

## AN ABSTRACT OF THE THESIS OF

Tara R. Nierenberg for the degree of Master of Science in Forest Science presented  
on November 25, 1996. Title: A Characterization of Unmanaged Riparian  
Overstories in the Central Oregon Coast Range.

Abstract approved:

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Riparian areas that can be used as reference sites on which to base goals of vegetation restoration have not been documented in the Oregon Coast Range. I examined the composition and distribution of unmanaged riparian overstories in the central Oregon Coast Range along nine streams which have experienced minimal disturbance from Native Americans and no detectable disturbance since Euro-American settlement.

I systematically located transects along nine streams, alternating sides of the streams. Each transect ran perpendicular to the stream and was subjectively divided into different vegetative and/or topographic units called landscape units (LU's). Rectangular plots were placed in each LU for characterization. LU1's were units that were closest to the stream, and LU2's were farther from the stream.

Red alder was the most frequently found tree species on both terraces and slopes, and on all LU1's. On LU2 terraces, alder was also the most frequently found species, but on LU2 slopes, Douglas-fir had the highest frequency. Red alder, Sitka spruce, and bigleaf maple were most commonly found occupying terrace sites, although bigleaf maple might be best adapted to conditions on terraces towards the base of slopes. Conversely, western hemlock and Douglas-fir were most commonly found occupying slope sites. Western redcedar was infrequently found, likely due to seed source limitations.

Age distributions and tree frequencies indicate that near-stream communities (LU1's) and terraces experience both intense and minor disturbances, and they experience both types of disturbances more frequently than communities farther from the stream (LU2's) or on slopes. According to fire records and reconnaissance, all streams appear to have been burned about 145 years ago. When equating a shade-intolerant tree age that was younger than this last catastrophic fire date with a disturbance, calculations of disturbance frequency using four different approaches indicate that between 2.6 and 4.5 disturbances per km per century large enough to regenerate trees occurred since the last stand-resetting fire along the nine creeks sampled.

Fifty-two percent of near-stream communities (LU1's) and 23% of communities farther from the stream (LU2's) contained no trees. This could be due to small plot size and/or high shrub competition. The No Tree overstory type was most similar in topographic conditions to the Pure Hardwood overstory type, suggesting that red alder and/or bigleaf maple might have previously occupied the No Tree sites and have since died leaving no or little evidence. It appears that a large-scale, intense disturbance such as fire is needed to allow the recruitment of trees into the shrub-dominated, No Tree areas, especially shade-intolerant trees such as Douglas-fir.

Any single definition of *natural* riparian vegetation is nearly impossible to construct, mainly because most ecosystems are composed of vegetation mosaics that are always changing in time and space. This change is associated with environmental variability, disturbance, and inter- and intra-specific competition. Also, differences in exogenous environmental conditions between pre-settlement times (circa 1850) and today, suggest that historic vegetation, ecological conditions, and resulting successional pathways might not mirror the vegetation, ecological conditions, and successional pathways of currently unmanaged riparian areas. Instead, results from this study, revealing the existence of mixtures of hardwoods, conifers, and no-tree areas over lengths of a stream, should be perceived as just one of many possibilities for a riparian overstory reference model.

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**A Characterization of Unmanaged Riparian Overstories in the Central Oregon Coast  
Range**

by

**Tara R. Nierenberg**

**A THESIS**

submitted to

**Oregon State University**

in partial fulfillment of  
the requirements for the  
degree of

**Master of Science**

**Presented November 25, 1996  
Commencement June 1997**

Master of Science thesis of Tara R. Nierenberg presented on November 25, 1996

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I understand that my thesis will become part of the permanent collection of Oregon State University libraries. My signature below authorizes release of my thesis to any reader upon request.

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Tara R. Nierenberg, Author

## Acknowledgements

I would like to thank the many people who helped me identify unmanaged Oregon Coastal riparian areas (Cindy McCain, Lynn Hod, Bob Metzger, Dan Karnes, John Martin, Jim Reim, and Jack Sleeper, all of the Siuslaw National Forest; Dr. Gordie Reeves, Dr. Bruce Hansen, Dr. Sarah Greene, and Scott Splean, all from Oregon State University), contributed to figuring out my sample design (Dr. Julia Jones and Dr. Mark Harmon of Oregon State University), allowed to me borrow their slides, database information, aerial photos or GIS mapping skills (Mike Klady and Cal Wettstein, from the Siuslaw; George Taylor and Kelly Christiansen from Oregon State University; Charlie Stein, and Kelly Moore from Oregon Department of Fish and Wildlife), or gave me permission to walk through and/or camp on their property and help me bake them salty blackberry pie (Franklin Creek access: Chris and Tom Richmond and 'Rocky,' the incredible creator of breakfast and morning song; Powder Creek access: Bev Johnson, Ed Hoffman, Tony Korwin, and Tony's goats).

During the middle stages (which consequently lasted a very long time), I think mostly of the generous resources that were offered to me either in the form of information, equipment, money, loaned articles and books, or raw brainpower. Many thanks to Dr. Robert Tarrant, Rob Pabst, Peter Impara, Rebecca Thompson, John Runyon, Sam Chan, Dr. Anne Hairston, Dr. Bob Beschta, Dr. Marv Pyles, Dr. Stan Gregory, and Dr. Pat Muir, from Oregon State University; and Glen Folkert, Dave LaFever, and Phil all in Forestry Supplies at OSU, who magically fixed the 'moosehorn' and sharpened the old tree corers like never before.

I could not have attempted data analysis without computer consulting expertise from OSU's Gody Spycher, the 'highland pauper,' statisticians Dr. Tom Sabin and Dr. Lisa Ganio, and Dr. Maciej Zwieniecki and Dr. Kevin Boston. Thank you all for kindly empathizing with the occasional blank SAS look on my face.

For the beginning of the end, I'd like to thank my committee members Dr. Tom Spies, Dr. Patricia Miller, and Dr. Lori Cramer, who bravely took the time to

weed through all of my ideas and typos, and who gave me some great suggestions. I should have worked more with all of you!

I'd especially like to thank my major professor, Dr. David Hibbs. For my future reference, Dave taught me that it's ok to be a professor and accidentally wear your slippers to school. Maybe this is why he always accepted me as a 'late morning' scientist. More seriously, I truly appreciate all of the patience and thoughtful feedback that you offered, Dave, as well as the many revisions that you astutely helped me to edit. I couldn't have asked for a better advisor. Oh yeah, and thanks for saving me from working at McDonalds.

Kathleen Avina too, gets her own paragraph, being my friend, field partner, and mucksister. Kathleen taught me all of the plants and trees in Oregon and amazingly let me free-associate ALL of my thoughts to her for summer days-on-end. Kat, thank you for making me laugh when I was stuck in the thorns, sharing my birthday, and unconditionally helping me to develop ideas. I'd also like to thank Birke Heeren for both precisely and amusingly help me collect field data.

Although cliché, I can't offer enough thanks to my friends, all of whom continually built up my personal energy, sometimes to their frustration. I will always remember all of the dinners that were made for me. Betsy Littlefield, Ruth Willis, Nicholas Gould, Kelly Sullivan, NaDene Sorensen, Dina Brown, Jenny Walsh, Jan Aagard, Maciej Zwieniecki, Alison Luckett, Alisa Nesje, Jennifer Gilden, Brad Withrow-Robinson, Heather Bonin, Eileen Helmer, Alice Murphy, I cherish you guys.

Most sincerely, I'd like to thank my Mom and Dad for believing in me when they had no idea what I was really doing 3,000 miles away.

Thank you China Delight.  
And thank you EH.

"I like trees because they seem more resigned to the way they have to live than other things do."

- Willa Cather

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(Harmon et al. 1986), and stream productivity through shading and detritus input (Bilby and Bisson 1992).

### ***Regulatory Definitions***

Current boundaries of riparian areas on State and private lands can be defined by riparian management areas (RMA's) which the Oregon Department of Forestry established in 1994 as part of the Oregon State Forest Practices Act. As of today, an RMA is defined as the area along a channel which varies with stream size and fish status. These categories include a) fish-bearing streams, b) non fish-bearing streams, and c) domestic use streams, and small, medium, or large (Adams 1994). The RMA for a medium-sized, fish-bearing stream, for example, is 70 feet on both sides of the channel (Adams 1994). Various silvicultural manipulations are allowed within RMA's, as long as a minimum amount of live conifer basal area is maintained or attained.

On federal lands, within the range of the Northern Spotted Owl, regulation in the Forest Ecosystem Management Assessment Team (FEMAT 1994) report defines riparian reserve areas by categories as well. These include a) fish-bearing streams (300 feet slope distance for both sides of the stream channel), b) permanently flowing nonfish-bearing streams (150 feet slope distance for both sides of the channel), c) constructed wetlands greater than 1 acre (150 feet slope distance from the edge of the wetland), d) lakes and natural ponds (300 feet slope distance), and e) seasonally flowing or intermittent streams, wetlands less than 1 acre, and unstable or potentially unstable areas (100 feet slope distance for both sides of the stream channel) (FEMAT Report 1993). If site potential tree heights (1 or 2 depending on the category) are taller than the given widths, or if soil saturation or the 100-year floodplain extend beyond the given distance, then the riparian reserve width is based on the largest

distance. Similar to the State rules, silvicultural manipulations are allowed within the federal riparian reserves.

## **Justification**

Since global warming began after the last glacial period about 18,000 years before present, precipitation has increased and several different large-scale vegetational communities have come and gone. A climate similar to the present one has existed along the Pacific Northwest Coast for the past 3,000 to 7,000 years (Benda 1994), and the current vegetation types have existed for about 4,000 years (Hibbs 1996). Anthropogenic disturbances such as Native American fires and animal trapping affected the Oregon Coast Range before the present vegetation types were in place (Hibbs 1996). These Indian-set fires possibly gave rise to Douglas-fir dominance in the Coast Range. Later, activities such as timbering, farming, splashdamming, mining, further beaver trapping, and fire control came with the first Euro-American settlers from the Hudson Bay Company in 1843 (Hibbs 1996; Bisson et al. 1992, Kauffman 1988).

Post-settlement activities have had a large impact on riparian areas throughout the Oregon Coast Range (Kauffman 1988). Features of the altered ecosystems might include reductions in stream biota diversity, changes in vegetation distributions, and losses of habitat structures requisite for the health of certain fish species' populations (Reeves, et al. 1995, Beschta 1996). Such changes can also alter chemical inputs and outputs; extreme changes alter the reduction-oxidation balance and increase the biological oxygen demand of the stream biota (Kauffman 1988).

Interest in enhancing the components of streams that maintain water quality, fish and wildlife populations, and ecosystem diversity has increased. Large coniferous woody debris, contributions of organic matter to streams and floodplains, and

adequate stream temperature/shade for fish and wildlife, aid in maintaining lateral, longitudinal, and vertical connections between aquatic and terrestrial systems (Naiman et al. 1992). However, a model riparian area to serve as a base line against which to judge other riparian systems has not been formulated for the Oregon Coast Range.

Any land manager wishing to manipulate ecological dynamics at either the stand or landscape level needs some kind of blueprint, even if only a rough guide is possible (Lorimer and Frelich, 1994). One option is to emulate riparian forests that have been untouched by Euro-Americans, and equate a model riparian area with pre-settlement conditions with the acknowledgment that Native Americans set large-scale, intense fires which may have burned through riparian areas. However, all stream systems in the Oregon Coast Range have been affected by Euro-Americans. As such, our best option is to define a reference site in present day Wilderness Areas or Natural Areas. These areas are the best models that we have today to reference because they have been least impacted by Euro-Americans, and they may represent conditions prior to Euro-American settlement.

The goal of this study, in accordance with the goals of Coastal Oregon Productivity Enhancement (COPE), was thus to quantify the compositions and distributions of dominant riparian overstories along unmanaged streams in the Oregon Coast Range, in stream reaches which, other than fire, have experienced no major direct disturbances from Euro-American settlers, and only minor disturbances from Native Americans. Only areas that have never been logged or splashdammed were considered in this research.

Although the combination of the variety of stream types and land uses in the Pacific Northwest presents a difficult challenge in identifying and evaluating fundamental, system-level components of ecologically healthy watersheds (Naiman et al. 1992), land managers must understand the biological characteristics that they are setting out to emulate in order to identify objectives for riparian rehabilitation (Beschta 1996). This study intends to provide land managers with a baseline description of

unmanaged riparian overstories in the Oregon Coast Range, for applications such as identifying objectives for riparian rehabilitation, or developing comprehensive forest management plans (COPE Progress Report, 1993). The results are aimed at heightening the awareness of reforestation possibilities for riparian ecologists, silviculturists, educators, and other land managers, and providing new information for the interrelated field of stream ecosystem management.



## 2. OBJECTIVES

The general purpose of this study was to infer characteristics about preEuro-American settlement (circa 1850) riparian forests in the central Oregon Coast Range by using present day unmanaged riparian forests, acknowledging the major elements of change since 1850. Presettlement riparian areas were approximated by characterizing present day Wilderness areas and other unmanaged areas, acknowledging that fire regimes changed circa 1850 from the Native Americans' annual fire regime to the settlers' more sporadic and variable fire regime, and changed again with current fire suppression policies. I intend to answer such questions as, were pre-settlement riparian areas conifer-dominated? Are natural disturbances frequent? Is regeneration common? The answers to these questions will be integrated into the discussion. This project is part of a larger research effort, Coastal Oregon Productivity Enhancement (COPE), and a baseline and necessary step to meet COPE's ultimate goal of developing new information on reforestation and management of riparian zones (COPE Report, April 1989). Specific objectives are as follows:

*Objective 1:* Quantify composition of dominant riparian forest overstory communities along undisturbed streams in the central Oregon Coast Range.

*Objective 2:* Quantify distribution of dominant riparian forest overstory communities along undisturbed streams (how vegetative communities change as one moves perpendicularly away from the stream) in the central Oregon Coast Range.

*Objective 3:* Relate composition and distribution of riparian forest overstory communities to environmental factors such as height-above-stream, physiographic

position, elevation, aspect, precipitation, distance from the coast, stream order, stream distance, and stream gradient.

*Objective 4:* Discuss how findings apply to riparian area management.

### 3. LITERATURE REVIEW

#### Land Use History and Policies

For traditional Native American cultures of the Pacific Northwest, riparian zones were a central part of survival (Honey et al. 1944). Unlike agrarians, the Native Americans' relatively low population density and less intensive technologies such as dipnets, fish traps, and seines imposed low impacts on the streams and fish populations. After the first wagon train filled with hunters and trappers from the Hudson Bay Company ventured to the "new land" of the Oregon Coast Range in 1843, however, many changes began to take place (Morris 1934). Euro-American pioneers soon began settling throughout the Oregon Coast Range, and it was at this time that humans began to directly alter the structure of the riparian forests.

W. Honey et al. (1944) noted that with the onset of pioneers, forest cutting clogged streams with debris; valley floodplains were cleared of forests for agriculture; soil erosion increased; miners changed the courses of rivers and streams to extract minerals; fish runs were over-exploited to produce food for export; drinking water demands increased; and later, railroads and highways changed the orientations of rivers. In the nineteenth and twentieth centuries lumbermen denuded some waterways by transporting logs with splashdams and reset riparian forests to alder and brush (Sedell et al. 1982). This heavy use continued for at least a century as the activity moved across the Coast Range. These large-scale disturbances decreased water quality, reduced fish populations, and reduced suitable habitat for wildlife, and regeneration of commercially valuable conifers.

In response to the latter disturbances, in 1973, the Oregon Department of Forestry established rules requiring buffer zones along streams. These rules focused on maintaining or increasing shade along streams and reducing sediment input. These

state laws came into effect about the same time as the enactment of the National Forest Management Act (NFMA) as a series of amendments to the Forest and Rangeland Renewable Resources Planning Act of 1974. Also, the federal Endangered Species Act (ESA) was passed in 1973, which prompted the formation of a state group called the Oregon Endangered Species Task Force. This group recognized old-growth forests as spotted owl habitat. NFMA regulations dictated fish and wildlife habitats to be managed to maintain viable populations with a minimum number of reproductive individuals, and habitat to be well distributed so that individuals can interact (Caldwell et al. 1994). Additionally, the Oregon Endangered Species Task Force named the spotted owl as an “indicator species” under the wildlife diversity requirements of NFMA. Throughout the 1980’s, conflict arose between protecting endangered species by protecting ecosystems and sustaining forest-dependent communities (Caldwell et al. 1994). This discord led to the creation of FEMAT in April, 1993 which developed policies aimed to break the strife over management of federal forests of the Pacific Northwest (see above Definition of Riparian Areas).

Twenty-one years after the Oregon Department of Forestry’s buffer zones were established, forest managers and fisheries biologists began recognizing the importance of large and long-lasting pieces of wood as structures for fish habitat, and they began focusing on such issues as water quality. To include the new objectives regarding recruitment of long-term sources of large conifers, both alive and dead, as well as to maintain or increase water quality and fish populations, Oregon Department of Forestry enacted new State riparian rules in September of 1994. The new rules are more flexible than the rules of 1973, and they include expanded stream classifications to consider stream flow and fish status, allowing for site specificity (see above Definition of Riparian Areas). The new rules strive to protect interrelated riparian functions on private and State lands.

Currently, public natural resource organizations, including the Oregon Department of Forestry, are interested in monitoring the new rules, and private land

owners are concerned about the value of the rules as guidelines for their own riparian woodlands. One way to assess the success of the new riparian rules, as well as reinforce the validity of their objectives, is to compare future managed sites under the riparian rules guidelines with reference sites that have never been logged nor majorly disturbed by humans. Presently, the vegetative species composition and structure are not scientifically documented for coastal Oregon riparian zones. A riparian inventory is fundamental and essential to any study or assessment of riparian zone conditions in coastal Oregon (COPE Progress Report, 1993). In general, management of riparian zones is severely hindered by a lack of information about the ecological characteristics and dynamics of unmanaged riparian zone vegetation. This study intends to contribute that information.

## **Fire History**

Due to the warmer and drier climate of the Hypsithermal period (8,000-4,000 B.P), oak savannah dominated the Willamette Valley for over 6,000 years, where conditions prevented the establishment of a closed canopy forest (Boyd 1986). Despite the cooler modern climate amenable to forest growth in the Willamette Valley, Kalapuya Indians perpetuated oak savannahs by setting annual fires for the purposes of tracking large game, locating hostile enemies, cycling nutrients for spring green-up, clearing the ground to better find honey and grasshoppers (Douglas 1826), and for harvesting tarweed (*Madia spp.*) and tobacco (Boyd 1986). While the Native Americans used fire to maintain an oak savannah as a young seral stage, they also left groves of conifers such as Douglas-fir, possibly for wildlife cover (Douglas 1826).

Although the main part of the Coast Range was not heavily inhabited at the time of Kalapuyan fire activity in the Willamette Valley (Morris 1934), some fires made their way to the margins and interior of the Coast Range. The Kalapuyans

seasonally utilized plants such as salal (*Gaultheria shallon*), Oregon grape (*Berberis nervosa*), and other berries (*Rubus and Vaccinium spp.*) (Boyd 1986). A few Salishan Tillamook and various coastal Penutian peoples inhabited the coast at the time of the Kalapuyans, but salmon was their main sustenance (Boyd 1986). Ripple (1994), however, states that the Tillamook Indians of the Oregon Coast Range used fire for hunting game, which could have ignited some coastal fires.

In 1812, seasonal trappers and traders began coming into contact with the Native Americans, and in 1841, Charles Wilkes from the Hudson Bay Company tallied the Kalapuya population as 600, due to an malaria epidemic brought over by the Europeans (Boyd 1986). Large-scale annual burnings by the Kalapuyans continued over segments of the valley until Euro-American settlers forced an end to them in the mid-1840's (Boyd 1986).

In 1845-1855, many Euro-American settlers migrated to the Willamette Valley and Coast Range. It was during this period when the great fires were said to have occurred, spanning from the Cascades to the Coast Range (Morris 1934). It was said that it was so difficult to navigate in the thick smoke from a fire in 1845 (Nestucca fire), that sailors had to remain at the mouth of the Columbia (Munger 1944). Another great fire was recorded in 1846, extending from Tillamook down to Coos Bay. Also, the Umpqua fire in 1846 burned most of the current Mapleton district (Morris 1934). In 1849, 500,000 or more acres of forest burned during the Florence fire between the Siuslaw and Siletz rivers (Morris 1934). By 1908 it became a law not to set intentional fires, but many people kept burning for farming purposes (Teensma et al. 1991). Large fires continued to arise, including the Tillamook fire in 1933, when 225,000 acres were burned (Morris 1934). By 1933, commercial logging had become extensive and strict fire control was in effect (Morris 1934). The last large-scale fire recorded was the Tillamook burn in 1933, but my study sites were not in its range.

Fires in the Coast Range probably do not have a regular cyclical frequency, but they are high-intensity stand-replacing fires, occurring at intervals from 150 to 350 years (Teensma et al. 1991). Furthermore, Coast Range forest stands are more even-aged than those of the central Western Cascades, due to less underburning and higher fire intensity (Teensma et al. 1991). From charcoal records in Little Lake, Oregon, Long (1996) reconstructed fire history of the last 9,000 years for the Oregon Coast Range. He found that for the last 2,000 years, the Coast Range fire return is about every 175 years.

Impara (in progress) is presently engaged in a systematic dendrochronologic study of fire history and fire regimes in the Oregon Coast Range. He is investigating the interaction of topographic and climatic patterns on the process of fires to address the role of fire as an ecological process and its effects on the Central Oregon Coast Range forest ecosystem over the last 500 years. Similarly, Chen (in progress) is currently composing chronicles of fire occurrences in the Oregon Coast Range.

The effects of fire on riparian vegetation can be direct through burning, and indirect, by causing erosion within an entire watershed (Hall 1988). Erosive forces tend to import woody debris into the riparian forests and stream channel. Crown fires can temporarily reduce interception and transpiration, as well as increase water flow and alter chemical composition (Hall 1988). Fire tends to enrich soils by hastening nutrient cycling. It also creates large segments of substrate for new regeneration, especially for shade-intolerant species.

Fire suppression in the Willamette Valley and Coast Range has been changing the landscape. Shade tolerant species have been encroaching, and the oak savannahs have been shrinking. In the Coast Range, shade-intolerant species such as Douglas-fir need fire for regeneration (Means 1982) because it creates bare mineral soil and open conditions. Fire suppression will hence be a limiting factor in Douglas-fir natural regeneration if management continues to enforce fire suppression beyond the Coast Range's estimated fire return interval of about 175-250 years (Long 1996; Benda

1994). Also, the decrease in small fires might already be changing the course of succession in some areas of Coast Range forests.

## **Riparian Zone Characteristics**

### ***Vegetation***

Riparian studies have focused on the general effects of different management practices on stream ecosystems (Hibbs, 1987; Newton, 1989; Chan et al. 1993) and on the function and structural influences of large woody debris (Sedell and Swanson 1982; Grette 1985; Harmon et al. 1986; Ursitti 1990; Beschta, 1991), but relatively few published articles have characterized unmanaged riparian areas, especially in the Oregon Coast Range. Recently, however, Poage (1995) demonstrated the existence of multiple fires in some riparian zones of the Coast Range by studying two sample areas. He also cited the existence of remnant old-growth riparian trees, the patchy mosaic of riparian vegetation, the structural differences between deciduous- and coniferous-dominated riparian stands, and the spatial scale of aggregation of riparian vegetation patches. Pabst and Spies (submitted) carried out a gradient analysis for understory vegetation in unmanaged Coast Range riparian areas, and found the salmonberry and sword fern are the most commonly found species. Rot (1995) examined the interaction of valley constraint, riparian landform, and riparian plant communities size and age upon channel configuration of small, low gradient streams of the western Cascade Mountains. Chan et al. (in preparation) are working in red alder-dominated riparian sites to assess the effect of different levels of overstory and understory retention on the response of six planted tree species to manipulated growing conditions in the Oregon Coast Range. So far, their data are suggesting that blanket regeneration prescriptions across a landscape do not yield productive conifer



growth (COPE Symposium, 1993- Regeneration of Riparian Areas). Similarly, the Adaptive COPE team is in the process of determining the most successful method of establishing conifers in riparian zones in the Oregon Coast Range, also using understory and overstory treatments (COPE Symposium 1993- Restoration Ecology of Coastal Riparian Areas).

