## AN ABSTRACT OF THE THESIS OF

Mayumi Takahashi for the degree of Master of Science in Forest Resources presented on July 17,2003.
Title: The Land-Water Interface: Patterns of Riparian Vegetation and Channel Morphology in an Oregon Coast Range System

Abstract approved: $\qquad$
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This study was conducted to describe variation of riparian vegetation in an Oregon Coast Range system according to geomorphic characteristics and in relation to streamflow. Specific objectives of this study were to: 1) examine if the vegetation composition and structure of the riparian forest varied among channel-reach morphologies, 2) examine how the composition and structure of the riparian forest changed with distance from the stream, and 3) extract major underlying environmental gradients explaining riparian forest community from riparian vegetation data.

A $30 \mathrm{~m} \times 30 \mathrm{~m}$ sample site was randomly located on each side of upper Camp Creek in each of 19 reaches, and within each site three consecutive $30 \mathrm{~m} \times 10 \mathrm{~m}$ belt-transects established perpendicular to the stream flow. Overstory and understory vegetation was sampled in each belt transect. Environmental variables sampled included slope, aspect, height above summer low flow, elevation above sea level. Non-metric Multidimensional Scaling and Indicator Species Analysis was used to describe characteristics of riparian plant communities.

Distinct riparian vegetation patterns were observed in upper Camp Creek with increasing distance from stream. Both overstory and understory vegetation quickly changed with increasing distance from stream. Areas within ten meters from stream were characterized as mesic riparian environments while areas twenty meters away from stream were characterized as upland conifer forest environments. Vegetation composition was ordered
along an inferred moisture gradient from streamside to hillslope, and distance from stream and height above summer low flow were almost equally correlated to the gradient. Tall shrubs including salmonberry, sword fern and vine maple are important component of riparian vegetation. Channel-reach morphology little differentiated riparian vegetation. A few species were significantly abundant in a specific reach of channel morphology. However, results of this study about relationships between channel-reach morphology and riparian vegetation were inconclusive.
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# The Land-Water Interface: <br> Patterns of Riparian Vegetation and Channel Morphology in an Oregon Coast Range System 

## by

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A THESIS<br>submitted to<br>Oregon State University

in partial fulfillment of the requirements for the
degree of
Master of Science

Presented July 17, 2003
Commencement June 2004

## ACKNOWLEDGEMENTS

I am very happy to take this opportunity to express my appreciation to those who helped me to complete this research project. For the valuable suggestions, continued support and great encouragement throughout this project, I would like to thank Barbara Schrader, my major advisor. You are definitely more than an advisor for me. I will remember all your support since I met you here at OSU in summer 1999.

My committee members, Lisa Ganio and Fred Swanson, have been helpful and supportive when I asked for their advice. I thank you two for helping me to find my way to get here. Special thanks go to Doug Bateman, Bob Gresswell, and Martha Cavit for providing GIS and environmental data on Camp Creek and taking time to discuss this project. Great help for plant identification was provided by Richard Halse and Ed Jensen. For the valuable field assistance over a period of three months, I would like to thank Jen Pavone. Despite steep and brushy conditions of riparian forests in Camp Creek, your patience and reliable job made it possible high data quality. Helpful field assistance was also provided by Ke Du, Etsuko Nonaka, and Yutaka Hagimoto. I was happy to share field experience with you even though it was a tough job.

I would like to express my appreciation to the support offered by my fellow graduate students. Thank you all for correcting my writing and teaching me English, refreshing me with a chat, and giving me opportunities to go around in beautiful Oregon. For the long-term support, I would like to thank Takuma Yamanaka.

Finally, I would like to thank my family, especially my mother, Seiko Takahashi. Without your support and encouragement, I could never have started my student life here. Thank you for believing me.

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The Land-Water Interface:<br>Patterns of Riparian Vegetation and Channel Morphology in an Oregon Coast Range System

## INTRODUCTION

Riparian ecosystems are complex assemblages of organisms and the environment existing adjacent to and near flowing water (Lowrance et al. 1985). The interface between the aquatic and terrestrial environments plays an important role in watershed environments and is critical to maintaining both aquatic and terrestrial ecosystems. To protect and maintain ecological functions of riparian forests, riparian buffer zones are increasingly recognized as important management tools. However, the integration of terrestrial characteristics and stream function and character is poorly understood, yet critical to understanding linkages at the landwater interface. In particular, it is important to understand how riparian vegetation varies within a watershed, within a reach, according to geomorphic characteristics, and in relation to stream flow. In this section, I describe what is known and what is not known about the structure and composition of riparian forest vegetation in the Oregon Coast Range, the functions riparian forests perform, and interactions between channel morphology and riparian vegetation.

## Characteristics of Riparian Forests

Riparian forests in the Oregon Coast Range have been characterized as a mixture of hardwood, conifers, and shrub-dominated openings. Dominant hardwood species include red alder (Alnus rubra), bigleaf maple (Acer macrophyllum) and dominant coniferous species include Douglas-fir (Pseudotsuga menziesii), western hemlock (Tsuga heterophylla), and
western redcedar (Thuja plicata) (Barker et al. 2002). Understory plant communities of riparian forests in the Oregon Coast Range are dominated by tall shrubs such as salmonberry (Rubus spectabilis), vine maple (Acer circinatum), stink black currant (Ribes bracteosum), and red elderberry (Sambucus racemosa) (Pabst and Spies 1998).

Each species of riparian vegetation has its particular tolerance to soil moisture, shade, and inundation. Red alder tolerates poor drainage conditions and some flooding during the growing season; consequently, it prevails on soils where drainage is restricted along stream bottoms. Red alder germinates readily on newly deposited or exposed mineral substrates, and has rapid juvenile growth that allows it to outcompete shrubs and conifers in some situations. Red alder requires more sunlight than most of its tree associates and is intolerant of shade (Burns and Honkala 1990b). Bigleaf maple and western redcedar are very tolerant of shade, and tolerant of moist soils and inundation to various degrees. Bigleaf maple has a shallow, wide spreading root system well suited to the shallow or saturated soils on which it often grows (Burns and Honkala 1990b). Douglas-fir is classed as intermediate in overall shade tolerance except in its youth. The species' rapid growth and longevity, and the thick, corky bark are the main adaptations that have enabled it to survive better than less fire-resistant associates. Without fire or other severe disturbance, Douglas-fir would gradually be replaced throughout much of its range by the more shade tolerant conifers, such as western hemlock (Burns and Honkala 1990a).

Ecological characteristics of riparian forests are distinct because of their interaction with the aquatic systems. Riparian forests are shaped by forces originating within and beyond the streamside corridor. Disturbance, productivity, and spatial heterogeneity of microenvironments regulate species richness. The high diversity of the riparian forests is related to disturbance caused by floods, spatial heterogeneity created by debris flows, lateral river migration, large wood inputs to site productivity and landform, variation in local climate
as a function of elevation, and cold air drainage (Naiman et al. 2000). As a result of these factors, structure and composition of riparian forests are highly variable. On a local scale, riparian vegetation changes laterally from streamside to upslope but also longitudinally from headwaters to lower reaches. On a regional scale, woody plant communities change along broad gradients in climate and geology (Ohmann and Spies 1998). Species composition of riparian forests is also known to be affected by soil pH , soil moisture and depth to water table, the severity and frequency of flooding, and competition for germination sites.

To describe the association between riparian vegetation patterns and fluvial processes, we conducted an intensive field survey of riparian areas in a mountain stream network. Tree species diversity in riparian forests are known be lower than that in upland stands (Pabst and Spies 1999, Nierenberg and Hibbs 2000). If classified by growth habitats, conifers increase with distance and height from stream, while hardwoods do not significantly vary with distance from stream (Minore and Weatherly 1994, Pabst and Spies 1999). The classification by growth habitat is often used to describe riparian vegetation, especially when vegetation patterns are estimated from digital images or air photos, yet the classification by growth habitat may overlook characteristics of each species. Patterns of each species were not always documented in previous studies. It is, however, important to describe vegetation pattern at a species level as well as at a community level. Our study describes how riparian vegetation varies with distance from stream both at a species level and at a community level, if vegetation patterns at both scales are consistent with each other, and what species is a generalist or a specialist in riparian forests at a small scale within riparian forests.

Herb and shrub species are important components of riparian vegetation, yet only one study has described details of their pattern (Pabst and Spies 1998). Herb and shrub species may be more useful to describe characteristics of riparian vegetation than tree species at a small scale, because of their species diversity and nature of their habitats. Pabst and Spies
(1998) found that vegetation composition was ordered along a complex environment gradient running from streamside to hillslope, and species diversity followed a decreasing trend from active fluvial surfaces to lower hillslopes. Their study sites were located more north than our study site. We looked at consistency of patterns of riparian vegetation between our study and theirs, and described particular patterns in our study area.

## Functions of Riparian Forest Buffers

Riparian forests perform a wide range of functions such as protecting water quality by reducing the amount of sediments, nutrients and other pollutants that enter streams, lakes, and other surface waters; stabilizing stream banks and reducing channel erosion; providing habitat for terrestrial organisms; and maintaining habitat for fish and other aquatic organisms by moderating water temperatures and providing large woody debris (LWD) (Gregory et al.1991). These functions are widely recognized, and in order to protect and maintain the riparian forests, the riparian buffer strips along streams, within which vegetation retention and special management practices are required, are increasingly important as watershed management tools (Belt et al. 1992, Wenger 1999).

For example, in Oregon, forest managers have been required to leave riparian buffers along streams after harvest since 1972 (Hibbs and Bower 2001). In 1993, the Northwest Forest Plan (FEMAT 1993) proposed a set of standards applied to riparian buffer widths. Within riparian reserves, cutting of trees is limited to treatment of forest stands to maintain suitable habitat conditions for fish and aquatic species. Such cutting is allowed only after watershed analysis. In 1994, Oregon Department of Forestry (ODF) revised its riparian regulations, called the Stream Rules, under the Oregon Forest Practices Act (Oregon Department of Forestry 1994). These statewide regulations for forest operations on private, state, and local government land are used to meet the federal Clean Water Act for silvicultural activities. The

1994 Stream Rules increased emphasis on retaining streamside conifers as future sources of LWD (Hairston-Strang and Adams 1998). LWD deposited into the stream is the most critical component of physical structure of stream substrate, which provides essential habitat for many fish. Trout populations appear sensitive to levels of LWD persisting in streams well after the time of logging (Connolly and Hall 1999). Pools are especially important habitats for adult coastal cutthroat trout (Oncorhynchus clark clarki), and downed wood in streams provide the structure to promote scouring of pools and enhance the physical complexity of salmonid habitats (Connolly and Hall 1999). LWD from red alder is smaller and less resistant to decay in streams than large logs of decay-resistant conifers such as Douglas-fir or western redcedar (Anderson et al. 1978), although red alder dominates many riparian stands in the Pacific Northwest (Hayes et al. 1996). The 1994 Stream Rules therefore increased the requirements for leaving conifers to protect and improve fish habitats. Riparian Management Areas (RMAs) in Oregon range from 50 ft on small fish-bearing streams to a maximum of 100 ft on large streams. The first 20 ft can not be harvested; some cutting is allowed beyond 20 ft if the buffer exceeds the target basal area for conifers (for example, $120 \mathrm{ft}^{2} / 1000 \mathrm{ft}$ of a medium fishbearing stream in the Oregon Coast Range) (Oregon Department of Forestry 1994).

Today, as in Oregon, many states of the U.S. are developing programs to protect riparian forests and require riparian buffer strips. Riparian buffer strip requirements (width, shade, canopy cover, or trees to be left), however, may vary widely, depending on the specific functions required for a particular buffer (Castelle et al. 1994). For the purpose of maintaining inputs of LWD, a buffer width of at least one tree height is recommended although for stability purposes, a width equal to three tree heights may be necessary (Collier et al, 1995). The widths necessary for reducing nitrate concentrations vary based on local hydrology, soil factors, slope and other variables (Wenger 1999). Even with general guidelines, complexity of underlying environmental factors affecting riparian vegetation makes it difficult to establish
effective and sufficient riparian buffer strips. In order to design better conservation and management strategies, basic ecological information about the composition and structure of riparian forests is still needed, and understanding the major patterns in the vegetation and underlying mechanisms responsible for the vegetation is important.

## Channel-Reach Morphology and Riparian Vegetation

Restoring and maintaining fish populations and their habitats is also a key purpose of watershed management. Describing associations between channel-reach morphology and riparian vegetation is a step towards understanding interactions between terrestrial and aquatic environments, linking potentially to fish habitat and abundance. Channel reaches define a useful scale over which to relate stream morphology to channel processes, response potential, and habitat characteristics (Rot et al. 2000). Fish abundance is sensitive to stream dynamics and habitat units defined by their structures, functions, responses to disturbance, and capability of maintaining aquatic organisms (Connolly and Hall 1999, Young et al. 1999). Fish habitat units such as pools and riffles are hierarchically nested within channel reaches of at least 10 to 20 channel widths in length.

Riparian vegetation is one of many important factors affecting channel-reach morphology, as well as valley-wall confinement and large wood loading. Riparian vegetation influences channel morphology and response potential by providing root strength that contributes to bank stability. Wood from riparian areas also provides significant control on the formation and physical characteristics of pools, bars, and steps (Montgomery and Buffington 1997). The influence of riparian vegetation on channel morphology such as large wood loading has been studied (Harris 1987, Hession 2001, Hession et al. in press). However, influences of channel morphology on riparian vegetation have not been documented.

Riparian vegetation is not only affecting channel morphology but is affected by
fluvial process caused by nature of channel morphology. For example, moisture tolerant early succession species may be more abundant in Pool-Riffle reaches, sites possibly more prone to flooding and containing wider floodplains than other reaches. On the other hand, high transportation capability of Bedrock reaches may prevent formation of a floodplain and bring sharp drops of bank adjacent to stream that makes possible presence of the species intolerant to water disturbance. Describing associations between channel-reach morphology and riparian vegetation is very challenging, but it is an important step to understanding interactions between terrestrial and aquatic environments.

## Objectives

The research objective for this study was to describe variation of riparian vegetation in an Oregon Coast Range system according to geomorphic characteristics and in relation to streamflow. Specific objectives of this study were to:

1. Examine if the vegetation composition and structure of the riparian forest varied among channel-reach morphologies.
2. Examine how the composition and structure of the riparian forest changed with distance from the stream.
3. Extract major underlying environmental gradients explaining riparian forest community from riparian vegetation data.

