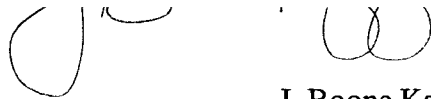


AN ABSTRACT OF THE THESIS OF

Danna J. Lytjen for the degree of Master of Science in Fisheries Science presented on June 10, 1998. Title: Ecology of Woody Riparian Vegetation in Tributaries of the Upper Grande Ronde River Basin, Oregon.

Abstract approved **Redacted for Privacy**



J. Boone Kauffman

Two studies on Catherine Creek and Meadow Creek of the Upper Grande Ronde River basin, quantified several physical and biotic influences on woody riparian community composition and structure. The Catherine Creek study examined the association of woody riparian species with elevational and geomorphic gradients. The Meadow Creek study examined the influence of mammal herbivory on composition and abundance of woody riparian species.

At Catherine Creek, twenty nine plots were established at 50 m intervals of elevation from near the stream origin at 2207 m in the Wallowa Mountains to the foothills of the Grande Ronde Valley at 988 m. Woody plant community composition was associated with the dominant environmental variable, elevation. Distribution of dominant riparian species was strongly associated with fluvial surfaces. Black cottonwood (*Populus balsamifera*) was associated with gravel and cobble bars proximal to the stream channel, and along with ponderosa pine (*Pinus ponderosa*) was also associated with elevated boulder bars. Alders (*A. incana* and *A. viridis*) and willows (*Salix bebbiana*, *S. boothii*, *S. exigua*, *S. lucida*, *S. melanopsis*, *S. prolixa*, and *S. sitchensis*) were associated with annual floodplains.

At Meadow Creek, grazing by cattle was ended in 1991 on the entire study reach and three deer and elk exclosures were built within the reach adjacent to the creek. Inside

deer/elk exclosures from 1991 to 1995, mean heights of tagged cottonwoods, willows, and alders increased by 86% to 180%. Outside exclosures, mean heights of cottonwoods and alders increased 109% and 99% respectively, but willows showed little change in height. Both inside and outside of exclosures mean crown volume of cottonwoods increased over 1000% and mean crown volume of alders increased over 600%. Willow volume inside exclosures increased 376% in root sprouting (clonal) species and 528% in crown sprouting (non-clonal) species, while outside of exclosures volume increased 79% and 144% respectively. On both sides of exclosure fences, beaver herbivory had a significant effect on cottonwood height growth in 1994 and 1995, and on height and crown volume growth of willows in 1995. Over 50% of stem density increase on transects was attributable to expansion within two large clones of *Salix melanopsis* inside exclosures. Excluding these two clones, overall woody plant density increased by 72% from 3.7 plants per 100 m² of transect in 1991 to 6.3 plants per 100 m² of transect in 1995.

Ecology of Woody Riparian Vegetation
in Tributaries of the Upper Grande Ronde River Basin, Oregon

by

Danna J. Lytjen

A THESIS

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Oregon State University

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Danna J. Lytjen, author

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Ecology of Woody Riparian Vegetation in Tributaries of the
Upper Grande Ronde River Basin, Oregon

CHAPTER 1
INTRODUCTION

Woody riparian vegetation is increasingly recognized for its influence on aquatic habitat. The roles vegetation plays in influencing water quality and habitat include temperature modification provided by shading (Meehan et al. 1969, Li et al. 1994), influences of root networks and wood debris on bank morphology and channel complexity (Nanson 1981, Hickin 1984, Clifton 1989), flow resistance which reduces flood energy and allows deposition of fine sediments on the banks and floodplains (Hickin 1984, Clifton 1989, Gregory et al. 1991), and organic inputs to the stream including litter, insects, and modified nutrients from hyporheic flow (Fisher and Likens 1973, McLemore and Meehan 1988, Cummins et al. 1989). Shrubs also provide cover, nesting habitat, and food for small mammals, insects, and birds (Kauffman 1982, Taylor 1986).

As stocks of native anadromous fishes decline in the Pacific Northwest, the quality of headwater rearing and spawning habitat has become a major concern. Although many streams in the Blue Mountains of northeastern Oregon currently lack woody riparian vegetation, historical accounts cite an abundance of willow thickets and cottonwood along streams (Spaulding 1953, Evans 1991). Great numbers of beaver, otter, and anadromous fishes were associated with such reaches (Rich et al. 1950, Spaulding 1953, Evans 1991).

Woody riparian plant species are not only adapted to tolerate, but require flood disturbance for dispersal, establishment, and persistence. Willow (*Salix* spp.) and cottonwood (*Populus* spp.) withstand shearing, scouring, burial, and inundation and recover quickly by sprouting new branches from buried stems and new plants from detached pieces (Sigafos 1964, Everitt 1968, Wilson 1970). Recolonization of scoured

floodplains by riparian plants usually occurs rapidly by vegetative regrowth or seed (Gecy and Wilson 1990). Seeds of riparian plants are often abundant, short lived, borne by water or wind, and mature around the time of the peak hydrograph (Moss 1938, McBride and Strahan 1984). Floods modify surfaces by scouring or depositing sediments (Everitt 1968, Morisawa 1968, Hupp and Osterkamp 1985). Fluvial surfaces created and modified by floods are colonized by different plant species according to surface elevation, substrate particle size, water availability, and the stochastic nature of plant propagule dispersal (McBride and Strahan 1984, Bradley and Smith 1986, Baker 1990).

