the spring and fall seasons (fig. 1). Vegetation condition and topographic features can be used to assess the likelihood that a site is in a cold-air drainage. Red alder and other naturally occurring woody vegetation can show evidence of previous frost events. Areas where fog hangs for long periods indicate potential for a frost pocket. Valleys exhibiting a gentle gradient from high elevation areas or topographic features that form blockages tend to slow the flow of cold air and be more frost-prone. Frost risk is increased if there is a cold-air dam such as a ridge of mature trees downhill or downwind (a planting unit that is surrounded by timber can create a frost pocket).

There is evidence that soils with a high summer water table may be more prone to frost risk. These soils provide a good supply of late-growing season soil moisture—prolonging red alder growth well into the early fall. Alder in this de-hardened state are very vulnerable to early frost. This type of an effect is usually very clustered within a plantation. Exposed sites in the Cascade foothills, that are prone to east-winds in the winter, also have a high risk of freeze related mortality and damage. The effects of cold associated with normal seasonal weather can be mitigated a considerable amount through site selection. However, young red alder plantations will always be vulnerable to the effects of arctic outbreaks in the early-autumn because red alder tends to grow late into the growing season and is usually not hardened-off by early-autumn.

Figure 1—Shown is an example of how topographic conditions can be evaluated to judge the risk of cold damage—“Dw” has a high risk of frost—cold air accumulation; “Ll” on mid- to upper slope positions has enough “air” drainage to prevent serious frost. Note photograph plantation failure from cold damage on “Dw” and vigorous, well-stocked plantation just upslope on soil “Ll”.

Summer drought and heat stress contribute significantly to reduced performance of newly planted red alder seedlings. Regeneration difficulties have been particularly noted on droughty sites typified by south-southwest aspects, steep slopes, and coarser textured soils. Units with heavy textured soil that have been seriously compacted from ground-based logging tend to have excessive alder mortality on logging trails—root system development seems to be seriously impeded and moisture stress results as the crown foliage mass continues to develop.

There may be portions of a planting unit that is unsuitable for red alder—frost, wind, or drought prone. If these micro-sites are large enough to be identified and flagged-out, Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) or some other species should be planted. An example of this would be units in the Cascade foothills. The mid- and lower-slopes can be ideal for red alder and the ridge-top slope position unsuitable. Steep southwest slopes in a unit with predominantly moderate slope and favorable aspect are another example.

Red Alder Site Productivity

Site productivity for red alder is an important consideration for commercial production. Site index based on the heights of an appropriate sample of trees near index age (i.e., base-age 20 or 50-years for red alder) is a common practice for making this determination. Most often site index can not be estimated directly from tree height measurements because the tree species of interest is not presently growing in even-aged stands, of the correct age, in the vicinity of sites to be regenerated. A useful estimate of red alder site productivity (base age 50-years, Worthington 1960) can be obtained in the absence of site trees to measure following the procedures given in, "A Method of Site Quality Evaluation for Red Alder" (Harrington 1986).

The evaluation process requires that the user score soil-site factors that pertain to geographic/physiographic characteristics, soil moisture/aeration, and soil fertility/physical properties. Applying the site quality evaluation method requires the soil survey/soil series profile descriptions, long-term meteorological data, local knowledge and on-site observation.

Soil survey and soil series profile descriptions provide information on the following: 1) elevation; 2) physiographic position; 3) aspect and slope; 4) soil texture; 5) soil depth; 6) soil rock and gravel content; 7) soil parent material; 8) soil pH; 9) soil organic matter, and 10) soil bulk density. Published long-term meteorological data from the recording station closest to the planting unit is used to determine growing season precipitation (April 1 through September 30). Local knowledge is used to assess special hazards (frost pockets, exposure, wind, etc.), internal soil drainage, and approximate depth to the summer water table.

On-site observation is required to: 1) confirm the soil-site factors taken from the soil survey; 2) determine site specific special hazards; 3) verify internal drainage and summer water table depth assumptions; 4) evaluate the character of red alder growing in the vicinity of the unit (frost or heat damage, health, stem form, etc.).

Experience has shown that this approach classifies sites accurately as to good, intermediate or poor sites for growing red alder. The accuracy of the method can be increased by giving more of a deduction in site-points for droughty sites, exposed windy sites, frost pockets, and when pH in the surface soil is 4.0 or less.

Lands selected for growing red alder should be good sites and have a very low risk of poor establishment success. Generally, the best sites biologically for growing red alder are also some of the best sites for growing Douglas-fir.

Planting Stock

All stock types (containerized plug, bare-root, plug+1/2 transplant) have been used successfully to establish red alder plantations (Radwan et al. 1992, Dobkowski et al. 1994). Research trials have shown that survival and early growth of bare-root seedlings is predicted by the following morphological characteristics and other factors: (1) basal caliper (measured 25mm above the root collar); (2) height; (3) height to the lowest healthy bud or lateral branch; (4) percent of the stem with healthy buds or branch laterals; (5) total vegetation ground cover in years 1 and 2; and (6) root system fullness. Root System fullness for bare-root seedlings is classified as follows:

Good (fig. 2)—An abundance of fibrous, flexible, heavily branched roots, and an absence of heavy, stringy, non-branched roots; root mass is dense enough to indicate a good balance with the shoot; abundant *Frankia* nodulation present.

Fair (fig. 3)—One or several heavy, woody, non-branched roots, but a portion of the root system is fibrous and well-branched, shoot appears proportionately heavier than the root system (i.e., shoot and roots are not "well balanced"); *Frankia* nodulation present.

Poor (fig. 4)—Root systems are predominately composed of heavy, woody, non-branched roots, or if there are fibrous roots, they are too few to support the tree; the root system is clearly out of balance with the shoot. *Frankia* nodulation is rare.

Basal caliper appears to be the most significant factor for seedling survival and growth—presumably because more stored carbohydrates are available for new root growth early in the growing season. This allows the tree to develop an active root system before the demands from rapid leaf growth begins.

Figure 5 gives an example from one experiment showing the relationship between the probability of achieving an age-1 plantation-height target and seedling root system, basal caliper and height (A. Dobkowski, unpublished data 2004). This result from a logistic regression analysis indicates that seedlings with a good root system, basal caliper of 6 mm or more, and height of 60 cm has a 0.80 probability of achieving the age-1 height target.

Results from this and other field experiments, coupled with operational experience, suggests the following specifications for bare-root seedlings (Ahrens 1994, Dobkowski et al. 1994, Molina et al. 1994, Kendall et al. 2003):

- Height—range 45-100 cm—with approximately 70% of the seedlings between 60 and 70 cm;
- Basal caliper (measured 25 mm above the root collar)—5 mm minimum caliper—with approximately 70% of the seedlings between 6 and 9 mm;
- Root systems characterized by an abundance of fibrous, flexible, heavily branched roots, and an absence of heavy, stringy, unbranched roots, root mass dense enough to indicate a good balance with the shoot; many Frankia nodules;
- Healthy branches or buds along the full-length of the stem; and
- Free from disease and top-damage.

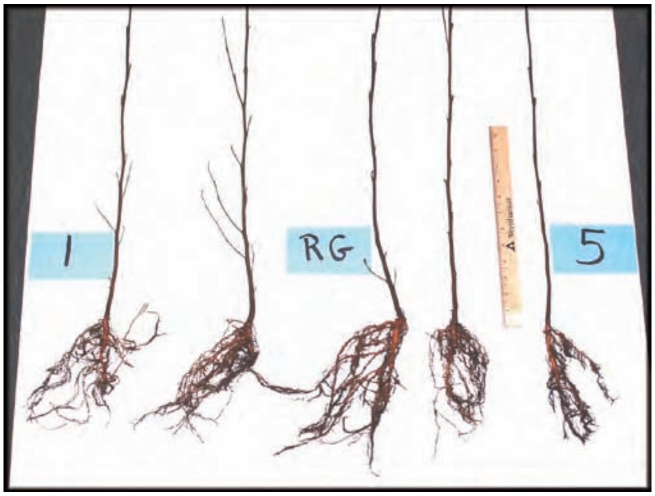

Figure 2—Shown are bare-root seedlings (1+0)—height and basal caliper suitable for out-planting—“Good” root systems.

Figure 4—Shown are bare-root seedlings (1+0)—height and basal caliper suitable for out-planting—“Poor” root systems.

Figure 3—Shown are bare-root seedlings (1+0)—height and basal caliper suitable for out-planting—“Fair” root systems.

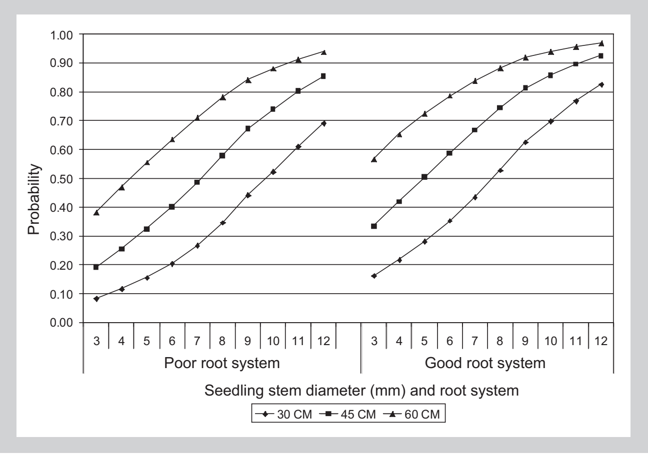

Figure 5—Shown is the probability of bare-root seedlings, with poor or good root systems, achieving 1-meter in height one growing season after planting.

Bare-root seedlings with these attributes, when planted on good sites and with proper site preparation, will achieve survival and height-age targets most of the time. Generally, large seedlings (large caliper, balanced height and caliper, good root systems and *Frankia* nodulation) are preferred—even when taking into consideration that the logistics of handling and planting large stock is more problematic and can incur more cost. Smaller stock types and seedlings generally have a much greater risk of poor performance.

Weed Control

Heavy first and second-year weed competition, particularly grass and herbaceous plant life-forms, has been shown to be detrimental to red alder survival and growth (Figueroa 1988, Dobkowski et al. 1994). Weed competition thresholds based on first-year cumulative ground cover of grass/sedge, forbs ferns, and woody plants:

- Minimal Effects – Below 20%;
- Growth Impacts – 30% to 80%; and
- Survival Impacts – Greater than 90%.

Weed competition occurring late in the first growing season, and in the second growing season, can have serious impacts on rapid tree growth. Effective control of weed competition can often be the difference between plantation success and failure (fig. 6).

Figure 7 (A. Dobkowski, unpublished data 2004) shows the probability of achieving plantation height age targets by seedling basal stem diameter and height at time of planting with heavy (80%+ cumulative vegetation ground cover) and very-low weed competition (10%-15% cumulative vegetation ground cover). This result indicates that even seedlings with larger basal caliper (7 to 9 mm) do not perform satisfactorily under heavy weed competition. Conversely, most seedlings large enough for operational out-planting (basal caliper greater than 5 mm and height of greater than 45 cm) perform well under low weed competition.

Weed control prescriptions need to consider weed communities that existed in the under-story of the harvested stand as well as weed invasion by forbs, grasses, and woody shrubs into newly harvested areas. There are currently a very limited number of herbicides for site preparation and the release of planted red alder from weed competition. For practical purposes, all broadcast herbicide control measures must be taken prior to planting. Atrazine 90 WSP™ (active ingredient, Atrazine; Helena Chemical Company 2005; Washington State only), Accord Concentrate™ (active ingredient, glyphosate; Dow AgroSciences 2005), and Escort™ (active ingredient, Metsulfuron methyl; DuPont 2005) are registered/labeled for use in red alder site preparation. Atrazine 90 WSP can be broadcast over the top of dormant red alder as a release treatment. Accord is labeled for the release of hardwoods from weed competition, but only as a directed spray—not as a broadcast application.

Check regulations before applying these or any herbicides—read and follow herbicide labels very carefully when applying herbicides.

Cumulative vegetation ground cover in the first growing of less than 10-15% is desirable for rapid stand establishment and growth and to maintain ground cover in the second growing season below competition thresholds for red alder survival and growth. If ground cover of herbaceous weeds is expected to exceed 30-40% in year two, it is advisable to use herbicides in late-winter/early-spring, when red alder are still dormant and weeds are active. A broadcast application of Atrazine 90 WSP™ in late-winter and/or a directed spray of Accord Concentrate™ applied in early-Spring can be effective as a release treatment.

Anecdotal evidence suggests soil scarification that exposes mineral soil (when combined with weed control) can increase survival and growth when heavy slash/forest floor is present.

Planting

Out-plant Timing

A planting date should be selected to balance the risks of freeze damage and drought stress. The spring planting period begins when the probability of a killing frost is low and ends before there is an appreciable seasonal drying of the soil.

Figure 6—This photograph shows an example of the effects of through weed control on first year field performance for red alder (pre-plant application Atrazine and Glyphosate on the left vs. no weed control on the right). Meter-stick shown for reference.

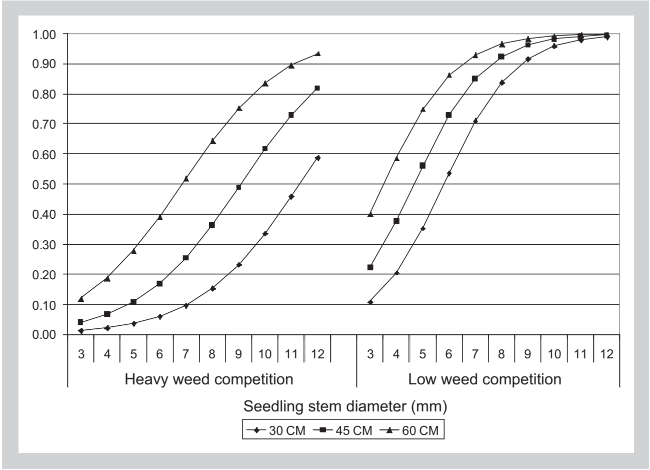

Figure 7—The probability of bare-root seedlings with "good" root systems achieving 1-meter height, one growing season after planting, given high and low levels of weed competition.

The recommended planting window for elevations less than 300 m, is mid-March to mid-April. Planting in November through February can result in serious freeze damage (top-kill and diminished root growth potential). Planting in late April to mid-May may not allow enough time for an adequate root system to develop before the onset of summer drought stress. It is advisable to begin planting in early March (at sites with minimal risk of spring frost) rather than planting into late April or early May.

Other considerations at time of planting

Red alder seedlings should be lifted from the nursery beds or styro-blocks/plugs in early January, freezer stored (-2°C) until the spring planting time is reached. Seedlings should be defrosted slowly under cover at approximately 4 to 5°C. Once the seedlings have thawed they should be cooler stored (2°C) until planted. It is advisable to keep seedlings frozen until just before the planting date—minimizing cooler storage to a week or less. Because red alder can de-harden very rapidly when removed from cold storage, seedlings stored in the field on the day of planting need to be protected from heat to prevent premature de-hardening. On-site daily storage under an insulated truck canopy or in the shade of standing timber covered with a heat shield (i.e., Mylar™) seedling protection tarp is recommended. Take only the number of seedlings that can be planted in one-day from cold storage to the field.

Red alder seedlings are brittle and prone to breakage. Planting crews accustomed to handling conifers need to be cognizant that alder seedlings require more care. Careless loading of seedlings into planting bags can result in considerable breakage to roots and stems. Care needs to be taken when closing the planting hole to assure that the stem is not wounded by the planter's boot.

To partially offset the effects of heat and drought on newly planted seedlings, deep planting (ground level approximately 25-50 mm above the root collar) is recommended. Minimizing the scalping of forest floor during the planting process can reduce heat girdling; exposed mineral soil at the base of the stem from scalping acts as a heat-sink, and the thin bark of alder is readily damaged. Similarly alder planted directly against logging slash or stumps is easily damaged by sun-scald and/or mechanical abrasion—make certain that the planting spot is clear of surface slash for approximately a 30-cm diameter around the stem.

Conclusion

It is essential that "Best Management Practices" for site selection, plantation establishment and silviculture be followed in order to achieve successful red alder plantations. Achieving uniform stocking and rapid early growth, so that the stand "captures the site" within the first 3-years, is critical. It is essential that early intensive silviculture be practiced in order to assure rapid site occupancy. Rapid site occupancy by the crop promotes full stocking, rapid growth and good stem quality.

Red alder can be difficult to grow successfully in plantations – generally the species is "less forgiving" than conifers when planted on the "wrong" sites, and/or with improper silvicultural practices. For example; planting frost-prone sites or ineffective herbaceous weed control may reduce growth of Douglas-fir, but can result in extensive mortality and very poor growth of red alder. Effective weed control is more difficult for red alder because of the limited number of herbicides available for use on red alder, particularly for release treatments following planting. Also, the planting window is much narrower for red alder than for Douglas-fir (March 15–April 15 for red alder, vs. early-winter to early-spring for Douglas-fir). The consequence of planting red alder too early or too late can be excessive mortality.

Though the risks of failure and difficulty of growing red alder may be higher than growing conifers, we have learned how to mitigate the risks (through site selection, nursery practices and silviculture). The uncertainties of growing red alder must be weighed against the demand for red alder in commercial applications in the world-wide lumber market. Plantation-grown red alder can produce quality saw-logs in a relative short rotation of 25 to 30 years (compared to 60-years plus for other important North American hardwoods). Some landowners think that red alder will continue to have increasing value potential because of its desirable commercial wood properties and relatively short rotation for saw-logs.

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— Red Alder: A State of Knowledge —

Response of Young Red Alder to Pruning

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Abstract

Red alder (*Alnus rubra, Bong*.) is the most common hardwood in Washington, Oregon and British Columbia. It is used for a variety of products including firewood, pulp, and solid wood products such as furniture, cabinets and musical instruments. Pruning may be a viable management technique for increasing clear wood and, thus, value in managed stands but little information has been available. To determine the biological effects of pruning red alder, we selected 530 trees in 3-, 6- and 10-year-old plantations. Sample trees were from plots that had different previous silvicultural treatments, providing a range of growth rates. Pruning removed one third of the live crown, was performed on seven dates throughout the year, and included both live and dead branches as well as a sub-sample of intentionally damaged collars around dead branches. The rate of branch occlusion (healing) was well correlated with tree growth at breast height and with distance from the base of the live crown. Live branches occluded more rapidly than dead branches and dead branches occluded more rapidly if the branch collar was intentionally wounded during pruning. The number of epicormic branches induced by pruning was minimal, but increased with tree age and where trees were growing in an open condition. No stem breakage or sunscald was observed as a result of treatment. Six years following pruning, 91% of pruned branches less than 1 cm in diameter and 80% of branches 2–3 cm in diameter had completely occluded. Those that had not occluded by that time were on trees with low growth rates. Time of year of treatment had little effect on tree growth rates, occlusion rate, epicormic branch formation, and damage. Pruning young trees did not result in any damage or loss of growth. To maximize the amount of clear wood it would be best to prune as soon as logistically possible. Thus, if economic incentives are present for clear wood, landowners and managers may want to consider pruning young trees, taking into account the possible need for multiple lifts.

Keywords: red alder, *Alnus rubra*, pruning, branch occlusion, silviculture

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Introduction

It is well known that initial density affects diameter growth. We can produce larger diameter trees more quickly if they are grown at wider spacings than if they are grown at narrower spacings. Associated with wide spacings, however, is the production and retention of large diameter branches, especially on the lower bole of the tree. These branches reduce the log grade and consequently reduce the products (and values) for which the log can be used. Some foresters have speculated that the lowest-cost option to produce quality wood would be to grow the trees at spacings close enough to cause natural death and abscission of the lower branches. However, this strategy assumes that dead branches will be shed soon after the abscission process is complete and that stem breakage will occur at a point close to the tree bole. It will also either increase the time required to produce trees of a specified size or require thinning after branches have naturally abscised. An alternative strategy would be to plant at wide initial spacings and plan to artificially prune the trees. While pruning can be an expensive process, the costs may be justified if increases in log quality can be transformed into increases in log value.

Pruning red alder has not previously been examined in a comprehensive manner. The only published report is that of Berntsen (1961) where 21-year-old trees were pruned, then examined 22 years later to see what the effects were on wood quality. Bernsten concluded that pruning did increase the amount of clear wood produced, but warned that epicormic branches could result in defects such as knots or blemishes. No other information is available specific to alder, however, much information is available in the forestry or horticultural literature on the effects of pruning on plant growth and on methods for pruning (O'Hara 1989). In addition, there is substantial information in the botanical literature on the physiological responses of plants to wounding (i.e. the removal of live branches).

Studies on the time of year of pruning are generally limited to only a few dates and do not include information on the phenological status of the trees. In addition, the results differ by species and the response variable considered. For example, Krinard (1976) concluded that summer pruning of eastern cottonwood was better than spring pruning because it resulted in fewer and shorter epicormic branches. McQuikin (1950) recommended pruning eastern hardwoods (except red maple) in late winter or early spring to achieve fastest wood occlusion; he recommended pruning red maple in late spring or early summer to reduce excessive bleeding (sap exudation). Neely (1970) reported May-pruned eastern hardwoods healed more quickly than July- or March-pruned trees. October-pruned trees healed much more slowly than trees pruned at the other three dates. Childs and Wright (1956) reported higher incidence of infection in Douglas-fir spring-pruned wounds than fall-pruned wounds. Shigo (1976) reported different decay mechanisms invaded eastern hardwoods depended on the time of the wounding. Leben (1985) concluded that spring wounding of red maple resulted in less dieback around the wounds and less decay than fall wounding. Puritch and Mullick (1975) reported water stress substantially slowed formation of an impervious layer in grand fir seedlings. Biggs and Cline (1986) reported irrigation to speed up formation of the impervious layer at some sampling dates. Given the range of responses reported in the literature, we could not predict the time of year or growth conditions that would be optimum to prune red alder.

Most pruning studies have dealt with the removal of live branches, but a few have also examined dead branches. Shigo (1986) indicates that branch collars should not be damaged when live branches are pruned, but recommendations are contradictory on the treatment of dead branches. It appears that injuring the branch collar when removing the dead branches will greatly speed up filling in the cavity at the base of the branch, however, Shigo et al. (1979) suggests that this will increase the amount of decay associated with the dead branch. Casual observations have noted that occlusion rates over dead branches on red alder can be slow.

We designed a study to determine the biological effects of pruning young red alder. The study focused on four questions. Are there any negative effects, such as sunscald, sap exudation, or production of epicormic branches, associated with pruning young red alder? If there are negative effects, do they vary by time of year of pruning? What effects do factors such as tree age, growth rate or height on the bole have on the rate of occlusion? Are there positive or negative effects of wounding the collar area around dead branches? A second study (DeBell et al. 2006) quantified internal decay rates associated with a subset of treatments.

Materials and Methods

Alder plantations established at the Washington State Department of Natural Resources' Meridian Seed Orchard near Lacey, Washington and at the Centralia Mining Company—now owned by TransAlta Corporation—near Bucoda Washington, were selected to represent a variety of age groups and silvicultural regimes. The Meridian Seed Orchard included both thinned and non-thinned areas (at 1- and 2-m spacings respectively) from 3-year-old plantations established in 1989, and areas that had been previously irrigated and non-irrigated in 6-year-old plantations established in 1986. Trees selected at TransAlta were in 10-year-old plantations that had been established in 1982; these trees had been planted as part of a spacing trial and included a range of spacings from 2 to 4 m. Initial diameter at 1.3 m and total height are given in table 1. Mean annual precipitation at both locations is 1245 mm with 150 mm falling as rain from June 1 through September 30. Mean annual, mean January minimum, and mean

Table 1—Initial d.b.h. and height, and mean diameter growth from 1991 to 1997.

AGE	Treatment	Mean d.b.h. 1991 (cm)	Mean ht 1991 (m)	D.b.h. growth 1991-1997 (cm) Min	Max	Mean
3	Thinned	4.8	4.7	2.1	12.5	7.5
	Not thinned	4.1	4.1	0.5	6.5	3.3
6	Irrigated	11.6	11.6	1.2	10.6	5.0
	Not irrigated	9.5	9.5	0.8	12.0	4.6
10	n/a	13.3	10.5	1.4	10.3	4.6

August maximum temperatures are 10.1, 0.1 and 25.1 °C, respectively, at the Lacey site and 10.6, 0.6, and 25.3 °C at the Bucoda site (Daly, 1994. http://www.ocs.orst.edu/prism).

The time-of-year portion of the study examined trees pruned on seven separate dates selected to cover the range in tree phenology. The dates (and general phenological condition) were: May 1 (budbreak and leaf expansion), June 15 (active height and diameter growth), August 1 (active diameter growth, height growth primarily over), September 15 (diameter growth continuing but some leaf abscission beginning), November 1 (leaf abscission almost complete), January 1 (deep dormancy, cold temperatures), and March 1 (trees still dormant but temperatures moderating). The first five dates were in 1992 and the last two were in 1993.

