Chapter 3

Compatible Management of Red Alder-Conifer Ecosystems in Southeastern Alaska

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1. Research Proposition and Hypotheses

Forest clearcutting has been the primary timber management practice in forests of southeastern Alaska since commercial timber harvesting began in the 1950s, and the dense, even-aged conifer stands that subsequently developed have broad and undesirable consequences for some nontimber

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resources–most notably, fish and wildlife. Because a few earlier reports suggested that red alder (*Alnus rubra* Bong.) helps mitigate some negative effects of timber harvesting (Deal 1997, Wipfli 1997, Hanley and Barnard 1998), we studied the influence of red alder on a broad set of nontimber resources in young conifer forests (40-year-old; equivalent to early third stage of Appendix 1, Chapter 1) in southeastern Alaska (Figure 1). It is unclear what the ecological functions of red alder are in young forested ecosystems in southeastern Alaska. Key questions include: Does red alder affect forest understory development, tree growth, and timber production? How does red alder influence

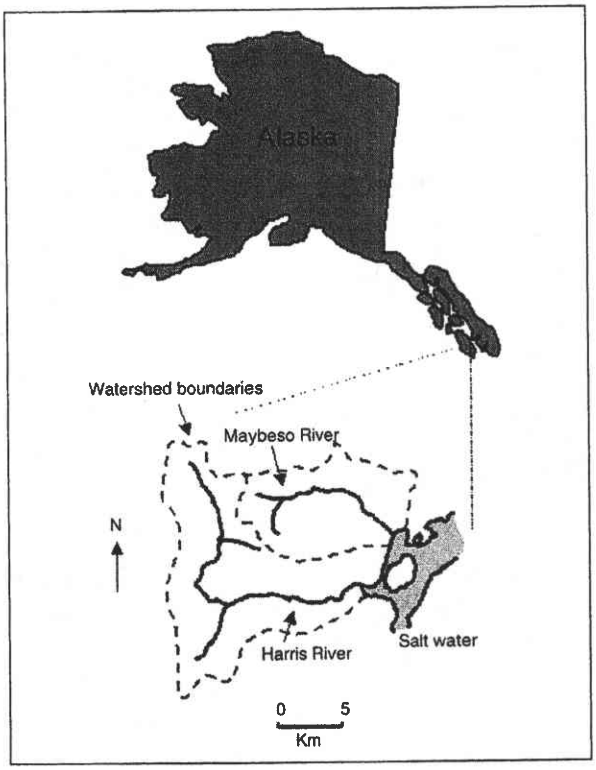

Figure 1. Study area in southeastern Alaska, USA.

food and habitat for fish and wildlife? How does red alder function in strean and riparian habitats? Does red alder influence forest ecosystem diversity anc productivity?

This paper is a synthesis of overall findings from a series of studies withii an integrated research program. Details of individual studies (methods, dat analysis, results) from each research component either have been or are bein published in stand-alone papers in various journals, and those papers are iden tified at various places within this chapter.

The three main themes of the project were (1) influence of red alder on spe cific ecosystem components, i.e., on vegetation, birds, invertebrates, wood and fish (Figure 2); (2) flow and use of wood among habitats (Figure 3); an

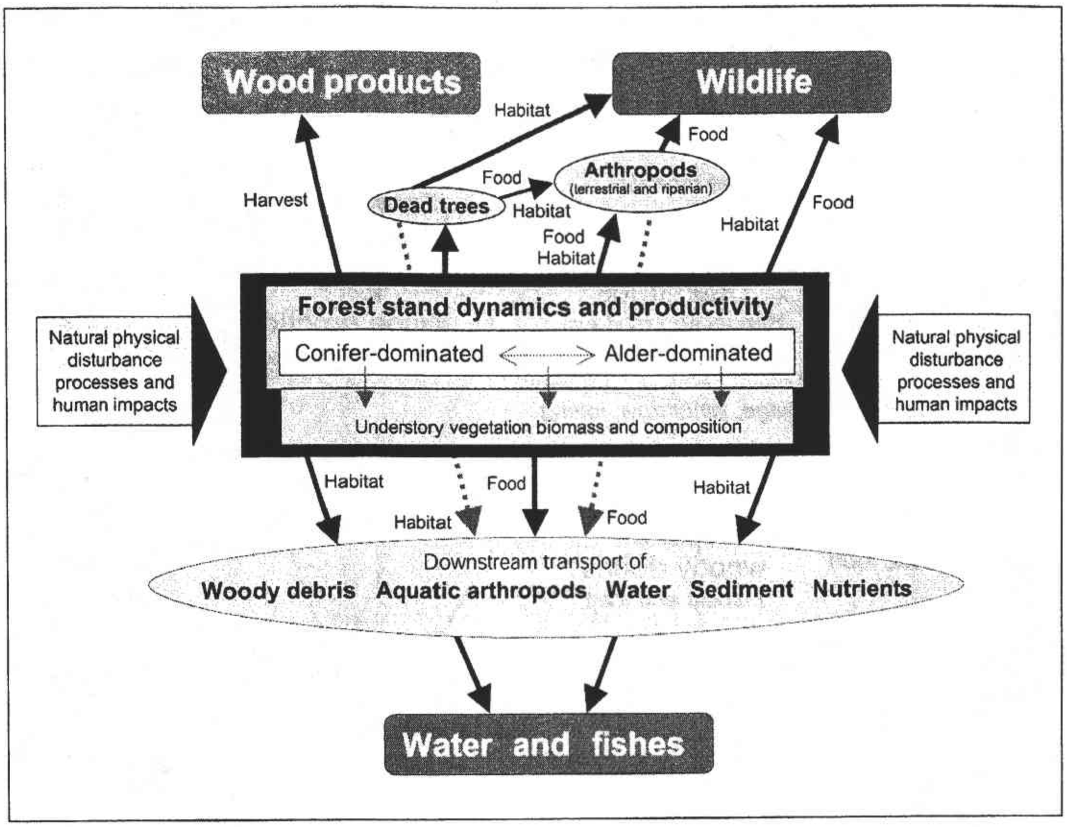

Figure 2. Hypothesized tropic and habitat linkages among prevalent ecosystem components in young-growth stands across a conifer-red alder canopy gradient.

(3) influence of red alder on ecosystem linkages and processes (Figure 4). We hypothesized that red alder increases the abundance and diversity of understory plants, which in turn influence aquatic and terrestrial invertebrate communities (abundance and species richness) and the bird and fish communities that feed on these prey. We also predicted that dead wood, especially red alder, serves important biological functions (e.g., food) affecting invertebrate communities in riparian and aquatic habitats. We investigated interactions in seven major resource areas–geomorphic processes; wood production (live and dead trees); understory vegetation; avian ecology; terrestrial invertebrates; aquatic and riparian ecology; and fish ecology–across non-riparian, riparian, and associated headwater stream habitats.