## METHODS

## Study Area

This study was conducted in Camp Creek in the Oregon Coast Range (Figure 1) from June to September 2002. Camp Creek is a stream tributary to the Umpqua River. The study area is located in $43^{\circ} 5^{\prime} \mathrm{N}$ and $123^{\circ} 43^{\prime} \mathrm{E}$. Legal coordinates are T23S R08W Section 1920, 28-30 and T23S R09W Section 24,25 . The basin of the study area is about 1,000 ha. Local geology of the study area is characterized by uplifted ocean floor sediment and basalt flows from the tertiary period of the Miocene and Eocene epochs (Franklin and Dyrness 1973). Mountain slopes are generally steep. Slope of the study area ranged from $0^{\circ}$ to $57^{\circ}$. The elevation of the study area ranges from 170 m to 784 m . Regional climate is temperate and seasonally wet. Average annual precipitation ranges between $1,000 \mathrm{~mm}$ to $1,600 \mathrm{~mm}$, with rainfall between October and May. There were a number of debris flows from the February 1996 flood.

The study area contains the Western Hemlock vegetation zones of the Oregon Coast Range (Franklin and Dymess 1973) where major forest tree species are western hemlock, Douglas-fir, and western redcedar. Red alder is a common riparian dominant. Most of the study area is owned and managed by the USDI Bureau of Land Management, Coos Bay District Office, and the rest of the area is owned by industrial private owners (Figure 2). A paved road is along the stream. Part of the forests in the basin has been clear cut between 1950 to present and the birth dates of the rest of forest are from 1800 to 1849 or prior to 1800 (Figure 3, Figure 4). The areas along the main stem have not been harvested and old growth forests have been left although there were a few stamps of conifers in sampling sites. Some fire scars on Douglas-fir and western hemlock were found, but there was no indication of a widespread fire influence.


Figure 1. Location of the Study Area (Camp Creek)


Figure 2. Ownership of Upper Camp Creek Study Area


2
Camp_basin.shp
Camp_rd.shp - Camp_streams.shp

Figure 3. Harvest Patterns of Upper Camp Creek


Figure 4. Overstory Vegetation of Upper Camp Creek Study Area

The study area is part of a large landscape study being conducted by the Cooperative Forest Ecosystem Research (CFER) Program. This CFER study focuses on the abundance of coastal cutthroat trout above barriers to fish passage. Upper Camp Creek was sampled in the summer of 2000 by CFER scientists, stream reaches were classified, and habitat units were surveyed for fish. During this summer, the main stem of upper Camp Creek was divided into 23 reaches and assigned channel-reach morphologies (Table 1) according to a hybridized version of the Hierarchical Stream Classification System (Frissell et al. 1986), Reach Characteristics for Channel Reach Morphology in Mountain Drainage Basins (Montgomery and Buffington 1997), and the Oregon Department of Fish and Wildlife Aquatic Inventory System (Moore et al. 2002). Reaches were defined by major tributary junctions, geologic barriers to fish migration, major changes in channel and valley form, or fish-bearing tributary junctions. Although the main stem contains 23 reaches, only 19 of them were surveyed because the highest reaches were very steep and it was unsafe to collect data. The channelreach morphologies classified by CFER scientists were also used in this study, with the study area containing six Bedrock (BR), three Cascade (CA), five Pool-Riffle (PLRI), and five StepPool (STPL) reaches (Figure 5). Along reaches 1 to 13, Camp Creek is a third order stream and along reaches 14 to 19 , it is a second order stream.

Table 1. Diagnostic features of channel-reach morphologies
(From Montgomery and Buffington 1997)

|  | Alluvial channel-reach morphologies |  |  |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | Dune ripple | Pool riffle | Plane bed | Step pool | Cascade | Bedrock | Colluvial |
| Typical bed material | sand | gravel | gravel-cobble | cobble-boulder | boulder | rock | variable |
| Bedform pattern | multilayered | laterally oscillatory | featureless | vertically oscillatory | random | irregular | variable |
| Roughness elements | sinuosity bedforms grains banks | sinuosity <br> grains <br> banks | grains banks | bedforms grains banks | grains banks | boundaries (bed and banks) | grains |
| Sediment sources | fluvial bank failure | fluvial bank failure | fluvial bank failure debris flows | fluvial <br> debris flows hillslope | fluvial <br> debris flows hillslope | fluvial <br> debris flows hillslope | debris flow hillslope |
| Sediment storage elements | overbank bedforms | overbank bedforms | overbank | bedforms | lee sides of flow obstructions | pockets | bed |
| Confinement | unconfined | unconfined | variable | confined | confined | confined | confined |
| Pool spacing (channel-width) | 5 to 7 | 5 to 7 | none | 1 to 4 | $<1$ | variable | unknown |




Figure 5. Sample Sites and Sample Plots

## Site Selection and Establishment

A $30 \mathrm{~m} \times 30 \mathrm{~m}$ sample site was randomly located on each side of Camp Creek in each reach (Figure 5). The length of each reach was estimated from a GIS layer. For each reach, two random numbers were generated and used as the locations (meter) of sample sites generally from the downstream reach starting point. Distances from the reach starting point were measured in the field with a measuring tape. Sample site selection was constrained by the longitudinal sampling design. If riparian areas at randomly selected site locations were not suitable, the sample point was moved to the nearest suitable sample site until the riparian area became straight enough to sample. Nine site locations were changed due to channel sinuosity.

At each site, overstory trees were sampled in three consecutive $30 \mathrm{~m} \times 10 \mathrm{~m}$ belttransects established perpendicular to the stream flow, and identified as Belt1, Belt2 and Belt3 (Figure 5). Belt1 was established at the edge of the stream, and slope distances were corrected to measure out horizontal distance. Sample sites established on the road side of the stream were frequently area-limited. Of the sample sites established adjacent to the road, two sites had two belts, and three sites had only one belt.

Within each belt, understory vegetation was sampled in three circular subplots of 2m radius equally spaced nine meters apart from each other and identified Subplotl, Subplot2, and Subplot3 (Figure 5). The three subplots were centered within the overstory belts at 2.5, 15 and 27.5 meters distance from the stream edges. In 38 total sites, 318 subplots were established. Vegetation data collected in the subplots were averaged over each belt.

## Data Collection

## Physical site characteristics

Physical characteristics collected for each site included aspect (degree), elevation above sea level (meter), reach type, and stream order. Elevation of the site was estimated from 10-m Digital Elevation Models. Stream orders were determined from topographic maps.

Data collected for each subplot were slope (\%), aspect (degree), and height above summer low flow (meter) on Belt1. Horizontal height above summer low flow on Beltl was measured every $0.5-\mathrm{m}$ by using height poles and clinometers. Using distances between subplots and corresponding slopes, height above summer low flow for subplots on Belt2 and Belt 3 was calculated. Height for subplots on Belt 2 and Belt 3 were given by the following equation:

Height of Belt $(\mathrm{n}+1)=$ Height of Belt $(\mathrm{n})+12.5 *$ Slope $(\%) / 100 \quad(\mathrm{n}=1,2)$

## Vegetation data

Overstory tree data collected in the $30 \mathrm{~m} \times 10 \mathrm{~m}$ belts included species and diameter at breast height $(\mathrm{DBH})(\mathrm{cm})$ for all trees greater than 10 cm DBH. Vegetation data collected in the $2-\mathrm{m}$ radius subplots included percent cover for all overstory, shrub, and herb species. Cover was estimated visually as the percentage of circle ground area covered by each species in $1 \%$ increments up to $5 \%$ and then in $5 \%$ increments up to $100 \%$.

## Analysis \& Data adjustment

## Physical site characteristics

Aspect (azimuth that a slope faces) was transformed into heat load index (Beers et al. 1966). A reasonable transformation of heat load for slopes in the northern hemisphere is to make the scale symmetrical about the northeast-southwest line (McCune and Keon 2002). The following formula rescales aspect to a scale of zero to one, with zero being the coolest slope (northeast) and one being the warmest slope (southwest). Heat load index $=\{$ cosine $(45-$ degrees) +1$\} / 2$

## Vegetation data

Tree density (stems/ha) and basal area ( $\mathrm{m}^{2} /$ ha) was calculated based on DBH of trees $>10 \mathrm{~cm}$ DBH. Percent cover of trees had been estimated in subplots. The size of subplots was, however, used to capture understory vegetation and it likely under-represents overstory vegetation. Since cover data would provide information of trees $<10 \mathrm{~cm}$ DBH that was not included in DBH data, I report results of the tree cover but will not analyze the data as rigorously as density and basal area data. Each sample unit was classified according to plant association (Hemstrom and Logan 1986).

## Community analysis

Species diversity was measured in three ways; Alpha, Beta, and Gamma diversity. Whittaker (1972) defined the three levels of diversity; Alpha diversity: diversity in individual sample units; Beta diversity: amount of compositional variation in a sample; Gamma diversity: overall diversity in a collection of sample units. Each of them can be calculated in various ways. In this analysis, Alpha diversity is species richness; the number of species in a sample unit (species/belt). Gamma diversity was the number of species in the entire study
area. Beta-diversity is a simple measure of the amount of compositional heterogeneity in a sample and it tells us the difficulty of ordination of the data set (McCune and Grace 2002). Beta diversity was calculated as $\beta_{w}=$ (the number of species in the whole sample units)/(the average of species richness in a sample unit)-1. If $\beta_{w}=0$, then all sample units have all of the species. A number of community analysis tools were used to examine vegetation patterns including Non-metric Multidimensional Scaling (NMS), Multi-Response Permutation Procedure (MRPP) and Blocked MRPP (MRBP), and Indicator Species Analysis (ISA) using the PC-ORD statistical package (McCune and Mefford 1999).

Non-metric Multidimensional Scaling (Kruskal 1964, Mather 1976) was used to extract several dimensions of plant species space capturing most of the variation within an original higher dimensional species space, and to provide graphical representations of plant community relationships with environmental variables. Advantages of NMS are that it avoids the assumption of linear relationship among variables, which most major ordination analyses requires, and that its use of ranked distances relieves the "zero-truncation problem," a problem that plagues all ordinations of heterogeneous community data sets (McCune and Grace 2002). This technique iteratively searched for the minimal stress configuration of $n$ items in $k$ dimensions within the data set from a calculated distance matrix. Stress was described as the departure from monotonicity between the distance measures in original space versus ordination space. Autopilot mode with "slow and thorough" option in PC-ORD (McCune and Mefford 1999) used the best of 40 runs with a random starting configuration with real data. Fifty runs with randomized data were used for a Monte Carlo test of significance of the final
stress. Sorensen distances; $D_{i, h}=\frac{\sum_{j=1}^{p}\left|a_{i j}-a_{h j}\right|}{\sum_{j=1}^{p} a_{i j}+\sum_{j=1}^{p} a_{h j}}$ (distance between items $i$ and $h$ )
(Czekanowski 1913) expressed community resemblance. Environmental variables were superimposed on the resulting ordination using a joint plot, based on the correlation of those variables with the axes of the plant community ordination. The ordinations were rigidly rotated to load the variable with the highest correlation onto one axis.

Multi-Response Permutation Procedure and Blocked MRPP (Mielke 1984) were used to test if the structure and composition of riparian vegetation differ among reach types or among belt types. They are non-parametric multivariate tests of differences between priori defined groups, and compare the vegetation data of sample units within the groups to the vegetation data that is randomly allocated to sample units. An advantage of MRPP and MRBP is that they do not require distributional assumptions such as multivariate normality and homogeneity of variances that are seldom met with ecological community data (McCune and Grace 2002). In order to reduce the influence of outliers, Sorensen distances were used to calculate average within-group distances for MRPP. Since MRBP requires equal sample sizes, the seven sample units in the five sites where Belt1 only, or Belt1 and Belt2 were established were removed in the analysis of MRBP. Euclidean distance and median alignment were used for MRBP because Sorensen distance is incompatible with median alignment. Alignment results in both positive and negative values, but Sorensen distance require nonnegative data.

Indicator Species Analysis (ISA) (Dufrene and Legendre 1997) was used to describe environmental conditions of belt types inferred from indicator species. Indicator species analysis assigns indicator values (IV) to each species based on their concentration of abundance in particular groups and relative frequency within a group. Groups were belts (Belt1, Belt2, and Belt3) and reach-channel morphology (Bedrock, Cascade, Pool-Riffle, and Step-Pool) in this study. A perfect indicator species of a particular group should always be present in that group but it should never occur in other groups. The IV ranges from zero (no indication) to 100 (perfect indication). A Monte Carlo test with 1,000 random permutations
was used to test the statistical significance of the IV for each species. The p-values are based on the proportion of randomized trials with indicator value equal to or exceeding the observed indicator value. In this study, indicator species was used in statistical rater than ecological sense.

## RESULTS

## Characteristics of Sample Units

## Height above summer low flow

Height above summer low flow increased with distance from stream at most of the sites (Figure 6), however there were expected variations on flatter sites. Correlation values between height above summer low flow and distance from stream was strong ( $r=0.74$ ). Over the study area, mean height of Belt1 $(1.4 \mathrm{~m})$ was significantly lower than that of Belt2 $(5.8 \mathrm{~m})$ and Belt 3 ( 11.7 m ) (Table 2). Height above summer low flow increased with distance from stream in all sites except one, where the stream made a bend around site and Belt3 was adjacent to the stream. However, variation of height above summer low flow among Belt3s was greater than that among Belt1s. Height above summer low flow ranged from 0.4 m (Site 28) to 2.8 m (Site 2) among Belt 1 s while 1.8 m (Site 21) to 24.9 m (Site 6) among Belt 3 s .

Height above summer low flow by channel-reach morphologies (Table 3) showed some trends, but the trends were not as strong as those by belt types (Table 3, Figure 7). In Belt1, height above summer low flow of Step-Pool reaches was lowest and that of Pool-Riffle was second lowest (Figure 8). There were no sample units of Belt1 higher than 2 meters in Step-Pool reaches. Mean height above summer low flow of Bedrock reaches was the same as that of Cascade reaches. The lowest sample unit of Belt1 in Bedrock reaches and in Cascade reaches was 0.9 meters (Site 20) and 0.75 meters (Site 31), respectively.

