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Managing Young Upland Forests in Southeast Alaska for Wood Products, Wildlife, Aquatic Resources, and Fishes: Problem Analysis and Study Plan

Mark S. Wipfli, Robert L. Deal, Paul E. Hennon, Adelaide C. Johnson,
Toni L. De Santo, Thomas A. Hanley, Mark E. Schultz, Mason D. Bryant,
Richard T. Edwards, Ewa H. Orlikowska, Takashi Gomi

Authors

Mark S. Wipfli is a research ecologist, Pacific Northwest Research Station, 1133 N. Western Ave., Wenatchee, WA 98801; **Robert L. Deal** is a research silviculturist, Pacific Northwest Research Station, 620 SW Main St., Suite 400, Portland, OR 97205; **Takashi Gomi** is a hydrologist, Department of Forest Resources Management, University of British Columbia, Vancouver, BC; **Paul E. Hennon** is a plant pathologist, **Adelaide C. Johnson** is a hydrologist, **Toni L. De Santo** is an avian ecologist, **Thomas A. Hanley** is chief wildlife biologist, **Mark E. Schultz** is an entomologist, **Mason D. Bryant** is a research fishery biologist, **Richard T. Edwards** is a research aquatic ecologist, and **Ewa H. Orlikowska** is a forest ecologist, Pacific Northwest Research Station, 2770 Sherwood Lane, Juneau, AK 99801.

Abstract

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Red alder (*Alnus rubra* Bong.) appears to influence the productivity of young-growth conifer forests and affect the major resources (timber, wildlife, and fisheries) of forested ecosystems in southeast Alaska. We propose an integrated approach to understanding how alder influences trophic links and processes in young-growth ecosystems. The presence of red alder is expected to increase understory biomass, and aquatic, riparian, and terrestrial invertebrate abundance, providing more food for herbivores, fish, and birds. We predict that most red alder trees will die standing, and woody debris will be small and mobile in streams. Nitrogen fixation by red alder in mixed stands may result in larger, more commercially valuable conifers. Inclusion of red alder in the regenerating stand may therefore mitigate some negative impacts of clearcutting, and may increase total wood production from the landscape.

Keywords: Red alder, young-growth management, vegetation, wildlife, fish, invertebrates.

Contents

Introduction

This study proposes an integrated approach to examine the function of young-growth ecosystems (fig. 1) and to understand how red alder (*Alnus rubra* Bong.) influences trophic links and processes (figs. 2 and 3) in managed young-growth ecosystems. Forest managers have historically regarded red alder as an undesirable species and have attempted to remove it from riparian and upland forest stands. However, red alder appears to have a positive influence on the productivity of young-growth conifer forests and associated resources in southeast Alaska. Our study will:

- Assess physical disturbances associated with red alder establishment.
- Evaluate the role of headwater processes within a landscape to assess conditions necessary for the establishment of alder-conifer stands.
- Assess history of physical disturbance processes (such as landslides) within the landscape to evaluate possible habitat changes associated with these disturbances in managed forests.
- Investigate whether red alder in mixed stands enhances conifer growth and wood production.
- Contrast the mode of death of red alder trees and conifers (i.e., die standing or by uprooting or bole snapping).
- Compare biomass of understory vegetation and forage for herbivores and invertebrates across a range of alder-conifer mixtures (0 to 80 percent alder).
- Assess the role of alder across a range of alder-conifer mixtures on the abundance of aquatic, riparian, and terrestrial invertebrates that provide food for fish and birds.
- Determine whether red alder influences stream nitrogen levels.
- Assess critical processes for maintaining downstream fish habitat including the supply, storage, and transport of woody debris and sediment.
- Assess red alder's impact on woody debris and sediment movement in streams.
- Measure fish abundance in relation to red alder.
- Determine the tradeoffs and compatibilities between the amount of alder in a stand, production of understory vegetation, growth and yield of Sitka spruce (*Picea sitchensis* (Bong.) Carr.) and western hemlock (*Tsuga heterophylla* (Raf.) Sarg.), woody debris, and fish food resources.
- Address the potential of alder as a "tool" for restoring important ecosystem functions in regenerating forests of southeast Alaska.
- Synthesize findings by describing the simultaneous beneficial and detrimental influences of red alder to several key resources across a range of its occurrence in mixed-species stands.

We hypothesize that management of red alder can enhance the major resources (timber, wildlife, and fishes) of forested ecosystems, and that the presence of red alder in young-growth stands may mitigate the impacts of clearcutting in areas where pure conifer regrowth would compromise these resources.

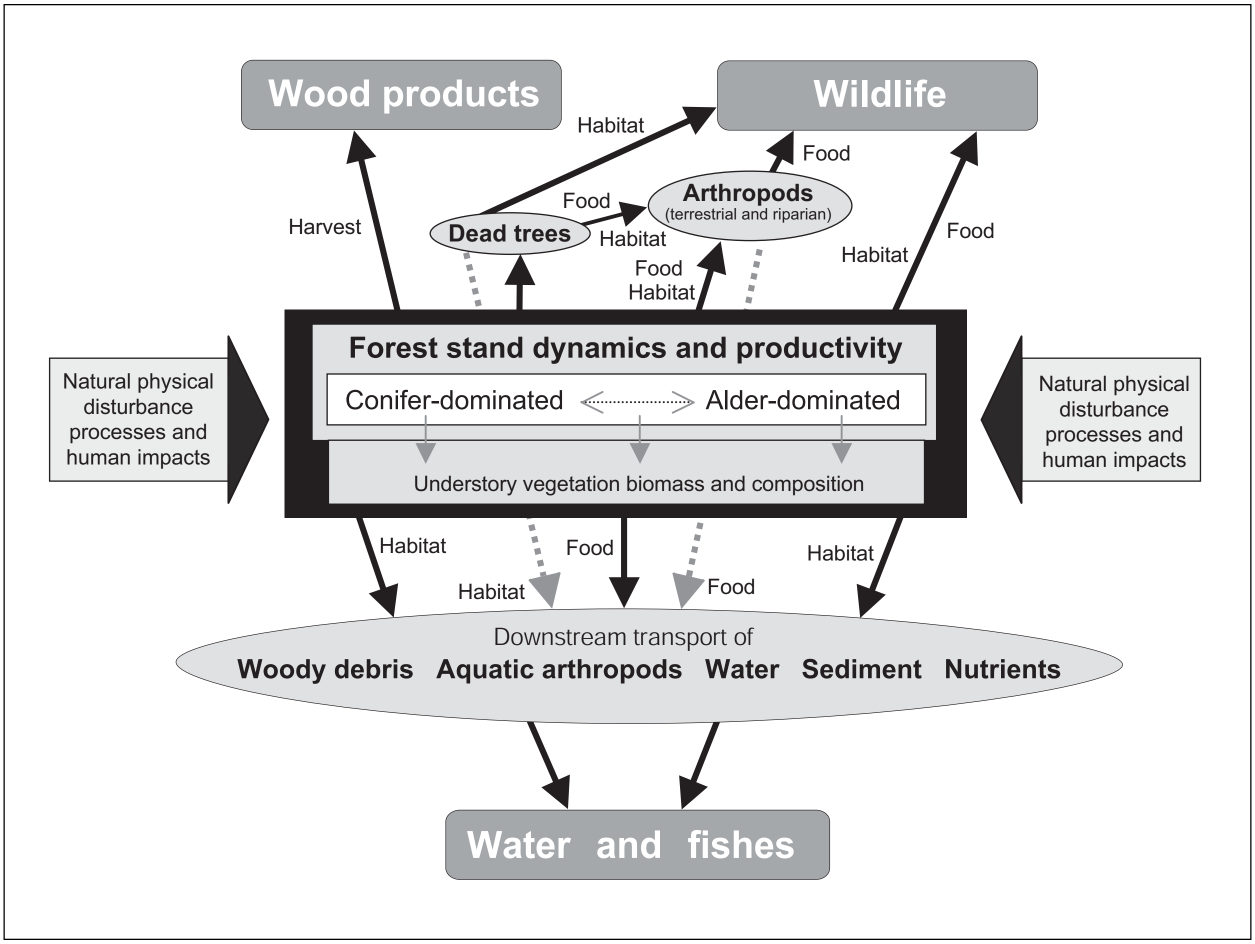

Figure 1—Major links among ecosystem components in young-growth conifer and mixed red alder-conifer forests.

There are three major integrating themes in this study:

1. Influence of alder in the ecosystem: vegetation, birds, invertebrates, wood, fishes (fig. 1).
2. Flow of wood among habitats (fig. 2).
3. Influence of alder on ecosystem links and processes (fig. 3).

Justification and Management Implications

Since the 1950s, clearcutting has been the dominant timber management practice in southeast Alaska forests. The dense, uniform, even-aged stands that develop after clearcutting have many negative consequences for wildlife and fish (Dellasala et al. 1996; Hanley 1993; Schoen et al. 1981,1988; Thedinga et al. 1989; Wallmo and Schoen 1980). Canopy closure generally occurs 25 to 35 years after cutting and is followed by a nearly complete elimination of understory vegetation for 100 years or longer (Alaback 1982, 1984b; Tappeiner and Alaback 1989). After the canopy closes above small streams, trophic status changes from autotrophic (dominated by organisms that manufacture their own energy) to heterotrophic (dominated by consumers) (Hetrick et al. 1998a, Sedell and Swanson 1984) and may affect overall aquatic productivity. The

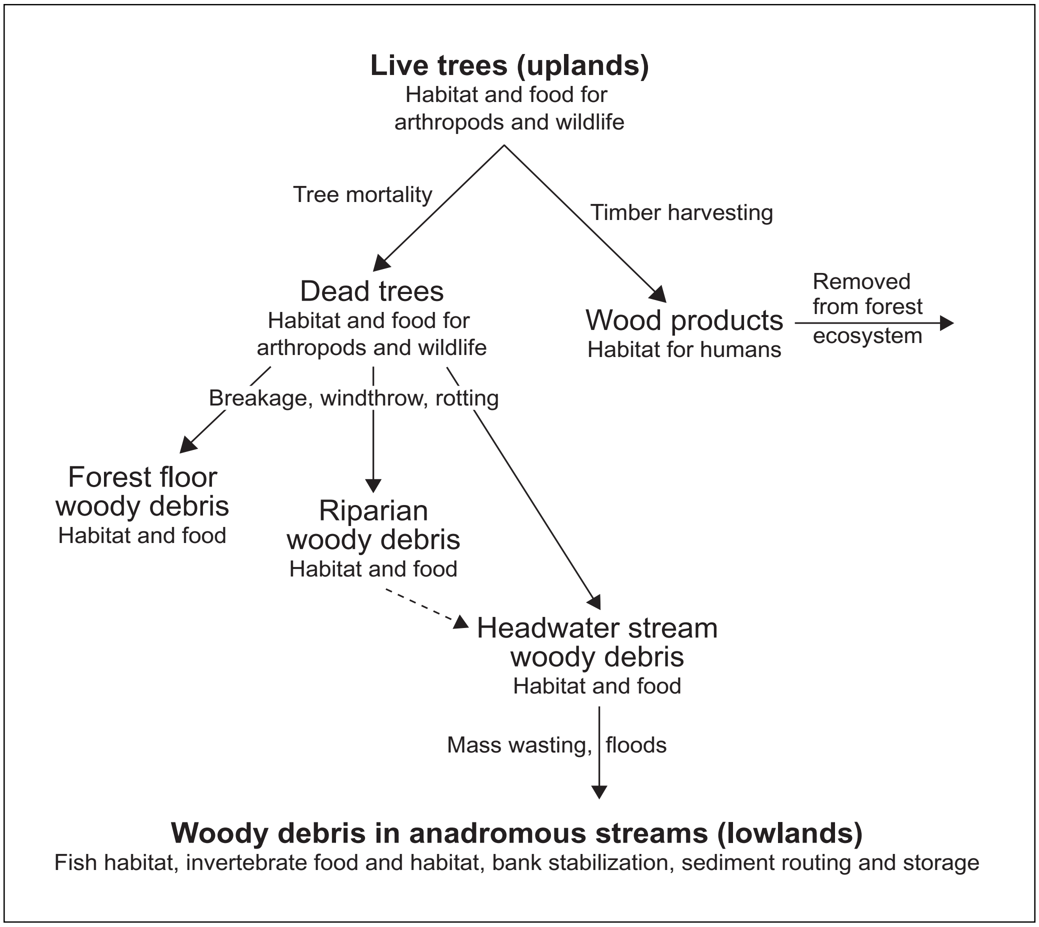

Figure 2—Flow and function of wood among habitats.

removal of streamside timber also reduces the amount and size of large wood in a stream, with a subsequent loss of bird[1] and fish habitat (Bisson et al. 1987, Bryant 1985). Changes in forest structure result in an alteration of supply, storage, and transport of woody debris and sediment through processes such as mass wasting, windsnap and blowdown, and bank erosion (Johnson et al. 2000, Smith et al. 1993). Subsequently, there is increasing interest in developing forest management practices that maintain or enhance biodiversity and assure long-term sustainability of forest products, wildlife, and aquatic resources.

Recent studies of young-growth stands of red alder mixed with conifers indicate that the presence of alder may mitigate some of the impacts of clearcutting in southeast Alaska. Mixed alder-conifer stands have species-rich, highly productive understory vegetation with biomass similar to that of old-growth stands of the region (Deal 1997, Hanley and Barnard 1998, Hanley and Hoel 1996). Habitat quality for small mammals in even-aged alder-conifer stands may be equal to that of old-growth forests (Hanley 1996; Hanley

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[1] De Santo, T.L. 1996. Unpublished data. On file with: Forestry Sciences Laboratory, 2770 Sherwood Lane, Suite 2A, Juneau, AK 99801.

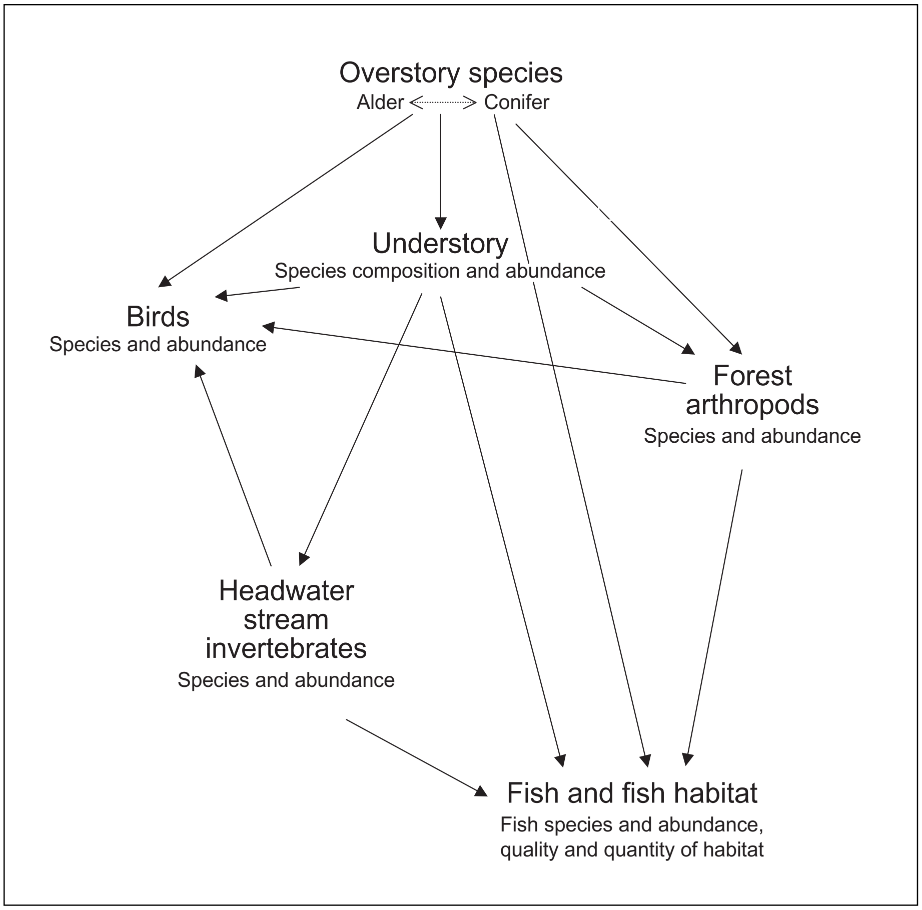

Figure 3—Proposed influence of red alder on ecosystem links and processes.

and Barnard 1999a, 1999b). Although inclusion of alder will not mitigate all wildlife-habitat problems (e.g., lack of snow interception for deer winter range), it may provide more benefits than would thinning of even-aged conifer stands. Attempts to reestablish understory herbs and shrubs through thinning young-growth conifer stands have led to conifer regeneration with little new herbaceous colonization (Deal and Farr 1994). Red alder may convey further benefits in riparian forests. Riparian forests with some red alder appear to produce more prey for fishes than conifer riparian forests (Piccolo and Wipfli 2002, Wipfli 1997). This is significant because over half of the prey biomass ingested by juvenile salmonids in southeast Alaska is terrestrial and originates from adjacent riparian vegetation. If similar processes occur in upland forests, the presence of red alder may increase invertebrate production, providing more food for animals such as birds, bats, small mammals, and fish, in turn affecting their abundance and production.