Despite the unique effects–both positive and negative–of red alder noted in past research, to our knowledge no studies have investigated the ecological functions of red alder concurrently on multiple resources of stream, riparian, and non-riparian habitats in southeastern Alaska. Basic information on silvics, stand growth and yield, tree species mixtures, succession, tree mortality and decay, and understory vegetation is lacking, as well as the effects of red alder on invertebrates, fish, and wildlife. Most information about red alder in Alaska is speculative or based on research from other regions. Further, linkages

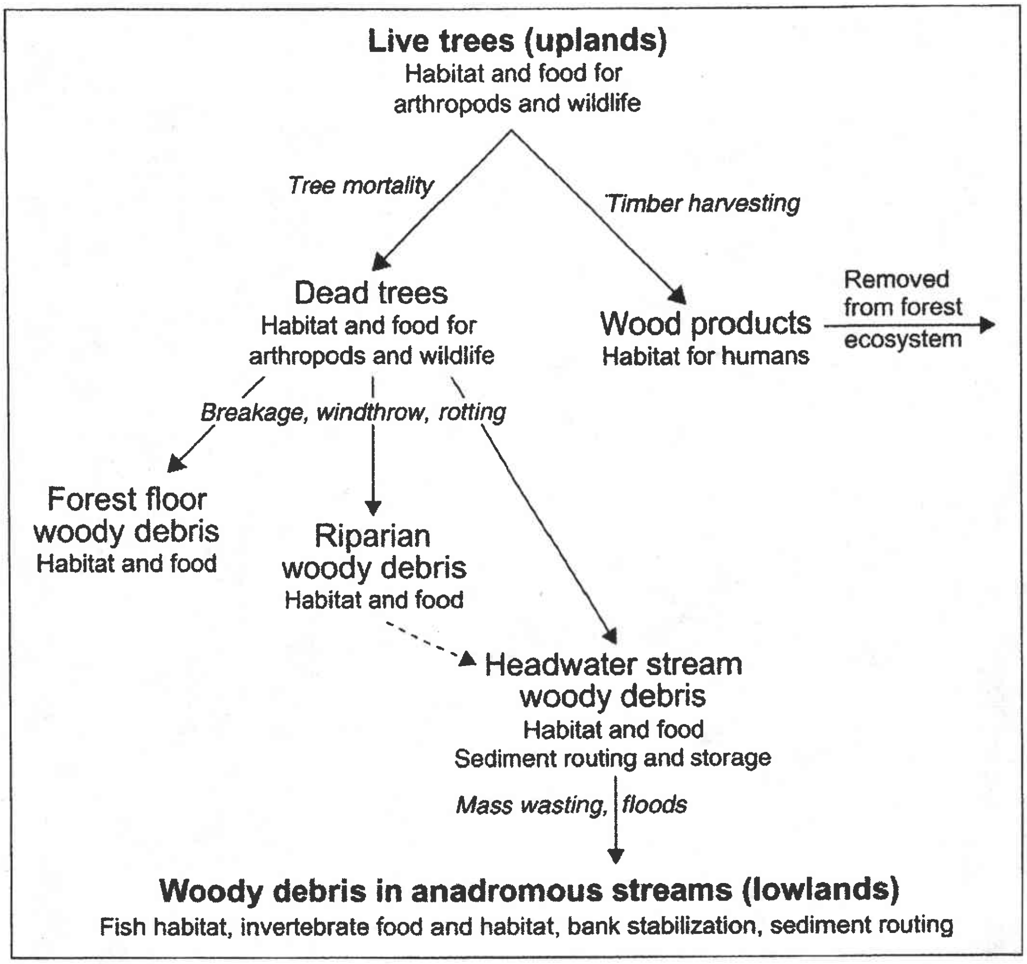

Figure 3. Flow and function of wood among habitats. Processes of delivery in italics.

among resources are important for understanding ecological function ar management implications of red alder. Consequently, this interdisciplinai project targeted understanding the function of red alder in young foreste ecosystems, and the influence of red alder on the linkages among biologi hydrologic, and geomorphic processes, and between terrestrial and aquat environments.

2. Trends in Forest Management in Alaska, Oregon, and Washington

Forest ownership in Alaska, Oregon, and Washington is dominated t Federal and other public ownership where it comprises 72%, 64%, and 55% total forestland, respectively (Smith et al. 2001). Recent management of the public forests has emphasized policy and guidelines that accelerate the deve opment of late-succession stand characteristics (Franklin et al. 1981, Frankl et al. 1997). Forest management has increasingly emphasized multip

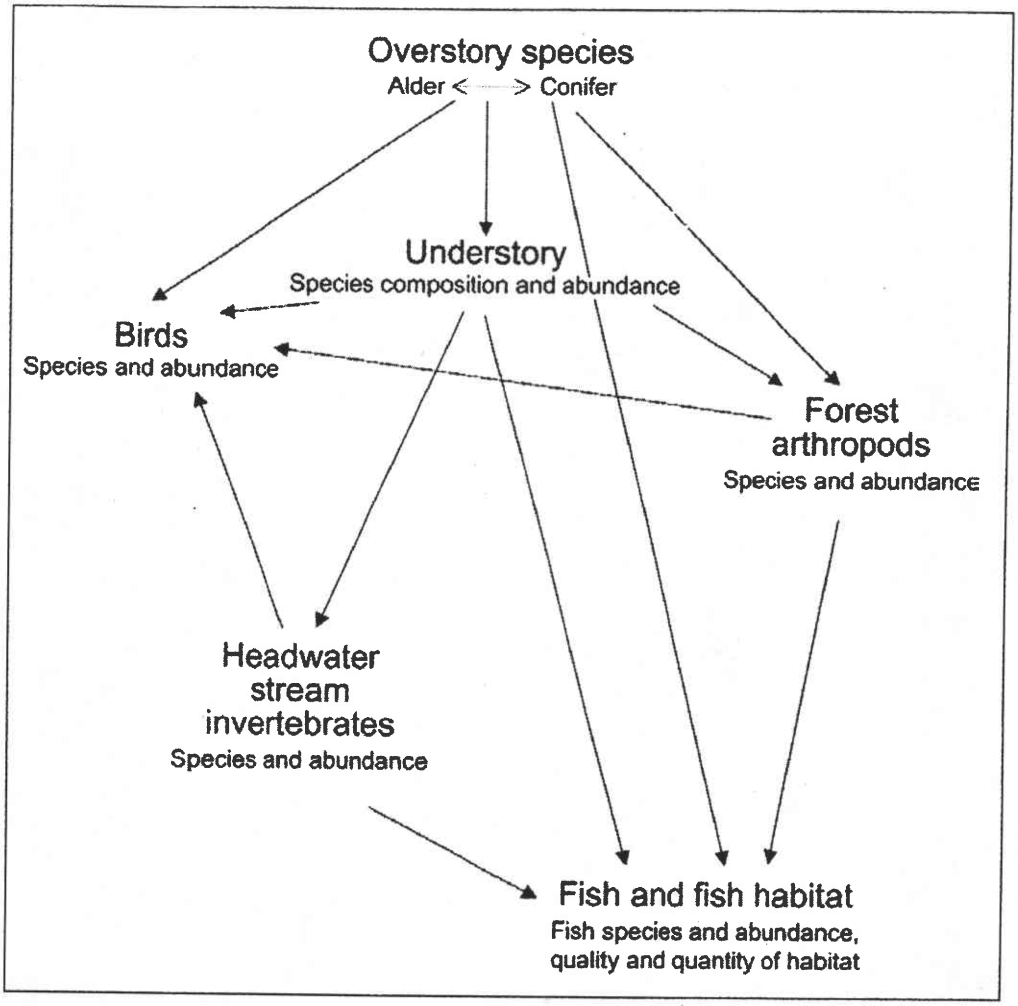

Figure 4. Hypothesized influence of red alder on ecosystem linkages and processes.

resource management, and recent region-wide forest management plans have prescribed policy and silvicultural guidelines to manage forests based on ecosystem management (Salwasser 1994, USDA Forest Service 1997).