Some studies have characterized the composition and distribution of riparian vegetation, although not necessarily in unmanaged ecosystems (Kauffman et al. 1985; Carlson 1989; Evenden 1989; Gecy and Wilson 1989; Ursitti 1990; Giordano and Hibbs 1993; Minear 1994; Benda 1994). Swanson et al. (1982) examined the structure and composition of current riparian vegetation along different watersheds in the H.J. Experimental Forest on the Willamette National Forest. They found that in a sampling of first- through third-order streams, larger streams have higher shrub cover as well as larger shrubs and smaller trees, apparently in response to greater light availability due to an opening of the overstory. They also found that variation in this large herb/small tree strata is associated with substrate type and disturbance history. Most of their research, however, along with others (Meehan, et al. 1977; Rot 1995) focuses on how vegetation affects streams, stream biota, and channel configuration.

Minear (1994) examined historical change in riparian vegetation along the McKenzie River and two associated tributaries in the Oregon Cascades and found that the construction of dams, agriculture and clear cuts, have resulted in a decrease in mature riparian conifers by 44% from levels in the 1940's, and an increase in riparian hardwoods by 45%. Sedell et al. (1982) documented the features of streams in old-growth forests of the Pacific Northwest and Alaska and noted an abundance of woody debris, a mix of coniferous and deciduous leaf litter, and large gaps which allow algae to establish in the stream. Meehan et al. (1977) and Swanson et al. (1982) developed hypothetical succession models for riparian zones, which accounted for the phasings of deciduous and coniferous dominance.

Campbell and Franklin (1979) characterized riparian shrub and herb communities along small streams in the Oregon Cascades and found distance from stream and stream size to be important determinants of vegetation type. Relating to riparian forest succession, they also noted that stands composed of permanently young seral stages may be salient features of active riparian zones. Also in the Cascades, Kauffman, et al. (1985) identified 258 stands of vegetation representing 60 vegetative communities along Catherine Creek in northeastern Oregon. They believed that the contributing factors to species diversity included soil characteristics, streamflow dynamics, plant community interactions, animal effects, and humans' effects, although the main objective of their study was to provide a vegetation inventory.

Presettlement vegetation studies have been carried out all over the United States for various types of land classes (Vale, 1975), but few studies have characterized riparian vegetation, especially before large-scale human disturbances took place (Carlson, 1989). One possibility for the scarcity of research on riparian areas is the paucity of unmanaged riparian sites. Also, riparian zone research is caught between scientific disciplines as well as between habitat components (Swanson, et al. 1982). Finally, riparian vegetation in forested mountains has smaller economic value than upslope vegetation, and this sets riparian research at a low priority.

### ***Disturbances***

Varying types, frequencies, intensities, extents, and timings of nonhuman disturbances have tremendous effects on riparian systems (Agee 1988; Resh et al. 1988; Andrus and Froehlich 1988; Gecy and Wilson 1989; Swanson 1994; Reeves et al. 1995; Benda 1994). A general definition of disturbance in a stream ecosystem can

be defined as any relatively discrete event in time, originating either endogenously or exogenously, that is characterized by a frequency, intensity, and severity, and disrupts ecosystem, community, or population structure and changes resources or the physical environment (White 1979; Resh et al. 1988). Disturbance processes common on uplands typically decrease toward the channel as fluvial disturbances increase (Agee 1988), although where the stream is flush against the valley wall, upland processes and fluvial processes affect the riparian zone at more equivalent intensities (Swanson 1994). Overall, disturbance tends to increase age-class diversity of riparian forests (Stromberg et al. 1993). To preserve evolutionarily significant units (ESU's) of anadromous salmonids in watersheds of the Pacific Northwest, Reeves et al. (1995) advocate not returning to the natural disturbance regime, but rather creating a range of habitat conditions at scales in space of  $10^3$  km, and in time of  $10^1$  -  $10^2$  years. Predominant disturbances in riparian areas include floods, debris flows due to geomorphology and landform type, fire or lack of fire, herbivory, and wind (Wissmar and Swanson 1988).

### *Fluvial disturbances*

Hydrologic disturbances act in two ways: seasonal flow variation and catastrophic flooding events. (Hall 1988). Seasonal decreases in average channel width in the H.J. Andrews Experimental Forest in Blue River, Oregon ranged from 60% for first-order streams to 16% for fifth-order streams (Swanson et al. 1982). Summer drought in Oregon therefore has a significant influence on vegetation. Minimum flows in the Pacific Northwest occur in August and September due to lack of precipitation, but melting snow pack and increased precipitation cause peak flows in the winter months. Winter high water tends to cut streambanks as well as deposit sediment and debris (Hall 1988), and it is a mechanism for seed dispersal. Along the

Gunnison River in Colorado, Auble et al. (1994) defined three vegetative cover types that they claimed were solely determined by inundation duration. They acknowledged, however, that no single water level variable can explain riparian vegetation responses, and mentioned that recurrence interval is an important parameter as well in defining riparian vegetation types. Auble et al. (1994) concluded that it is possible for major changes in riparian vegetation to take place without changing mean annual flow because riparian vegetation is especially sensitive to changes in minimum and maximum flows. In the western Cascades of Oregon, Rot (1995) found the composition of a mature/old-growth riparian plant community to be determined by fluvial disturbances and successional processes.

On the lower White River floodplains south-central Arkansas, Bedinger (1971) found a relationship between the frequency and duration of flooding and the distribution of forest tree species. For example, comparing forest-species assemblages on the White River, a floodplain which was saturated 35-40% of the time displayed distinct differences than a floodplain that was saturated every year for a relatively shorter duration. Flooding, at 10 to 100- year intervals, can kill near-stream vegetation through uprooting, and terrace washout (Stromberg et al. 1993). Associated flood processes such as shear stress, sediment deposition and erosion, soil moisture, depth to groundwater, and soil oxygen concentration (Auble et al. 1994) can create new landforms on which vegetation can establish, disperse seeds, maintain species diversity, aid in nutrient cycling and productivity, and initiate species replacement patterns (Stromberg et al. 1993). Specifically, sediment deposition can batter vegetation as well as regenerate it by initiating sprouting or laying down new substrate (Swanson et al. 1982). Flooding and high water can also form elevational gradients, where plants exhibit varying tolerances for water and sediment (Wissmar and Swanson 1988).

Some species require floods for optimum germination and growth of seedlings because of the resulting mineral deposits, removal of herbaceous and shrubby

competition, and moistening of landforms at the appropriate time (Hall 1988; Stromberg et al. 1993). Flood-dependent species growing in areas distant from the channel are hence reliant on 25- 50- or 100-year floods for their regeneration. Stromberg et al. (1993) found that herbaceous understory vegetation in high-elevation floodplains of the Hassayampa River in Arizona eventually shifted in composition from a dominance of exotic annuals to more diverse mixtures of native and exotic annual grasses and forbs after a 10-year flood. They also found that survivorship of overstory trees was related to floodplain elevation, distance from the stream, and water depth, whereas survivorship of shrubs more closely corresponded to topographic position on the floodplain. A lack of or decrease in flooding is often a greater disturbance to riparian forests than is flooding (Sparks et al. 1990).

### *Geomorphology and Landforms*

Geomorphic processes and valley floor landforms (Swanson 1980; Franklin et al. 1982; Swanson et al. 1988; Gregory et al. 1989; Grant and Swanson 1995) strongly interact with and provide a template for terrestrial and aquatic communities. Vegetation composition, distribution, and age-classes over riparian landscapes are determined by the interactions between geomorphology, landforms, and vegetation itself (Campbell and Franklin 1979; Swanson 1980; Rot 1995). Moreover, different intensities and frequencies of exogenous events make for geomorphic variation, resulting in varying vegetation responses (Swanson 1980). Precipitation, for example, induces base-flow erosion and physiological responses of individual plants, whereas extreme storms can cause periods of accelerated erosion, initiating secondary succession (Swanson 1980).

Landforms have their greatest effect on vegetation development through microclimate, soils, and hydrology (Swanson 1980; Rot 1995). Vegetation often

varies with respect to physiographic position, slope, and aspect, three variables which contribute to moisture gradients, temperature, and quantity and type of nutrients (Swanson et al. 1988). Results of this environmental variation are usually seen in mesic vegetational communities existing along streams, and more xeric types on the ridges, as well as a greater extent of mesic types on aspects that do not face the afternoon sun (Swanson 1980). Effects of fluvial disturbances on vegetation development also vary with geomorphic features such as channel substrate (bedrock, boulder, cobble, gravel, sand) (Resh et al. 1988) and stream order (Naiman et al. 1992). Grant and Swanson (1995) developed a valley floor width index which described variation in the shape of the valley floor for different reaches in two mountain streams in western Oregon. This index consists of the ratio of the approximate width of the (Holocene) valley floor (surfaces less than or equal to 3 meters above base flow) to the active channel width. This index may be part of a predictor of vegetation mosaics in riparian areas (Avina, in progress).

Geomorphic processes, or mechanical transport of organic and inorganic material (Swanson et al. 1988), which includes surface erosion and mass movement, can tip, split, or uproot seedlings and trees, herbs, and shrubs. Surface erosion and stream bank cutting can create fresh sites for seedling establishment, and filter plant species by preferentially moving seeds. Overbank deposition of fine sediment may suppress herbs through suffocation, but also facilitate species which root on disturbed bare mineral soil. A process that this study could not have possibly captured due to its single place in time was channel movement. However, the physical and biological organization of riparian forests can often be highly attributed to channel migration, which appears to affect the distribution, successional pathway and size of forest stands (Gregory et al. 1989).

### *Landslides and Debris Flows*

Temporal and spatial variation in sediment supply strongly affects morphology and landforms (Benda 1988). This variation accrues strong effects on riparian vegetation (Gecy and Wilson 1989; Benda 1994), especially in humid mountainous areas (Veblen and Ashton 1978). Debris flows can strongly influence vegetation types by creating a variety of substrates. In the Oregon Coast Range, episodic debris flows result in gravelly substrate, while the absence of debris flows results in a mixed bedrock and boulder substrate sometimes at the scale of a stream reach (Benda 1990). Benda and Dunne (1987) claim that landslides and debris flows are the primary sources of silts and clays in low-order streams, whereas fluvial processes account for only 10 to 20% of the total sediment yield. They estimated recurrence intervals of debris flows in the Oregon Coast Range to be on the order of centuries. Pyles (personal communication) cites that about 60% of landslides in the Coast Range occur at inner-gorge reaches, where the valley is v-shaped and constrained. Similarly, Benda (1994) claims most landslides occur in bedrock hollows. Benda (1988) also states that landslide/debris flow-prone first- and second-order channels comprise up to 95% of the total number of channels.

The frequency of relatively small-scale (< a stream reach) stream-side landslides is difficult to find in literature. This is mainly due to the fact that most landslides are recorded from aerial photos, where small-scale soil processes are nearly impossible to detect (Pyles, personal communication). From personal observation, I believe small-scale landslides (4 square meters) to be frequent. Since the Oregon Coast Range has a large component of Tyee Sandstone, a soft, unstable parent material, an elk climbing on a hillslope, for example, can trigger a mini landslides up to 2 m<sup>2</sup>. It is possible for these “mini landslides” to occur on a daily basis on the scale of a few square meters up to a stream reach, creating gaps and enough bare soil to alter community dynamics.

Benda (1988) found that landslides trigger debris flows in first- and second-order channels in the Oregon Coast Range. These debris flows have been found to move at a velocity of 16 m/s along a second-order channel in the Oregon Coast Range; 71% of first-, second-, and third-order stream debris flows were deposited at tributary junctions with angles typically close to 90 degrees (Benda 1988). In mid-order streams in the Oregon Coast Range, landslides and debris flows can deposit sediment and vegetative material from 1,000-10,000 m<sup>3</sup> (Naiman et al. 1992). Low-order streams tend to have landslides and debris flows occurring at the most extreme magnitudes and relatively average frequencies; mid-order streams tend to have landslides and debris flows occurring at the overall highest magnitudes and relatively average frequencies, and high-order streams experience few landslides and more floods at higher frequencies (Naiman et al. 1992). The patterns of landforms created by debris flows depend on valley floor geometry, location of debris flow producing tributaries, and the longitudinal sequence of reaches (Grant and Swanson 1995).

In the Western Oregon Cascades, Gecy and Wilson (1990) found that overall, vegetative sprouting accounted for 77% of the re-establishing cover after a debris flow, yet 67% of the re-establishing individuals were seedlings and not vegetative sprouts. Total cover was highest on light intensity scour, sprouting was highest on light and moderate scour, and seedling density was highest on fine and gravel deposits. Red alder established predominantly as seedlings. Gecy and Wilson (1990) did not confirm the results of Campbell and Franklin (1979), though, who found that the topographic position relative to the stream had a significant influence on total cover and vegetative regrowth after debris flows. Gecy and Wilson (1990) attributed this anomaly to the fact that topographic position would not have a visible effect on community gradient patterns until later in succession. Furthermore, Gecy and Wilson (1990) found that after a debris flow, tree species establishing within the hardwood- and conifer-dominated reaches were often the same species that were present in the adjacent undisturbed areas.



## *Animals*

Mountain beaver (*Aplodontia rufa*) and fur beaver (*Castor canadensis*) strongly control processes in riparian forests and stream channels (Naiman et al. 1992). They are continual pruners of shrubby vegetation, which lessens competition for the establishment of regenerating near-stream tree species. Furthermore, their selective foraging can alter tree species composition and related habitat availability for other wildlife (Hall 1988). Johnston and Naiman (1990) found beaver herbivory to decrease tree density and basal area by 43% within forage zones around beaver ponds. Beavers also contribute large amounts of woody debris to streams since most of the wood they fell is not ingested (Naiman et al. 1992).

Their burrows sometimes pipe water into mass movement prone areas, thereby increasing the potential for soil mantle failure (Pierson 1977). Their dam building changes flow regimes, sediment storage, and nutrient fluxes, and tends to flood nearby vegetation (Pierson 1977). These changes can cause long-term shifts in forest stand succession. Beaver ponds are known to provide overwintering areas for some coastal fishes, lentic species, and stream-dwellers preferring slower velocities (Naiman et al. 1992). Their ponds also serve as important storage sites for detritus entering the stream (Naiman et al. 1992), hence regulating nutrient availability downstream. Deiter and McCabe (1989) found that in South Dakota along the Big Sioux River, grazed areas had a low tree density relative to ungrazed areas, as characterized by scattered large trees with few young trees present. Most of the trees (90%) were sandbar willows (*Salix exigua*).

Other wildlife such as deer (*Odocoileus hemionus* and *O. virginianus*) and elk (*Cervus elaphus*) tend to alter the abundance of understory through browsing or trampling. Also, from personal observation, I have seen elk trigger small landslides (< 2 sq. meters) on slopes underlain by soft Tyee Sandstone. Birds, slugs, and insects also play a large part in riparian area interactions.

## Physiological Characteristics and Regeneration Requirements of Major Tree Species

Red alder (*Alnus rubra*) can be characterized as an invader species (Agee 1988) which colonizes first after disturbance. It requires bare mineral soil and mesic conditions for regeneration (Harrington 1990), and has short-lived propagules, a relatively short life span of an average of 80 years (Harrington et al. 1994), and low shade-tolerance. Red alder disperses across many microsites after flooding, and grows quickly on favorable sites (Agee 1988).

Red alder maintains certain adaptations which enable it to dominate on floodplains. One adaptation is red alder's ability to fix nitrogen (Harrington 1990), which is frequently a limiting nutrient in sand/gravel substrate relatively devoid of organic matter due to flood scouring (Rot 1995). Red alder's growth is unaffected by flooding during winter dormancy and tolerant during the growing season (Harrington et al. 1994). Red alder maintains a fast juvenile growth rate (Harrington 1990), and it is able to reproduce by seed by the young age of 3 (Harrington et al. 1994). Red alder can also endure disturbances because it can sprout when young and produce adventitious roots (Harrington et al. 1994). Alder's small, winged seeds makes wind dissemination very effective (Harrington 1990). Red alder has been known to grow in pure stands or mixed stands of either other shade-intolerant species, such as Douglas-fir, or more shade-tolerants, such as western redcedar or western hemlock (Harrington et al. 1994). However, it must maintain canopy stature to survive in mixed stands (Harrington et al. 1994). Gecy and Wilson (1990) found that red alder seedlings were abundant only on the hardwood-dominated reach after a debris flow in the western Cascades.

Bigleaf maple (*Acer macrophyllum*) is known to be abundant in moist, deep, gravelly soils, and even in seepage areas, although it is not as flood-tolerant as red alder, Sitka spruce, or western redcedar (Minore and Zasada 1990). Bigleaf maple is not usually able to survive long periods of flooding (Minore and Zasada 1990), and it

has been noted to sprout in response to frequent, low intensity high-water events, longer-term winter high water, or herbivory (Fried et al. 1988). Under various ages of Douglas-fir stands in western Oregon, the ideal time for bigleaf maple to establish was found to be after Douglas-fir canopy thinning and before understory invasion (Fried et al. 1988). Bigleaf maple is therefore of intermediate shade-tolerance, and it requires some shade for successful establishment. Fried et al. (1988) found that in western Oregon, bigleaf maple rarely occurred in pure stands, but rather, especially on upland sites, it was typically mixed with conifers.

Douglas-fir (*Pseudotsuga menziesii*) is well adapted to fire, but poorly adapted to flooding, making it more of a near-stream avoider (Agee 1988). It is easily killed by sediment suffocation or inundation (Hermann and Lavender 1990). Douglas-fir regenerates best on bare mineral soil and is shade-intolerant (Hermann and Lavender 1990), and unable to reproduce under dense stands of itself. It bears deep roots and is more windfirm than most conifers (Minore 1979). Gecy and Wilson (1990) found Douglas-fir seedlings to be most abundant on conifer-dominated reaches after a debris flow in the western Cascades.

Western hemlock (*Tsuga heterophylla*) is generally poorly adapted to floods and can be labelled a near-stream avoider (Agee 1988). However, western hemlock is noted to survive on floodplain habitats (Minore 1979), and as an adaptation to high water, it can produce adventitious roots (Minore 1979). Hemlock tends to grow at higher elevations where large alluvial fans are infrequent and steeper headwaters compose the terrain (Packee 1990). It is able to grow under low light conditions, and is often found establishing on nurse logs (Packee 1990). Western hemlock has very shallow (yet extensive) roots (Minore 1979) and is susceptible to blowdown. Gecy and Wilson (1990) found that after a debris flow in the western Cascades, hemlock seedlings were most abundant on conifer-dominated reaches.

Sitka spruce (*Picea sitchensis*) has a range that is limited mostly to the coastal temperate zone (Franklin and Dyrness 1973), and it establishes as a pioneer species

on immature soils recently exposed by uplift from the sea (Harris 1990). Sitka spruce best regenerates on mineral or organic soils, and sometimes establishes on rotten wood (Harris 1990), requires a high water table with adequate drainage (Harris 1990), and is commonly found on floodplain habitats (Minore 1979). Spruce tends to come in on highly disturbed sites (Harris 1990) and is able to sprout adventitious roots (Minore 1979). It is fairly shade-tolerant and has been noted to grow to larger diameters faster than its associate species in the coastal zone (Franklin and Dyrness 1973), *Tsuga heterophylla* (Minore 1979).

Western redcedar (*Thuja plicata*) is very flood tolerant, and it has been found to be more flood tolerant than red alder (Minore 1979). Western redcedar is also very shade-tolerant, and on good sites it can grow at a relatively fast rate (Minore 1990). Western redcedar grows on disturbed mineral soils, requires a high water content in its seedbed (Minore 1990), bears relatively shallow roots, and is fairly windfirm (Minore 1979). It is able to sprout adventitious roots on low-hanging limbs, broken-off branches, and fallen live boles (Minore 1979). Seed crop frequency can be erratic from year to year, and seed flight tends to remain close to the source tree (Minore 1979).

## **4. FIELD SAMPLING PROCEDURES**

### **General Overview**

To meet the stated objectives, a two year observational study was conducted along riparian areas of representative streams in the Oregon Coast Range. The scope of inference includes the range of geographical areas sampled in the north and central Oregon Coast Range (Figure 1). One field season (4 summer months) included ground sampling of areas that were minimally disturbed by humans in the last 150 years.

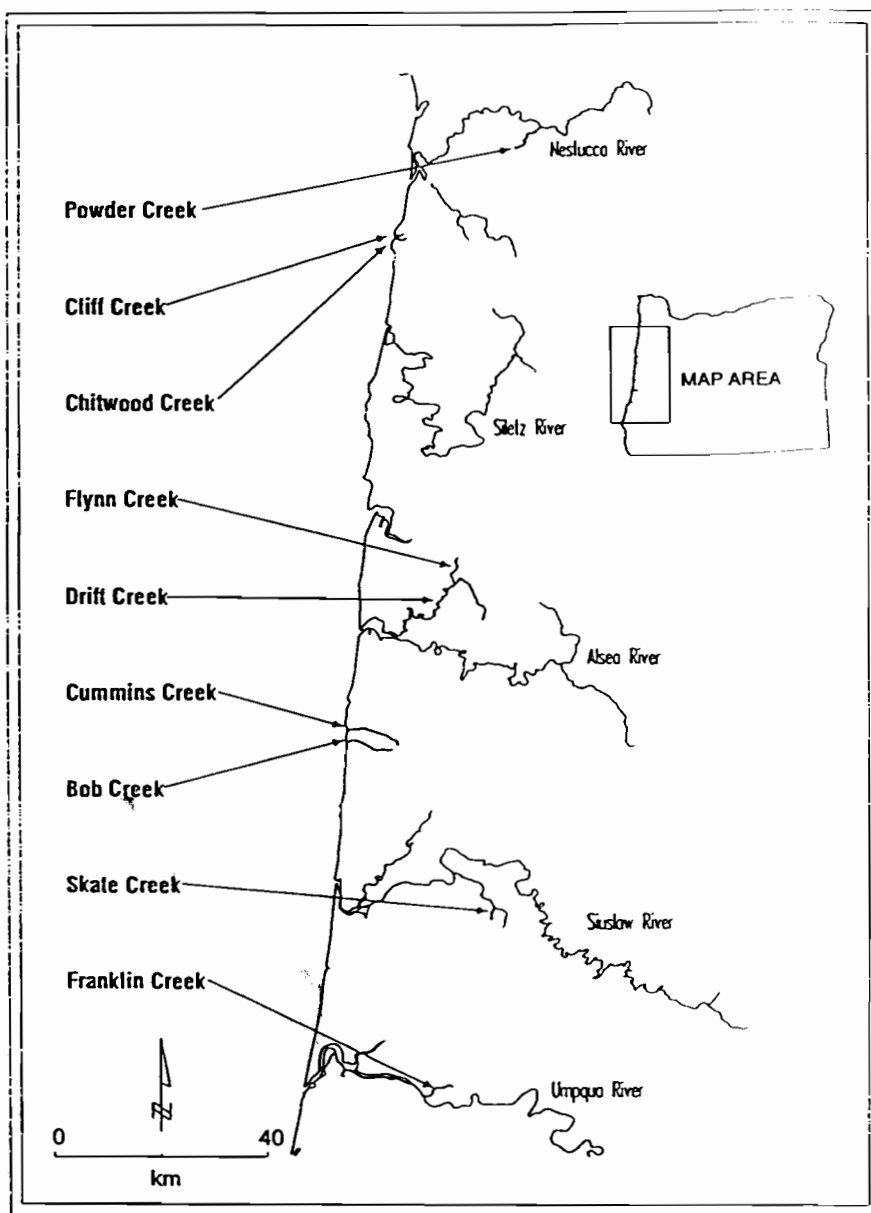


Figure 1. Nine creeks sampled in the Central Oregon Coast Range.

## Site Selection

The main criteria for stream selection was to choose stream sections where no riparian vegetation was logged or otherwise disturbed by humans up to the valley ridge. Some portions of some of the creeks surveyed were found to have possibly experienced timber cuts; in such cases, sampling was restricted to no less than 200 meters upstream and 400 meters downstream from any significant disturbances (Gregory, Beschta, Grant, personal communication 1995) so that the age classes and composition of forest overstory and understory were minimally altered by upstream or downstream activities. Although some reaches of certain creeks might have experienced minimal human disturbance such as homesteading or timber extraction, the creeks that I chose to sample have experienced the least human alterations in terms of both frequency and intensity in all of the Oregon Coast Range (Bruce Hansen, Jim Sedell, Gordie Reeves from Oregon State University; Cindy McCain, Bob Metzger, Mike Clady, Lynn Hod, from Siuslaw National Forest - personal communications 1993-4). Streams surveyed include **Flynn Creek** (T12S R10W S12 and S1; 44°32'15" latitude/123°51'15" longitude) and **Drift Creek** (T13S R10W S8 and S9; 44°27'00" latitude/123°55'00" longitude), which are in Wilderness Areas north and south of Waldport, OR; two reaches of **Cummins Creek** (T15S R12W S11; 44°16'00" latitude/124°05'30" longitude and T15S R11W S16; 44°00'45" latitude/124°00'30" longitude), two reaches of **Bob Creek** (T15S R12W S23; 44°15'00" latitude/124°06'00" longitude and T15S R11W S28; 44°13'45" latitude/124°00'30" longitude), which are both in Wilderness Areas near Yachats, OR off of Cape Perpetua; **Franklin Creek** (T22S R10W S9; 43°40'15" latitude/123°54'00" longitude) which is near Reedsport, OR off of the lower Umpqua River; **Skate Creek** (T18S R9W S26 and S35; 43°58'00" latitude/123°45'00" longitude), a tributary of Knowles Creek near Mapleton, OR; **Cliff Creek** (T6S R11W S10 and S11; 45°03'45" latitude/124°00'00" longitude) and **Chitwood Creek**

(T6S R11W S2 and S3; 45°04'00" latitude/124°00'00" longitude), both in Cascade Head Natural Area near Neskowin, OR; and Powder Creek (T4S R8W S8 and S9; 45°14'30" latitude/123°41'00" longitude), off of the Big Nestucca River near Blaine, OR. To capture the variation of the north and central Oregon Coast Range, the chosen streams had a variety of pools, riffles, orders, substrates, elevations, and distances from the coast.