Table 2. Characteristics of Sample Units

|  | Belt1 | Belt2 | Belt3 |
| :--- | ---: | ---: | ---: |
| Height $(\mathrm{m})$ | $1.4(0.09)$ | $5.8(0.49)$ | $11.7(1.1)$ |
| Slope $(\%)$ | $32.5(2.8)$ | $43.7(7.4)$ | $45.8(4.7)$ |
| Heatload_B | $0.56(0.03)$ | $0.54(0.04)$ | $0.52(0.04)$ |
| Standard error in parentheses |  |  |  |
| Belt attributes are explained in Table13 |  |  |  |
| N: Belt1 $=38$, Belt2 $2=35$, Belt3 $=33$ |  |  |  |



Figure 6. Height above summer low flow vs. distance from stream

Table 3. Sample Unit Characteristics by channel-reach morphologies

|  |  | Belt1 | Belt2 | Belt3 |
| :--- | :--- | :--- | :--- | :--- |
| $\widehat{E}$ | BR | $1.5(0.17)$ | $6.2(0.99)$ | $11.0(2.1)$ |
| $\stackrel{\rightharpoonup}{5}$ | CA | $1.5(0.22)$ | $7.1(1.5)$ | $14.1(2.9)$ |
| $\stackrel{\sigma}{\sigma}$ | PLRI | $1.31(0.22)$ | $5.1(0.94)$ | $11.7(2.3)$ |
| $\frac{\square}{工}$ | STPL | $1.18(0.13)$ | $5.2(0.71)$ | $10.7(1.7)$ |
| $\stackrel{\circ}{\circ}$ | BR | $36.1(4.3)$ | $59.6(22.8)$ | $41.2(11.6)$ |
| $\stackrel{\omega}{0}$ | CA | $40.9(10.3)$ | $48.6(13.5)$ | $60.6(12.2)$ |
| $\stackrel{\circ}{0}$ | PLRI | $30.8(5.3)$ | $31.4(8.17)$ | $35.5(4.6)$ |
| $\omega$ | STPL | $24.7(3.7)$ | $36.0(6.7)$ | $52.1(6.1)$ |

Standard error in parentheses
$\mathrm{N}:$ Belt1, $B R=12, C A=6, P L R I=10, S T P L=10$
N: Belt2, $B R=10, C A=6$, PLRI $=9$, STPL $=10$
$\mathrm{N}:$ Belt $3, \mathrm{BR}=10, \mathrm{CA}=6, \mathrm{PLRI}=9, \mathrm{STPL}=8$


Figure 7. Height by channel-reach morphologies

## Slope, elevation, and other variables

Streamside samples were of moderate slope, and transitioned quickly to steeper upslope condition (Table 2). Mean slope of streamside samples was approximately $10 \%$ lower than that of Belt2. There was little difference between Belt2 and Belt3. Among channel-reach morphologies, Cascade and Bedrock reaches had the steepest streamside slopes (Table 3, Figure 9) while Pool-Riffle and Step-Pool reaches were less steep, although there was much overlap in the data.

Elevation above sea level and distance from headwaters were inversely related (Table 4). Cascade reaches were highest in elevation and shortest in distance from headwater. There was no difference among channel-reach morphologies in heat load index (Table 5).


Figure 8 . Height by channel-reach morphologies (Belt1). Labels indicates sites dominated by red alder


Figure 9. Slope by channel-reach morphologies (Belt1).
Labels indicate sites dominated by red alder

Table 4. Site Characteristics

|  | reach | channel morphology | heatload index | road | elevation (m) | headwater distance ( m ) | stream order | pure <br> red alder |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| site1 | 1 | BR | 0.34 | 1 | 175 | 7640 | 3 | Belt2 |
| site2 | 1 | BR | 0,56 | 0 | 175 | 7568 | 3 |  |
| site3 | 2 | STPL | 0.99 | 1 | 184 | 7432 | 3 |  |
| site4 | 2 | STPL | 0.63 | 0 | 183 | 7369 | 3 | Belt2 |
| site5 | 3 | PLRI | 0.05 | 0 | 180 | 7144 | 3 |  |
| site6 | 3 | PLRI | 0.86 | 1 | 180 | 7129 | 3 | Belt1 |
| site7 | 4 | CA | 0.05 | 0 | 182 | 7016 | 3 |  |
| site8 | 4 | CA | 0.40 | 1 | 182 | 6998 | 3 |  |
| site9 | 5 | PLRI | 0.99 | 0 | 191 | 6808 | 3 |  |
| site10 | 5 | PLRI | 0.99 | 1 | 195 | 6286 | 3 | Belt1 |
| site11 | 6 | BR | 0.99 | 1 | 199 | 5960 | 3 | Belt1 |
| site12 | 6 | BR | 0.12 | 0 | 207 | 5550 | 3 |  |
| site13 | 7 | STPL | 0.02 | 0 | 214 | 5202 | 3 |  |
| site14 | 7 | STPL | 0.32 | 1 | 214 | 5167 | 3 | Belt1 |
| site15 | 8 | BR | 0.63 | 0 | 217 | 4816 | 3 | Belt1 |
| site16 | 8 | BR | 0.32 | 1 | 219 | 4739 | 3 |  |
| site17 | 9 | PLRI | 0.38 | 1 | 219 | 4636 | 3 | Belt1 |
| site18 | 9 | PLRI | 0.56 | 0 | 220 | 4625 | 3 |  |
| site19 | 10 | BR | 0.24 | 0 | 223 | 4517 | 3 |  |
| site20 | 10 | BR | 0.34 | 0 | 226 | 4406 | 3 |  |
| site21 | 11 | BR | 0.96 | 0 | 226 | 4282 | 3 |  |
| site22 | 11 | BR | 0.06 | 0 | 232 | 4106 | 3 |  |
| site23 | 12 | STPL | 0.99 | 0 | 237 | 3814 | 3 |  |
| site24 | 12 | STPL | 1.00 | 1 | 247 | 3541 | 3 |  |
| site25 | 13 | PLRI | 0.46 | 0 | 249 | 3244 | 3 |  |
| site26 | 13 | PLRI | 0.36 | 1 | 249 | 3168 | 3 | Belt 1,2,3 |
| site27 | 14 | STPL | 0.01 | 1 | 260 | 3000 | 2 |  |
| site28 | 14 | STPL | 0.03 | 0 | 261 | 2944 | 2 |  |
| site29 | 15 | PLRI | 0.03 | 0 | 268 | 2795 | 2 | Belt1 |
| site30 | 15 | PLRI | 0.01 | 1 | 279 | 2751 | 2 | Belt 1 |
| site31 | 16 | CA | 0.97 | 0 | 277 | 2662 | 2 |  |
| site32 | 16 | CA | 0.02 | 1 | 281 | 2658 | 2 | Belt2 |
| site33 | 17 | STPL | 0.00 | 0 | 288 | 2453 | 2 |  |
| site34 | 17 | STPL | 0.30 | 1 | 296 | 2248 | 2 | Belt2 |
| site35 | 18 | CA | 0.96 | 0 | 297 | 2052 | 2 |  |
| site36 | 18 | CA | 0.56 | 1 | 298 | 2036 | 2 |  |
| site37 | 19 | BR | 0.75 | 0 | 300 | 1776 | 2 |  |
| site38 | 19 | BR | 0.05 | 1 | 306 | 1766 | 2 |  |

road: 1 indicates sites on the road side, 0 on the other side
Pure red alder: sample units completely dominated by red alder.

Table 5. Site Characteristic mean values by channel-reach morphologies

| Reach | heatload index | elevation | headwater |
| ---: | ---: | ---: | ---: |
| BR | $0.45(0.10)$ | $225(12)$ | $4760(529)$ |
| CA | $0.49(0.17)$ | $253(23)$ | $3904(988)$ |
| PLRI | $0.47(0.12)$ | $223(11.6)$ | $4859(582)$ |
| STPL | $0.43(0.14)$ | $238(13)$ | $4317(603)$ |

Standard error in parentheses
$N: B R=12, C A=6, P L R I=10, S T P L=10$

## Characteristics of Overstory Vegetation

Seven species and 1,067 stems were recorded as trees larger than 10 cm DBH in the entire study area. Red alder, western hemlock, and bigleaf maple were the most frequent species occurring in the study area, with Douglas-fir and western redcedar occurring at lower frequencies (Table 6). Fifty-one percent of all trees were red alder (543 stems), and 29.4\% were western hemlock ( 311 stems). Grand fir (Abies grandis) and western yew (Taxus brevifolia) were rare species ( 4 stems each) and removed in the following analysis.

There were significant trends in both tree density and basal area with distance from stream (Table 6, Figure 10, Figure 11). Red alder was the most abundant species in Belt1, while Douglas-fir and western redcedar were the least abundant. Red alder decreased in both frequency and abundance with increasing distance from stream. Bigleaf maple slightly increased in basal area with distance from stream but its tree density was evenly distributed across belts. Douglas-fir and western hemlock were less frequent and less abundant in Belt 1 than in Belt2 and Belt3. Western redcedar showed a similar pattern to other conifers. The greater mean basal area in Belt2 of western redcedar ( $12.7 \mathrm{~m}^{2} / \mathrm{ha}$ ) was related to two large trees ( 200 cm and 225 cm DBH ) occurring in one Belt2 sample. Without this one sample, the basal area of Belt2 $\left(6.1 \mathrm{~m}^{2} / \mathrm{ha}\right)$ would become lower than that of Belt3 $\left(9.9 \mathrm{~m}^{2} / \mathrm{ha}\right)$. Although all conifers had similar patterns in tree density and basal area, gradients and magnitude varied among the species. Overall mean tree density of western hemlock was more than five times as great as that of Douglas-fir and western redcedar, however there was little difference in overall mean basal area among those species. With regard to the distance from stream, tree density increased most rapidly for western hemlock, and basal area increased most rapidly for Douglas-fir.

Table 6. Tree Counts, Density, and Basal Area

|  | Counts | Mean tree density (stems/ha) |  |  |  | Mean basal area (m^2/ha) |  |  |  |
| :--- | ---: | ---: | ---: | ---: | ---: | ---: | ---: | ---: | ---: |
|  | overall | overall | belt1 | belt2 | belt3 | overall | belt1 | belt2 | belt3 |
| bigleaf maple | 94 | $28.6(4.6)$ | $25.4(8.3)$ | $28.6(7.2)$ | $32.4(8.3)$ | $5.1(1.0)$ | $3.7(1.8)$ | $4.7(2.1)$ | $7.2(2.0)$ |
| red alder | 543 | $168.3(19.2)$ | $251.4(32.7)$ | $170.5(36.2)$ | $70.2(21.1)$ | $7.3(0.9)$ | $13.1(1.8)$ | $5.7(1.1)$ | $2.3(0.7)$ |
| Douglas-fir | 57 | $17.7(3.2)$ | $5.3(3.0)$ | $21.6(5.3)$ | $27.8(7.6)$ | $12.6(2.4)$ | $3.2(1.8)$ | $14.1(3.8)$ | $21.9(5.9)$ |
| western redceder | 54 | $16.7(2.5)$ | $10.5(3.1)$ | $21.0(5.8)$ | $19.2(3.6)$ | $9.2(2.5)$ | $5.4(1.8)$ | $12.7(6.9)$ | $9.9(2.5)$ |
| westem hemlock | 311 | $97.3(10.4)$ | $62.3(14.1)$ | $107.6(18.5)$ | $126.8(20.6)$ | $8.9(1.1)$ | $5.1(1.3)$ | $13.1(2.2)$ | $11.3(2.0)$ |

Standard error in parentheses
N : belt $1=38$, belt $2=35$, belt $3=33$, total $=106$
grand fir and western yew were rare species and removed in this analysis


Figure 10. Mean Tree Density by Belt Types


Figure 11. Mean Basal Area by Belt Types

There were few trends in basal area and tree density associated with channel-reach morphologies (Table 7, Figure 12, Figure 13) although MRPP on basal area indicated that there were weak differences among reaches. Red alder was dominant in all reaches, with highest densities in Step-Pool reaches. Western hemlock was frequent and abundant in Bedrock reaches, large Douglas-fir was observed in Step-Pool reaches, and western redcedar in Cascade reaches. Douglas-fir was absent from Cascade and Pool-Riffle reaches and bigleaf maple was absent from Pool-Riffle reaches.

Red alder dominated 15 sample units (Belt1 of Site 6, 10, 11, 14, 15, 17, 29, and 30, Belt2 of Site 2, 4, 32, and 34, and all three belts of Site 26) (Table 4). A pure red alder sample unit, S14B1, had the highest basal area ( $43.9 \mathrm{~m}^{2} / \mathrm{ha}$ ) and the second highest tree density ( 833 stems/ha). S14B2 next to S14B1 was not dominated by red alder but it had the highest tree density of red alder (867 stems/ha) (Figure 14, Figure 15).

Pure red alder sample units were concentrated in sample units of Belt1 relatively low in height from summer low flow. Most pure red alder sample units were associated with PoolRiffle reaches (Figure 8).

Table 7. Tree Density and Basal Area by channel-reach morphologies -Belt1-

|  | Tree density (stemsha) |  |  |  | Basal area (m $\left.{ }^{\wedge} 2 / \mathrm{ha}\right)$ |  |  |  |
| :--- | ---: | ---: | ---: | ---: | ---: | ---: | ---: | ---: |
|  | BR | CA | PLRI | STPL | BR | CA | PLRI | STPL |
| ACMA | $30.6(17.1)$ | $22.2(16.5)$ | $0(0)$ | $46.7(20.6)$ | $4.1(2.3)$ | $4.9(3.5)$ | $0(0)$ | $6.2(2.9)$ |
| ALRU | $252.8(68.2)$ | $177.8(48.4)$ | $198.7(51.7)$ | $346.7(68.9)$ | $13.3(3.7)$ | $10.0(3.2)$ | $10.9(2.8)$ | $16.9(3.8)$ |
| PSME | $11.1(8.5)$ | $0(0)$ | $0(0)$ | $6.7(4.4)$ | $2.0(1.4)$ | $0(0)$ | $0(0)$ | $9.8(6.6)$ |
| THPL | $8.3(6.0)$ | $22.2(7.0)$ | $6.7(4.4)$ | $10.0(7.1)$ | $2.9(1.9)$ | $11.1(3.6)$ | $7.9(5.5)$ | $2.6(2.4)$ |
| TSHE | $102.8(33.4)$ | $44.4(18.6)$ | $33.3(26.8)$ | $53.3(16.6)$ | $9.7(3.1)$ | $2.1(1.4)$ | $3.5(2.6)$ | $3.1(1.1)$ |

Standard error in parentheses
$\mathrm{N}:$ Belt $1, B R=12, C A=6, P L R I=10, S T P L=10$


Figure 12. Tree Density by channel-reach morphologies


Figure 13. Basal Area by channel-reach morphologies






Figure 14. Tree Density vs. Height above summer low flow


Figure 15. Basal Area vs. Height above summer low flow

## CHARACTERISTICS OF UNDERSTORY VEGETATION

## Species diversity

Eighty-four species ( 22 shrubs and 62 herbs) were observed in the entire study area (Table 8). Species diversity was highest in Belt1 (Table 9). Average of species richness in individual sample units (average of Alpha-diversity) was greatest in Belt1 because species richness of herbs in Belt I was about five species greater than that of other belts. Surprisingly, there was little difference in species richness of shrubs with increasing distance from stream.