New silvicultural systems and mixed-species forests that provide sustainable wood production and protection of other forest values are also being developed in southeastern Alaska (McClellan et al. 2000, Deal et al. 2002, Wipfli et al. 2002). However, even-aged silvicultural systems that utilize clearcutting have been implemented almost exclusively in the western hemlock (*Tsuga heterophylla* (Raf.) Sarg.)–Sitka spruce (*Picea sitchensis* (Bong.) Carr.) forests of southeastern Alaska since the establishment of large-scale timber operations in the early 1950s (Harris and Farr 1974). Little is known about the consequences of forest management practices in this region other than even-aged silvicultural systems for hemlock-spruce forests. Basic information on even-aged forests with red alder is lacking. Most information on red alder in Alaska is speculative or based on research from other regions. The information that does exist for southeastern Alaska indicates that red a may enhance some ecosystem components (Deal 1997, Wipfli 1997, Ha and Barnard 1998, Piccolo and Wipfli 2002). It is important for reso managers to understand the ecological function of red alder in even-aged est ecosystems so they can potentially mitigate some of the negative imp of clearcutting on forest, wildlife, and aquatic resources.

3. Ecological Consequences of Forest Clearcutting

Forest clearcutting in southeastern Alaska began in the 1950s. Loggin the first two decades was particularly intense; large clearcuts, log dragg and cutting on steep slopes caused heavy soil disturbance. Nearly 200 hectares (ha) in southeastern Alaska were harvested this way (USDA Fo Service 2001) and are now dominated by dense, even-aged conifer sta (Figure 5A). This has had undesirable consequences for some nontir resources such as fish and wildlife (Wallmo and Schoen 1980, Thedinga e 1989, Hanley 1993, Dellasala et al. 1996). Canopy closure in these stands erally occurs 25 to 35 years after cutting, and is followed by a nearly comp elimination of understory vegetation for 100 years or longer (Alaback 1 1984; Tappeiner and Alaback 1989). These even-aged conifer forests l simple, uniform stand structures, notably lack the diverse structures of ma forests, and are poorly suited for many wildlife species (Franklin et al. 19

The effects of clearcutting on streams include increased short-term prir production, reduced allochthonous (leaf litter) inputs, and loss of woody de for sediment retention and fish habitat (Bilby and Bisson 1998, Bisson Bilby 1998). Short-term increases in primary production result from incre light and temporary increases in nutrient inputs from decomposing log debris (Fisher and Likens 1973). Longer term consequences include redu invertebrate abundance as canopies overgrow the stream, leading to less available for fish and other consumers (Piccolo and Wipfli 2002, Wipfli Musslewhite, in review). Removal of streamside timber also reduces amount and size of large wood in streams, which leads to a subsequent los fish habitat (Bryant 1985, Bisson et al. 1987). Changes in forest structure the supply, storage, and transport of woody debris and sediment through r wasting, blowdown and other forms of tree mortality, and stream cha erosion (Swanston and Marion 1991, Smith et al. 1993, Bilby and Bi 1998, Johnson et al. 2000). Consequently, there is increasing interest in fo management practices that maintain or enhance productivity and biodiver and assure long-term sustainability of forest products, wildlife, and aqu resources.

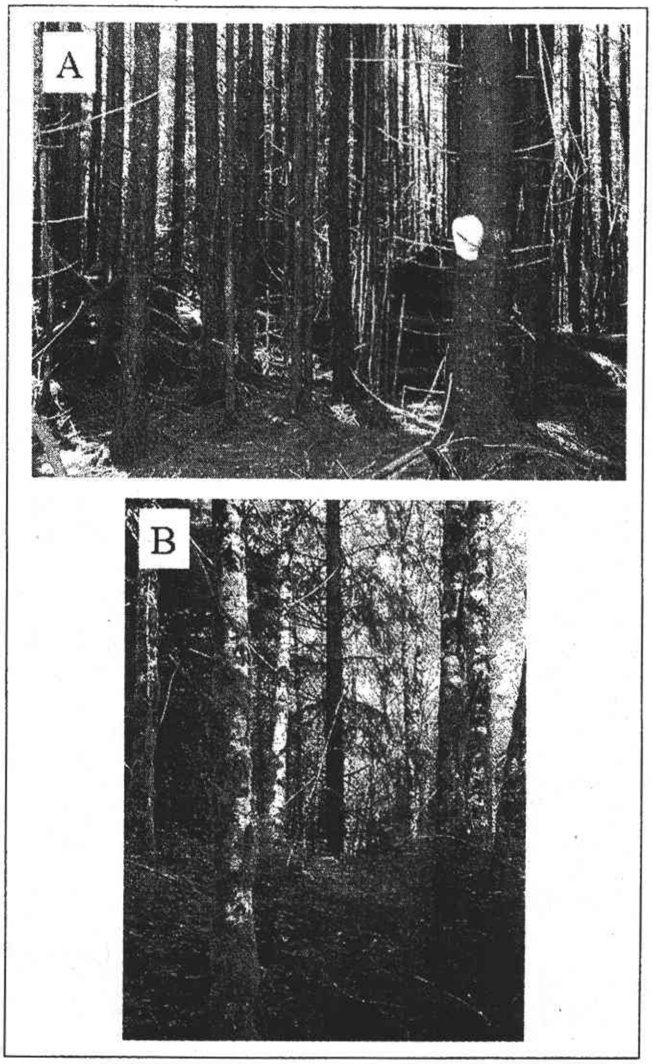

Figure 5. Biologically simplified, 40-year-old, even-aged conifer ecosystem (A) and a mixed red alder-conifer ecosystem of the same age (B) showing the more diverse stand structure and abundant understory.

4. Red Alder Distribution and Biology

Red alder is the most common hardwood tree in the Pacific Northwest (Harrington 1990), extending from southern California to southeastern Alaska (Hibbs et al. 1994) (Figure 1, Chapter 1). It is a relatively short-lived, shade-intolerant pioneer with rapid juvenile height growth. Alder, in association with symbiotic *Frankia* spp., fixes atmospheric nitrogen that often improves soil fertility. Red alder can be an aggressive pioneer on avalanche paths, roadsides, log landings, log skid trails, and other areas where mineral soil has been freshly exposed to seedfall, forming both pure and mixed stands (Harris and Farr 1974, Harrington et al. 1994). In Alaska, alder often grows with Sitka spruce, black cottonwood (*Populus balsamifera* L. ssp. *trichocarpa* (Torr. and Gray ex