On each treatment date 20 trees from the 3-year-old plantation (10 thinned and 10 not thinned); 20, 6-year-old trees (10 irrigated and 10 not irrigated); and 20, 10-year-old trees were pruned to examine the effects of time of year, growth rate, and bole height on response. Pruning was done with a handsaw and the pruners were instructed to not wound the branch collars of either dead or live branches. Furthermore, at the May 1 pruning date, 40 additional 10-year-old trees and 60 additional 6-year-old trees were pruned at the same two sites. This second group of trees had the live branches pruned in the same manner as described above, however, half of all trees at each site had dead braches pruned by removing the entire branch collar (i.e., the swelling around the base of the branch, particularly on the lower side). Removing the entire branch collar (cutting the branch flush with the stem) considerably increased the size of the wound created for all but the smallest branches which had minimal branch collars.

Prior to pruning, all trees to be pruned were marked at 0.3 m on the bole and then every 1 m up the bole until pruning height was reached. Trees in the time-of-year portion of the study were pruned up to a point representing one-third of the existing live crown. For most trees this was approximately a height of 3.3–5.3 m, although 1 tree was pruned up to 7.3 m. All trees in the damaged-branch-collar portion of the study were pruned to 3.3 m. Each pruned branch was tallied by stem section from which it was removed (0–0.3 m, 0.3–1.3 m, 1.3–2.3 m, etc), whether it was alive or dead, and by 1-cm diameter class. Epicormic branches present before pruning were also tallied by stem section and then removed (usually with hand clippers).

After the 1992 growing season, all study trees were measured for stem diameter at 1.3 m, total height, and height to live crown. Diameter at 1.3 m, total height, and number and length of new epicormic branches was remeasured after each growing season from 1993 to 1997. Percent occlusion of all pruning wounds was also measured after each growing season from 1993 to 1997 by visually estimating the percent of the wound area that had been covered by callus (tissue formed over and around a wound). Each tree in the 10-year-old plantation was coded for proximity and direction of adjacent openings that might induce epicormic branching. These codes were not based strictly on spacing of adjacent trees, but also if the opening was sufficiently large to cause a discontinuity in crown closure and allow light to fall upon the bole of the edge tree. Form was assessed after the 1994–1997 growing seasons by measuring stem diameter at 0.3, 1.3, 2.3, and 3.3 m heights on the pruned study trees and on unpruned trees in the same plantations with 1992 diameters similar to those of the pruned trees.

Results and Discussion

Damage to pruned trees

Following pruning, no problems were encountered with sap exudation (bleeding), sunscald, stem lesions, top breakage, excessive production of epicormic branches, or damage by red-breasted sapsuckers on trees from any pruning date. Top breakage and sapsucker damage have been observed on red alder trees operationally pruned when 50% or more of the live crown was removed (C. Harrington, personal observation) but removal of 33% of the live crown in this study did not predispose the trees to damage.

The frequency of epicormic branches increased immediately after pruning (table 2). However, by 1997, the 3-year and 6-year old trees had less than 1 epicormic branch per tree and most of these branches were short and small in diameter. There was a reduction in the percent of trees with epicormic branches in all the plantations throughout the study period. The mean number of epicormic branches per tree remained relatively the same in the 6- and 10-year-old

Table 2—Frequency, mean number and size of epicormic branches at the time of pruning (1992 and 1993) and after the 1994 and the 1997 growing seasons.

Age	% Trees with epicormic branches			Mean number of epicormic branches per tree			% Epicormic branches with a length >=15 cm	
	1992-1993*	1994	1997	1992-1993*	1994	1997	1994	1997
3	41	69	29	1.2	1.9	0.7	0	36
6	5	27	19	0.1	0.8	0.5	3	27
10	33	91	89	0.8	7.4	7.3	65	80

*At time of pruning

plantations and decreased by 37% for trees from the 3-year-old plantation. No relationship was found between the time of year that pruning took place and the number of epicormic branches produced.

Epicormic branches were more likely to be present in a more open environment. At the time of pruning, 56% of the trees in the thinned portion of the 3-year-old plantation—the more open environment—had epicormic branches, compared to only 27% in the non-thinned portion (although both portions had a mean of less 2 small epicormics per tree). By the end of 1994, the crowns had closed in the thinned portion and the number of trees with epicormic branches and the mean number of epicormic branches per tree in the thinned and not thinned portions of the plantation were not significantly different. Although most areas in the 10-year-old plantation had a closed canopy, there were some openings sufficiently large enough to cause discontinuities in crown closure throughout the study period. Trees that had an opening directly adjacent to them (n=50) generally had more epicormic branches per tree than trees with no opening present within 2 rows (n=58), unless the opening was to the north side of the tree (fig. 1, a). If an opening was present 1 row away (n=41), it did not increase the number of epicormics formed unless the opening was in a southerly direction (fig. 1, b).

Berntsen (1961) suggested that production of epicormic branches could be a problem when pruning red alder; however, closer examination of the data from his study (Rapraeger 1949 report on Cascade Head pruning and thinning study, data on file, Olympia Forestry Sciences Laboratory) indicated that the stem sections he examined came from a 21-year-old red alder stand that was heavily thinned (two-thirds of the stems removed) and the large overstory conifers were girdled at the same time as pruning. Thus, the red alders were exposed to a major change in their light environment at the same time as pruning. Even so, the trees at Cascade Head had fairly low numbers of epicormic branches 10 years after these treatments were imposed (14 per tree on the 5-m section that had been pruned) and most (75%) were less than 0.1 cm in diameter. Thus, both the Cascade Head study and our observations confirm that although red alder does produce epicormic branches following pruning, it is not particularly prone to doing so. The results from the Cascade Head study are also consistent with our observation that epicormic branches are more likely to form and persist on older trees.

Growth Rate and Stem Form of Individual Trees

Stem form appeared to be very slightly altered by pruning in all the plantations; however, the differences were not significant ($p \leq 0.05$). The differences in form were most pronounced in the 10-year-olds and although differences between stem form in pruned trees in comparison to trees not pruned was greater in year 5 than in year 2 (fig. 2), it was still not statistically significant. From year 2 (1994) to year 5 (1997), the mean diameter of the bole at heights closer to the base of the live crown, once pruned, increased at a rate greater than the rates at sections lower down on the bole. If this trend continues, it appears the boles of pruned trees will become more cylindrical.

The rate of branch occlusion at various heights up the bole also indicates greater rates of diameter growth closer to the base of the live crown. For example, after 3 growing seasons (trees pruned in May, 1992), mean percent occlusion of live branches 2 to 3 cm in diameter pruned in sections at 1-m intervals (starting at 0.3) up the bole of the trees were 51%, 56%, 60%, 61%, 77%, and 95% (ending at 5.3 m height), respectively. Separated into tree age groups, all 3 ages showed the same trends, although it was more difficult to discern in the 3-year-olds due to smaller branch sizes, reduced number of sections, and more rapid percent diameter growth.

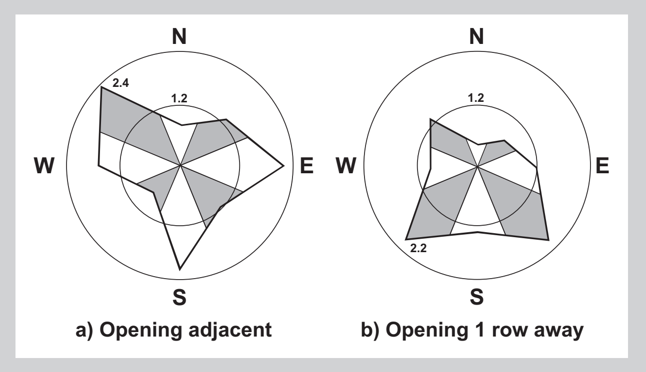

Figure 1—Mean number of epicormic branches in 1994 present on 10-year-old trees that a) had an adjacent opening and b) had an opening 1 row away. Trees with no opening within 2 rows had a mean of 1.2 epicormics per tree and are represented by the smaller inner circle.

Factors affecting branch occlusion

There were substantial statistical differences in the degree of branch occlusion by initial branch size, tree size, tree age, and overall growth rate of the tree. For example, 2 years after pruning, mean percent occlusion of branch wounds in the 3-year-old and 6-year-old plantations ranged from only 67% (non-irrigated portion of the 6-year-old plantation) to 94% (thinned portion of the 3-year-old plantation) (fig. 3). Silvicultural factors that affected the rate of diameter growth, such as thinning or irrigation, also had an effect upon the rate of occlusion. Differences in rates of occlusion between the different tree ages can be attributed to both the initial differences in branch size by plantation and to tree growth rates. For example, branches 1 cm in diameter or smaller were 97%, 74%, and 45% of the branches pruned in the 3-, 6-, and 10-year-old plantations respectively.

Mean percent occlusion was also closely related to both branch size and basal area growth (fig. 4). Stem diameter growth varied significantly by age and treatment, as well as by initial tree size (table 1). Diameter growth as a percent of initial diameter prior to pruning (1991) to the end of the 1994 growing season was 49% for the 3-year-olds, 21% for the 6-year-olds, and 17% for the 10-year-olds. These age trends in growth rate as a percentage of initial diameters are also reflected in the mean percent occlusion by 2-cm diameter growth classes. For example, live branches 2 to 3 cm in diameter pruned in the 3-year-old plantation had a mean percent occlusion of 65%, 94%, and 100% for a d.b.h. (diameter at 1.3 m) growth of 0 to 2 cm, 2 to 4 cm, and 4 to 6 cm, respectively. For the same branch diameter and the same dbh growth classes, the mean percent occlusion was 59%, 70%, and 94% for the 6-year-old plantation and 31%, 46% and 51% for the 10-year-old plantation. So, for any given amount of d.b.h. growth, the younger trees grew more in respect to their initial diameter and occluded wounds at a faster rate.

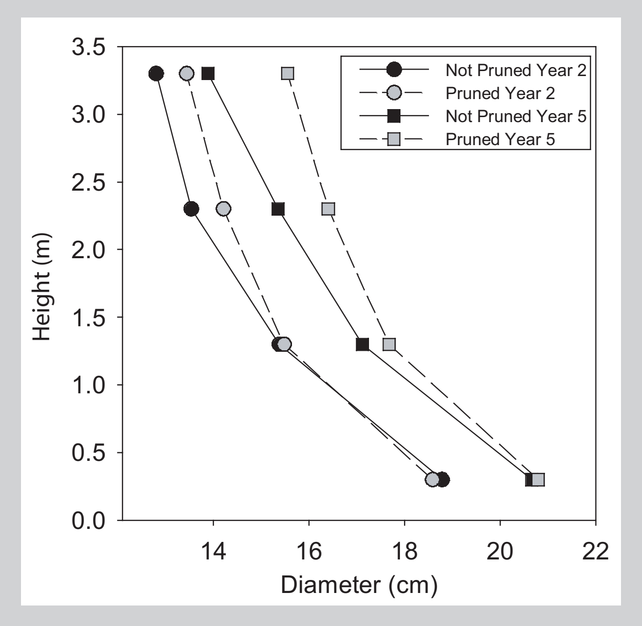

Figure 2—Stem diameter at 0.3, 1.3, 2.3 and 3.3 m height within the 10-year-old plantation on both pruned and non-pruned trees in years 2 and 5.

As expected, at the time of the first occlusion assessment at the end of the 1994 growing season, the branches that had been pruned at the earlier pruning dates showed greater occlusion. For example, the percent of live 2 to 3 cm-branches that had reached 90% occlusion or greater was 16% for the May 1, 1992 pruning date, 14% for the June 15, 1992 pruning date, 2% for the August 1, 1992 pruning date, and 1% for the 4 subsequent pruning dates (September 15, 1992; November 1, 1992; January 1, 1993 and March 1, 1993). By the end of the 1995 growing season, the early spring treatments (May '92 and March '93) exhibited slightly slower than expected occlusion rates, but branches of all size classes for all the pruning dates reached 90% or greater mean occlusion by the end of the 1997 growing season (fig. 5).

Occlusion of live vs. dead branches and effect of branch collar treatment

We compared the rates of occlusion for pruning live branches without wounding the branch collar, dead branches pruned without wounding the branch collar, and dead branches pruned by removing or damaging the branch collar. For each of the smallest branch size classes (the size classes where n>100), differences among the three categories were small at the time of the first assessment in 1994 and even smaller in 1995, but two consistent and statistically significant patterns were present. First, the mean rate of occlusion was greater for live branches than for dead branches that were pruned without wounding the branch collar (fig. 6). Second, even though damaging or removing the branch collar during pruning increased the

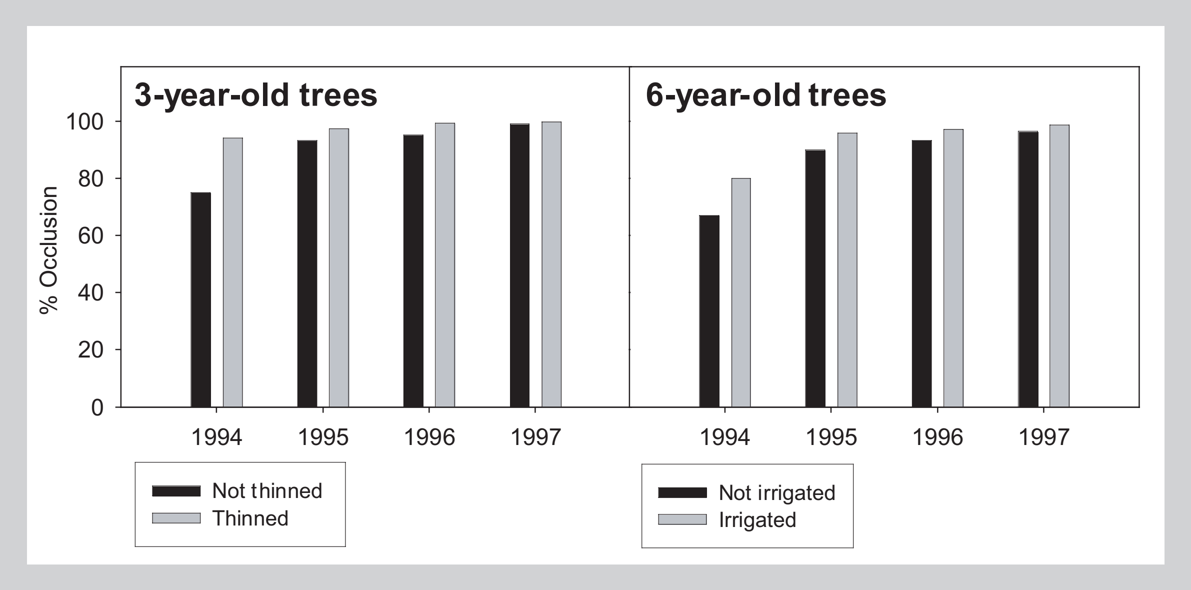

Figure 3—Mean percent occlusion of all pruned branches in the 3- and 6-year old plantations 1 to 5 years following pruning (dependant upon time of pruning).

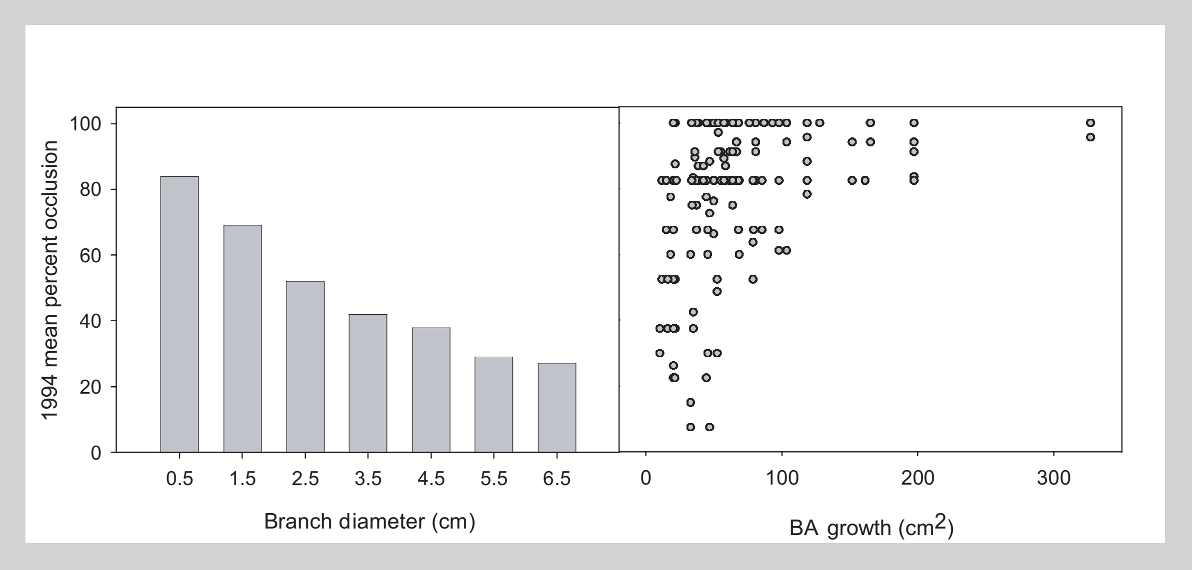

Figure 4—Relationship between percent occlusion of branches pruned in 3-, 6-, and 10-year-old red alder stands by diameter of pruned branch and basal area growth measured at 1.3 m.

size of the wound to be occluded, wounds associated with damaged branch collars occluded more quickly than those associated with undamaged branch collars. Although this difference in occlusion rates between injured and uninjured branch collars is unlikely to be of practical importance, it indicates that pruners do not need to be especially careful to avoid injuring branch collars. Additional examination of the wood around these wounds also indicated no difference in the amount of internal decay associated with damaged or undamaged branch collars or the time it took to form clear wood (DeBell et al. 2006).

Red alder wood decays rapidly after the death of the tree; thus, in past years some foresters have speculated that alder might not be a good candidate for thinning or pruning because of the potential damage associated with these activities. More recent evidence, however, has shown that living red alder trees are quite effective in compartmentalizing decay (Allan 1993). Allen's study on Vancouver Island showed decay volumes to be small and most decay associated with natural breakage did not spread outward beyond the location on the bole where damage was sustained. Additional assessments of decay

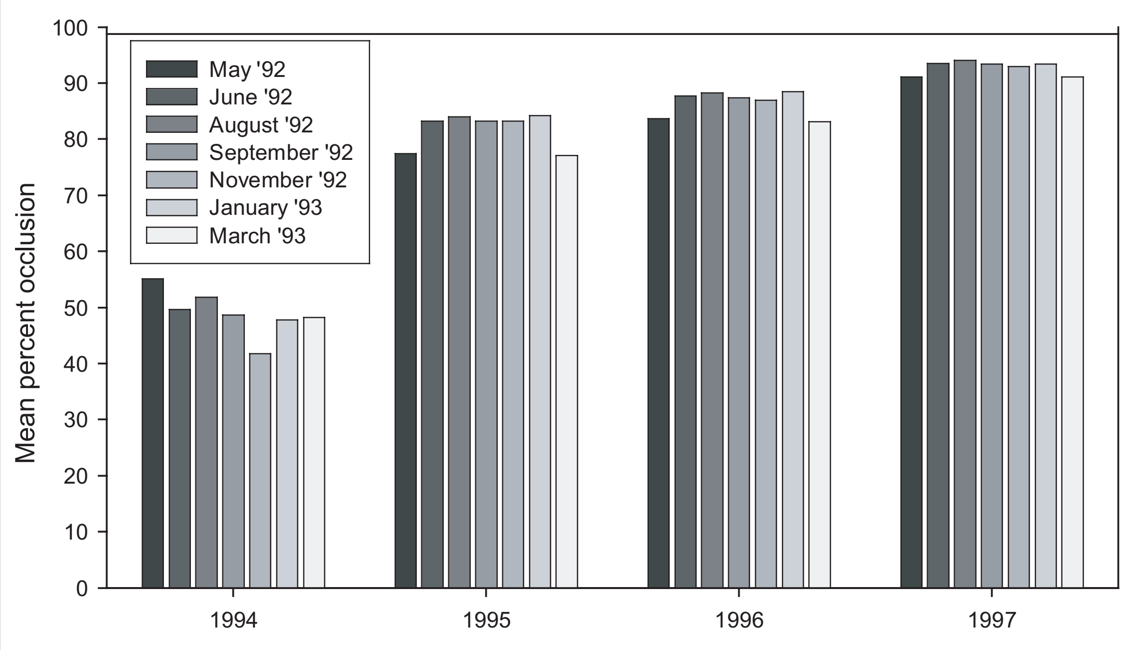

Figure 5—Mean percent occlusion for all branches sizes at all pruning dates at 4 successive assessment years.

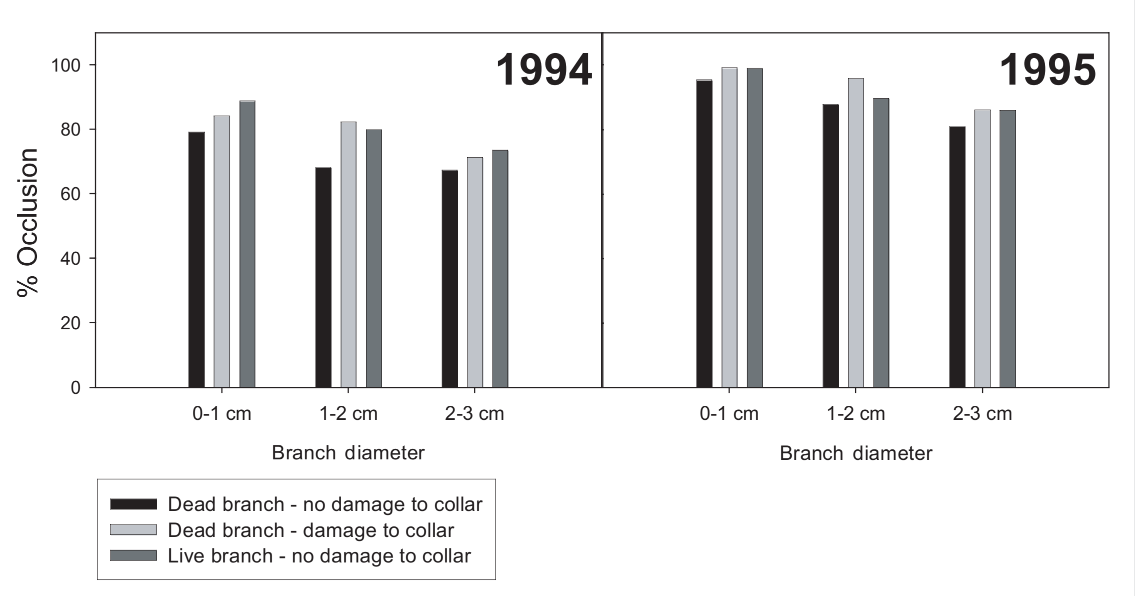

Figure 6—Comparison of occlusion rates by branch size classes and year for live branches pruned without damaging the branch collar and dead branches pruned with and without damaging the branch collar during pruning.

associated with pruning were made in the Cascade Head pruning study (C.W. Jacobs memo dated Feb 28, 1947 on rot found in alder stands, on file Olympia Forestry Sciences Laboratory). The wood in and near 25 knots on 6 pruned trees was assessed for signs of decay 10 years after pruning by sampling with an increment borer. On 24 of the 25 knots, the decay was found to be confined to the knot area; on the 25th knot, the rot extended to the pith and about 25 cm below the branch, but did not extend into the wood formed after pruning. The companion study to our young-stand pruning (DeBell et al. 2006) also found minimal amounts of rot associated with the branch scars. Thus, there is no evidence that decay will be a problem after pruning young red alder.

Conclusions

Pruning at plantation ages 3, 6, or 10, did not have negative effects on the incidence of decay or defects within the tree bole, production of significant numbers of epicormic branches, or growth of the tree. Contrary to reports for several other species, the results were consistent across all seven pruning dates; thus, time of year of pruning had little or no effect. Differences in rates of occlusion could largely be accounted for by the differences in growth rate due to tree age or other management activities (such as thinning or irrigation). Although our study examined the effects of wounding the branch collars only on dead branches, we suspect that incidental damage during the pruning operation to branch collars of live branches should not be a source of concern. However, because there was no practical benefit from removing the branch collar, and it would take more time and effort to do so, we would not recommend it as a standard practice.

Because both small and live branches occlude more quickly than large or dead branches, pruning at an earlier age would not only result in a smaller knotty core, but would produce straight-grained clear wood more quickly after pruning. In addition, if epicormic branches are a concern, pruning young stands appears to result in the lowest number of epicormic branches. Epicormic branch production was also most closely tied to the presence of openings on the south side of the tree, thus, trees north of stand boundaries or gaps are the poorest candidates for pruning. From a biological standpoint, there appear to be no obstacles and several benefits to pruning red alder at an early age; thus, the decision of timing of pruning should be based on economic factors.