## Frequency of species

Oxalis (Oxalis spp.) and sword fern (Polystichum munitum) were the most frequent species, occurring in almost all sample units ( $98 \%$ and $97 \%$ of the all sample units, respectively) (Table 10, Figure 16). Besides oxalis and sword fern, 8 species including salmonberry, lady fern (Athyrium filix-femina) and galium (Galium spp.) were present in more than $80 \%$ of all sample units in Belt1 (Table 10, Figure 16). Galium and oxalis were present in all sample units in Belt1. After sword fern and oxalis, trillium (Trillium spp.) was the most frequent species occurring in $76 \%$ of the all sample units in Belt3 and salmonberry was occurring in $77 \%$ of the all sample units in Belt2.

Occurrence rates among 29 species present in more than $20 \%$ of the all sample units showed three patterns with increasing distance from the stream; increasing, decreasing and even. Five species increased with distance from stream including red huckleberry, dwarf Oregon-grape (Berberis nervosa), trillium, fairybells (Disporum sp.), and inside-out flower (Vancouveria hexandra) while 17 species including stink currant (Ribes bracteosum) coast boykinia (Boykinia elata), and yellow monkey-flower (Mimulus guttatus) decreased with distance from the stream. Five species including vine maple did not vary among belt types. Since oxalis and sword fern occurred in almost all sample units, there was no pattern on their occurrence rates with distance from the stream.

Table 8. Plant Lists

|  | Code | Common name | Scientific name |
| :---: | :---: | :---: | :---: |
| $\begin{aligned} & \stackrel{\bullet}{\mathbb{2}} \\ & \stackrel{\rightharpoonup}{2} \end{aligned}$ | TSHE | western hemlock | Tsuga heterophylla (Rat.) Sarg. |
|  | PSME | Douglas-fir | Pseudotsuga menziesii (Mirbel) Franco |
|  | THPL | western redcedar | Thuja plicata Donn ex D. Don |
|  | ALRU2 | red alder | Alnus rubra Bong. |
|  | ACMA3 | big-leaf maple | Acer macrophyllum Pursh |
|  | *CADE27 | incense-ceder | Calocedrus decurrens (Torr.) Florin |
|  | * ABGR | grand fir | Abies grandis (Dougl. ex D. Don) Lindl. |
|  | - TABR2 | western yew | Taxus brevifolia Nutt. |
|  | - UMCA | California-laurel | Umbellularia californica (Hook. \& Arn.) Nutt. |
| $$ | GASH | salal | Gaultheria shallon Pursh |
|  | VAPA | red huckleberry | Vaccinium parvifolium Sm. |
|  | VAOV2 | evergreen huckleberry | Vaccinium ovatum Pursh |
|  | SARAP | red elderberry | Sambucus racemosa L. ssp. pubens (Michx.) House |
|  | OECE | indian-plum | Oemleria cerasiformis (Torr. \& Gray ex Hook. \& Arn.) Landon |
|  | RUSP | saimonberry | Rubus spectabilis Pursh |
|  | RUPA | thimbleberry | Rubus parviflorus Nutt. |
|  | RUDI2 | Himalayan blackberry | Rubus discolor Weihe \& Nees |
|  | RIBR | stink currant | Ribes bracteosum Dougl. ex Hook. |
|  | COCOC | hazelnut | Corylus cornuta Marsh. var. californica (A. DC.) Sharp |
|  | ACCl | vine maple | Acer circinatum Pursh |
|  | BEAQ | tall Oregon-grape | Berberis aquifolium Pursh |
|  | BENE2 | dwarf Oregon-grape | Berberis nervosa Pursh |
|  | - CONU4 | Pacific dogwood | Cornus nuttallii Audubon ex Torr. \& Gray |
|  | - RHMA3 | Pacific thododendron | Rhododendron macrophyllum D. Don ex G. Don |
|  | *SYAL | common snowberry | Symphoricarpos albus (L.) Blake |
|  | * HODI | oceanspray | Holodiscus discolor (Pursh) Maxim. |
|  | *ROGY | baldhip rose | Rosa gymnocarpa Nutt. |
|  | - RILA3 | tailing black currant | Ribes laxiflorum Pursh |
|  | *SALIX | willow | Salix L. |
|  | *RHPU | cascara backthorn | Rhamnus purshiana DC. |
|  | *WHMO | whipplevine | Whipplea modesta Torr. |
| $\begin{aligned} & \text { Ne } \\ & \stackrel{0}{\top} \\ & \hline \end{aligned}$ | LIBO3 | twinflower | Linnaea borealis L. |
|  | SMST | star-flowered false Solomon's-seal | Smilacina stellata (L.) Desf, |
|  | STREP3 | twistedstalk | Streptopus Michx. |
|  | DISPO | fairybells | Disporum Salisb. ex D. Don |
|  | TRILL | trillium | Trillium L. |
|  | MADI | false lity-of-the-valley | Maianthemum dilatatum (Wood) A. Nels. \& J.F. Macbr. |
|  | CLUN2 | queen's cup | Clintonia uniflora (Menzies ex J.A. \& J.H. Schultes) Kunth |
|  | CLPAP | small-leaved montia | Claytonia parviflora Dougl. ex Hook. ssp. parviflora |
|  | CLSI2 | candy flower | Claytonia sibirica L. |
|  | STCA | Northem starwort | Stellaria calycantha (Ledeb.) Bong. |
|  | Saxifrag | saxifrage family | Saxifragaceae |
|  | BOEL 2 | coast boykinia | Boykinia elata (Nutt.) Greene |
|  | TITR | foamflower | Tiarella trifoliata L. |
|  | CHGL5 | ground ivy-leaved water-carpet | Chrysosplenium glechomifolium Nutt. |
|  | ANDE3 | three-leaved anemone | Anemone deltoidea Hook. |
|  | THOC | western meadowrue | Thalictrum occidentale Gray |

Table 8. Plant Lists (continued)


[^0]Table 9. Diversity Measures

|  |  | overall | belt1 | belt2 | belt3 |
| :--- | :--- | ---: | ---: | ---: | ---: |
| Gamma-diversity | all species | 93 | $\mathbf{7 9}$ | $\mathbf{7 2}$ | $\mathbf{7 1}$ |
|  | trees | 9 | 7 | 6 | 7 |
|  | shrubs | 22 | 15 | 18 | 18 |
|  | herbs | 62 | 57 | 48 | 46 |
| Average of Alpha-diversity | all species | $\mathbf{2 0 . 6}(\mathbf{0 . 5})$ | $\mathbf{2 4 . 6}(\mathbf{0 . 8})$ | $\mathbf{1 8 . 5}(\mathbf{0 . 8 )}$ | $\mathbf{1 8 . 3}(\mathbf{0 . 7 )}$ |
|  | trees | $2.8(0.1)$ | $2.7(0.2)$ | $2.9(0.2)$ | $2.9(0.2)$ |
|  | shrubs | $3.7(0.1)$ | $4(0.2)$ | $3.3(0.2)$ | $3.7(0.3)$ |
|  | herbs | $14.1(0.5)$ | $17.9(0.6)$ | $12.4(0.7)$ | $11.6(0.6)$ |
| Beta-diversity | all species | 3.5 | 2.2 | $\mathbf{2 . 9}$ | $\mathbf{2 . 9}$ |
|  | trees | 2.2 | 1.6 | 1.1 | 1.4 |
|  | shrubs | 5 | 2.8 | 4.5 | 3.9 |
|  | herbs | 3.4 | 2.2 | 2.9 | 3 |

Standard error in parentheses
N : belt $1=38$, belt $2=35$, belt $3=33$, total $=106$
Alpha-diversity: the number of species in a sample unit (species/belt)
Gamma-diversity: the number of species in the entire study area
Beta-diversity: (Gamma-diversity / Average of Alpha-diversity) - 1

Table 10. Occurrence Rate

|  | Occurrence rate (\%) |  |  |  |
| :---: | :---: | :---: | :---: | :---: |
|  | overall | belt1 | belt2 | belt3 |
| VAPA | 48 | 39 | 40 | 67 |
| RUSP | 81 | 97 | 77 | 67 |
| R RUDI2 | 34 | 42 | 29 | 30 |
| ᄃ RIBR | 24 | 53 | 9 | 6 |
| ${ }^{\text {a }} \mathrm{ACCl}$ | 69 | 71 | 74 | 61 |
| BENE2 | 25 | 11 | 23 | 45 |
| DISPO | 30 | 13 | 43 | 36 |
| TRILL | 56 | 34 | 60 | 76 |
| MADI | 23 | 37 | 23 | 6 |
| CLSI2 | 63 | 68 | 60 | 61 |
| STCA | 39 | 66 | 31 | 15 |
| SAXIFRAG | 50 | 87 | 37 | 21 |
| boel2 | 30 | 71 | 9 | 6 |
| TITR | 34 | 45 | 20 | 36 |
| THOC | 36 | 50 | 31 | 24 |
| VIGL | 55 | 82 | 46 | 33 |
| $\sim$ CIAL | 36 | 58 | 31 | 15 |
| \% STCO14 | 52 | 84 | 46 | 21 |
| I MIGU | 42 | 82 | 20 | 21 |
| VAHE | 37 | 29 | 34 | 48 |
| DIFO | 33 | 32 | 34 | 33 |
| OXALI | 98 | 100 | 97 | 97 |
| GALIU | 78 | 100 | 63 | 70 |
| POACEAE | 68 | 89 | 57 | 55 |
| BLSP | 47 | 55 | 34 | 52 |
| PTAQ | 25 | 37 | 20 | 18 |
| POMU | 97 | 95 | 97 | 100 |
| ATFI | 71 | 87 | 69 | 55 |
| ADAL | 54 | 63. | 51 | 45 |



Figure 16a. Occurrence Rate -Shrubs-

N : belt $1=38$, belt $2=35$, belt $3=33$, total $=106$ the species occurring in more than 20\% of the all sample units were presented


Figure 16b. Occurrence Rates -Herbs-

## Abundance of species

Overall shrub cover was $29 \%$ on average (Table 11). Shrub cover was highest in Beltl and there was no significant difference between Belt2 and Belt 3 . Overall herb cover was $44 \%$ on average. Herb cover slightly decreased with increasing distance from stream although there was no significant difference among belt types. Most understory species cover were less than $5 \%$ with only four of 84 species ( 2 shrubs and 2 herbs) exceeding mean cover values greater than 5\% (Table 12, Figure 17).

Although it was difficult to find decreasing or increasing patterns of very frequent species such as oxalis and sword fern with occurrence rates, their mean percent cover described decreasing or increasing patterns of their abundance well (Table 12, Figure 17). Salmonberry and oxalis decreased with increasing distance from the stream while sword fern increased (Figure 18). Vine maple seemed to be independent of distance from the stream (Figure 18).

Table 11. Total Percent Cover

|  | overall | belt1 | belt2 | belt3 |
| :--- | ---: | ---: | ---: | ---: |
| Shrubs | $29.1(2.4)$ | $37(4.6)$ | $23.9(3.8)$ | $25,6(3.7)$ |
| Herbs | $43.9(1.5)$ | $45.9(2.7)$ | $43.8(2.5)$ | $41.6(2.4)$ |

Standard error in parentheses
N : belt $1=38$, belt $2=35$, belt $3=33$, total $=106$

Table 12. Mean Percent Cover by species

|  | overall | belt1 | belt2 | belt3 |
| :--- | ---: | ---: | ---: | ---: |
| ACCI | $12.5(1.6)$ | $12.4(2.6)$ | $12(2.7)$ | $13.1(3.1)$ |
| RUSP | $11.1(1.7)$ | $18.8(3.2)$ | $6.9(2.2)$ | $6.6(2.8)$ |
| POMU | $23.9(1.3)$ | $18.2(2)$ | $26.2(2.3)$ | $28(2.3)$ |
| OXALI | $7.1(0.6)$ | $8.9(1.3)$ | $7.3(1)$ | $4.9(0.6)$ |

Standard error in parentheses
Species abundant more than $5 \%$ were presented
N : belt $1=38$, belt $2=35$, belt $3=33$, total $=106$


Figure 17. Mean Percent Cover





- Belt3

Figure 18. Percent Cover vs. Height above stream


Figure 18. Percent Cover vs. Height above stream (continued)

## Community analysis

## Data adjustment

Before Indicator Species Analysis and NMS ordination was conducted on a cover matrix and a basal area matrix, the data were adjusted to reduce the influence of outliers and improve assumptions of homogeneity of variance. The raw cover matrix data were comprised of 106 sample units (belts) x 93 species ( 9 trees, 22 shrubs, and 62 herbs, Table 8). In order to reduce average skewness of species and the coefficient of variation of species totals, 33 species ( 4 trees, 9 shrubs, and 20 herbs) occurring in fewer than $5 \%$ of all sample units were removed. Then percent cover of all species was arcsine squareroot transformed because this transformation is recommended for proportion data to improve heteroscedasticity. Outliers were identified by examining a frequency distribution of average Sorensen distance between sample units, and then 6 sample units were identified as outliers (standard deviation of average distance: $2.14-2.62$ ). I, however, retained them in all analysis because they were not strong outliers and they seemed to be part of the variation of the population. The cover matrix after adjustments was 106 sample units $\times 60$ species. Diversity measure was presented in Table 9 .

The raw basal area matrix was 106 sample units (belts) $\times 7$ species. In order to reduce average skewness of species and the coefficient of variation (CV) of species totals, 2 species that occurred in fewer than $5 \%$ of the total sample units were removed and then basal area of all species was $\log$ transformed after being added 1. Outliers were identified by examining a frequency distribution of average Sorensen distance between sample units. Four sample units were identified as outliers. However, I retained them in all analysis because three of them were not strong outliers (standard deviation of average distance, 2.26-2.88), and the other one was a strong outlier (3.65) but seemed to be part of the variation of the population. The basal area matrix after adjustments was 106 sample units $\times 5$ species.

Indicator Species Analysis was conducted on the basal area matrix and the cover
matrix excluding tree species. NMS ordination was conducted on the cover matrix including tree species.