Biotic disturbance in the form of grazing and browsing may also shape riparian plant community composition. The succulent growth of riparian shrubs is attractive to domestic cattle (*Bos taurus*), elk (*Cervus elaphus*), mule deer (*Odocoileus hemionus*) and beaver (*Castor canadensis*). Meadow-riparian habitat is the most highly preferred habitat of cattle and female mule deer (Roath and Krueger 1982, Loft et al. 1991). The rapid growth response of riparian shrubs, an adaptation to natural fluvial disturbance, gives riparian shrubs some resilience against browsing. However, a decline in stature or loss of riparian woody vegetation structure can result when density of herbivores is such that herbivory continually exceeds current years growth (Hanley and Taber 1980, Schulz and Leininger 1990, Keigley 1997).

With the increasing recognition of the influence of vegetation on water quality and stream morphology (Gregory et al. 1991, Beschta 1995, Kauffman et al. 1997), managers have embarked upon stream rehabilitation projects that include attempts to revegetate riparian areas. Planning and executing appropriate projects depend upon the ability to recognize the existing condition and site potential and to integrate natural processes as part of the recovery process. Understanding plant distribution in relation to the dynamic environments of riparian zones will help insure success of restoration projects.

This thesis summarizes two studies in the upper Grande Ronde River Basin of northeastern Oregon that explore the relationships of woody riparian vegetation and its environment. The first, on Catherine Creek in the Wallowa Mountains, investigates distribution and abundance of woody riparian species on a longitudinal elevation gradient and on a lateral geomorphic gradient from the headwaters at 2200 m to the foothills of the

Grande Ronde Valley at 988 m. The objectives of the study were: (1) quantify occurrence and abundance of woody riparian species along gradients of elevation, stream order, and stream gradient; (2) quantify occurrence of woody riparian species in relation to valley width, geomorphic surfaces, and substrates; and (3) characterize influence of vegetation on stream habitat through quantification of vegetation stature and shade on the stream.

The second study, on Meadow Creek in the northern Blue Mountains, investigates the growth dynamics of woody riparian vegetation in the third and fourth years after cessation of cattle grazing. The objectives of the study were: (1) quantify growth of woody deciduous riparian vegetation subsequent to cattle removal; (2) compare rates of growth of woody riparian vegetation within ungulate (deer and elk) exclosure fences and on adjacent areas accessible to ungulates; and (3) quantify rates of woody plant establishment on streambanks and gravel deposits after cessation of cattle grazing.

CHAPTER 2

Woody Riparian Vegetation Distribution on Elevational and Geomorphic Gradients Along Catherine Creek, Oregon

Danna J. Lytjen

ABSTRACT

The association of woody riparian species with elevational and geomorphic gradients was studied on Catherine Creek, a tributary of the Grande Ronde River, in northeastern Oregon. Twenty nine plots were established at 50 m elevation intervals, from the stream origin at 2207 m in the Wallowa Mountains to the foothills of the Grande Ronde Valley at 988 m.

Woody plant community composition was correlated with the dominant environmental variable, elevation. Also correlated with elevation were stream width and to a much lesser degree, stream gradient. Valley width, which was not correlated with elevation, was narrowest in the middle elevation canyon. The headwaters were conifer (*Abies lasiocarpa*, *Pinus contorta* and *Picea engelmannii*) dominated with very little shrub cover. The large mid-elevation canyon had a conifer overstory (*Abies grandis*) with a strong element of black cottonwood (*Populus balsamifera*) and woody deciduous shrubs, many of which could also be found in mesic uplands. Lower elevations at the mouth of the canyon and in the foothill valleys were conifer (*A. grandis* and *Pinus ponderosa*) and cottonwood dominated, with a different set of riparian shrubs.

A lateral geomorphic gradient of geomorphic surfaces deposited or modified by flood events was increasingly apparent in the middle and lower elevations plots where most deciduous species were found. Distribution of dominant species was strongly associated with these geomorphic surfaces. Black cottonwood was associated with new bars proximal to the stream channel, and was also associated with elevated old boulder bars along with ponderosa pine (*Pinus ponderosa*). Alders (*Alnus incana* and *A. viridis*) and willows (*Salix bebbiana*, *S. boothii*, *S. exigua*, *S. lucida*, *S. melanopsis*, *S. prolixa*, and *S. sitchensis*) were associated with annual floodplains.

These results highlight the importance of dynamic heterogeneity in the physical environment to the diversity and abundance of riparian woody plant species. Riparian species are adapted to tolerate natural disturbances and their communities are rejuvenated and maintained by disturbance in a dynamic shifting mosaic.