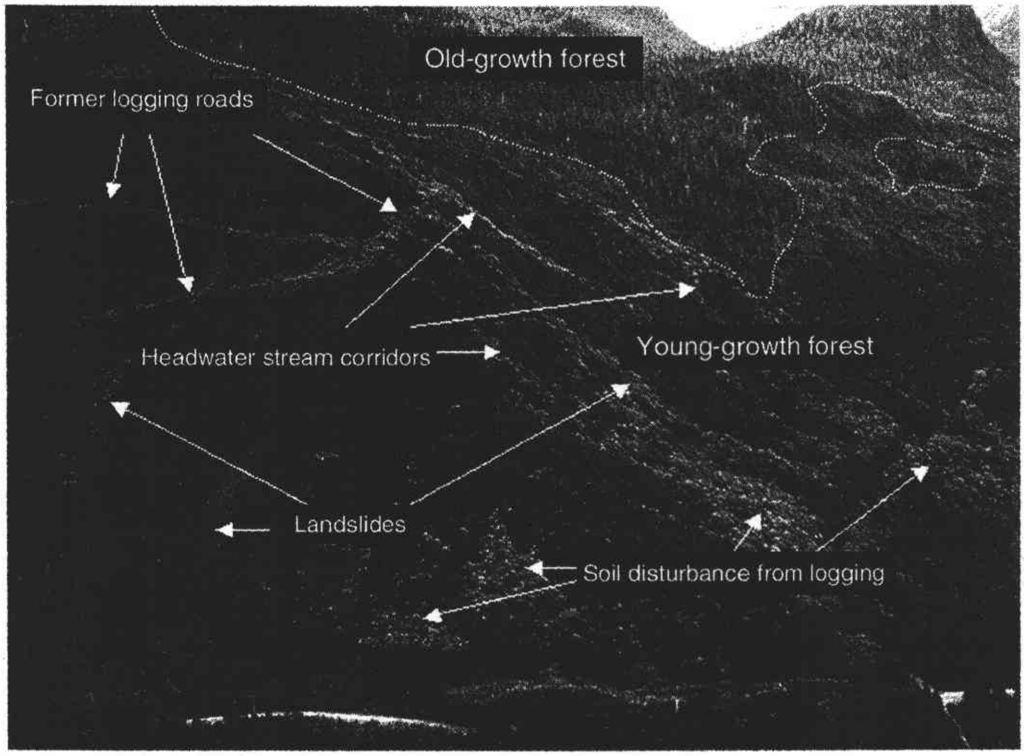

Figure 6. Distribution and occurrence of red alder in a section of the Maybeso drainage, Prince of Wales Island, southeastern Alaska.

Hook.) Brayshaw) and willows (*Salix* spp.) (Harris and Farr 1974, Ruth and Harris 1979). Extensive soil disturbance caused by mass wasting, road building, and tractor logging since the 1950s in southeastern Alaska has increased the abundance of red alder (Ruth and Harris 1979) (Figure 6).

5. Red Alder as a Tool to Mitigate Negative Effects of Timber Harvest

Red alder appears to benefit forested ecosystems throughout the Pacific Northwest in several ways, and may hold promise for mitigating some negative impacts of timber harvesting. Conifers often grow faster in the presence of alder (Miller and Murray 1978) because of improved soil fertility (Bormann et al. 1994). In southeastern Alaska, understory plant coverage in even-aged, red alder-conifer stands was more than six times that of a nearby even-aged, spruce-hemlock stand (Deal 1997). Hanley and Hoel (1996) found no significant differences in total understory biomass between 40-year-old red alder riparian forests and mature riparian and upland forests, which are considered benchmark standards for suitable vegetation composition and biomass for deer.

The importance of red alder to birds breeding in coniferous forests of the Pacific Northwest (western Oregon and Washington, Coastal British Columbia, and southeastern Alaska) is not clear. Dense conifer stands appear to have low bird diversity (Kessler and Kogut 1985) and abundance (Schwab 1979); higher densities of live deciduous trees have been shown to support greater diversity and abundance of birds in young-growth forests (Gilbert and Allwine 1991, Huff and Raley 1991, McComb 1994). The simple stand structure and sparse forest understory of dense young-growth conifer stands appear to limit the number of nest sites available to birds, and reduce the concealment of nests, a feature associated with successful nesting for some open-cup nesting species (reviewed by Kelly 1993, Martin 1993). Deciduous vegetation in coniferous stands is important for successful nesting for some songbirds in Douglas-fir plantations in British Columbia (Easton and Martin 2002). Red alder may be an important foraging substrate (Gilbert and Allwine 1991, McComb 1994), but this relationship has not been studied. Because insects from foliage are 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 may be more successful when foraging for insects in red alder trees. Therefore, mixed red alder-conifer stands potentially provide more food, more and safer nest sites, and reduced susceptibility to nest predation for certain bird species.

Riparian management that alters plant communities may change food resources within a stream and its surroundings (Cummins et al. 1989). Little is known about the influence of these developing riparian communities on headwater stream productivity and downstream fish. Red alder could have a variety of impacts on streams, such as changes in light penetration and allochthonous inputs. These effects could lead to changes in aquatic productivity and terrestrial invertebrate inputs to streams (Wipfli 1997). Some riparian tree species contribute more terrestrial invertebrate mass to streams than others (Mason and Macdonald 1982), and red alder appears to support relatively high levels of prey for fish (Wipfli 1997, Piccolo and Wipfli 2002, Allan et al., in press). This is significant because over half of the prey biomass ingested by juvenile salmonids in southeastern Alaska is terrestrial and originates from adjacent riparian vegetation (Wipfli 1997).

Riparian red alder and other vegetation types along streams can also have major influences on stream riparian soil nutrient levels. For example, red alder stands have increased soil nitrogen levels from a few years after harvest until the stand senesces and is replaced by conifers (Luken and Fonda 1983). Groundwater and hyporheic flows move red alder-derived nitrogen into adjacent streams and can increase nutrient stocks and algal standing stocks in streams with sufficient light levels (Fevold 1998).

Habitats immediately adjacent to headwater streams may have a significant influence on foodwebs in fish-bearing reaches downstream. Over 70% of streams within a drainage network are headwater streams (Benda and Dunne 1997), and are sources of sediment, water, nutrients, and organic matter for downstream habitats (Gomi et al. 2002). Transport of organic and inorganic material in headwater streams draining upland forests 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), creating various channel environments and modifying patterns of riparian structure and hyporheic exchange in downstream reaches (Gregory et al. 1991, Swanson et al. 1998). Movement of detritus 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). Red alder in headwater stream riparian zones may influence physical and biological processes in these systems. Because red alder decays faster than conifers and is a desirable food source for invertebrates (McComb 1994), it likely affects the detritus and invertebrates exported from headwaters to downstream habitats.

An increase in red alder in riparian forest canopies may have both positive and negative impacts on aquatic communities. Higher aquatic productivity and more food for fish and wildlife may be outweighed by loss of fish habitat (Hicks 1989, Bilby and Ward 1991, Ralph et al. 1994) resulting from decreased large woody debris inputs (Grette 1985, Andrus et al. 1988, McDade et al. 1990), wood longevity (Anderson et al. 1978, Benda and Cundy 1990, Keim et al. 2000), and increased sediment loading from fewer large conifers (Megahan 1982). Understanding where red alder occurs both naturally and as a result of management may explain the morphological, functional, and community-level changes that occur in streams as succession from red alder to conifer occurs.