### Transect Layout

*Note to the reader:* I do not distinguish between terraces and floodplains. Since there is no commonly agreed-upon definition of either terrace or floodplain thus far in the literature, for purposes of simplicity, all relatively flat stream-side surfaces are called terraces in this thesis.

Transects were located at intervals of 200 meters along streams. Placement of the first transect on each stream was randomized streamright or streamleft; subsequent transects were located on alternate sides of the river. Two hundred meter intervals were small enough to maintain field efficiency yet large enough to ensure that sequential samples were statistically independent.

Transects ran perpendicular to the stream. If the transect encountered < 2m of terrace, we sampled out to 30m (Table 1). If the transect fell upon > 2m but < 30m of terrace (i.e., the terrace turned into slope before 30 meters), we sampled to the slope, and then 30 meters up the slope. If the transect ran along an area with a terrace of > 30m, we sampled the terrace out to 30m, then estimated where the slope began, but did not sample the slope. Sampling therefore ended at 30 meters away from the stream unless the landform was part terrace (greater than two meters) and part slope before a 30 meter distance away from the stream.



## Landscape Unit Designation

*Landscape units* (LU's), or patches (Forman and Godron 1981), were subjectively delineated while walking up each transect. A landscape unit could be defined by a combination of topographic position and dominant vegetation type. The boundaries of a given LU were defined by shifts in dominant overstory vegetation, understory vegetation, and/or topographic position. Examples of changes in topographic position include first terrace to second terrace, first terrace to slope, or second terrace to slope. Examples of change in vegetation are the dominant understory changing from *Rubus spectabilis* to *Polisticum munitum*, or the dominant overstory type shifting from <50% conifer >50% conifer, or no treed areas to treed areas. LU's closest to the stream were called LU1's. Moving farther away from the stream could generate LU2's, LU3's and even LU4's, depending on how many vegetational and/or topographical patches were subjectively delimited. If a transect contained homogeneous dominant understory and overstory, as well as no topographical changes for 30 meters, only one LU would be defined on that transect.

Table 1. Variable transect lengths and determinants of lengths for all transects.

<b>Terrace Width To Slope (meters away from the stream)</b>	<b>Sampling Length Along Transect (away from the stream)</b>
< 2	to 30 meters
> 2 width < 30	to slope and 30 meters up the slope (slope distance)
> 30	to 30 meters and estimate where slope begins

## Plot Layout

Each LU was sampled. Given the example of an LU dominated by *Rubus spectabilis* (RUSP) adjacent to an LU dominated by *Polystichum munitum* (POMU), a plot would be placed in both the RUSP-dominated LU and the POMU-dominated LU. Similarly, along a transect, a plot would be placed in a hardwood-dominated LU and a conifer-dominated LU, and/or in a first terrace LU and a second terrace LU. The first plot (plot 1) in an LU1 was always placed adjacent to the stream, and not in the center of the LU1. There was always at least one plot on a transect, which was adjacent to the stream. If more than one plot was installed along the transect, the middle plot(s) were centered within each LU that they represented. The upper most plot was always placed at a 10 meter distance from the previous plot with the goal of attaining statistical independence. Plots were centered on the transect. Plots were always 15 meters wide in the direction parallel to the stream. Plot length (length at right angles to the stream) of LU1 plots is defined in Table 2.

Table 2. Variable plot sizes and determinants of plot sizes for all plot 1's.

<b>Terrace Width To Slope (perpendicular to the stream)</b>	<b>Plot Size of First Plots Adjacent to the Stream</b>
< 2 meters	15 meters along the stream by 5 meters away from the stream *
> 2 meters	15 meters along the stream by 2 meters away from the stream

\* same procedure for constrained stream sides (slopes).

LU1 plots that were 5 meters away from the stream (Table 2) were chosen as such because these were narrow terraces that were smaller than two meters, and few were able to support trees due to winter submergence. The 2 meter distance away from the stream was chosen so that a narrow terrace only slightly wider than two meters, possessing a “thin strip” of vegetation before the slope began, could be exclusively captured. Wider terraces also had a plot 1 size of 15 meters along the stream by 2 meters away from the stream so that plot sizes of all LU1 terraces (greater than 2 meters) would be consistent. All other plots were 15 meters along the stream by 5 meters away from the stream.

### **Transect Data Collection**

At the transect level, data collection included stream width (meters), stream gradient (%), aspect (°), and valley form (constrained 1 side / constrained 2 sides / unconstrained). All other physical information elevation (meters above sea level), precipitation (cm/year), distance from the coast (kilometers), and stream order (1-5), was described from topographic maps and precipitation maps for each 200 meter interval. In addition, a sketch was drawn on the data sheets to delineate where the plots were placed along the transect and to display vegetative and topographic components and changes.

### **Plot Data Collection**

In the center of each plot, variables recorded included height-above-stream (meters), slope (%), woody plant cover using a moosehorn densiometer (Garrison 1949) [all woody plants, hardwood tree cover, conifer tree cover], and physiographic

position [terrace 1 to 4, slope]. A first terrace could have either been narrow or wide. Second, third, and fourth terraces were denoted by benches in the topography.

Distance from the stream to the center of each LU was recorded, as was the width perpendicular to each LU. When an LU width exceeded the sampling endpoint of 30 meters away from the stream, the width was arbitrarily recorded as 100 meters. This was frequently done for the last LU on transects which ran up to the ridge.

### **Overstory Data Collection in Plots**

For each tree in a plot, we noted the species and measured diameter at breast height (dbh). We also cored the largest tree of each species. Only the largest tree per plot was used in the analysis unless otherwise stated. For the trees that were too big to core (dbh > 80cm), we inferred an age dating back to the last catastrophic fire known to the area (Table 3) (Impara, in progress). The biggest trees which were recorded as the oldest in the data set represent a conservative age estimate, reflecting only the minimum number of years since the last large-scale fire. In other words, these biggest trees are at least 145 years old. This method might miss identifying significantly older old-growth remnants, but my objective in collecting fire information was to set a baseline disturbance frequency; not to inventory remnant trees.

Table 3. Dates and names of last catastrophic fires in the western Oregon Coast Range and oldest ages used for the largest trees in each creek basin (Impara, in progress).

Creek	Most recent stand - replacing fire name and date	Imposed age (from the summer of 1994 (years))
Flynn/Drift	Florence Burn - 1849	145
Chitwood/Cliff	Nestucca Burn - 1850	144
Skate	Florence Burn - 1849	145
Powder	Nestucca Burn - 1859	144
Franklin	Coos Bay Burn - 1868	126
Cummins/Bob	Florence Burn - 1849	145

In each plot, dominant forest overstory type was recorded with the coding system:

- 1 - no trees
- 2 - pure hardwood (100% hardwood stems)
- 3 - hardwood/conifer (51% - 99% hardwood stems)
- 4 - conifer/hardwood (51% - 99% conifer stems)
- 5 - pure conifer (100% conifer stems)

If the plot contained 50% hardwoods and 50% conifers, the tree with the largest diameter determined whether the plot was hardwood/conifer or conifer/hardwood. Dominant understory species were recorded as percent cover, as well as the average height of the dominant herbs, shrubs, and ferns.

Tree regeneration (trees < 8 cm dbh) data collection included inventorying the species, number of each species, and substrate (log/ mineral soil/ organic soil) on which the seedlings were growing.

## 5. DATA ANALYSIS

### Landscape Unit 1 and 2 (LU1's and LU2's)

#### *Transformations*

To make comparisons of the vegetative and physical characteristics within both LU1's and LU2's, a variety of transformations were required to meet statistical assumptions of normality. The variable landscape unit width required a log transformation in LU1's because the distribution was skewed toward high values, the shape of the residuals was funnel-like, and the maximum value divided by the minimum value approached ten (Sabin and Stafford 1990). Although the differences in sample sizes between combinations of treatments was observable from the residuals, the log transformation resulted in the best possible transformation. The log transformation is based upon the assumption that variances are proportional to the corresponding means. The variable landscape unit width also required a log transformation in LU2's as well as the variable height-above-stream.

The variable total tree basal area required a  $(\log + 1)$  transformation (Sabin and Stafford 1990) in both LU1's and LU2's. The value of one was added so that the log transformation could be carried out on plots with no trees. In questions regarding differences in individual species' basal areas within overstory types in both LU1's and LU2's, each of the species' basal areas also warranted a  $(\log + 1)$  transformation. For questions addressing differences among species' basal areas in only the plots that contained trees, all species' basal areas required a  $(\log + 1)$  transformation, as did total basal area.

The variable aspect was transformed via the Beers method (Beers, et al. 1966). The Beers aspect transformation assumes that the effect of aspect can be coded as a cosine function with the maximum (2) shifted to the southwest quadrant and the minimum (0) to the northeast quadrant. The variable slope is not included on terraces due to measurement errors in the field.

### ***Statistical Models***

For both LU1's and LU2's, first a randomized (no blocking) analysis of variance (ANOVA) with a one-way structure of terrace/slope (topography) was used to detect differences in variables such as landscape unit width, height-above-stream, and slope. Secondly, a randomized ANOVA with a two-way structure of topography and overstory type was used to detect differences in the same above variables. If the interaction term was significant ( $p\text{-value} < 0.05$ ), the main effects were not tested. If the interaction term was not significant, the main effects were tested separately.

For assessing differences in variables such as total tree basal area and basal area of individual species among the overstory types in which they were found, a randomized ANOVA with a two-way structure of topography and overstory type was used.

To assess differences in individual species' basal areas, a randomized, two-way ANOVA was applied using topography and species. A randomized ANOVA was used to detect differences in the basal area of only treed plots with a one-way structure of topography.

LU1's lacked overstory type 3, the Hardwood/Conifer type, on slopes. As such, ANOVA that included overstory type as either a main effect or in the interaction term, used SAS Type IV sums of squares (Statistical Analysis Software, Version 6.0) to compensate for the missing treatment combination. ANOVA that did not include overstory type, used SAS Type III sums of squares.

Since western redcedar was not found on LU2 terraces, SAS Type IV sums of squares were used in the ANOVA that includes this missing treatment combination. SAS Type III sums of squares were used for all other statistical procedures in the ANOVA's pertaining to LU2's. The p-value significance level was 0.05 for all one-way and two-way comparisons in all ANOVA's unless otherwise stated.

When statistical differences were detected in an ANOVA, a Least Squares Means test was applied. A Least Squares Means test is one type of a Means Separation test. It details where differences exist given all of the "treatment" combinations. A Least Squares Means test adjusts for differences in sample sizes and possible spurious correlations by giving an estimated mean for equal sample sizes. Thus, when reporting the magnitude of a difference, the value reported is actually derived from *adjusted* means. Similarly, when detailing where differences exist, the means reported are actually *adjusted* means. A Least Squares Means test uses a Fisher's Protected Least Significant Difference F-statistic, and the p-value significance level was <0.05 unless otherwise stated.

In addition to adjusted means via the Least Squares Means procedure, variables that required log-transformations back-transformed as medians. All data that were transformed to a log scale hence back-transform as both *adjusted* and as *medians*. The reader is reminded that neither adjusted means nor adjusted medians correspond with the tables that display the raw means, but I chose to display the raw means so that the reader can achieve a broader understanding of the data.



Ninety-five percent confidence intervals were derived by multiplying the standard error of the adjusted mean by a multiplier from a t-distribution. The resulting number was then added to the adjusted mean to arrive at the upper limit and subtracted from the adjusted mean to arrive at the lower limit. If a variable was log transformed, all confidence interval calculations were carried out before the back-transformation to the original scale. If the variable required a  $(\log + 1)$  transformation, all calculations were carried out before back-transformation to the original scale, then the value of one was subtracted from both the upper and lower confidence limits on the original scale.

When questioning differences in frequencies of overstory types, a Chi-Square test was applied. Chi-Square is denoted by:  $\Sigma(\text{observed value} - \text{expected value})^2 / \text{expected value}$ . Chi-square tests require an expected cell count of at least five. Any value under five will not allow the test to generate a valid p-value. When questioning differences in species' frequencies, a Chi-Square test of equal proportions was used in conjunction with pairwise confidence intervals. Testing differences in species' frequencies on terraces versus slopes utilized only pairwise confidence intervals, which is also called a z-test for testing the equality of two proportions.

**Changes From LU1 to LU2: assessing differences between near-stream communities and communities farther from the stream.**

### ***Transformations***

For all cases (A-D) in Figure 4, landscape unit width required a log transformation, total basal area required a  $(\log + 1)$  transformation, and individual species' basal areas warranted a  $(\log + 1)$  transformation.

## ***Statistical Models***

To assess differences in variables between LU1's and LU2's of different transect configurations, otherwise stated as *cases* (Figure 4), a randomized block design ANOVA was used by blocking on transect to exclude effects other than the variable of consideration. "Blocking" transects equalized comparisons among transects. For examining differences in the variables landscape unit width, height-above-stream, woody plant cover, conifer cover, hardwood cover, species' basal area, and total basal area between LU1's and LU2's, a two-way structure of plot (plots from LU1 and LU2) and transect was used. No interaction terms were used in the models. SAS Type III sums of squares were used for all ANOVA in this section. The p-value significance level was 0.05 for all comparisons unless otherwise stated. Similar to the above sections, a Least Squares Means test was performed for all differences that were detected in an ANOVA. When comparing frequencies of overstory types between plots 1 and 2, a z-statistic for equal proportions was used.

## **Differences Among LU1's From Different Transect Configurations / Differences Among LU2's From Different Transect Configurations**

### ***Transformations***

For both of these sections, only the variable total basal area required a (log + 1) transformation.

### ***Statistical Models***

For assessing differences either among LU1's of different transect configurations or among LU2's of different transect configurations, a randomized ANOVA was used with a one-way structure of plot (plots from LU1 only). No interactions were considered in the ANOVA models. All ANOVA models applied SAS Type III sums of squares, with a p-value significance level of 0.05. As in above sections, when differences were detected in the ANOVA, a Least Squares Means test was carried out to show where the differences occurred. The consequent adjusted means or medians are displayed in tables.

### **Differences Among Terraces and Slopes**

#### ***Transformations***

When seeking differences among species' basal areas between terraces and slopes, all of the species' basal areas required a  $(\log + 1)$  transformation. When examining differences in a given species' basal area between terraces and slopes for only the plots where each respective species was found, all of the species' basal areas required log transformations.

### ***Statistical Models***

To assess differences in the variables: basal area among species, basal area of individual species, total basal area, cover of hardwoods, conifers, and all woody

plants, a randomized ANOVA was used with a one-way structure of topography. A Least Squares Means test was used to detect where the differences occurred and the magnitude of the differences. SAS Type III sums of squares were applied for all comparisons, and the p-value significance level was 0.05.

### **Ages of the Largest-Stemmed Trees**

No statistical procedures were used for this section; only means, standard deviations, and ranges were examined.

## 6. RESULTS

### Summary of Whole Data Set

The data set is comprised of 50 transects, 50 plots in the first landscape unit (LU1), 47 plots in the second landscape unit (LU2), 18 plots in the third landscape unit (LU3), and 3 plots in the fourth landscape unit (LU4), totaling 118 plots. Individual sections are not designated for landscape units 3 and 4 in this thesis due to small sample size. However, information from LU3/4's is included in the sections *Differences Among Terraces and Slopes*, *Overstory Type Ages*, *Terrace and Slope Tree Ages*, and *Individual Tree Species Ages* to increase the sample size in the analyses and therefore provide more information about the riparian landscape as a whole. Figures 2 and 3 display LU3's apart from the other landscape units also to portray a view of the whole landscape. No other sections address LU3's or LU4's.

Distance from the coast of the 50 sites ranged from 0.6 kilometers to 31.5 kilometers; precipitation per year ranged from 208.3 centimeters to 274.3 centimeters. Stream orders ranged from 1 to 4, stream width ranged from 1 meter to 20 meters, and stream gradient ranged from 2% to 35%. Elevations ranged from 12.2 meters above sea level to 390.1 meters above sea level. Twenty-eight percent (14 of 50) of the transect sites fell along unconstrained stream reaches. Forty-eight percent (24 of 50) fell along stream reaches that were constrained by only one side, and twenty-four percent (12 of 50) were constrained on two sides. The average terrace width was 34 meters. In other words, on unconstrained streambanks, the average distance from the channel to the slope was 34 meters.

## Landscape Units and Topographical Traits

First, I examined the distribution of landscape units along the transects. I found that as one moves away from the stream, average height above the stream increases (Figure 2) as does landscape unit width (perpendicular from the stream) (Figure 3). However, the standard deviations of these two latter variables increase with distance from the stream as well. Although the sample sizes in Figures 2 and 3 are relatively small, the data suggest that height above the stream and distance from the stream, as well as landscape unit width and distance from stream, are functionally related. LU4 was not included in Figures 2 or 3 because of small sample size and the fact that all end distances of LU4's were given the value of 100 to equalize the meaning of the unknown distance to the ridge.

*Limitations:* Since LU1 was always placed adjacent to the stream as opposed to in the center of the landscape unit, height-above-stream does not necessarily represent the average value of the landscape unit, but rather the value is most representative of the two or five meters closest to the stream. The average height-above-stream for the whole landscape unit is thus at least the given value. This does not, however, affect the width or distance from the stream of LU1's since these two latter variables were derived from measurements of the landscape unit itself and not from plot measurements.

Also, since the width of LU1's always maintains a beginning distance away from the stream of zero, and since distance from stream is calculated by adding the beginning distance and end distance and dividing by two, width and distance from the stream of LU1's are 100% correlated. However, the width and stream distance of other LU's are not necessarily correlated. The functionally linear relationship between the three landscape units is therefore not imposed and is biologically meaningful.

### Topographic Traits of Landscape Units

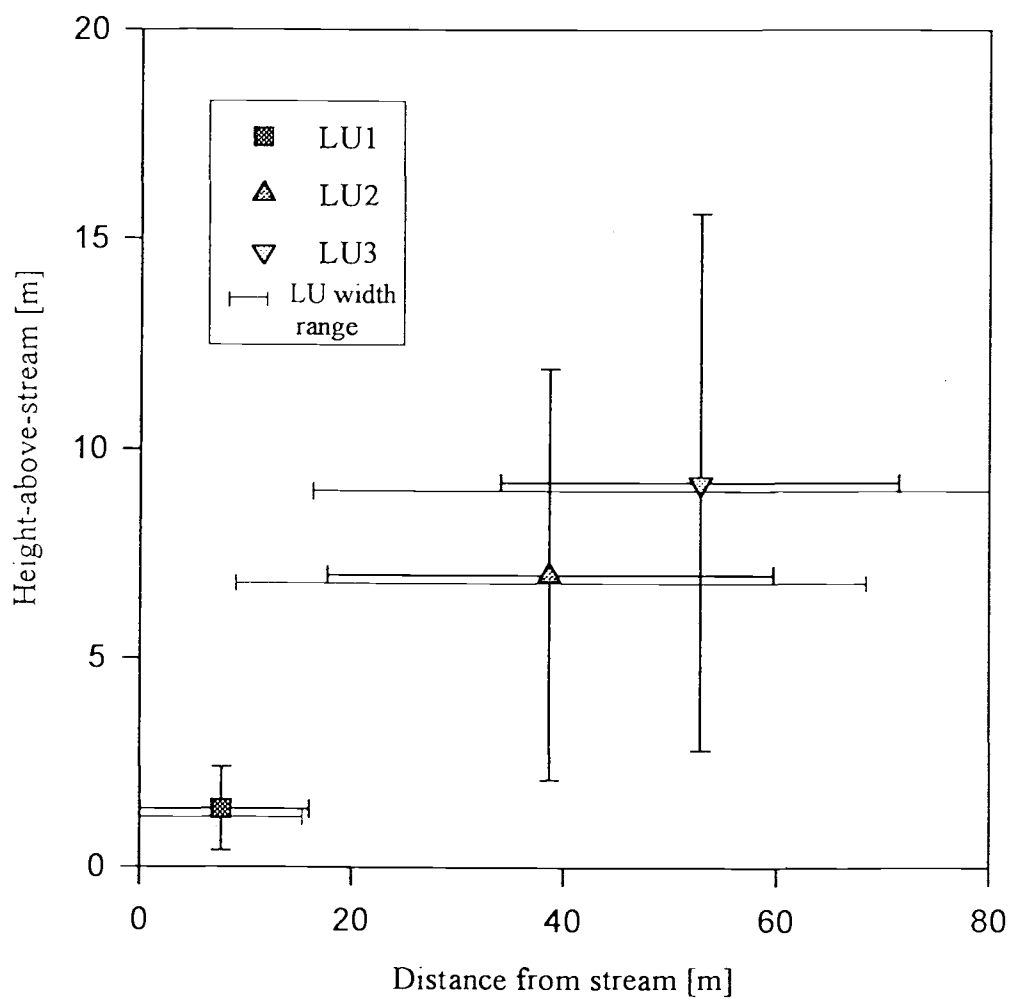


Figure 2. Relationship between average height-above-stream and average distance from the stream. The light horizontal bar is the range for each landscape unit; the darker vertical and horizontal bars indicate one standard deviation.

### Topographic Traits of Landscape Units

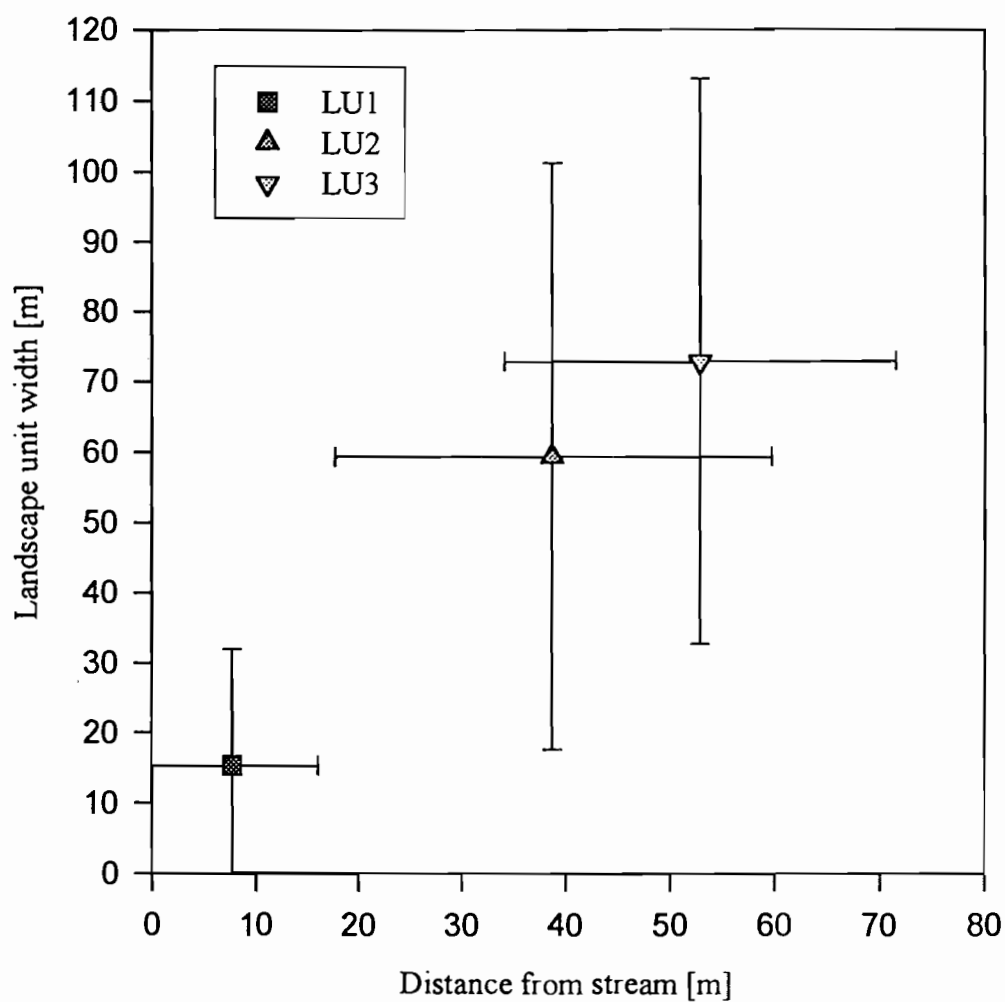


Figure 3. Relationship between average landscape unit width and average distance from the stream. The vertical and horizontal bars are standard deviations.