## Indicator Species Analysis

Indicator Species Analysis was conducted in terms of distance from stream (Table 13). Indicator species ( $p<0.05$ ) for Belt1 included coast boykinia, yellow monkey-flower, salmonberry, and, red alder, all species that are moisture tolerant. Indicator species for Belt3 included western hemlock, red huckleberry, trillium, and dwarf Oregon-grape, generally shade tolerant species occurring in upland conifer forest environments. There was no indicator species for Belt2 likely because of the transition nature of Belt2 between riparian and upland environments.

Indicator values were based on both species relative frequency within a group and concentration of abundance in particular groups. Coast boykinia greatest in Indicator Value for Belt1 was present in $71 \%$ of all sample units in Belt1 while $8 \%$ in Belt2 and $6 \%$ in Belt3. Eighty-six percent of species total abundance was concentrated in Belt1 but only $9 \%$ in Belt2 and $6 \%$ in Belt3. Therefore, Indicator Value of coast boykinia for Belt1 was significantly higher than that for other belts. Small-leaved montia (Claytonia parviflora) and American brooklime (Veronica americana) had relatively smaller Indicator Value among indicator species for Belt1, but they were strong indicator species for Belt1. Eighty-six and eighty-one percent of their total abundance were concentrated in Belt1, respectively, but they were present only $21 \%$ of all sample units in Belt1. Low frequencies in Belt1 reduced their Indicator Values, but high concentration in Belt1 kept their significance. Conversely, oxalis had a relatively greater Indicator Value among indicator species for Belt1 but was a weak indicator species for Belt1 because their relative abundance and frequency were great in Belt1 but also great in Belt2 and Belt3. Similarly, sword fern had the second highest Indicator Value
for Belt3 but was a weak indicator species for Belt3. Sword ferm would be expected to occur everywhere in the study area but the possibility to occur in Belt 3 would be slightly greater.

Table 13. Indicator Species Analysis by Belt Types

| Belt | Cord | Common name |  | Scientific name | IV | Mean IV (SD) |
| :--- | :--- | :--- | :--- | ---: | ---: | ---: | p-value

IV: Observed Indicator Value
$p$-value: $p=(1+$ number of runs>=observed)/( $1+$ number of randomized runs)
Mean IV (SD): Mean Indicator Values from randomized groups and standard deviation

Indicator Species Analysis was also conducted in terms of channel-reach morphologies (Table 14). A few species were selected as indicator species ( $\mathrm{p}<0.05$ ) and there were no indicator species for Bedrock reaches. Western redcedar was an indicator species for Cascade reaches, Salmonberry for Step-Pool reaches, and stink currant for Pool-Riffle reaches although their significance was relatively low.

Table 14. Indicator Species Analysis by channel-reach morphologies

| Reach type Cord | Common name | Scientific name | IV |  | Mean IV (SD) | p-value |
| :--- | :--- | :--- | ---: | ---: | ---: | ---: |
| Bedrock |  | No indicator species |  |  |  |  |
| Cascade | THPL | western redcedar | Thuja plicata | 36 | $17.6(7.0)$ | 0.026 |
| Pool-Riffe | RIBR | stink currant | Ribes bracteosum | 38 | $24.4(6.3)$ | 0.037 |
| Step-Pool | RUSP | salmonbery | Rubus spectabilis | 36.4 | $30.5(3.1)$ | 0.038 |
| IV: Observed Indicator Value |  |  |  |  |  |  |
| p-value: $p=(1+$ number of runs>=observed)/(1+number of randomized runs) |  |  |  |  |  |  |
| Mean IV (SD): Mean Indicator Values from randomized groups and standard deviation |  |  |  |  |  |  |

## NMS ordination

Results of NMS ordination revealed that riparian vegetation differed strongly among belt types and the strongest axis was almost equally correlated to both distance from stream and height above summer low flow (Figure 19, Figure 20). Species correlated to NMS axes implied that moisture tolerance was an important factor to describe distribution of riparian vegetation.

A 3-dimensional representation was chosen by NMS Autopilot in PC-ORD. It provided a stable solution with a statistically significant reduction in stress as compared to the randomized data (final stress $=13.56$, final instability with 148 iterations $=0.00001$ ). Site and belt attributes were represented in Table 15. After rotating to load the variable with the highest correlation, HEIGHT, onto Axis1, the three axes represented $86.8 \%$ of the plant community variation. Axis1, 2, 3 represented $56.1 \%, 14.9 \%$, and $15.8 \%$ of the variation, respectively (Table 16).

Axis1 representing a strong moisture gradient from streamside to hillslope was positively correlated to species abundant in upland conifer environments such as western hemlock, trillium, sword fern, red huckleberry, and Douglas-fir, and negatively correlated to mesic species; red alder, saxifrage family, and salmonberry (Table 16). HEIGHT ( $r=0.67$ ) and DISTANCE $(\mathrm{r}=0.62)$ were positively correlated to Axis1. Other variables were not highly correlated to Axis1 (Table 17). Plant associations of Western Hemlock Series shift along Axis1 from the western hemlock/salmonberry association, to the western hemlock/salmonberry-vine maple association, to the western hemlock/vine maple/sword fern association, to the western hemlock/sword fern association (Figure 20a). A small group of the western hemlock/Oregon oxalis association was located in the center of Axisl and the western hemlock/dwarf Oregon grape association at high values on Axis1. According to results of the


Axis 1
Figure 19a. Ordination on Plant Cover (Axis1-Axis2)


Axis 1
Figure 19b. Ordination on Plant Cover (Axis1-Axis3)

Table 15. Site and Belt Attributes

| $\begin{aligned} & \stackrel{y}{0} \\ & \stackrel{y}{i n} \end{aligned}$ | ASPECT | aspect to the stream (degree) |
| :---: | :---: | :---: |
|  | HEATLOAD | (cosine( $45-$ ASPECT) +1 )/2 |
|  | ELEVATION | elevation above sea level (meters) |
|  | HEADWATER | distance from the headwaters (meters) |
|  | ORDER | stream order |
|  | ROAD | 1 indicates sites on the road side, 0 on the other side |
|  | REACH TYPE | types of channel reach morphology |
| $\frac{9}{0}$ | DISTANCE | distance from the stream (meters) |
|  | HEIGHT | height above summer low flow (meters) |
|  | SLOPE | average slope of three sub-plots in a belt |
|  | ASPECT_B | average aspect of running water in sub-plots in a belt |
|  | HEATLOAD B | (cosine(45-ASPECT_B)+1)/2 |

Table 16. Statistics from NMS, MRPP, and MRBP

| NMS | Total variance | 86.8 |
| :--- | :--- | ---: |
|  | Axis1 | 56.1 |
|  | Axis2 | 14.9 |
|  | Axis3 | 15.8 |
| MRBP by belt types | A-statistic | 0.081 |
|  | p-value | $<10^{\wedge}-19$ |
| MRPP by reach types | A-statistic | 0.011 |
|  | p-value | 0.17 |

Table 17. Correlation with NMS Axes

|  | Axis1 |  | Axis2 |  | Axis3 |  |
| :--- | ---: | ---: | ---: | ---: | ---: | ---: |
|  | $r$ | r-sq | $r$ | $r$-sq | $r$ | $r$-sq |
| HEIGHT | 0.672 | 0.451 | -0.05 | 0.002 | -0.034 | 0.001 |
| DISTANCE | 0.622 | 0.387 | -0.051 | 0.003 | -0.075 | 0.006 |
| SLOPE | 0.405 | 0.164 | 0.001 | 0 | -0.063 | 0.004 |
| HEATLOAD_B | -0.005 | 0 | -0.011 | 0 | 0.007 | 0 |
| HEATLOAD | -0.025 | 0.001 | -0.107 | 0.011 | -0.108 | 0.012 |
| ELEVATION | 0.04 | 0.002 | -0.133 | 0.018 | 0.133 | 0.018 |
| HEADWATER | -0.033 | 0.001 | 0.156 | 0.024 | -0.09 | 0.008 |
| ORDER | -0.024 | 0.001 | 0.004 | 0 | -0.196 | 0.038 |

Peason and Kendall correlation with ordination axes, $\mathrm{N}=106$
Attributes are explained in Table15

Table 18. Correlation with NMS Axes

| Axis 1 |  | Axis2 |  | Axis 3 |  |
| :---: | :---: | :---: | :---: | :---: | :---: |
| TSHE | 0.69 | ACCI | 0.69 | ACMA3 |  |
| TRILL | 0.63 | OXALI | 0.41 | HYTE | 0.41 |
| POMU | 0.44 | RUSP | 0.38 | GALIU | 0.37 |
| VAPA | 0.39 | THPL | 0.33 | Saxifrag | 0.31 |
| PSME | 0.37 | ATFI | 0.32 | RUSP | 0.29 |
| THPL | 0.36 | ADAL | 0.26 | ADAL | 0.26 |
| VAHE | 0.32 | STREP3 | 0.23 | Poacea | 0.24 |
| LIBO3 | 0.30 | POMU | 0.19 | CIAL | 0.23 |
| TRLA6 | 0.28 | MAOR3 | 0.17 | STCA | 0.21 |
| BENE2 | 0.28 | OESA | 0.16 | CLSI2 | 0.20 |
| ANDE3 | 0.27 | OECE | 0.16 | RIBR | 020 |
| DISPO | 0.24 | SARAP | 0.15 | OXALI | 0.19 |
| VIOLA | 0.24 | CHGL5 | 0.15 | ATFI | 0.19 |
| ACMA 3 | 0.23 | Saxifrag | 0.10 | OECE | 0.19 |
| ACTR | 0.23 | HYTE | 0.10 | MIGU | 0.19 |
| COCOC | 0.22 | CIAL | 0.07 | SARAP | 0.18 |
| GASH | 0.18 | STCA | 0.05 | MAOR3 | 0.17 |
| ASCA2 | 0.17 | DIFO | 0.05 | DIFO | 0.11 |
| ADBI | 0.15 | BEAQ | 0.04 | STCO14 | 0.09 |
| BEAQ | 0.14 | MIGU | 0.03 | ALRU2 | 0.09 |
| BLSP | 0.10 | CLSI2 | 0.03 | CHGL5 | 0.06 |
| ACCI | 0.09 | GALIU | 0.03 | EQAR | 0.06 |
| ADAL | 0.07 | VEAM2 | -0.01 | OSCH | 0.04 |
| OSCH | 0.06 | SMST | -0.01 | BOEL2 | 0.04 |
| SMST | -0.03 | RIBR | -0.02 | VIGL | 0.03 |
| RUPA | -0.05 | VAOVZ | -0.02 | SMST | 0.02 |
| TITR | -0,05 | ANDE3 | -0.02 | VEAM2 | 0.02 |
| OECE | -0.09 | COCOC | -0.03 | PEPA31 | 0.01 |
| VAOV2 | -0.10 | DISPO | -0.04 | MADI | 0.00 |
| PTAQ | -0.11 | boelz | -0.05 | ClUN2 | -0.03 |
| STREP3 | -0.12 | MADI | -0.05 | ASCA2 | -0.03 |
| RUDI2 | -0.13 | THOC | -0.07 | CLPAP | -0.05 |
| THOC | -0.13 | ALRU2 | -0.07 | POMU | -0.06 |
| CLUN2 | -0.14 | EQAR | -0.08 | THOC | -0.06 |
| MADI | -0.15 | PEPA31 | -0,10 | ACCI | -0.08 |
| DIFO | -0.16 | TSHE | -0.11 | RUDI2 | -0.08 |
| CLPAP | -0.17 | ACTR | -0.11 | RUPA | -0.09 |
| MAOR3 | -0.18 | STCO14 | -0.11 | STREP | -0.09 |
| OESA | -0.20 | BLSP | -0.12 | OESA | -0.10 |
| HYTE | -0.22 | TRILL | -0.12 | DISPO | -0.10 |
| CHGL5 | -0,23 | CLPAP | -0.13 | THPL | -0.11 |
| SARAP | -0.27 | PTAQ | -0.13 | ADBI | -0.11 |
| VEAM2 | -0.29 | RUPA | -0.13 | VAOV2 | -0.14 |
| PEPA31 | -0.32 | Poaceas | -0.13 | PSME | -0.14 |
| RIBR | -0.42 | CLUN2 | -0.15 | TRLA6 | -0.16 |
| OXALI | -0,43 | VAPA | -0.17 | BLSP | -0.16 |
| EQAR | -0.45 | VIGL | -0.17 | ANDE3 | -0.17 |
| boelz | -0.46 | TITR | -0.22 | PTAQ | -0.17 |
| ATFI | -0.49 | ADBI | -0.24 | GASH | -0.17 |
| VIGL | -0.51 | LIBO3 | -0.26 | VAHE | -0.18 |
| CLSI2 | -0.52 | ACMA3 | -0.28 | ACTR | -0.18 |
| GALIU | -0.62 | GASH | -0.28 | BENE2 | -0.19 |
| CIAL | -0.63 | ASCA2 | -0.31 | COCOC | -0.19 |
| migu | -0.64 | VIOLA | -0.33 | BEAQ | -0.22 |
| STCO14 | -0.67 | BENE2 | -0,40 | TRILL | -0.23 |
| STCA | -0.69 | VAHE | -0.41 | VIola | -0.28 |
| RUSP | -0.71 | OSCH | -0.42 | VAPA | -0.32 |
| Poaceae | -0.71 | PSME | -0.42 | TITR | -0.36 |
| Saxifrag | -0.73 | RUDI2 | -0.43 | LIBO3 | -0.44 |
| ALRU2 | -0.87 | TRLA6 | -0.49 | TSHE | -0.67 |

Pearson and Kendall correlations with ordination axes, $\mathrm{N}=106$ Plant cords: see Table8


## Axis 1

Plant Associeation
-
TSHE/BENE
TSHE/OXOR

- TSHE/RHMA-GASH
- TSHE/RUSP

TSHE/RUSP-ACCI
TSHE/POMU
TSHE/ACCI/POMU

Figure 20a. Ordination on Cover (Axis1-Axis2) Overlaid by Plant Association


Axis 1

Plant Associeation
TSHE/BENE TSHEJOXOR TSHE/RHMA-GASH - TSHE/RUSP

TSHE/RUSP-ACCI

- TSHE/POMU TSHE/ACCI/POMU

Figure 20b. Ordination on Cover (Axis1-Axis3) Overlaid by Plant Association
plant covers (Table 10, Figure 16), the species positively correlated to Axisl tended to be more frequent as the distance from stream increased and the species negatively correlated to Axisl tended to be less frequent. The species not correlated to Axisl such as vine maple, deer fern (Blechnum spicant), foam flower (Tiarella trifoliata), and bleeding heart (Dicentra formosa) varied little in occurrence rate with increasing distance from stream.