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Time and Distance to Clear Wood in Pruned Red Alder Saplings

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Abstract

Pruning trials in young alder stands were sampled to evaluate response to pruning. Effects of pruning (1) live branches on different dates, and (2) dead branches with or without damaging the branch collar were assessed on trees pruned in 3- and 6-year-old plantations, respectively. Six years after pruning, stem sections were collected and dissected in the longitudinal-radial plane to expose the center of the stem and branch stub. Ring counts and linear measurements were made for various boundaries or points, including time of pruning, stub length, defect, and beginning of clear wood formation. Pruning during the growing season and, to a lesser extent, late in the growing season when leaf abscission was beginning, resulted in shorter times and distances to formation of clear wood (2.1 years, 14.5 mm) than pruning in the dormant season or just prior to the beginning of the growing season (2.6 years, 18.6 mm). Cutting the branch collar on dead branches led to shorter times and distances to clear wood (2.8 years, 21.9 mm) than intentionally avoiding such wounding (3.5 years, 24.8 mm); these differences were associated with shorter branch stubs as there were no differences in the amount of defect. Epicormic branching was minimal in the two pruning studies, averaging less than one branch per tree in the date of pruning test and only two branches per tree in the branch collar wounding study. Assessments for comparable unpruned trees indicated that times to form clear wood after branch death would be markedly greater and that epicormic branching was equal to or greater than that determined for pruned trees. Although statistically significant differences occurred among different pruning dates and with branch collar wounding, the decision to prune or not prune is of much greater practical importance, regardless of when (date) or how it is done. Such pruning decisions can be made by using this information on time and distance to clear wood in economic analyses developed with available data on tree growth, log volume, lumber recovery, pruning costs, and price differentials for clear vs. knotty wood.

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Introduction

Red alder (*Alnus rubra* Bong.) is an important hardwood in the coastal forests of Oregon, Washington, and British Columbia (Harrington 1990). For decades it was considered primarily a weed species that provided unwanted competition to conifers in these forests, but red alder is now recognized for some highly valued ecological and economic contributions. Rapid early growth and ability to fix atmospheric nitrogen make it a very desirable species for restoring and enhancing productivity of forest sites after natural and human-caused disturbances (Tarrant and Trappe 1971). Its wood is desired for fuel, fiber, and solid wood products; as with other hardwood species, clear wood has the highest value and is used in furniture, cabinetry, and paneling. Red alder grows rapidly at young ages and recent silvicultural research has indicated that alder sawlogs can be produced in plantations on short rotations (30 years or less) with wide spacings (c.f., DeBell and Harrington 2002, Hibbs and DeBell 1994). Wide spacings, however, also lead to large, long-lived branches on the lower bole that can reduce log grade and value of lumber recovered. Such branching can be reduced by growing the trees at denser spacing to facilitate natural pruning (Hibbs and DeBell 1994) but diameter growth will be reduced. Another alternative is to grow the trees at wide spacing and manually prune the lower branches as is done to produce clear wood in other species throughout the world (Hanley et al. 1995, Haygreen and Bowyer 1996).

Although there is a long history of pruning hardwood species in other regions, there is little research or experience with regard to pruning red alder. Berntsen (1961) examined stem sections of 43-year-old alder that had been pruned 22 years before. He found that stubs of pruned limbs were sometimes grown over within two years; decay was present in every dead or pruned stub but it rarely extended beyond the knot and it did not hinder the increment of clear wood. Berntsen (1961) also found that epicormic branches frequently originated, singly and in clusters, where other branches had been naturally or artificially pruned; these were apparently of such size and number to negate any gains in wood quality from pruning. Such branches, more common in hardwoods than conifers, form from suppressed buds located throughout the stem that are released (or sprout) following stand or tree disturbance. If the epicormic branches are abundant, persist and grow to large size, the resulting knots may reduce quality and value of the logs at harvest below that of unpruned trees. Berntsen (1961) therefore concluded that the desirability of pruning was questionable until more was learned about the cause and control of epicormic branching.

Our research was conducted in young, rapidly growing red alder plantations. We investigated how the trees responded to pruning in terms of how long it took to form clear wood and also the degree to which epicormic branches were formed. Existing pruning trials (Brodie and Harrington 2006) offered the opportunity to assess: (1) effects of date (season) of pruning live branches, and (2) the nature of the cut for dead branch pruning (e.g., does it make a difference whether live tissue around the branch collar is wounded in the operation?). For some hardwood species, substantial differences in wound occlusion and subsequent decay may exist among seasons or dates of pruning (i.e., McQuilkin 1950). If such differences occur in red alder, pruning operations will need to be scheduled accordingly. If differences are negligible, however, pruning can be scheduled with greater flexibility. The study of pruning dead branches resulted from observations that some dead branches that broke off naturally did not occlude quickly. Also dead branches sometimes would break off inside the stem and leave a pocket or hole that filled in rather slowly. We hypothesized that wounding the branch collar would *rejuvenate* the tissues around the branch collar resulting in faster occlusion; in addition, making the pruning cut through the branch collar (closer to the stem) would also reduce stub length). We examined correlations between time and distance to clear wood formation and stem size (radius), stem (cambial) age, branch diameter, branch angle, and radial growth rate after pruning. We also evaluated epicormic branching on the pruned study trees and on comparable unpruned trees in the surrounding plantation.

Figure 1—Young red alder plantation near Lacey, Washington.

Methods

Origin and Nature of Sample Trees

Stem samples for our investigation originated and represent subsamples from two trials of pruning methods (Brodie and Harrington 2006) that were superimposed on selected portions of research plantations of young red alder (fig. 1) at the Washington State Department of Natural Resources' Meridian Seed Orchard, 12 km east of Olympia and near Lacey, Washington (47° 00 ' N, 122° 45 ' W). Detailed descriptions of the site, design and establishment of the research plantations, and early growth and stand development were reported in DeBell et al. (1990) and Hurd and DeBell (2001). Early results of the pruning trials are

Table 1—Size of trees at pruning and at time of sampling (6 years later)[1].

Measure and time		Study 1-date of pruning			Study 2-branch collar wounding		
		Mean	**Min**	**Max**	**Mean**	**Min**	**Max**
DBH (cm):	At pruning	6.7	4.7	9.1	11.0	7.8	13.4
	At sampling	12.4	8.2	18.9	19.2	15.3	24.7
Height (m):	At pruning	7.0	5.6	8.2	9.4	8.3	10.1
	At sampling	13.2	9.1	16.5	17.1	15.8	19.4

[1] Number of observations is 60 trees for study 1 and 30 trees for study 2.

given in Brodie and Harrington (2006). The soil at the site is a deep, excessively drained loamy fine sand formed in glacial outwashes and trees were irrigated to supplement the low rainfall (15 cm) falling during the May 1 – September 30 period. Climate is mild with an average growing season of 190 frost-free days; mean annual temperature is 10.1°C, mean January minimum temperature is 0.1°C, and mean August maximum temperature is 25.1°C. The plantations were established with 1-year-old seedlings and kept weed-free by tilling, hoeing, and selective application of herbicides.

One pruning trial (date of pruning) subsampled for our study was installed in a 3-year-old plantation (4 years from seed), spaced (after thinning) at 2 m by 2 m or 2500 trees per hectare. Live branches were pruned from the lower one-third of the crown of 10 trees without damaging branch collars on each of seven dates. Dead branches present in the same region of the stem were also removed at the same time. Most branches were removed by handsaw, but small trees or very small branches with inadequate wood to support a saw were cut with hand clippers. At time of pruning, the trees averaged 7.0 m tall and 6.7 cm in diameter at breast height (table 1), and were pruned to an average height of 3.2 m. Ten trees each from five of the pruning dates, representing a range of phenological stages, were selected for dissection and evaluation: January 1 – mid-dormant season, March 1 – immediately prior to budbreak, May 1 – early growing season (leafed out), June 15 – mid-growing season (leafed out), and September 15—toward the end of the growing season (beginning of some leaf abscission). In addition, 10 trees that had not been pruned were selected for comparative measurements.

The second pruning trial (branch collar wounding) was installed in a 6-year-old plantation (7 years from seed), spaced (after thinning) at 2.8 m by 2.8 m or 1250 trees per hectare. All branches (dead and alive) were pruned on the lower bole by handsaw on May 1. At pruning, the trees averaged 9.4 m tall and 11.0 cm in diameter at breast height (table 1). Two pruning methods were tested on dead branches only: (1) without damaging branch collars (sometimes referred to as a "Shigo cut" [Shigo 1986]), and (2) with deliberate wounding of branch collars. Ten trees were randomly selected for each treatment. All trees treated were selected for dissection and evaluation in our study; an additional 10 trees (of identical age) that had not been pruned were also sampled in an adjacent planting of nearly the same spacing.

Sample Collection, Preparation, and Measurement

Six years after pruning treatments were implemented, the trees for both studies were felled and several measurements taken on stem and branch characteristics. These included total height and diameter at breast height (table 1), height and diameter of every dead branch remaining on the bole, and the same measurements on live branches occurring at a height below the highest dead branch. Height and diameter of epicormic branches were also recorded.

Five pruning scars (or branches or branch scars if sampling an unpruned tree) distributed between the stump and 4.8 m on the bole (nearly all were below 3.3 m) on each study tree were selected for sampling and their height recorded; a 15-cm thick section centered on the scar (or branch) was cut by chain saw. Each section was labeled by tree number and sample location on the bole (1=lowest and 5=highest) and placed in a heavy plastic bag for transport to the laboratory.

Two of the five sections (2 and 4) from the date of pruning study were used to assess presence of decay organisms in the branch stub. After excision from the stub, small samples of woody tissue were surface sterilized by flame; they were then pressed into malt extract agar in petri plate cultures, and examined over time for growth of decay fungi. The remaining three sections (1, 3, and 5) from each tree in the date of pruning study and all five sections from the branch collar wounding study were then kiln-dried at 63°C for 48 hours to reduce decay.

After drying, each section was examined visually to determine the location and orientation of the branch scar (pruned or unpruned) of interest. A band saw was used to dissect each section in the longitudinal-radial plane through the center of the branch and stem pith. Occasionally two

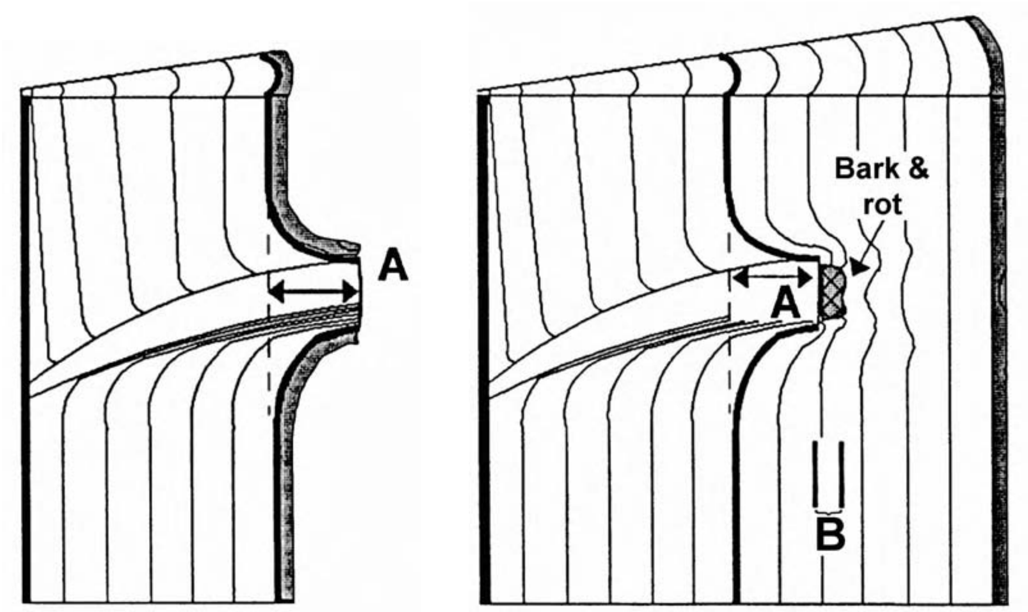

Figure 2—Diagrammatic stem sections showing branch stub immediately after pruning and 6 years later. Healing (occlusion) region is separated into stub length (Zone A) and region beyond the stub where defects may occur (Zone B). Adapted from Petruncio et al. (1997).

or more cuts were needed to achieve good radial exposure through the branch. The radial surface was then sanded with a belt sander to aid identification of rings and various growth and healing (occlusion) boundaries (fig. 2).

Qualitative branch characteristics (dead or alive, pruned or unpruned) were recorded as were various ring counts. Linear measurements such as branch diameter, ring widths, and distances from the pith to point of branch death (branch collar wounding study only), end of stub, occlusion, and beginning of clear wood were determined to the nearest 0.1 mm. Ring counts and distances as defined in Petruncio et al. (1997) plus some additional variables were calculated from the above measurements (table 2). For pruning treatments applied during the growing season, some measurements of ring count (CAM) and radial distance (AW, RIB) were adjusted as appropriate based on the phenology of stem cambial growth (i.e., seasonal pattern of cumulative radial increment) as determined in the plantations and reported in DeBell and Giordano (1994).

Summary and Analysis of Data

Analysis of variance procedures were used to assess effects of treatments (date of pruning in study 1, and branch collar wounding in study 2) on time and distance to clear wood, and treatment means were separated by least significant difference procedures (SAS 1994). Correlation matrices containing all variables were examined to evaluate relationships to time and distances to produce clear wood on pruned trees. All samples (stem sections) were assumed to represent independent observations. Differences among treatment means and correlation coefficients were considered significant if $p<0.05$. Data on live, dead, and epicormic branches originating on the bole below 3.3 m were summarized by 1.0 m height intervals above the stump (0.3 m).

Results

The young trees in the plantation responded well to pruning. No trees died, and except for the pruning wounds, none were obviously injured in the pruning operation. There was no excessive sap flow or bleeding from wounds. At time of sampling, external evidence of pruning scar locations was still observable but occlusion was complete on all trees and there were no visual differences among treatments.

General Nature of Tree Characteristics and Pruning-Healing Variables

Values for pruning-healing variables measured on the stem sections for Study 1 and Study 2 are listed in table 3. Age and size of the stem sections and branches differed substantially between the two studies at time of pruning: cambial age of the stem section (3.6 vs. 5.0 years); its mean radius (25.5 vs. 48.5 mm); mean stub diameter (13.4 vs. 17.0 mm); and stub length (13.2 vs. 18.7 mm) had much lower values in Study 1. Average time (ABR) and distance (ABW) to clear wood also differed markedly, even though radial growth rate after pruning (RWAP) was rather similar in the two studies (5.7 and 6.0 mm/yr).

Table 2—Definition of variables.

Ring counts	
CAM	Number of rings from the pith to the year pruned. i.e., age of cambium when pruned
AR	Number of rings (years) to grow over zone A. i.e., since the year of pruning to the stub end
BR	Number of rings (years) to grow over zone B, i.e., from the end of stub to clear wood
ABR	Total number of rings (years) of zones A and B combined
DPRG	Number of rings between branch death and pruning (study 2 only)
Distances (mm)	
AW	Zone A width = stub length: the distance from the stem cambium at the time of pruning to the stub end (See Fig. 2)
BRDIA	Stub end diameter
BW	Zone B width: the radial distance from the end of stub to clear wood (Fig. 2)
ABW	Width of zones A and B combined (ABW = AW + BW)
RIB	Radius from pith to year of pruning (RIB= ROS – AW)
ROS	Radius-over-stub: distance from pith to end of stub
ROO	Radius-over occlusion (ROO = ROS + BW)
DPDIS	Distance from point (ring) of branch death to prune (study 2 only)
Other measures	
BRANG	Branch angle (measured from vertical)
RWAP	Average ring width (rate of growth) for the 6 years after pruning

Study 1 — Date of Pruning

Although there were no significant differences among pruning dates for number of rings (AR) from time of pruning to end of the pruned stub, significant differences were present among some treatment means for other “healing” or occlusion variables (table 4a). On average, fewer than 2 years (1.4 to 1.9) and no more than 15.2 mm (AW) of radial growth were needed to reach the end of the branch stub. Such values are, of course, strongly influenced by growth rate after pruning and closeness of the prune to the stem (stub length). Statistically significant differences among pruning dates in time and distance from the end of the stub to formation of clear wood (BR and BW) reflect defects of various kinds (primarily bark or rot). Pruning in the dormant season (January 1) and just prior to the beginning of the growing season (March 1) resulted in longer times beyond the stub to clear wood (BR) than for pruning in mid-June (0.86 and 0.82 vs. 0.41 years); distances from the end of stubs to clear wood (BW) were, on average, twice as long for January pruning as those for any other date (5.1 vs. 2.5 mm). Because total time (ABR) and distance to clear wood (ABW) is the summation of both A and B variables (radius or time at pruning to end of stub plus end of stub to clear wood), they both show significant differences among treatment dates. In general, pruning during the growing season (May 1 and June 15) and, to a lesser degree, late in the growing season when some leaf abscission has started (September 15) results in shorter times and distances from pruning to formation of clear wood (average–2.1 years and 14.5 mm radial distance) than does pruning in the dormant season (January 1) or just prior to the beginning of the growing season (March 1) (average–2.6 years and 18.6 mm radial distance).

The relatively short time to produce clear wood after pruning live branches contrasts sharply with the time required for branches in unpruned trees to die, break off, and heal over. Many of the unpruned trees still had live and dead branches on the lower stem: one third still had live branches in the 1.3 to 2.3 m section and two thirds had live branches in the 2.3 to 3.3 m section. Dead branches were even more common; one third of the unpruned trees had dead branches in the lowest (0.3 to 1.3 m) section and all trees had some dead branches on the bole below 3.3 m. All trees evaluated in this study were components of intensively measured research plantations; as such, lower dead branches were no doubt broken off sooner and closer to the bole by activities of field personnel than would be typical in production plantations. Thus, not only is the presence of dead branches on the unpruned study trees likely to be lower than what would usually be expected, but also our assessment of times and distances required to produce clear wood beyond those branches that did break off may be biased toward the low end. Even so, average times and distances to clear wood after branch death were markedly greater in unpruned trees (4.2 years and 23.9 mm) than after pruning in pruned trees (2.4 years and 16.2 mm).

Table 3—Values of healing-pruning variables measured on pruned branch stubs of studies 1 (date of pruning) and 2 (branch collar wounding).

		Study 1				Study 2			
Variable (unit)	Code	Mean	Std dev	Min	Max	Mean	Std dev	Min	Max
Age branch was pruned (years)	CAM	3.6	0.9	1.0	5.0	5.0	0.2	4.0	5.0
Rings in zone A (years)	AR	1.7	1.2	0.0	6.0	2.9	1.2	1.0	7.0
Width of zone A= stub length (mm)	AW	13.2	7.1	0.0	32.0	18.7	5.5	6.0	30.0
Rings in zone B (years)	BR	0.6	0.8	0.0	3.0	0.3	0.5	0.0	1.0
Width of zone B (mm)	BW	3.0	3.6	0.0	17.0	4.9	4.4	1.0	21.0
Rings in zones A and B (years)	ABR	2.4	1.3	0.0	6.0	3.2	1.3	1.0	7.0
Width of zones A and B (mm)	ABW	16.2	7.8	0.0	37.0	23.5	6.8	7.0	38.0
Radius-inside-bark (mm)	RIB	25.5	8.4	8.0	51.0	48.5	7.2	29.0	69.0
Radius-over-stub (mm)	ROS	38.4	8.9	16.0	60.0	67.2	8.5	46.0	90.0
Radius-over-occlusion (mm)	ROO	41.4	9.8	20.0	75.0	72.0	10.2	47.0	107.0
Ring width after pruning (mm/year)	RWAP	5.7	1.8	2.3	11.0	6.0	1.6	2.7	11.0
Stub diameter (mm)	BRDIA	13.4	6.8	4.6	38.6	17.0	5.2	6.6	33.8
Rings between branch death and prune (years)	DPRG	N/A	N/A	N/A	N/A	1.1	0.5	0.0	3.0
Distance between branch death and prune (mm)	DPDIS	N/A	N/A	N/A	N/A	9.2	5.7	0.0	27.0
Branch angle (degrees)	BRANG	35.3	11.4	4.0	68.0	36.7	11.4	3.0	77.0

The preliminary assessment of decay organisms indicated that decay fungi were present in the branch stubs of unpruned trees to a somewhat greater extent than in the wound centers or branch stubs of pruned trees (29% vs. 19%, respectively, for the average of all dates). There was a trend by pruning date in the percentage of stubs from pruned trees that contained decay fungi, however: January - 4%, March - 8%, May - 22%, June - 21%, and September - 39%.

Study 2 — Pruning and Branch Collar Wounding

Times and distances between pruning and the end of the stub (AR and AW) and to the production of clear wood (ABR and ABW) differed significantly between sections with damaged and undamaged branch collars (table 4b). The amount of defect beyond the stub (reflected in BR and BW), however, was essentially the same in the two treatments, 0.3 years and about 5 mm of radial growth. The times and distances to production of clear wood after pruning averaged slightly more than 3 years and about 23 mm of radial growth. Times and distances associated with intentional wounding of the branch collar were shorter, and were associated with shorter stub lengths (AW) for limbs pruned at the stem (damaged branch collars) rather than those pruned just beyond at the branch collar.

As discussed above, estimates of remaining branches on unpruned trees are probably conservative. Because the plantation in the branch collar wounding study was older, no trees had live branches (except for epicormic branches) below 3.3 m. All unpruned trees, however, still had dead branches in the 1.3 to 2.3 m bole section and higher, and a few had a branch in the lowest 0.3 to 1.3 m section. Times and distances required for formation of clear wood for those branches in unpruned trees that did die and break off were at least one year longer and 5 mm greater in distance than those required by pruned trees.

Other Factors that Influence "Healing" Variables

Correlations among all variables listed in table 2 were examined to determine which factors (other than date of pruning and branch collar wounding) might influence time and distance to formation of clear wood. Correlation coefficients for most variables that were significantly correlated with one or more healing variables are listed in tables 5a and 5b.

Only live branches were evaluated in the date of pruning study (table 5a), and the factors associated with *increased* time and distance to formation of clear wood (ABR and ABW) were branch diameter (increased lengths

Table 4a—Treatment means for "healing" variables Study 1—date of pruning. Means in a column followed by the same letter are not significantly different at p = 0.05.

Date	AR	AW	BR	BW	ABR	ABW
	yrs	mm	yrs	mm	yrs	mm
January 1	1.7a	14.5bc	0.9b	5.1b	2.6ab	19.6b
March 1	1.9a	15.2c	0.8b	2.4a	2.6b	17.6ab
May 1	1.4a	10.9a	0.5ab	2.6a	1.8a	13.5a
June 15	1.7a	11.0a	0.4a	2.9a	2.2ab	13.9a
September 15	1.8a	13.8abc	0.6ab	2.2a	2.4ab	16.0ab

Table 4b—Treatment means for "healing" variables (study 2). Means followed by the same letter are not significantly different at p = 0.05.

Treatment	AR	AW	BR	BW	ABR	ABW
	yrs	mm	yrs	mm	yrs	mm
Damaged	2.54a	17.0a	0.32a	4.9a	2.85a	21.9a
Undamaged	3.17b	20.2b	0.30a	4.8a	3.47b	24.8b

Table 5a—Correlation (r) of healing variables to other characteristics of stem cross sections (study 1-date of pruning). Based on 106 samples (all dates, live branches only): minimum r for statistical significance at p = 0.05 is 0.20.

Healing variable	Other characteristics				
	RIB	CAM	BRDIA	BRANG	RWAP
AW	-0.37	-0.44	0.36	0.28	0.10
AR	-0.43	-0.45	0.14	0.17	-0.05
BW	0.20	-0.02	0.22	0.11	0.25
BR	0.14	-0.02	0.42	0.18	-0.08
ABW	-0.25	-0.41	0.43	0.31	0.20
ABR	-0.29	-0.40	0.38	0.27	-0.08

Table 5b—Correlation (r) of healing variables to other selected characteristics of stem cross sections (study 2—branch collar wounding). Based on 88 samples (both treatments, dead branches only): minimum r for statistical significance p = 0.05 is 0.21.

Healing variable	Other characteristics		
	RIB	BRDIA	RWAP
AW	-0.13	0.15	0.25
AR	-0.03	0.32	-0.23
BW	0.24	0.33	-0.09
BR	-0.20	0.07	-0.25
ABW	0.05	0.33	0.15
ABR	-0.07	0.32	-0.31

of both stub [AW] and defect [BW] and time to grow over defect [BR]), branch angle (mainly increased stub length), and radial width after pruning (RWAP) (increased defect [BW]). Increased radius (RIB) and age (CAM) of the stem section at pruning were associated with *decreased* time and distance to formation of clear wood, primarily because stub lengths (AW) for stem sections having larger radii and greater numbers of rings were significantly shorter and fewer years were required to grow over them.