## **The Nearest-Stream Community: Landscape Unit 1 (LU1)**

*Limitations.* The variable *slope* is only included for slopes and not for terraces or all plots combined due to measurement errors.

*Reminder to the reader.* Since it is possible for two or more first terraces or two slopes to occur on the same transect when a change in vegetation rather than a change in physiographic position denotes the landscape unit, the width of LU1's, LU1 terraces, and LU1 slopes does not necessarily equate to the width of the physiographic unit (terrace or slope). For example, LU1 differed from LU2 19 times due solely to vegetative differences. Refer to the section, *Changes From LU1 to LU2* for a detailed description of LU changes.

## ***Topography***

### ***General Topogprahy***

LU1's occurred on terraces 68% of the time and on slopes 32% of the time. There was no difference in landscape unit widths between terraces and slopes (Table 4). There was a difference in height-above-stream between slopes and terraces; adjusted mean height-above-stream was 0.92 meters higher on slopes than on terraces (Table 4).

Table 4. Mean landscape unit width (LUW), mean height-above-stream (HAS), and mean slope, with standard errors (parentheses), for all LU1's combined (LU1A), LU1 terraces (LU1T), and LU1 slopes (LU1S). Means in the same row followed by the same letter are not significantly different at  $p < 0.05$  (Least Squares Means Test).

	<b>LU1A</b> <b>n=50</b>	<b>LU1T</b> <b>n=34</b>	<b>LU1S</b> <b>n=16</b>
<b>LUW (m)</b>	15.9 (2.4)	12.4 (1.7) a	21.6 (6.2) a
<b>HAS (m)</b>	1.4 (0.1)	1.1 (0.1) a	2.1 (0.3) b
<b>Slope (%)</b>	n/a	n/a	44.7 (4.4)

### *Topography of Overstory Types*

To attain a more detailed picture of the topography of LU1's, I examined topographical features for each overstory type in LU1's. I found a marginally significant interaction of overstory type and topography for median landscape unit width ( $F\text{-stat} = 2.24$ ;  $p\text{-value} = 0.09$ ) (Table 5 displays the means). Since this difference was marginal, the significance levels for landscape unit width among all overstory type and topographical combinations were assessed with a Bonferroni  $p$ -value. Dividing the number of combinations (20) by the  $t$ -test alpha level of 0.05 resulted in a Bonferroni alpha level of 0.002. Thus, I concluded that there was no significant interaction between topography and overstory type for the variable landscape unit width. Furthermore, no differences were detected in median landscape unit width among either main effect of overstory type or topography. The interaction of overstory type and topography was significant, however, for the variable height-above-stream (Table 5). On slopes, mean height-above-stream in Pure Conifer plots

Table 6. Adjusted mean height-above-stream (HAS) within overstory types and corresponding adjusted 95% confidence intervals, for LU1 terraces (LU1T) and LU1 slopes (LU1S). Means followed by the same letter are not significantly different at  $p < 0.05$  (Least Squares Means Test). a/b = significant column differences; x/y = significant row differences.

Overstory Type	LU1T		LU1S	
	HAS (m)	95% Confidence Intervals	HAS (m)	95% Confidence Intervals
No Trees	1.00 a x	0.62 ↔ 1.39	1.48 a x	0.99 ↔ 1.96
Pure Hardwood	1.19 a x	0.64 ↔ 1.74	2.00 a x	0.89 ↔ 3.11
Hardwood/Conifer	1.25 a x	0.46 ↔ 2.04	n/a	n/a
Conifer/ Hardwood	1.66 a x	0.75 ↔ 2.57	2.55 a x	1.43 ↔ 3.66
Pure Conifer	1.00 a x	0.09 ↔ 1.91	4.50 b y	3.39 ↔ 5.61

distribution towards low numbers because it has a relatively high tolerance for moist conditions on low terraces (Harris 1990). I would also consider western redcedar to be skewing the distribution, since it too has a tolerance for moist conditions on low terraces (Minore 1990), but its frequency was too low to be skewing the average. As such, 67% (4/6) of LU1's containing spruce were on terraces. Furthermore, when spruce is removed from the Pure Conifer distribution, mean height-above-stream rises from 1.0 meters (Table 5) to 1.4 meters.

## *Vegetation*

### *Overstory Types and Basal Area of Species Within Overstory Types*

Fifty-two percent of LUI's had no trees (Table 7). To assess whether variable plot size played a role in this high percentage, we examined the two plot sizes separately: 70% (35 of 50) of plot 1's were two meters, and out of those, 46% (16 of 35) did not contain trees. Of the five meter plots, 67% (10 of 15) also had no trees. Thus, since there is a small difference between two and five-meter plots in the percent of LUI's with no trees, I believe that the difference in plot size does not contribute to the high frequency of treeless areas.

Thirty-six percent of LUI's contained at least some hardwoods; 28% contained some conifers (Table 7). Twenty-eight percent of the plots were predominantly hardwood while only 20% of the plots were predominantly conifers. Of the plots that contained trees, 75% of the plots were on terraces, and 25% were on slopes. On terraces, twice as many plots were hardwood-dominated as conifer-dominated, and conversely, on slopes, twice as many plots were conifer-dominated than hardwood-dominated.

There was no difference in the frequencies of overstory types between terraces and slopes when all five overstory types were compared, when the types were regrouped as Hardwood-dominated, Conifer-dominated, and No Trees, or when they were regrouped as Trees and No Trees (Table 7).

There was no significant interaction between overstory type and topography associated with median total basal area, nor was there a difference in median total basal area between terraces and slopes. However, there was a difference detected in median total basal area among overstory types (Table 8). Among the overstory types, median total basal area in the Pure Hardwood type was less than median total basal area in both the Conifer/Hardwood type and Pure Conifer type. As a reminder to the

Table 7. Frequency (% plots) of overstory types in all LU1's (LU1A), LU1 terraces (LU1T), and LU1 slopes (LU1S). Mean basal areas (sq. m/ha) with standard errors (parentheses) are given for individual species within the overstory types in which they were found.

Overstory Type		LU1A n=50	LU1T n=34	LU1S n=16
No Trees		52%	47%	63%
Pure Hardwood		20%	24%	13%
	Red Alder	57.3 (5.4)	59.9 (6.3)	47.1 (14.7)
Hardwood/Conifer		8%	12%	0%
	Red Alder	90.1 (3.4)	90.1 (4.2)	-
	Sitka Spruce	61.5 (17.3)	61.5 (21.1)	-
	Douglas-fir	83.0 (15.5)	83.0 (18.9)	-
	Western Hemlock	17.7 (5.0)	17.7 (6.1)	-
Conifer/Hardwood		8%	9%	6%
	Red Alder	45.4 (5.3)	66.4 (5.9)	14.0 (2.8)
	Sitka Spruce	120.0 (27.1)	195.8 (39.2)	6.4 (2.2)
	Douglas-fir	157.1 (31.2)	154.4 (46.1)	161.2 (57.0)
	Western Hemlock	3.7 (1.1)	6.1 (1.8)	-
Pure Conifer		12%	9%	19%
	Sitka Spruce	87.1 (26.2)	5.5 (1.6)	209.5 (74.0)
	Douglas-fir	20.1 (0.1)	33.5 (10.0)	-
	Western Redcedar	59.4 (16.3)	97.6 (25.0)	2.1 (0.7)
	Western Hemlock	12.4 (3.9)	-	31.1 (11.0)

reader, basal areas in Table 8 are actually adjusted basal areas from the Least Squares Means Test which adjusts for possible spurious correlations. The overstory type

Hardwood/Conifer was not included in the estimations since it was not found in any plots on slopes, and the overstory type No Trees was not included in the estimations because by definition, this type contains no basal area and it is hence not related to the question of interest.

There was a marginally significant difference in median alder basal area between terraces and slopes (F-stat = 3.90; p-value = 0.06), but no difference in median alder basal area between the three overstory types in which alder was found (Table 7 displays the means). The interaction between topography and overstory type was not associated with median alder basal area either. Statistical procedures were unable to calculate the magnitude of the difference in alder basal area between terraces and slopes because of the lack of the Hardwood/Conifer type on slopes. No differences were detected in any other species' basal area between terraces and slopes, nor among the overstory types in which each species was found, nor in the interaction between topography and overstory type. Western redcedar was only found in one overstory type (Pure Conifer), so no questions involving differences in redcedar basal area between overstory types were addressed.

Table 8. Adjusted median total basal area (TBA) within overstory types, and corresponding 95% confidence intervals for all LU1 plots. Medians followed by the same letters are not significantly different at  $p < 0.05$  (Least Squares Means Test).

Overstory Type	TBA (sq. meters/ha)	95% Confidence Intervals
Pure Hardwood	32.05    a	17.77 ↔ 57.19
Conifer/Hardwood	175.10   b	89.42 ↔ 341.99
Pure Conifer	118.08   b	60.14 ↔ 230.93

### *Basal Areas and Frequencies of Individual Species*

For the variable basal area on treed plots, no significant interaction was found between species and topography (Table 9). No differences were detected in median total basal area between terraces and slopes. Species differed in median basal areas: median basal area of red alder was higher than median basal area of Sitka spruce, Douglas-fir, western redcedar, and western Hemlock (Table 10). The median values are low compared to the means because they are reflecting the high number of zeros in the data set. Also, the Least Squares Means test adjusts sample sizes for spurious correlations which consequently significantly lowered the basal areas.

Since red alder has a higher median basal area than all other species. Also, red alder, Sitka spruce, and Douglas-fir have similar mean basal areas, which are all much greater than their respective median basal areas. Given the two latter statements, two circumstances become apparent: 1) red alder occurs more often than Sitka spruce and Douglas-fir (Table 11), (i.e., red alder has fewer zero basal area values than Sitka spruce or Douglas-fir, as noted by red alder's higher median basal area. This explains why the orders of magnitude of red alder and Sitka spruce basal areas were switched in the means table (Table 9) and the medians table (Table 10), 2) where red alder occurs, it has a lower basal area than Sitka spruce and Douglas-fir, and where Sitka spruce and Douglas-fir occur, they have large basal areas (Table 12).

No differences were found when testing for the equality of species' proportions on LU1's; however, pairwise comparisons of 95% confidence intervals (Table 11) reveal that the red alder confidence interval is the only one not to overlap with any other species. Although these two above tests yielded different answers, my conclusion is that red alder was found more frequently than any other species. This explains why, when red alder's basal area values were lower than the values of Sitka spruce and Douglas-fir where red alder was found, the median red alder basal area

Table 9. Frequency of species (Freq.), expressed as % of all LU1's; mean basal area (MBA) (sq.m/ha) and standard errors (parentheses) of species for all LU1's (LU1A), LU1 terraces (LU1T), and LU1 slopes (LU1S). Basal area means were derived only from plots with trees.

Species	LU1A n=50		LU1T n=34		LU1S n=16	
	Freq. n=50	MBA n=24	Freq. n=34	MBA n=18	Freq. n=16	MBA n=6
Red Alder	38	48.4 (8.6)	44	57.6 (9.59)	25	20.3 (14.1)
Sitka Spruce	12	53.4 (26.5)	12	47.2 (27.9)	13	72.0 (69.6)
Douglas-fir	10	50.8 (24.5)	12	49.7 (28.2)	6	53.7 (53.9)
Western Redcedar	6	12.4 (11.0)	6	16.2 (14.7)	6	0.70 (0.69)
Western Hemlock	6	6.3 (3.8)	6	4.9 (4.0)	6	10.4 (10.4)

Table 10. Adjusted median basal area (MBA) of individual species, and corresponding 95% confidence intervals for individual species in only LU1's that contained trees. Medians followed by the same letter are not significantly different at  $p < 0.05$  (Least Squares Means Test).

Species	MBA (sq. meters/ha)	95% Confidence Intervals
Red Alder	14.01 a	5.47 ↔ 31.80
Sitka Spruce	3.53 b	0.62 ↔ 6.63
Douglas-fir	2.88 b	0.33 ↔ 5.25
Western Redcedar	1.47 b	0 ↔ 2.18
Western Hemlock	1.73 b	0 ↔ 2.74



Table 11. 95% confidence intervals for species' frequencies (% plots) in all LU1's.

Species	95% Confidence Intervals
Red Alder	24 ↔ 51
Sitka Spruce	3 ↔ 20
Douglas-fir	1 ↔ 18
Western Redcedar	0 ↔ 12
Western Hemlock	0 ↔ 12

Table 12. Mean basal area (MBA) (sq.m/ha) and standard errors (parentheses) of species derived only from LU1 plots where each respective species was found.

Species	MBA
Red Alder n = 19	61.0 (8.7)
Sitka Spruce n = 6	213.5 (79.3)
Douglas-fir n = 5	243.6 (70.1)
Western Redcedar n = 3	99.0 (84.5)
Western Hemlock n = 3	50.4 (16.4)

was higher than the median basal areas of both Sitka spruce and Douglas-fir. There were no differences among species' frequencies between terraces and slopes.

## Landscape Unit 2 (LU2)

### *Topography*

#### *General Topography*

LU2's were on slopes 64% of the time and on terraces 36% of the time. This is in contrast to LU1's, which were on terraces 36% more often than on slopes. Furthermore, the average height above the stream in LU2's (Table 13) is almost four times the average height above the stream in LU1's (Table 4), and the upper range in LU2's extends four times as far as well.

Unlike LU1's, a difference was detected in landscape unit width between terraces and slopes (Table 13 displays means). Median LU2 width was 24.84 meters wider on slopes (adjusted median = 51.41 meters) than on terraces (adjusted median = 26.57 meters). Median height-above-stream was 6.90 meters higher on slopes (adjusted median = 9.45 meters) than on terraces (adjusted median = 2.55 meters).

Table 13. Mean landscape unit width (LUW), mean height -above-stream (HAS), and mean slope, with standard errors (parentheses), for all LU2's (LU2A), LU2 terraces (LU2T), and LU2 slopes (LU2S). Means in the same row followed by the same letter are not significantly different at  $p < 0.05$  (Least Squares Means Test).

	<b>LU2A</b> <b>n=47</b>	<b>LU2T</b> <b>n=17</b>	<b>LU2S</b> <b>n=30</b>
<b>LUW (m)</b>	53.9 (5.4)	37.4 (0.8)	71.8 (7.5)
<b>HAS (m)</b>	7.0 (0.7)	2.6 (0.2)	9.5 (0.7)
<b>Slope (%)</b>	n/a	n/a	53.3 (2.8)

### *Topography of Overstory Types*

There was no significant interaction between topography and overstory type (Table 14). Unlike LU1's, there was a difference detected in median landscape unit width between overstory types; the median width in No Tree stands was less than the median widths in Hardwood/Conifer stands and Pure Conifer stands (Table 15). The main effect of topography was not significant for landscape unit width. In contrast to LU1's, for the variable height-above-stream, there was no significant interaction between topography and overstory type, nor was either main effect significant. On only slopes, there were no differences in slope among overstory types.

Table 14. Mean landscape unit width (LUW) and mean height-above-stream (HAS), with standard errors (parentheses), for each overstory type on all LU2 plots (LU2A), LU2 terraces (LU2T), and LU2 slopes (LU2S). Mean slope is only included on LU2 slopes.

Overstory Type	LU2A n = 47		LU2T n = 17		LU2S n = 30		
	LUW (meters)	HAS (meters)	LUW (meters)	HAS (meters)	LUW (meters)	HAS (meters)	Slope (%)
No Trees	25.8 (3.8)	5.9 (0.4)	20.3 (1.6)	2.9 (0.1)	29.0 (6.0)	7.6 (0.4)	48.6 (1.7)
Pure Hardwood	52.3 (6.2)	5.5 (0.7)	22.1 (3.6)	1.8 (0.1)	82.4 (7.8)	9.1 (1.0)	47.4 (3.1)
Hardwood Conifer	108.0 (1.6)	8.8 (1.2)	116.0 (n/a)	2.5 (n/a)	100.0 (n/a)	15.0 (n/a)	70.0 (n/a)
Conifer Hardwood	88.4 (4.5)	9.1 (0.6)	18.5 (n/a)	3.0 (n/a)	100.0 (n/a)	10.1 (0.7)	56.0 (3.7)
Pure Conifer	67.7 (6.0)	7.4 (0.7)	51.8 (0.9)	2.9 (0.3)	76.4 (7.5)	9.9 (0.9)	56.1 (2.9)

Table 15. Adjusted median landscape unit width (LUW) within overstory types and corresponding adjusted 95% confidence intervals, for all LU2 plots. Medians followed by the same letter are not significantly different at  $p < 0.05$  (Least Squares Means Test).

Overstory Type	LUW (meters)	95% Confidence Intervals
No Trees	19.13    a	11.36 ↔ 32.46
Pure Hardwood	34.71    ab	20.69 ↔ 58.56
Hardwood/Conifer	107.70   b	33.44 ↔ 347.23
Conifer/ Hardwood	43.01    ab	17.64 ↔ 104.58
Pure Conifer	46.75    b	30.88 ↔ 76.81

## *Vegetation*

### *Overstory Types and Basal Areas of Species Within Overstory Types*

In all LU2's, Pure Conifer was the most prevalent overstory type (Table 16). Forty percent of LU2 plots contained at least some hardwoods; 55% contained at least some conifers. Almost twice as many plots were predominantly conifer (51%) as predominantly hardwood (25%). Among the plots that contained trees, 63% were on slopes and 37% were on terraces. On terraces, 6% more plots were conifer-dominated than hardwood-dominated, and on slopes, 39% more plots were conifer-dominated than hardwood dominated.

There was no difference in the frequencies of overstory types between terraces and slopes when all five overstory types were compared, when the types were regrouped as Hardwood-dominated, Conifer-dominated, and No Trees, or when they were regrouped as Trees and No Trees (Table 16).

Table 16. Frequency (% plots) of overstory types in all LU2's (LU2A), LU2 terraces (LU2T), and LU2 slopes (LU2S). Mean basal areas (sq. m/ha) with standard errors (parentheses) are given for individual species within the overstory types in which they were found.

Overstory Type		LU2A n=47	LU2T n=17	LU2S n=30
No Trees		24%	24%	23%
Pure Hardwood		21%	29%	16%
	Bigleaf Maple	37.7 (9.6)	37.4 (20.3)	37.9 (9.5)
	Red Alder	28.4 (4.9)	21.4 (3.7)	35.3 (8.5)
Hardwood/Conifer		4%	6%	3%
	Bigleaf Maple	38.1 (7.8)	-	76.1 (n/a)
	Red Alder	64.9 (13.3)	129.7 (n/a)	-
	Sitka Spruce	39.0 (1.5)	31.7 (n/a)	46.3 (n/a)
Conifer/Hardwood		15%	6%	20%
	Bigleaf Maple	32.4 (8.0)	119.9 (n/a)	17.8 (7.9)
	Red Alder	16.4 (2.4)	-	19.2 (3.0)
	Sitka Spruce	30.2 (11.6)	211.2 (n/a)	-
	Douglas-fir	87.8 (13.6)	-	102.5 (17.0)
	Western Redcedar	7.0 (2.7)	-	8.2 (3.6)
	Western Hemlock	12.1 (4.6)	-	14.1 (6.3)
Pure Conifer		36%	35%	38%
	Sitka Spruce	108.0 (29.5)	95.1 (44.7)	114.9 (40.2)
	Douglas-fir	99.5 (24.2)	104.6 (40.5)	96.8 (31.6)
	Western Redcedar	1.9 (1.1)	-	2.9 (1.7)
	Western Hemlock	35.6 (8.4)	36.9 (17.3)	35.0 (9.6)

Similar to LU1's, there was no interaction between topography and overstory type related to species' basal area, nor was there a difference in total basal area between terraces and slopes (Table 16). There was a difference found in median total basal area among overstory types (Table 17). Among the overstory types, median total basal area in the Pure Hardwood type was less than median total basal area in the Conifer/Hardwood type and Pure Conifer type (Table 17). The overstory type No Trees was not included in the estimations since those plots did not contain any basal area.

Within only the overstory types in which each species was found, the interaction of topography and overstory type was not significant for the variable basal area (Table 16). No differences were detected in median basal area between terraces and slopes for any species, nor were any differences found in any species' median basal areas among the overstory types in which they were found.

### *Basal Areas and Frequencies of Individual Species*

Among treed plots, the interaction of species and topography was not significant for the variable basal area (Table 18). There was a marginally significant difference in median basal area among species ( $F\text{-stat} = 1.93$ ;  $p\text{-value} = 0.09$ ). To further investigate this marginal difference, a Bonferroni  $p\text{-value}$  was used ( $\alpha\text{ level} = 0.001$  with 36 combinations) to assess all combinations. No combinations met the Bonferroni significance level, thus I concluded that there was no difference in median basal areas among species. Furthermore, no differences were identified in median total basal area between terraces and slopes.

There were no differences among the frequencies of species when testing for the equality of all species' proportions. Pairwise 95% confidence interval comparisons (Table 19) confirm that there were no differences among any of the six species' frequencies, since none of the confidence intervals overlapped. No

Table 17. Adjusted median total basal area (TBA) within overstory types, and corresponding adjusted 95% confidence intervals for all LU2 plots. Totals followed by the same letter are not significantly different at  $p < 0.05$  (Least Squares Means Test).

Overstory Type	TBA (sq. m/ha)	95% Confidence Intervals
Pure Hardwood	47.43 a	26.28 ↔ 84.97
Hardwood/Conifer	140.56 ab	37.94 ↔ 513.24
Conifer/ Hardwood	219.94 b	81.52 ↔ 589.52
Pure Conifer	153.29 b	95.72 ↔ 245.12

Table 18. Frequency of species (Freq.), expressed as % plots; mean basal area (MBA) (sq. m/ha) and standard errors (parentheses) of species for all LU2's (LU2A), LU2 terraces (LU2T), and LU2 slopes (LU2S). Basal area means were derived only from plots with trees.

	LU2A n=47		LU2T n=17		LU2S n=30	
Species	Freq. n=47	MBA n=36	Freq. n=17	MBA n=13	Freq. n=30	MBA n=23
Red Alder	26	14.7 (4.9)	29	18.2 (10.0)	23	12.7 (5.5)
Sitka Spruce	19	59.0 (24.8)	29	62.6 (37.5)	13	57.0 (33.8)
Douglas-fir	21	64.1 (21.2)	12	48.3 (33.5)	26	73.0 (28.2)
Western Redcedar	4	2.2 (1.6)	-	-	7	3.5 (2.5)
Western Hemlock	19	19.2 (7.4)	12	17.0 (13.8)	23	20.4 (8.9)
Bigleaf Maple	13	18.9 (7.5)	12	23.6 (16.4)	13	16.2 (7.7)

Table 19. 95% confidence intervals for species' frequencies in all LU2's.

Species	95% Confidence Intervals (% plots)
Red Alder	13 ↔ 38
Sitka Spruce	8 ↔ 29
Douglas-fir	9 ↔ 32
Western Redcedar	0 ↔ 9
Western Hemlock	8 ↔ 29
Bigleaf Maple	3 ↔ 22

differences were detected among species' frequencies between terraces and slopes. Similar to LU1's, the frequency of red alder was relatively high compared to Sitka spruce, Douglas-fir, and bigleaf maple (Table 19). However, where red alder was found, its basal area was lower than Sitka spruce, Douglas-fir, and bigleaf maple, and where Sitka spruce, Douglas-fir, and bigleaf maple were found, their basal areas were large (Table 20).

### Changes From LU1 to LU2

#### *Frequencies and Types of Changes*

Three transects only had one plot. Hence, 6% (3/50) of LU1's did not change to LU2's. On the transects that did have more than one plot, LU1's differed from



Table 20. Mean basal areas (MBA) (sq. m/ha) and standard errors (parentheses) of species derived only from LU2 plots where each respective species was found.