Axis2 was dominated by the abundance of vine maple (Acer circinatum) (Table 18), and variables of the physical site characteristics showed no relationship with Axis2 (Table 17). Plant associations shift along Axis2 from the western hemlock/dwarf Oregon grape association to the western hemlock/sword fern association, the western hemlock/salmonberry association, and the western hemlock/Oregon oxalis association, to the western hemlock/vine maple/sword fern association and the western hemlock/salmonberry-vine maple association (Figure 20a).

Axis3 represented a closed canopy forest gradient from conifers to hardwoods (Table 18). Between western hemlock and bigleaf maple, overstory species were arranged from Douglas-fir, western redcedar, to red alder according to correlation with Axis3. In Belt3 of Site15 and Belt2 of Site30, highest on Axis3, bigleaf maple was most abundant (basal area 68 and $48 \mathrm{~m}^{2} /$ ha, respectively). In Belt 3 of Sitel5, Salmonberry cover value was $58 \%$ in spite of being in Belt3. The western hemlock/rhododendron-salal association was located lowest on Axis3 and the western hemlock/salmonberry association located middle to high while other plant associations spread low to high along Axis3 (Figure 20b). There was no strong correlation between any site and belt variables and Axis3 (Table 17).

MRBP with sites as blocks and belts as treatments estimated that there were significant differences among belt types $\left(\mathrm{A}=0.018, \mathrm{p}<10^{-9}\right)$. In NMS ordination, belt types did not clearly separate sample units. However, most of the sample units of BeltI occupied the
area low on Axis1 and most of the sample units of Belt 3 occupied the area high on Axis1 although the sample units of Belt2 overlapped with Belt1 and Belt3 (Figure 19a, b).

Riparian vegetation varied little among reach types. Results of MRPP on overstory basal area of Belt1 estimated there were weak differences among reach types ( $\mathrm{A}=0.049$, $\mathrm{p}=0.04$, Table 16); while MRPP on plant cover of Belt1 indicated that there was no difference ( $\mathrm{A}=0.011, \mathrm{p}=0.17$ ).

We acknowledged the lack of independence of three belt transects within each site. They were, however, treated as if they were independent each other in NMS ordination analyses due to analysis tools available at present. The data were additionally analyzed on each of Belt1, Belt2, and Belt3 to describe characteristics of each belt (Appendix A). Within each belt, sample units were independent each other because sample site were randomly selected.

## DISCUSSION

The objective of this study was to describe variation of riparian vegetation in an Oregon Coast Range system according to geomorphic characteristics and in relation to streamflow. Results of this study apply only to this study area and they should not be extrapolated outside of the study area. However, there are several studies of riparian vegetation conducted in the Oregon Coast Range (Hibbs and Giordano 1996, Pabst and Spies 1998, 1999, Nierenberg and Hibbs 2000, Barker et al. 2002) and it is valuable to discuss similarities and dissimilarities among these studies.

## Vegetation Patterns with distance from Stream

Headwater streams (orders 1-3) like upper Camp Creek where this study was conducted are influenced more strongly by the riparian vegetation than streams lower in the drainage. In headwater streams, riparian forests shade the stream and provide nearly all of the food for the aquatic community by dropping leaves, branches, and insects into the stream (Klapproth and Johnson 2000). As stream size increases, importance of terrestrial organic input reduces and autochthonous primary production and organic transport from upstream is enhanced (Vannote et al. 1980).

It is important to describe vegetation patterns from streamside to upland especially in headwater streams. The timing and quality of food resources of aquatic systems depends on species composition of riparian vegetation. For example, decomposition of large woody debris from the dominant coniferous species in the Oregon Coast Range is slower than that of LWD from common riparian deciduous species (Harmon et al. 1986, Sedell et al. 1974) and deciduous trees seasonally shade streams, moderating water temperatures. I describe vegetation patterns of each species as well as patterns by conifers and hardwoods.

## Hardwoods

Results of this study indicated that two hardwood species showed different patterns with increasing distance from stream; red alder decreased in density and basal area while bigleaf maple density was uniform and basal area increased with increasing distance from stream. Since red alder basal area decreased more rapidly than that of bigleaf maple increased, total hardwood basal area resulted in showing a moderately decreasing pattern. By grouping those two species, distinctiveness of their patterns will be overlooked. Pabst and Spies (1999) found that total hardwood basal areas was relatively constant compared with that of conifers, but there was no information about basal area of each hardwood species. Minore and Weatherly (1994) found that total hardwood basal area did not differ significantly with distance from the stream. Each species, however, showed a different pattern; red alder decreased at 15 m from the stream while bigleaf maple was constant. Nierenberg and Hibbs (2000) found that red alder were more frequently present in terraces than in slopes but bigleaf maple showed the contrary pattern. Barker et al (2002) found that Importance Value Index (IVI), which was the summation of tree relative density, relative frequency and relative basal area, for red alder decreased from floodplain to terrace to transitional slope, but IVI for bigleaf maple was even.

Not only in our study area but also generally in the Oregon Coast Range, red alder and bigleaf maple are likely to show different patterns with increasing distance from stream. It is important to look at patterns of each species. To take an instance of species characteristics, red alder is excellent in nitrogen fixation and its litter contains two to four times as much nitrogen as most other hardwood or coniferous litter contains (Newton et al. 1968). Aquatic invertebrates utilize leaf litter with depending on microbial conditioning and consequently the quality of litter from the riparian zone has a significant impact on dynamics of the stream ecosystem (Swanson et al. 1982). From the point of view of food resources for aquatic
organisms, red alder and bigleaf maple may play different roles in headwater streams. It is important to describe vegetation patterns of each species to understand the influence of riparian vegetation on aquatic ecosystems.

## Conifers

Among coniferous trees, all species show the similar patterns with increasing distance from stream although magnitude and steepness of the values varies to some extent. Western hemlock was greatest in tree density from near stream to further, but its basal area was about equal to or lower than other conifers because of small DBH of current trees. Western redcedar was expected to be more abundant near stream than far from stream because of its tolerance to moist soils and inundation to various degrees. However, western redcedar seemed to be a generalist in this study area because it was not significantly abundant in any belts. Minore and Weatherly (1994) found that western redcedar decreased with increasing distance from the stream, but that Douglas-fir basal area at 15 m was as much as $150 \%$ of that at 10 m and $230 \%$ of that at 5 m and western hemlock and Pacific yew also increased. The rapid increase of Douglas-fir was consistent with the result of our study, but the decreasing pattern of western redcedar was not. Nierenberg and Hibbs (2000) found that Douglas-fir and western redcedar occurred on slopes about twice as often as on terraces, and western hemlock grew on slopes more than twice as often as on terraces. Importance Value Index of both Douglas-fir and western hemlock increased from floodplain to transition slope but there was no information about IVI for western redcedar because western redcedar was not the most dominant species in Oregon Coast Range (Barker et al. 2002). Given that terraces were closer to the stream than slopes were, our study indicated the same results that all coniferous species increase with distance from stream and western hemlock was the most frequent species among conifers.

In the Oregon Coast Range, Sitka spruce (Picea sitchensis) and Port-Orford-cedar (Chamaecyparis lawsoniana) are also common species (Pabst and Spies 1999) but they were not present in our study area because of geography of the study site. Sitka spruce zone stretches the length of Washington and Oregon's coast and it is generally only a few kilometers in width while Port-Orford-cedar is commonly found in southwestern Oregon and northwestern California.

## Major Vegetation Gradients

The results of NMS ordination implied that there were three gradients describing variation of riparian plant community; a strong moisture gradient from streamside to hillslope, a closed canopy forest gradients from conifers to hardwoods, and a vine maple gradient. Pabst and Spies (1998) hypothesized that there were five major factors within this trans-riparian gradient that influence vegetation patterns of shrub and herbs in riparian forests: 1) hillslope processes and associated moisture gradients; 2) hydrological disturbance; 3) tolerance of saturated, valley-floor soils; 4) shade tolerance; and 5) mineral soil disturbance. Of the five factors, hillslope processes and associated moisture gradients was consistent with the inferred moisture gradient of this study. Hydrological disturbance and tolerance of saturated, valleyfloor soils were likely included in the inferred moisture gradient slightly, but not as strong as to be extracted.

Species heavily correlated to Axisl of the NMS ordination imply that moisture tolerance differentiated distribution of riparian vegetation. Mesic species positively correlated to Axis1 included red alder, salmonberry, Cooley's hedge-nettle (Stachys cooleyae), yellow monkey-flower, and coast boykinia. Coast boykinia is usually abundant in stream banks, moist mossy rocks and moist forest. Cooley's hedge nettle appears along moist roadside, clearings thickets and open woods. Yellow monkey-flower is abundant on wet ledges, weeping rock
faces, on gravel bars, and along streams (Alaback et al. 1994). Species negatively correlated to Axisl including western hemlock, trillium, sword fern, red huckleberry, Douglas-fir, westem redcedar implied upland conifer forests with understory species shade tolerant but less moisture tolerant. We, therefore, inferred that Axis1 represented a moisture gradient from streamside to hillslope.

Axis 2 of the NMS ordination was dominated by vine maple. In this study, vine maple was independent of both distance from the stream, and height above summer low flow. However Pabst and Spies (1998) found that vine maple was associated with distance from stream, and height above summer low flow high as well as conifer tree cover, and slope.

The species negatively correlated to Axis 3 such as twinflower (Linnaea borealis), foamflower (Tiarella trifoliata), or red huckleberry (Vaccinium parvifolium) were shade tolerant species occurring under dense conifer forests. Red huckleberry is usually abundant in soils rich in decaying wood, often on stumps or logs in coniferous forests. Trillium and dwarf Oregon-grape are shade tolerant and occur in closed forests. Most understory species positively correlated to Axis 3 are associated to hardwood forests while understory species negatively correlated to Axis3 are associated to coniferous forests. Therefore, Axis3 implied a closed canopy forest gradients from conifers to hardwoods although it was difficult to interpret Axis 3 with underlying environment factors.

## Plant association

Tall shrubs such as salmonberry, vine maple, sword fern, and dwarf Oregon grape seemed to be important components of riparian vegetation. According to plant association (Hemstrom and Logan 1986), salmonberry dominates well-watered sites with red alder while sword fern occupies well-drained sites on hillslope with western hemlock, dwarf Oregon grape occurs in well-drained sites on south- and west-facing hillslope with Douglas-fir, and vine
maple occurs in warmer site than salmonberry or sword fern dominated. Pabst and Spies (1998) hypothesized two major organizing factors; colonizing ability following disturbance, and shade tolerance, and they concluded that those factors led to two habitats: disturbed, productive valley floors with dense canopies of growing shrubs; and relatively undisturbed, productive hillslope with dense, conifer canopies. The former seemed to be coincident with the western hemlock/salmonberry association, and the latter with the western hemlock/sword fern association. Besides those factors, warmer environments seemed to lead the western hemlock/salmonberry-vine maple association and the western hemlock/vine maple/sword fern association.

## Large Woody Debris

Large woody debris from riparian vegetation performs important roles both biologically and physically in small and intermediate-sized mountain streams in the Pacific Northwest. LWD may be the principal factor in determining characteristics of aquatic habitats and those streams are primarily shaped by external factors including LWD, channel stabilization by riparian vegetation, hillslope erosion processes (Swanson et al. 1982). In our study area, overstory vegetation in $30 \%$ of all sample units near stream was dominated by deciduous trees. The floodplains dominated by red alder at the expense of coniferous species may limit future recruitment of preferred LWD into stream (Nierenberg and Hibbs 2000). However, as Spies et al (2002) suggesting that the role of hardwoods in riparian area is often underappreciated with today's emphasis on growing large coniferous species for instream structure, preferred balances between deciduous and coniferous species should be given more careful consideration to according to management purposes. Trees growing at a distance of 10 m from the stream channel have a 0.2 probability to contribute large wood to the stream when they fall randomly. A tree growing on the bankfull channel has a probability of 0.5 of
falling into the stream channel (Robinson and Beschta 1990). In terms of contribution to LWD, species composition of riparian forest near stream is more important than further away from the stream. In the study area, unconfined riparian areas near stream tended to be dominated by red alder while western hemlock was abundant in riparian areas higher than average height above summer low flow. Sites that are conifer-dominated may indicate high potential for LWD inputs to stream.

## Channel-Reach Morphology and Riparian Vegetation

Because riparian areas encompass the interaction between the active stream and stable terrestrial environments, geomorphology would be a logical integrator between these linked systems. Geomorphology defines the physical template of the stream in relation to surrounding landform. Choosing the correct temporal and spatial scale for these observation is challenging, but critical to understanding riparian-stream dynamics. The focus of this study was on a reach-scale classification based on stream configuration containing pools, riffles, boulders, as well as gradient and constrained character of stream. Pool-Riffle reaches in general were the least constrained reaches encountered in the study area, while Cascade reaches had the highest gradient, and theoretically should be the most constrained. Step-Pool and Bedrock reaches fall between Pool-Riffle and Cascade in constraining stream flow. Interpreting plant species distribution in relation to reach morphology was quite challenging. Realizing that reaches are quite variable within a given classification, a few vegetation patterns emerged that deserve consideration.

Red alder dominated all reach types, but was significantly more abundant in Step-Pool reaches compared with Cascade and Pool-Riffle. I expected that red alder and salmonberry, species most responsive to fluvial disturbance to be highest in the most unconstrained reaches, primarily in Pool-Riffle. Instead, stink currant was most associated with Pool-Riffle reaches,
and red alder and salmonberry dominated Step-Pool reaches, more intermediate in channel constraint. In general, riparian areas of Step-Pool reaches had lower heights than those of Pool-Riffle reaches, possibly resulting in increased seasonal flooding of sites.

Western hemlock was most abundant in Bedrock reaches. Since Bedrock reaches lacked a contiguous alluvial bed and were confined by valley walls, boundaries between bed and banks were more distinct than other reaches. Although mean height above summer low flow of streamside samples in Bedrock reaches was not significantly high, sharp drops of banks adjacent to the stream in Bedrock reaches were observed in the field and the sharp drops of the banks might be associated to less fluvial disturbance, which would contribute to western hemlock abundance.

Western redcedar was more abundant in Cascade reaches compared to all other reaches. Cascade reaches were located closer to headwaters than other reaches. Therefore, stream width would be narrower and valley would be most confined. Though western redcedar occurs along a wide moisture gradient, it is worth considering if geomorphic conditions contribute to western redcedar abundance.