This is an integrated study (fig.1) that compares mixed alder-conifer stands with pure conifer stands to assess differences in physical disturbance history associated with tree composition; stand structure and tree mortality; understory vegetation; invertebrate, bird, and bat communities; and food resources for fish and birds (fig. 3). This study will take the first step toward establishing an integrated research program to address ecological processes critical for the establishment and growth of alder-conifer forests.

Expected Science and Management Inferences

In southeast Alaska, red alder is expected to increase the abundance of terrestrial invertebrates, providing a greater food resource for insectivores, such as birds (figs. 1 and 3). In riparian forests, increased production of invertebrates is expected to produce more food for fish. A greater biomass of understory vegetation is expected to occur in young forests with red alder; thus, habitat for birds and forage available to herbivores, such as deer, is expected to increase. Red alder is expected to produce rapid early growth but experience higher mortality than conifers as young forests develop. Most trees are expected to die standing regardless of treatment; thus, woody debris produced is expected to be small, partially decomposed, and devoid of large root systems. Such woody debris would be mobile and transient in streams, allowing sediment to move unimpeded downstream (fig. 2). Reduced conifer wood production is expected to occur with the presence of red alder, but individual conifers may be larger and more commercially valuable in mixed stands. Diversity of wood products is expected to be greater in mixed stands, and alder may be a valuable wood product in the future. Inclusion of red alder in a regenerating stand may allow for clearcutting in areas where purely even-aged conifer stands would compromise other resources (e.g., fish and wildlife). Inclusion of red alder also may increase total wood production from the landscape.

A considerable body of literature exists on the growth of red alder in forests of Oregon, Washington, and British Columbia. Some of this literature deals with mixed red alder/ Douglas-fir forests (*Pseudotsuga menziesii* (Mirb.) Franco). We expect to observe some similar general patterns of red alder growth, competition with conifers, and mortality in southeast Alaska. The distribution of red alder regeneration within the landscape may be different in southeast Alaska; red alder requires more soil disturbance in Alaska to colonize sites after timber harvesting. Processes such as tree growth and development of forests may be somewhat slower in Alaska. The age at which red alder reaches senescence and gives way to competition with conifers may be considerably different in Alaska. Plants that have a dominant influence on understory conditions in alder forests to the south (e.g., salmonberry (*Rubus spectabilis* Pursh)) may be less aggressive colonizers in Alaska, and may be replaced by understory plants preferred for browse by Sitka black-tailed deer (*Odocoileus hemionus sitkensis*). The decay of all types of wood is expected to be slower in Alaska owing to cooler average air and water temperatures. Slower decay is expected to allow for a greater persistence of both legacy and newly recruited wood for physical and biological functions in streams. We expect the influence of red alder on streams to differ with landscape location, or topographic position, which will dictate natural large woody debris patterns (storage and transport trends). Once these patterns of disturbance are understood, the effects of alteration of forests (conversion from old- to young-growth forests dominated with alder and conifer) on aquatic habitats can be assessed.

Although this study centers on young-growth forests in Alaska, the potential exists to expand our understanding of the occurrence and role of alder in unmanaged ecosystems in southeast Alaska and other ecosystems across the landscape. Southeast Alaska contains more extensive tracts of virgin, old-growth forest than does any other part of the United States. Alaska offers unique opportunities to study ecological interactions among alder, site conditions, and animals in an evolutionary context. Standards for ecological reference sets of “natural” conditions can be established more accurately in Alaska than elsewhere. Practical applications of study results are immediate in Alaska, and potential opportunities for other outcomes (e.g., ecological reference sets) are greatest in Alaska. Differences owing to latitude need to be quantified before research results from a particular geographic area are applied elsewhere; however, our approach of integrating disparate disciplines can be used as a framework for other studies on the manipulation of vegetation to achieve complex resource objectives.

Background on Red Alder

Red alder, the most common hardwood tree in the Pacific Northwest, is a relatively short-lived, shade-intolerant pioneer with rapid juvenile height growth (Harrington 1990). Red alder is the only commercial tree species west of the Rocky Mountains with the capacity to fix atmospheric nitrogen, and alder is an important species for the hardwood industry in the Pacific Northwest (Heebner and Bergener 1983, Hibbs et al. 1994). Its range extends from southern California to southeast Alaska (Harrington 1990). In Alaska, red alder is found throughout the southeastern panhandle northwest to Yakutat Bay in riparian areas, along roadsides and avalanche slopes, on stream bottoms with rocky, moist soils, and along beaches where creeks enter seas (Hulten 1968, Viereck and Little 1972).

Little information is available about red alder and its ecological role in Alaska. Basic information on silvics, stand growth and yield, tree species mixtures, succession, tree mortality and decay, and understory vegetation is lacking, and most information about alder in Alaska is speculative or based on research from other regions.

Establishment

Low winter temperatures and lack of precipitation during the growing season appear to be the primary limits to the range of red alder (Harrington et al. 1994). It grows in climates from humid to superhumid with annual precipitation from 400 to 5600 mm. Red alder grows in a wide range of soils, from well-drained gravels or sands to clays and organic soils. It grows primarily on soils of the orders Inceptisols and Entisols but also occurs on some Alfisols, Ultisols, and Histosols (Harrington 1990). Alder can tolerate poor drainage and some flooding during the growing season. It is not commonly found on droughty soils. The most productive stands are found on deep alluvial soils in river and stream flood plains; however, some productive stands also are found on upland sites on residual or colluvial soils (Harrington et al. 1994). Tree development is best in elevations below 450 m in British Columbia, Washington, and northern Oregon. In Alaska, red alder generally occurs near sea level.

As a pioneer species, red alder requires high light levels and is common on exposed mineral soil. Its ability to fix atmospheric nitrogen permits establishment on geologically young or disturbed sites with little soil nitrogen. It can form pure stands on alluvium, avalanche paths, or other disturbed sites. Red alder is an aggressive pioneer on avalanche paths, roadsides, log landings, skid trails, and other areas where mineral soil has been freshly exposed to seedfall (Harrington et al. 1994, Harris and Farr 1974). In Alaska, red alder is commonly found along beaches and streams, on avalanche tracks and landslides, and as a pioneer species with Sitka spruce, black cottonwood (*Populus trichocarpa* Torr. and Gray) and willows (*Salix* spp.) on land recently exposed by glacial retreat or land uplift (Harris and Farr 1974, Ruth and Harris 1979). In southeast Alaska, intensive logging since the 1950s has increased the amount of alder, particularly in upland areas where heavy soil disturbance resulted from tractor logging and high-lead cable operations.

Regeneration

Red alder can reproduce by seed or can sprout vigorously from the stump when young. Alder seeds have little or no dormancy, and germination of stored seeds is not improved by stratification (Berry and Torrey 1985, Radwan and DeBell 1981).

Alder germination is controlled by light quality (Bormann 1983, Haeussler and Tappeiner 1993), and germination is reduced to varying degrees by the presence of understory vegetation. Alder requires more light than its associated tree species, and is classed as intolerant of shade (Minore 1979). Haeussler and Tappeiner (1993) concluded that buried seedbank is not important in alder. Red alder sprouts vigorously from the stump when young and can be coppiced on short cycles (Harrington and DeBell 1984). Older trees rarely sprout, and coppice regeneration cannot be expected after saw-log size material is harvested (Harrington 1984). Because of reduced sprouting vigor, manual cutting of older alder trees can be an effective method of alder control (DeBell and Turpin 1989), but results from cuts made at different times during summer can differ (Pendl and D'Anjou 1990).

Stand Density and Tree Growth

Density in natural stands can be as high as 124,000 seedlings per hectare at age 5 (DeBell 1972) and 1,665 trees per hectare at age 20 (Worthington et al. 1960). Live crown ratios in crowded pure stands are very low, and trees often form narrow, domelike crowns. Branch retention and crown shape are strongly related to light levels in the canopy. Trees grown in low densities develop large lower branches that live longer and take longer to fall off than do branches that develop in more dense stands (Harrington et al. 1994). Red alder self-prunes very well when grown in dense stands. Shaded lower branches rapidly die and fall off, leaving clear boles. Epicormic branching has been reported after thinning, especially after late or heavy thinning (Berntsen 1961b, Smith 1978, Warrack 1964).

Red alder is relatively short-lived, maturing at about 60 to 70 years and reaching a maximum age of about 100 years (Worthington et al. 1962). On favorable growing sites, trees can be 30 to 40 m tall and 55 to 75 cm in diameter. Red alder has rapid juvenile height growth and on favorable sites 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 (Harrington and Curtis 1986, Smith 1968). On favorable sites, alder trees may be 9 m tall at age 5, 16 m at age 10, and 24 m at age 20 (Harrington 1990). In western Oregon, Zavitkovski and Stevens (1972) reported net primary productivity in red alder stands during the years of maximum growth (10 to 15 years old) averaged 26 t/ha per year. In pure stands on favorable sites, red alder can achieve annual 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). Radial growth generally begins in mid-April and continues until mid-September in the Puget Sound area of Washington state (Reukema 1965). Growth slows after the juvenile stage. Stand maximum cubic volume (about 500 m^3/ha) is attained at age 50 to 70 (Chambers 1983, DeBell et al. 1978, Skinner 1959, Worthington et al. 1960). Associated conifers have slower juvenile growth, but they sustain height growth longer than alder. On an average upland site, Douglas-fir and red alder can attain the same height at about age 45 (Williamon 1968).

Plant Associates

Red alder grows in both pure and mixed stands, with pure stands typically confined to stream bottoms and lower slopes (Harrington et al. 1994). It is more common in mixed stands and occurs as a minor component in most north Pacific cover types (Eyre 1980). Tree associates include Douglas-fir, western hemlock, western redcedar (*Thuja plicata* Donn ex D. Don), Sitka spruce, black cottonwood, and willow. Shrub associates include salmonberry, red elderberry (*Sambucus racemosa* L.), salal (*Gaultheria shallon* Pursh) and devil's club (*Oplopanax horridus* Miq.). Herbaceous plant associates include skunkcabbage (*Lysichiton americanus* Hulten & St. John), western swordfern (*Polystichum munitum* (Kaul fuss) K. Presl), and ladyfern (*Athyrium filix-femina* (L.) Roth).

Many alder stands in western Oregon have few associated conifers, and these stands may ultimately be replaced by shrub communities (Carlton 1990, Newton et al. 1968). Red alder is common on previously logged sites in the Pacific Northwest (Hibbs et al. 1994), where understories tend to be dominated by swordfern or salmonberry or both, often to the near-term exclusion of conifer regeneration (Newton et al. 1968, Tappeiner and Zasada 1993, Tappeiner et al. 1991). Salmonberry in the coastal Pacific Northwest is a particularly aggressive shrub that often forms dense shrub canopies. This makes it difficult for conifers to become established from seed and can create a serious problem for tree regeneration and growth (Howard and Newton 1984, Knapp et al. 1984, O'Dea 1992, Tappeiner and Zasada 1993, Tappeiner et al. 1991, Walstad and Kuch 1987, Walstad et al. 1986, Zasada et al. 1992). The abundant shrub layer also may explain the scarcity of tree regeneration in streamside areas (Hibbs and Giordano 1996). Neither Henderson (1970) nor Carlton (1990) found many tree seedlings in their studies of riparian and upland alder stands.

Growth Patterns

Although most of the research in mixed alder-conifer stands has been descriptive (as will be this study), some general growth trends are apparent. Alder must remain in the upper canopy to survive in mixed stands. Reaction of alder to competition is influenced by many factors, including the size, species composition, and density of the competing vegetation in the upper canopy and in the understory. Stand density strongly influences survival and growth of alder. The growth of closely spaced dominant alder was reported to decrease with increasing density of subordinate Douglas-fir (Shainsky and Radosevich 1991). Turnbull (1963) provides a scholarly treatise on assessing growth of mixed stands, including problems with quantitative comparisons of pure and mixed stands and their species components.

Succession

Successional sequences in mixed alder-conifer stands are not well understood. Observation of mature forests in the Pacific Northwest suggests that 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 whereas 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).

Nitrogen Fixation

The ability of red alder to fix atmospheric nitrogen can increase both nitrogen content and nitrogen availability in soil. Nitrogen fixed in the nodules is added to the soil in four ways: direct excretion from living roots and nodules, decomposition of dead roots and nodules, leaching from foliage, and decomposition of litter rich in nitrogen. Maximum annual fixation rates of 320 kg/ha (Trappe et al. 1968) in pure stands and 130 kg/ha in mixed stands (Binkley 1981) have been reported. Red alder increases the organic content of soils (Tarrant and Miller 1963, Trappe et al. 1968), and even if alder is shaded out following canopy closure in mixed stands, it may make substantial contribution to soil nitrogen prior to that time (Berg and Doerksen 1975). Soil structure and organic matter are thought to be major drivers of ecosystem productivity (Powers 1991), and alder increases organic matter in the soil by producing large quantities of rapidly decomposable biomass. Alder produces more litter than do conifers (Zavitkovski and Newton 1971), and the litter of other trees is more rapidly decomposed and incorporated into soil organic matter when mixed with nutrient-rich alder litter (Bormann and Sidle 1990).

A well-documented study of mixed alder-conifer stands at the Wind River research site in southwestern Washington compared a nitrogen-deficient stand of mixed Douglas-fir and red alder with adjacent pure stands of Douglas-fir (Miller and Murray 1978, Tarrant 1961, Tarrant and Miller 1963). After 48 years, mixed alder-conifer stands showed slightly increased growth of Douglas-fir and significant growth of alder, with overall wood production nearly double that of adjacent pure Douglas-fir stands. Douglas-fir site index (50 year) was increased by an average of 6.4 m. 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 production in Douglas-fir plantations (Atkinson et al. 1979, Tarrant et al. 1983).

Riparian Nitrogen Levels

The high rainfall and rapid discharge response to storms characteristic of Pacific Northwest streams rapidly leach minerals from watersheds. Consequently, streams in the region generally contain low concentrations of limiting plant nutrients, particularly nitrogen and phosphorus (Gregory et al. 1987). These low nutrient levels, combined with low light levels beneath dense riparian canopies, limit primary production within streams. In areas with significant anadromous fish runs, low nutrient inputs from catchments are partially offset by the input of nitrogen and phosphorus from spawning fish (Minikawa and Gara 1999, Rice and Bailey 1980). Within the upper reaches, however, anadromous nutrient inputs are indirect and small, and autochthonous production is probably limited by nitrogen or phosphorus availability.

Logging can increase primary production by reducing light limitation, and by temporarily increasing nutrient inputs from decomposing logging debris. Once the flush of postharvest nutrients moves through the system, however, concentrations return to preharvest levels in the absence of other factors. Where regrowth of nitrogen-fixing species such as red alder occurs, nitrogen inputs to streams may be elevated for decades after harvest. Red alder stands show significantly increased soil nitrogen stocks from a few years after harvest until the stand senesces and is replaced by conifers (Luken and Fonda 1983). Groundwater and hyporheic flows move alder-derived nitrogen into adjacent streams and can dramatically increase nutrient stocks and algal standing stocks in streams with sufficient light levels (Fevold 1998).