Species	MBA
Red Alder n = 12	44.0 (37.3)
Sitka Spruce n = 9	236.0 (223.9)
Douglas-fir n = 10	230.6 (142.3)
Western Redcedar n = 2	40.4 (12.3)
Western Hemlock n = 9	76.7 (60.5)
Bigleaf Maple n = 6	113.2 (39.5)

LU2's by either a change in vegetation or topography, or both. LU1 changed to LU2 40% (19/47 times) when only vegetation changed. In other words, 40% (19/47) of LU1's changed to LU2's solely due to changes in vegetation (Cases A and D in Figure 4). Of this vegetative change, 11% (2/19) was due solely to understory shifts; the remaining 89% (17/19) changed because of shifts in overstory type. Forty-seven percent (22/47) of LU1's changed to LU2's because of simultaneous changes in topography and vegetation. Changes in both topography and understory occurred 18% (4/22), whereas changes in both topography and overstory occurred 81% (18/22). The remaining 13% (6/47) changed only because of topographic changes.

### ***Differences Between LU1 and LU2 Within Different Transect Configurations***

#### ***Case A: 1st terrace to 1st terrace; only vegetative change***

In Case A of Figure 4, first terrace to first terrace, where just vegetative change defined the transition to an LU2, there was a marginally significant difference in average height-above-stream between LU1's and LU2's (Table 21), where LU2's were a little higher than LU1's. There was a difference in LU width: the median width of LU2's was 19.5 meters wider than the width of LU1's (Table 21.)

Vegetatively, the only difference detected between the LU1's and LU2's of Case A was in the mean cover density of hardwoods: the mean cover density of hardwoods in LU1's (63%) was double the mean hardwood cover density of LU2's (31%). No differences were found in the mean cover densities of conifers or all woody plants between LU1's and LU2's. In only treed plots, there were no differences among species' median basal areas between LU1's and LU2's. There were no differences in median total basal area between LU1's and LU2's. Sample size was too few to test for differences in basal areas of individual species between LU1' and LU2's. There were no differences in the frequency of either the hardwood-dominated overstory types nor the conifer-dominated overstory types between LU1's and LU2's, and the sample size was too small to test for differences in the frequency of the No Tree overstory type between LU1's and LU2's.

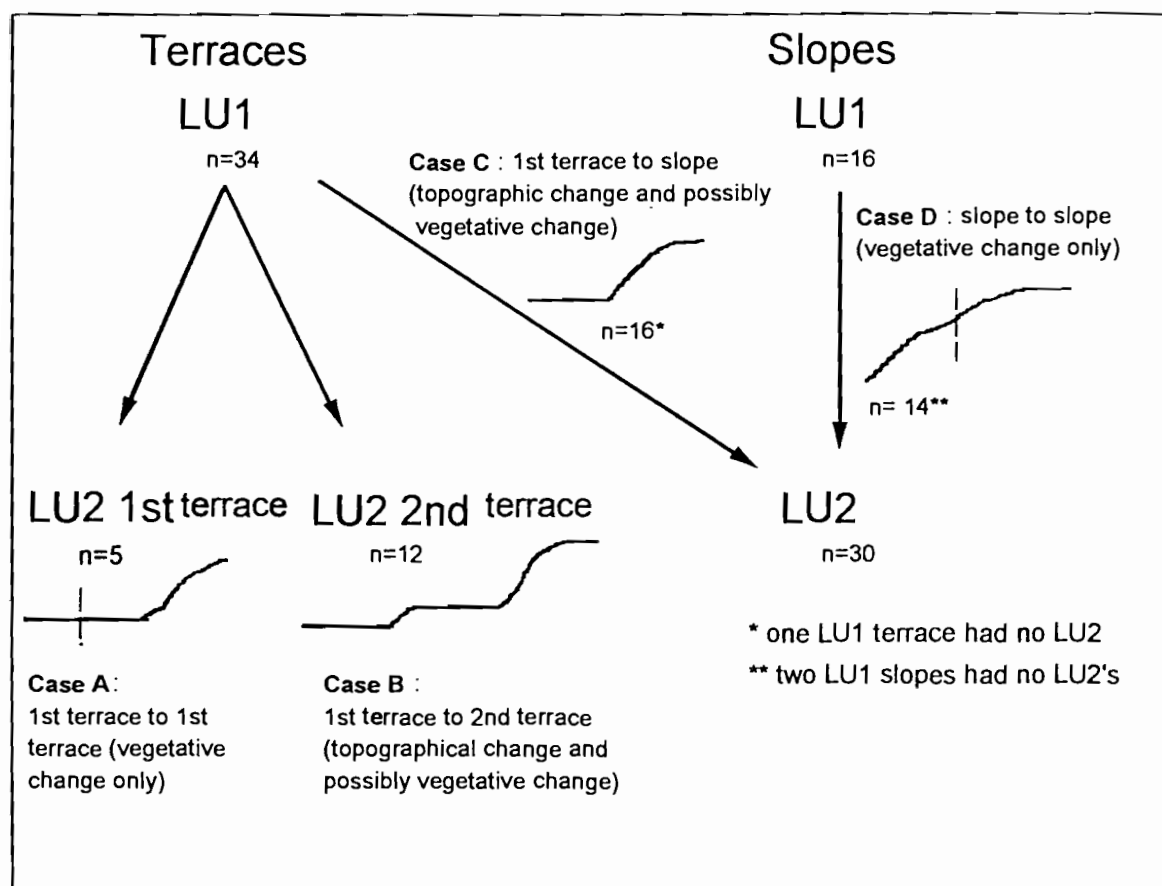


Figure 4. Different possibilities of LU1 changing to LU2: Case A) first terrace to first terrace (vegetative change only) Case B) first terrace to second terrace (topographical change and possibly vegetative change) Case C) first terrace to slope (topographical change and possibly vegetative change) Case D) slope to slope (vegetative change only).

Table 21. Adjusted medians or means and 95% confidence intervals ( $\leftrightarrow$ ) for variables that significantly differ (\*\*) between LU1's and LU2's for each case in Figure 4.  $p < 0.05$  (Least Squares Means Test). '@' = marginal difference between LU1 and LU2 ( $p$ -value  $0.06 < > 0.09$ ).

Variable	Case A: 1st terrace to 1st terrace	Case B: 1st terrace to 2nd terrace	Case C: 1st terrace to slope	Case D: slope to slope
mean height- above-stream (m)				
LU1:	1.3 (0.8 $\leftrightarrow$ 1.7) @	0.8 (0.2 $\leftrightarrow$ 1.5) **	1.2 (0 $\leftrightarrow$ 2.4) **	1.7 (0 $\leftrightarrow$ 3.5) **
LU2:	1.8 (1.3 $\leftrightarrow$ 2.2)	2.8 (2.1 $\leftrightarrow$ 3.4)	7.2 (5.9 $\leftrightarrow$ 8.4)	12.0 (10.2 $\leftrightarrow$ 13.8)
median LU width (m)				
LU1:	7.6 (3.4 $\leftrightarrow$ 7.0) **	10.1 (7.0 $\leftrightarrow$ 14.7) **	8.6 (5.9 $\leftrightarrow$ 12.7) **	11.0 (8.0 $\leftrightarrow$ 8.1) **
LU2:	27.1 (12.6 $\leftrightarrow$ 63.1)	26.0 (17.9 $\leftrightarrow$ 37.8)	41.2 (28.1 $\leftrightarrow$ 60.5)	49.4 (35.8 $\leftrightarrow$ 81.4)
mean hardwood cover (%)				
LU1:	64 (33 $\leftrightarrow$ 93) **	58 (53.7 $\leftrightarrow$ 62.2)	45 (42.0 $\leftrightarrow$ 47.9)	17 (14.3 $\leftrightarrow$ 19.6)
LU2:	31 (0 $\leftrightarrow$ 60)	41 (36.7 $\leftrightarrow$ 45.2)	38 (35.0 $\leftrightarrow$ 40.9)	35 (32.3 $\leftrightarrow$ 37.6)
mean conifer cover (%)				
LU1:	31 (26.0 $\leftrightarrow$ 35.9)	10 (0 $\leftrightarrow$ 30) **	35 (31.9 $\leftrightarrow$ 38.0)	26 (13 $\leftrightarrow$ 43) **
LU2:	52 (47.1 $\leftrightarrow$ 56.9)	41 (21 $\leftrightarrow$ 61)	39 (35.9 $\leftrightarrow$ 42.0)	57 (43 $\leftrightarrow$ 70)
mean of all woody plant cover (%)				
LU1:	38 (26.8 $\leftrightarrow$ 49.2)	17 (14.9 $\leftrightarrow$ 19.1)	63 (61.0 $\leftrightarrow$ 65.0)	85 (63 $\leftrightarrow$ 100) **
LU2:	57 (45.8 $\leftrightarrow$ 68.2)	22 (19.9 $\leftrightarrow$ 24.1)	64 (62.0 $\leftrightarrow$ 66.0)	38 (16 $\leftrightarrow$ 60)
total basal area (sq. m/ha)				
LU1:	36.7 (1.4 $\leftrightarrow$ 638.1)	5.7 (1.3 $\leftrightarrow$ 20.8) **	8.9 (2.4 $\leftrightarrow$ 29.5)	1.9 (0 $\leftrightarrow$ 8.2) **
LU2:	36.3 (1.3 $\leftrightarrow$ 613.0)	32.1 (10.0 $\leftrightarrow$ 100)	23.5 (7.3 $\leftrightarrow$ 74.2)	59.9 (19.2 $\leftrightarrow$ 90.4)
frequency of conifer- dominated overstory types (number of plots)	LU1: 2/4 LU2: 2/4	LU1: 1/6 ** LU2: 5/6	LU1: 3/11 @ LU2: 8/11	LU1: 2/12 ** LU2: 10/12

Table 21, Continued

frequency of hardwood- dominated overstory types (number of plots)	LU1: 2/4  LU2: 2/4	LU1: 4/8  LU2: 4/8	LU1: 5/7  LU2: 2/7	LU1: 2/5  LU2: 3/5
frequency of No Tree overstory type (number of plots)	LU1: 1/2  LU2: 1/2	LU1: 7/10 @ LU2: 3/10	LU1: 8/14  LU2: 6/14	LU1: 10/11 ** LU2: 1/11

*Case D: slope to slope; only vegetative change*

In the other case of sole vegetative change constituting a new LU, Case D of Figure 4 (slope to slope), height-above-stream in LU2's was an average of 10.3 meters higher than in LU1's (Table 21). Also, the median width of the LU2's was 38.4 meters wider than the median width of LU1's. Vegetatively, there were both differences between LU1's and LU2's in cover densities of conifers and all woody plants, but not hardwoods: average conifer cover in LU2's was 31% higher than in LU1's, and average woody plant cover was 47% denser in LU1's than in LU2's. In only treed plots, there were no differences detected among species' median basal areas. However, median total basal area was 58 sq. m/ha greater in LU2's than in LU1's. Sample size was too few to test for differences in basal areas of individual species between LU1' and LU2's. The frequency of the No Tree overstory type was significantly greater in LU1's than in LU2's. Conversely, conifer-dominated overstory types were found more frequently in LU2's than in LU1's. There were no differences detected in the frequency of hardwood-dominated overstory types between LU1's and LU2's.

*Case B: 1st terrace to 2nd terrace; topographical change and possibly vegetative change as well*

On transects where LU1's are first terraces and LU2's are second terraces, Case B of Figure 4, mean height-above-stream was 1.9 meters higher in LU2's than in LU1's (Table 21). Furthermore, the median width of LU2's was 15.9 meters wider than the width of LU1's. Vegetatively, mean conifer cover was 31% higher in LU2's than in LU1's. There were no differences found in mean cover densities of either hardwoods nor all woody plants between LU1's and LU2's. In just treed plots, no differences were detected among species' median basal areas between LU1's and LU2's, but median total basal area was 26.4 sq. m/ha greater on LU2's than on LU1's. Sample size was too few to test for differences in basal areas of individual species between LU1's and LU2's. There was a marginally significant difference in the frequency of the overstory type No Trees between LU1's and LU2's ( $p$ -value = 0.09): No Trees was borderline more frequent in LU1's than in LU2's. There was an equal frequency of hardwood-dominated overstory types between LU1's and LU2's, and the frequency of conifer-dominated overstory types was greater in LU2's than in LU1's (Table 21).

*Case C: 1st terrace to slope; topographic change and possibly vegetative change as well*

In Case C in Figure 4, where transects shifted from first terrace to slope, mean height-above-stream was 5.0 meters higher for LU2's than for LU1's (Table 21). Also, the median width of LU2's was 32.6 meters wider than the width of LU1's. There were no differences between LU1's and LU2's in cover densities of hardwoods, conifers, or all woody plants. On only treed plots, no differences were detected among the medians of species' basal areas between LU1's and LU2's, and

there was no difference in median total basal area between LU1's and LU2's. Sample size was too few to test for differences in basal areas of individual species between LU1' and LU2's. There was a marginally significant difference in the frequency of conifer-dominated overstory types: conifer-dominated overstory types were borderline more frequent in LU2's than in LU1's. There were no differences in the frequency of hardwood-dominated overstory types, nor in the frequency of the No Trees type between LU1's and LU2's.

### ***Differences Among LU1's From The Four Different Transect Configurations***

Examining only the LU1's in Figure 4, a difference was found in height-above-stream between the four cases. Mean height-above-stream in Case D (1.7 meters), slope to slope, was greater than mean height-above-stream in Case B (0.8 meters), first terrace to second terrace (Table 22). Among only LU1's, no differences were found in LU width between the four cases. Vegetatively, there were no differences detected among the six species' mean basal areas, nor were there differences found in median total basal area. There was, however, a distinction between woody plant cover among the LU1's. Mean woody plant cover on the LU1's in Case D (85%), slope to slope, was greater than in Case B (17%), first terrace to second terrace, and in Case C (38%), first terrace to slope. Moreover, mean woody plant cover among the LU1's in Case A (63%), first terrace to first terrace, was greater than in Case B (17%), first terrace to second terrace (Table 22). There was no difference in mean conifer cover among the LU1's between cases, but there was a difference detected in hardwood cover. For just LU1's, mean hardwood cover in Case D (16 %), slope to slope, was lower than mean hardwood cover in Case A (45 %), Case B (58 %), and Case C (63%) (Table 22).

Although no statistical procedures were carried out on differences in overstory type frequencies among LU1's of different cases, the highest prevalence of the No Tree type is on LU1 slopes that are adjacent to LU2 slopes (Case D), and the lowest frequency of the No Tree type is on LU1's which are first terraces that are adjacent to LU2's that are also first terraces (Case A) (Table 23).

Table 22. Adjusted medians or means with 95% confidence intervals ( $\leftrightarrow$ ) for variables that significantly differ among the LU1's between cases in Figure 4; '@' = marginal difference among LU1's (p-value  $0.06 < p < 0.09$ ). Means within a row followed by the same letter do not significantly differ at  $p < 0.05$  (Least Squares Means Test).

Variable	Case A: 1st terrace to 1st terrace	Case B: 1st terrace to 2nd terrace	Case C: 1st terrace to slope	Case D: slope to slope
mean height-above-stream (m)	1.3 ab 0.8 $\leftrightarrow$ 1.7	0.8@ a 0.1 $\leftrightarrow$ 1.5	1.2 ab 0.8 $\leftrightarrow$ 1.6	1.7@ b 1.3 $\leftrightarrow$ 2.1
mean woody plant cover (%)	63 bc 43 $\leftrightarrow$ 83	17 a 0 $\leftrightarrow$ 40	38 ab 3 $\leftrightarrow$ 73	85 c 64 $\leftrightarrow$ 100
mean hardwood cover (%)	45 a 25 $\leftrightarrow$ 65	58 a 36 $\leftrightarrow$ 81	63 a 27 $\leftrightarrow$ 100	16 b 0 $\leftrightarrow$ 38
mean LU width (m)	9.4 a 0 $\leftrightarrow$ 22.3	12.6 a 4.4 $\leftrightarrow$ 20.8	10.4 a 3.2 $\leftrightarrow$ 17.6	18.2 a 10.6 $\leftrightarrow$ 25.8
median total basal area (sq. m/ha)	37.8 a 3.6 $\leftrightarrow$ 329.3	6.1 a .80 $\leftrightarrow$ 26.9	9.17 a 2.1 $\leftrightarrow$ 32.4	1.9 a 0 $\leftrightarrow$ 9.5
mean conifer cover (%)	31 a 0 $\leftrightarrow$ 65	10 a 0 $\leftrightarrow$ 30	35 a 17 $\leftrightarrow$ 52	26 a 7 $\leftrightarrow$ 45



Table 23. Frequencies (number of plots) of 3 different overstory types among the LU1's of the different cases from Figure 4.

	<b>Case A:</b> 1st terrace to 1st terrace	<b>Case B:</b> 1st terrace to 2nd terrace	<b>Case C:</b> 1st terrace to slope	<b>Case D:</b> slope to slope
frequency of No Tree overstory Type (number of plots)	1/26	7/26	8/26	10/26
frequency of hardwood- dominated overstory types (number of plots)	2/13	4/13	5/13	2/13
frequency of conifer- dominated overstory types (number of plots)	2/8	1/8	3/8	2/8

### *Differences Among LU2's From the Four Different Transect Configurations*

Examining only the LU2's in Figure 4, there was a difference detected between the cases for the variable height-above-stream. Mean height-above-stream was highest in Case D (12.0 meters), slope to slope (Table 24). Additionally, LU2's in Case C (7.2 meters), first terrace to slope were higher above the stream than LU2's in Case A (1.8 meters), first terrace to first terrace, and Case B (2.8 meters), first terrace to second terrace. There was a marginally significant difference detected in LU width between the four cases in LU2's: mean LU2 width in Case D (71.3 meters), slope to slope was borderline wider than mean LU2 width in Case B (36.1 meters), first terrace to second terrace (Table 24). Among the LU2's, there were no differences found between the cases in mean basal area among the six species, nor were there differences detected in median total basal area, average woody plant cover, average conifer cover, or average hardwood cover.

Table 24. Adjusted medians or means with 95% confidence intervals ( $\leftrightarrow$ ) for variables that significantly differ among the LU2's between cases in Figure 4; '@' = marginal difference among LU2's (p-value  $0.06 < p < 0.09$ ). Means within a row followed by the same letter do not significantly differ at  $p < 0.05$  (Least Squares Means Test).

Variable	Case A: 1st terrace to 1st terrace	Case B: 1st terrace to 2nd terrace	Case C: 1st terrace to slope	Case D: slope to slope
mean height- above-stream (m)	1.8 a 0 $\leftrightarrow$ 4.5	2.8 a 0 $\leftrightarrow$ 4.5	7.2 b 5.7 $\leftrightarrow$ 8.7	12.0 c 10.4 $\leftrightarrow$ 13.6
mean LU width (m)	40.5 ab 8.8 $\leftrightarrow$ 72.2	36.1@ a 15.7 $\leftrightarrow$ 56.5	56.2 ab 38.3 $\leftrightarrow$ 73.7	71.3@ b 52.4 $\leftrightarrow$ 90.2
median total basal area (sq. m/ha)	36.3 a 3.8 $\leftrightarrow$ 286.1	32.1 a 8.0 $\leftrightarrow$ 120.5	24.0 a 7.1 $\leftrightarrow$ 76.5	59.9 a 17.3 $\leftrightarrow$ 201.4
mean conifer cover (%)	52 a 11 $\leftrightarrow$ 93	41 a 15 $\leftrightarrow$ 67	39 a 17 $\leftrightarrow$ 62	57 a 34 $\leftrightarrow$ 81
mean hardwood cover (%)	31 a 0 $\leftrightarrow$ 71	42 a 17 $\leftrightarrow$ 67	38 a 17 $\leftrightarrow$ 60	35 a 12 $\leftrightarrow$ 59
mean cover of all woody plants (%)	57 a 19 $\leftrightarrow$ 96	22 a 0 $\leftrightarrow$ 47	63 a 42 $\leftrightarrow$ 85	39 a 16 $\leftrightarrow$ 61

Although no statistical procedures were carried out on differences in overstory type frequencies among LU2's of different cases, conifer cover is highest in LU2's that are slopes which were adjacent to LU1's that were also slopes (Table 25).

#### Differences Among Terraces and Slopes For All Landscape Units (1-4)

The average distance away from the channel that slope began was 12.8 meters (sd = 12 meters; range = 0  $\leftrightarrow$  60 m). Sixty-two LU's were on slopes and 56 LU's were on terraces. In treed plots, species' median basal areas differed between terraces

Table 25. Frequencies (number of plots) of 3 different overstory types among the LU2's of the different cases from Figure 4.

	<b>Case A:</b> 1st terrace to 1st terrace	<b>Case B:</b> 1st terrace to 2nd terrace	<b>Case C:</b> 1st terrace to slope	<b>Case D:</b> slope to slope
frequency of No Tree overstory Type (number of plots)	1/11	3/11	6/11	1/11
frequency of hardwood- dominated overstory type (number of plots)	2/11	4/11	2/11	3/11
frequency of conifer- dominated overstory type (number of plots)	2/25	5/25	8/25	10/25

and slopes. On slopes, median bigleaf maple basal area was less than median red alder basal area, Douglas-fir basal area, and western hemlock basal area (Table 26).

Moreover, median western redcedar basal area was less than median red alder, Douglas-fir, and western hemlock basal areas on slopes. On terraces, median red alder basal area was greater than the median basal area of any other species. Median Sitka spruce basal area was greater than median western redcedar, western hemlock, and bigleaf maple basal area (Table 26). There were no differences in mean total basal area between terraces and slopes. On plots with red alder, median basal area differed between terraces and slopes: alder basal area was 26.6 sq. m/ha higher on terraces than on slopes (Table 27). Similarly, on plots with bigleaf maple, median bigleaf maple basal area was 61.1 sq. m/ha higher on terraces than slopes. No other differences were detected in species' basal areas between terraces and slopes when examining only the plots that contained each respective species.

Table 26. Adjusted median basal areas and 95% confidence intervals ( $\leftrightarrow$ ) of six species on terraces and slopes for all landscape units. Medians followed by the same letter are not significantly different at  $p < 0.05$  (Least Squares Means Test); v/w/x/y/z = column differences; a/b = row differences.

Species	Median Basal Area on Terraces (sq. m/ha)	Median Basal Area on Slopes (sq. m/ha)
Bigleaf maple	0.2 0 $\leftrightarrow$ 1.16 y a	0.3 0 $\leftrightarrow$ 1.36 x a
Red alder	13.5 6.87 $\leftrightarrow$ 26.03 v a	3.5 1.61 $\leftrightarrow$ 6.67 w b
Douglas-fir	1.8 0.53 $\leftrightarrow$ 4.24 xz a	3.1 1.41 $\leftrightarrow$ 6.08 w a
Western redcedar	0.3 0 $\leftrightarrow$ 1.47 xy a	0.4 0 $\leftrightarrow$ 1.41 x a
Western hemlock	0.7 0 $\leftrightarrow$ 2.12 xy a	2.4 0.99 $\leftrightarrow$ 4.86 w a
Sitka spruce	2.9 1.10 $\leftrightarrow$ 6.22 z a	1.4 0.43 $\leftrightarrow$ 3.19 xw a

Table 27. Adjusted medians or means with 95% confidence intervals ( $\leftrightarrow$ ) for variables that significantly differ between terraces and slopes for all landscape units. Means or medians followed by the same letter are not statistically different at  $p < 0.05$  (Least Squares Means Test). a/b = row differences.

Variable	Terraces	Slopes
median red alder basal area on only plots containing red alder (sq. m/ha)	50.4 a 33.1 $\leftrightarrow$ 74.4	23.8 b 15.3 $\leftrightarrow$ 35.9
median bigleaf maple basal area on only plots containing maple (sq. m/ha)	148.4 a 99.4 $\leftrightarrow$ 214.8	87.3 b 67.3 $\leftrightarrow$ 109.9
median Sitka spruce basal area on only plots containing spruce (sq. m/ha)	106.7 a 41.8 $\leftrightarrow$ 272.3	156.0 a 54.0 $\leftrightarrow$ 450.3

Table 27, Continued

median western hemlock basal area on only plots containing hemlock (sq. m/ha)	55.7      a 19.8 ↔ 156.0	50.9      a 28.0 ↔ 92.2
median Douglas-fir basal area on only plots containing Douglas-fir (sq. m/ha)	249.6    a 131.2 ↔ 474.8	169.0    a 107.4 ↔ 265.8
median western redcedar basal area on only plots containing cedar (sq. m/ha)	86.4      a 7.5 ↔ 992.2	15.0      a 3.2 ↔ 70.1
mean hardwood cover (%)	50          a 38 ↔ 61	36          b 25 ↔ 47
mean conifer cover (%)	47          a 31 ↔ 62	52          a 38 ↔ 66
mean cover of all woody plants (%)	38          a 22 ↔ 54	36          a 22 ↔ 50
mean total basal area (sq. m/ha)	168.0    a 110.4 ↔ 226.0	157.0    a 105.4 ↔ 208.6

Average hardwood cover was 14% higher on terraces than on slopes (Table 27), but no differences were found either in conifer cover or all woody plant cover between terraces and slopes. The most frequently found overstory type on both terraces and slopes was the No Tree overstory type (Figure 5). The second most commonly found overstory type on terraces was the Pure Hardwood type, and the second most commonly found overstory type on slopes was the Pure Conifer type.