While patterns between vegetation and channel-reach morphology emerged, they were admittedly weak. Conclusions regarding relationships between reach morphology classification and vegetation from this study are tentative, and bear further investigation. Limitations of the current study to answer geomorphic questions include; 1) random location of vegetation sample sites within a reach, instead of sampling a specific geomorphic configuration, 2) inference is limited to the upper reaches of Camp Creek and does not span the entire range of geomorphic conditions, and finally 3) the reach level scale alone may be inappropriate for examining relationships between the stream and terrestrial environment.

Relationships between geomorphology and riparian vegetation may be best integrated at multiple scales, combining finer and coarser scale information. For instance, relationships
between substrate and riparian species composition are used in riparian classification systems. Valley width and configuration is used at a coarser scale to define reach type classifications (Montgomery and Buffington 1997). These variables may add increased understanding to analysis of vegetation patterns and local scale geomorphology.

For instance, sites may be selected where characteristics of each channel-reach morphology are represented well, or to classify reaches at a finer scale. Length of reaches in this study was long available ranging from 123 to 914 meters. Sample sites did not necessarily represent characteristics of each channel-reach morphology especially in the longer reaches. The study area was located in second and third order stream and the elevation above sea level ranged from 175 to 306 meters, and stream widths were generally narrow with fairly steep banks. Recommendations for future work include extending the study area into the lower reaches of a stream to encompass a wider range of geomorphic condition and establishing sample sites with considering topographical changes (Pabst and Spies 1998, 1999, Nierenberg and Hibbs 2000).

## Management Implications

In the study area, mesic riparian environments frequently disturbed by fluvial process seemed to extend to 20 meters from streamside, and upland conifer environment become distinct after 20 meters. The entire study area is protected as Riparian Reserves under the Northwest Forest Plan since the study area is owned by BLM. Cutting of trees is limited to treatment of forest stands to maintain suitable habitat conditions for fish and aquatic species. The Initial Riparian Reserve widths apply to all watersheds until watershed analysis is completed. Initial Riparian Reserve width on fish-bearing streams consist of the stream and the area on either side of the stream extending from the edges of the active stream channel to the top of the inner gorge, or to the outer edges of the 100-year floodplain, or to the outer edges of riparian vegetation, or to a distance equal to the height of two site-potential trees, or 300 feet slope distance, whichever is greatest. Those federal riparian area requirements are wide enough to cover mesic riparian environment and they are much wider than the state riparian requirements.

If requirements of Riparian Management Areas under the Oregon Forest Practices Act applied to the study area, current Riparian Management Areas would provide buffer zones wide enough to cover mesic riparian environments in terms of protecting distinctive riparian vegetation more biologically and physically diverse. However, in lower reaches where stream width and floodplains becomes wider, 30 meter RMAs may not be sufficient to cover the riparian environments. In the flatter riparian areas adjacent to a stream junction, red alder with dense salmonberry layer extended to 30 meters. Therefore, it may not be efficient to apply a fixed width buffer to entire basin even in headwater streams.

Wenger (1999) mentioned that there was a range of variables that influenced the effectiveness of buffers including slopes of banks, rainfall, soil moisture content, floodplain width, catchment size and vegetation, and illustrated to apply a flexible width buffer with
considering some of those variables. I would recommend to extend RMAs to edge of floodplain for mesic riparian environments to be covered. To achieve more efficient and sufficient watershed management, it is important to take account of landform of riparian forests.

## Suggestion for Further Studies

Only two of the environmental variables sampled, distance from stream and height above summer low flow, were useful to describe variation of riparian vegetation in the study area. Distance from stream, height above summer low flow seemed to be a good surrogate of moisture gradients and they may imply water influences too. A series of plant association implied soil temperature might be one of the factors driving patterns of riparian vegetation. Therefore, sampling soil moisture and temperature would be a next step to describe variation of riparian vegetation deeply.

Besides distance from the stream, geomorphic landform such as floodplain, terrace, and slope was also used as variables in multivariate analysis, for example canonical correspondence analysis (Sagers and Lyon 1997, Lyon and Sagers 2002) and detrended correspondence analysis (Sagers and Lyon 1997, Rot et al. 2000, Lyon and Sagers 2002). Rot et al. (2000) found that riparian vegetation was differentiated by four landform classes; floodplain, terrace, slope, and just above the active channel, floodplain contained more hardwoods than conifers, and conifers dominated other landforms. Although we did not use landform classifications in our study and second and third order streams like our study area seemed to be too small to have wide floodplain and terraces, landform classes might be useful to describe variation of riparian vegetation in lower reaches. Since there are likely some relationships between landform and channel-reach morphology, weak patterns found with regard to channel-reach morphologies might be explained by landforms as well.

Riparian vegetation varies among different areas. Further studies across region and across watersheds are recommended.

In this study, three belt transects were nested in each site but treated as if they are independent in the community analyses except for MRBP. Randomly placed plots without blocking of sites would have added to the variation due to site, reducing our ability to detect the treatment effects of belts. Complete random sampling, however, would take more time and labor than nested designs, and result in fewer samples under limited time and labor. As a sampling strategy, nested, hierarchical designs are logical, efficient and provide a multilayered view of a complex world, but statistical tools for analyzing nested designs are poorly developed (McCune and Grace 2002). A method of nonparametric MANOVA that can accommodate nested designs was devised by Anderson (2001). Although it is a new tool, use of nonparametric MANOVA could give us a good multilayered view of the variation.

## CONCLUSION

Distinct riparian vegetation patterns were observed in upper Camp Creek with increasing distance from stream. Both overstory and understory vegetation quickly changed with increasing distance from stream. Areas within ten meters from stream were characterized as mesic riparian environments while areas twenty meters away from stream were characterized as upland conifer forest environments. Vegetation composition was ordered along an inferred moisture gradient from streamside to hillslope, and distance from stream and height above summer low flow were almost equally correlated to the gradient. Tall shrubs including salmonberry, sword fern and vine maple are important component of riparian vegetation. Channel-reach morphology little differentiated riparian vegetation. A few species were significantly abundant in specific reaches. However, results of this study about relationships between channel-reach morphology and riparian vegetation were inconclusive.

Riparian buffer zones are increasingly recognized as important watershed management tools and requirements for the riparian buffers must be based on scientific evidences to achieve management purposes. Baseline information to characterize the composition and structure of riparian forests was still needed, and research focusing on linkage between characteristics of channel morphology and riparian vegetation is necessary to facilitate better watershed management.

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## Appendix A: NMS Ordination of Cover Matrix of Each Belt

1) Results of NMS ordination on cover matrix of Belt1 gave a 3-dimensional representation. The three axes represented $85 \%$ of the plant community variation. Axis1, 2, and 3 represented $44 \%, 18 \%$, and $24 \%$ of the variation, respectively (Table A1). HEIGHT was strongly correlated to Axis1 $(\mathrm{r}=0.66)$ (Table A2), Axis1 was positively correlated to western hemlock and negatively correlated to mesic species; red alder, galium, grass family, and Enchanter's-nightshade (Table A3).

Table A1. Statistics from NMS and MRPP on Belt

|  |  | Belt1 |
| :--- | :--- | ---: |
| NMS | Total variance | 0.85 |
|  | Axis1 | 0.44 |
|  | Axis2 | 0.18 |
|  | Axis3 | 0.24 |
| MRPP by reach types | A-statistic | 0.011 |
|  | p-value | 0.17 |

Table A2. Correlation of Variables with NMS on Belt 1

|  | Axis1 |  | Axis2 |  | Axis3 |  |
| :--- | ---: | ---: | ---: | ---: | ---: | ---: |
|  | $r$ | -sq | $r$ | $r$-sq | $r$ | $r$-sq |
| HEIGHT | 0.656 | 0.43 | 0.001 | 0 | 0.099 | 0.01 |
| DISTANCE | - | - | - | - | - | - |
| SLOPE | 0.185 | 0.034 | -0.083 | 0.007 | 0.335 | 0.113 |
| HEATLOAD B | 0.285 | 0.081 | 0.234 | 0.055 | 0.142 | 0.02 |
| HEATLOAD | -0.078 | 0.006 | 0.159 | 0.025 | -0.103 | 0.011 |
| ELEVATION | -0.255 | 0.065 | -0.028 | 0.001 | 0.295 | 0.087 |
| HEADWATER | 0.273 | 0.075 | -0.024 | 0.001 | -0.273 | 0.074 |
| ORDER | 0.181 | 0.033 | 0.206 | 0.042 | -0.209 | 0.044 |
| ACMA3 | -0.216 | 0.047 | 0.063 | 0.004 | 0.523 | 0.274 |
| ALRU2 | -0.594 | 0.353 | -0.34 | 0.116 | -0.596 | 0.355 |
| PSME | 0.189 | 0.036 | 0.326 | 0.107 | 0.21 | 0.044 |
| THPL | 0.431 | 0.186 | -0.204 | 0.042 | -0.145 | 0.021 |
| TSHE | 0.507 | 0.257 | 0.54 | 0.291 | 0.636 | 0.405 |

Peason and Kendall correlation with ordination axes, $\mathrm{n}=38$
Attributes are explained in Table15

Table A3. Correlation of Species with NMS on Belt 1

| Axis1 |  | Axis2 |  | Axis3 |  |
| :---: | :---: | :---: | :---: | :---: | :---: |
| TSHE | 0.66 | RUDI2 | 0.68 | TSHE | 0.66 |
| ACCI | 0,46 | TSHE | 0.57 | ACMA3 | 0.49 |
| COCOC | 0.44 | LIBO3 | 0.52 | TRILL | 0.46 |
| TRLA6 | 0.42 | EQAR | 0.35 | BLSP | 0.44 |
| POMU | 0.42 | TITR | 035 | OSCH | 0.36 |
| ADBI | 0.41 | PTAQ | 0.35 | VAHE | 0.35 |
| TRILL | 0.38 | BENE2 | 0.32 | ADAL | 0.35 |
| THPL | 0.37 | STCO14 | 0.32 | CHGL 5 | 0.32 |
| LibO3 | 0.35 | OSCH | 0.30 | BOEL2 | 0.29 |
| PSME | 0.34 | CLPAP | 0.30 | GASH | 0.29 |
| PTAQ | 0.34 | VAHE | 0.29 | BENE2 | 0.25 |
| OESA | 0.27 | TRILL | 0.28 | STREP3 | 0.23 |
| VAHE | 0.26 | CLUN2 | 0.25 | LIBO3 | 0.21 |
| VAPA | 0.25 | VEAM2 | 0.24 | MIGU | 0.17 |
| BEAQ | 0.23 | PEPA 31 | 0.23 | VEAM2 | 0.16 |
| BENE2 | 0.16 | GASH | 0.20 | VAOV2 | 0.15 |
| THOC | 0.16 | TRLA6 | 0.20 | VAPA | 0.14 |
| RUDI2 | 0.15 | MADI | 0.17 | MADI | 0.14 |
| CLPAP | 0.09 | VIGL | 0.12 | TITR | 0.12 |
| GASH | 0.08 | Poaceae | 0.11 | ADBI | 0.12 |
| CHGL5 | 0.08 | BEAQ | 0.11 | ATFI | 0.11 |
| DISPO | 0.05 | SARAP | 0.09 | ANDE3 | 0.09 |
| ANDE3 | 0.04 | ADBI | 009 | ACTR | 0.09 |
| ACTR | 0.04 | COCOC | 0.09 | TRLA6 | 0.07 |
| MADI | 0.03 | VAPA | 0.07 | PSME | 0.07 |
| STREP3 | 0.01 | BLSP | 0.05 | HYTE | 0.06 |
| OSCH | 0.00 | PSME | 0.05 | CLUN2 | 0.05 |
| CLUN2 | -0.01 | VAOV2 | 0.04 | VIOLA | 0.05 |
| OECE | -0.01 | ACMA3 | 0.04 | ACCI | 0.04 |
| VIGL | -0.04 | BOEL2 | 0.02 | EQAR | 0.03 |
| SMST | -0.06 | POMU | 0.01 | CLPAP | 0.03 |
| DIFO | -0.06 | ANDE3 | 0.01 | PEPA31 | 0.02 |
| VEAM2 | -0.07 | ACTR | 0.01 | RUDI2 | 0.01 |
| ADAL | -0.09 | RUPA | 0.00 | RIBR | -0.01 |
| VAOV2 | -0.09 | STCA | -0.02 | RUPA | -0.04 |
| STCO14 | -0.10 | MIGU | -0.02 | DISPO | -0.06 |
| VIOLA | -0.16 | RIBR | -0.06 | THOC | -0.06 |
| RUPA | -0.18 | DIFO | -0.08 | COCOC | -0,06 |
| BLSP | -0.18 | THPL | -0.09 | POMU | -0.06 |
| MAOR3 | -0.22 | GALIU | -0.11 | Saxifrag | -0.08 |
| PEPA31 | -0.24 | CLSI2 | -0.11 | PTAQ | -0.11 |
| OXALI | -0.26 | VİLA | -0.13 | OECE | -0.11 |
| SARAP | -0.27 | THOC | -0.14 | OESA | -0.12 |
| TITR | -0.27 | OESA | -0.14 | STCO14 | -0.12 |
| RIBR | -0.29 | HYTE | -0.19 | SMST | -0.16 |
| EQAR | -0.30 | MAOR3 | -0.19 | BEAQ | -0.17 |
| BOEL. 2 | -0.30 | DISPO | -0.20 | MAOR3 | -0.18 |
| RUSP | -0.32 | ALRU2 | -0.23 | GALIU | -0.19 |
| STCA | -0.36 | Saxifrag | -0.25 | THPL | -0.27 |
| ACMA3 | -0.36 | SMST | -0.28 | CIAL | -0.31 |
| CLSI2 | -0.36 | STREP3 | -0,30 | OXALI | -0.32 |
| HYTE | -0.40 | CIAL | -0.33 | STCA | -0.33 |
| Saxifrag | -0.43 | CHGL5 | -0.33 | Poaceae | -0.34 |
| ATFI | -0.45 | OECE | $-0.34$ | VIGL | -0.35 |
| MIGU | -0.47 | ADAL | -0.35 | SARAP | -0.46 |
| CIAL | -0.49 | ATFI | -0,36 | CLSI2 | -0.55 |
| Poaceae | -0.50 | RUSP | -0.48 | DIFO | -0.58 |
| GALIU | -0.53 | OXALI | -0.54 | ALRU2 | -0.70 |
| ALRU2 | -0.71 | ACCI | -0.65 | RUSP | -0.73 |

Pearson and Kendall correlations with ordination axes, $n=38$
Plant cords: see Table8


Axis 1
Figure A1. Ordination on Belt1 (Axis1-Axis2) Overlaid by Plant Association


Axis 1

Figure A2. Ordination on Belt1 (Axis1-Axis3) Overlaid by Plant Association
2) Results of NMS ordination on cover matrix of Belt2 gave a 3-dimensional representation. The three axes represented $92 \%$ of the plant community variation. Axis1, 2, and 3 represented $33 \%, 39 \%$, and $21 \%$ of the variation, respectively (Table A4). HEIGHT was strongly correlated to Axis1 $(\mathrm{r}=0.72)$ (Table A5). Axis1 was positively correlated to trillium and western hemlock, and negatively correlated to red alder, candy flower, Cooley's hedge-nettle, Northern starwort. Axis2 was positively correlated to vine maple, and negatively correlated to Douglas-fir, wild ginger (Asarum caudatum) and western starflower. Axis3 was positively correlated to western hemlock and negatively correlated to bigleaf maple (Table A6).