Little research has been done to quantify the impact of red alder on riparian nitrogen levels and stream production, or to assess how its significance varies with location and stream type. The net effect of red alder on stream nutrient stocks presumably depends on its location (riparian versus upland), soil characteristics, channel morphology, and hydrologic response.

Effect of Red Alder on Forest Growth

The Wind River site also has been used to study the effect of mixed alder-conifer stands on stand growth and yield (Binkley and Greene 1983), mensuration (Miller and Murray 1978, Tarrant 1961), soil chemistry (Tarrant and Miller 1963), Douglas-fir nutrition (Reid 1983, Tarrant 1961), economics (Atkinson et al. 1979, Cole et al. 1978), and biogeochemistry (Binkley and Sollins 1990, Binkley et al. 1992). Researchers also investigated the effect of distance on the influence of red alder's nitrogen fixation. Miller et al. (1993) found that some positive influence of nitrogen-fixing red alder extended about 15 m beyond the edge of a mixed alder-conifer stand, indicating that the influence of alder may extend beyond immediately adjacent trees. These results may have implications for areas where red alder is mixed in stands through skid roads, along streams, or irregularly distributed across the landscape.

Research at a mixed alder-conifer stand at Cascade Head in coastal Oregon has yielded different results in productivity. The Cascade Head stand is much more productive than the Wind River stand. 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 nitrogen-deficient soils, where the rate of nitrogen supply limits forest productivity, the addition of alders to conifer stands increased productivity, nitrogen levels, and nitrogen availability without decreasing soil pH. On fertile sites where growth was less limited by nitrogen availability of nitrogen also increased, but with no corresponding increase in productivity (Binkley et al. 1992).

Effect of Red Alder on Stand Structure and Understory

The mixed alder-conifer site at Cascade Head also has been used to investigate effects of alder on stand structure and understory vegetation (Franklin and Pechanec 1968, Pechanec and Franklin 1968), tree growth (Berntsen 1961a), nutrient cycling (Binkley et al. 1992, Bollen et al. 1967, Tarrant et al. 1968) and mensuration (Miller and Murray 1978). 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. Ground-dwelling cryptogams were more common and better developed in the mixed alder-conifer and pure conifer stands. Some suppressed Sitka spruce saplings were present in the mixed and pure alder stands, but new conifer seedlings were found only in the pure conifer stand.

Several studies suggest that red alder can inhibit Douglas-fir growth. 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 remains 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 at open-grown rates while being suppressed. Newton et al. (1968) 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. The researchers suggested that to attain full stocking of Douglas-fir, the stocking and distribution of red alder would need to be controlled either by thinning or by using herbicides to kill the alder. They recommended a stocking of 20 to 40 red alder trees per acre (50 to 100 per ha), uniformly distributed throughout the stand.

Impacts of Clearcutting Coniferous Forests

Clearcut logging has negative consequences for wildlife habitat in southeastern Alaska (Hanley 1993, Samon et al. 1989; Schoen et al. 1981, 1988; Wallmo and Schoen 1980). The principal problem is that dense conifer regeneration and canopy closure result in a depauperate understory from about 25 to 150 years stand age (Alaback 1982, 1984a, 1984b). Silvicultural thinning of regenerating stands promotes tree growth but has insignificant effects on understory, with widely spaced thinnings resulting in a second layer of western hemlock regeneration (Deal and Farr 1994). Even-aged stands with depauperate understories have become common since the widespread use of high-lead clearcut logging, where logs are transported through the air and soil disturbance is minimized. Earlier clearcut logging techniques involved considerable soil disturbance and resulted in more red alder establishment and dominance on logged sites (Ruth and Harris 1979). Until recently, those sites were largely ignored in analyses of secondary succession in southeastern Alaska. Alaback (1982, 1984a, 1984b) deliberately excluded red alder patches from his chronosequence studies because modern logging methods minimize the presence of red alder.

Mixed red alder-conifer even-aged stands do not appear to have the same consequences for wildlife as pure conifer even-aged stands in southeastern Alaska. Understory of red alder-dominated, even-aged second-growth stands appears to be quite different from that of pure conifer stands. Hanley and Hoel (1996) found no significant differences in total understory biomass between 40-year-old red alder riparian forests and old-growth upland and old-growth riparian forests. Deal (1997) found total understory canopy coverage in even-aged, red alder-conifer stands more than six times that of a nearby even-aged, spruce-hemlock stand. Hanley and Barnard (1998) studied within-stand variation in understory species composition and biomass in 16 even-aged stands of mixed red alder-Sitka spruce-western hemlock. The sites were upland stands 28 to 39 years old. Understory biomass averaged 175.4 ± 54.6 kg/ha ("mixed" microsites) to 570.0 ± 111.0 kg/ha ("alder" microsites) and was comparable to old-growth forest in species richness. Forbs and ferns were more abundant under alder overstories than under conifer overstories. A calculation of food value of the understory for black-tailed deer illustrates the ecological significance of these differences: 202 deer-days per ha in the "alder" microsites, 73 deer-days per ha in the "mixed" alder-conifer microsites, and 45 deer-days per ha in the "conifer" micro-sites. Hanley (1996) earlier found no significant differences in the abundance and growth rates of deermice (*Peromyscus keeni*), long-tailed voles (*Microtus longicaudus littoralis*), and common shrews (*Sorex cinereus streatori)* in mixed red alder-conifer even-aged stands compared with nearby old-growth stands. Similar results have been reported for small mammals, amphibians, and birds in the Pacific Northwest (McComb 1994, McComb et al. 1993).

Although red alder-dominated and mixed alder-conifer stands in the Pacific Northwest have been studied from a timber perspective (e.g., Hibbs et al. 1994), few studies of the biomass or successional dynamics of their understories have been conducted (Carlton 1990, Henderson 1970, Newton and Cole 1994). Whereas salmonberry dominates the shrub layer in much of the Pacific Northwest, devil's club is the dominant understory shrub in southeast Alaska and creates different understory conditions (Deal 1997, Hanley and Barnard 1998, Hanley and Hoel 1996, Newton and Cole 1994). The abundance of herbs in Alaska understories appears to be a major difference from the Pacific Northwest. More information is needed about ecological interactions between red alder, site factors (including disturbance), and understory vegetation before we can understand cause-and-effect or design optimal silvicultural applications.

Lifespan of Red Alder

Red alder is relatively short-lived compared to its associated trees species. Worthington et al. (1962) give the maximum age for red alder at about 100 years. Smith (1968) reports 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 and other disease symptoms as early as 40 years of age. On less productive sites, disease symptoms and mortality occurred at stand age 60 to 70, with few red alder stands remaining intact beyond 100 years. In Oregon, Washington, 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).

Red alder has rapid early height growth in the Northwest (DeBell and Giordano 1994; DeBell and Wilson 1978; Hoyer et al. 1978; Smith 1968, 1978; Smith and DeBell 1974), an ecological strategy common in pioneering plants of disturbed sites. With few resources allocated for defense, red alder is attacked by a number of biotic agents. Newton (in Hoyer et al. 1978) suggests that pure alder stands show little stratification, that alder needs continual dominance, and that tree mortality occurs soon after a tree drops to codominant status. Red alder is replaced by longer lived, more tolerant conifers that sustain growth rates longer. The time required for this transition has not been well documented (Harrington et al. 1994). It is unclear whether the senescence and mortality of red alder that occurs as young-growth forests develop in Alaska results from pathogenic factors or from red alder’s inability to maintain rapid height growth in competition with conifers.

Pathogens

Many pathogens occur on red alder in the Pacific Northwest and Alaska, but the extent to which they cause tree mortality is unknown (Driver 1978). Much of the literature provides lists of fungi on red alder. Funk (1981) lists 12 fungi that are pathogens or weak pathogens on red alder in British Columbia. The ecology of these diseases is not addressed, but Funk’s book gives microscopic characteristics that are helpful in identifying fungi. Hepting (1971) provides a general review of the pathology of red alder. Many fungi attack the leaves of red alder, but none are considered serious diseases. *Taphrina japonica* Kusano causes a noticeable leaf blister and curl in some areas (Mix 1949). *Microsphaera alni* (Wallr.:Fr.) G. Wint. is abundant on alder leaves, but it attacks late in the season just before leaves senesce and fall anyway (Reed 1913). Alder catkins are attacked and distorted by two fungi, *Taphrina occidentalis* W.W. Ray and *T. alni* (Berk. and Boome) Gjaerum (Mix 1949).

In a review of the diseases of red alder, Harrington et al. (1994) suggest that several stem canker pathogens may cause tree damage. The canker fungus *Didymosphaeria oregonensis* Good. is particularly abundant on red alder, causing infection bands of rough bark on living stems (Boyce 1961, Funk 1981). We have observed this disease in abundance on red alder in young-growth stands in southeast Alaska. Physiological damage may be negligible, as the fungus infects periderm, leaving the phloem relatively unaffected. Species of the Ascomycete *Nectria* have been reported on red alder; *N. galligena* Bres. can form target-shaped cankers where phloem and cambial tissues are killed (Ashcroft 1934, Brandt 1964). The decay fungus *Hymenochaete agglutinans* Ellis is also listed as a canker-causing pathogen (Harrington et al. 1994).

Both pathogenic and saprophytic species of the root fungus *Armillaria* occur on red alder. Rhizomorphs of *Armillaria* species are frequently observed under the bark of recently killed red alder in southeast Alaska. Management activities can elevate levels of *Armillaria* species. Centuries of coppice management in old, mixed-species forests in England likely favors the development of several pathogenic *Armillaria* species on European alder (*Alnus glutinosa (L.*) Gaertner (Rishbeth 1991). Although intentional coppice is not practiced in Alaska, repeated short rotations of red alder or natural events such as landslides that remove cover could increase *Armillaria* populations, as was found in England. *Phytophthora cambivora* (Petri) Buisman attacks the root collar of *Alnus glutinosa* in Germany (Hartmann 1995), but it is not known on red alder. The possibility of planting red alder as a form of crop rotation to mitigate the serious root pathogen *Phellinus weirii* (Murrill) Gilbertson of Douglas-fir in the Pacific Northwest has spurred research on red alder and its influence on the rhizosphere (Hansen 1975, Li et al. 1968, Neal et al. 1968, Nelson 1975, Wallis 1968). The root disease form of *Phellinus weirii* does not occur in Alaska, however, and this form of disease management is unnecessary. Sieber (1990) studied commensal fungi in living red alder leaves and twigs to evaluate potential candidate mycoherbicides. *Gnomonia setacea* (Pers.:Fr.) Ces. & DeNot*, Gnomoniella tubaeformis* Groves, and *Phomopsis* sp. were the most common fungi isolated from leaves; *Winterella* (*Ophiovalsa) suffusa* (Fr.:Fr.) Kuntze and *Phomopsis* sp. were the most common from twigs.

The most important disease agents of Sitka spruce and western hemlock have received more study than alder disease agents in Alaska forests. Tree pathogens can be found at all stand ages, or stages of stand development (Oliver and Larson 1990), but disease generally is ecologically and economically important in older stands (Hennon 2000, Hennon and McClellan 1999). Tait et al. (1985) recorded a number of insects and pathogens on young-growth western hemlock and Sitka spruce, but all were considered minor in importance, and none initiated tree mortality. Porcupines (*Erethizon dorsatum*) are the exception, as they kill dominant conifer trees in young-growth stands (Eglitis and Hennon 1997).

Heart rot and hemlock dwarf mistletoe (*Arceuthobium tsugense (*Rosendhal) G.N. Jones) (the latter is mainly restricted to western hemlock) are important diseases of trees in stands 150 years or older. Dwarf mistletoe is largely absent or is eventually eliminated through stand development in young-growth stands after clearcutting. Heart rot can occur earlier in young-growth stands if tree wounding by animals or logging activities is common (Hennon and DeMars 1997). Heart rot causes devastating timber losses (Buckland et al. 1949; Farr et al. 1976; Kimmey 1956, 1964; Weir and Huber 1918) and is a common agent in small-scale disturbance (Hennon 1995) in old-growth forests of southeast Alaska.

Mode of Death

Hennon (1995) argues that the mode of tree death (i.e., uprooting, broken bole, standing) should be considered in studies of tree mortality because of the ecosystem processes it influences. It may be more important ecologically to determine how a tree dies than what kills it. Several studies have classified the type of tree death in old-growth forests (Hennon and McClellan 1999, Hocker 1990, Nowacki and Kramer 1998, Ott 1997). Quantifying types of tree death has not been attempted in young-growth forests with red alder, except that Steinblum et al. (1984) and Keim et al. (2000) note more uprooting of alder along streams than in forests away from streams in Oregon. Red alder is more windfirm than Sitka spruce where they are both planted in England (Gordon and Hall 1978). Windthrow may be uncommon in red alder because of the intermingling of roots and branches, the absence of leaves during winter storm when soils can be waterlogged, and the relatively deep-rooting habit of the species on well-drained soils (Harrington et al. 1994). Most red alder tree mortality is assumed to result in dead standing trees unless landslides or bank erosion near streams occurs.

In young-growth stands, high tree density may lead to mortality for alder. Mortality related to tree density in red alder occurs when densities exceed 45 to 50 percent of that required for crown closure (Hibbs and Carlton 1989, Puettmann et al. 1992). DeBell and Giordano (1994) observed that most red alder trees die by suppression in winter or spring after other trees have leafed out; presumably energy supplies are finally exhausted. In pure stands in British Columbia, DeBell (1975) and Smith (1968) found that alder density declines from about 120,000 stems per acre at age 1 to 2 years to 14,000 stems per acre at age 8 to 11 years. Puettmann (1994) lists a number of studies on tree densities in red alder forests. Hibbs (1987) and Hibbs and Carlton (1989) describe thinning to certain densities relative to crown closure to exercise some control over this natural mortality.

Decay

Every important tree species in North America is invaded and decayed by one or more species of heart-rot fungi (Gilbertson and Ryvarden 1986). More species of fungi, the most important of which are Basidiomycetes, attack and deteriorate the wood of dead trees than live trees. Wood decay by fungi occurs when enzymes degrade the major constituents of wood—cellulose and lignin. There are two pathways for the many species of wood decay fungi (Boyce 1961, Hartig 1874): “brown rot fungi” degrade only cellulose, and “white rot fungi” degrade both cellulose and lignin (Blanchette 1980, Cowling 1961). Both result in greatly reduced strength of wood, but they generate different woody debris structures and thus have different ecosystem functions (Hennon 2000). Brown rot leaves a residue, partially modified lignin, in which the strength and much biomass of wood has been lost, but the volume is largely left intact (Forest Products Laboratory 1958). The residue from brown rot can contribute a large annual biomass to the soil and provide a zone of high microbial activity (Harvey et al. 1976). White rot can consume all the wood, leaving trees or logs with hollows. Otjen and Blanchette (1986) further classify types of white rot based on different micromorphological patterns of decay.

Decomposition of live and dead trees can be different. Decay of living trees in southeast Alaska is primarily by white rot fungi for western hemlock and by brown rot fungi for Sitka spruce (Kimmey 1956). *Fomitopsis pinicola* (Sw.:Fr.) P. Karst., a fungus that causes a brown cubical rot, appears to be the dominant decomposer of dead hemlock and spruce trees in old-growth forests (Hennon 2000, Hennon and Loopstra 1991). Edmonds (1999) reports that decay of young-growth conifers in western Washington was mainly by white rot.