6. Research Approach

We investigated geomorphic processes, wood production (live and dead trees), understory vegetation, avian ecology, terrestrial invertebrate communities, aquatic and riparian ecology, and fish ecology, across non-riparian, riparian, and associated headwater stream habitats in young (40-year-old), regenerating forests. We sampled selected response variables (see Wipfli et al. 2002) within these components in sub-basins encompassing a range of red alder abundance (measured as a proportion of live stand basal area and percentage of canopy coverage) in two adjoining watersheds during 2000-2001 on Prince of Wales Island, southeastern Alaska (Figure 1). We selected two distinct types of study sites: non-riparian where the focus was to evaluate the influence of red alder on vegetation, birds, and invertebrates; and stream-riparian where the focus was the effect of red alder on vegetation, stream nutrients, organic detritus, invertebrates, woody debris, and fish (Figures 5, 6, 7). In

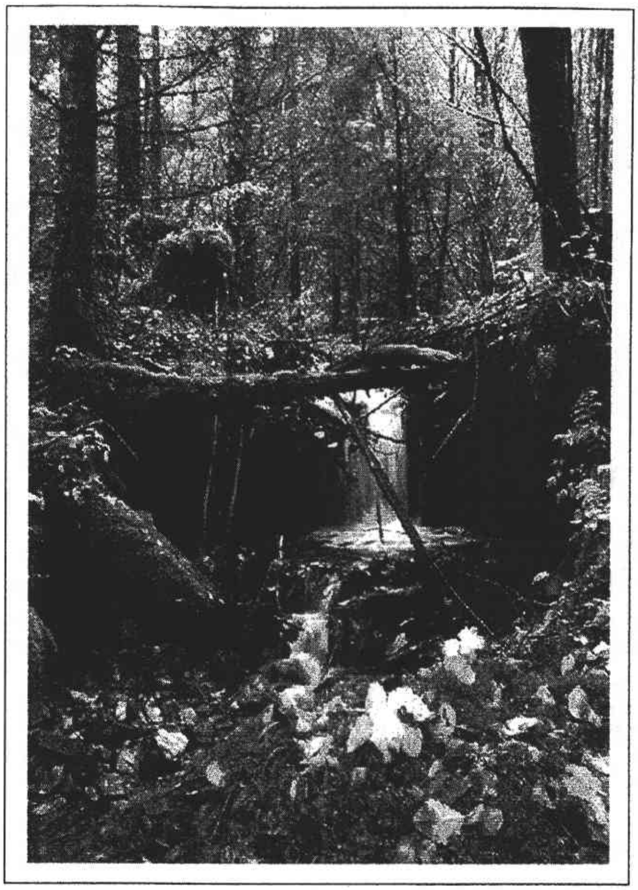

Figure 7. Headwater stream draining an upland forest where it has already transitioned into a lower gradient, fish-bearing reach.

some cases, these were common sites (a given study plot included both site types), and in other cases they were neighboring (but not necessarily contiguous). Wipfli et al. (2002) provide detailed objectives, hypotheses, rationales, methods, and site descriptions.

One independent variable was common to all aspects of sampling: the proportion of red alder (i.e., as a percentage of basal area of live trees, or percentage of canopy cover for stream studies). One of our goals was to construct an empirical model to show how resources might vary along the continuum of red alder dominance. We intended for managers to be able to use this model as a predictive tool for selecting the proportion of red alder to be managed in association with single or multiple resource objectives, at the stand, stream reach, or watershed scale.

To minimize among-site variability, we selected study sites in neighboring Maybeso and Harris watersheds by using composition of tree species (percentage of red alder in young-growth conifer stands) as the primary site selection criterion. These watersheds have large areas of relatively uniform stand age and productivity, a wide range of red alder-conifer mixtures, and are representative of many forests in southeastern Alaska. They were among the first areas harvested in southeastern Alaska when commercial timber harvesting began in the 1950s (USDA Forest Service 1997).

7. Research Findings

Most of the red alder in these drainages occurred in areas with slope gradients >15° (Johnson and Edwards 2002). Approximately 90% of this red alder occurred as a consequence of soil mass wasting (debris avalanches and debris flows) and 10% was a result of cable logging or road building. Streams influenced by mass wasting had significantly more red alder than streams with no apparent soil mass wasting history. About one-third of the red alder occurring in areas with slope gradients <15° was associated with logging roads, most of which are now abandoned. The remaining red alder on the lower gradient slopes typically grew on alluvial fans, landslide deposits, flood-reworked landslide deposits, and areas disturbed by logging tractors (Figure 6).

Soil particle size and moisture, influenced by landslides and slope position, also affected red alder distribution. Red alder was commonly found along zones of shallow subsurface flow or discharge. Larger particle-sized soils, commonly found in the alluvial fans, supported more red alder than sites with finer soils. Mineral soils associated with the various soil disturbances (e.g., abandoned logging roads, landslides, stream corridors) supported more red alder than sites on organic soil material. Lower water retention in coarse-textured soils also favored alder regeneration.

Responses to the presence of red alder varied considerably (Figure 8). Although most of the resources increased with the proportion of red alder (e.g., understory vegetation abundance and browse for wildlife, songbird and aquatic invertebrate abundance, terrestrial arthropod abundance, red alder woody debris in streams), some decreased at higher red alder densities (e.g., total wood production), while still others declined or remained unchanged (e.g., total large woody debris, fish densities). Red alders in non-riparian stands had different tree diameter and height distributions than conifers, and mixed red alder-conifer stands provided greater complexity than stands dominated by conifer or red alder (Deal et al., in review). The diameter distribution of live red alder trees approached a normal distribution, but the distribution was skewed towards smaller trees for conifers. Height growth of red alder was initially much greater than that of conifers, but conifers emerged from red alder overstory 20 to 30 years after logging and averaged 4 to 9 m above the red alder canopy. The more evenly mixed red alder-conifer stands had a wider variety of tree sizes than either the conifer-dominated sites or the red alder-dominated sites. Overall, these mixed red alder-conifer stands provided more heterogeneous structures than even-aged conifer stands that are common after disturbances such as clearcutting. Total understory plant cover and herbaceous

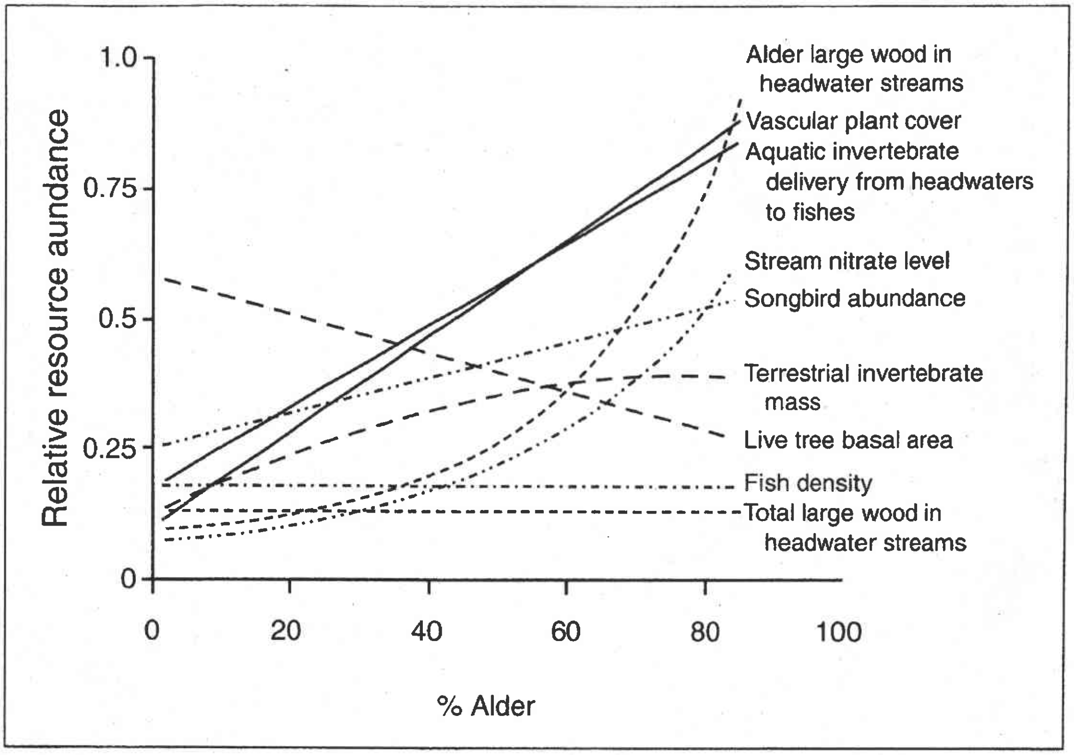

Figure 8. Responses of forest ecosystem components to the proportion of red alder in mixed red alder-conifer forests in southeastern Alaska. Responses start out from the y-axis at an approximate position that would be expected in unharvested systems in southeastern Alaska and progress along the x-axis (red alder gradient) that reflects their relative response across the red alder gradient.

cover increased with increasing proportions of red alder (Figure 8). Understory plant communities were more diverse and contained more biomass in mixed red alder-conifer stands than those in pure conifer stands (Deal et al., in review).