Table A4. Statistics from NMS and MRPP on Belt2

|  |  | Belt2 |
| :--- | :--- | ---: |
| NMS | Total variance | 0.92 |
|  | Axis1 | 0.33 |
|  | Axis2 | 0.39 |
|  | Axis3 | 0.21 |
| MRPP by reach types | A-statistic | 0.035 |
|  | p-value | 0.15 |

Table A5. Correlation of Variables with NMS on Belt2

|  | Axis1 |  | Axis2 |  | Axis3 |  |
| :--- | ---: | ---: | ---: | ---: | ---: | ---: |
|  | $r$ | $r$-sq | $r$ | $r$ | $r$-sq | $r$ |
| HEIGHT | 0.72 | 0.519 | 0.06 | 0.004 | 0.021 | 0 |
| DISTANCE | - | - | - | - | - | - |
| SLOPE | 0.445 | 0.198 | 0.074 | 0.005 | 0.307 | 0.094 |
| HEATLOAD_B | 0.008 | 0 | -0.337 | 0.113 | -0.066 | 0.004 |
| HEATLOAD | -0.045 | 0.002 | -0.076 | 0.006 | 0.211 | 0.045 |
| ELEVATION | 0.114 | 0.013 | -0.151 | 0.023 | -0.206 | 0.042 |
| HEADWATER | -0.154 | 0.024 | 0.131 | 0.017 | 0.149 | 0.022 |
| ORDER | 0.011 | 0 | 0.123 | 0.015 | 0.308 | 0.095 |
| ACMA3 | 0.314 | 0.098 | -0.124 | 0.015 | -0.295 | 0.087 |
| ALRU2 | -0.826 | 0.682 | -0.301 | 0.091 | -0.079 | 0.006 |
| PSME | 0.405 | 0.164 | -0.242 | 0.058 | 0.09 | 0.008 |
| THPL | 0.406 | 0.165 | 0.375 | 0.141 | 0.103 | 0.011 |
| TSHE | 0.701 | 0.491 | 0.13 | 0.017 | 0.669 | 0.447 |

Peason and Kendall correlation with ordination axes, $n=35$
Attributes are explained in Table15

Table A6. Correlation of Species with NMS on Belt2

| Axis 1 |  | Axis2 |  | Axis3 |  |
| :---: | :---: | :---: | :---: | :---: | :---: |
| TRILL | 0.62 | ACCI | 0.69 | TSHE | 0.78 |
| TSHE | 0.58 | ATFI | 0.54 | LIBO3 | 0.59 |
| THPL | 0.45 | THPL | 0.47 | VAPA | 0.51 |
| ADAL | 0.44 | SARAP | 0.45 | GASH | 0.49 |
| VAPA | 0.39 | VEAM2 | 0.45 | TITR | 0.48 |
| BLSP | 0.39 | POMU | 0.41 | BENE2 | 0.44 |
| DISPO | 0.36 | OXALI | 0.34 | VAOV2 | 0.41 |
| LIBO3 | 0.34 | MAOR3 | 0.33 | TRLA6 | 0.27 |
| VIOLA | 0.33 | STREP3 | 0.33 | PTAQ | 0.25 |
| VAHE | 0.32 | RUSP | 0.31 | VIOLA | 0.24 |
| ANDE3 | 0.31 | TSHE | 0.24 | BLSP | 0.20 |
| PSME | 0.27 | COCOC | 0.21 | ANDE3 | 0.17 |
| SMST | 0.26 | OECE | 0.17 | VAHE | 0.17 |
| COCOC | 0.23 | SMST | 0.14 | TRILL | 0.16 |
| TRLA6 | 0.21 | ANDE3 | 0.13 | SMST | 0.14 |
| ACTR | 0.20 | ADAL | 0.12 | RUPA | 0.13 |
| BEAQ | 0.19 | MADI | 0.09 | PSME | 0.13 |
| CLPAP | 0.15 | OESA | 0.07 | POMU | 0.13 |
| ACCI | 0.15 | VAOV2 | 004 | cococ | 0.13 |
| POMU | 0.15 | TRILL | 0.01 | ACCI | 0.10 |
| OECE | 012 | BEAQ | 0.00 | STREP3 | 0,10 |
| TITR | 0.11 | BLSP | 0.00 | ALRU2 | 0.07 |
| ACMA3 | 0.09 | VAPA | -0.01 | CLUN2 | 0.07 |
| GASH | 0.08 | GASH | $-0.03$ | CHGL 5 | 0.07 |
| BENE2 | 0.04 | STCO14 | -0.06 | BOEL2 | 0.06 |
| VAOV2 | 0.04 | LIBO3 | -0.07 | DISPO | 0.06 |
| ASCA2 | 0.03 | DISPO | -0.07 | OECE | 0.04 |
| STREP3 | 0,00 | DIFO | -0.08 | ACTR | 0.02 |
| PTAQ | -0.03 | TITR | -0,08 | THPL | 0.01 |
| ADBI | -0.03 | CIAL | -009 | MADI | -0.01 |
| VEAM2 | -0,04 | BOEL2 | -0,09 | BEAQ | -0.02 |
| THOC | -0.04 | CLUN2 | -0,09 | OSCH | -0.02 |
| RUDI2 | -0.07 | STCA | -0.09 | DIFO | -0.05 |
| CLUN2 | -0.10 | CHGL5 | -0.09 | EQAR | -0.08 |
| CHGL5 | -0.10 | RIBR | -0.10 | THOC | -0.08 |
| MADI | -0.13 | HYTE | -0.10 | MAOR3 | -0.08 |
| BOEL2 | -0.13 | EQAR | -0.13 | OESA | $-0.10$ |
| OSCH | -0.13 | CLSI2 | -0.14 | VEAM2 | -0.12 |
| OESA | -0.16 | Saxifrag | -0.15 | RUDI2 | -0.12 |
| RUPA | -0.17 | GALIU | -0.17 | ASCA2 | -0.12 |
| MAOR3 | -0.19 | MIGU | -0.18 | VIGL | -0.13 |
| SARAP | -0.21 | ACTR | -0.21 | ADBI | -0.14 |
| DIFO | -0,23 | PTAQ | -0.22 | SARAP | -0.21 |
| ATFI | -0.24 | Poaceae | -0.24 | RUSP | -0.23 |
| RIBR | -0.27 | BENE2 | -0.28 | CLSI2 | -0.24 |
| VIGL | -0.32 | VIOLA | -0.30 | OXALI | -0.24 |
| HYTE | -0.39 | THOC | -0.30 | CLPAP | -0.24 |
| MIGU | -0.40 | RUPA | -0.31 | ATFI | -0.25 |
| OXALI | -0.43 | ALRU2 | -0.31 | MIGU | -0.29 |
| EQAR | -0.49 | CLPAP | -0.36 | RIBR | -0.31 |
| GALIU | -0.52 | ADBI | -0,40 | STCA | -0.32 |
| CIAL | -0.60 | ACMA3 | -0.43 | Poaceae | -0.35 |
| Poaceae | -0.63 | RUDI2 | -0.45 | STCO14 | -0,36 |
| Saxifrag | -0.68 | VIGL | -0.46 | Saxifrag | -0.40 |
| RUSP | -0.68 | VAHE | -0.46 | ADAL | -0.41 |
| STCA | -0.70 | OSCH | -0,47 | CIAL | -0.42 |
| STCO14 | -0.71 | TRLA6 | -0.52 | GALIU | -0.50 |
| CLSI2 | -0.72 | ASCA2 | -0.54 | HYTE | -0.51 |
| ALRU2 | -0.86 | PSME | -0.62 | ACMA3 | -0.77 |

Pearson and Kendall correlations with ordination axes, $\mathrm{n}=35$ Plant cords: see Table8


Axis 1

Figure A3. Ordination on Belt2 (Axis1-Axis2) Overlaid by Plant Association


Axis 1
Figure A4. Ordination on Belt2 (Axis1-Axis3) Overlaid by Plant Association
3) Results of NMS ordination on cover matrix of Belt3 gave a 2-dimentional representation. The two axes represented $74 \%$ of the plant community variation. Axis1, and 2 represented $44 \%$ and $30 \%$ of the variation, respectively (Table A7).

Table A7. Statistics from NMS and MRPP on Belt3

|  |  | Belt3 |
| :--- | :--- | ---: |
| NMS | Total variance | 0.74 |
|  | Axis1 | 0.44 |
|  | Axis2 | 0.3 |
|  | Axis3 | - |
| MRPP by reach types | A-statistic | -0.007 |
|  | p-value | 0.55 |

Table A8. Correlation of Variables with NMS on Belt 3

|  | Axis1 |  | Axis2 |  |
| :--- | ---: | ---: | ---: | ---: |
|  | $r$ | $r$-sq | $r$ | $r$-sq |
| HEIGHT | 0.344 | 0.118 | -0.006 | 0 |
| DISTANCE | - | - | - | - |
| SLOPE | 0.258 | 0.066 | 0.192 | 0.037 |
| HEATLOAD_B | -0.034 | 0.001 | 0.183 | 0.033 |
| HEATLOAD | 0.224 | 0.05 | -0.036 | 0.001 |
| ELEVATION | -0.033 | 0.001 | -0.087 | 0.008 |
| HEADWATER | 0.039 | 0.002 | 0.099 | 0.01 |
| ORDER | 0.041 | 0.002 | 0.072 | 0.005 |
| ACMA3 | 0.273 | 0.075 | 0.566 | 0.321 |
| ALRU2 | -0.535 | 0.286 | -0.035 | 0.001 |
| PSME | 0.188 | 0.035 | -0.309 | 0.096 |
| THPL | -0.1 | 0.01 | -0.029 | 0.001 |
| TSHE | 0.226 | 0.051 | -0.548 | 0.3 |

Peason and Kendall correlation with ordination axes, $n=33$
Attributes are explained in Table15

Table A9. Correlation of Species with NMS on Belt3

| Axis1 |  | Axis2 |  |
| :---: | :---: | :---: | :---: |
| BENE2 | 0.52 | ACMA3 | 0.66 |
| GASH | 0.49 | RUSP | 0.64 |
| VAPA | 0.49 | ATFI | 0.42 |
| RUDI2 | 0.46 | CHGL5 | 0.41 |
| SMST | 0.45 | GALIU | 0.39 |
| ACMA3 | 0.40 | MIGU | 038 |
| VAHE | 0.37 | RIBR | 0.36 |
| PSME | 0.36 | MAOR3 | 0.35 |
| TRLA6 | 0.29 | OECE | 0.34 |
| THOC | 0.28 | VEAM2 | 0.34 |
| TSHE | 0.28 | EQAR | 0.34 |
| OECE | 0.28 | ADAL | 0.32 |
| TRILL | 0.25 | OXALI | 0.31 |
| BLSP | 0.22 | Poaceae | 0.31 |
| ANDE3 | 0,22 | Saxifrag | 0.31 |
| VIOLA | 022 | HYTE | 0.30 |
| LIBO3 | 0.20 | SARAP | 0.24 |
| BOEL2 | 0.20 | STCA | 0.16 |
| RUPA | 0.20 | CLSI2 | 0.14 |
| COCOC | 0.18 | STREP3 | 0.12 |
| POMU | 0.18 | DIFO | 0.12 |
| OSCH | 0.17 | ACCI | 0.10 |
| CLUN2 | 0.16 | POMU | 0.04 |
| MADI | 0.16 | VIGL | 0.02 |
| ACTR | 0.09 | VAOV2 | 0.02 |
| ASCA2 | 0.09 | PTAQ | 0.02 |
| PTAQ | 0.03 | STCO14 | 0.01 |
| MAOR3 | 0.03 | RUPA | -0.01 |
| DISPO | 0.00 | BOEL2 | -0.02 |
| VAOV2 | -0.06 | THPL | -0.07 |
| ADBI | -0.07 | ALRU2 | -0.07 |
| SARAP | .007 | GASH | -0.10 |
| BEAQ | -0 08 | CIAL | -0.13 |
| TITR | -0.09 | SMST | -0.15 |
| VIGL | -0.12 | CLUN2 | -0.16 |
| ADAL | -0.13 | BLSP | -0.16 |
| THPL | -0.14 | DISPO | -0.20 |
| STREP3 | -0.16 | MADI | -0.21 |
| DIFO | -0. 19 | COCOC | -0.21 |
| ACCI | -0.21 | RUDI2 | -0.21 |
| HYTE | -023 | ANDE3 | -0.22 |
| RIBR | -0.27 | OSCH | -0.22 |
| STCO14 | -0.28 | BENE2 | -0.23 |
| GALIU | -0.29 | BEAQ | -026 |
| CHGL5 | -0.45 | ASCA2 | -0.27 |
| Poaceae | -0.46 | THOC | -0.27 |
| ATFI | -0.50 | ACTR | -0.29 |
| MIGU | -0.56 | TRLA6 | -0.30 |
| RUSP | -0.56 | VAHE | -0.37 |
| CIAL | -0.57 | ADBI | -0.38 |
| VEAM2 | -0.57 | VAPA | -0.41 |
| EQAR | -0.57 | PSME | -0.41 |
| STCA | -0.57 | TITR | -0.47 |
| CLSI2 | -0.57 | LIBO3 | -0.49 |
| OXALI | -0.58 | TRILL | -0.53 |
| ALRU2 | -0.58 | VIOLA | -0.57 |
| Saxifrag | -0.69 | TSHE | -0.63 |

Pearson and Kendall correlations with ordination axes, $n=33$
Plant cords. see Table8


Axis 1
Figure A5. Ordination on Belt3 Overlaid by Plant Association


[^0]:    Cord: according to the PLANT data base (USDA NRCS, 2002)
    "*n indicates rare species; species occurred in fewer than $5 \%$ of all sample units