Fungi

Various fungi attack the wood of alder (Hepting 1971). Farr et al. (1989) published the most exhaustive list of fungi on the genus *Alnus*. Most of the several hundred taxa listed are found on leaves, twigs, or wood of live or dead trees. Volk et al. (1994, see page 35) report 33 fungal species on *Alnus* in a survey of wood-inhabiting fungi in Alaska. Volk et al. (1994) also provide separate lists of fungi found on the wood of Sitka spruce and western hemlock. Most of the fungi that inhabit alder are found on dead trees. Harrington et al. (1994) list the most important heart rot fungi to red alder in British Columbia: *Heterobasidion annosum* (Fr.:Fr.) Bref., *Sistotrema brinkmannii* (Bres.) J. Eriksson, *Pholiota adipsoa* (Fr.: Fr.) P. Kumm., *Trametes* sp., and *Meruliopsis corium* (Fr.:Fr.) Ginns. The most important wood-decay fungus of live red alder is probably *Phellinus igniarius* (L.:Fr.) Quel. (Driver 1978, Worthington 1957), which causes a white rot. Interestingly, we do not see *P. igniarius* in red alder in southeast Alaska and neither did Allen[2] in British Columbia.

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[2] Allen, E.A. 1992. Unpublished data. On file with: Pacific Forestry Centre, 506 West Burnside Road, Victoria, BC V8Z 1M5.

Allen found that the number of living red alder trees with heart rot on Vancouver Island increased with age (to 94 percent for trees >75 years), but decay volumes were not correlated with tree age. For trees 60 to 80 years old, volume losses to decay were only about 3.5 percent. Allen indicates that most of the decay in red alder is associated with wounds such as scars, forks, and broken tops. The upward-growing, sprawling habit of red alder branches and its relatively weak wood probably contribute to broken branches and tops. Decay is limited, however, because red alder is able to compartmentalize the decay to tissues near the wound.

The white rot fungus *Hypoxylon fuscum* (Pers.:Fr.) Fr. (an Ascomycete, not a Basidiomycete) is exceedingly common as a decomposer of dead alder wood (Rogers 1968). Miller (1961) observes that the "fungus is on almost every limb of *Alnus* that has recently died anywhere in the North Temperate Zone." Rogers (1968) presents some evidence, based on the apparent speed of colonization after tissue death, that this fungus may live as a commensal in live alder. It thus would have a competitive advantage over other fungi to quickly and more fully colonize recently killed alder tissue.

Decay Resistance

Wood from different tree species differs in its decay resistance. This variation is due mainly to the deposition of fungitoxic substances in cell walls during their transformation from sapwood to heartwood (Eslyn and Highley 1976). Hardwood trees contain more sugars, starches, proteins, and nutrients in the inner bark and the sapwood than do conifers (Harmon et al. 1986). The decay resistance (sometimes called durability) of Alaska tree species has been tested along with many other tree species to determine how long different woods can be used when in contact with water and or soil. The heartwood from red alder, Sitka spruce, and western hemlock are all rated in the same broad group as "slightly or nonresistant" (Forest Products Laboratory 1987), indicating that they decay rapidly. The sapwood of red alder, Sitka spruce, and western hemlock were tested *in vitro* for resistance against white rot, brown rot, and soft rot organism (Eslyn and Highley 1976). Red alder was susceptible to brown rot and soft rot agents and very susceptible to white rot; western hemlock and Sitka spruce had relatively good resistance to decay except for brown rot fungi, which caused significant decay. In another test, the sapwood of different species was placed outdoors in Mississippi and rated for decay: red alder was classed as "nonresistant," decaying in less than 7 years; Sitka spruce and western hemlock were "moderately resistant," lasting 8 to 13 years (Eslyn et al. 1985).

Decay of Wood in Streams

Decay of wood in streams is receiving more recent attention from researchers. Saturation with water has been shown to decrease oxygen concentrations in wood to levels low enough to prevent penetration by fungal hyphae (Savory 1954). Bacteria are responsible for most decomposition of saturated wood (Crawford and Sutherland 1979) and operate only on the surface where oxygen concentrations are adequate. Bilby et al. (1999) report lower decay rates in submerged logs of all trees studied (including red alder and western hemlock) than in logs of similar size and species in the terrestrial environment. Cederholm et al. (1997) found that partially submerged red alder logs had significant deterioration in only 3 years in Washington. Micro-organism and insect larvae were responsible for the rapid decomposition of *Alnus glutinosa* twigs in a river in France (Chergui and Pattee 1991). The authors measured a 60-percent weight reduction in 2.5 years and expected full decomposition of the twigs in 4 to 5 years. Alder trees mechanically pulled over into Oregon streams had more wood decay and broke more frequently than did Douglas-fir (Keim et al. 2000). Red alder with attached roots was effective in trapping coarse woody debris, but after 3 years, the alders were losing structural integrity owing to advancing decay and breakage. Anderson et al. (1978) report on several aquatic invertebrates that contribute to the degradation of red alder and western hemlock wood in Oregon streams. They found that the activity of most invertebrates does not involve deep boring or penetration into the wood, and the wood supported a smaller biomass of invertebrates than did leaf litter.

Role of Riparian Forests in Stream Processes

Riparian zones play a major role in regulating nutrient and energy flow in low-order streams (Cummins et al. 1989, Wallace et al. 1997, Webster and Benfield 1986, Webster et al. 1992). Leaf litter and wood from riparian vegetation enters the lotic system and affects microbial and benthic macroinvertebrate communities that consume and process this organic material (Anderson et al. 1978, Bisson and Bilby 1998, Cummins et al. 1989, Hax and Golladay 1993, Sedell et al. 1975, Vannote et al. 1980). This allochthonous (plant and invertebrate) material typically constitutes the energy base in low-order forested streams (Fisher and Likens 1973, Minshall 1967, Triska and Sedell 1976).

Riparian and stream productivity are essential for sustaining salmonid fisheries in southeast Alaska. These fisheries are critical to the economy and quality of life of peoples of this region, as well as other regions of the North Pacific Rim. To maintain a natural flow of sediment, woody debris, and water from headwater channels to the receiving fish channels, the Tongass National Forest has implemented a policy of providing riparian buffers to the class III to IV channels that lack anadromous fish (USDA FS 1997).

Riparian buffer effectiveness in maintaining a natural flow of sediment, woody debris, and water appears to be site specific. A buffer region that includes a natural source of large woody debris (whole trees) and sediment is more likely to be effective than a buffer of the same size that does not encompass a natural source of both large woody debris and sediment. Mechanisms that introduce woody debris and sediment include landslides, blowdown, bank erosion, and flooding (fig. 4).

Effect of Riparian Trees on Terrestrial Invertebrates in Stream Food Webs

Although it is understood that stream ecosystems are closely linked to and dependent on associated riparian zones for organic matter and nutrient inputs, little attention has focused on the relation between riparian vegetation and terrestrial invertebrate communities. Also not well understood is the influence of riparian vegetation on the way terrestrial invertebrates enter streams (e.g., as prey for fishes, or as allochthonous material contributing nutrients and organic matter). Some riparian tree species contribute more terrestrial invertebrate mass to streams than others (Mason and Macdonald 1982). Southwood (1961) reported that deciduous trees generally have more associated invertebrate species than do conifers. Plant community successional stage also influences invertebrate abundance and species assemblage (Mispagel and Rose 1978). Schowalter et al. (1981) reported lower invertebrate mass 1 year after clearcutting but higher mass 2 years after clearcutting, relative to an uncut forest in the Pacific Northwest. Mundie (1974) indicated that aerial insects were more abundant in a deforested than forested setting in coastal British Columbia, Canada, and that terrestrial insects may be seasonally important salmonid food.

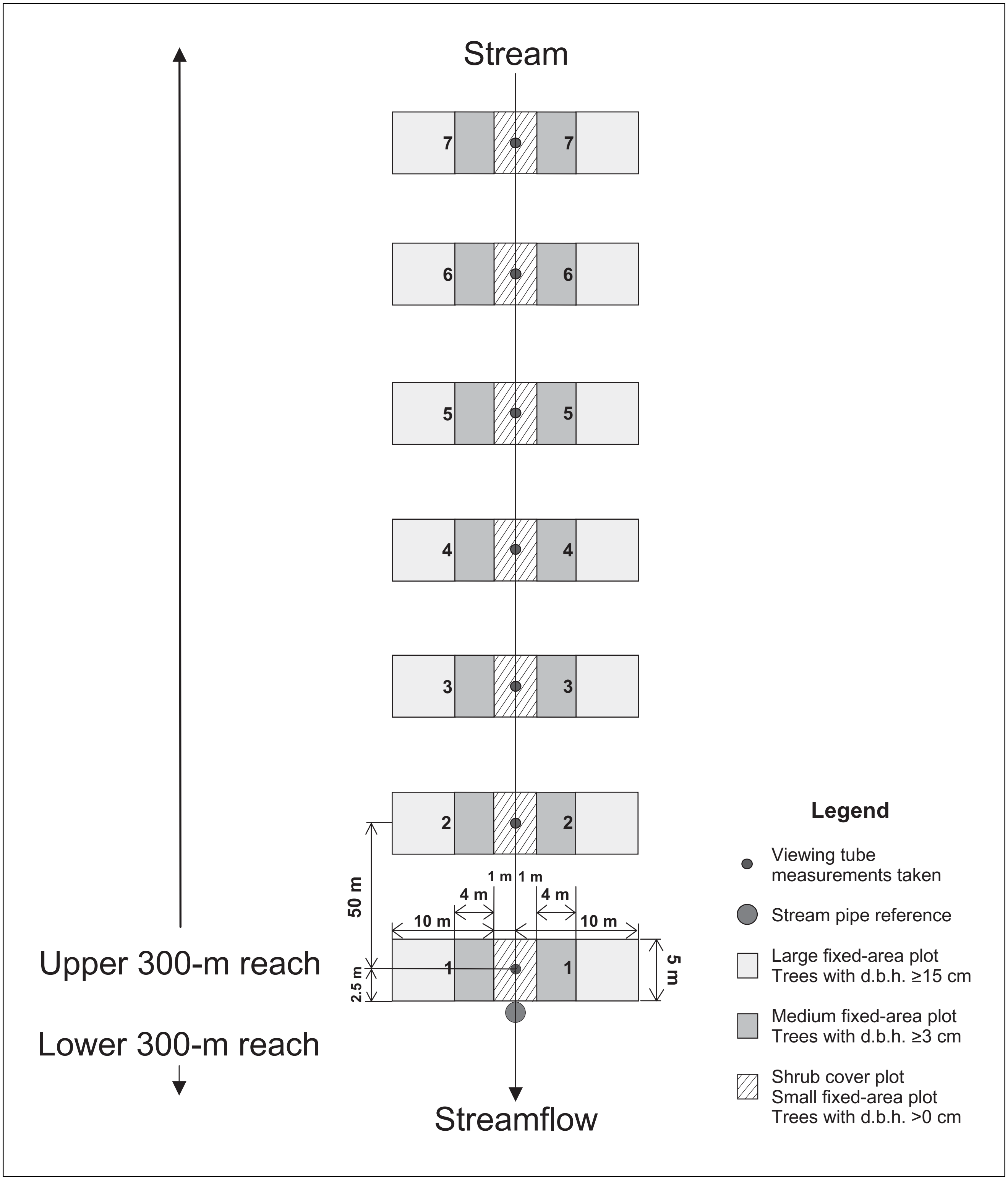

Figure 4—Riparian sampling layout. Lower 300-m reach (not shown) was sampled by using the same design as the upper 300-m reach.

Riparian management activities that alter plant communities may change food resources within and surrounding a stream. Riparian plant communities govern allochthonous inputs (Cummins et al. 1989, Webster and Benfield 1986) and autochthonous production (instream primary production) (Cummins et al. 1989, Fisher and Likens 1973). In southeast Alaska, clearcutting in riparian zones has given rise to even-aged young-growth riparian communities at various successional stages. Alder often regenerates along stream margins along with variable amounts of Sitka spruce, western hemlock, western redcedar, Alaska yellow cedar *Chamaecyparis nootkatensis* (D. Don) Spach), black cottonwood, and willow. Little is known about the influence of these developing riparian communities on upland stream productivity and downstream fishes. Alder could have a variety of impacts on streams, such as changes in solar penetration and allochthonous inputs. These effects could lead to changes in autochthonous production (Cummins et al. 1989; Fisher and Likens 1973; Hetrick et al. 1998a, 1998b) and quality and quantity of plant litter inputs (Cummins et al. 1989, Webster and Benfield 1986) and terrestrial invertebrate inputs (Wipfli 1997). These factors could all impact the amount of food in downstream fish-bearing reaches.

Impacts of Changes in Riparian Forest Canopy

Changes in forest canopy may have both positive and negative impacts on aquatic communities. On the positive side, riparian forests with some alder have been shown to produce more prey for salmon than have conifer forests (Wipfli 1997). However, this benefit may be outweighed by a decrease in large woody debris input (Andrus et al. 1988, Grette 1985, McDade et al. 1990), decrease in wood longevity (Anderson et al. 1978, Benda and Cundy 1990, Keim et al. 2000), and increases in sediment loading (Megahan 1982); factors resulting in loss of fish habitat in systems dominated by alder (Bilby and Ward 1991, Hicks 1989, Ralph et al. 1994). An understanding of changes associated with forest alteration may be obtained by estimating processes associated with natural woody debris loading (Potts and Anderson 1990) (or defined as woody debris budgets (Benda and Sias 1998)). In addition, an understanding of the locations where alder occurs both naturally and as a result of management may give insight into the morphological, functional, and community-level changes that occur in streams as succession from alder to conifer occurs. With this knowledge, it may be possible to link upslope processes and associated aquatic habitats (i.e., pools) (Andrus et al. 1988, Bilby and Bisson 1998).

Of particular interest to land managers are questions concerning the upper limit of fish habitat, conditions that regulate the use of the upper sections of watersheds, and the impacts of upslope forest management. The intensity of interactions between upslope processes and fish populations is likely related to proximity. Salmonid populations occupying habitats at or near the upper limit of habitat (“transition zones”) (fig. 4) are more likely to be affected by upslope forest processes. Transition zones generally occur in reaches with gradients between 5 and 20 percent, tend to be sparsely populated, and may be occupied only seasonally in southeast Alaska (Bryant 1983). Fish in these zones are closely linked to—and are likely part of—downstream populations.

Bird Abundance Associated with Red Alder

Bird abundance has been found to be low in young-growth stands of dense conifer (Schwab 1979 as cited by Easton and Martin 1998). A positive association between bird abundance and the density of live deciduous trees has been found in young-growth forests (reviewed by Huff and Raley 1991, McComb 1994, Ruggiero et al. 1991) and regenerating clearcuts (Morrison 1981, Santillo et al. 1989). The role of deciduous trees, however, is not understood, and little is known about the interactions between alder and birds in the Pacific Northwest (reviewed by McComb 1994), particularly in southeast Alaska.

The importance of alder to southeast Alaska birds has not been well studied (Gende and Willson 2001), but it is generally thought to be of value (Sidle 1985). Alder may provide advantages in term of food and nesting sites. Some aerial insectivores (e.g., flycatchers) have shown direct relations with alder, with increased numbers of individuals in alder stands (Gilbert and Allwine 1991). Because insects from foliage can be a primary food source for insectivorous birds (Airola 1979, Holmes 1990) and insect biomass is greater in deciduous vegetation (Stiles 1980, Willson and Comet 1996), it follows that birds in southeast Alaska may forage for insects in alder trees.

Alder within second-growth stands may improve the quality of nesting habitat for some bird species. Dense conifer young-growth stands typically lack a well-developed understory. Consequently, the number of nest sites for birds may be limited, and nest concealment, which is associated with successful nesting for some open-cup nesting species (reviewed by Kelly 1993, Martin 1993; but see D'Eon 1997), may be lower in conifer stands. Furthermore, some nest predators (e.g., red squirrels (*Tamiasciurus hudsonicus*)) have been found to be more abundant in coniferous forests.[3] Birds nesting in mixed alder-conifer stands may have more nest sites to choose from, safer nest sites to choose from, and a reduced chance of encountering some types of nest predators.

Coniferous trees in southeast Alaska typically have low numbers of leaf-chewing arthropods (Mask 1992). Red alder and, to a lesser extent, Sitka alder (*Alnus sinuata* (Regel) Rydb.) probably provide a critical source of protein throughout the summer. Little is known about the life cycle of insects on alder foliage in southeast Alaska.