Douglas-fir was found about twice as many times on slopes than on terraces, as was bigleaf maple and western redcedar. Western hemlock was found more than twice as many times on slopes than on terraces (Table 28). Red alder was found

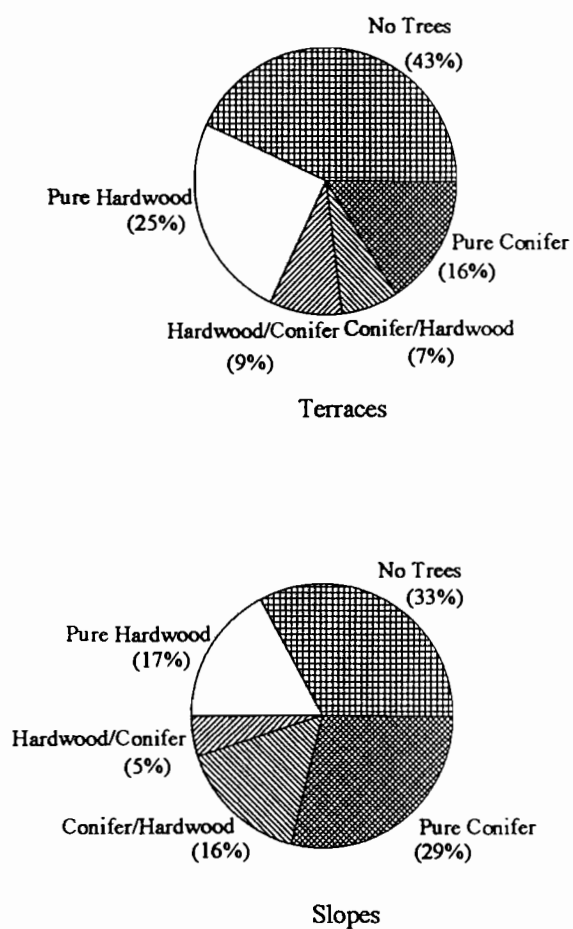


Figure 5. Percentage of overstory types found on terraces and slopes for all landscape units.

Table 28. Frequency of plots (%) containing each species on terraces and slopes for all landscape units.

Species	Terrace Frequency n = 56 plots	Slope Frequency n = 62 plots
Bigleaf maple	7%	13%
Red alder	68%	50%
Douglas-fir	18%	31%
Western redcedar	7%	13%
Western hemlock	12%	34%
Sitka spruce	29%	21%

more than any other species on both terraces and slopes, although it was found more frequently on terraces, as was Sitka spruce.

### Species' Heights-Above-Stream

For all landscape units, red alder was the species most frequently found at the lowest height-above-stream (Figure 6). However, alder was found most frequently in all height-above-stream categories. Both Douglas-fir and western hemlock were second-most frequently found species at the highest height-above-stream categories. These two latter species also exhibited a pattern of increasing frequency with increasing height-above-stream. No western hemlock was found in the lowest height category. Sitka spruce also displayed a pattern of increasing frequency with increasing

height-above-stream, although its frequency peaked before the highest height-above-stream category, at 2-6m. Bigleaf maple's frequency increased with increasing

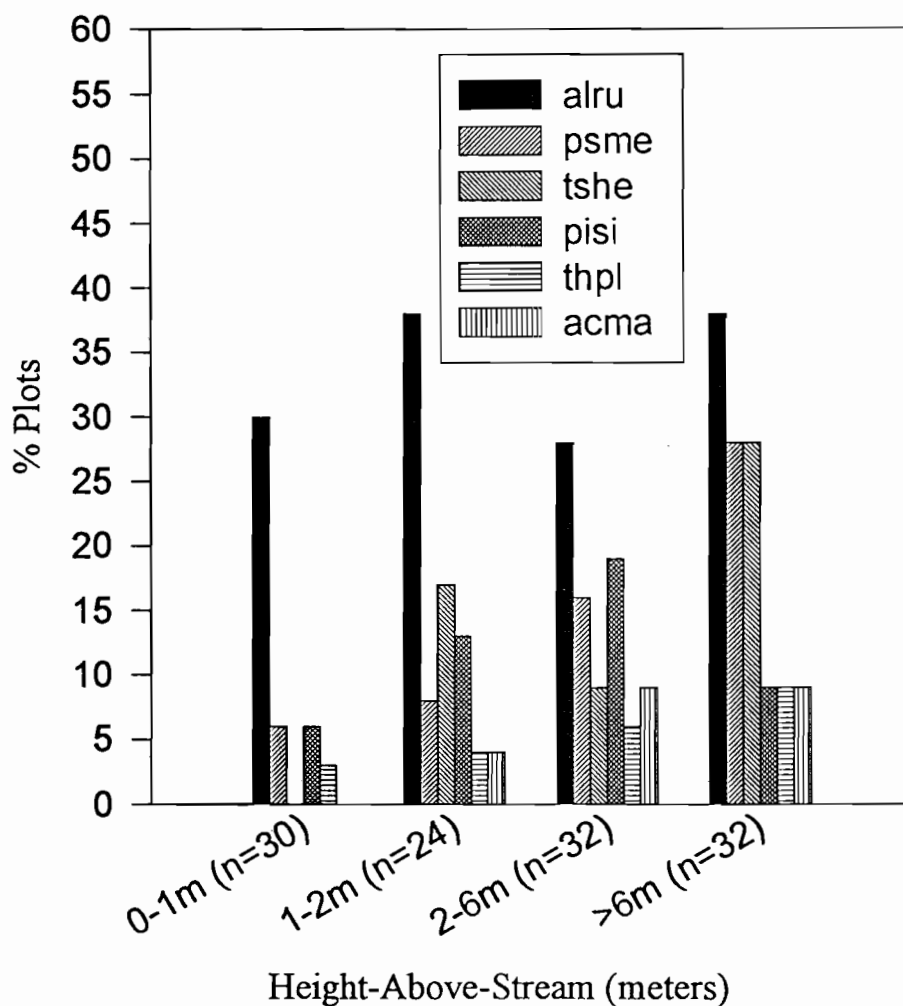


Figure 6. Including all landscape units, percentage of plots containing each species which fall in the four height-above-stream categories.



height-above-stream too, as did western redcedar's frequency, although bigleaf maple was found equally often in the last two height categories. Both bigleaf maple and western redcedar were found relatively infrequently in general, so sample size is small to make definitive conclusions about the probability that they will be found at certain heights-above-stream.

## Tree Ages

### *Landscape Unit Ages*

As a reminder to the reader, this section addresses only the largest tree per LU, and assumes they are the oldest trees on the landscape unit. Furthermore, trees that were greater than 80 cm dbh were too big to core, and were given an imposed age of 145 years old which equates with the date of the last recorded, large-scale fire in the creek basin (Methods Chapter, Table 3).

For all creeks combined, the largest trees on LU2's were an average of 24 years older than the largest trees on LU1's (Figure 7). Moreover, considering only transects that had trees on both the LU1's and LU2's, 13/18 of the LU1's supported trees that were younger than the LU2's of the same transect, i.e., 72% of the LU1's experienced disturbances which regenerated trees more recently than LU2's on the same transect.

Forty-eight percent (24/50) of the LU1's contained trees, and 76% (35/47) of the LU2's contained trees. Examining only LU's with trees, and only one largest tree (which was cored) per LU, the mean tree age of the largest trees in LU1's was younger than the mean tree age of the largest trees in LU2's in six of the nine creeks sampled (Table 29). Powder Creek (PO in Table 29) and Bob Creek (BM/BU in

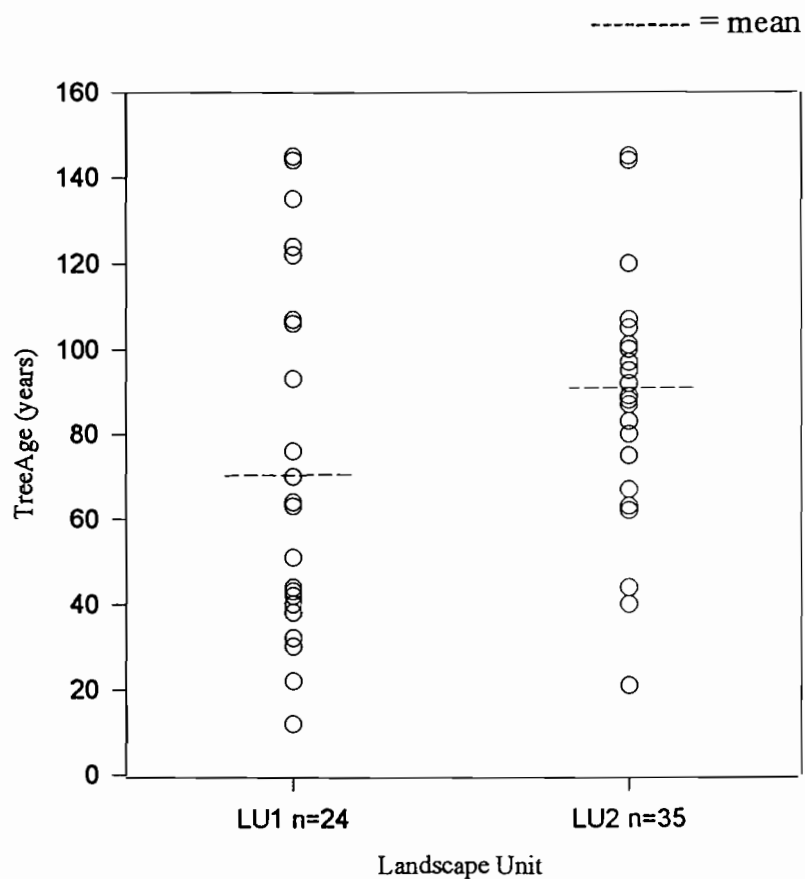


Figure 7. Scatter plot of tree age distributions in LU1's and LU2's for each dominant tree per plot. n = number of plots containing trees. Mean tree age in LU1's = 74.1 years, standard error = 9.1. Mean tree age in LU2's = 98.0 years, standard error = 6.1.

Table 29) were the two creeks along which the mean tree age of the largest trees on LU1's was older than the mean tree age of the largest trees on LU2's.

When comparing the largest corable ( $< 80\text{cm dbh}$ ) trees on an LU with the date of the last catastrophic fire in the creek basin for all LU's (including LU's with no trees) (Table 29), only 42% (21/50) of the LU1's supported trees that were younger than the last stand-resetting fire which occurred about 145 years ago, and 46% (22/47) of the LU2's supported trees that were younger than the last stand-resetting fire. Treeless LU's are assumed the age of the last fire since no disturbances have since propagated trees.

It is possible to determine the mean number of disturbances per transect since the last stand-resetting fire when including all of the LU's with trees, by counting the number of times on a transect that the dominant tree on an LU is younger than the last fire age (145 years), and equating it with a disturbance that initiated its establishment (Table 29). Given that shade-intolerant trees require a lot of light and mineral soil for their regeneration, I'm assuming that shade-intolerant trees usually require some sort of tree-regenerating disturbance to provide for these conditions. The size, frequency, or intensity of the disturbance is not known. I included both shade-tolerant and shade-intolerant trees in the estimations to calculate a range, however, I acknowledge that it is most realistic to only equate the shade-intolerants with some tree regenerating disturbance, since shade-tolerants do not necessarily require a disturbance for their regeneration. Admittedly, the biggest trees which were too large to core can be older than 145 years if the fire did not kill them; my estimations provide minimum occurrences of disturbances. Moreover, any fires more recent than 145 years were smaller in scale than the last regional catastrophic fires (Impara, in progress), and therefore might not be different than a small landslide, for example, in tree-regenerating scale. Fires more recent than 145 years are thus irrelevant to this data, since it is doubtful that they are responsible for the establishment of these big "matrix" trees which are scattered throughout the basins.

Table 29. Dominant tree ages and species per LU along transects (the same age classes are grouped as 1 disturbance); t = terrace and s = slope; '-' = no trees found; 'x' = either red alder or Douglas-fir is also in the LU and younger than the given oldest tree age, indicating a second disturbance since the last fire. Double lines represent new creeks or new sections of the same creek. ALRU = red alder; PISI = Sitka spruce; TSHE = western hemlock; THPL = western redcedar; PSME = Douglas-fir; ACMA = bigleaf maple. \*BM = Bob Creek (lower); BU = Bob Creek (upper); CD = Cummins Creek (lower); CH = Chitwood Creek; CL = Cliff Creek; CT = Cummins Creek (tributary); CU = Cummins Creek (upper); DR = Drift Creek; FM = Flynn Creek; FR = Franklin Creek; FT = Flynn Creek (tributary); PO = Powder Creek; SE = Skate Creek (east fork); SW = Skate Creek (west fork).

Transect name*	LU1 tree age	LU2 tree age	LU3 tree age	LU4 tree age	number of disturbances since fire per transect		terrace at the base of slope?
					t	s	
BM1A	-	21 t ALRU	29 t ALRU	-	1	0	
BM1B	145 t PISI x	145 t PISI	-	-	0	0	
BU1A	-	95 s TSHE	-	-	0	1	
BU1B	107 s TSHE	-	-	-	0	1	
BU2A	-	107 s TSHE	-	-	0	1	
BU2B	-	95 s THPL x	-	-	0	1	

Table 29, Continued

CD1A	40 t PISI x	120 s PISI	-	-	1	1	yes
CD1B	30 t ALRU	67 t PISI x	-	-	2	0	
CD2A	22 t ALRU	100 t ACMA	75 s THPL	-	2	1	yes
CD2B	-	101 t PISI	-	-	1	0	
CD3A	70 t ALRU	-	25 s ALRU	-	1	1	
CD3B	32 t TSHE x	44 t TSHE	-	-	1	0	
CD4A	-	-	99 s TSHE	-	0	1	
CH1A	42 t ALRU	145 s PISI	-	-	1	0	yes
CH1B	-	144 s TSHE x	-	-	0	0	
CL1A	-	144 s PISI	-	-	0	0	
CL1B	93 t ALRU	63 t ALRU	90 s PISI	-	1	1	yes
CL2A	64 t ALRU	89 t PISI	-	-	2	0	

Table 29, Continued

CT1A	-	87 s PSME	-	-	0	1	
CT1B	-	88 s PSME x	-	-	0	1	
CU10B	51 s PISI x	97 s PISI	-	-	0	2	
DR1A	145 s PISI	-	-	-	0	0	
DR1B	-	145 t PISI	-	-	0	0	
DR2A	63 t PISI	145 t PSME x	-	-	1	0	
DR2B	43 t ALRU	-	-	-	1	0	
DR3A	44 s ALRU	40 s ALRU	-	-	0	1	
DR3B	-	83 s ALRU	-	-	0	1	
FM1A	135 s PSME x	145 s PSME	-	-	0	0	
FM1B	122 t PSME	145 s PSME	-	-	1	0	yes
FR2A	76 s ALRU	-	145 s TSHE	-	0	1	

Table 29, Continued

FR2B	124 t THPL	145 s PSME	-	-	1	0	yes
FR3A	-	105 s ACMA	-	-	0	1	
FT1A	-	-	50 s ALRU	-	0	1	
FT1B	-	145 s PSME	-	-	0	0	
PO1A	144 t PSME x	92 s ALRU	-	-	0	1	yes
PO1B	-	-	89 s ALRU x	-	0	1	
PO2B	106 t PSME x	-	-	-	1	0	
PO3A	38 t PISI	83 t ALRU	-	-	2	0	
PO3B	-	-	69 s ALRU	-	0	1	
SE1A	-	75 s ACMA	69 s TSHE	-	0	1	
SE1B	32 t ALRU	62 s TSHE	46 s ALRU	-	1	2	yes
SE2A	-	-	101 s TSHE x	-	0	1	

Table 29, Continued

SE2B	12 t ALRU	80 s TSHE	-	-	1	1	yes
SW1A	-	145 s PSME	-	-	0	0	
SW1B	-	145 t PSME	-	75 s ALRU	0	1	
<b>TOTALS</b>	>>>>>>	>>>>>>	>>>>>>	>>>>>>	<b>22</b>	<b>27</b>	

When more than one tree displayed similar ages on the same transect (within 12 years apart for shade-tolerants and within 8 years apart for shade-intolerants), only one disturbance was assumed for the transect. This calculation came to a total of 49 disturbances for 50 transects, or an average of 0.98 disturbances per transect. Twenty-two of these disturbances were on terraces and 27 were on slopes (Table 29). Since the total amount of streamside sampled was 9.6 km (50 transects), another way to present this figure is that 5.1 disturbances occurred per 9.6 km of stream sampled per 145 years. In other words, on average, at least 3.5 disturbances large enough to regenerate trees occurred per km per century since the last stand-resetting fire along the nine creeks sampled in the Oregon Coast Range (Table 30).

When viewing all of the dominant trees *per species* per LU, and counting the LU's which support red alder or Douglas-fir (the two shade-intolerant pioneer species) that are younger than the oldest tree in that same LU (as noted by an 'x' in Table 29), 14 more disturbances can be counted since the last stand-resetting fire: 7 occurring on terraces and 7 occurring on slopes. Adding these numbers onto the previous figures which only included one oldest tree per LU (above paragraph), 29



disturbances took place on terraces since the last stand-resetting fire, and 34 disturbances took place on slopes. This totals to an average of at least 63 disturbances occurring per 50 transects, or 1.26 disturbances per transect. In other words, when including the oldest tree *per species* per LU, on average, at least 4.5 disturbances large enough to regenerate trees occurred per km per century since the last large-scale fire in the nine creeks sampled in the Oregon Coast Range (Table 30).

Table 30. Summary of total number of disturbances occurring on terraces and on slopes since the last fire, and the average number of disturbances on terraces and slopes combined since the last fire per km per century, using four different data sets.

Data Set	Total number of disturbances on terraces since the last fire per 50 transects (9.6 km) per 145 years	Total number of disturbances on slopes since the last fire per 50 transects (9.6 km) per 145 years	Average (minimum number of disturbances per km per century since the last fire)
oldest tree per LU	22	27	3.5
oldest tree <i>per species</i> per LU	29	34	4.5
oldest tree per LU (- shade-tolerants)	20	17	2.6
oldest tree <i>per species</i> per LU (- shade-tolerants)	27	24	3.6*

\* most biologically meaningful estimation

Since it is possible that shade-tolerant species came in with no initiating disturbance, another way to calculate minimal disturbance frequency is not to equate the ages of the most shade-tolerant species which are younger than the fire age with a disturbance event. Since western hemlock and western redcedar were the two most shade-tolerant species found (Minore 1979), I calculated disturbance frequency again without these two species, just including the oldest trees in an LU. The average,

minimum number of disturbances since the last stand-resetting fire on terraces recalculated to 20, and the number of disturbances on slopes recalculated to 17 (Table 30). This would total 37 disturbances that occurred per 50 transects; an average of 0.74 disturbances per transect, or 2.6 disturbances per km per century (Table 30).

When viewing the oldest (i.e., dominant) tree *per species* per LU, and not including the two most shade-tolerant species (western hemlock and western redcedar), this figure came to a total of 51 disturbances that occurred per 50 transects; 27 on terraces and 24 on slopes (Table 30). In other words, when viewing the oldest tree *per species* per LU, and not including the two most shade-tolerant species found, on average, at least 1.02 disturbances occurred per transect, or 3.6 disturbances occurred per km per century since the last stand-resetting fire (Table 30).

As a reminder to the reader, the above disturbance frequency calculations could be under-estimated, since only the oldest (dominant) trees per species per plot were cored. Subdominant trees may indicate more recent disturbance and were not dated. Conversely, it is also possible that the calculations are over-estimations of disturbance frequency because some of the fires known to each area (Table 3) might not have swept through each entire basin, rendering the biggest tree that were too large to core older than 145 years. This might specifically be true in Skate Creek, where Reeves et al. (1995) claim their study sites in that basin were in forests more than 330 years of age. However, Reeves et al. (1995) did not mention coring any trees. Ward (1977) claims that in the Oregon Coast Range, large-scale fires generally consume about 70% of the forest, leaving up to 30% of the area as unburned islands (Ward 1977). However, due the fact that during field reconnaissance I did not observe any of my sample areas as “islands of unburned trees,” I believe it is more likely that most of the calculations are under-estimated.

It is possible that the similar ages in all of Bob Creek upstream transects (BU's in Table 29), suggest that one disturbance might have occurred about 107

years ago in this stream reach. Transects with the last letter ending with “A” occur on the opposite side of the stream as transects with the last letter ending in “B.” As such, all transects on both sides of Bob Creek upstream would have been affected by the disturbance 107 years ago. A large-scale disturbance may have also occurred in Cliff Creek (CL’s), and in the tributary of Cummins Creek (CT’s) (Table 29).

Of just the LU1’s, 16 disturbances occurred since the last large-scale fire on LU1 terraces and 4 occurred on LU1 slopes (Table 29). Nine disturbances took place on terraces that were adjacent to slopes, possibly in seepage areas at the base of slopes (Table 29).

### ***Terrace and Slope Tree Ages***

Fifty-five percent (31/56) of terraces contained trees, whereas 66% (41/62) of slopes contained trees. The largest trees on terraces were an average of 15 years younger than the largest trees on slopes (Figure 8).

When comparing the oldest tree age with the date of the last catastrophic fire in the creek basin for all LU’s (including LU’s with no trees) (Table 29), only 44% (25/56) of the terraces supported trees that were younger than the last stand-replacing fire, and 46% (29/62) of the slopes supported trees that were younger than the last stand-replacing fire. Treeless LU’s are assumed the age of the last fire since no disturbances have since propagated trees.

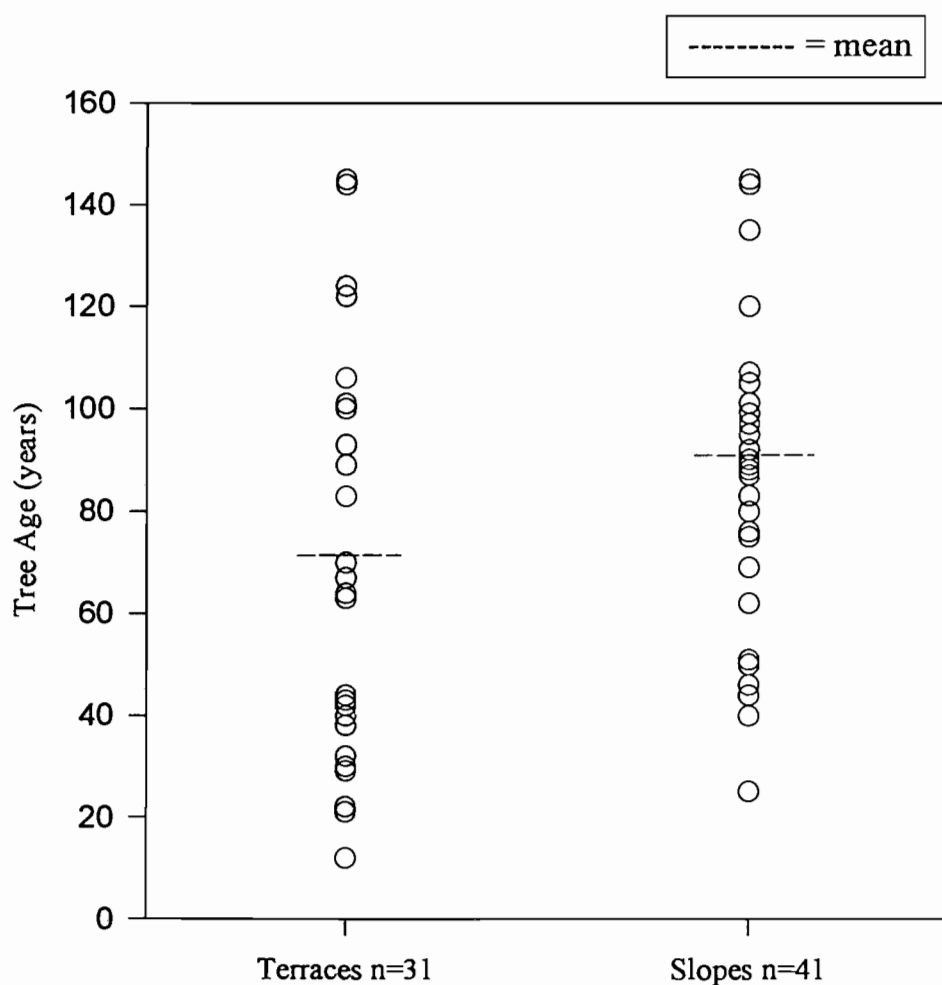


Figure 8. Scatter plot of tree age distributions on terraces and slopes for each dominant tree per plot.  $n$  = number of plots containing trees. Mean tree age on terraces = 77.3 years, standard error = 8.1. Mean tree age on slopes = 92.0 years, standard error = 5.8.