In contrast to table 5a which examines correlations between distances and times to clear wood production and other stem and branch traits after pruning *live* branches of trees in the 3-year-old plantation used for the date-of-pruning study, table 5b shows correlations among some of the same plus additional variables after *dead* branches were pruned from trees in the 6-year-old plantation used for the branch collar wounding study. Healing variables for dead branches were not correlated with cambial age (CAM) or branch angle (BRANG) as they were for live branches in the date-of-pruning study (table 5a). Neither were distance or time from branch death to pruning (DPDIS and DPRG) related to any of the healing variables. Stem radius at pruning (RIB) and defect (BW), however, were positively correlated. Larger diameter branches (BRDIA) had slightly (though not significant statistically) longer stubs (AW), greater defect (BW), took more years to grow over stub (AR), and resulted in longer times and distances to clear wood (ABR and ABW). Increased radial growth

Table 6—Epicormic branching in pruning studies compared with comparable unpruned trees of the same age.

	Study 1 (date of pruning)				Study 2 (branch collar wounding)			
	Stem section (ht (m) above ground)				Stem section (ht (m) above ground)			
	0.3 to 1.3	1.3 to 2.3	2.3 to 3.3	All heights	0.3 to 1.3	1.3 to 2.3	2.3 to 3.3	All heights to 3.3 m
Trees with 1 or more epicormic branches (%)								
Pruned	16.0	6.0	12.0	20.0	55.0	20.0	25.0	65.0
Unpruned	9.1	17.3	36.4	54.5	60.0	40.0	30.0	90.0
Mean number of epicormic branches per tree (number) all trees								
Pruned	0.20	0.10	0.24	0.60	1.45	0.20	0.40	2.05
Unpruned	0.18	0.36	0.82	1.36	1.20	0.90	0.40	2.50
Mean diameter of epicormic branches (mm)								
Pruned				2.5				2.3
Unpruned				3.3				2.1

after pruning (RWAP) was associated with decreased time to grow over stubs (AR), any defect (BR), and produce clear wood (ABR). Although RWAP was also significantly correlated with increased stub length (AW), no reasons for this relationship are apparent.

Epicormic Branching (Both Studies)

Epicormic branching was minimal in the two pruning studies. Averaged over all pruned trees, there was less than one epicormic branch per tree in the date of pruning study and only two branches per tree in the branch collar wounding study (table 6). The branches averaged only 2-3 mm in diameter at 6-7 years after pruning. Moreover, such epicormic branching as did occur could not be attributed to pruning because an examination of 10 comparable unpruned trees near each study revealed that incidence of epicormic branching was equal to or greater than in their pruned counterparts. The percentage of trees with epicormic branches and the number of branches per tree tended to be greater for the lowest (0.3-1.3 m) stem section than for the two higher stem sections (table 6); and only in this lower section was epicormic branching sometimes greater for pruned than for unpruned trees.

Discussion and Conclusions

That vigorous red alder saplings can heal over and produce clear wood after only 2 to 3 years and about 25 to 40 mm (or about 1 to 1.5 inches) of *diameter* growth following pruning (fig. 3) is good news for forest owners and managers who may wish to accelerate the production of clear wood on relatively short rotations. Berntsen's (1961) earlier work on alder trees that were pruned at age 21 also indicated that *some* pruning stubs were grown over in two years but there was no indication as to the proportion of wounds that healed over in that time. In our study, clear wood was being laid down over about 60% of the pruning wounds within two years, and nearly 80% of the wounds within 3 years.

Our date-of-pruning trial identified differences among pruning dates that were significant statistically, but managers will want to consider whether a difference of 0. 8 years or 6 mm in time and radial distance is sufficient to warrant scheduling of operations to coincide with the *best* times for pruning. Certainly it would not if one had to postpone pruning operations until the next year to do it at the optimal time. Nevertheless, the finding that early to mid-growing season is, in fact, the most effective time for rapid healing is fortunate from the standpoint of operational planning because many other silvicultural activities such as planting and fertilizing usually must be scheduled before or after the growing season. Although no other research on date of pruning has been done for red alder, our results are generally consistent with findings for eastern hardwoods. Neely (1970), for example, found that spring (May) wounds healed much more rapidly than wounds created in summer (July), fall (October), or winter (March) for ash, honey locust, and pin oak. Although McQuilkin (1950) recommended pruning eastern hardwoods (except red maple) in late winter and early spring to achieve fastest wound occlusion, he favored pruning red maple in late spring or early summer to reduce excessive bleeding. Leban (1985) concluded that spring wounding of red maple led to less dieback around the wound and less decay than fall wounding. Colder than normal temperatures at time of the January pruning in our study may have been responsible for greater tissue damage and defect (BW or rot plus bark) in January than occurred for other pruning dates (decay associated with this pruning date, however, was low).

Figure 3—Stem section from tree pruned as part of the branch collar wounding study. Clear wood was produced after only 2 years following pruning.

Our study of branch collar wounding indicated that it is unnecessary to avoid wounds of the branch collar (i.e., as in a "Shigo cut") when pruning dead branches of red alder. Healing times and distances to clear wood were, in fact, slightly shorter when branch collars were intentionally wounded. Most pruning studies with other hardwood species have involved removal of live branches, and it has been recommended that branch collars should not be damaged when live branches are pruned (cf., Shigo 1986). Shigo et al. (1979), working with black walnut, recommend against injuring the branch collar even when pruning dead branches because it may increase the amount of decay spreading inward (and upward and downward) from the dead branch. Ring shakes and dark vertical streaks also were associated with injured branch collars (flush cuts) in the black walnut trees. We saw little evidence of such development of decay (or shake and discolorization) in red alder, however. And years ago, Berntsen (1961) also reported that "decay rarely extended beyond the extremities of knots." Recent work has determined that living red alder is very efficient in its ability to compartmentalize decay, and most decay events do not extend beyond the injured tissue (Allen 1993, Harrington et al. 1994).

Our examination of the healing over of broken branches in unpruned trees indicated that times and distances to clear wood were substantially greater than those associated with pruning of either live or dead branches. Such data obviously applies only to the period after the branch has died and has broken off; if one adds the period prior to such events to that recorded in our comparison, one is probably looking at differences of 5 or more years to produce clear wood in the lower 3 m of stem of unpruned trees. Thus, the decision *to prune or not prune* is of much greater practical importance than that of when to prune live branches or how to prune dead ones.

Examination of correlation coefficients served mainly to underscore some logical relationships between stem and branch traits and healing. Times and distances to clear wood were longer as branch diameter and branch angle increased. Healing times and distances for trees in the 3-year-old plantation were shorter, however, for stem sections of greater cambial age and larger diameter (radius). Apparently it was easier to make close prunes (shorter AW) on larger rather than smaller stems. We suspect this finding was associated with use of clippers to prune branches on some of the smaller trees that lacked sufficient rigidity for use of the saw; the relationship did not occur in the larger trees in the 6-year-old plantation pruned in the branch collar study, all of which were pruned by saw. Correlation coefficients for the date of pruning study suggested that increased growth rate after pruning was associated with greater defect (BW). Such a trend seems counter-intuitive and may be associated with some peculiarity or confounding relationship in our sample, and it was not apparent in the branch collar wounding study. The correlation in the latter study of increased radial growth rates with decreased time to grow over the stub, defect, and produce clear wood, however, is what one would expect.

Epicormic branching does not appear to be a problem when young, vigorous red alder trees are pruned. More than half of the pruned trees had no epicormic branches; those that did averaged fewer than two epicormic branches per tree and these were small, averaging only 2.4 mm in diameter. Moreover, such epicormic branching as did occur was just as prevalent or more so in unpruned trees in the same plantation. Only in the lowest section of the bole (0.3 to 1.3 m) did the incidence of epicormic branching average slightly higher in pruned than unpruned trees. The tendency toward increased sprouting in the lowest section of both pruned and unpruned trees in the branch collar damage study (6-year-old plantation) may result from decreased apical control at greater distances from the terminal, and the much greater distance from the live crown in pruned than in unpruned trees may account for the slightly greater epicormic branching at this level in pruned trees.

Why do our findings and interpretations with respect to epicormic branches differ so greatly from those of Bernsten (1961)? We believe at least two factors may contribute: (1) general vigor, and (2) other changes in the stand environment. Trees in Berntsen's study were undoubtedly less vigorous; they were 21 years old and growing in natural stands when pruned whereas ours were growing in 3- and 6-year-old plantations. Red alder grows very rapidly in height during the first two decades, especially so in the first 10 years (Harrington and Curtis 1986). Beyond that time height growth is markedly reduced, and some studies have shown that response of natural alder stands to an initial thinning at older ages is much reduced and sometimes negligible (Berntsen 1962, Warrack 1964). In addition, tree crowns begin to lose their conical form at about the same time, indicating that apical control is diminishing. Skillings' (1958) research on defects and healing following pruning in northern hardwoods is consistent with our suggestion that tree vigor plays a role; he found epicormic branching to be substantial in lower crown classes, but limited in dominant and codominant trees. In another study (Skilling 1959) on yellow birch (a relative of red alder), only dominant and codominant trees were pruned; epicormic branching was slight and branches short-lived, and "for all practical purposes could be disregarded." Secondly, other information indicates that the pruned trees examined by Berntsen (1961) came from a stand that was not only pruned, but also had been released from overtopping conifers and thinned at the same time (Rapraeger 1949, Berntsen 1962). If so, the epicormic branching may have been a response to sudden opening of the stand by release and thinning as well as pruning, and perhaps was particularly stimulated by the combination of these treatments at a stand age (21 years) when growth (particularly height growth) is normally decreasing. Other studies have indicated that epicormic branching can increase when red alder stands are thinned, and such observations were made primarily in stands thinned beyond age 15 (Warrack 1964, Smith 1978). Some epicormic branching may occur even when younger stands are thinned, however (Hibbs et al. 1989). In another pruning trial established in a 10-year-old plantation, trees at the edge of the stand or near openings had greater numbers of epicormic branches than trees in fully-stocked portions of the stand (Brodie and Harrington 2006). Given these observations, we suggest that epicormic branching is unlikely to be a problem when pruning is done on interior trees early in the life of alder plantations—i.e., when height growth is in its most rapid phase (before age 15)—and at least a year or so after (or before) any significant thinning of the stand. There may be logistical as well as biological reasons to schedule thinning and pruning operations in different years.

Trees in our study were pruned by removal of about one-third of the live crown (retaining crown ratios of 50% or more) and no top breakage occurred. Pruning 50% or more of the total height on young trees, however, may greatly increase the chances that high winds will snap off the top during the first growing season or so after pruning. Such damage has been observed when operational plantations were pruned to that degree. Although not a problem in these trials, there is some anecdotal evidence that pruning can increase the attractiveness of the bole to sapsuckers (possibly because increased sugar content at base of now raised live crown).

Based on this work and that reported in Brodie and Harrington (2006), there seem to be no major biological concerns about pruning live and dead branches in the lower one-third of crowns of young red alder. Pruning can be done at anytime of the year (even during the growing season; if anything, preferably so) and without particular concern about damage to branch collars. On average, clear wood will be produced in fewer than 3 years and less than 40 mm (1.5 inches) of diameter growth after pruning. Decisions on whether or not to prune must be based on price differentials for clear versus knotty wood and the costs of investments in pruning. Currently available data on tree growth, log volume, and lumber recovery can be used to evaluate the economic benefits (or lack thereof) of pruning stands of various ages on sites of different quality, and harvested at a range of ages.

Acknowledgements

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— Red Alder: A State of Knowledge —

On the Effects of Tree Crop Rotation: Red Alder Following Alder or Douglas-fir; Douglas-fir Following Fir or Alder

Mariano M. Amoroso[1] and Eric C. Turnblom[2]

Abstract

Red alder (*Alnus rubra* Bong.) has been proposed for use in crop rotation due its ability to symbiotically fix atmospheric nitrogen. The ability of this species for increasing nutrient status and ameliorating site deficiencies have been recognized, however whether this will have an effect on a subsequent "crop" or if it can be used in a crop rotation scheme remains unknown. A Douglas-fir – red alder conversion study established in 1984 may shed light on some of these issues. Results 20 years after establishment showed that the previous presence of red alder resulted in an overall increased productivity of the site compared to the adjacent Douglas-fir site.

Keywords: crop rotation, Douglas-fir, red alder, Washington State

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Introduction

Crop rotation is the alternation of different crops in the same field in some regular sequence. It differs from the haphazard change of crops from time to time, in that a deliberately chosen set of crops is grown in succession in cycles over a period of years; the crop sequence is not randomly chosen either, but is intentionally selected with a specific objective. This technique appeared primarily as a solution to the decline in crop yields resulting from having the same crop continuously grown in the same place. The practice of crop rotation has been widely accepted and successfully applied in the field of the agriculture. There are both direct and indirect benefits from rotational practices. Among them are pest control, maintenance of organic matter and soil nitrogen, protection and complete use of soil, balanced used of plant nutrients, economy of labor, and risk reduction. However, the effectiveness of rotating crops will ultimately depend on the type of crops and crop rotation timing.

When it comes to forestry, "rotation" is recognized as a guide for the economic age to which each stand can be grown before it is succeeded by the next one. It is also a more complex but flexible concept since rotation could also be understood in ecological terms. In practice the rotation time is set by two principles, the physical and the financial rotation, since one can almost never be considered without the other (Smith et al. 1997). In either case the goal is to maximize or optimize the long-term sustained yields and capital return respectively. Nevertheless, forestry faces some of the same issues as agriculture and sometimes silvicultural practices are needed for pest control, maintenance of adequate levels of organic matter and nitrogen in the soils, as well as soil protection. Additionally, and even though it has not been practically demonstrated, the repeated cultivation of same forest stands in some sites could possible result in yield declines.

The concept of crop rotation has not been applied to forestry for practical reasons such as rotation lengths, lack of a variety in crops as well as the fact that forestry is a younger discipline compared to agriculture. The unmodified application of this agriculture concept in forestry will not be that simple for managerial, biological and economical reasons; however, there might be situations, such as in the case of short rotations of fast growing species, where it could be feasible. Other cases could also include situations where some kind of immediate site amelioration is needed, or where the presence of a particular species in the previous crop will result in an improvement of the site quality and thus an increase in the yield of the future species.

Red alder (*Alnus rubra* Bong.) has been proposed for use in both crop rotation and in mixtures with other species (Tarrant and Trappe 1971, Atkinson et al. 1979, DeBell 1979). Due to its ability to symbiotically fix atmospheric nitrogen, this species can increase levels of nitrogen and organic matter to a site (Tarrant and Miller 1963, Trappe et al. 1968, Harrington 1990), and has been experimentally planted to serve as a nitrogen source for other species (Briggs et al. 1978), as an alternative to N fertilization in N-stressed forests, and on other eroded or low fertility areas (Tarrant and Trappe 1971, Heilman 1979). Additionally, it could be used in a crop rotation system or as an alternative in areas containing coniferous root pathogens, such as *Phellinus weiri* (Hansen 1979, Harrington 1990) or Swiss needle cast. The ability of this species for increasing nutrient status and ameliorating site deficiencies have been recognized (Harrington 1990) and some attempts were made simulating different rotation schemes (Atkinson et al. 1979); however, whether this will have an effect on a subsequent "crop" or whether it can be use in a crop rotation scheme remains unknown.

A unique semi-natural experiment was established in 1984 at the so-called "Thompson Site" on the Cedar River Watershed, WA in which two adjacent stands were clear-cut harvested in the same year, one predominantly Douglas-fir (*Pseudotsuga menziesii*, Mirb. Franco), the other predominantly red alder. Each of the stands were divided in two and then replanted to red alder and Douglas-fir respectively; representing alder plantations following both an alder and a fir stand, and v*ice versa*. The goal of this study was to determine the effect of red alder soil nutrient status (leaching vs. mineralization and nitrification rates) on soil fertility, as well as on the growth of subsequent forest rotations (Van Miegroet et al. 1990, 1992). The authors concluded that even though the presence of red alder generally improves the N fertility of the site, the experiment was not able to demonstrate, after 4 years, an improvement in growth (based on height measurements only) of the seedlings planted on sites previously occupied by alder over those planted after Douglas-fir cover (Van Miegroet et al. 1990). Another finding of the study was a decrease in soil and solution pH in the upper soil horizon. The authors hypothesized a phosphorus deficiency and later, two different levels of phosphorus fertilization were applied as well as one level of nitrogen fertilization. No further aboveground analyses of this study were conducted since then. Based on the potential of this alternative on some areas, we decided to investigate the outcomes twenty years after study establishment with the following objectives:

- Whether the presence of red alder improves site fertility and thus growth and productivity of subsequent rotations, or whether it may have a negative impact.
- Whether there are any differences in succeeding species in relationship to this potential growth change.
- Whether the supplementation with N and P may have an effect on productivity.

Methodology

Site characteristics

The study was conducted at the Thompson Research Center (aka "Thompson Site") at the Cedar River Watershed, King County, WA. The site has a mean annual temperature of 49.6°F and a mean annual precipitation of 51.2 inches. Two adjacent stands originating after fire in the 1930s were clear-cut harvested in 1984, one predominantly Douglas-fir (*Pseudotsuga menziesii*, Mirb. Franco), the other predominantly red alder (*Alnus rubra* Bong.). At the time of harvesting the stands presented the following characteristics: the Douglas-fir stand had approximately 445 stems per acre (SPA) and 218 ft^2 per acre of basal area with a Douglas-fir site index of 106 ft at 50 years breast height age (site class III); the red alder stand was about 324 stems per acre and 156 ft^2 per acre of basal area with a Douglas-fir site index of 111 feet at 50 yr breast height age (site class III). Both stands were around 50 years old.

Experimental design

The study consists of a Split-split Plot Design. In each of the original stands an area of 2.5 acres was cut, divided in two, and replanted in 1985 with 500 SPA to red alder and Douglas-fir respectively; this representing red alder plantations following both an alder and a fir stand, and v*ice versa*. Eight tenth-acre experimental plots were set in each replanted area adding up to a total of 32 plots. Later on, in an effort to assess the effects of additional site amelioration, between two and four of the eight plots in each new plantation were fertilized as follows: i) 180 pounds/acre N as urea at 8 years where Douglas-fir was planted; and ii) 180 and 360 pounds/acre of P at 7 years where red alder was planted. After the fertilization treatments were applied, treatment descriptions resulted as follows:

1. FF C: Cut DF stand, plant 1-1 DF, control (no fertilization)
2. FF N: Cut DF stand, plant 1-1 DF, fertilize 180 pounds/acre N
3. FA C: Cut DF stand, plant RA wildings
4. FA P360: Cut DF stand, plant RA wildings, fertilize 360 pounds/acre P
5. FA P180: Cut DF stand, plant RA wildings, fertilize 180 pounds/acre P
6. AA C: Cut RA stand, plant RA wildings
7. AA P360: Cut RA stand, plant RA wildings, fertilize 360 pounds/acre P
8. AA P180: Cut RA stand, plant RA wildings, fertilize 180 pounds/acre P
9. AF C: Cut RA stand, plant 1-1 DF
10. AF N: Cut RA stand, plant 1-1 DF, fertilize 180 pounds/acre N

We decided to include only the higher level of phosphorus fertilization in this analysis (RA plots with 180 pounds/acre P were not considered).

Analysis

Data were analyzed as a linear repeated measures experiment with two factors, treatment and time. The treatment factor consisted in the combinations of rotation pattern and fertilization (8 levels), and the time factor in three times post establishment (5, 10 and 20 years). For purposes of the analysis, each of the eight plots representing a rotation pattern were considered as replicates. The authors recognize that in fact, the plots are not strictly independent. So, results obtained from hypothesis testing are likely to have larger p-values in reality than would first appear.

The model describing both fertilization and time is presented as follow:

$$y_{ijk} = \mu + t_i + h_{k(i)} + q_j + tq_{ij} + e_{ijk} \qquad (1)$$

where:

y_{ijk} = (QMD, Volume, Height) for rotation / fertilization combination i, time j, replicate k

μ = overall average response

t_i = the fixed effect of the i-th rotation/fertilization level

$h_{k(i)}$ = the error accounting for variation between plots

q_j = the effect of time period j

tq_{ij} = time by treatment interaction

e_{ijk} = the leftover error not accounted for by time or treatment

Attempts were made to add covariates to the model to account for uncontrolled factors, especially density, but the results showed the variables not to be significant. A strong interaction was apparently occurring for "FA C" and "FA P" treatments with time. This was resolved with covariance adjustments in the 3rd. measurement when historical records revealed storm damage in those plots. Statistical differences among treatments were tested by using orthogonal contrasts (0.1 level); tables for comparisons between treatments are presented in what follows.

It is important to note before presenting the results that the domain of the study may limit the scope or range of conditions to which results apply (one soil type, location, etc.) It is important to note that some of the plots have suffered physical damage by weather and other abiotic agents, so the results must be interpreted in light of this knowledge.

Table 1—Contrast results for Quadratic Mean Diameter at ages 5, 10 and 20.

Contrast	Age = 5	Age = 10	Age = 20
ALDER SITE VS. FIR SITE	**SIGNIF.**	**SIGNIF.**	**SIGNIF.**
FFC vs. AFC	NS	SIGNIF.	SIGNIF.
FFC vs. FFN	NS	NS	SIGNIF.
AFC vs. AFN	NS	NS	NS
FAC vs. AAC	NS	NS	SIGNIF.
AAC vs. AAP	NS	NS	NS
FAC vs. FAP	NS	NS	NS
FAP vs. AAP	NS	NS	SIGNIF.

Table 2—Contrast results for Mean Total Height at ages 5, 10 and 20.

Contrast	Age = 5	Age = 10	Age = 20
ALDER SITE VS. FIR SITE	**NS.**	**NS**	**SIGNIF.**
FFC vs. AFC	NS	SIGNIF.	SIGNIF.
FFC vs. FFN	NS	NS	NS
AFC vs. AFN	NS	NS	NS
FAC vs. AAC	NS	NS	SIGNIF.
AAC vs. AAP	NS	NS	NS
FAC vs. FAP	NS	NS	SIGNIF
FAP vs. AAP	NS	NS	SIGNIF.

Results

Diameter growth

Both DF and RA exhibited significantly greater QMD in the control plots growing after RA compared to DF (fig. 1). For DF these differences in growth resulted to be significant at age 10 (table 1). From the same figure it can be seen what happened with red alder through time. At age 5 RA growing after DF had a greater QMD compared to the FA rotation. However, 15 years later it seems that initial difference no longer remains and has turned slightly in favor of the AA rotation. Interesting also is the effect RA has on both species growth patterns. When growing after DF, RA resulted in a greater QMD than DF after 20 years. However, growing after RA and despite the initial differences, DF resulted in a larger diameter. Interesting was also the fact that at initial ages alder trees growing after alder presented a smaller QMD compared to those growing after DF. Even though a toxicity effect was initially hypothesized, Van Miegroet et al. (1990) concluded that such response could have been a consequence of competition with a more intense understory vegetation development in the N-richer site.

The fertilization treatments also showed some interesting results (figs. 2 A, B). Nitrogen fertilization resulted in a growth increment only when DF grew after DF. The addition of phosphorus on the RA plots seems to have a small effect in the AA plots resulting in greater QMD although differences were not significant (table 1).

Height growth

Height growth of DF and RA appears to be enhanced if RA is the previous crop (fig. 3). In addition to this, fig. 3 shows the higher initial growth of RA compared to DF as it has been reported in the literature but also that the stand dynamics is reaching the time where attained heights of RA and DF are just about to reverse as a consequence of RA height growth slowing down.

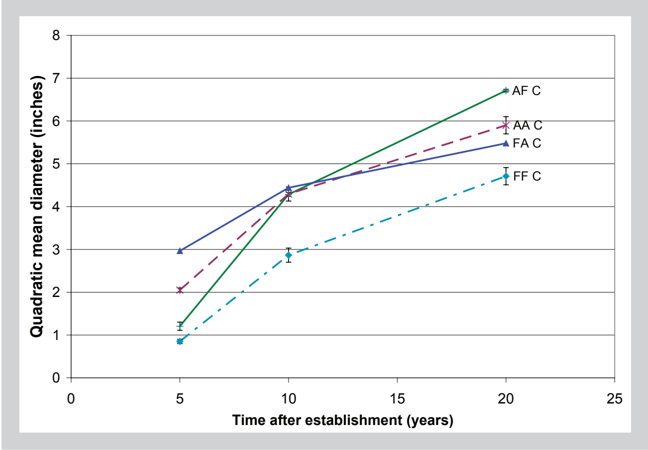

Figure 1—Quadratic mean diameter at 5, 10 and 20 years after establishment. Vertical bars represent standard errors.

The addition of fertilizers had also some influences on the height growth of both species. While nitrogen fertilization resulted in no added increment for DF, phosphorus increased the total height of RA growing after both RA and DF (figs. 4 A, B). It can be seen again that DF growing after RA resulted in taller trees but no differences where found between the control and the fertilization treatment (table 2). In the RA plots the addition of P may result in slightly taller trees. It is interesting that RA height growth slowed down sooner where RA was planted after DF.