Commercial Value of Red Alder

The wood of red alder is pale reddish brown, moderately dense and uniformly textured, with an attractive grain well suited for cabinet work. It is used in the production of wood products such as furniture, cabinets, and pallets (Resch 1980), composite products such as plywood and flakeboard (Bollen et al. 1967), and fiber-based products such as tissues and writing paper. Alder is a common fuelwood both for home use and for commercial drying (Briggs et al. 1978, Resch 1980). In Alaska, red alder is used for smoking fish and carving but otherwise is not used commercially.

Although the commercial value of red alder has traditionally been lower than that of associated conifers, red alder is the major hardwood tree species in the Pacific Northwest, and its value has increased substantially in recent years. In 1991, the harvest of red alder in the Pacific Northwest Region was over 480 million board feet (Western Hardwood Association 1992), and Gedney (1990) reported a supply of over 9 billion board feet of red alder sawtimber in western Oregon. Alder exports to Asia and Europe grew to over 65 million board feet in 1992, and in 1991 alder accounted for 10 percent of volume of all U.S. hardwood lumber exports to Europe and Asia (Tarrant et al. 1994). The scarcity of young red alder is now a concern to a wood products industry that continues to grow (Hibbs et al. 1994).

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[3] De Santo, T.L. 2000. Unpublished data. On file with: Forestry Sciences Laboratory, 2770 Sherwood Lane, Suite 2A, Juneau, AK 99801.

Perceptions of Red Alder

Traditionally, many forest managers have tried to eliminate alder from forest stands. The value and use of alder has increased (Plank and Willits 1994, Plank et al. 1990, Waggener 1978), and recent research has shown that alder log values compare favorably with those of Douglas-fir on a net scale basis (Plank et al. 1990). Economic comparisons between alder and Douglas-fir show alder to be a viable alternative to softwoods (Tarrant et al. 1983). The market performance of red alder is strong (Western Hardwood Association 1992), and alder prices have increased steadily since 1980. Interest in managing red alder is high, and research on red alder over the past 50 years is providing information on its potential uses. Red alder research is being strengthened through the work of the Hardwood Research Cooperative and with previous and current research at the Forest Service Pacific Northwest Research Station (DeBell et al. 1978; Harrington 1984, 1986, 1990; Harrington and Curtis 1986; Harrington and DeBell 1984; Trappe et al. 1968; Worthington et al. 1960).

Importance of Upland Forests and Associated Red Alder for Aquatic Habitats

Because total area of upland forests and associated headwaters comprises 70 to 80 percent of watersheds, they are potentially important sources of sediment, water, nutrients, and organic matter for downstream habitats. Transport of organic and inorganic material from upland forest and headwater streams may affect physical and biological processes in downstream reaches. For instance, sediment produced in headwater systems moves through channel networks and alters channel morphology (Benda and Dunne 1997). Sediment transported from headwater tributaries creates various channel environments and modifies patterns of riparian structure and hyporheic exchange in downstream reaches (Gregory et al. 1991, Swanson et al. 1998). Movement of detrital material and invertebrates from headwaters to downstream food webs may alter productivity, population density, and community structure of stream biota in downstream reaches (Wipfli and Gregovich 2002). The occurrence of red alder in these uplands, including in riparian zones of headwater streams, may have a substantial influence on the physical and biological processes operating in these systems. Because red alder decays faster than conifers and is a more desirable food source for invertebrates, it likely affects the sediment, detritus, and invertebrates exported from headwaters to downstream habitats.

Objectives and Hypotheses

There are three main themes of this research: (1) influence of alder on specific ecosystem components, i.e., on vegetation, birds, invertebrates, wood, and fishes (fig. 1); (2) flow of wood from riparian forests to adjacent streams, and from upland to lowland habitats (fig. 2); and (3) influence of alder on ecosystem links and processes (fig. 3). In southeast Alaska, red alder may increase the abundance and diversity of understory plants, in turn influencing aquatic and terrestrial invertebrate communities and the bird and fish communities that feed on these prey (figs. 2 and 3). Alder also may decay more quickly than conifers, affecting the residence time of wood in terrestrial and aquatic habitats, and its movement and distribution in streams (fig. 2).

Study sites will represent a continuum of alder-conifer mixtures. To reduce the range of site variability, we will select study areas in the Maybeso and Harris watersheds on Prince of Wales Island, Alaska, using composition of tree species as a primary site selection criterion. These watersheds have large areas of relatively uniform stand age and productivity, and a wide range of alder-conifer mixtures. Sites will be selected and sampled during the 2000 and 2001 field seasons. The objectives for each component of the study require specific selection criteria, but we will seek to maximize sites that can be used for all resources, including timber, wildlife, and fish. See table 1 for a complete listing of sites.

Table 1—Common study sites, site description, drainage, and components studied at each site in Maybeso and Harris watersheds, Prince of Wales Island, Alaska

Study site	Preliminary assessment of red alder abundance	Components studied									
		Drainage	Geomorphology	Stream nitrogen	Woody debris	Riparian vegetation	Upland vegetation	Aquatic ecology	Fish	Birds	Terrestrial arthropods
Alluvial Fan	High	Maybeso	X	X			X			X	X
Big Spruce	Medium	Maybeso	X	X	X	X	X	X	X	X	X
Broken Bridge East	High	Maybeso	X	X	X	X		X			
Broken Bridge West	Medium	Maybeso	X	X	X	X		X			
Brushy	High	Maybeso	X		X	X	X	X	X		
Cedar 1	Low	Maybeso	X	X	X	X	X	X	X	X	
Cedar 2	Low	Maybeso	X	X	X	X	X	X	X		
Cotton	Medium	Maybeso	X	X	X	X		X	X		
Cotton Tributary	High	Maybeso	X	X	X						
Creature Creek	Low	Maybeso	X	X	X	X		X	X		
Gomi	Medium	Maybeso	X	X	X	X		X	X		
Lost Bob	Low	Maybeso			X	X		X	X		
Lower Broken Bridge	High	Maybeso			X				X		
Lower Good Example	Low	Maybeso	X		X		X		X		
Lower Morning	Medium	Maybeso	X				X		X		
Upper Good Example	Low	Maybeso	X	X	X	X	X	X		X	X
Upper Morning	Low	Maybeso	X	X	X	X		X		X	
Group Photo	Medium	Harris	X				X			X	X
Mile 22	High	Harris	X	X	X	X	X	X	X	X	X

To assess the effect of alder in young-growth forests, and to evaluate the potential tradeoffs in alder-dominated and conifer-dominated forests, we will investigate interactions in six areas: wood production, vegetation, and tree disease; terrestrial invertebrate ecology; wildlife ecology; aquatic and riparian ecology; fish ecology; and geomorphic processes. Objectives and hypotheses are summarized by discipline on the following pages. See appendices for detailed description of methods.

Stand density, vegetation, and tree mortality (app. 1)—

Objective 1: Compare total stand density across a range of alder-conifer mixtures.

Hypothesis: Mixed alder-conifer young-growth stands have lower total stand basal area and tree stocking than do pure conifer stands, and both stand density and tree stocking decline with increasing proportion of alder in stand.

Rationale: Stand growth and wood production are maintained much longer for conifers than for alders, and at the stand age of this study (40 to 50 years), it is expected that spruce and hemlock wood production will be greater than for red alder. In nitrogen-limited sites in the Pacific Northwest (Miller and Murray 1978, Tarrant 1961), however, mixed alder-conifer stands accumulated more wood than did pure conifer stands. In contrast, more productive sites generally show less wood production, biomass, and net primary productivity (Binkley et al. 1992) in red alder compared with pure conifer stands. Little is known about the productivity of alder in Alaska, but if highly productive conifer sites in southeast Alaska follow patterns in the Pacific Northwest, then growth and wood production of mixed alder-conifer stands should be less than in pure conifer stands.

Objective 2: Compare understory plant diversity and biomass in stands across a range of alder-conifer mixtures.

Hypothesis: Mixed alder-conifer young-growth stands have greater understory plant diversity and biomass than do pure conifer young-growth stands.

Rationale: Dense conifer regeneration and canopy closure in stands 25 to 150 years old result in greatly reduced understory plant diversity and abundance (Alaback 1982, 1984b). Red alder stands, however, appear to have significantly greater understory biomass (Hanley and Hoel 1996) and greater canopy coverage (Deal 1997) than do conifer stands. It is expected that increasing proportions of alder in these mixed alder-conifer stands will provide greater understory plant diversity and abundance.

Objective 3: Compare stand growth and regeneration in stands across a range of alder-conifer mixtures.

Hypothesis: Pure conifer young-growth stands have more tree regeneration than do mixed alder-conifer stands, and regeneration decreases with increasing proportions of alder in stands. Tree diameter growth is greater for overstory conifers (dominant and codominant trees) in mixed alder-conifer young-growth stands than in pure conifer stands, and tree diameter growth increases with increasing proportions of alder in stand.

Rationale: Stands 40 to 50 years old are in the stem-exclusion stage of stand development in southeast Alaska (Alaback 1982, Deal et al. 1991), and new tree regeneration will be limited. Red alder generally colonizes heavily disturbed sites with exposed mineral soil. Conifers regenerate on logs and organic material (Harmon and Franklin 1989, Yount 1997), and the lack of rooting medium in alder stands is expected to reduce tree regeneration. Red alder stands are less dense and provide more growing space for trees than do unthinned natural conifer stands. It is expected that dominant conifers in mixed alder-conifer stands will show increases in diameter growth compared with pure conifer stands.

Objective 4: Compare frequency and type of tree mortality (mode of tree death) in stands across a range of alder-conifer mixtures.

Hypothesis: The greatest frequency of tree mortality occurs in trees of the smallest size class. More trees die standing than by bole breakage or uprooting. The amount of white and brown rot wood decay produced in these stands differs by species of dead tree.

Rationale: Most woody debris that reaches the forest floor or streams is the result of tree mortality. This pattern of tree mortality differs from that of old-growth forests wherein some dominant trees die and produce various structures (e.g., hollow logs from broken boles or attached root systems from uprooted trees). The pathway of wood decomposition (brown rot or white rot) also may influence physical and biological functions.

Objective 5: Compare total stand density, tree diameter distribution, and size-specific tree mortality across a range of riparian alder-conifer mixtures.

Hypothesis: Young-growth riparian stands with a greater alder component will have lower total stand density and tree mortality than will stands with less alder.

Rationale: A greater alder composition in young-growth riparian stands will result in widely spaced stands and less competition for light. This decreased density will result in lower mortality among trees, and most dead trees will be small in diameter. Conifers will have larger diameter than in upland stands owing to light-enhanced diameter growth, and will create a good source of large woody debris for habitat improvement of adjacent streams.

Objective 6: Compare the spatial distribution and stocking of alder and conifer trees between upland and riparian stands across a range of alder-conifer mixtures.

Hypothesis: Riparian stands will have less alder, and the alder will be aggregated close to stream margins, whereas alder in upland stands will be more densely stocked and randomly distributed.

Rationale: Frequent surface soil disturbance in riparian areas, owing to hydrological processes such as floods, tends to favor aggregations of alder. Surface soil disturbance in upland areas is expected to be more randomly distributed, associated with events such as landslides or forest blowdown.

Objective 7: Measure size and condition of woody debris entering the forest floor and streams, including type of decay, species of wood, and presence or absence of attached root system.

Hypothesis: The amount of white and brown rot wood decay produced in these stands differs by the abundance and species of dead trees.

Rationale: Wood decay type (i.e., white rot and brown rot) and extent of decay in dead trees will influence abundance of invertebrates in dead stems, wildlife use of dead stems, persistence of dead standing trees, woody debris on the forest floor, and mobility of woody debris in streams.

Terrestrial invertebrate ecology (app. 2)—

Objective 8: Compare terrestrial invertebrate abundance and species richness in foliage, branches, and stems of woody vegetation as well as in leaf litter in stands across a range of alder-conifer mixtures.

Hypothesis: Terrestrial invertebrate abundance and species richness are greater in mixed alder-conifer young-growth stands than in conifer young-growth stands.

Rationale: Invertebrates are larger and more abundant in mixed alder-conifer young-growth stands than in conifer young-growth stands because red alder increases the food value of neighboring plants (Mason et al. 1992).

Wildlife ecology (app. 3)—

Objective 9: Compare bird density and species richness in mixed alder-conifer and conifer stands.

Hypothesis: Bird density and species richness are greater in mixed alder-conifer young-growth stands than in conifer young-growth stands.

Rationale: Young-growth stands dominated by conifers have little understory vegetation. Sparse understory vegetation probably results in reduced nesting and foraging substrate for understory bird species. Alder in young-growth stands may provide resources for foraging and nesting that are unavailable in conifer stands.

Objective 10: Conduct behavioral observations of foraging birds in mixed alder-conifer young-growth stands.

Hypothesis: Insectivorous birds forage on alder more often than on conifer in mixed alder-conifer young-growth stands.

Rationale: Nearly all birds are insectivorous during some stage of their life cycle, and all shrub and forest birds in southeast Alaska feed insects to their young. Insect populations are generally greater in deciduous vegetation. If this holds true in southeast Alaska, and if we find that avian species diversity and abundance are higher in young-growth stands containing alder, then birds may be selecting these areas to take advantage of the insect resources these stands provide. Understory vegetation also provides other types of food resources (primarily berries) for some understory birds (e.g., thrushes (*Turdidae*)) in southeast Alaska.

Objective 11: Compare nesting success in mixed alder-conifer young-growth stands and in conifer-dominated young-growth stands.

Hypothesis: Nest predation is lower in mixed alder-conifer young-growth stands than in conifer-dominated young-growth stands.

Rationale: Young-growth forests without understory vegetation provide little nesting substrate or nest cover. Nest predation is the leading cause of nest failure in southeast Alaska.

Objective 12: Compare summer food value for deer in young-growth stands differing in their proportion of alder component.

Hypothesis: Understory plant species richness, canopy coverage, biomass, and food value for deer increase with increasing proportion of alder in young-growth stands.

Rationale: Dense conifer regeneration and canopy closure in conifer stands 25 to 150 years old results in greatly reduced understory and plant diversity and abundance (Alaback 1982, 1984b). Understory of red alder stands appears to have significantly greater biomass (Hanley and Hoel 1996) and greater canopy coverage (Deal 1997). Food value of understory for deer depends on plant species composition as well as biomass, and the greater abundance of forbs under alder than conifer is expected to benefit food value for deer (Hanley and Barnard 1998).

Aquatic and riparian ecology (app. 4)—

Objective 13: Compare the amount of export of invertebrates and detritus from fishless headwater streams to downstream fish-bearing habitats across a gradient of riparian alder abundance.

Hypothesis: Headwater streams with more alder in their riparian zones will deliver more invertebrates (aquatic and terrestrial) and organic detritus via fluvial transport to downstream habitats than will streams with less alder.

Rationale: Alder is more nutritious than conifers and therefore will support more riparian and aquatic invertebrates, which in turn will get carried downstream to fish habitats via fluvial transport.

Objective 14: Compare invertebrate abundance in and along headwater streams, including on woody debris at various stages of decay, in stands with different alder-conifer mixtures.

Hypothesis: Invertebrate abundance and species richness are greater in young-growth riparian stands and associated headwater streams that contain more alder, and are greater on decaying alder wood than conifer wood.

Rationale: Alder is more nutritious than conifers and therefore will support greater densities and more species of invertebrates.

Objective 15: Compare nutrient concentrations among streams that differ in the amount of upstream red alder and in discharge and disturbance history.

Hypothesis: The concentration of nitrate in stream water is directly proportional to the amount of alder in the catchment and inversely proportional to the discharge rate.

Rationale: Soil nitrogen concentrations in alder-dominated soils are higher than in soils dominated by conifer species. Alder-derived nitrate moves from upland soils to streams via groundwater flows and hyporheic exchange. Where past logging practices have increased the amount of alder in small catchments, stream nutrient concentrations and productivity may vary with alder coverage.

Fish ecology (app. 5)—

Objective 16: Compare salmonid densities in stream reaches below and within conifer-dominated and alder-dominated upslope riparian forests.

Hypothesis: Salmonid densities will be higher in stream reaches below and in conifer-dominated upslope riparian forests than in reaches with alder-dominated upslope riparian forests.