Total basal area (wood production) decreased significantly with increasing proportion of red alder basal area (Deal et al., in review) (Figure 8). In contrast, tree density did not vary with red alder composition. Average diameter of all live conifers significantly decreased with increasing proportion of red alder basal area but there was no significant difference in mean diameter of the largest conifer trees in these stands. These large-diameter trees have important future ecological contributions, particularly for providing large woody debris in streams and riparian habitats.

Some vegetation responses differed between riparian corridors and non-riparian stands. In riparian stands, red alder was highly clumped and was concentrated along stream margins. Tree density, basal area of live and dead trees, and mean diameter of live conifers were not significantly related to the proportion of red alder within riparian forests (Orlikowska et al., in review). The number of large-diameter conifers was similar in riparian stands across the full range of red alder-conifer mixtures. Mean diameter of dead conifers increased slightly with increasing proportion of red alder. Similar to non-riparian sites, most dead trees within riparian stands were small and had died standing.

Few large trees were found dead in any of our sampled forests; most dead trees were small standing stems (Deal et al., in review). This pattern of dead tree occurrence was similar between riparian and non-riparian sites. There was no correlation between increasing proportion of red alder basal area and basal area of dead trees. There was a significant decrease in dead tree density with increasing proportion of red alder basal area. The number of dead conifer stems generally exceeded that of dead red alder even in stands of relatively balanced composition. More than 60% of all dead trees were found standing, with small percentages each of broken boles, down trees with broken roots, and uprooted trees. This pattern of tree death was similar for both conifers and red alders, and for small and large trees. Small dead conifers were by far the most abundant on a stem density basis (Deal et al., in review). The dominant agent of decay in dead red alder and conifer was white rot, for both small and large trees.

The greater diversity and abundance of vascular plants found with more alder improved habitat for small mammals (Figure 8). Deer forage also significantly increased with increasing proportion of red alder basal area (Deal et al., in review), thereby increasing summer deer-carrying capacity (Hanley and Hoel 1996). There was no significant relationship between the percentage of red alder and songbird diversity (De Santo, in prep.). Although most songbird species did not vary with the percentage of red alder, the abundance of the Pacific-slope flycatcher (*Empidonax difficilis*), an aerial insectivore, increased with the percentage of alder in forest stands, resulting in higher overall bird abundance (Figure 8). Nesting density of all songbird species combined was also positively associated with the percentage of red alder, and given that nesting success did not differ between stand types, total stand-level nesting success was presumably higher in the red alder stands (De Santo, in prep.).

The biomass of flying insects, primarily Diptera, Lepidoptera, and Plecoptera, significantly increased as the percentage of basal area of red alder increased (Figure 8) (Schultz, in prep.). Malaise trap catch of winged invertebrates in the nearly pure conifer stands was 60% and 35% of that caught in stands with a high proportion (70%) of red alder in 2000 and 2001, respectively. Further, riparian red alder leaf litter samples had higher invertebrate taxonomic richness than samples of conifer leaf litter. Highly decayed conifer wood had higher abundances of invertebrates within the wood than less decayed conifer or red alder in any decay class. And highly decayed red alder wood supported greater taxonomic richness than either conifer decay class (LeSage 2003).

Streams with more red alder in their adjacent riparian zones transported significantly more invertebrates and organic detritus from headwaters to downstream, fish-bearing habitats than streams with predominantly conifers along their banks (Figure 8). Streams at the higher end of the red alder density continuum delivered about four times more invertebrate biomass than streams canopied predominantly with conifers (Wipfli and Musslewhite, in review). Aquatic invertebrate mass composed 3/4 of the fluvial export from headwaters to fish-bearing habitats, while terrestrial species composed 1/4 of the export. Midges were the most abundant invertebrates in the stream transport, followed by baetis mayflies and nemourid stoneflies. The amount of organic detritus transported downstream was also significantly greater in streams with more red alder growing along their banks than streams with little red alder (Wipfli and Musslewhite, in review).

Nitrate concentrations within study streams varied from 4 to 387 μg nitrate-nitrogen per liter (Figure 8) (Johnson and Edwards 2002). Streams with the highest nitrate concentrations had high riparian red alder basal area coverage, but not all streams with extensive red alder had high nitrate concentrations. Streams originating in alpine areas generally had larger catchments and higher discharge, which apparently diluted the nitrogen originating from red alder-influenced soils. Those streams had lower nitrate concentrations than smaller streams with similar alder densities (Johnson and Edwards 2002).

The number of red alder, large woody debris pieces in streams increased with increasing proportion of red alder in the riparian stand (Figure 8) (Gomi et al., in review). However, significant relationships between the volume of large woody debris and sediment stored behind these pieces and the proportion of red alder in riparian zones were not found. Woody debris and sediment supply appeared to be governed by other factors such as recruitment, transport capacity, and decomposition rates. Recruitment of large woody debris from the hillslopes to the stream channels was related to a number of factors including valley topography (e.g., valley incision), past logging practices, and natural physical disturbance history. Much woody debris from the original old-growth forest (Appendix 1, Chapter 1-fifth development stage) still persisted in the stream channels and provided physical function in streams (Gomi et al., in review).

Red alder appeared to have no direct relationship with salmonid densities (Figure 8) (Bryant et al., in review). Dolly Varden char (*Salvelinus malma* Walbaum) and juvenile coho salmon (*Oncorhynchus kisutch* Walbaum) densities were related to stream habitat conditions: including gradient, pool abundance, and the amount of large wood. Dolly Varden char were found in all reaches of the streams and in all streams where fish were present, whereas juvenile coho salmon were found in some but not all streams, and were most abundant in the lower gradient reaches. The density of all species decreased as gradient increased. The relatively low densities of all fish species combined with the limited amount of habitat suggests that the amount and quality of habitat were the primary factors limiting salmonid populations in these streams.