Volume

The presence of RA in a rotation scheme increased the total volume per acre in the DF control plots compared to the FF rotation (fig. 5). After 20 years DF growing after RA doubled the volume per acre of DF after DF. This result parallels those found for diameter and height. No significant differences were found for RA following RA or DF.

Even though some trends can be seen and differences are expected to become significant with time (figs. 6 A, B), the fertilization treatments resulted in no significant effects (table 3).

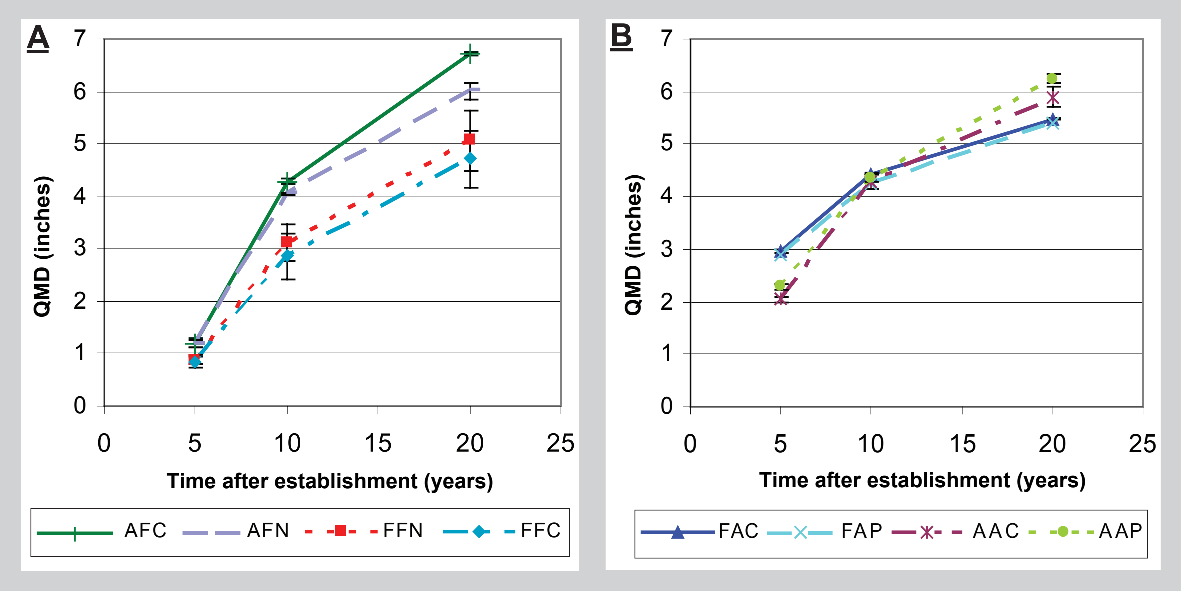

Figure 2—Quadratic mean giameter for Douglas-fir (A) and red alder (B) after 5, 10 and 20 years of establishment. Vertical bars represent standard errors.

Table 3—Contrast results for Volume per Acre at ages 5, 10 and 20.

Contrast	Age = 5	Age = 10	Age = 20
ALDER SITE VS. FIR SITE	**NS**	**NS**	**SIGNIF.**
FFC vs. AFC	NS	NS	SIGNIF.
FFC vs. FFN	NS	NS	NS
AFC vs. AFN	NS	NS	NS
FAC vs. AAC	NS	NS	NS
AAC vs. AAP	NS	NS	NS
FAC vs. FAP	NS	NS	NS
FAP vs. AAP	NS	NS	NS

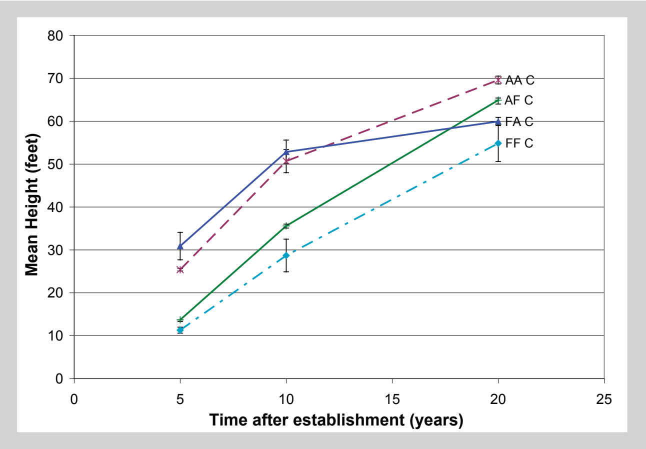

Figure 3—Mean total height at 5, 10 and 20 years after establishment. Vertical bars represent standard errors.

Conclusions

Results 20 years after establishment show that the presence of red alder resulted in an overall increased productivity of the site compared to the adjacent Douglas-fir site (table 3). The Douglas-fir plantation established after a red alder stand not only exhibited the greatest productivity measured as volume per acre but also doubled that of Douglas-fir growing after a Douglas-fir stand.

In a red alder – red alder rotation scheme growth is enhanced after an initial decline. However, without site amelioration red alder plantations following Douglas-fir yield almost as much as alder following alder.

Results for the fertilization treatment showed that N fertilization in a red alder – Douglas-fir rotation scheme may not result in growth benefit, furthermore it might be detrimental. P fertilization, on the other hand, may be beneficial if the level of nitrogen is not limiting. These results follow what is known as "the law of the limiting factor" that states that the addition of a nutrient will only result in increments when all the rest of growth limiting factors (other nutrients in this case) are not limiting. Fertilization on sites that may have been already enriched by the presence of red alder will not result in any extra growth since nitrogen is no longer the limiting growth factor. The addition of phosphorus on the other hand, could have positive consequences in these situations.

The results presented here only reflect the biological aspect of a crop rotation scheme and the different response to the fertilization treatments. Since no economical analyses are presented and the practice of forest fertilization usually involves a significant capital investment, implementation of fertilization programs should also be evaluated by cost-benefit or other appropriate analyses.

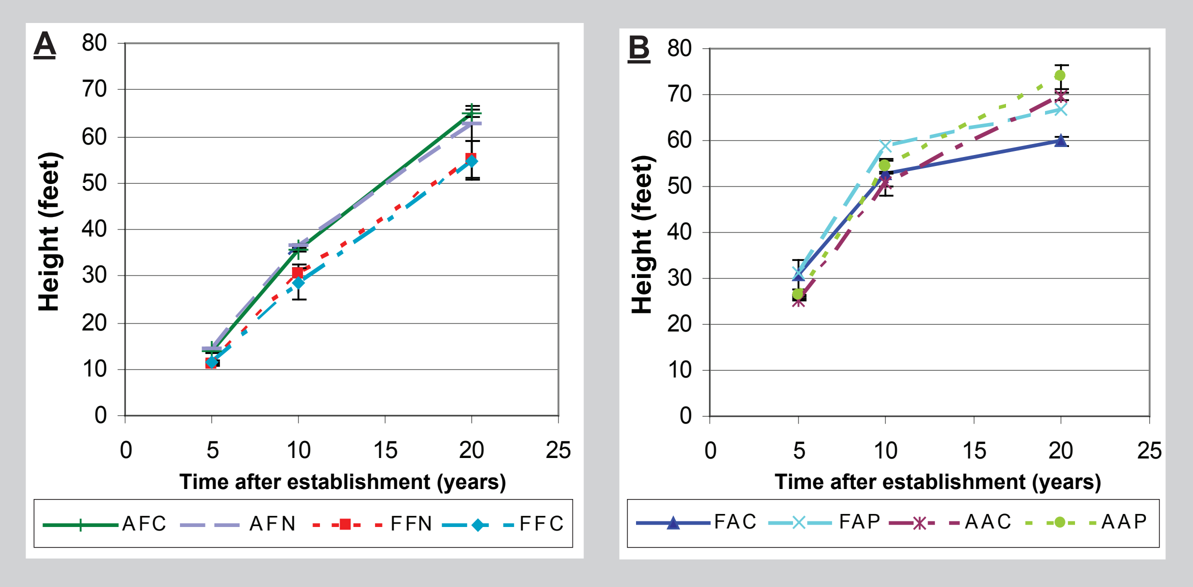

Figure 4—Mean total height for Douglas-fir (A) and red alder (B) after 5, 10 and 20 years of establishment. Vertical bars represent standard errors.

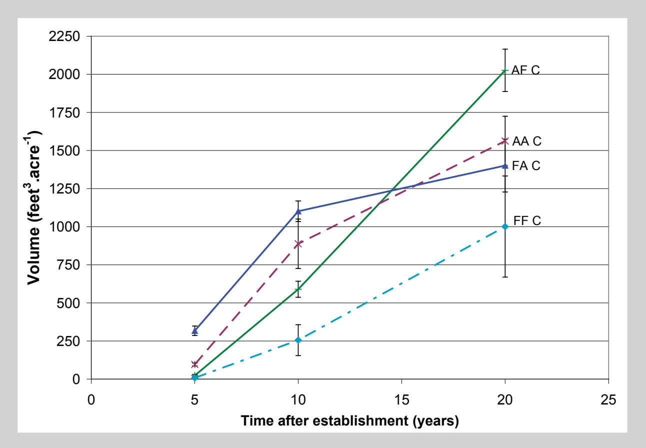

Figure 5—Mean volume per acre at 5, 10 and 20 years after establishment. Vertical bars represent standard errors.

Some comments need to be made again with respect to the results of this study. The domain of this study may limit the scope or range of conditions to which results apply. For this reason results should be understood carefully since the outcomes can be strongly influenced by site quality. Further, N-fixation rates for red alder have been reported to vary significantly from site to site and this will undoubtedly affect the outcomes in other situations.

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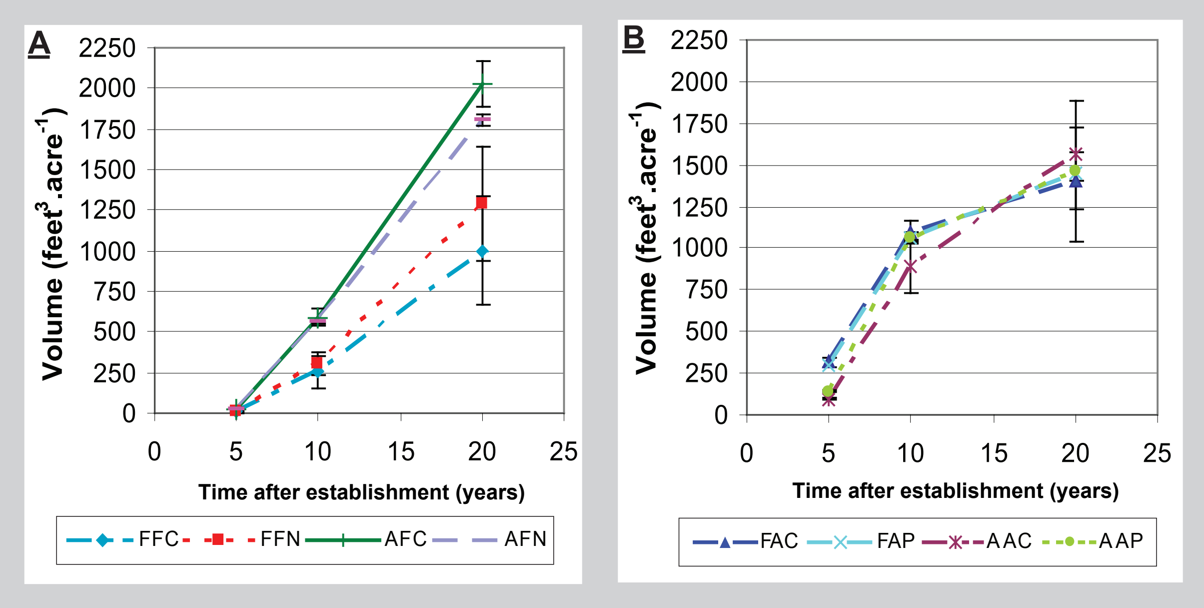

Figure 6—Mean volume per acre for Douglas-fir (A) and red alder (B) respectively after 5, 10 and 20 years of establishment. Vertical bars represent standard errors.

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Economics

(Supply / Markets / Returns)

Overview of Supply, Availability, and Regulatory Factors Affecting Red Alder in the Pacific Northwest

Glenn R. Ahrens[1]

Abstract

The inventory of red alder timber in the Pacific Northwest is about 265 million cubic meters (30.5 billion board feet), however much of this is not available due to economic, policy, or regulatory factors. Of the total annual harvest of 4.64 million cubic meters (~598 million board feet), 87% comes from private lands in Washington (64%) and Oregon (23%). The remainder comes from other lands in Washington and Oregon (5%), British Columbia (6%), and California (2%).

The current supply of alder is a legacy of past practices, which increased the alder component during most of the 1900s. Modern forest practices generally reduce the alder component. Regulations protecting riparian zones, unstable slopes, and wildlife habitat reduce the availability of alder timber. Declines in abundance of alder are becoming apparent and the rates of removal of alder in the 1990s do not appear sustainable. Knowledge of and management for alder are increasing however, and there is much potential for foresters to maintain or increase alder. The supply of alder in the future depends on the uncertain balance of these positive and negative factors.

Keywords: red alder, timber supply, availability, management, regulatory factors.

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Introduction

As the value and utilization of red alder have increased in the Pacific Northwest, so too have concerns about sustaining supplies of red alder timber. A previous assessment of hardwood supply in the Pacific Northwest (Raettig et al. 1995) concluded that short-term supply was favorable, but there was cause for concern about long-term supply due to lack of management for hardwoods. Since 1995, harvest volumes of red alder have declined and shortage of alder logs has been cited as a major factor limiting lumber production and sales (Washington Hardwoods Commission). Increasing prices for red alder sawlogs are also consistent with declining alder timber supply (fig. 1.) The last assessment of hardwood supply in the region was based on USFS forest inventory data for Oregon (federal lands 1976, non-federal lands 1986, 1987) and Washington (1991), with no information from other states or British Columbia (BC). Updated information on timber inventory across the range of alder is now available and it is important to revisit the question of alder supply for the International Symposium, Red Alder: A State of Knowledge (March 23-25, 2005, University of Washington, Seattle).

This paper provides an overview of red alder timber supply and the major factors affecting the alder resource across the geographic range of the species. The purpose is to revisit the key trends identified in the 1995 analysis (Raettig et al.) and provide an updated assessment of the red alder resource, including:

- Timber inventory, growth, and removal;
- Forest management practices and regulations, and
- Sustainable supplies in the future.

Timber Inventory

The total inventory of about 265 million cubic meters (30.5 billion board feet Scribner) of red alder is well-distributed across Washington (36%), BC (35%), and Oregon (27%), with small amounts in California (3%) and Alaska (1%) (fig. 2). These inventory volumes indicate the relative abundance of red alder across its range and should not be confused with actual timber supply.

Note that the relatively large inventory estimate for red alder in BC (91.9 million m^3) is for all stand types in the coast region (Canadian National Forest Inventory System 2001). Previously published estimates of the alder inventory in BC of about 33 million m^3 (Massie 1996) were based only on the amount of alder in stands where alder was the most abundant species (leading species). For comparison, an updated estimate for the amount of alder in stands where alder is the leading species in coastal BC is 29.7 million m^3 (Canadian National Forest Inventory System 2001).

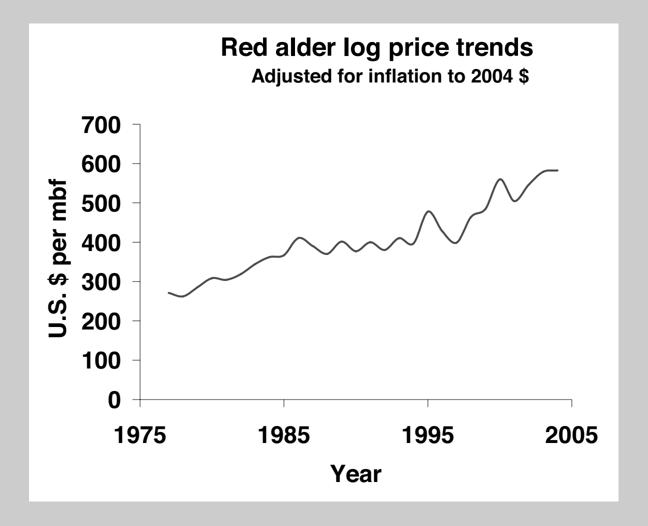

Figure 1—Price trends for red alder sawlogs (8-inch and larger at small end) for northwest Oregon and southwest Washington. Prices represent delivered log prices per 1000 board feet Scribner log scale. Source: Oregon Department of Forestry quarterly log price reports.

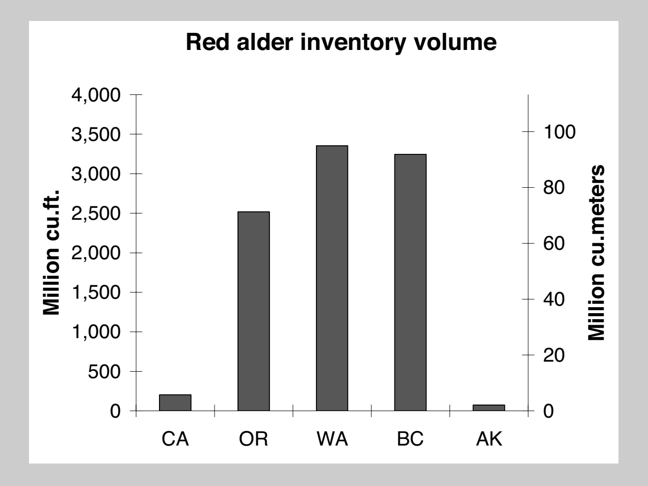

Figure 2—Timber inventory volume to a 10-cm top (4-inch) of red alder across its range in California (CA 1995 inventory - Waddell et al. 1996), Oregon (OR 1997 inventory – Azuma et al. 2002), Washington (WA 2001 inventory – Gray et al. 2005), BC (BC 2000 inventory – Canadian National Forest Inventory System 2001), and Alaska (AK 2000 inventory – van Hees 2003). Inventory for federal lands in Washington and Oregon: HIserote and Waddell 2004.

Timber harvest and removal

The actual supply of alder for industrial utilization depends on the portion of the timber inventory that is made available for harvest. This is influenced by many factors including landowner goals, policies, regulations, local resource quantity and quality, access, logging costs, transportation costs, etc. Recent volumes of alder removal are used below to provide an indication of available alder wood volumes from forests across the range of alder (fig. 3). Removals include some wood volume that may not be utilized. Consistent estimates of removal volumes are

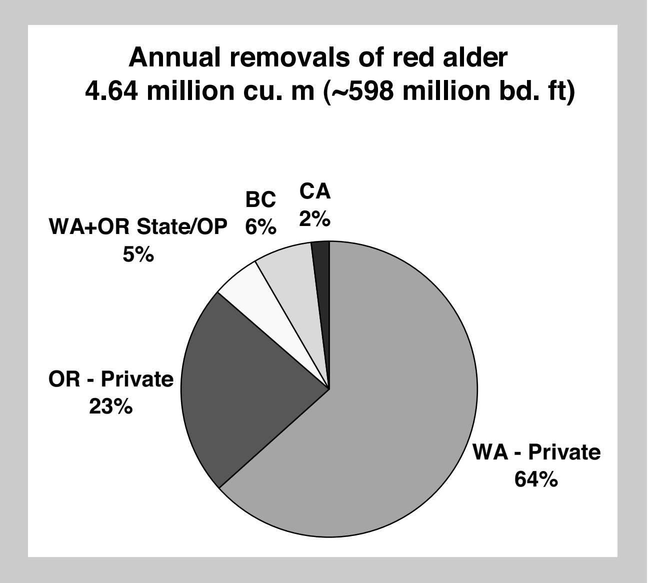

Figure 3—Annual removals for red alder showing the relative proportion of the total removals provided by selected states and ownerships. Data sources for the U.S. as in Figure 1. Figures for BC are harvest volumes reported by the BC Harvest Billing System for 1998-2000, with board-foot volume computed using the average ratio of board-foot : cubic foot volume removals reported for alder in the U.S. (3.65 bf/cf).

provided by inventory reports for all U.S. states. For BC, actual harvest volumes were used.

Annual removals of red alder totaled about 4.64 million m^3 (598 million board feet Scribner scale) across the range of the species (fig. 3). About 87% of the alder removals were provided by private lands in Washington (64%) and Oregon (23%). Non-federal public forests in Washington and Oregon (primarily State-owned) provide about 5 percent of total removals, which is relatively small in proportion to the share of the alder resource in State ownership (14%). Removals of alder from federal forests in Washington and Oregon amount to less than 1% of the total and are not shown.

Annual harvest volumes of alder in coastal BC amount to about 6% of total alder removals, which is small in proportion to the amount of alder in BC (35% of the total inventory). Removals of alder in northern California amount to about 2% of the total, similar to the state's share of the inventory (2.5%). Alder is being harvested and utilized in Northern California, particularly from Industrial Private lands. No estimates of harvest or removals of alder in Alaska were found. With less than 1% of the total alder resource, potential harvest and utilization of alder from Alaska could be locally important but it would amount to less than 1 % of the total alder harvest.

Washington and Oregon are the major sources of alder supply, accounting for over 90% of the harvest. Total inventory of alder in California and Alaska are too low to have a major impact on the overall supply of alder. While there may be potential to increase supplies of alder from BC forests, current plans for timber supply areas and tree farm licenses in BC do not indicate substantial increases in harvest of alder in the future (BC Ministry of Forests 1999-2004. H. Reveley, pers. Comm, BC Ministry of Forests, Defined Forest Area Management, Coastal Region.).

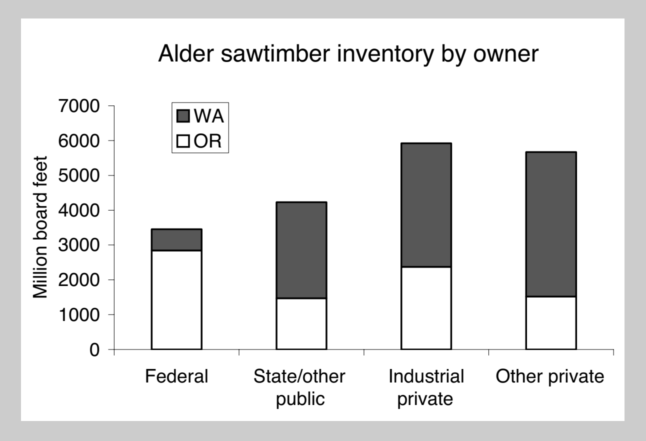

Figure 4—Inventory of red alder sawtimber (million board feet Scribner scale) across major land ownerships in Washington (2001 - Gray et al. 2005) and Oregon (1997 - Azuma et al. 2002).

Therefore, discussion of resource trends affecting alder supply will focus on Washington and Oregon. Within these two states, a further breakdown of the alder inventory shows that private owners have 60% of the resource, about evenly divided between industrial and non-industrial (small woodlands or family forestlands) ownership (fig. 4). Between the two states, Washington has about 2 times as much alder as Oregon.

Forest resource trends

The current supply of alder is a legacy of past management practices, which increased the component of alder and other hardwoods in the Pacific Northwest (fig. 5). During most of the 1900's, growth and inventory of hardwoods increased, while rates of removal and utilization were low (Raettig et al. 1995, Figure 17, p. 42). Since the 1970's, however, removals of alder have increased while forest management to favor conifers has become increasingly effective. This is expected to reduce both the abundance of hardwood-dominated forest and the proportion of hardwoods in conifer-hardwood mixtures. The increase in abundance of hardwoods seems to have stopped in the 1990s (fig. 5).

Declines in abundance of alder are particularly apparent as illustrated by decreases in estimates of growing stock inventory since the previous inventories in both Oregon (28% decrease) and Washington (24% decrease) (Raettig et al. 1995, Azuma et al. 2002, Gray et al. 2005). Likewise, estimates of the area of hardwood-dominated

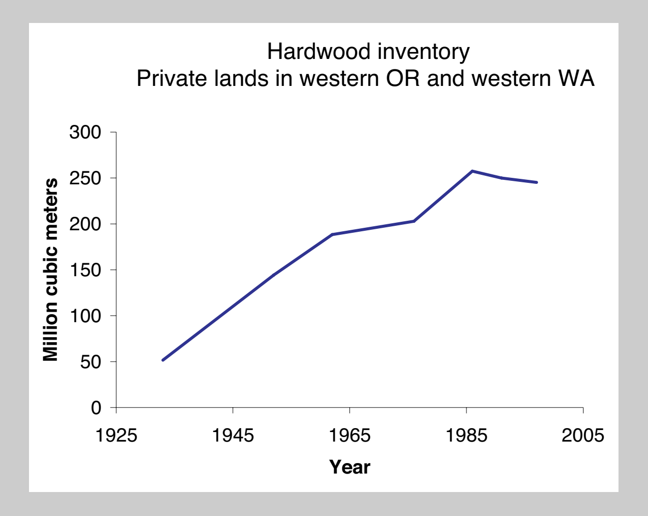

Figure 5—Hardwood inventory volume estimates on private lands in Washington and Oregon from 1931 to 2001 (from Haynes, tech. coord. 2003).