Rationale: High-gradient first- and second-order stream channels in heavily managed sites are prone to landslides and debris flows. As a result of such disturbances, these sites have been colonized and vegetated with alder. Debris flows can affect fish habitat by filling in pools, straightening channels, removing large woody debris, and adding fine sediment to spawning gravel. There will be a higher quantity and quality of habitat to support a higher diversity and density of salmonids in transition reaches not affected by landslides. Therefore, we expect salmonid densities to be higher in upper stream reaches (transition zone) not affected by debris flows (i.e., upslope conifer forest).

Objective 17: Assess seasonal variation and relative species abundance of salmonids in upper high-gradient reaches (transitions zones) (fig. 4).

Hypothesis a: Salmonid densities will be higher in upper high-gradient reaches (transition zones) during spring and fall than during summer.

Rationale a: Upper sections of small tributaries are more likely to be used for spawning by adult fish such as coho salmon (*Oncorhynchus kisutch*) and Dolly Varden char (*Salvelinus malma*) during fall, and by cutthroat trout (*Oncorhynchus clarki clarki*) during spring. Upper sections have smaller drainage area and are more likely to become intermittent during low flows that occur in summer. Upper reaches may be affected by upslope disturbances such as landslides that can scour channels, removing large wood and pool habitat, and can deposit substantial amounts of sediment.

Hypothesis b: The relative abundance of salmonid species will differ between downstream reaches and transition reaches. Downstream abundance will be coho salmon > Dolly Varden char > cutthroat trout. Transition reach abundance will be Dolly Varden char > cutthroat trout > coho salmon.

Rationale b: Steeper gradient results in decreased habitat for juvenile coho salmon. Upstream effects will result in a reduction of large wood and pools in the upper reaches of fish-bearing streams. Downstream deposition of large wood by landslides may result in greater habitat complexity, which is generally favored by juvenile coho salmon.

Objective 18: Assess the relation between the abundance of alder in a riparian forest and stream inputs and processes.

Hypothesis: Large woody debris volume, riffle substrate size, and number of pools will decrease as the ratio of alder to conifer increases.

Rationale: The presence of alder in upslope riparian reaches indicates greater and more recent disturbance activity than is typical in conifer-dominated riparian forests. Disturbance activities in these reaches tend to be landslides and debris flows that remove or bury large woody debris, add fine sediment, and fill in pools.

Geomorphic processes (app. 6)—

Objective 19: Describe geomorphic processes and land use history at study sites selected by Wood Compatibility Initiative colleagues.

Rationale: Dominant disturbance processes are related to landform type and type of forest cover. This analysis will provide (1) an increased understanding of the role of headwater disturbance processes in the formation of aquatic habitats in a watershed context and (2) a means to assess the relevance of habitat changes (both positive and negative) that occur as a result of alteration in land use (conversion from old-growth to second-growth forest with stands of alder and conifer). No hypothesis will be tested for this objective.

Objective 20: Assess processes that deliver sediment and woody debris to streams from alder-dominated and conifer-dominated forests, and compare delivery rates (fig. 4).

Hypothesis: Sediment and woody debris input to headwater channels is higher from alder stands than from conifer stands.

Rationale: Woody debris and sediment are delivered to stream systems through the processes of blowdown, bank erosion, forest mortality, and landsliding. On steep terrain, landsliding is the dominant source of woody debris and sediment (Gomi 2002). Given that the presence of alder often indicates a history of landsliding, we expect more sediment and woody debris delivery in these regions than in conifer-dominated regions.

Objective 21: Estimate differences in sediment storage capacity in headwater streams within conifer-dominated and alder-dominated forests.

Hypothesis: Sediment storage capacity in upland streams (above fish habitat) is greater in forests dominated by conifers than in alder-dominated forests.

Rationale: The presence of alder in steep ecosystems often indicates that landslides have occurred. Landslides typically erode woody debris and sediment from steep regions above fish habitat; thus we expect more woody debris in reaches where there has been no history of landsliding.

Quality Assurance-Quality Control Procedures

Documenting Measurement Error

An essential element of this project's study plan is documenting the types and amount of measurement error. Measurement error can occur in many ways but typically has at least two fundamental components. The first is "observer bias" or error that occurs among individuals, i.e., when more than one individual obtains values for the same variable, such as diameter at breast height (d.b.h.). This occurs because no two individuals will consistently obtain the same values when recording observations. This is especially true for categorical data that entail subjective assessments (e.g., vegetative cover estimated to the nearest 10 percent), but may frequently occur with measurements of continuous variables (e.g., d.b.h.).

A second source of measurement error is inconsistency in measuring the same variables at multiple sites. At least three factors contribute to this inconsistency. The first is natural variation that precludes applying techniques in a similar fashion at all locations. For example, d.b.h. values may be influenced by tree taper, ground slope, microrelief, or many other factors. The second component is related to the resolution at which observations are recorded. Generally, the finer the resolution, the greater the potential for measurement error. For example, it is easier to estimate vegetative cover consistently to the nearest 25 percent than to the nearest 5 percent. Estimating the weight of small birds or mammals to the nearest 0.1 g on a 1-g scale will almost certainly contribute substantial measurement error to the data, whereas accurate estimates to the nearest 0.5 g may be achievable. The third component is the human element: humans cannot repeat a process without some variation in the way the technique is applied.

We will document measurement error by repeat sampling or simultaneous sampling of a given variable. For repeat sampling, the time interval between successive measurements will be relatively short to reduce the influence of natural variation over time on our estimates of measurement error. For both types of documentation, a randomly selected subset of previously sampled units representing 5 to 10 percent of the total sample units will either be revisited (e.g., vegetation plots) or simultaneously sampled by two individuals (e.g., bird surveys). Measurement error will be recorded as the difference between the two measurements of the same variable. In circumstances where there exists potential observer bias, different recorders will visit the same site.

Data Management and Archiving

Standard protocols for data management will ensure long-term integrity and availability of project data. Field observations will be recorded primarily on handheld electronic data recorders with additional information written in field notebooks. The data will be downloaded to floppy disk daily and backed up to minimize the chance of data loss. Upon returning to the office, raw data files will be inspected by the field crew leader, formatted in spreadsheets, and added to the master database by the database manager. A spreadsheet on the database computer tracks the data through these steps. The database is written to a compact disc (CD) monthly, and the raw and formatted data files are archived on a data library CD that is backed up biannually. Backup copies of each CD and handwritten notes are stored in a fireproof cabinet at the Juneau Forestry Sciences Laboratory and at an offsite location. Data will be proofread for errors independently of the data collection and entry process.

Below is the expected timeline for completing the project:

	1999	2000	2001	2002	2003	2004
Study plan	X	X				
Fieldwork		X	X			
Manuscript writing				X	X	
Publishing					X	X

English Equivalents

When you know:	Multiply by:	To find:
Meters (m)	3.28	Feet
Centimeters (cm)	0.39	Inches
Micrometers (µm)	3.9×10^{-5}	Inches
Millimeters (mm)	0.039	Inches
Square meters (m^2)	1.20	Square yards
Cubic meters (m^3)	35.3	Cubic feet
Kilograms (kg)	2.21	Pounds
Grams (g)	0.035	Ounces
Hectares (ha)	2.47	Acres
Kilograms per hectare (kg/ha)	0.89	Pounds per acre
Metric tons per hectare (t/ha)	890	Pounds per acre
Cubic meters per hectare (m^3/ha)	0.011	Cubic feet per acre
Milliliters (mL)	0.034	Fluid ounces
Celsius (°C)	1.8 and add 32	Fahrenheit

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Appendix 1: Methods for Sampling Stand Density, Vegetation, and Tree Mortality

Study Sites

To evaluate potential tradeoffs in stand density and understory plant diversity and biomass between alder-dominated and conifer-dominated forests, we will sample across a range of alder-conifer mixtures. The proportion of alder basal area is the major criterion for stand selection, with stands representing a continuum from pure conifer to predominantly alder. To reduce variability among stands we will limit sites to stands 40 to 50 years old in the Maybeso and Harris watersheds on Prince of Wales Island. These watersheds contain large areas that were logged during the 1950s and have stands of relatively similar age and site productivity, with a wide range of alder-conifer composition.

Study areas were selected from a pool of potential sites identified by using aerial photographs and Forest Service district files. Field visits were used to identify stands and select study areas based on tree species composition. To control or reduce variability among sites, the following selection criteria were used: (1) stands that were logged and naturally regenerated, (2) stands that had no intermediate management activities such as tree thinning or alder girdling, (3) stand size of generally 5 to 10 ha with a minimum size of 2 ha, (4) stand elevation of less than 150 m, (5) stand slopes of 10 to 40 percent, and (6) no unusual site conditions within stands such as gravel borrow pits, recent logging roads, or beaver ponds. Nine stands were selected for use.

A total of 13 headwater streams in the Maybeso and Harris watersheds were chosen as study sites; 6 with 600-m reaches and 7 with 300-m reaches. “Reach location” refers to the uppermost portion of the fish-transition zone, marked by a white mesh net and plastic pipe and sand bags along the streambank (used for sampling transport of prey and detritus downstream). The upper 300-m reach starts at that stream sampling station and extends 300 m upstream, and the lower 300-m reach starts 50 m downstream from the stream sampling station and extends 350 m downstream.

Objective 1

Compare total stand density across a range of alder-conifer mixtures.

Objective 2

Compare understory plant diversity and biomass in stands across a range of alder-conifer mixtures.

Objective 3

Compare stand growth and regeneration in stands across a range of alder-conifer mixtures.

Objective 4

Compare frequency and type of tree mortality (mode of tree death) in stands across a range of alder-conifer mixtures.

Objective 5

Compare total stand density, tree diameter distribution, and size-specific tree mortality across a range of riparian alder-conifer mixtures.

Objective 6

Compare the spatial distribution and stocking of alder and conifer trees between upland and riparian stands across a range of alder-conifer mixtures.

Objective 7

Measure size and condition of woody debris entering the forest floor and streams, including type of decay, species of wood, and presence or absence of attached root systems.

Overstory vegetation data methods—

Data collection—Variable-radius plots will be used to assess stand density, the proportion of alder basal area in each stand, patterns of alder frequency and distribution throughout the stand, and understory vegetation. Larger fixed-area plots will be used to determine stand and tree growth, tree mortality, tree height growth patterns, and the effect of stand density on understory vegetation.

The size and shape of each stand will be delineated, and a grid of 20 variable-radius plots will be systematically installed throughout the stand. We will use a metric 4-basal-area-factor (BAF) prism plot (about 20-BAF, English units) to sample live and dead trees in the expected tree diameter distribution of this study (Dillworth and Bell 1967). In addition, we will install one 0.0025-ha fixed-area plot (radius 2.82 m) at each variable-radius plot to measure live and dead trees at least 3 cm in diameter at breast height (d.b.h.). The 3-cm d.b.h. tree threshold is the minimum diameter for the class of woody debris known as “fine woody debris.”

Fixed-area plots will be installed at five randomly selected variable-radius plot locations in each stand. Each fixed-area plot will contain nested circular plots to sample trees in different size classes (Avery and Burkhart 1994): one 0.05-ha plot (radius 12.62 m), and three 0.0025-ha plots (radius 2.82 m). One of the smaller plots will be located at plot center, and two will be located 8 m from plot center in randomly selected directions. All live and dead trees greater than 20 cm d.b.h. will be measured in the 0.05-ha plot. All live and dead trees greater than 3 cm d.b.h. will be measured in the 0.0025-ha plots.

Two 1-m^2 vegetation quadrats (quads) and two 2-m-radius shrub plots will be established at each variable-radius overstory plot. The quads and shrub plots will be located 4 m north and 4 m south of plot center, and the shrub plots will be centered on the vegetation quads. Vegetation cover for all vascular plants will be estimated, and tree regeneration will be tallied on the quadrat and shrub plots. One quadrat at each overstory plot will be randomly selected for biomass sampling.

Within each 0.05-ha overstory plot, eight 1-m^2 vegetation quads and eight 2-m-radius shrub plots will be established. Four of the quads will be located 4 m from the plot center, one in each of the four cardinal directions (N, E, S, W), and will be used for biomass sampling. The other four quads will be 8 m from the plot center along the NE, NW, SE, and SW directions, and will be used for vegetation cover estimates.

In the riparian stands, nested fixed-area plots will be used to assess stand density, the proportion of alder basal area, alder stocking and distribution in the riparian zone, and type of tree mortality. Seven pairs of nested fixed-area plots (one of each pair on the left bank and one on the right) will be established along each 300-m reach of each stream. Each fixed-area plot will contain a small (5 m^2), a medium (25 m^2), and a large (50 m^2) plot. The small plot will be 5 m along the bank of the stream by 1 m into the riparian forest. The medium plot will be located 5 m parallel to the stream by 5 m into the forest. The large plot will be established 5 m parallel to the streambank by 10 m into the riparian forest (fig. 4). Plots will be sampled as one walks upstream, beginning at the stream-pipe sampling reference point. Sites will be named according to their location relative to the reference point: upper or lower stream reach, plot location, distance, and streambank. Left and right bank will be named while one looks upstream. The first pair of plots of the upper 300-m reach will be located at the sampling pipe. Each successive pair will be 50 m from the beginning of the previous one, so that all seven pairs of plots will be spaced evenly across the 300-m stream reach. The plots of the lower 300-m stream reach will start 50 m downstream from the stream sampling station and extend 350 m downstream.

Canopy coverage measurements will be taken from a point in the center of the stream 2.5 m from the edge of the fixed-area plot and 2.5 m from the sampling pipe. Measuring points will be 50 m apart (fig. 4). There should be seven canopy coverage measurements within each 300-m stream reach.

Methods for woody debris data collection are detailed in appendix 4.

On each variable-radius plot, tree species, d.b.h., and crown position will be measured for all tallied live trees within the prism plot. Species, d.b.h., and type of tree mortality (uprooted, broken, dead standing, dead down) will be recorded for all dead trees. On the 0.0025-ha fixed-area plot, tree species, d.b.h., and crown position will be measured for all live trees at least 3 cm d.b.h.; species, d.b.h., and type of tree mortality will be measured or noted for dead trees at least 3 cm d.b.h.

For each fixed-area nested plot, tree species, crown class, d.b.h., height, percentage of live crown, and tree condition data such as top damage will be measured for all live trees to provide current stand structural information. The same information listed above will be collected for dead trees to provide information on tree mortality. The deterioration class (1= at least half the bark retained, 2 = less than half the bark retained) and the type of wood decay (white rot or brown rot) will be noted for all dead trees over 3 cm d.b.h. on fixed-area plots. Tree crown width will be measured for two randomly selected trees from each species and crown class to determine tree crown dimensions. Tree increment cores or stem sections will be taken from two randomly selected trees from each species and crown class for tree-ring analysis to determine tree age and changes in diameter growth. In addition, one dominant alder and one dominant conifer tree will be selected from each 0.05-ha plot for tree age and height growth analysis. These trees will be destructively sampled with stem sections collected at base, 1.3 m, 3 m, and every subsequent 2 m up the bole to the top of the tree.

On each fixed-area plot in the riparian stands, tree species, tree status (live or dead), and d.b.h. will be measured for all tallied trees. For dead trees, the type of mortality (uprooted, broken, dead standing, dead down, leaning over the stream) will be recorded. Within each small fixed-area nested plot all trees will be recorded; trees at least 1 m tall or at least 3 cm d.b.h. will be tallied; and all trees at least 3 cm d.b.h. will be measured. Within each medium fixed-area nested plot, all trees at least 3 cm d.b.h. will be measured. Within each large fixed-area nested plot, all trees at least 15 cm d.b.h. will be measured. Percentage of canopy coverage will be estimated by looking through a 30-cm long, 10 cm (inside diameter) plastic tube. The observer will stand in the center of the stream, hold the tube 90 degrees from level, look up at the forest canopy, and estimate the percentage of alder, conifer, and open canopy (Piccolo and Wipfli 2002).

Shrub cover will be estimated on small fixed-area plots located along streambanks (fig. 4).