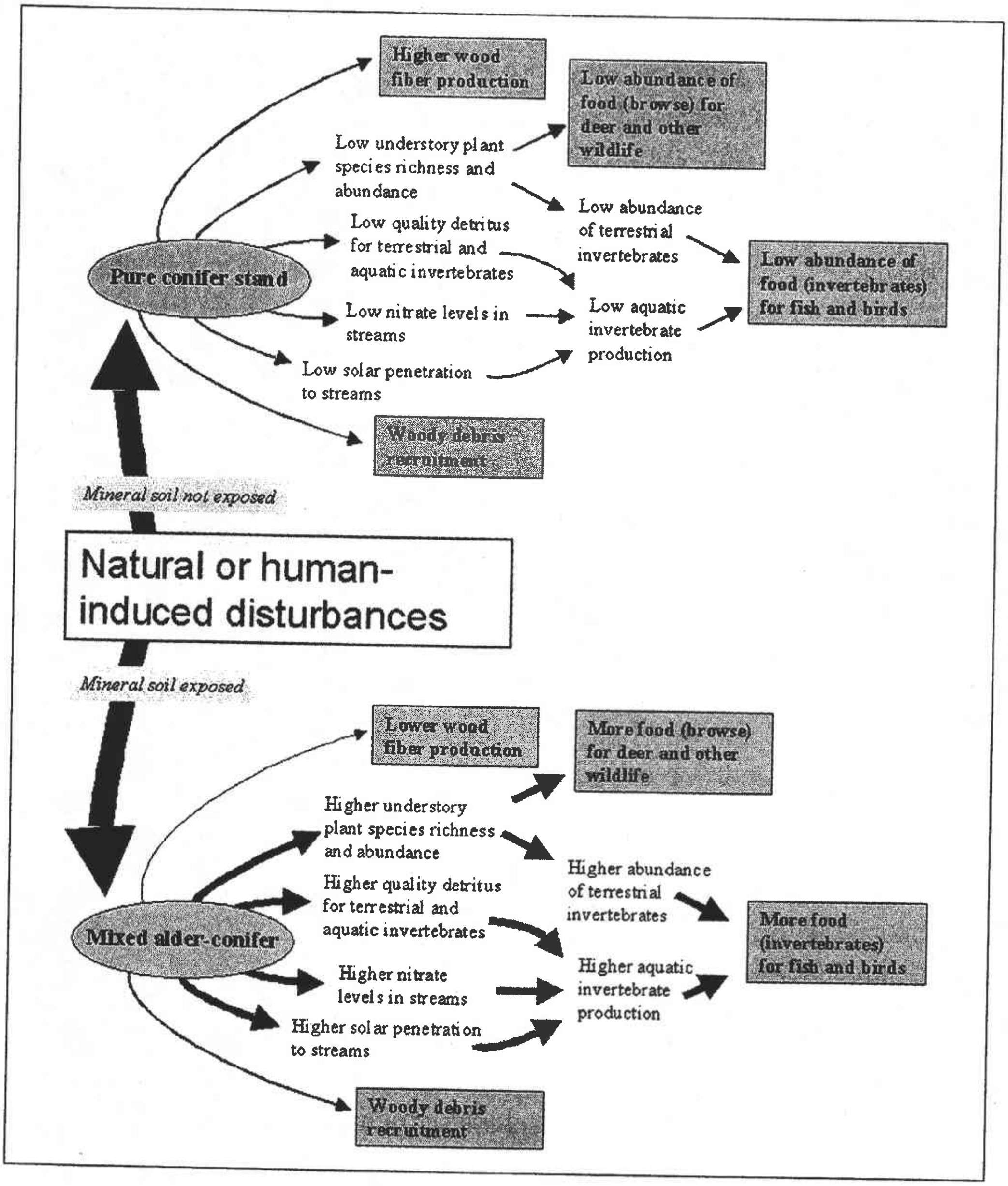

Figure 9. Disturbance-induced trajectories of conifer or mixed alder-conifer forests, and the subsequent influence on the linkages within associated communities. Arrow thickness represents relative magnitude of response.

8. Integration and Synthesis

Young, regenerating forests progress along one of several trajectories following forest clearcutting or other disturbance (Figure 9). If the trajectory is toward a pure or nearly pure conifer forest (resulting from lack of adequate soil disturbance), the subsequent forest community develops a sparse and non-diverse plant understory, which in turn leads to little wildlife browse and sparse foliage for herbivorous invertebrates (Figures 5A, 9). Nearly pure conifer forests also provide less nitrate and light for stream producers and consumers, which can lead to fewer aquatic invertebrates in the associated headwater streams, ultimately providing less food for birds and downstream fish. They also provide fewer nesting sites for songbirds, and support lower songbird density.

Alternatively, if the forest regeneration trajectory includes red alder (that develops as a result of adequate soil disturbance), a markedly different community develops. This regenerating forest is characterized by a more species-rich and abundant understory plant community (habitat and browse for wildlife such as deer), more terrestrial invertebrates, higher nitrate levels and more light reaching streams, which in turn leads to more aquatic invertebrates that are prey for selected bird species and downstream fish (Figures 5B, 9). This second scenario appears to support a greater overall diversity and productivity in the forest ecosystem.

An interesting pattern of red alder regeneration can be observed throughout harvested landscapes of southeastern Alaska: the tree is common in young-growth stands that regenerated before 1970 and is rare or absent on sites regenerated after that date, except along headwater streams and in landslide areas. Prior to 1970, harvesting and yarding practices commonly used tractors to drag logs across forest floors and streams. After 1970, there was greater use of high-lead cable logging systems that partially suspended logs above ground and stream surfaces (J. Russell, USDA, Forest Service, Sitka, Alaska, personal communication, 2002). Much less soil disturbance occurred in the post-1970 logging, reducing the amount of subsequent red alder regrowth. The current trend towards partial harvest or clearcutting with helicopter yarding will also result in less soil disturbance. Harvests that avoid streams and steep slopes will further reduce the chance for red alder regeneration. Although pre-1970 logging practices were later viewed as destructive to components of the forest ecosystem, the promotion of red alder regeneration clearly had some compensatory effects on forest ecosystem processes that are missing from current practices.

We documented that the life history of red alder in southeastern Alaska operates at a faster pace than conifers, which is consistent with what has been found elsewhere (Franklin and Pechanec 1968, Miller and Murray 1978). The rapid, early growth of red alder allows it to initially outgrow conifers in height, although conifers eventually overtopped red alders (Deal and Orlikowska 2002). Because of their relative intolerance to shade, the small red alder trees in our 40-year-old forests died while conifers of the same size persisted, resulting in different diameter and height distributions for red alders and conifers, both live and dead trees. The larger red alders will probably eventually succumb to low light levels and die at stand ages 60 to 100 years, and overstory conifer death will likely begin much later. These different stand development patterns of red alders and conifers appear to provide a wider range of forest structures in mixed red alder-conifer stands than expected for pure conifer or pure red alder stands, and benefit the plant and animal communities living there.

The forest structures of mixed red alder-conifer stands versus pure conifer stands have significant effects on forest ecosystem resources. Mature forests have complex forest structures including a wide range of tree sizes, snags, logs, and multiple canopy layers (Franklin et al. 1981). A major reason for improved understory plant diversity and abundance in partially cut stands is the wider range of tree size in these stands, compared to the simpler even-aged forests that develop after clearcutting (Deal and Tappeiner 2002). Mixed red alder-conifer stands also have a wide range of tree sizes and contain more open forest canopies than even-aged conifer forests, providing the complex and diverse forest structures important for wildlife.

Red alder stands may leave a legacy in these forests long after they have died and decayed. Gaps created where one or more large red alders have died leave conifer stands more open (Newton and Cole 1994). These gaps may also develop a second canopy by invasion of new trees. Longer term stand development is less certain, but without additional soil disturbances and enlargement of openings, western hemlock or other conifers are more likely to colonize the opening than red alder. The resulting complex canopy and open forest structure may occur decades earlier than in pure conifer forests where overstory tree death may not begin until stands are 150 years old. The longer term benefit of red alder may be that its death accelerates the transition to a mature forest structure.