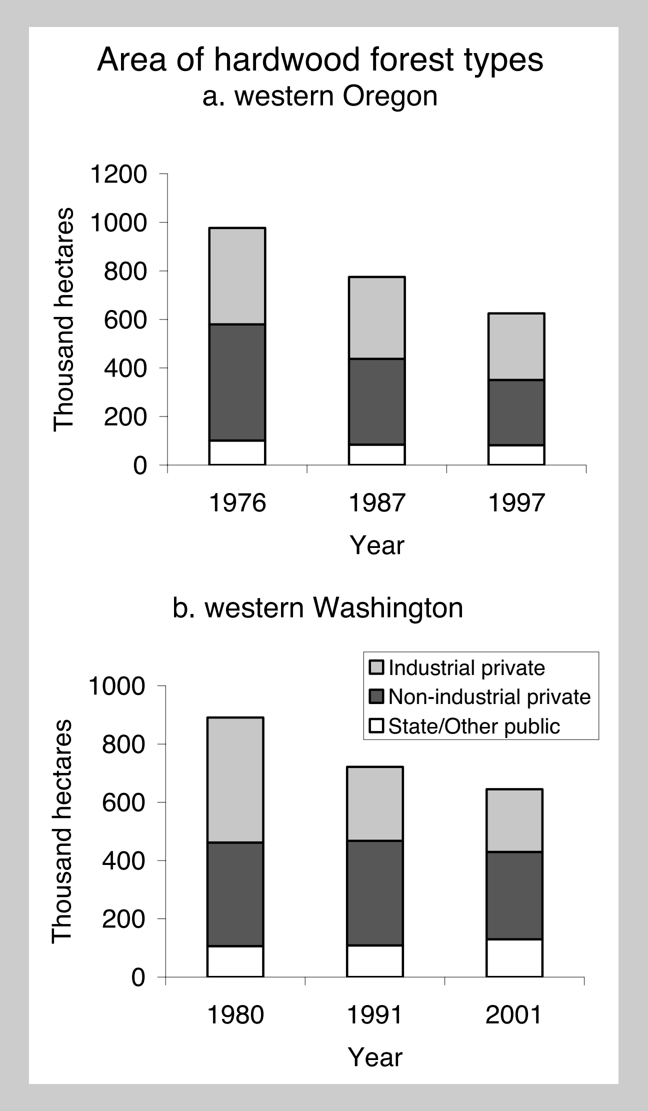

Figure 6—Periodic estimates of the area of hardwood forest types in western Oregon (a. Raettig et al. 1995, Azuma et al. 2002) and western Washington (b. Raettig et al. 1995, Gray et al. 2005).

forest decreased by about one third over the last 3 periodic inventories in both Washington (1980, 1991, 2001) and Oregon (1976, 1987, 1997). The trend is apparent on both industrial and non-industrial private lands (fig. 6). Similar trends are described by Alig et al. (2000), who projected a 35% decrease in alder timberland on forest industry lands and an 18% decrease on non-industrial private timberland in the westside Pacific Northwest for the period 1980-2010.

During the 1990s, removals, mortality, and forest conversion (to non-forest) contributed to a 28% net loss of hardwood inventory on non-federal lands in Washington (fig. 7). In Oregon, both removals and mortality are lower, and forest conversion is negligible, so that there was 14% net growth in total hardwood inventory between 1987 and 1997. Removals and mortality are proportionally higher for alder than other hardwoods in both states. For Washington and Oregon combined, red alder comprises 73% of the hardwood removals and mortality, but only 58% of the hardwood inventory. Annual removals plus mortality of alder in the two states exceed growth on industrial forests by 30%; removals plus mortality are about equal to growth on non-industrial private forests (fig. 8).

Since some of the forest growth occurs in areas that are not available for harvest, the levels of alder removal in Washington and Oregon during the 1990s do not appear to be sustainable. Future declines in available supplies of alder should be expected on private lands—the primary source of alder timber supply.

Policy and regulatory factors reducing alder supply

Availability of alder timber for harvesting is reduced by landowner policies and forest practices regulations. Forest policy clearly limits timber supply on federal lands in the U.S. since these lands contain about 17% of the alder inventory but provide less than 1% of the total alder timber harvest. On actively managed state forests, alder is harvested along with softwoods, although state forest policies do limit the amount of harvest more than on private lands. Protection of riparian areas, unstable slopes, and retention of trees for wildlife habitat reduces the harvestable portion of the alder resource on all ownerships.

Protection of riparian areas and unstable slopes are expected to have a disproportionate impact on availability of alder compared to conifers due to the relatively high abundance of alder in these areas. Accurate estimates of the amount of alder affected are difficult to obtain due to the variety of protection requirements and options across the range of alder, along with diverse landowner behavior in implementation.

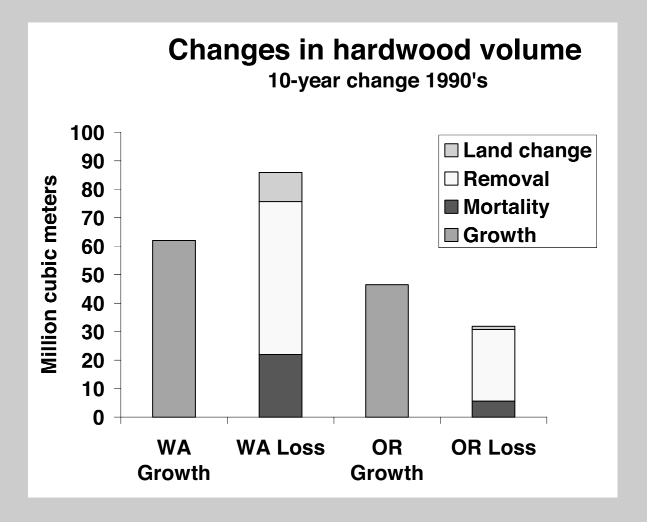

Figure 7—Changes in hardwood timber volume between inventories in western Washington (WA 1991-2000, Gray et al 2005) and western Oregon (OR 1987-1997, Azuma et al. 2002).

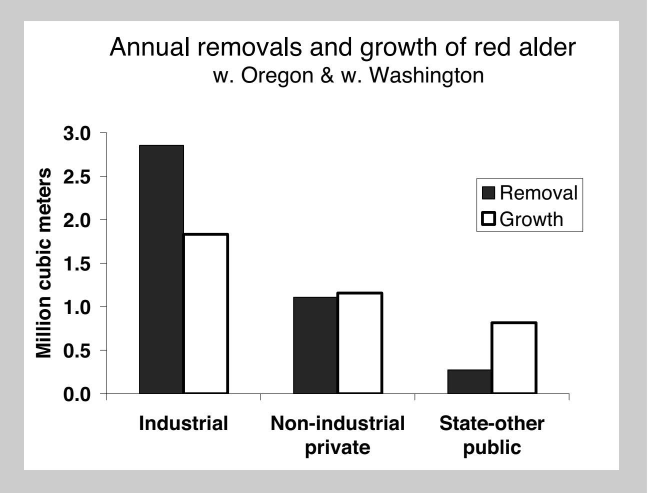

Figure 8—Annual removals and growth of red alder in western Oregon (1997 – Azuma et al. 2002) and western Washington (2001 – Gray et al. 2005).

Estimates of the amount of alder that is unavailable due to policy and regulation have been made for Washington, based on analysis using Geographic Information Systems (GIS) to overlay land ownership and protection (buffer) areas on maps of alder occurrence. A study for western Washington estimated about 7.6 billion board feet of red alder available for harvest after deducting about 46% of the resource as unavailable due to landowner policies and riparian regulations (Washington Hardwoods Commission 2002). This same assessment estimated that while riparian buffers comprise about 8% of the timberland area, they contain 18% of the red alder sawtimber volume.

Comprehensive assessments of alder availability using spatial analysis (GIS) have not been published for Oregon or BC. General estimates of about 5-10% of the alder resource affected by riparian regulations have been made (Raettig et al. 1995, G. Lettman, Oregon Dept. of Forestry, pers. Comm.). Under a scenario of increasing riparian harvesting restrictions, Adams et al. (2002) projected a 24.4% reduction in harvest volume (all species) on private timberlands in western Oregon assuming a 100-foot no cut buffer. Given the overall warmer, drier conditions in western Oregon compared to Washington, the moisture-loving red alder should be even more concentrated in riparian areas compared to upland areas in Oregon.

Much of the alder in BC does not appear to be available for harvesting. The alder harvest in BC is quite low for the level of inventory. Review of allowable harvest determinations and discussions with BC Ministry foresters suggest a variety of factors limiting availability of alder (Pederson 2000, 2001, 2002, 2004. H. Reveley, pers. comm., BC Ministry of Forests, Coastal Region.). Much of the alder in BC may not be economically available due to difficult access and high costs of logging and transportation. While delivered log prices for alder in BC are comparable to associated conifer values (2004 prices per cubic meter were $70, $55, and $110 for red alder, western hemlock, and Douglas-fir respectively; Log Market Reports from BC Ministry of Forests, Revenue Branch), relatively low economic returns per hectare are still expected for alder, which discourages both harvesting and management focused on alder in BC. Concentration of alder in riparian protection zones was also indicated as a reason for relatively low harvest volumes.

Riparian protection rules as implemented in Washington are generally more restrictive than those in Oregon and BC, based on the widths of no-harvest buffers along predominant stream types (table 1). The current emphasis on retention and development of a conifer component in riparian areas provides some potential for removal of alder in riparian zones, particularly under site-specific plan options in both Oregon and Washington. Due to the complexity of the riparian protection rules, private forest owners may not choose to harvest in riparian zones even when they have the option to do so. Compliance monitoring in Oregon showed that 60% of riparian management areas surveyed were treated with no-harvest prescriptions and only 2% were treated with a hardwood conversion/conifer restoration prescription (Robben and Dent 2002). In Washington, only 23 riparian hardwood conversion plans were filed, out of thousands of forest practices applications, by non-industrial private owners during 2002-2004 (Washington Department of Natural Resources, Small Forest Landowner Office). Harvesting behavior by industrial forest owners in Washington has not been summarized.

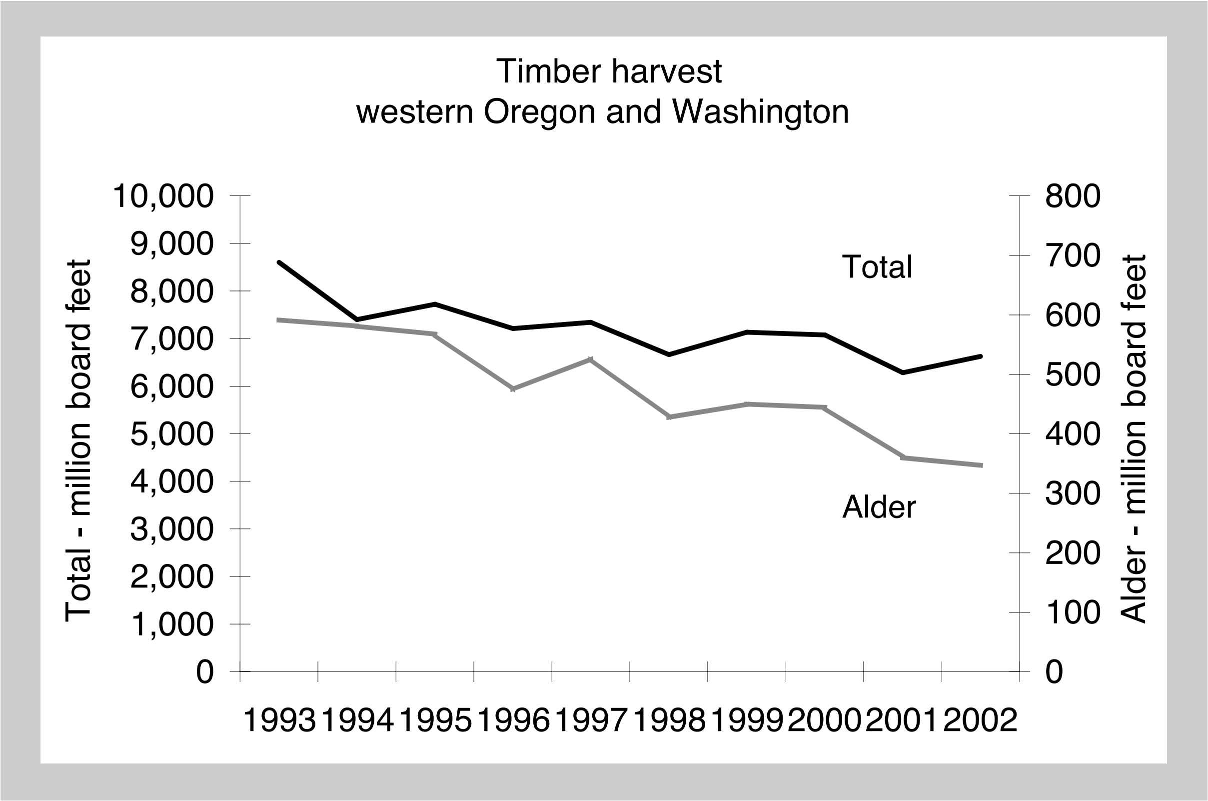

Figure 9—Annual timber harvest rates for red alder and for all species (total) in western Oregon (Oregon Department of Forestry Timber Harvest reports) and western Washington (Washington Department of Natural resources timber harvest reports for all species, Washington Hardwoods Commission hardwood processor reports for red alder).

Declining timber harvest volumes

The declining area and volume of alder available for harvest does indicate decreases in supply of alder timber in the future. The question remains as to how soon and how much lower? Timber supply projections for Oregon and Washington in the 1990s predicted reductions in hardwood timber supply using various assumptions about forest management and harvesting behavior on private lands (Sessions et al. 1990, Adams et al. 1992). More recent timber harvest projections for western Oregon and Washington have not projected specific hardwood harvest levels (Adams et al. 2002, Zhou et al. 2005).

While there is still no comprehensive timber supply assessment focused on red alder in the Pacific Northwest, trends in timber harvest levels between 1994 and 2003 do show a gradual decline in the volume of alder harvested annually in Washington and Oregon (fig. 9). The harvest of alder generally goes up or down with total harvest and the total timber harvest level also declined between 1994 and 2003. The volume of alder harvested, however, declined about 33% while the total harvest declined only 20% (based on 3-year running averages). A reduced proportion of alder in the total timber harvest is the expected result of the declining hardwood component in Oregon and Washington. Total timber harvest projections for western Oregon and Washington indicate slight decreases in the overall timber harvest level during the next 2 decades (Zhou et al. 2005).

Management of alder

There has been a great deal of research focused on management of red alder since the 1980's, as illustrated by numerous presentations (OSU Hardwood Silviculture Cooperative, Weyerhaeuser Co., USFS PNW Research Station) at the 2005 Symposium, *Red Alder: A State of Knowledge* (March 23-25, 2005 University of Washington, Seattle). Nearly 20 years of private and public research focused on alder management indicate the potential for relatively high yields (8-12 m^3/ha/year) in short rotations (25-35 years) in managed stands.

In a detailed assessment of management plans and practices affecting alder across major forest ownerships, Raettig et al. (1995) identified several key issues preventing management for alder, including: uncertainty about economic returns, lack of information on growth and yield in managed stands, and lack of experience with alder management. These issues persist across the range of alder, even after 10 more years of alder research and continued increases in alder prices (fig. 1).

Non-industrial private forest owners in general do not manage intensively to favor conifers and they are expected to produce an increasing share of the alder given the reductions in alder on industrial ownerships. While this generality continues to hold, alder supply from non-industrial forests has also declined slightly and conversion of these ownerships to non-forest uses reduces sustainable alder supply in the future.

Recent revisions of management plans for state forests in northwest Oregon (2001) address the potential for maintaining alder for both timber and habitat purposes. In Washington, increasing the production and harvest of red alder has been recommended as increased alder timber values are incorporated in the Washington Department of Natural Resources' timber marketing program (Jon Tweedale, WA DNR pers. Comm.).

Along with the growing knowledge-base for management of alder, on-the-ground management for alder appears to be increasing. Forest managers often leave alder during weeding and pre-commercial thinning of young forests when it appears to be the best crop tree. Nursery production and planting of alder seedlings also appear to be increasing. These observations are based on informal surveys of forest managers across private and state ownerships conducted in the course of producing and teaching alder management workshops in Oregon and Washington between 1997 and 2004 (45 events, ~1500 participants). Attitudes about alder have clearly changed since the 1980's, however, formal surveys have not been conducted to quantify increases in management for alder.

When harvests of red alder were at their highest levels during the 1990s, alder comprised about 6% of the total timber harvest in western Oregon and western Washington, and about 1% of the harvest in coastal BC. While a gradual decline in alder is now evident after decades of conifer forestry, management for alder on a relatively small portion of the landscape (~5%), along with continuing production of incidental alder could maintain current levels of supply. Raettig et al. (1995) estimated at most 1% of the managed forest landscape was intentionally regenerated to red alder. Although there are indications that this will increase, the question remains: will the major forest landowners manage more alder in the future?

Conclusions

A gradual decline in available supplies of red alder timber is now evident in Washington and Oregon, which currently provide over 90% of alder supply. Major factors that reduce supply of red alder include management favoring conifers, increased protection of riparian areas, shifts in public timber policy, and conversion of forest to non-forest land use. Knowledge of and management for alder are increasing and there is much potential for forest managers to maintain or increase alder across its range. Changes in policy and practice could also greatly increase availability of current alder inventory in BC (or federal lands in the US). The supply of alder in the future depends on the uncertain balance between these positive and negative factors.

Increased management of alder timber is the key to sustaining alder supply. While increased log prices for alder have stimulated great interest, major forest landowners are still reluctant to invest in managing alder until management techniques become well-demonstrated and there is better information on growth and yield in managed stands.

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Red Alder Market Implications for Management; Reasons for Optimism

C. Larry Mason[1]

Abstract

In 2000, red alder *(Alnus rubra)* log prices, after more than two decades of steady price gains, surpassed Douglas-fir *(Pseudotsuga menziesii)* log prices for the first time in history and have retained a price lead ever since. Alder, once considered a negative value weed, is now recognized as a valuable commercial timber species. As a result, there is increasing interest among forest managers in the potential for investments in alder plantations. A common concern, however, is an uncertainty about the future reliability of strong alder log markets. This paper will consider available information on alder log and lumber market influences and offer speculation that alder products appear well positioned for continued market success.

Keywords: red alder, hardwoods, wood market economics

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Introduction

While red alder has long been recognized by tree farmers as a suitable species to plant in areas that are wet, nutrient poor, infected by Swiss needle cast or root rot, or in other ways unsuitable for Douglas-fir, until recently alder has not been widely considered as a plantation alternative to Douglas-fir on high quality sites. A strong performance by alder log prices in recent years when compared to Douglas-fir prices may lead some foresters to reconsider the potential for planting alder on their best sites. The following graph displays historic prices, adjusted for inflation to 2004 dollars, for Douglas-fir and red alder saw logs (average price of #2 and #3 saw logs for each species) from 1970 to 2004 in the Puget Sound region of western Washington. Alder log prices surpassed those for Douglas-fir for the first time in history in 2000 and have retained a price lead ever since. Historically, alder log prices have been less volatile than Douglas-fir prices and display a stronger upward trend (fig. 1).

Financial performance simulations can help in making species comparisons for return on planting investment. For demonstration purposes, assumptions will be that plantations are hardy and on a good site, costs and prices are treated in constant dollars, 5% is the expected real rate of return, results are reported based upon current log prices and management cost estimates before taxes, and yield estimates in thousand board feet (MBF) and ton wood are consistent with expectations listed below (Mason 2003).

- DF-45. A 45-year Douglas-fir rotation; no commercial thin. (30 MBF & 70 tons)
- RA-35. A 35-year Red Alder rotation. (20 MBF& 30 tons)

A soil expectation value (SEV) calculation suggests that, due to price advantage and shorter rotation length, alder plantations may provide better return on investment than Douglas-fir plantations (fig. 2).

A common concern, however, is an uncertainty about the future reliability of strong alder log markets. Alder logs are manufactured into a number of primary lumber products for domestic and export markets. An examination of available information about alder product markets will provide a better understanding of the future potential performance of alder log prices.

Alder Lumber

In March of 2004, the Hardwood Review Weekly reported its North American Hardwood Outlook for 2004. Alder lumber sales were characterized as some of the hottest in the hardwood markets with strong domestic and overseas demand. The expectation was that demand would continue to exceed production for the foreseeable future. A little more than a year later, in spite of little to no gain for other species in hardwood lumber export markets, this forecast held true (Hardwood Review 2005). Alder export sales increased world wide by more than 30% in the first five months of 2005 as compared to the first five months of 2004 (table 1) with big gains in important international markets like China and the European Union (figs. 3 and 4).

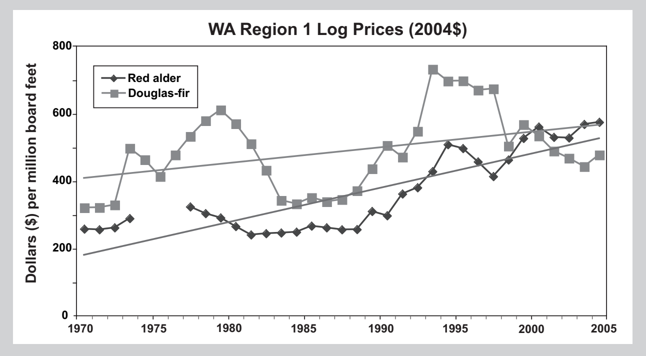

Figure 1— Historic prices, adjusted for inflation to 2004 dollars, for Douglas-fir and red alder saw logs (average price of #2 and #3 saw logs for each species) from 1970 to 2004 in Region 1 (Puget Sound) of western Washington. Source: Log Lines, Fox, U. S. Dept of Labor.

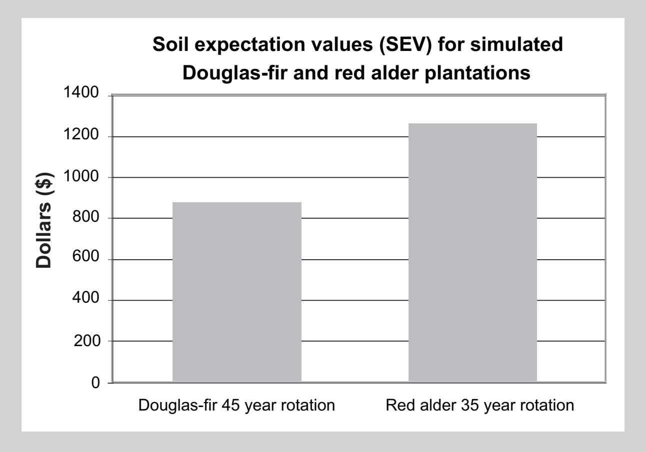

Figure 2—Simulated soil expectation value (SEV) comparison at a 5% target rate of return for Douglas-fir and red alder plantations. Source: Rural Technology Initiative.

Most wood species experience fluctuating demand for individual lumber grades with favorable markets for some items coincident with poor markets for others. Alder lumber, however, is in increasing demand for the full spectrum of lumber grades with product sales limited only by supply. The higher grades of select, #1, and #2 have long been desirable for furniture and cabinet manufacture due to the excellent workability characteristics of this species (fig. 5). Workability is important to manufacturers not only to ensure production of high quality products but also to reduce operation costs. Good workability minimizes unit production time, increases product recovery, and extends the life of production equipment and materials. Unique to alder, because of its uniform color and grain characteristics, is its ability to readily accept both light and dark stains which

Table 1—Alder lumber export statistics for Jan-May of 2004 and 2005. Source: Hardwood Review (2005) and USDA Foreign Agricultural Service (2005).