Data analysis—

- Overstory data

Tree data for the 20 variable-radius plots will be combined by stand to assess stand density, the proportion of alder basal area in each stand, and patterns of alder frequency and distribution within each stand. Tree data for the five large fixed-area plots will be combined by stand to determine stand and tree growth, tree mortality, tree height and diameter distribution, and tree regeneration. Regression analyses will be used to determine the relation between the proportion of alder basal area and the following variables: stand density, wood production, stand growth, tree height and diameter growth, and tree regeneration.

- Riparian stand data

Riparian tree data for all 13 streams will be combined by stream reach to assess stand density, the proportion of alder basal area in each stand, species composition, alder distribution and frequency, tree mortality, and tree diameter distribution. Regression analyses will be used to determine the relation between the proportion of alder basal area and the following variables: stand density, wood production, and diameter growth. Results will be compared to upland stands.

- Mortality data

Regression analyses will be used to explore how the proportion of alder in young-growth stands influences woody debris recruitment, in total (i.e., number of stems and volume), by tree species, by decay type, and with unique structures (e.g., attached root system). Mortality rates will be calculated from the number of live and dead trees (extrapolated from nested plot data to per-hectare data) in each stand for both alder and conifers. Mortality for each species also will be expressed as basal area and percentage of basal area. Two-factor analysis of variance (ANOVA) will be used to contrast the mean diameter of live and dead trees by tree species (alder or conifer—first factor) and by site (second factor) to describe whether large or small trees are dying (and giving rise to woody debris) in these stands. By using trees dissected for stem analysis, the amount of decay in live alder (percentage of infected trees and mean percentage of volume affected per tree) will be contrasted by stand age (40-year-old stands versus 100-year-old stands) by using Student's t-test.

For the riparian stands, regression analyses will be used to assess how the proportion of alder may impact recruitment of woody debris in total and by tree species. Mortality rates of alder and conifers will be calculated from the number of live and dead trees in each stand. Mortality for each species also will be expressed as basal area and percentage of basal area. Two-factor analysis of variance (ANOVA) will be used to contrast the mean diameter of live and dead trees by tree species (alder or conifer—first factor) and by site (second factor) to describe whether large or small trees are dying (and giving rise to woody debris) in these stands. Differences in size of woody debris recruited (i.e., diameter of dead trees) will be contrasted by site and tree species by using analysis of variance.

Understory vegetation data methods—

Data collection—

- Ground vegetation cover

We will use cover classes (Daubenmire 1959) to visually estimate the percentage of cover of each species rooted in the quad: conifer seedlings 3 to 10 cm tall, all ferns, herbaceous plants, club mosses, common mosses and liverworts, and lichens (terrestrial and fallen epiphytics). Cover will be recorded for recently downed logs (trees that have died and fallen since logging date). Estimates will be recorded with the accepted abbreviations in the plant code list in field notebooks.

- Seedlings

We will tally and record the number of alder and conifer seedlings in the following height classes:

(0.3) 0.1 to .5 m

(1) 0.5 to 1.5 m

(2) 1.5 to 2.5 m

(3) 2.5 to 3.5 m (<3.0 cm d.b.h.)

- Shrub cover

Cover of shrubs and conifer regeneration (10 cm tall and up to 3 cm d.b.h.) will be estimated by species in the 2-m-diameter shrub plot, whether or not they are rooted in the plot. Cover of recently downed logs in the shrub plot will be recorded. The average height of each shrub species in the shrub plot will be recorded. For the riparian stands, on each small fixed-area plot, each shrub species and its relative abundance will be recorded as percentage of cover.

- Biomass of clipped species

Biomass will be estimated for shrubs, conifer seedlings, ferns, and herbaceous plants rooted within the quad. Generally, if a plant is more than 50 percent dead, it will not be included in the samples. However, in the case of woody plants, dead branches will be removed, and the rest of the plant will be included in the biomass.

Herbs: Collect subsamples of each species, including ferns, horsetails, and *Lycopodium* spp.

Shrubs: Separate each species into three components: leaves (including flowers), twigs (growth of current year), and stems (prior years' growth).

Conifer seedlings: Separate into two components: new (growth of current year) and old (prior years' growth).

Data analysis—Biomass data for the 20 vegetation quadrats at the variable-radius plot locations will be combined by stand. Regression analyses will be used to determine how the proportion of alder basal area affects species richness and biomass of vascular plants. Correlations between overstory and understory variables will be determined from each alder-conifer stand sampled in this study. Overstory variables include biomass and canopy coverage of vascular plant species. Regression equations will quantify tradeoffs between stand structure and understory variables. Understory species composition and biomass will be quantified in terms of food value for deer (deer-days per ha) with a nutritional model for deer habitat (Hanley and Rogers 1989) described in appendix 3. Biomass and cover data for the 0.2-ha overstory plots will be analyzed by using regression equations to determine the effect of stand density and tree species composition on biomass.

For the riparian stands, data for shrub percentage of cover will be combined by stream reach, and regression analyses will be used to assess the relation between alder basal area and species richness.

Appendix 2: Methods for Terrestrial Invertebrate Sampling

Study Sites

The terrestrial invertebrate study will use the same eight second-growth sites and the same four old-growth sites selected for the wildlife studies (app. 3). Of the second-growth sites, four are alder-conifer mixed stands and four are conifer-dominated. The four old-growth sites do not have alder.

Objective 8

Compare terrestrial invertebrate abundance and species richness in foliage, branches, and stems of woody vegetation as well as in leaf litter in stands across a range of alder-conifer mixtures.

Methods—

Data collection—

- Migrating arthropods

In each stand, traps will be permanently installed around the boles of three trees of each tree species, by using methods described by Hanula and New (1996). Traps will be located 1.5 to 2 m from the ground and will have a detachable cup that contains 70-percent ethanol solution. Invertebrates crawl up the tree into the trap and fall into the collecting cup. Sampling will occur from May through September. Invertebrates collected in the traps will be measured (Hodar 1996) and identified at least to family (alder-conifer mixed stands: 22 sample times × 4 stands × 3 tree species [red alder, western hemlock, Sitka spruce] × 3 bole traps per species = 792 samples; conifer stands: 22 sample times × 4 stands × 2 tree species [western hemlock, Sitka spruce] × 3 bole traps per species = 528 samples).

- Flying invertebrates

Malaise traps will be used to collect flying and some crawling invertebrates. The traps will be set up for 48 hours. A sample will be collected after the first 24 hours and another before the traps are taken down. There will be one trap per stand, and each stand will be sampled during the same period. Sampling will occur from May through September. Invertebrates collected in the traps will be measured (Hodar 1996) and identified at least to family (8 sampling times × 8 stands × 2 samples per stand = 128 samples).

- Foliage-feeding invertebrate sampling

Branch clippings will be sampled from red alder, western hemlock, and Sitka spruce (Johnson 2000). Clippings will be taken from trees of various sizes and in areas near openings and streams. If the crowns of Sitka spruce cannot be reached at a particular site, Sitka spruce will not be sampled there. Sampling will occur from May through September.

Once a week, three branch tips from three trees of each species will be clipped for leaf-chewing invertebrates. Invertebrates will be shaken from a branch onto a white bag, dispensed into a jar containing 70-percent ethanol solution, measured (Hodar 1996), and identified. The number of invertebrates per unit of foliage will be used to determine the density of invertebrates (Werner 1969).

The ratio of invertebrate weight to foliage weight will be determined for each sample. For western hemlock and Sitka spruce, the length of primary and secondary branches will be recorded and used to estimate biomass of the needles. For red alder, leaf biomass will be determined by stripping the leaves into a paper bag, recording the weight of the “wet” leaves and then subtracting the oven-dry weight. Invertebrate weight and weight per unit weight of foliage will be estimated by using formulas based on body length for each invertebrate order (Ganihar 1997) (alder-conifer mixed stands: 22 sample times × 4 stands × 3 tree species [red alder, western hemlock, Sitka spruce] × 3 bole traps per species = 792 samples; conifer stands: 22 sample times x 4 stands × 2 tree species [western hemlock, Sitka spruce] × 3 bole traps per species = 528 samples).

- Leaf-litter invertebrates

A fixed area of leaf litter will be randomly collected from study sites. Berlese funnels will be used to separate the insects from the leaf litter. Four leaf litter samples will be collected per study site. This sampling will be done once in summer and once in fall. Invertebrates collected will be measured (Hodar 1996) and identified.

Data analysis—The number and morphological species description will be determined for each tree species and study site. An average of the number and weight of each species or grouping of species will be calculated for each sample date. Stand-to-stand differences will be determined by using t-tests of the average number and weight of invertebrates for each tree species. Frequency diagram will be produced for the number of individuals per date for each tree species.

Appendix 3: Methods for Wildlife Sampling

Study Sites

We will select 12 young-growth forest stands (approximately 1 ha each) consisting of at least 20 percent alder and 12 young-growth stands consisting almost exclusively of conifer from stands within the Harris and Maybeso watersheds on Prince of Wales Island, Alaska.

Objective 9

Compare bird density and species richness in alder-conifer mixed and conifer stands.

Bird species diversity and abundance methods—

Data collection—Point-count censuses (Bibby et al. 1992): Limited radius (40-m) censuses of 8-minute duration will be conducted three times at each station during the breeding season (early May until early to mid-July). Surveys will not be conducted during heavy rain or high wind.

Data analysis—Compare estimated bird densities between stand types by using a t-test. Bird density data from point-count censuses will be compared to measures of understory vegetation and forest structure as reported in the vegetation component of this study.

Objective 10

Conduct behavioral observations of foraging birds in mixed alder-conifer young-growth stands.

Foraging data methods—

Data collection—Within stands of different habitat types, observe individual birds during foraging, noting foraging substrate used and prey taken.

Data analysis—In these approaches, the bird is the experimental unit. Bird foraging data are contrasted with substrate availability.

Objective 11

Compare nesting success in mixed alder-conifer young-growth stands and in conifer-dominated young-growth stands.

Nesting success methods—

Data collection—

- Artificial nest predation (Bayne et al. 1997)

Make artificial thrush-sized eggs (23 × 17 mm) out of porcelain clay dipped in plastic polymer (Plastidip[1]) and artificial thrush-sized nests out of moss (6- to 7-cm-diameter nest cup, 10- to 15-cm outer diameter). Let nests and eggs air for 2 days to let odors dissipate, and wear rubber gloves and boots during experiment to minimize scent trails to nests. In early to mid-June, place two handmade moss nests containing two artificial eggs at 15-m intervals along 150-m transects (nest density is 0.13 nests per meter or 1 nest every 7.5 m, for a total of 20 nests per transect). Place nests in “thrush-like” places (i.e., up to 2.5 m aboveground on a stump or log or next to a tree trunk). Check

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[1] The use of trade or firm names in this publication is for reader information only and does not imply endorsement by the U.S. Department of Agriculture of any product or service.

nests 3 and 12 days after experiment begins. The day the eggs are placed is day 1. Record all types of disturbance to nest and eggs, inspecting eggs for “bite” or peck marks to determine predator.

- Natural nest monitoring

Natural nests will be located and monitored every 1 to 3 days until the young fledges or the nest fails. Nest success will be calculated by using the Mayfield method (Hensler and Nichols 1981; Mayfield 1961, 1975) if sample sizes permit (i.e., n > 15) or by simple percentages if sample sizes are smaller. Once a nest is no longer active (after failure or fledging of all nesting attempts for the season within that nest site), the following physical characteristics of the nest site will be recorded: height above ground, support structure, and estimated percentage of concealment of nest in four cardinal directions and from above and below.

Data analysis—Angular transformed percentage of data of proportion of nests depredated will be analyzed by using a Wilcoxon two-sample test. Mayfield daily nest survival rates will be analyzed with the computer program CONTRAST, which uses a chi-square analysis with multiple comparisons (Hines and Sauer 1989, Sauer and William 1989). Angular transformed percentage of data of simple percentage nesting success will be analyzed with a Wilcoxon two-sample test. Differences in nest-site characteristics of safe and unsafe nest sites and between nests in habitat types (mixed alder-conifer and conifer) will be analyzed with a Wilcoxon two-sample test.

Objective 12

Compare summer food value for deer in young-growth stands differing in their proportion of alder component.

Summer food resources for black-tailed deer methods—

Data collection—Data will be collected as described in the understory vegetation component in appendix 1.

Data analysis—Understory species composition and biomass will be quantified in terms of food value for deer (deer-days per ha) by use of a nutritional model for deer habitat evaluation (Hanley and Rogers 1989). The Hanley and Rogers model converts a multivariate data set of biomass, digestible energy, and digestible protein for the full list of plant species into one measure of food value for deer—the number of deer-days that could be supported by that food at a specified level of nutritional requirement. Values of digestible energy and digestible protein for each species will come from a composite, regional database of nutritional data for forages in southeast Alaska.[2]

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[2] Hanley, T.A. 2002. Unpublished data. On file with: Forestry Sciences Laboratory, 2770 Sherwood Lane, Suite 2A, Juneau, AK 99801.

Appendix 4: Methods for Aquatic and Riparian Invertebrate Sampling

Study Sites

We will select a subset of study sites used for all study components, as well as additional riparian stands that meet criteria particular to aquatic ecology study (riparian stands with alder blend, fish transition zones, class 3 and 4 streams), for a total of 13 study streams.

Objective 13

Compare the amount of export of invertebrates and detritus from fishless headwater streams to downstream fish-bearing habitats across a gradient of riparian alder abundance.

Invertebrate transport data methods—

Data collection—We will measure transport of invertebrates and detritus from fishless habitats to fish-bearing transition zones across a range of alder-conifer mixtures. Sampling protocols will be similar to those described in Allan (1995), Hauer and Lamberti (1996), and Wipfli and Gregovich (2002).

We will select 13 streams within vegetation plots with riparian habitats that represent a range of alder gradient. Transport of invertebrates and detritus will be sampled with 250-µm mesh nets attached to 10-cm plastic tubes anchored in the stream with sandbags. Samples will be collected three times a year (April, June, and August) at all sites. Nets will be placed in streams on the same day for all streams, and contents will be collected one day later (1 sample × 13 streams × 3 seasons = 39 drift samples per year). Invertebrates will be placed in ethanol, and later sorted, counted, and identified to the lowest reliable taxon (likely genus) for analysis.

Immediately after the June 2000 sampling, we will select five of the streams for use in testing the hypothesis that the transport rate of invertebrates (number of invertebrates per unit volume of water) is equal along the stream reach. We will place one net in each of the five streams (following the protocol described above) 150 m upstream of the first point sampled (see above) for a 24-hour period.

Data analysis—Data will be natural logarithm-transformed and analyzed by using least squares linear regression, with percentage of alder as the independent variable and invertebrate abundance (count density) as the dependent variable (SAS 1989). Data for the five-stream experiment will be analyzed with a t-test, and streams will be the replicates (n = 5).

Objective 14

Compare invertebrate abundance in and along headwater streams, including on woody debris at various stages of decay, in stands with different alder-conifer mixtures.

Habitat use by invertebrates methods—

Data collection—Sampling protocols used in similar studies in other regions (Anderson et al. 1978, Cummins et al. 1989, Hax and Golladay 1993, Sedell et al. 1975, Vannote et al. 1980) will be followed and modified where appropriate.

This component looks at decay of woody debris and processing of leaf litter in stream and riparian habitats. We are interested in comparing the decay processes and associated fungal and macroinvertebrate communities that break down alder and spruce woody debris and leaf litter in streams and associated riparian habitats in forested uplands in southeast Alaska. The study will compare the various pathways of decay and the macroinvertebrates colonizing woody debris in streams and riparian zones.

- Stream habitat

We will compare invertebrate communities (e.g., abundance, species composition) on spruce and alder woody debris, and compare loss of wood mass over time. Boles from alder and spruce will be collected, cut into small pieces (5 cm diameter by 20 cm length), dried, weighed, and sorted into four categories: early decay alder, late decay alder, early decay spruce, and late decay spruce. Pieces will be arranged in random order and secured with cable locks to rigid plastic rafts so that each raft has one piece from each category. Rafts will be strengthened by a gutter nail affixed perpendicular to the wood pieces, and also labeled with a steel tag. Nine rafts will be placed at seven sites in six streams in forests with a range of alder component (9 rafts × 7 sites = 63 rafts × 4 pieces per raft = 252 total pieces). Gutter nails and steel leaders will be used to anchor rafts to the streambed. Placements will be in pools, runs, and riffles. Rafts will be set in June 2000.