The fate of dead trees, and the pathways from tree to stream woody debris are complex (Bisson et al. 1987, Benda and Cundy 1990, Bilby and Bisson 1998) but we gained more insight on them for both red alder and conifer. Nearly all of the dead alder and conifer wood recruited from these young-growth forests was small. This small wood entered streams and riparian forest floors, but appeared to play a minor role in retaining and routing stream sediment (Gomi et al., in review). Its main function is probably biological, providing substrate and food for invertebrates as in the case with leaf litter (Richardson 1992). The legacy wood from mature trees before the forests were cut provided physical functions (Figure 10). Although the larger live red alder and conifer trees in these stands may become future woody debris, it will take decades before the larger dominant and co-dominant trees begin to die. Because of their different life histories, we anticipate that larger red alders will die and fall to the forest floor and into streams well before larger conifers do, serving as an intermediate source of woody debris.

Red alders apparently serve important biological functions in forest ecosystems by providing nitrogen, high-quality organic matter for decomposers and invertebrates, and better light penetration through the forest canopy than pure conifer stands (Hibbs et al. 1994, McComb 1994). We observed more invertebrates in streams with more riparian red alder; and red alder stems and

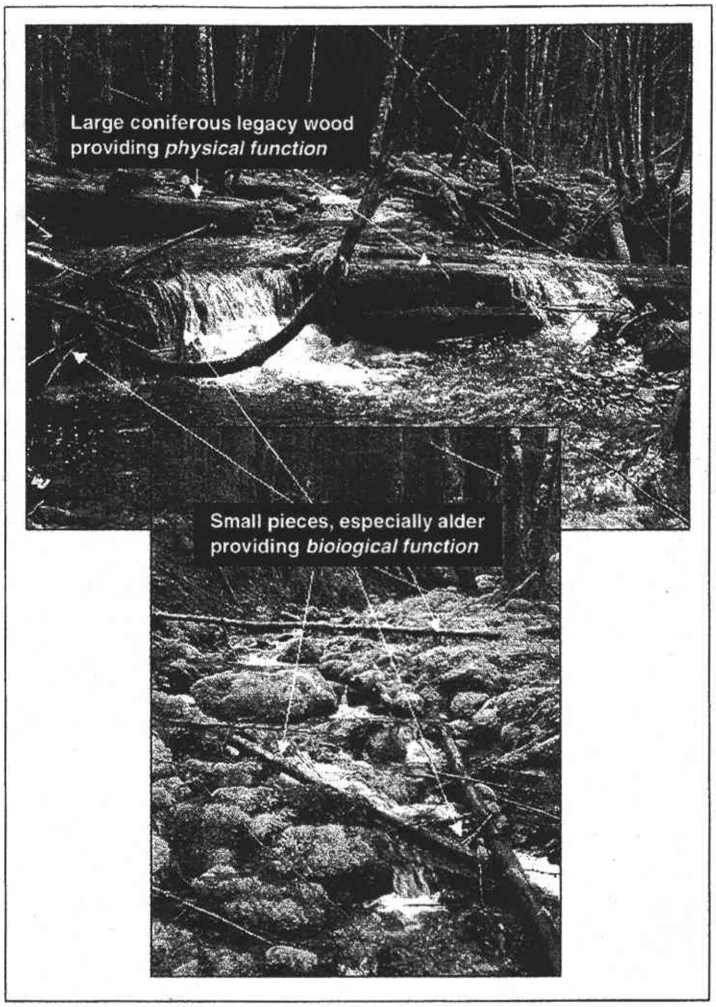

Figure 10. Red alder and conifer woody debris provides both physical and biological functions in streams and their riparian zones.

leaf litter supported greater invertebrate species richness than conifers. The smaller wood pieces–typically red alder–provided more habitat for invertebrates than larger pieces because of their higher surface-to-volume ratios. Management that balances the biological benefits of red alder with the physical benefits of larger conifers in young successional forests should offer the most benefits–both biological and physical–to stream and forest ecosystems.

Red alder increased the abundance of food in its immediate vicinity and in downstream reaches. Within red alder stands, vegetation for both invertebrate and vertebrate herbivores was increased by the presence of red alder, an observation consistent with previous work in southeastern Alaska (Hanley 1996, Deal 1997, Wipfli 1997, Hanley and Barnard 1998, Piccolo and Wipfli 2002). Increased prey availability likely affects many more species, such as bats and other small mammals, birds, and other wildlife in these young forested ecosystems. Also noteworthy was the trophic influence that upland red alder had on more distant habitats. Fish habitats downstream of red alder-dominated reaches were supplied with invertebrates (food for fish) and organic detritus (food for invertebrates) from upstream headwaters (Piccolo and Wipfli 2002, Wipfli and Gregovich 2002). And aquatic food webs downstream of red alder received more prey and detritus than those below conifer-dominated reaches (Wipfli and Musslewhite, in review).

Although these results are a snapshot in time approximately 40 years after timber harvest, the influence that these differing forest regeneration trajectories have is dramatic. Divergence between red alder- and conifer-dominated stands probably occurred early in post harvest development, and will likely continue for at least the next several decades before red alder die out (Deal and Orlikowska 2002). The influence of red alder on soil nitrogen supplies and plant associates may linger decades beyond the life span of the red alder itself.

9. Management Implications

These results suggest that red alder has an important ecological function in forested ecosystems in southeastern Alaska and corroborates other findings (Pechanec and Franklin 1968, Tarrant et al. 1983, McComb et al. 1993, Deal 1997, Wipfli 1997, Hanley and Barnard 1998). Several ecosystem responses showed positive relationships with increasing proportions of red alder, while a few did not. There are both benefits and tradeoffs of mixed red alder-conifer stands, but from an ecosystem perspective, benefits of including red alder in young-growth conifer forests seem to outweigh the negative aspects of red alder occurrence. Rather than viewing red alder as an undesirable, early-successional tree and managing it accordingly, there may be instances where managers can manipulate sites or existing vegetation to favor the establishment or maintenance of red alder. Altering the composition of young-growth forests to encourage a component of red alder may help improve habitat and food resources for deer, songbirds, and fish thereby offsetting some of the negative consequences and main criticisms of timber harvesting, particularly clearcutting.

Based on these findings, how would a resource manager manipulate the composition of a stand? Opportunities for increasing red alder in forests involve encouraging its reproduction (e.g., seeding, planting, regeneration through soil disturbance) in newly harvested or disturbed areas, and thinning to favor alder where the species already occurs. If deliberate red alder regeneration could be incorporated into present harvest plans while minimizing the mass wasting and sedimentation that resulted from the large-scale disturbances that favored red alder growth in the past, managers might be able to exploit the positive benefits of red alder and improve structure and function of young forests. Deliberately disturbing the soil surface enough to promote red alder regeneration at an appropriate scale and pattern, depending upon local site conditions could be beneficial in established even-aged forests that contain little or no red alder.

Although these results are from research conducted in the temperate rainforests of southeastern Alaska, they have much broader geographic and ecologic implications. Red alder is widely distributed throughout the west coast of North America (Harrington 1990), and other species of alder occur throughout the world (Murai 1964). These alder species undoubtedly have biological properties similar to red alder in southeastern Alaska, and presumably have similar ecological effects in other ecoregions and ecosystems where they persist. Developing or maintaining alder beyond the young regenerating forested ecosystems as demonstrated here will likely affect associated plant and animal species, populations and communities, and ecosystem structure and function.

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