Alder LBR Exports by Country	Jan-May 2004 Vol. (m3)	Jan-May 2005 Vol. (m3)	Change 05 vs. 04	Jan-May 2004 Value (1000 $)	Jan-May 2005 Value (1000 $)	Change 05 vs. 04
China	47,397	65,349	+37.9%	$12,897	$19,620	+52.1%
Canada	13,467	18,515	+37.5%	$3,751	$4,283	+14.2%
Mexico	11,740	12,380	+5.5%	$4,065	$4,552	+12.0%
Italy	7,990	8,774	+9.9%	$5,125	$6,517	+27.2%
Germany	3,031	6,657	+119.6%	$2,506	$5,433	+116.8%
Spain	5,483	4,961	-9.5%	$3,479	$3,601	+3.5%
Taiwan	5,504	4,049	-26.4%	$1,548	$1,209	-21.9%
Philippines	1,388	2,617	+88.5%	$617	$1,365	+121.2%
Vietnam	855	1,907	+123.0%	$313	$746	+138.2%
Portugal	1,762	1,501	-14.8%	$952	$829	-12.9%
World Total	107,159	135,315	+26.3%	$40,304	$52,589	+30.5%

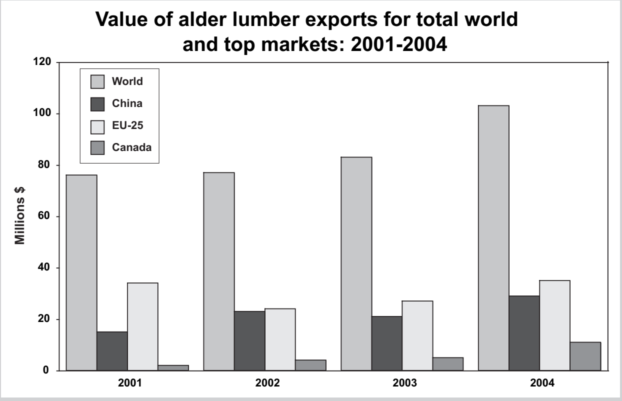

Figure 3—Value of alder lumber exports for total world and top markets: 2001-2004. Source: USDA Foreign Agriculture Service.

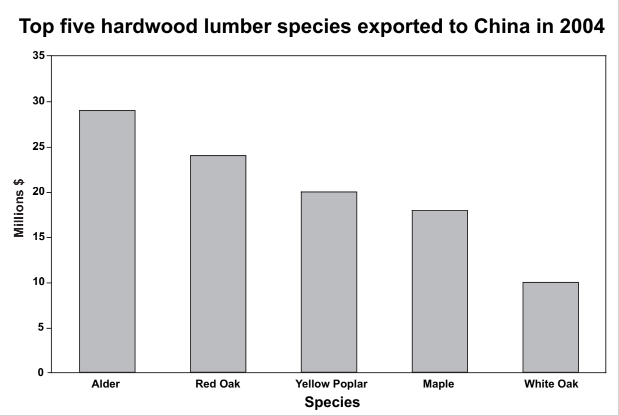

Figure 4—Top five hardwood lumber species imported to China in 2004. Source: USDA Foreign Agriculture Service.

change its appearance to resemble that of more expensive hardwoods such as black cherry *(Prunus serotina)*. After many years of serving as a low cost substitute, alder has gained an industry nickname of "poor man's cherry." Current wholesale kiln-dry prices for the highest quality alder lumber are respectably comparable to those of Douglas-fir with ranges from $1000/MBF to over $2000/MBF depending upon grade (Redmond 2005).

Recent market popularity of "southwest rustic" furniture and cabinets has increased industry demand for knotty lower grades of alder lumber such as frame, standard, and #3 shop. Strong markets for these grades have resulted in prices that currently range from $550 to $825/MBF (Redmond 2005). Emergence of strong demand for lower quality lumber for furniture and cabinet products has created tight supplies for pallet markets with subsequent price improvements for this low grade product. Pallet and crating manufacture is the largest hardwood end-use application in the United States with an estimated consumption of 3.5 billion board feet of lumber for 2005 (Hardwood Review

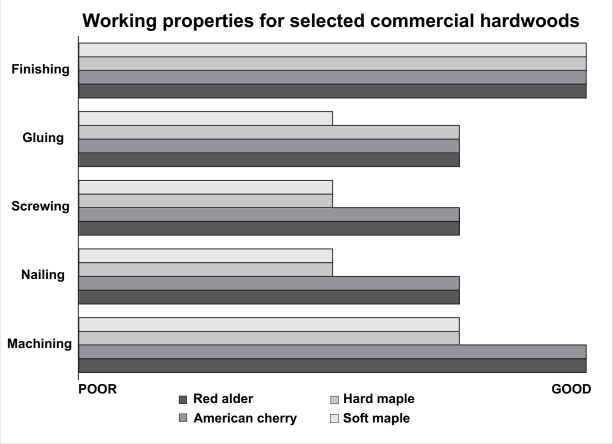

Figure 5—Working properties for selected commercial hardwoods. Source: American Hardwood Export Council.

2005). Alder pallet lumber has long been preferred by markets within the grocery industry because it imparts no resins or other toxins to foodstuffs. Alder pallet lumber, an equivalent to utility grades of other species, has seen prices in excess of $300/MBF during 2005 (Redmond 2005).

With favorable markets for pallet stock, chip production is limited to trim and side-cut. While chip prices have been lackluster for all species, hardwood chips are in stable demand as hardwood fiber is needed to produce high quality paper. Given that the west produces less than 3% of the total U. S. supply of hardwood chips (Warren 2004), alder chip markets are not likely to experience price reduction due to oversupply or substitution.

Discussion

Red alder log and lumber prices have demonstrated stable upward growth for the last several decades. Hardwood markets tend to be less cyclical than commodity-driven softwood markets. The use of alder in the manufacture of value-added wood products means that the demand is secured by niche-product positions with little risk of substitution (Eastin et al. 1999). Favorable price positions have been established for the full spectrum of alder lumber grades. Alder logs have generally been priced between the more expensive cherry and the lower priced varieties of maple species *(Acer)*. The uniform grain pattern and light color of alder allow it to be stained to match changing consumer preferences and market trends. Alder is widely used as a substitute for more expensive traditional species like cherry. Past price relationships indicate that cherry and maple provide the upper and lower bounds for alder price fluctuations. No evidence was found in a review of the literature and trade publications to suggest that this relationship might not continue. Important to markets such as the European Union, alder is not an old growth or tropical hardwood species. Alder has well-established export positions and is the preferred species in the fast-growing China market.

Trend analysis of Pacific Northwest hardwood timber harvest and growing stock (dominated by alder) indicates that standing inventories will far exceed harvest volumes (Haynes 2003) through 2050. Regulatory constraints on harvest, however, appear to limit market supply of logs relative to growing domestic and international demand resulting in continued upward price pressure.

International trade data available from the USDA Foreign Agriculture Service show that alder export lumber markets are expanding faster than other international markets for U.S. hardwood species. The short rotation length and strong market position of red alder should result in increased interest in alder plantation establishments on well-drained, high sites in western Oregon and Washington that have previously been preferred for Douglas-fir.

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Red Alder—Regeneration and Stand Initiation: Techniques and Field Craft as Related to Final Returns on Early Investments

Pete Holmberg[1]

Abstract

Red alder (*Alnus rubra* Bong.) exhibits juvenile height growth rates that far exceed other commercially important conifer species in the U.S. Pacific Northwest. This rapid growth rate together with desirable wood characteristics and promising market prospects are attractive to forest managers. However, red alder's silvical characteristics and site sensitivity imply high early investment costs as well as risk factors that might well be higher than for conventional conifer management. Relatively certain high return on investments require careful site selection and judicious management, particularly during the first decade, in ensuring uniform tree spacing. This detailed attention to spacing require substantial early investments in site preparation, planting and planting stock, pre-commercial thinning, and pruning. This paper illustrates how Hardwood Silviculture Cooperative studies have influenced a Washington State Department of Natural Resources manager's assumptions about red alder cultivation in relation to silvics and expected returns on investments.

Keywords: Red alder, return on investment, silviculture, plantation, stumpage, techniques and field craft.

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Summary

Red alder (*Alnus rubra* Bong.) exhibits juvenile height growth rates that far exceed commercially important conifer species in the U.S. Pacific Northwest. In addition, the species is highly phototropic and has low apical dominance. Therefore, in order to secure maximum return on investment, spacing in red alder plantations must be carefully managed from the earliest stages. This requires substantial early investments. Although accurate growth simulators for managed stands of red alder are yet to be developed, data from natural stands as well as plantation growth data from Hardwood Silviculture Cooperative (HSC) research through year 12 are sufficient to enable initial projections of merchantable volume and financial plus-ups attributable to intensive management. HSC data sets are from 26 plantations initiated at varying densities and subjected to differing silvicultural treatments. This information lends itself to initial projected estimates and also indicates that growth (and thus yield) of intensely managed red alder plantations dramatically exceeds that of natural stands. Assessments of relative magnitudes of return on investments may thus be performed. If current red alder stumpage trends hold, return on investments from intensively managed red alder plantations could be on the order of twice or more high site mixed Douglas-fir and western hemlock plantations that are grown to culmination of periodic annual increment. A drawback of red alder stands is the high risk associated with frost and ice-storm damage (casual observation indicates this risk may considerably reduced in red alder plantations); which has frequently caused irredeemable damage to the commercial value of natural red alder stands.

Introduction

A forester considering cultivation of red alder (*Alnus rubra* Bong.) in Oregon, Washington, or British Columbia would be well served to take into account the Hardwood Silviculture Cooperative's (HSC) red alder plantation data. This cutting edge research describes growth responses of red alder to intensive management on 26 plantations throughout western Oregon, Washington and British Columbia. Each site has four initial planting densities subdivided into varying treatments that cover a range of pruning and thinning options through year 12. From an operational perspective, feasible approaches gleaned form this research should be adapted to practical techniques and field craft that should be analyzed from cash flow and investment perspectives for a whole rotation. Facts, or in their absence, logical assumptions, regarding site selection, site preparation, stocking control, planting stock, thinning techniques, and pruning together with market assumptions and financial investment analysis must be brought together into a plausible and practical whole. To that end, this paper will present such a synthesis in the form of an optimal silvicultural prescription for a red alder rotation on a suitable, and presumably typical, site. The prescription will, in particular, endeavor to devise a regime for treatments and investments likely to best attain the desired high-value outcome.

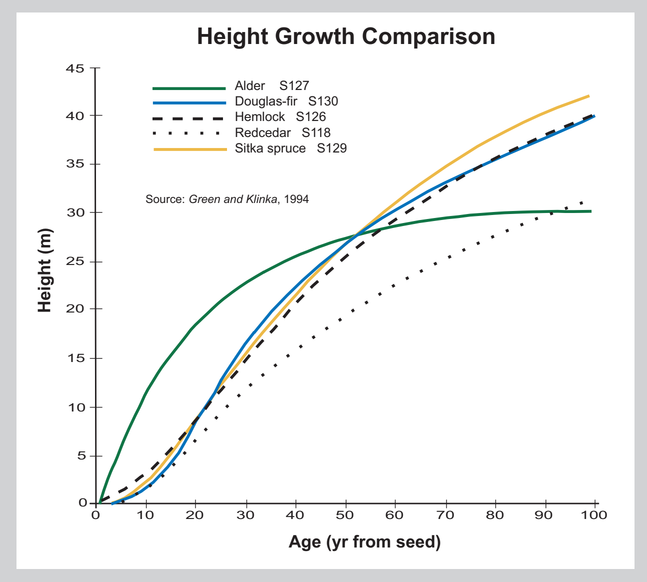

Figure 1—Height growth of red alder compared to commonly associated commercial conifers. Source: Peterson, E.B., Ahrens, G.R., and Peterson, N.M. (eds). 1996. Red Alder Managers' Handbook for British Columbia. FRDA Report 240.).

The Case for Red Alder

Pros

So, why red alder? Biologically, red alder has juvenile height growth rates that exceed Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco var. *menziesii*), western hemlock (*Tsuga heterophylla* (Raf.) Sarg.), and western redcedar (*Thuja plicata* Donn ex. D.Don) by as much as a factor of four during the first five decades. Figure 1 illustrates this situation. Not until around age 50 do most of these conifers overtake red alder in total height. Red alder's quick accumulation of merchantable biomass implies short rotations and therefore relatively assured markets and favorable investment recovery.

Red alder occupies a special niche in domestic and world markets due to grain uniformity, stain acceptance, and workability. These markets—the Chinese furniture industry in particular—are likely to foster an increasing demand for superior quality red alder for an extended future. Probably adding to this trend is the fact that countries and regions outside the native range of red alder have not taken on their own cultivation programs for red alder as many have done with Douglas-fir.

Thus, an image of the future begins to form in which red alder emerges as a market niche of potentially sustained high value.

Natural Stand—Ample stocking as well as stem sweep

Planted 525 TPA—Straight and clear

Planted 100TPA—Branches and forks

Figure 2—The photos above show phototropic-induced stem sweep in a natural stand (upper left), excessive branching and multiple stems due to low apical dominance (right), and straight and clear stems with around six feet of crown lift in a stand planted at 525 trees per acre at age nine (lower left). Source: Hardwood Silviculture Cooperative.

Cons

Is there a downside? As we shall see, red alder cultivation requires disciplined adherence to specific site selection criteria as well as to silvicultural regimes that have considerable front-end investments. Financial rewards will be tightly linked to specific sites that capitalize on red alder's high juvenile growth rates and to regimes that judiciously manage red alder's high degree of phototropism and low apical dominance (fig. 2). Associated risks for irrecoverable error might dissuade foresters to whom lower but more conventional returns on investment from conifer plantations represent their risk management comfort zone. More about this later.

Red alder (rightly, at present) is touted as immune to most pests that affect conifer forests. However, little is known about pests that might yet emerge as epidemics should sizable acreages in pure red alder plantations begin to proliferate. At present, outside of susceptibility of older trees to white heart rot (*Phellinus igniarius*) and sapsucker (*Sphyrapicus* spp) bark and cambium damage, there are few pests known to have caused serious damage to red alder in forest stands. Regarding mechanical damage (and associated compartmentalized rot), it is well known that red alder is more sensitive than conifers to logging damage, and natural stands of red alder are also more prone to top breakage from ice or snow storms (with subsequent generation of multiple tops due to low apical dominance). One should note, however, that casual observation of plantation red alder indicates that straight and well-spaced red alders are less susceptible to top breakage than natural stands with their clumpy spacing and near-universal stem sweep.

Thus, the robust picture of red alder management becomes nuanced with some negative factors that must be minimized through judicious management and site selection. Next, I will discuss two of these factors, site selection and mechanical damage, in more detail.

Site Selection

Red alder, because of its ability through bacterial root nodules, to fix and use atmospheric nitrogen and thereby fertilize itself, grows competitively on a wide variety of sites. However, within this wide spectrum, there is a limited range of sites suitable for cultivating superior commercial-grade red alder. Characteristics of this limited range are: (1) moist but well drained soils; (2) northerly through easterly aspects, especially on steeper and drought-prone slopes; (3) a frost-free growing season (paying particular attention to avoiding localized frost pockets); and (4) a relative absence of elk (which may cause rubbing and trampling damage). One should also avoid areas prone to even rare (such as bi- or tri-decadal) ice storms and heavy snow loads. Thus, sites suitable for intensive management for red alder are also excellent sites for Douglas-fir (or other low elevation westside conifers), site class I to high III. Site selection will most likely become less time consuming (but not less critical) with development of GIS site selection models such as the newly fielded Washington Department of Natural Resources pilot model.

Mechanical Damage

As regards mechanical damage from snow and ice, a brief digression on risk assessment is warranted. In conifer forestry, site characteristics are relatively easy to determine, and errors in judgment are often benign. Not so with red alder. Imagine, for example, a red alder plantation selected per the above site criteria but with only a casual look to rare historic weather. Imagine also that a more judicious look at rare historical weather would have revealed ice storms having occurred only every 10 to 20 years, and that we are now at a point at which our fictional red alder plantation has, though significant investments and treatments, progressed as intended to mid-rotation. Consider the effects on this stand of a single ice storm lasting but a few hours and causing a ¼-inch ice build-up on this red alder plantation versus a similarly aged conifer stand. Personal observations indicate that in both red alder and conifer stands the weight of the ice might cause top breakage at stem diameters down to around 6 inches. In observed conifer stands, apical dominance generally re-established single new leaders, and the resultant future grade defect could be bucked out at harvest with a relatively modest loss of value. In observed natural red alder stands, on the other hand, high phototropism combined with low apical dominance caused broken-topped trees to often sprout multiple new leaders (and epicormic branches on stems around larger openings) to quickly dominate canopy openings. The result was significant loss of commercial value; only the stem portion below the breakage could develop future commercial value. Thus, careful site selection and risk assessment are imperative. A single brief ice event one or two decades after planting may render a red alder plantation nearly financially worthless. One must therefore carefully analyze site-related risks before committing to intensive and expensive red alder management. Next, we will consider some techniques and field craft that should prove useful in preparing, reforesting, thinning, and pruning a correctly sited red alder plantation.

Site Preparation

When it comes to site preparation, one should realize that herbicide control of competing vegetation after planting is infeasible, because current herbicides fail to distinguish between red alder and undesirable vegetation. Hence, the site preparation stage prior to planting is the only feasible opportunity to control vegetation, and gambling with the outcome ought not be an option. Other important considerations regarding red alder and site preparation are: (1) salmonberry *cannot* be controlled through manual means, only herbicides or broadcast burning are effective; and (2) certain woody species, notably vine maple, may be "plucked out" in the course of logging the previous stand. The up-shot is that if vegetative suppression is likely to cause seedling mortality, site preparation is imperative. If red alder captures the site early due to proper site preparation and planting, rapid growth rate, and full stocking, it will outgrow all other vegetation, and further vegetation control will be unnecessary. In most cases, however, site preparation with herbicides capable of controlling targeted vegetation is necessary in order to assure full stocking and even spacing of planted seedlings. I will re-visit the importance of even spacing and full stocking i.e., no planting mortality, later when I discuss how silvical characteristics of red alder are used to produce high-value log characteristics.

Planting Techniques and Field Craft

First, a primary activity objective for planting is a practically 100 (and no less than 95) percent first-year survival with good vigor on, or close to, a nine-foot-square grid pattern. Red alder seedlings are different from their conifer counterparts in that seed germination in a bare root seed bed is poor and unpredictable. (A trial is currently underway at Webster Nursery to study if this obstacle can be overcome—moisture regimes and frost control may prove crucial factors.) To overcome the uncertain germination rate, DNR's Webster Nursery grows a so-called "plug-½" that, coupled with proper temperature and irrigation regimens and newly developed techniques for top-mowing, produces a relatively inexpensive high quality red alder seedling in eight to 10 months. The seeds are germinated in very small containers in an atmospherically controlled and "fertigated" greenhouse in April, thus achieving higher germination rates than with bare root sowing. These mini-plugs are lifted and transplanted into a bare-root bed in early summer, inoculated with *Frankia* bacteria to speed formation of nitrogen-fixing root nodules, lifted from the bare-root bed and put in freezer storage in January or February, and thawed and stored in a cooler approximately two weeks prior to out-planting. Seedling characteristics when packed and stored are: (1) crown height of 12 to 31 inches (30 to 80 cm), (2) caliper of 5 mm, (3) healthy buds and branches along the entire length of the stem, (4) prolific root nodules, and (5) healthy terminal. Seedling care at out-planting must be extensive to prevent damage to succulent terminals and buds, desiccation, and root damage. Tree planters must, for example, avoid stuffing too many seedlings into their planting bags and exposing unplanted seedlings to heat and drying.

The planting window is short: mid-March through mid-April, and after predicted last frost for the site at hand.

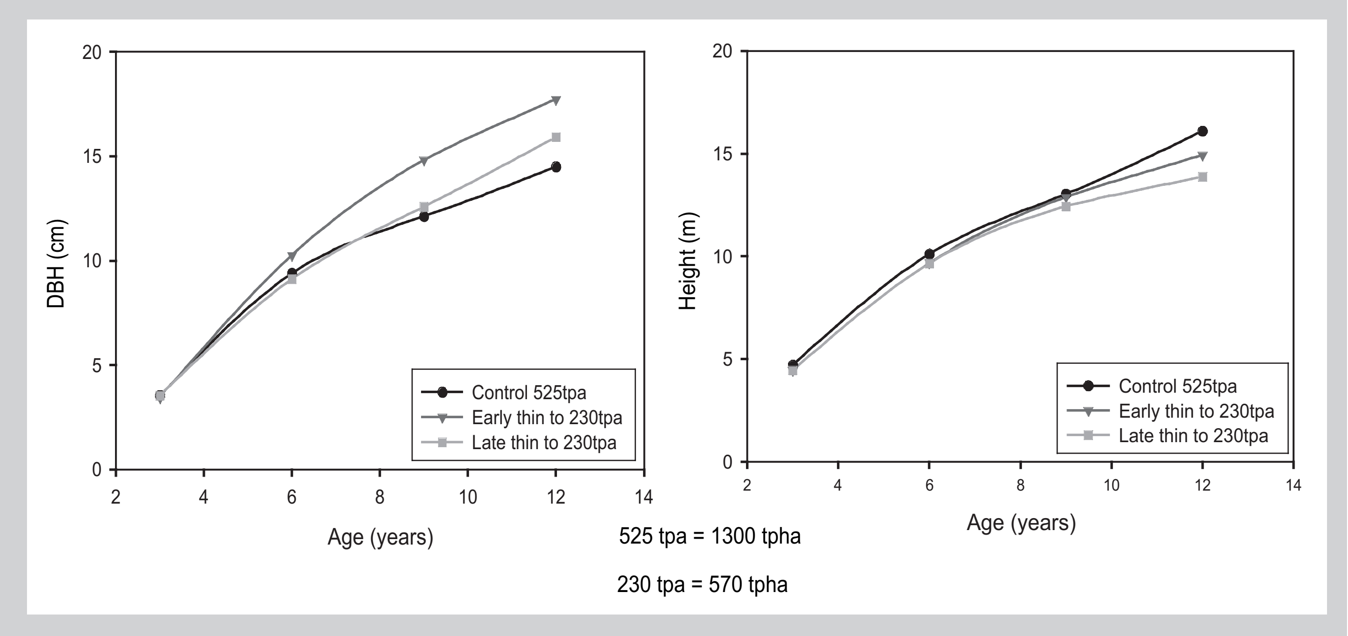

Figure 3—Results of diameter and height response of red alder stands planted at 525 trees per acre to early and late pre-commercial thinning through age 12. Source: Hardwood Silviculture Cooperative.

Planting Density

In determining stand establishment criteria, rotational stand objectives must first be clearly defined. By combining a defined desired end-state objective with silvical characteristics of red alder seedlings and saplings, one is positioned to chart the optimal pathway from the initial stand condition to the desired end state. Accordingly, I assert that a desired end state objective for a commercial red alder plantation is maximum return on investment manifested by full stocking at rotation's end with each tree's lowest 22 feet (6.7 meters) being a log of superior grade. A superior grade log is straight, clear, and with a dbh of at least 15 inches (38 centimeters). This implies (1) even spacing to preclude stem sweep (fig. 2) and (2) stocking that is periodically adjusted to (a) induce natural pruning at branch diameters of one-half inch or less (no "black knots") and (b) sustain diameter and height growth at maximal levels when considering natural pruning criteria without inducing opportunities for phototropic stem sweep. The HSC—using 12-year plantation data from test plots in Oregon, Washington, and British Columbia—found promise in planting red alder at nine-foot square spacing (525 trees per acre or 1,300 trees per hectare).

The HSC further tested the concept of planting 525 trees per acre by comparing the response to pre-commercial thinning (PCT) at various ages. The graphs in figure 3 compare dbh and height growth in response to PCT to 230 trees per acre at four ("early") versus eight ("late") years since planting.

The results clearly indicate that diameter growth benefits from thinning as early as age four while height growth response is not as succinct. There are also indications that stands receiving the late PCT have a tendency to catch up with earlier thinned stands (fig. 3). Moreover, casual observation of several red alder plantations aged four through 15 indicate that thinning at age four delays natural pruning processes and results in excessive branch diameters in the lower crown. Accordingly, one might deduce (while awaiting further research) that the window of consideration for PCT opens at age four, but the optimal time (factoring in both the value of clear wood and growth rate) is most likely in the eight to 10-year range. From this author's viewpoint, these emerging parameters (planting at nine-foot spacing and PCTing near age 10 and taking out one-half of the trees per acre) are on, or very near, the optimal silvicultural pathway towards the highest possible return on investment. As we shall soon see, financial analysis of the entire rotation lends credibility to this assumption.