### ***Individual Tree Species Ages***

When viewing all of the plots, Douglas-fir, Sitka spruce, and western hemlock dominants all exhibit the oldest ages (Figure 9). However, no Douglas-fir canopy dominants less than 85 years were found. Shade-tolerant conifer dominants such as western hemlock and Sitka spruce, however, were found younger than 85 years old. Red alder dominants were also found under 85 years old. Other than red alder, there were no canopy dominants less than 30 years old (Figure 9). No red alder dominants more than 95 years were found (Figure 9). Western hemlock and Sitka spruce dominants exhibited the widest age ranges (Figure 9).

### **Regeneration**

Twenty-one plots out of 118 (18%) contained visible regeneration. Of these plots, 52% contained Sitka spruce seedlings (< 8 cm dbh), 19% contained red alder, 24% contained western hemlock, and 4% contained Douglas-fir (one seedling). No western redcedar or bigleaf maple regeneration was found.

A total of 130 seedlings were found (Table 31). Of these, 86% were Sitka spruce seedlings, 8% were red alder seedlings, 5% were western hemlock seedlings, and 1% were Douglas-fir seedlings. Ninety-two percent (119/130) of the seedlings that were found were growing on nurse logs. Regeneration of more than one species was never found in a plot.

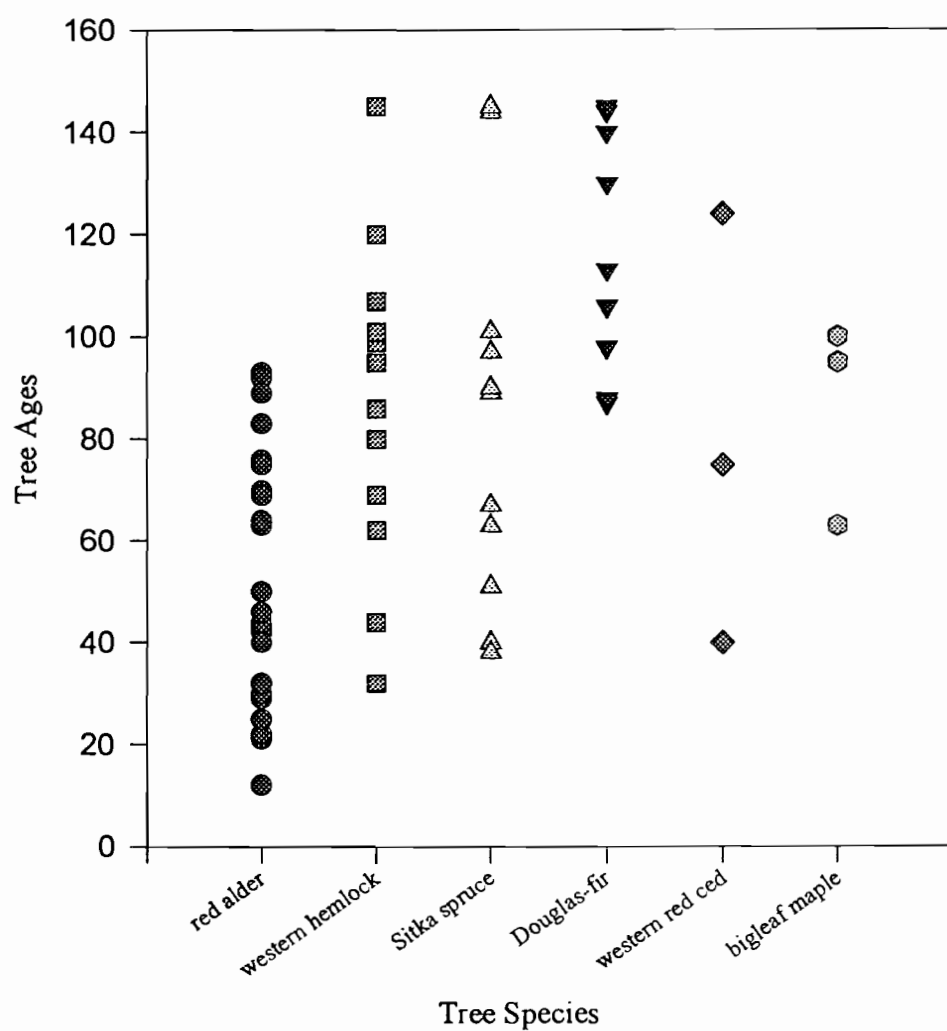


Figure 9. Scatter plot of the oldest tree age per plot for all landscape units (1-4).

Table 31. Number of seedlings found (< 8" dbh) per species for all LU's sampled.  
 PISI = Sitka spruce; TSHE = western hemlock; ALRU = red alder; PSME =Douglas-fir.

Species	Number of Seedlings	Substrate
PISI	107	log
PISI	4	organic
PISI	0	mineral
ALRU	7	log
ALRU	0	organic
ALRU	4	mineral
TSHE	5	log
TSHE	2	organic
TSHE	0	mineral
PSME	0	log
PSME	0	organic
PSME	1	mineral

## 7. DISCUSSION

### Species' Distributions/Habitat Preferences

#### *Red Alder*

Red alder was the most frequently found species (Tables 9 and 18). Its median basal area was higher than all other species on LU1's (Table 10), and on terraces of all LU's (Table 26). However, in just plots where alder was found, its basal area was lower than most other species (Tables 12 and 20). This indicates that alder is a frequently-found riparian species, but where it is found, it maintains either relatively small diameters or small numbers of stems.

Red alder forms denser stands on terraces than on slopes, as seen in its higher median basal area on terraces than on slopes for all the LU's where alder was found (Table 27). Also, on LU1's, red alder was found almost twice as often on terraces as on slopes (Table 9), and on all landscape units, it was the most frequently-found species in the lowest height-above-stream category (Figure 6). This coincides with what is known about red alder (Harrington 1990; Harrington et al. 1994; Rot 1995) in that it is well-adapted to floodplains (see Introduction). However, alder was extensive throughout the entire riparian area, both on terraces and slopes (Table 28), and in all height-above-stream categories (Figure 6).

Because alder requires a mineral soil seed bed for successful establishment (Harrington 1990), the higher frequency of alder on terraces compared with slopes may indicate that patches of mineral soil are exposed more frequently on terraces. Moreover, because alder is quite shade-intolerant (Harrington 1990), these patches must have been fairly large, at least a tree height across.



The mean, median and range of ages found in red alder dominants was the youngest among all of the species (Figure 9). Red alder was therefore the most recently regenerating species found. This indicates that alder has been able to establish and survive in riparian areas more frequently than most of its competitors.

### *Bigleaf maple*

Bigleaf maple was not found on any LU1's. Apparently, this is not due to a poor seed source because bigleaf maple had a relatively high frequency (Tables 18 and 19) and mean basal area (Table 20) on LU2's. Seed predation or browsing could have reduced seedlings or seeds close to the stream. Fried et al. (1988) found that rodents can reduce bigleaf maple seedling emergence up to 98% in western Oregon. It could also be that there was not enough shade under which seedlings could establish (Fried et al. 1988). Additionally, the near-stream soils could have been insufficiently drained, too shallow, or composed of particle sizes that were too small (Minore and Zasada 1990). The ideal conditions for bigleaf maple regeneration and growth are probably located in a zone right behind the near-stream zone, where soils are still mesic, but inundated for shorter periods of time, possibly less herbivory occurs, and there is more potential for landslides which deliver gravelly colluvium. This supported by the fact that bigleaf maple's frequency showed an increase after 2 meters above the stream (Figure 6), where soils are probably still moist, but they are better drained than at the lower height-above-stream categories.

Although a greater number of slope plots than terrace plots contained bigleaf maple (Table 28), and mean maple basal area was the same on terraces and slopes in LU2 plots containing trees (Table 18), where bigleaf maple was found, median basal area was significantly higher on terraces than on slopes (Table 26). These results suggest that either more bigleaf maple stems were found on terraces than on slopes

and/or bigleaf maple exhibited larger diameters on terraces than on slopes. This latter statement, combined with its preference for deep, moist soils (Minore and Zasada 1990), as well as its high frequency at moderate heights-above-stream (Figure 6), implies that bigleaf maple is better adapted to conditions on terraces but towards the base of the slope.

### *Sitka spruce*

Sitka spruce had a relatively high frequency (Tables 9 and 18), and where it was found, it had a relatively high basal area (Tables 9, 12, 18, 20, and 26). On LU1's, it was found almost an equal number of times on slopes as on terraces (Table 9). On LU2's, spruce was found almost twice as often on terraces than on slopes (Table 18). Spruce was also found much more often on second terraces than on first terraces (Tables 9 and 18). Since Sitka spruce tolerates little flooding and requires moderate drainage (Harris 1990), these results indicate that spruce is best adapted to conditions on LU2 terraces, since they are drier than LU1 terraces, but not as dry as LU2 slopes. This is also evidenced by its high frequency at moderate heights-above-stream (Figure 6). Since spruce is known to establish on highly disturbed sites as well as require mineral or mineral/organic alluvium for adequate regeneration (Harris 1990), these LU2 terraces must still be in the zone of fluvial influence. There also could have been a sufficient amount of rotten wood for nurse log regeneration on either the first or second terraces where spruce was often found, since spruce frequently establishes on rotting organic material in alluvial zones where there is frequent flooding and/or competition from brush (Harris 1990).

### *Douglas-fir*

Douglas-fir was found almost twice as often on LU2's as on LU1's (Table 18 vs. 9, Table 19 vs. 11). Moreover, twice as many slope plots as terrace plots had some Douglas-fir (Table 28), and it was most frequently found at high heights-above-stream (Figure 6). Regeneration conditions therefore favor Douglas-fir more often on slopes than on terraces, perhaps indicating that more of the slope area is suitable for Douglas-fir due to better-drained soils (Hermann and Lavender 1990). However, Douglas-fir did do well on those terrace sites where it occurred, as indicated by a high basal area relative to other species (Tables 12 and 20) and a relatively high frequency in all height-above-stream categories (Figure 6). Since Douglas-fir typically does not tolerate flooding (Hermann and Lavender 1990), nor establish on nurse logs, its productivity on terraces implies that when the terraces flood, it is not for long durations.

Since Douglas-fir was more frequently found on slopes, and since it requires mineral soil for establishment (Hermann and Lavender 1990), landslides could be a mechanism enabling Douglas-fir regeneration on slopes. However, no Douglas-fir canopy dominants less than 80 years old were found in this study (Figure 8), and only 1 Douglas-fir seedling was found (Table 31). Some of the x's in Table 29 might be Douglas-fir trees that are younger than 80 years old, but these would be relatively few. Thus, slope landslides alone, within at least the past 80 years, have not been large enough or extensive enough for prolific Douglas-fir regeneration. Large-scale fire is therefore the most effective disturbance which can regenerate Douglas-fir (Means 1982).

Douglas-fir displays the oldest mean and median age of all species found, and it does not occur in the young age classes (Figure 9, Table 31). This fits the generally expected pattern for Douglas-fir (Means 1982), of regeneration after the last large-scale fire but limited regeneration since then. There have been no large-scale fires in the study areas in at least 145 years (Impara, in progress), and the small-scale stream,

debris flow, and soil mass movement events apparently do not often provide the needed regeneration conditions.

### ***Western hemlock***

In LU1's, western hemlock was an infrequently found species (Tables 9 and 18). Its seed source is sometimes limited in the Oregon Coast Range, and its seed flight has been noted to have the slowest speed among 13 Pacific Northwest conifers, thus hindering its dispersal (Minore 1979). Where it was found, it occurred more than twice as often on slopes as on terraces (Table 28). Also, it was most often found at the highest height-above-stream category (Figure 6). Its median basal area was more than double on slopes as compared with terraces (Table 26). Since western hemlock frequently establishes on nurse logs (Packee 1990), there might be ample down wood available for its regeneration on slopes (as well as possibly on terraces, as noted above in the Sikta spruce description). This suggests that conditions are most conducive for hemlock on slopes, where organic material is higher than on terraces due to less alluvial deposition and more colluvial material. Also, western hemlock is known to grow in well-drained soils (Packee 1990), which are more characteristic of slopes than of terraces.

Hemlock was found in the younger age classes (Figure 9, Table 31). This is probably related to the fact that hemlock's regeneration is not necessarily due to a disturbance creating new substrate because of its high degree of shade-tolerance and tendency to regenerate on nurse logs (Packee 1990). It often regenerates under an established canopy.

### *Western redcedar*

Western redcedar was the least-frequently found species (Tables 9, 11, 18, 19, 28). Western redcedar's seeds do not fly as far as other conifers; dissemination usually occurs no further than 100 m of a seed source (Minore 1990). Additionally, in LU1's, although western redcedar was found just as frequently as western hemlock, and considerably less frequently than red alder (Table 11), redcedar's mean basal area was higher than alder's and hemlock's in just the plots where each respective species was found (Table 12). In LU1's where redcedar was found, it therefore exhibited a relatively large basal area. This is evidence that redcedar is seed-source limited; it regenerates well where there are parent trees, but parent trees must be rare. Similar to western hemlock, western redcedar is very shade tolerant, which enables it to regenerate under an established forest without an initiating disturbance.

Disturbed mineral soil is a requirement for regeneration from seed, as it is for red alder. Also, redcedar seedlings have been noted to be even more flood-tolerant than alder seedlings (Minore 1979). Western redcedar therefore takes up a similar niche as red alder in terms of water tolerance, and western hemlock in terms of shade-tolerance.

### *Conclusions*

These results from the Oregon Coast Range agree well with what Rot (1995) found in mature/old-growth riparian forests in the western Washington Cascades. In both areas, floodplains (terraces) were generally dominated by deciduous species such as red alder and bigleaf maple, and slopes were generally dominated by western hemlock, along with Douglas-fir and western redcedar. In my results, however, western redcedar was not necessarily dominant on slopes; sample size was too small

to make a statement about its dominance on either terraces or slopes. Rot (1995) would not have found Sitka spruce since it is not endemic to his study area.

Overall, however, all species were found growing on both slopes and terraces, in both LU1's and LU2's (except bigleaf maple), and in all height-above-stream categories. This suggests that flooding is not causing the near-stream exclusion of species such as Douglas-fir which tend to be flood-intolerant (Hermann and Lavender 1990). Although high water occurs annually in the Oregon Coast Range, precipitation is the primary cause since there is no snow, and this makes stream flows very flashy (Sedell and Swanson 1982). Thus, stream-sides are usually not inundated for long periods of time, enabling species that are not especially flood-tolerant, such as Douglas-fir and western hemlock, to reside near the stream. However, although flooding does not seem to limit any species, it does partition tree species across the topography due to interactions with variables such as soil drainage, soil type and amount of organic debris, and different heights-above-stream. Resilience to beaver and other animals also contributes to species distribution in relation to the stream. Other factors such as inter- and intra-species competition and seed source also sort out species distributions, but not necessarily in relation to the stream.

## **Disturbance Frequency and Location**

### ***LU1's and LU2's***

The age distributions on LU1's and LU2's (Figure 7) imply certain premises about disturbance. Where trees exist, the oldest trees on LU1's were generally younger than the oldest trees on LU2's (Figure 7). This suggests that fluvial disturbances and/or other near-stream disturbances occur more frequently closer to the stream (LU1's) than farther from the stream (LU2's). This study therefore

captured a point in time when disturbance regenerated trees more recently on LU1's than LU2's.

The scarcity of trees on LU1's and LU2's less than 145 years old (the last regional fire) (Table 29) and the high frequency of treeless areas indicates that there have not been many recent large-scale disturbances of sufficient intensity to regenerate trees on either LU1's or LU2's. This confirms the importance of fire for tree regeneration.<sup>7</sup> As stated in Results, when equating a tree age that was younger than the last regional catastrophic fire with a disturbance, calculations of disturbance frequency using four different data subsets indicate that between 2.6 and 4.5 disturbances large enough to regenerate trees occurred per km per century since the last stand-resetting fire along the nine creeks sampled (Table 30).

### *Slopes and Terraces*

The mean tree age of the dominant trees on terraces was younger than the mean tree age of the dominant trees on slopes (Figure 8). This suggests that disturbances occur more frequently on terraces than slopes. This study therefore captured a point in time when disturbance regenerated trees more recently on terraces than on slopes. This is confirmed when counting the trees on both terraces and slopes that were younger than the regional fire age, and equating them with a disturbance (Tables 29 and 30).

Although Table 29 reveals that slopes experienced more disturbances than terraces since the last large-scale fire, it does not take into consideration biological traits of each tree species. When excluding the most shade-tolerant species which do not necessarily require a disturbance for their regeneration, western hemlock and western redcedar, both data sets containing the oldest trees per landscape unit and the

oldest trees *per species* per landscape unit show that disturbance is more frequent on terraces than on slopes (Table 30). In addition to fluvial disturbances, other disturbances which tend to concentrate on terraces, such as herbivory and blow-down, further increase the frequency of disturbances on terraces. This pattern is also true for just LU1's, where 16 disturbances occurred on LU1 terraces since the last large-scale fire, and only 4 occurred on LU1 slopes (Table 29).

As one moves further away from the stream, tree basal area on both terraces and slopes increases. Median basal area was higher in LU2's (Table 17) than in LU1's (Table 8) for all of the overstory types. Also, when examining the different transect configurations, Case B, first terrace to second terrace, and Case D, slope to slope (Figure 4), supported higher median total basal area in the LU2's than in the LU1's. As one moves farther from the stream, disturbance frequency might therefore decrease on both terraces and slopes, in that trees have more time between disturbance events to grow to large sizes. Also, the above evidence suggests that basal area and/or tree density increases with increasing height-above-stream as well, which in turn suggests the possibility that disturbance frequency also decreases with increasing height above the stream.

### **Disturbance Intensity**

More plots on slopes contained trees than on terraces (Figure 8), and more LU2's contained trees than LU1's (Figure 7). This implies certain stipulations about disturbance intensity. In general, disturbance acts in two ways: it initiates new trees by creating or exposing substrate, and/or it wounds or kills trees or prevents them from establishing. If disturbance intensity is high, tree establishment and growth are usually discouraged, whereas if disturbance intensity is low, tree establishment and growth are usually favored (Agee 1988). Since a lower frequency of trees was found on both



terraces and LU1's, and since the oldest trees on terraces and LU1's were younger than the oldest trees on slopes and LU2's respectively (see above), I believe that over time, both types of disturbance intensities are occurring more frequently on terraces than on slopes, and on LU1's than on LU2's.

The 16% (9/56) of terraces at the bases of slopes which supported trees (Table 29) could have experienced localized perturbations which initiated the trees. These are unique areas that are susceptible to disturbances such as toe slope landslides or inundation by back-channel seepage when water rises in the spring. This might explain why four of these nine terrace plots at the base of slopes supported relatively young alder trees (Table 29).

### **The No Tree Overstory Type**

Fifty-two percent of LU1's had no trees (Table 7) for an average of 11 meters away from the stream (Table 5). Furthermore, 24% of LU2's had no trees (Table 16). These percentages do not imply, however, that all treeless areas were occupied by shrubs. Some plots merely did not capture trees because plot size was small relative to the space a tree occupies, hence yielding scale-dependent results. The high variance in tree density and basal area (Tables 9 and 18) reflects this small plot size. Furthermore, many forest types with gaps would have a substantial number of plots without trees. In retrospect, I should have indicated overstory type for the landscape unit as a whole instead of just in the plot. Also in retrospect, 6 LU1's were called terraces when they should have been labeled as part of the bank full-width because they got submerged during the winter and consisted mainly of unvegetated sand. Although many LU1's and LU2's supported no trees, it is important to remember that this study only characterized succession in one point in time, 145 years after large-scale fire, and it should not be thought of as a permanent or equilibrium stage.

To address the question of what occupied treeless LU1's before the present dominant vegetation types were in place, Tables 5 and 6 offer clues. Overall, mean height-above-stream in the No Tree overstory type is closest to mean height-above-stream in the hardwood-dominated overstory types (Table 5). Although height-above-stream on terraces (Tables 5 and 6) is the same in the Pure Conifer type and Pure Hardwood type, when Sitka spruce was removed from the distribution due to its tolerance for moist conditions on low terraces (Harris 1990), mean height-above-stream rose in the Pure Conifer distribution (see *Topography of Overstory Types* under LU1's). This renders mean height-above-stream in the No Tree overstory type closest to mean height-above-stream in the Pure Hardwood type for LU1 terraces, LU1 slopes, and all LU1 plots. In addition to height-above-stream similarities, the landscape unit width of No Trees in LU1's most closely resembled the width of hardwood-dominated overstory types (Tables 5 and 6). No Tree sites on LU1's are hence similar in location/conditions to Pure Hardwood sites. This combined with the fact that alder often succeeds to shrubs (Hemstrom 1986; Newton et al. 1968; Newton 1989) suggests the possibility that hardwoods once occupied the current LU1 treeless areas, and they have since senesced.

The trend for LU2's is not as clear (Table 14). Four out of the 7 topographical values in the No Tree type are closest to the values in the Pure Hardwood type, and 3 out of the 7 are closest to the values in the conifer-dominated types. It is likely that LU2's once contained more conifers than LU1's, since most conifers are less flood-tolerant than most hardwoods and would therefore exist farther from the stream.

## Riparian Zone Dynamics

### *Definition of Natural*

In most riparian areas, some type of large-scale and small scale (non-anthropogenic) disturbance is indigenous (Sprugel 1991), so that a mosaic of ecological conditions occurs within an ecosystem at any time due to natural disturbance (White 1979). Since this study was not longitudinal, in that it only captured a freeze frame in time, it has only characterized a snapshot of succession in both space and time. This makes the definition of *natural vegetation* problematic. A definition of natural might be possible if in that window of time I quantified a vegetation equilibrium, where patchy disturbance was balanced by regrowth (Sprugel, 1990). However, my study does not address this issue. Although many of the study sites burned at the same time and originated from a large disturbance at one temporal and spatial scale, the dynamic nature of riparian areas thereafter has molded vegetation into multiple successional stages at different sites (Figure 9), including a variety of species. Although I defined a range of variability, I captured one of possibly several vegetation communities, any of which could be deemed natural vegetation for any given location at some point in time. We could examine the same riparian transects five years later and find different overstory types dominating.

Furthermore, when Euro-Americans from the Hudson Bay Company first settled in the Oregon Coast Range, they trapped fur beavers (*Castor canadensis*), significantly reducing their populations. Both mountain beavers (*Aplodontia rufa*) and fur beavers have significant effects on riparian communities (see Introduction). Thus, the loss of beavers has considerably modified riparian areas in the Oregon Coast Range (Bisson et al. 1992).

In addition, the current lack of large-scale fire which once swept through the Coast Range about once every 175-250 years (Long 1996; Benda 1994) will act as a

disturbance in itself once it exceeds the range of the above variation. The main result of fire suppression, which we can see evidence of already, will be a shift in species' composition. This will likely include a decrease in the number of newly established shade-intolerant species, such as Douglas-fir (Figure 9, Table 31), which rely mainly on fire for regeneration (Means 1982), an increase in shade-tolerant species such as western hemlock and Sitka spruce (Figure 9), which do not necessarily require disturbance for their regeneration, and an increase in red alder and shrubs with smaller-scale disturbances. The decrease in fire frequency can alter larger-scale ecological interactions, such as causing a decline in certain types of wildlife which prefer relatively young Douglas-fir stands (McComb 1989), and alter long-term community dynamics (Franklin 1981). Although Poage (1995) found evidence for multiple fires in riparian zones, data from my study suggests a general pattern of relatively infrequent, large-scale fires which burn through most of the riparian area (Figure 9). Similar to Poage (1995), however, even the larger-scale and less-frequent fires that I'm proposing do not necessarily kill all trees, but rather they tend to leave visible remnants that we can see today, which I called the 145 year-old trees (Figure 9).