Three randomly selected rafts will be collected from each of seven sites in July 2001, and another three in July 2002. Rafts will be pulled from the stream and transferred to aluminum trays. Each piece will be transferred to a 5-gallon (19-liter) bucket, rinsed with a portable pressurized sprayer, and decay will be measured with a penetrometer (seven measurements per piece). The penetrometer will be modified for woody debris by affixing a size-14 sewing needle to the otherwise blunt tip. Contents of the bucket will be strained through a 250-µm sieve, and the invertebrates will be washed into sealed, 250-mL plastic bags with 80-percent ethanol solution. All pieces of wood will be dried and weighed to compare loss of wood mass over time, and invertebrates will be counted and identified to lowest reliable taxon.

We will compare invertebrate communities (percentage colonization) on woody debris from two distinct decay classes (early and late decay) of alder and spruce. Naturally occurring pieces (roughly 5 cm diameter by 25 cm length) of alder and spruce will be collected from 13 streams in forests with a range of alder component (2 early decay × 2 late decay × 2 tree species × 13 streams = 104 total pieces of woody debris). Sampling will be conducted during May and July of 2001 and 2002. Selected pieces will be removed from the stream (with a D-frame aquatic net placed downstream when appropriate). Decay and invertebrates will be measured as described above. Surface area will be figured for each piece of wood to calculate percentage colonization.

- Riparian habitat

We will compare invertebrate abundance and species composition on conifer and alder woody debris in riparian areas along streams. Methods mirror those described above for the stream component. We will collect old-decay and recent-decay conifer and alder wood debris from the riparian areas along 11 streams in forests with a range of alder component. Stream locations are separated into five 30-m sections, for a total of 150 m. Wood debris samples will be randomly selected from four of the five sections (4 samples × 11 streams = 44 total woody debris samples). A saw will be used to cut pieces to fit into 1-gallon (3.8-liter) plastic bags. Invertebrates will be washed from wood samples into a 5-gallon bucket with a pressurized backpack sprayer. Each wood piece will be dissected to remove all invertebrates that cannot be removed by pressure washing. Each wood piece will be measured so that biomass may be estimated. A

250-µm sieve will be used to separate excess water from the sample, and the sample will be placed into a sealed, 250-mL plastic bag, preserved with 80-percent ethanol solution, and returned to the lab for processing. Invertebrates will be collected from each wood sample, identified to the lowest reliable taxon, and counted.

We will compare invertebrate communities in alder and conifer leaf packs in riparian habitats along headwater streams. We will collect three litter samples of natural detritus from riparian habitats along each of the 11 streams (3 samples per habitat x 11 streams = 33 detritus samples). The three samples will be randomly chosen from three of the five stream sections. A section of 6-in (15.2-cm)-diameter stovepipe will be dropped at random within 1 m of the stream. Litter and woody debris contained within the stovepipe will be placed in sealed plastic bags. Invertebrates will be separated from the litter by using a Berlese funnel. Samples will be hand picked to assure all invertebrates have been separated from the litter. Samples will be transferred into a scintillation vial, preserved in 80-percent ethanol solution, and returned to the lab for processing. Each litter sample will be sorted into the following groups: alder, conifer, and woody debris. Leaves and woody debris will be dried in an oven at approximately 42 °C for 24 hours. Each component will be weighed individually so that alder and conifer composition can be estimated. Invertebrates will be collected from detritus, identified to the lowest reliable taxon, and counted.

Data analysis—Data for the 11-stream experiment will be log-transformed and analyzed with least squares linear regression, with percentage of alder as the independent variable and invertebrate abundance (count density) as the dependent variable (SAS version 8.0). Data for the five-stream experiment will be analyzed by using a t-test with streams as the replicates (n = 5).

Objective 15

Compare nutrient concentrations among 13 streams that differ in the amount of upstream red alder and in discharge and disturbance history.

Stream nutrient data methods—

Thirteen small permanent streams (about 10- to 20-ha subbasins) across the range of 0 to 39.5 m^2 basal area alder coverage will be sampled for concentrations of various form of nitrogen and phosphorus during the 2001 growth season. Regressions of various nutrient parameters against the aerial alder coverage will be used to detect the effect of alder on stream nutrient concentrations. Because other factors such as hydrologic contributing area and disturbance history also may influence nutrient dynamics through their effect on runoff patterns and retention, we will partition the data into categories suggested by the geomorphic study and explore their effects with multiple regression.

Appendix 5: Methods for Fish Sampling

Study Sites

Thirteen catchments in the Maybeso and Harris watersheds on Prince of Wales Island will be selected for the entire set of studies in the Wood Compatibility Initiative. All streams will be surveyed for fish distribution. We will select a subset of these for an intensive analysis of fish populations.

Stream selection criteria will be perennial flow allowing connection to downstream main-stem rivers, presence of spawning gravel, and absence of active beaver ponds or lakes. Study reaches will be designated on streams with headwaters having mixed alder-conifer and conifer-dominated riparian zones. A transition reach that extends to the upper limit of salmonid presence (gradient >7 percent) will be designated on every stream, while a moderate gradient reach (gradient 4 to 7 percent) and flood-plain reach (gradient <4 percent) will be designated on streams where these conditions exist and sampling was practical. Each reach will be identified and marked to serve as a permanent site for the duration of the study.

Objective 16

Compare salmonid densities in stream reaches below and within conifer-dominated and alder-dominated upslope riparian forests.

Objective 17

Assess seasonal variation and relative species abundance of salmonids in upper high-gradient reaches (transition zones).

Objective 18

Assess the relation between the abundance of alder in a riparian forest and stream inputs and processes.

Salmonid density and distribution and habitat data methods—

Data collection—

- Fish populations

For the initial fish-sampling period (summer 2000), up to three stream reaches (one in each gradient zone) in each study stream will be isolated with nets or natural barriers and sampled for salmonid populations. A target length of 100 m will be used to designate study reaches, although the characteristics of individual streams may force the use of shorter sections.

Each sample reach will be divided into 10-m subsections with beach seines or natural barriers to reduce potential fish movement, and fish will be captured with minnow traps or by electrofishing. Population estimates in each reach will be made with the generalized removal method (three-pass depletion) (White et al. 1982). Fish will be identified, counted, and measured, and a subsample of the catch weighed. In subsequent sampling periods, streams will be intensively sampled by using electrofishing and the three-pass depletion population estimate technique. To determine the point at which fish reach their upper limit in streams, we will electrofish in upstream reaches (>10 percent gradient) moving upstream until fish are no longer detected.

- Habitat measurements

Each fish sampling reach is surveyed by using a modified tier III habitat survey (USDA FS 2001). Key measurements include size, number, and volume of large wood pieces, pool size and depth, width-to-depth ratio, substrate composition, and sediment retention. A more intensive large woody debris (LWD) survey also will be used in a stratified sample at all streams. Channel conditions above study sites will be surveyed to determine landslide history. Comparison of key variables (e.g., LWD and sediment retention) will be made between sites with and without recent (<20 years) landslides.

Data analysis—Upslope effects on fish population will be measured by using the ratio of conifer to alder (X_1) and landslide frequency (X_2) above the transition zones of each stream. The relation between these two variables and the density of resident 60- to 180-mm Dolly Varden (Y_1) and 60- to 180-mm cutthroat trout (Y_2) will be examined with a linear model and tested for interaction between X_1 and X_2:

$$Y_I = a = b_1X_1 + b_2X_2 + b_3X_1X_2 .$$

The model will be applied to fish in the transition zone for three separate periods: spring, summer, and fall.

Longitudinal effects on fish density will be compared across seasons for the transition zone, moderate zone, and flood plain. Separate comparisons will be made for Dolly Varden and cutthroat trout by using a two-way ANOVA. Juvenile coho salmon are not expected to occur in most transition zones and will be excluded. If insufficient samples occur with cutthroat trout, then only Dolly Varden will be used in the analysis. Species distribution (i.e., proportion of species in each sample unit) will be compared through a chi-square test by using the same comparison used for longitudinal distribution described below.

The following tabulation shows the statistical design for comparison of longitudinal distribution of salmonid populations ($X_{i,k}$ where X = fish density, i = reach, y = season).

Reach	**Spring**	**Summer**	**Fall**
Transition	$X_{1,1}$	$X_{1,2}$	$X_{1,3}$
Moderate	$X_{2,1}$	$X_{2,2}$	$X_{2,3}$
Flood plain	$X_{3,1}$	$X_{3,2}$	$X_{3,3}$

A stepwise regression will be used to measure habitat response to upslope riparian forest (Y_1 = conifer to alder ratio) and disturbance history (Y_2 = landslide frequency). Habitat variables are number of pieces of large wood (X_1), pool volume (X_2), and substrate composition (X_3).

Appendix 6: Methods for Geomorphic Processes

Study Sites

The goals of the Wood Compatibility Initiative (WCI) are to improve our understanding of young-growth ecosystem function and to understand how alder influences trophic links and processes in managed landscapes. Meeting these goals depends on an understanding of both natural and human-caused distributions of disturbance processes in a watershed context. To achieve these goals, study sites are selected at two scales: landscape and individual headwater channel. The landscape-scale analysis is conducted to describe dominant disturbance pattern (both natural and human caused) within entire watersheds (i.e., Maybeso and Karta). Individual headwater channels (20 sites total: 14 in second growth and 6 in old growth) are studied to identify dominant processes (landslides, mortality, bank erosion, and catastrophic blowdown).

Objective 19

Describe geomorphic processes and land use history at study sites selected by WCI colleagues.

Landscape analysis methods—

Data collection—Using a model of blowdown (Kramer et al. 2001), a model estimating bank erosion (Hooke 1980), estimates of forest mortality,[1] and a model of landslide occurrence and deposition (assumption that landslides initiate on slopes over 30° and deposit on slopes between 5° and 15°) (Johnson et al. 2000), we will produce a map indicating general process occurrence within watersheds.

We will estimate the relative magnitude of each disturbance process within the Maybeso and Karta watersheds. We also will review literature and examine land use history by using aerial photographs and timber harvest records.

Data analysis—We will describe natural disturbance history and land use history within Maybeso and Karta. We also will determine the processes (by the means described in a previous section) that introduce the majority of woody debris deposits.

Objective 20

Assess processes that deliver sediment and woody debris to streams from alder-dominated and conifer-dominated forests, and compare delivery rates.

Headwater channel process analysis methods—

Data collection—We will select sites having variation in upslope topography and variation in percentage cover of alder and conifer, and then delineate forest cover for headwater regions contributing to each site by using infrared aerial photographs and thematic mapper. Estimates will be made of:

- Landslide rate[2]
- Bank erosion (Hooke 1980)

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[1] Hennon, P.E. 1997. Unpublished data. On file with: Forestry Sciences Laboratory, 2770 Sherwood Lane, Suite 2A, Juneau, AK 99801.

[2] Helmers, A.E. 1961–1985. Unpublished landslide inventory. On file with: Forestry Sciences Laboratory, 2770 Sherwood Lane, Suite 2A, Juneau, AK 99801.

- Catastrophic blowdown (Kramer et al. 2001)
- Forest mortality (Hennon, collaborator in WCI).

We will classify the mountain slope landform (USDA FS 1997) contributing to deposition sites by using a measuring tape and clinometer to assess longitudinal profiles above, through, and below transition areas from steep slopes (>15°, 25 percent) to low-gradient slopes (<4°, 7 percent). We will plot longitudinal profiles and categorize the variation as follows:

- Gradual slope change
- Moderate slope change
- Rapid slope change (sharply concave).

We will compare channel characteristics (channel substrate size) by using pebble counts (Wolman 1954) and channel widths directly above and below transition areas. We will estimate area contributing to each transition area by using field and map measurements.

Data analysis—We will create a series of tables to describe topographic characteristics of WCI study sites including average slope gradient of uplands contributing to streams, longitudinal gradients, substrate size above and below transition areas, vegetation type, landform type, landslide history, land use history, and an estimate of contributing area. We will describe dominant processes and evaluate the relation between the continuous variables percentage alder and landslide rate. We will determine the degree of variance explained by the regression and examine the F-statistics (overall relation linear trend). We will then examine t-statistics for each parameter and assess the power of the test. We will examine adherence of the assumptions of regression by using residual tables. Differences will be judged to be significant at $a = 0.05$ ($p = 0.10$).

Objective 21

Estimate differences in woody debris loading and sediment storage capacity in streams within conifer-dominated and alder-dominated forests.

Sediment storage capacity methods—

Data collection—Distributions and accumulations of organic debris along headwater channels will be measured. Organic debris in streams will be classified as woody debris or fine organic debris (FOD). Woody debris will be further classified as large woody debris (LWD) (pieces >0.5 m in length and ≥0.1 m in diameter) or fine woody debris (FWD) (pieces ≥0.5 m in length and 0.03 to 0.1 m in diameter). The LWD pieces recruited before logging activities will be identified as “legacy” based on decay process and the absence of a cut edge. To quantify the distribution and accumulation of woody debris at each site, the following properties of LWD will be measured: in-channel, bankfull, and total lengths; diameter; position; and orientation. In-channel length is the length of a LWD piece located within the wet channel width that significantly dissipates flow energy and affects sediment transport. Bankfull length is the length of a LWD piece within the banks of the channel. Total length is the length of the entire piece of

LWD, including terrestrial portions. Diameter at the middle of each woody debris piece will be recorded. Volume (V) of LWD will be calculated as follows for the in-channel, bankfull, and total volume components of LWD:

$$V = \pi \times (D/2)^2 \times L \ ,$$

where D is the mid-log diameter and L is length.

All LWD pieces will be classified as functional (interacting directly with streams), transitional (suspended just above streams and decomposed enough to interact with streams in the near future), and nonfunctional (no interaction with streams or suspended well above channels). Orientation of LWD will be measured in relation to a line parallel to the channel axis to determine the degree of interaction of LWD pieces with streams. Both left-hand (+) and right-hand (-) orientations of LWD from 0° to 90° were recorded in 5° intervals.

The FWD will be surveyed for channel position and number of pieces. Volume of FOD, such as accumulations of leaves, branches, and fine logging slash, will be categorized as small (<0.01 m^3), medium (0.01 to 0.1 m^3), and large (≥0.1 m^3) volumes where FOD accumulations contributed to or formed a sediment wedge.

Sediment storage behind woody debris and other obstructions (e.g., boulders and bedrock) will be measured in these headwater streams based on the geometry of sediment wedge (width (w), length of the wedge (L_w), and average depth at the front of the wedge (d)). Average depth of the sediment wedge will be measured by using a sediment probe at several points. The cause of sediment deposition will be categorized according to the formation elements of debris dam: LWD, FWD, FOD, rocks, and bedrock. The volume of sediment stored behind woody debris and other obstructions will be computed based on a rectilinear pyramid:

$$\text{Sediment volume} = (w \times L_w \times d)/3 \ ,$$

The approximation of a pyramid-shaped wedge is appropriate because the upstream end of stored sediment typically converges to a point in these small channels.

Data analysis—We will evaluate the relation between the continuous variables percentage basal area alder and sediment storage: We will determine the degree of variance explained by the regression and examine the F-statistics (overall relation linear trend). We then will examine t-statistics for each parameter and assess the power of the test. We will examine adherence to the assumptions of regression by using residual tables. A significance level of $\alpha = 0.05$ will be used for all statistical analyses.

Pacific Northwest Research Station

Web site	http://www.fs.fed.us/pnw
Telephone	(503) 808-2592
Publication requests	(503) 808-2138
FAX	(503) 808-2130
E-mail	pnw_pnwpubs@fs.fed.us
Mailing address	Publications Distribution Pacific Northwest Research Station P.O. Box 3890 Portland, OR 97208-3890

U.S. Department of Agriculture
Pacific Northwest Research Station
333 S.W. First Avenue
P.O. Box 3890
Portland, OR 97208-3890