Some Thoughts on Thinning Techniques and Field Craft as Related to Red Alder Silvics and the Objective of Maximum Return on Investment

From red alder's extreme shade intolerance comes a corresponding phototropism i.e., a strong proclivity to bend towards direct sunlight. In natural stands of red alder, stocking depends entirely on the stochastic nature of seed and seed bed availability, germination conditions, etc. Stocking therefore tends to be universally clumpy, and phototropic stem sweep becomes nearly universal. Crown ratios in densely stocked clumps quickly diminish to the point of being too low to respond to thinning, while diameters are uneven (although tree height is not), and

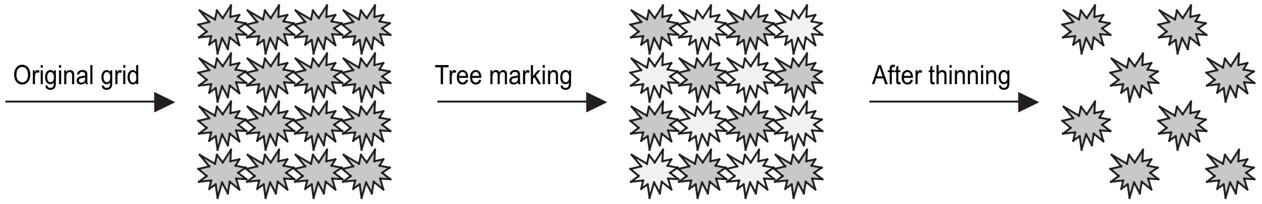

Figure 4—The even-spaced thinning solution: Start with 9-foot square spacing (far left). In thinning, remove every other diagonal row (gray crowns, center). The post-thinning spacing is even and square, although the squares are turned 45 degrees, at 9 feet x √2 ≈ 13 feet. Even spacing supports uniformly vertical phototropic response in red alder.

suppression mortality occurs. More stem sweep follows around openings created from suppression mortality (fig 2). From an economic standpoint, the stand has lesser valued, slow growing logs and makes inefficient use of available growing space. In intensively managed red alder plantations, we intend to preclude these negative factors. We accomplish that through *very* even initial spacing coupled with stocking controls intended to balance viable crown ratios (maintaining approximately 60 percent) with natural pruning at branch diameters of less than one inch. The need for even spacing may be considered proportional to red alder's phototropism. Therefore, red alder's need for uniform spacing in order to produce high-value logs is far greater than Douglas-fir or other conifers.

Thus, a question arises of how to "plant on a grid" and then sustain the grid through one or more thinnings. The first step, of course, is to select sites with even availability of planting spots—good soil throughout, requisite site preparation, and sufficient planting contract provisions to ensure a seedling every nine feet in a square pattern. Such strict spacing arrangements may be sustained when PCTing by taking out every other diagonal row (thus removing one-half of the basal area and trees per acre). PCT would shift the square pattern 45 degrees while widening the spacing by the square root of two (approximately 1.4). In other words, if planting is at nine foot spacing, PCT would be to 9 x 1.4 ≈ 13 foot spacing, and a subsequent commercial thinning would be to a spacing 13 x 1.4 ≈ 18 feet. Seen from above, the original grid, trees to be removed in thinning and the grid after thinning would appear as in figure 4.

Where Does This Take Us?

In review, we initially established a desired end-state and then devised the best way to get there from a silvically optimal initial stand condition. Note that we first established two desirable parameters for maximizing return on investment: full stocking and superior-grade first logs in practically every tree. Next we looked at planting as well as thinning techniques and field craft to maximize value potential value at final harvest. We noted that planting between 500 and 600 trees per acre on a uniform and square grid enabled us to PCT by removing one-half of the trees per acre and thus sustained a high and uniform rate of desirable stand development. The phototropic nature of alder compelled us to develop techniques and field craft to sustain uniform and square spacing before and after thinning. Thus, by removing every other diagonal row, we PCTed to 13-foot square spacing (from the initial spacing of nine feet). A subsequent commercial thinning—if we do one—would be to13 x √2 ≈ 18 feet, assuming that future research will indicate similar desirable development for slightly older stands. The final stocking would be around 130 evenly spaced trees per acre, with each tree being straight and clear (through natural pruning and possibly dead branch knock-down) up to at least 22 feet while sustaining maximal diameter accrual to attain the desired 15 inches dbh. Although, currently available data for natural stands indicate 14 inches at dbh for 120 trees per acre, I anticipate additional growth from judicious plantation management. We can now flesh out these concepts with a rudimentary regime simulation combined with robust financial analysis to scope whether or not the financial outcome warrants early investments.

Stand Development Simulation and Financial Analysis

Although the HSC has thus far developed 12 years of information on intensive red alder management, a notable gap exists in the lack of a good growth and yield simulator for managed stands. For the interim, I will note that existing knowledge lends itself to mathematical calculations sufficient to project rough stand averages at important decision nodes. Growth projections are derived by coupling HSC plantation growth data through year 12 with natural stand site index curves. However, growth and yield simulations based on site trees have inherent over-estimation bias that is perpetuated when used to extrapolate 12-year HSC plantation data to final rotation. A subjective downward adjustment of projections is therefore prudent. In order to remain financially conservative, it is also prudent to assume investments, such as thinning and dead branch knock-down, occur at the earliest possible juncture. Thus, growth and yield calculations with a prudent downward adjustment and coupled with what seems as reasonable future stumpage assumptions may be used for projecting returns on investments. The tabulation below contains what is, after comparison to feasible alternative regimes, thought to be both an optimal and practical rotation-length silvicultural prescription.

Stand chronology and cash flow tabulation:		
Activity	**Year**	**Cost/Revenue**
Site prep (aerial herbicide)	0	($110)
Plant (seedlings + contract)	0	($300)
PCT	4	($100)
Dead branch knock-down	8	($100)
CT (3 MBF/ac @ $200/MBF)	18	$600
Final Harvest (20 MBF/ac @ $600/MBF)	30	$12,000

The investment value of this rotation, using a discount rate of four percent, results in a bare land value (BLV) of just under $5,000 per acre. BLV is defined as net present value of an infinite succession of identical rotations.[1] Rotation length is therefore immaterial when comparing present value of silvicultural regimes of various rotation lengths to each other. This is because the calculated investment period in all cases is the same i.e., infinity. This would not be true if using the pure form of net present value (NPV), in which case comparison of different rotation length scenarios is invalid. Thus, comparing the BLV from the above stand tabulation to a likewise optimal mixed Douglas-fir – western hemlock regime final-harvested at culmination of periodic annual increment, one finds that the red alder regime is more than twice as profitable in terms of BLV.[2] Although the red alder projection is admittedly crude, its financial advantage over mixed conifer is sufficiently large to confidently state that red alder cultivation merits serious consideration on suitable sites.

Conclusions

- Red alder cultivation for commercial purposes requires management intensity not matched by conifer forestry and therefore requires a level of investment higher than for conifer plantations.

- Site selection is of critical importance in intensively managed red alder; effects of error in this regard are not benign as in conifer plantations.

- Windows for management intervention are relatively short, and if not acted upon, the commercial value of red alder regimes go from potentially superior to assuredly mediocre.
- Returns on investment show potential to be on the order of more than twice the value of mixed conifer rotations, given what today seems to be reasonable assumptions on growth, yield, and stumpage values, and provided that risk is analyzed and judiciously managed.
- Further research is needed to develop state-of-the-art growth and yield simulators for managed stands of red alder.

Acknowledgements

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[1] In the formula $BLV = NFV \div [(1 + i)^n - 1]$, "NFV" is net future value i.e., the net of all revenues and costs, each compounded until the end of the rotation; "i" is the compounding rate; and "n" is the number of years—compounding periods—in the rotation. BLV, or Bare Land Value, may be thought of as Net Present Value (NPV) for an infinite succession of identical rotations. Since the investment period would thus be equal i.e., infinity, BLV lends itself to equitable financial comparison of various regimes and rotation lengths.

[2] Net future value for the red alder regime when the value of all activities are accumulated at 5 – 1percent to year 30 is $11,117 per acre. Applied to the formula for calculating bare land value, the result is $4,955 per acre. By comparison, a similarly optimal regime for mixed Douglas-fir and associated conifers terminated at approximately the culmination of periodic annual increment (ages 40 to 60), yields a maximum bare land value in the $1,700 to $2,400 per acre range, depending upon species mix and other site specific variables and assumptions.

Alternate Plans for Riparian Hardwood Conversion: Challenges and Opportunities

Kevin W. Zobrist and C. Larry Mason[1]

Abstract

Many riparian stands in western Washington are dominated by red alder and other hardwood species. Riparian harvest restrictions designed to protect salmon habitat can be problematic in these stands, as they may preclude establishment of desirable large conifers while also resulting in economic losses for landowners. Washington forest practices rules allow for development of "Alternate Plans" which are intended to provide flexibility for solutions to avoid unintended consequences. A case study has been done of a hardwood conversion alternate plan. Observations from this case study have identified problem areas in the alternate plan approval process. Approaches such as templates may help address these problems.

Keywords: red alder, riparian management, economics

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Introduction

The state of Washington has recently updated its forest practices regulations, adding new restrictions on timber harvesting in riparian areas. The purpose of the new rules, known as the "Forests and Fish Rules," is to protect endangered salmon and other aquatic resources in compliance with the federal Endangered Species Act and Clean Water Act. In western Washington, the Forests and Fish Rules are specifically intended to put riparian stands on a trajectory towards desired future conditions (DFC). The DFC are conditions of mature, unmanaged riparian stands, characterized by large conifers that provide shade and a long-term source of large woody debris (LWD) thought to be important for fish habitat.

The Forests and Fish Rules for western Washington require a three-zone riparian buffer along fish-bearing or potentially fish-bearing streams. The total buffer width is one site potential tree height, which varies from 90 to 200 feet depending on site class. No harvest is allowed in a 50-foot core zone immediately adjacent to the stream. The next zone is the inner zone, which extends from the core zone to two-thirds or three-fourths of the site potential tree height depending on the size of the stream. Partial harvest may be allowed in the inner zone if the number and basal area of the conifers in the core and inner zones are projected to meet minimum requirements when the stand is 140 years old. The remainder of the buffer is the outer zone, in which harvest is allowed so long as 20 conifers per acre with a diameter at breast height (DBH) of 12 inches or greater are retained.

Many riparian stands in western Washington are dominated by red alder (*Alnus rubra*) and other hardwoods. In these situations, the Forests and Fish Rules can be problematic. Because of inadequate conifer density and basal area, no harvest will be allowed in either the core or inner zones. However, without active management to harvest some of the alder and establish a greater conifer component, it is unlikely that these riparian stands will achieve the DFC within the desired time frame. Instead, as the alder, which is not a long-lived species, becomes senescent, the riparian stand may become dominated by salmonberry (*Rubus spectabilis*) and other brushy vegetation. The lack of opportunity to harvest valuable hardwood timber in the riparian zone also means economic losses for landowners. The economic impacts of the riparian harvest restrictions can be significant, especially when no timber can be harvested from the inner zone (Zobrist 2003; Zobrist and Lippke 2003).

In order to accommodate situations where the rules may hinder the achievement of the DFC and to provide opportunities for landowners to find lower cost approaches for protecting riparian areas, the rules allow landowners to submit a site-specific alternate plan for managing a riparian stand. A case study has been done of one of the first "hardwood conversion" alternate plans to be submitted. This case study offers insights into some of the challenges of and opportunities for using alternate plans as a solution for the sustainable management of riparian hardwood stands.

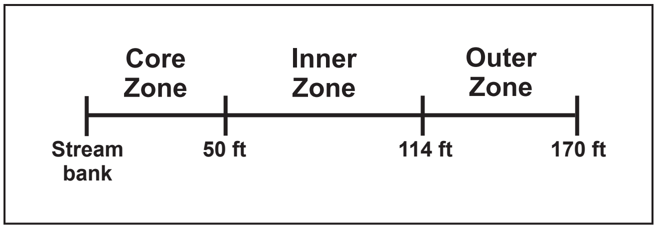

Figure 1—A 170-ft riparian buffer is required for small streams on site class II. The buffer includes a 50-ft core zone, followed by a 64-ft inner zone and a 56-ft outer zone.

Hardwood Conversion Case Study

The case study is of a hardwood conversion alternate plan that was submitted in 2002 by a small forest landowner in southwest Washington. The landowner planned to harvest a 26-acre stand that bordered 1,570 feet on the east side of a north-south stream. The stream ran dry in the summer, but it was identified as potential winter fish habitat and so was classified as fish-bearing. The stream was considered small, as its bankfull width was less than 10 feet. The stand was site class II, requiring a total riparian buffer width of 170 feet. The first 50 feet from the stream was the no harvest core zone. The inner zone then extended 64 feet from the edge of the core zone out to two-thirds of the buffer width (114 feet), as required for small streams. The remaining 56 feet was the outer zone (fig. 1).

The dominant species in the riparian zone was red alder, which was 30 years old, had a density of 105 trees per acre (TPA), and ranged in size from 6 to 18 inches DBH. There were also 35 TPA of 55-year-old Douglas-fir (*Pseudotsuga menziesii)* ranging in size from 6 to 40 inches DBH, along with a few (less than 6 TPA) other hardwoods, such as black cottonwood (*Populus trichocarpa*) and bigleaf maple (*Acer macrophyllum*) (fig. 2). The core and inner zones, which comprised approximately 4 acres, had an inadequate conifer component to allow harvesting in the inner zone under the default rules. The landowner proposed a hardwood conversion alternate plan to harvest some of the existing alder in both the core and inner zones to establish more conifers and generate some revenue.

The alternate plan addressed the riparian zone as two different management units, with unit 1 bordering the southern 1,070 feet of stream and unit 2 bordering the northern 500 feet of stream (fig. 3). For unit 1, the alternate plan proposed leaving all of the Douglas-fir and 49 red alder along the stream bank in the core zone while harvesting the rest of the hardwoods in that zone. For the inner zone the plan proposed leaving 13 Douglas-fir (12 less than 9 inches

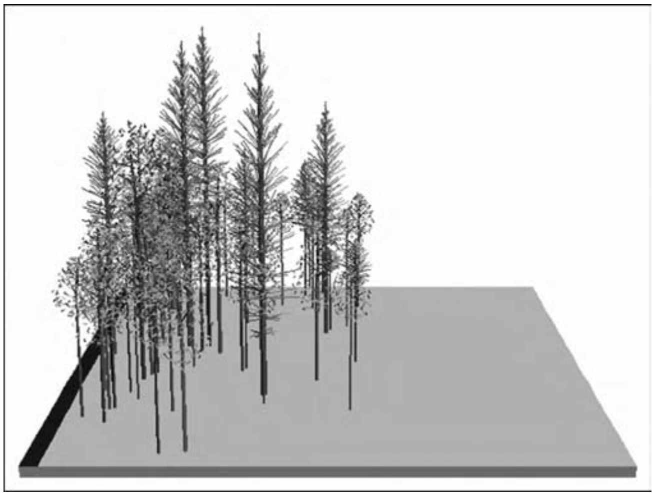

Figure 2—A visualization of the case study riparian stand, which is predominantly 30-year-old red alder with some older conifers and additional hardwood species present.

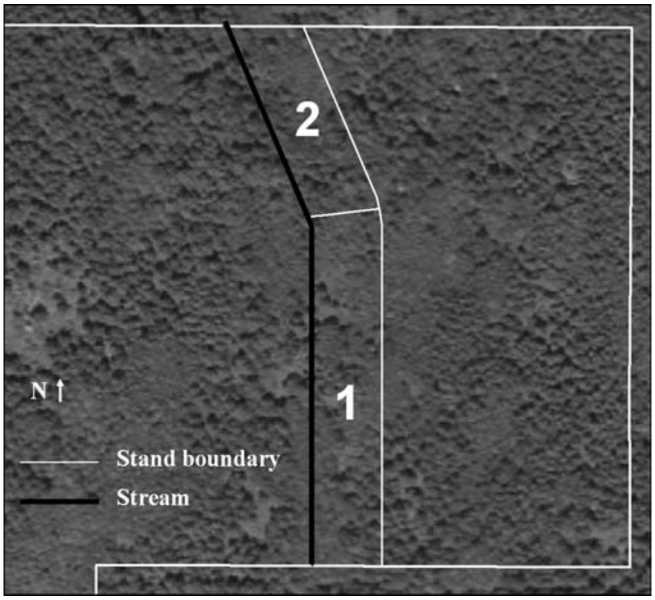

Figure 3—The case study riparian zone comprised two management units along 1,570 feet on one side of a small, north-south stream.

DBH and one with 28 inches DBH) and harvesting the remaining Douglas-fir and all of the hardwoods. All trees would be harvested in the outer zone. For unit 2, no harvest would be done in the core zone. The plan proposed to leave 8 Douglas-fir dispersed in the inner zone, while harvesting the remaining Douglas-fir and all of the hardwoods. All trees would be harvested in the outer zone.

The alternate plan called for the harvested areas to be replanted with 300 TPA of 1-1 seedlings. The seedlings would be 80 percent Douglas-fir and 20 percent western hemlock (*Tsuga heterophylla*). Brush control would be done at 3 years and 7 years after planting to ensure that the planted conifers become free to grow. To evaluate the expected results of the proposed alternate plan over time, the riparian stand was treated according the prescription and then projected over 140 years using the Landscape Management System (LMS). LMS is an analysis tool that integrates growth, treatment, and visualization models (McCarter et al. 1998). The projected stand conditions immediately, 10 years, 40 years, and 140 years after treatment are shown in fig. 4. These projections suggest that in the long term this alternate plan would result in a riparian stand dominated by large conifers and characteristic of the DFC.

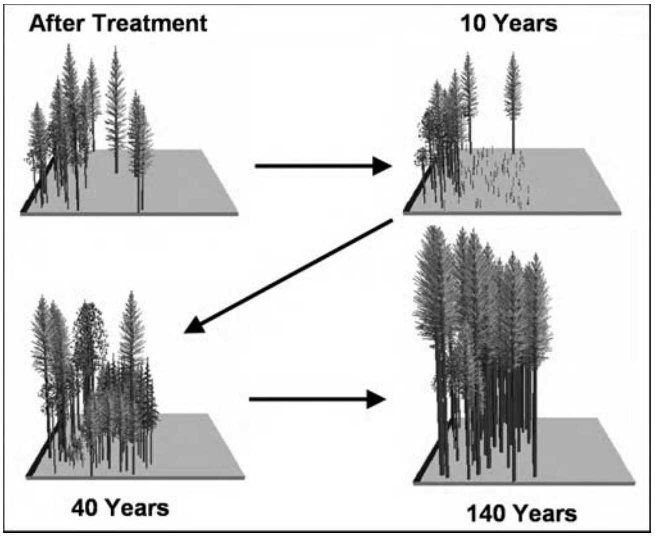

Figure 4—LMS simulation of the riparian stand conditions over time under the proposed alternate plan.

In order for an alternate plan to be approved, it must be reviewed by an interdisciplinary (ID) team that includes representatives from the Washington Departments of Natural Resources, Fish and Wildlife, and Ecology, along with local tribes. The ID team that reviewed this alternate plan proposed several revisions. The ID team proposed a wider no-harvest area in the core zone of unit 1. They proposed that only the smallest Douglas-firs be harvested in the inner zone, and only those leaning away from the stream. They also proposed in-stream LWD placement of 37 to 45 conifer logs originating from outside the riparian area (i.e. the upland portion of the harvest unit).

The economic costs of the revisions proposed by the ID team were unacceptable to the landowner. However, a compromise was reached in which the logs for LWD placement were allowed to include leave trees and downed wood from the core and inner zones. This eliminated the cost of using merchantable upland logs for LWD placement by allowing the placement of logs that would not otherwise have gone to the mill. The final revised plan included an additional 54 red alder and 5 cottonwood leave trees in the core zone of unit 1. In the inner zone of unit 1, 12 Douglas-fir leave trees were to be retained with an average DBH of 18 inches. In the inner zone of unit 2, 10 Douglas-fir leave trees were to be retained with an average DBH of 26 inches.

Table 1—Itemized cash flows for the original proposed alternate plan, the plan with proposed revisions, and the final approved compromise. Only the additional cash flows associated with the alternate plan are included.

Cash Flow	Proposed Plan	Proposed Revisions	Approved Compromise
Net Harvest Revenue	$12,210	$8,710	$8,710
Site Preparation	-$625	-$625	-$625
Planting	-$810	-$670	-$670
LWD Log Value	$0	-$4,000	$0
LWD Placement Cost	$0	-$1,000	-$1,000
Brush Control Year 3 (discounted at 5%)	-$275	-$230	-$230
Brush Control Year 7 (discounted at 5%)	-$225	-$190	-$190
Consulting Fees	-$1,500	-$1,500	-$1,500
Net To Landowner	$8,775	$495	$4,495

Using figures provided by the consulting forester who prepared the alternate plan, a breakdown of the costs and revenues for the original alternate plan, the proposed revisions, and the final, approved compromise is given in table 1. These are only the costs and revenues exclusive to the alternate plan that are above what would be expected if management was done according to the default rules. The original proposed plan would have resulted in a net return to the landowner of $8,775. The revisions proposed by the ID team would have reduced this by 94% to $495, at which point the landowner was no longer willing to pursue the alternate plan. The compromise resulted in a net return of $4,495, a 49% reduction from the original proposal.

Discussion

Alternate plans are potential solutions for situations such as hardwood-dominated riparian areas in which the regulatory prescription is unlikely to achieve the DFC in a timely manner. However, observations from this case study suggest that the development and approval of such plans may be problematic. The approval process can be long and costly for both the landowner and the agencies participating on the ID team. In this case, the plan development and approval process took approximately one year and involved three ID team field visits. The cost to the landowner was $1,500 for consulting fees, which was 17% of the net harvest revenue for the approved plan and represents approximately $1 per foot of stream. Agency costs included the personnel and equipment costs of the three field visits, plus the associated office time. Additional agency costs were expected for supervision of the LWD placement.

Another problem observed was the lack of guidelines for alternate plan development and approval. There were no objective, measurable performance criteria to gauge the effectiveness of the proposed plan or subsequent revisions. At the same time, a lack of economic guidelines almost resulted in a failure to reach an agreement. Without clear guidelines and objective, measurable performance criteria, the overall goals of alternate plans can easily get lost in the negotiation process and opportunities for “win-win” solutions of greater effectiveness and lower compliance costs can be missed.

The problems observed with this case study were not unexpected. This was one of the first alternate plans to be submitted, and as with any new process, time and experience are needed to work out logistical issues. The purpose of this case study was to identify areas of need and potential solutions for improving process efficiency and results. One such solution suggested in the rules is the development of alternate plan templates. These templates would be pre-established guidelines to expedite the development and approval of alternate plans for common situations. Conversion of predominantly hardwood riparian stands for conifer regeneration has been identified as a common situation for which a template approach would be appropriate.

Alternate plan templates for hardwood conversion present an opportunity to provide for short and long term riparian habitat goals while also providing economic relief to landowners. These templates could provide landowner incentives for future stewardship. They could also facilitate an increase in the available short term supply of red alder, as much of the current inventory is located in riparian areas. A streamlined approval process would make alternate plan implementation more feasible for both landowners and regulatory agencies, which is necessary for the large-scale success of alternate plans.

Several key elements will likely be needed for a successful hardwood conversion template. A narrow, no-harvest buffer will be needed immediately adjacent to the stream for interim shade, bank stability, and short term LWD recruitment. Sufficient harvest of the remaining riparian hardwoods will be needed to create adequate growing space for conifers. Regeneration specifications (species mix and density) should be appropriate for the site and for long term growth. The template process should be simple and affordable and provide sufficient economic benefits to landowners.

The observations from the case study suggest several challenges that will need to be addressed in developing a hardwood conversion template. Short term function needs, such as shade and bank stability, will need to be balanced with the long term establishment of the DFC. Specifically, the appropriate width of the no-harvest buffer adjacent to the stream will need to be identified. Appropriate regeneration strategies will need to be developed. These strategies will need to extend beyond planting, such as brush control and pre-commercial thinnings. This will increase landowner costs but may be necessary for establishing conifers while preventing the subsequent development of too densely stocked conditions. Treatment of existing conifers will also need to be addressed. As was the case for the case study, hardwood-dominated stands often include some conifers—too few to achieve the DFC, but enough to potentially impact regeneration. Finally, it will be important to establish sufficient conifers to achieve the DFC while still maintaining a hardwood component. Hardwoods play an important role in riparian forest ecosystems. Ultimately the goal is not the eradication of riparian hardwoods in favor of purely coniferous stands, but rather the sustainable management of both conifers and hardwoods.

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Metric Equivalents

When you know:	Multiply by:	To find:
Degrees Fahrenheit (°F)	(F-32)/1.8	Degrees Celsius (°C)
Inches (in)	2.54	Centimeters
Feet (ft)	.3048	Meters
Acres (ac)	.4047	Hectares
Trees per acre (TPA)	2.471	Trees per hectare
Thousand board feet (MBF)	2.4	Cubic meters (m^3)

English Equivalents

When you know:	Multiply by:	To find:
Degrees Celsius (°C)	(C* 9/5)+32	Degrees Fahrenheit (°F)
Centimeters (cm)	.3937	Inches (in)
Meters (m)	3.2808	Feet (ft)
Square meters per hectare (m^2/ha)	4.36	Square feet per acre (ft^2/ac)
Cubic meters per hectare (m^3/ha)	14.30	Cubic feet per acre (ft^3/ac)
Kilograms per hectare (kg/ha)	0.89	Pounds per acre (lb/ac)
Kilometers (km)	0.6214	Miles (mi)
Hectares (ha)	2.470	Acres

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