Numerous large-scale disturbances have affected most every riparian landscape throughout the Oregon Coast Range since before Euro-American settlement (Agee 1991; Teensma et al. 1991; Bisson et al. 1992). These include the changes in fire regimes, starting with the annual large-scale fires set by the Native Americans, to sporadic large-scale fires combined with many smaller-scale fires set by the early Euro-American settlers, to present day fire suppression. There has also been a decline in beaver populations, and increase in deer and elk populations. In addition, numerous exotic species such as Himalaya blackberry have been introduced since the mid-1800's (Boyd 1986) and have also helped change the structure of present day unmanaged riparian areas. For these reasons, saying that unmanaged riparian stands existing today are comparable to historic conditions circa 1850 might be an

overstatement. Even though the sites chosen for this thesis had never been logged, splashdammed, or homesteaded, they probably do not mirror ecological conditions that existed before Euro-American settlement. Although my study does not offer direct evidence that vegetation is different today than it was pre-settlement, the fact that exogenous conditions are different today suggests that we should not assume that this study is a characterization of historic riparian forests. Rather, studies of this sort should be looked upon as characterizations of imposed reference sites, acknowledging that although the sites are not a single definition of natural, nor exact analogues of historic processes and patterns, they are the best we have to emulate.

The expression *restoration*, implying emulation of a natural community, is also difficult to understand without qualifying exactly what functions one wishes to restore. We can not easily talk about the restoration of mythical natural structures; however, it may be feasible to discuss specifically chosen *processes*, and/or specifying a certain point in time. For example, instead of engineering gravel bars into a river, rehabilitation efforts might last longer and be farther reaching by manipulating flow processes to restore channel-stream bank interaction and lateral river movement, possibly through experimentation and adaptive management. The Trinity River in Northern California, currently under river “rehabilitation,” takes this broad approach of focusing on the whole river system instead of a single fish species (Barinaga 1996). Shifting systems, not attributes, should be the goal of any rehabilitation project (Reeves, et al. 1995), as well as changing processes rather than necessarily changing disturbance regimes (Reeves et al. 1995).

### ***Hardwood Component***

The Pure Hardwood overstory type maintained a relatively wide mean width of 52.3 meters in LU2’s (Table 14), and the mean width of the Hardwood/Conifer

Type extended the widest of all overstory types in all LU2 scenarios (Table 14). Also, I found a high frequency of red alder (Tables 11 and 19), and bigleaf maple basal area was high relative to other species (Table 20). Although it has been suggested that the presence of large conifer stumps in recently harvested riparian areas of the Oregon Coast Range indicates a historical dominance of conifers (Bacon and McConnell 1989; Newton 1989), it is apparent from the above results that a relatively large component of hardwoods exists in unmanaged riparian landscapes in the central Oregon Coast Range today. It is possible that observers like Bacon and McConnell and Newton did not focus on the spaces between the stumps, which might have been where many hardwoods were once located. If the number of conifer stems did indeed historically dominate riparian areas, the large component of hardwoods in unmanaged areas today lends evidence to present day unmanaged riparian areas not mimicing historical conditions (see above discussion).

Agee (1988) describes a situation in which disturbance creates alternating periods of early-successional or late-successional dominating species. This study may have captured vegetation in an earlier-successional stage as compared to the above-mentioned old-growth areas due to different combinations of non-anthropogenic disturbance histories, so that my study sites have not been provided with the time to support conifers which grow to large sizes. However, when just considering fire, both large-scale and small-scale fire was more common in pre-settlement landscapes. Agee's hypotheis hence does not necessarily lend evidence to the argument that my sites are in a younger successional stage than circa 1850, because the more common large-scale and small-scale fires in presettlement times would have precluded the development of old forests as compared to today.

Instead, it is likely that my sites merely have travelled on a different successional pathway, in that the competition conditions existing before/during/or after the last regional fires inhibited significant conifer regeneration, particularly Douglas-fir, derailing the successional pathway which might have been headed

towards large conifers. I believe that the synergistic effect of competition and absence of a large-scale, recent fire is contributing to a relatively large hardwood component in present-day riparian areas as compared to what is thought of as a higher conifer component in pre-settlement forests. Only a large-scale event such as fire appears to be able to reset the current successional pathway. In sum, I conclude that although the ecological processes of the sites in this study resulted in a relatively high frequency of hardwoods, which might not support common beliefs about historical conditions, the findings reflect present day unmanaged riparian conditions which can be used as one possibility for a reference model.

### *Conifer Component*

In the three transect configurations where height-above-stream was higher in LU2's than in LU1's (Case B, first terrace to second terrace; Case C, first terrace to slope; and Case D, slope to slope), conifer-dominated overstory types were more frequent in the LU2's than in the LU1's (Figure 4). This positive relationship of height-above-stream and conifer frequency, combined with the finding that the Pure Conifer type was higher above stream on LU1 slopes than in any other overstory type on LU1 slopes (Table 6), suggests that conifer frequency increases as ones moves heigher above the stream. This is also indicated by the fact that the frequency of conifer-dominated overstory types increases as height-above-stream increases in the four different cases (Table 25).

Furthermore, in all of the four different transect configurations (Figure 4), either hardwood cover was higher in LU1's (Case A, first terrace to first terrace), or conifer cover was higher in LU2's (Case B, first terrace to second terrace Case C, first terrace to slope, and borderline for Case D, slope to slope). This suggests that conifer frequency also increases as one moves farther away from the stream.

Additional evidence for this includes a shift from hardwoods to conifers with increased distance from the stream as a general trend: the most prevalent overstory type on LU1's was No Trees, followed by Pure Hardwoods (Table 7), whereas in LU2's, the most frequently found overstory type was Pure Conifer (Table 16).

## **Management Implications**

### ***Overstory Types***

One of the stipulations in the 1994 Oregon Riparian Rules allows the complete cutting of hardwood-dominated buffer zones beyond 10 feet of the high water level of the stream (Oregon Department of Forestry 1994), with the goal of establishing pure conifer stands. This particular stipulation assumes that pure conifer composition is best for water quality and fish and wildlife populations. Although this claim might be true, it does not coincide with what unmanaged riparian areas actually look like today. The rule also neglects terrestrial wildlife, since the greatest use by wildlife has been described in riparian communities dominated by a mix of coniferous and deciduous species (Kauffman 1988). Also, it targets adequate habitat for selected fish species in specific life cycle stages instead of targeting a variety of species at all life stages. Moreover, Maser et al. (1988) noted that historical riparian forests were once mosaics of varying species.

Large conifers such as Douglas-fir provide shade over the channel when they are alive, channel-influencing root masses along the banks, and regular inputs of nutrients through litter fall (Beschta 1989). When they are dead, they provide nutrients in the channel or on the forest floor, and refugia for fish and wildlife in the form of long-lasting woody debris (Oregon Department of Forestry 1993). Long lasting woody debris is an essential component to both a stream's habitat sustainability



and complexity (Harmon et al. 1986; Beschta 1989) by forming pools, retaining sediment and gravel, and retaining organic matter such as needles or leaves used as food by stream biota (Bilby 1988).

Hardwood species offer benefits to stream ecosystems as well. Although they provide only seasonal autochthonous detritus, the quality of hardwood detritus is higher than coniferous detritus (Gregory et al. 1989; Naiman et al. 1992; Bilby et al. 1992). Also, although hardwoods only provide seasonal shade, their shade is offered during critical periods of vegetative growth and intense solar radiation (Gregory et al. 1989). The roots of hardwoods also provide bank stability. Due to substantial accumulations of nitrogen and organic matter in the soil, alder is known to improve the growth of associated species (Bormann et al. 1994). Additionally, mature red alder stands have been found to support a rich amphibian and small mammal fauna (McComb 1989). My conclusion from the literature is that some mixture of both hardwoods and conifers and no tree areas is important over lengths of a stream to the processes that maintain fish and wildlife habitat and diversity and ecosystem productivity.

### *Landscape Unit Traits*

The width of landscape units becomes wider as one moves farther away from the stream (Figure 2). Since fluvial processes are closely linked with near-stream terrestrial patches (Swanson 1980), alluvial deposits are most prevalent in the LU1's. The process of patch size increasing as one moves farther from the stream (Figure 3) could be associated with the waning of overbank sediment deposition as one moves farther from the stream (Swanson 1980; Agee 1988).

Although it is not shown which LU1's in Figures 2 and 3 are topographical patches and which are vegetative patches, many are both because topography and

vegetation develop together (Swanson et al. 1988). More specifically, flooding can form elevational gradients, where plants establish according to moisture, light, and sediment movement tolerances (Wissmar & Swanson 1988). These elevational gradients might be explaining the occurrence of multiple terraces along a transect, which in turn might be accounting for the concurrent vegetation/topographic-defined LU's (Cases B and C in Figure 4).

The positive relationship between height-above-stream and distance from the stream (Figure 2), can be used to predict flood incidence on LU's. If water rises 2 meters in the nine streams surveyed, vegetation in LU1's up to an average of 8 meters away from the stream will get flooded. If high water reaches 5 meters above the stream, all LU1's in the study sites will get flooded (Figure 2).

### *Different Transect Configurations*

Different transect configurations supported different kinds of vegetation. For example, in Case A, 1st terrace to 1st terrace, mean hardwood cover was double in LU1's than in LU2's (Table 21). This indicates that where there are wide floodplains, a gradient of hardwoods exists, with the highest concentration closest to the stream. Similarly, in Cases B and D, where topography consists of 1st terrace to 2nd terrace and slope to slope respectively (Table 21), mean conifer cover was about double in the LU2's as it was in the LU1's. This implies a gradient of conifers which increases as one moves both away from the stream and higher above the stream. Combined with this latter finding, in Case D, slope to slope, the LU1's had the lowest frequency of hardwood cover (Table 22) and the highest frequency of the No Tree overstory type (Table 23), and the LU2's had the highest frequency of conifer-dominated overstory types (Table 25). Thus, the overall average picture on transects consisting of slope to slope is a higher concentration of conifers existing higher above and

farther away from the stream, and only a few conifers or a shrub or fern community existing close to the stream.

Topographically, the mean width of LU2's was relatively narrow on transects consisting of 1st terrace to 2nd terrace (Case B). Mean width was relatively wide on transects consisting of slope to slope (Case D) (Table 24).

### ***Woody Debris***

The average distance away from the channel to the base of the slope was 12.8 meters. As part of Robison and Beschta's (1990) model of the likelihood of a tree falling into the channel, the probability of a tree falling into a stream and providing coarse woody debris decreases with increasing distance from the stream. Their model predicts that on flat ground at a stream distance of about 13 meters, the probability of a (Douglas-fir) tree falling into a stream is greater than 50%. Since slopes composed at least half of the topography by 13 meters away from the stream in the 8 study sites, 50% appears to be an underestimation, thus raising the probability that a tree would fall into the stream. This underestimation is supported by an analysis of down timber on 17-70% hillslope in the Oregon Cascades, indicating that the probability of a tree falling downslope was 75% (R.L. Beschta, unpublished data in Robison and Beschta 1990). Since the average slope distance in the nine creeks surveyed in this study indicates a high probability of trees falling into the creeks according to Robison and Beschta's model (1990), time might therefore be the best way for wood to enter the stream, instead of employing expensive silvicultural manipulations which can wound other trees and increase stream sediment without beneficial root wads attached (Robison and Beschta 1990).

### *Reconstruction of a Successional Pathway*

This study's results suggest that the following successional pathway might have been common along the nine stream study sites. Given that there is no one absolute or inherent definition of natural (see above discussion), the reader should be reminded that the pathway does not reflect natural vegetation. Rather, "natural" might be thought of as a complex of variable composition, distribution, and ages. The following pathway is just one possible model for riparian vegetation that developed with a given set of previous ecological conditions and experienced a large-scale fire 145 years ago:

Numerous large-scale, stand-resetting fires swept through a majority of Coast Range riparian areas about 145 years ago (Morris 1934). These fires created new surfaces for regeneration due to the newly created bare mineral soil and patches which were large enough to let in sufficient amounts of light. Pioneer species such as Douglas-fir and red alder were then able to recolonize, likely from adjacent seed sources, although these oldest alder have since senesced (Figure 9). In the Oregon Cascades, Campbell and Franklin (1979) claim red alder to be the first tree species to invade mineral soil along the stream after a major disturbance.

Campbell and Franklin (1979) also found bigleaf maple to come in under moderate shade from the pioneers and commonly be the deciduous replacement after the shade-intolerants senesce. Most of the bigleaf maples probably established when the Douglas-firs (or alders) were either relatively young, or just beginning to thin (< 30 years), and before forbs and shrubs invaded (Fried et al. 1988). This can be seen in the oldest species' age distributions (Figure 9), where the oldest bigleaf maple came in about 40 years after the oldest Douglas-firs.

Sitka spruce also recolonized along with or soon after Douglas-fir (Figure 9), especially along the coastal belt (Franklin and Dyrness 1973), and possibly on organic debris (Harris 1990; Packee 1990). Spruce could have also continued to come in later since it is fairly shade-tolerant. Western redcedar, being an opportunist with

wide ranges of water and light tolerances (Minore 1990), could have come in at any time in the understory after the pioneers established if a seed source was available, as well as western hemlock, because these two species are very shade-tolerant, and their regeneration does not rely on large-scale disturbances (Minore 1979).

There was then a window of time when closely-aged cohorts of multiple species might have been establishing. Barring any seed predation, species composition would then be mostly influenced by inter- and intra- specific competition, mediated by each species' seed source, growth rate, and water and light requirements.

This window of time when a relatively even-aged forest was establishing was undoubtedly brief, however (maybe up to 30-50 years), because riparian areas tend to be very diverse and contain a lot of environmental variability (Kauffman 1988; Naiman et al. 1992; Agee 1988; Swanson et al. 1991), which would diversify tree composition and distribution. This variability is possibly related to such processes as groundwater movement, continuously creeping soils, back-channel seepage, and tree death providing large woody debris, all which contribute to forming microsites. Microsites are unique topographic features which lend high amounts of variability to the landscape.

Variability might also be attributed to disturbance, but disturbances large enough or intense enough to regenerate trees do not appear to be frequent, as seen in the few average numbers of disturbances since the last fire (Table 30). However, it is likely that there are more frequent disturbances of whatever qualifications necessary to regenerate trees than the calculations indicate (Table 30), because the calculations were minimum estimations based solely on the oldest tree ages in the plot. Additionally, I visually observed high variation in tree spacing, size, and frequency, which could be due to environmental variability or more frequent disturbance than this study captured. This variability is somewhat seen in the high variation of basal area (Tables 9, 10, 12, 18, 20) and species' frequencies (Tables 11 and 19). Small plot size might be contributing to this variation, but variation was high in all of the

data. Some disturbances might not necessarily be regenerating trees, but they may be limiting tree establishment or growth (Agee 1988). This would support the common belief that riparian disturbances create a patchy landscape (Poage 1995; Naiman et al. 1992; Gregory et al. 1991).

Exogenous and endogenous disturbances and/or regular environmental variability associated with either tree regeneration or tree-preventing conditions could have included fluvial disturbances, such as high water, deposition, erosion, scouring, saturation, base slope seepage, and lateral channel movement; colluvial disturbances such as slope failures, soil slump, soil creep, soil suffocation, and surface erosion; herbivory in the form of seed predation, browsing, trampling, or girdling by animals such as beaver, elk, or slugs; windthrow, winter frost, frost heaving, needle ice, open ground cracks from differential earth movement, and smaller-scale brush fires.

Some of the first cohorts of trees which established soon after the last large-scale fire are still visible today, as evidenced by the largest (oldest) trees (Figure 9), but a combination of the above disturbance types, intensities, frequencies, and extents, environmental variability, and competition from vegetatively reproducing shrubs, ferns, and herbs, created a mosaic of different species growing in multiple successional stages across the riparian landscape.

Any one of or combination of the above processes could have caused a relatively high seedling mortality and/or delayed tree regeneration. Also, since shrubs such as *Rubus spectabilis* (salmonberry) and *Ribes bractiosum* (stink currant) are aggressive colonizers after disturbance and extremely prolific in the Oregon Coast Range (Pabst and Spies, in preparation), their fast growth rates likely inhibited many seedlings (Campbell and Franklin 1979). Furthermore, *Ribes* and *Rubus spp.* maintain disturbance evader strategies, such as storing seeds in the soil (Agee 1988), also giving them an advantage over tree species. Red alder might have best survived this shrub competition due to its relatively fastest growth rate of all associated tree species (Newton, et al. 1968; Harrington 1994). However, since western hemlock and Sitka

spruce tend to grow on organic debris and are both shade-tolerant (Minore 1979), these species would have been favored where there was minimal disturbance to the forest floor.

The pioneer alder trees might have survived to occupy near-stream surfaces for at least 80 years (Newton et al. 1968; Harrington 1994), although red alder is known to live up to 150 years (Poage 1995). Once the alder senesced in the areas where it dominated, shrubs were able to dominate. Salmonberry (*Rubus spectabilis*) is thought to be the next successional community to hardwoods in the central Coast Range (Hemstrom, 1986), especially in old alder stands at low elevations (Carlton 1989). Salmonberry is known to inhibit the regeneration of most tree species (Campbell and Franklin 1979), especially shade-intolerant conifers such as Douglas-fir.

What was left are the shrubby, treeless areas that we see today (Tables 7 and 16), where red alder has possibly senesced, which require an intense disturbance to reset the successional pathway. Adjacent upland conifers, such as Douglas-fir and western hemlock, might eventually grow tall enough to shade out shrubs (Agee 1988), but the shrub patches might be too extensive for conifer encroachment.

Since there is no definition of natural for ecological communities, treeless areas are therefore neither inherently bad or good. Actually, due to the open nature of floodplains, they have been suggested as one of the original habitats of non-tree species before Euro-American modification (Marks 1983). Also, some places have always been shrub-dominated (Andrus and Froehlich 1988), especially at sharp meanders where the physics of water scours the opposite side, perpetuating *Rubus spectabilis* (Avina, personal communication 1996). As such, although many No Tree sites are able to grow certain trees very well, initial reforestation efforts might be best spent in areas not containing high amounts of shrubs, or in areas that are not across from sharp meanders. On a larger scale, without human intervention or fire, it is unlikely that trees will establish and survive in the dense shrub-dominated regions,

especially Douglas-fir (Means 1982), since fire is one of the few disturbances which creates patches large enough to allow in sufficient light and expose mineral soil for Douglas-fir regeneration.

## **Improvements**

One of the biggest lessons that I learned from this study is what I would do differently if I could do it over. Relating to the subjectivity of defining landscape units, I learned that instead of defining a landscape unit by either vegetation or topography, it would be best to first define a vegetative unit, then survey the topography, but not both. A drawback, however, is that two different topographical units might bridge one vegetative patch. However, since my results showed that 40% of the vegetative patches changed without a topographical change, whereas only 13% of the topographic patches changed without a vegetative change, fewer “bridges” would probably occur when defining a patch by vegetation as opposed to topography. Also, my main objective was to characterize the vegetation. Correlations between vegetation and topography would then be direct, so that reforestation suggestions could be landform-specific. This would also help create a more cohesive picture of the landscape, including the ecological interactions between landform and vegetation. Also, it would be more time efficient in the field to just seek one variable with which to define a landscape unit.

I would also increase plot size where vegetative units are large. Although sampling might take longer, overall plot size should be bigger so that the ratio of the size of organisms being captured in the plot (trees) to both the size of the plot and the spaces between trees is smaller. This would decrease tree frequency and basal area variance. The ideal plot size can be realized in a pilot study by examining the variance



of either basal area or tree frequency in the plots. However, variable plot sizes would be required for vegetative units that are small.

What I should have done in this specific study was added a criteria to the determinants of the plot size of plot 1's (Table 2). I should have made plot size on LU1 terraces that were deeper than 2 meters but less than 5 meters, 5m x 15m, instead of making all terraces greater than 2 meters in width a plot size of 2m x 15m. This would have increased plot size in a significant number of plots. The consistency of plot size for LU1 terraces should have been less important than making the plot large enough to capture trees.

Next, I should have sought out disturbance clues instead of noting if we ran into them. The same should have been done for regeneration. Noting disturbances and regeneration when we ran into them contributed an observer bias to sampling.

Something that would have added significant information is to have cored both the smallest and largest tree in each plot. This might have possibly acquired more information on disturbance frequency.

To make riparian characterization studies more repeatable, I recommend considering lateral boundaries when defining a landscape unit. This would make the definition of a landscape unit more meaningful and more applicable to management.

Something that might have aided in understanding the dynamics of the No Tree areas is to have identified large woody debris in these treeless areas. Unless the tree were an alder that had been dead for more than 10 years, it would have been possible to know the species that once occupied the landscape unit and gain a more complete understanding of successional dynamics. Granted, hardwoods decompose rapidly, but I could have at least acquired information on dead conifers. Information on woody debris in general would have been beneficial to this study, but due to a time constraint, this data collection was omitted.

Another sampling addition that would have contributed significant information is to have measured height-above-stream on the opposite side of the bank of the

transect. This would have enabled a calculation of the valley floor width index, created by Grant and Swanson (1995), and it would have offered a fuller picture of the valley floor.

One consideration of systematic sampling is that it might not be the best way to capture patterns, because the patterns might be systematic themselves. For example, in Cummins Creek we ended up following the pattern of hitting slope every time we placed a transect (every 200 meters) and observed skipping over the terraces in between the 200 meters. I believe Newton's third law might be at least partially explaining this occurrence, where if in a river, a section is scoured at a meander and sediment is removed, it is then deposited with equal (and opposing?) force downstream, aggrading onto a terrace. It has been noted that remarkable relationships exist among the wavelength, channel width, and radius of a stream curvature (Leopold 1994). This might explain a topography consisting of equidistant slopes and terraces.

Lastly, it would have been a great asset to have run through all steps of this study in a pilot study with an expert in riparian sampling techniques, even if the pilot study needed to be curtailed to one week. This way, I could have learned to measure slope correctly with a clinometer, and I could have learned to give equal ocular weight to rare species when identifying understory plant associations. Given that I felt the time constraint of one short field season, and since I enjoy working with little supervision, I did not think that exploring a pilot study with someone more experienced than I was worthwhile. I now know to request this for next time.

## **Future Research**

More information is needed on competitive interactions of riparian vegetation, the biology of tree species as specifically related to topographical position

and fluvial tolerances, and disturbance frequencies and histories of creek basins at various scales.

Although plot sampling coupled with univariate statistics yields adequate results, I believe that this type of study should be combined with some sort of three dimensional data collection technique. Since riparian areas are especially diverse ecosystems, a laser might be a good way to capture variation because it can identify vegetation layers and the channel itself (Runyon, personal communication 1995). This would help to create a more complete picture of the spatial variation. Heat sensors might also be useful, but their ranges are limited (Cablak, personal communication 1996). Combining remote sensing with ground sampling or ground truthing might then enable a computer pixel search for an algorithm, which could then identify any possible self-organization in the system. Landscapes might be found to display self-repeating patterns at the same scale (fractal landscape), at different scales (non-fractal, patterned landscape), or a lack of pattern (chaotic landscape). If self-organization is found, it may indicate structural sustainability within the system (Perry 1995).

Additionally, although the objective of this study was to identify general trends in riparian areas of the Oregon Coast Range, I think that carrying out smaller scale studies by blocking during sampling would create more detailed models of riparian area dynamics. I visually observed such high intercreek variation in characteristics such as valley floor shape, stream width, stream gradient, geomorphology, and dominant substrate type, that I feel there is almost too much variation to combine more than a few riparian areas into one dataset. Blocking (in data collection and analysis) on ecoregions (Resh et al. 1988) such as the north, central, and south coast, maybe combined with two east-west blocks, close to the coast or farther from the coast, would be more effective in sorting out variation than combining these geographical areas. The coastal fog belt (Franklin and Dyrness 1973) should get its own block. Granted blocking adds a bias to a study, akin to the biases

in Direct Gradient Analysis but since this preliminary study has been carried out, doing a second (or third!) study with pre-imposed gradients (blocks) would be complimentary information.

A tangent of this study that would be worthwhile to investigate is the frequency of disturbance per vegetative patch, as well as the frequency of small-scale landslides (about 4 square meters) on slopes in the Oregon Coast Range. However, the extent of study would have to be large, and the time scale long to capture a sufficient range of variation.

Since studies like this thesis can be used as reference models, there should be continual research at the same or comparable sites to capture variation in time. "Historical evaluations should be derived from several points in time and at sufficient scale to ensure that major disturbance events and resulting changes in pattern amount and distribution are defined" (Everett et al. 1994). Also, a comparison of managed versus unmanaged riparian areas would be informative.

Lastly, a question we can ask of unmanaged riparian areas which we see fit to emulate is, what can we do to help the system sustain itself? Hopefully this study has contributed to furthering knowledge on the complex interactions of the aquatic and terrestrial interfaces of the Oregon Coast Range, but I acknowledge that it is just the beginning step to understanding riparian area dynamics.

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