INTRODUCTION

Vegetation plays a critical role in maintaining water quality and stream habitat of native cold water fishes in the Pacific Northwest (Bustard and Narver 1975, Moore and Gregory 1988, Li et al. 1994). Vegetation influences the aquatic ecosystem by anchoring sediments and resisting erosion (Hickin 1984, Clifton 1989, Gregory et al. 1991), by providing allochthonous inputs including litter, insects, twigs, and modified nutrients from hyporheic flow (Fisher and Likens 1973, McLemore and Meehan 1988, Cummins et al. 1989), and by providing shade that prevents heating by solar radiation (Meehan et al. 1969, Li et al. 1994). The poor condition of riparian vegetation in the Columbia Basin has become an issue for land managers as native fish populations decline (Anderson et al. 1992, Wissmar et al. 1994). Land managers, accordingly, have begun to include riparian vegetation management and restoration in stream rehabilitation projects. Successful planning and execution of stream improvement projects depends upon the ability to recognize the existing site condition and potential of the site and to integrate natural processes as part of the recovery process (United States GAO 1988, Sedell and Beschta 1991, Kauffman et al. 1997). The Grande Ronde River basin in northeastern Oregon is a critical watershed for recovery efforts for Columbia River anadromous fishes.

Geomorphic features are often associated with elevation gradients which affect the potential energy dissipation as water flows down-valley. With decreasing elevation there are generally declines in stream gradient, increases in annual flow, and increases in channel size and in the amounts and kinds of fluvial surfaces (Minshall et al. 1985, Schlosser 1990). Western stream systems have highly dendritic patterns (more tributary junctures) and greater available relief than stream systems in the eastern U. S., resulting in more complex fluvial processes and varied geomorphology (Mitsch and Gosselink 1993). Therefore, riparian species distribution in western mountains should be examined for both the longitudinal of elevation and the lateral influences fluvial geomorphology. This study, on Catherine Creek in the Wallowa Mountains, northeastern Oregon, examines riparian vegetation in relation to its geologic, geomorphic, and fluvial environment from the headwaters to the foothills of the Grande Ronde Valley.

Plant species distribution along elevation gradients has been described for upland species in Arizona (Whittaker 1967) and for woody riparian species in central Idaho (Brunsfeld and Johnson 1985) and Utah (Webb and Brotherson 1988). Relationships between riparian bottomland species and fluvial geomorphology were described in the eastern United States (Hack and Goodlett 1960, Hupp and Osterkamp 1985). Woody plant species distribution has been related to valley form in the Sierra Nevada Mountains of California (Harris 1987) and in central and eastern Oregon (Kovalchik 1987, Crowe and Clausnitzer 1997). However, few studies have examined riparian vegetation within the context of both elevation and fluvial geomorphology. In the Basin and Range physiographic province of southeastern Oregon, Evenden (1990) classified riparian plant communities and examined relationships of species and communities with elevation and geomorphic variables. She found that woody species distribution corresponded well with elevation and valley bottom type. She also found that occurrence patterns of a few woody species corresponded with geomorphic surface but details of the relationships were not described. Geomorphology was included in classifications of riparian vegetation by Kovalchik (1987) and Crowe and Clausnitzer (1997) in central and eastern Oregon but relationships were not quantified. Classifications have grouped vegetation into discrete communities rather than relating the continuum of vegetation change, including species turnover and changes in physiognomy, to environmental gradients. Other studies of riparian vegetation in the Blue Mountains physiographic province have been floras (Head 1959, Strickler 1965, Mason 1975) or have focused on plant-animal interactions (Kauffman 1982, Case 1993).

This study of the vegetation of Catherine Creek may serve to demonstrate how plant species distribution and abundance are related to environmental factors, and additionally, how vegetation may influence the stream environment. My objectives were: (1) quantify the occurrence and abundance of woody riparian species along gradients of elevation, stream order, and stream gradient; (2) quantify the occurrence of woody riparian species in relation to valley width, geomorphic surfaces, and substrates; and (3) characterize the influence of vegetation on stream habitat through quantification of vegetation stature and effective shade on the stream.

METHODS

Site description and location

The study area consists of the stream segment from the headwaters of North Fork Catherine Creek at 2225 m elevation to Catherine Creek State Park in foothills at the edge of the Grande Ronde Valley at 988 m elevation within Townships 4 and 5 South and Ranges 41 and 42 East (Figure 2.1). The area is on the western slope of the Wallowa Mountains in the Blue Mountains physiographic province. Basin area at Catherine Creek State Park is 218 km². The highest point in the basin is at 2383 m elevation. Catherine Creek has spawning and rearing habitat for spring chinook (*Oncorhynchus tshawytscha*), summer steelhead (*O. mykiss*), and a resident population of bull trout (*Salvelinus confluentus*). All are species in serious decline in the region.

The drainage is underlain by Grande Ronde basalts which are part of the extensive Columbia River basalts (Walker and MacLeod 1991, Orr et al. 1992). The majority of precipitation falls as snow and summers are generally dry. An orographic precipitation gradient is apparent from precipitation records at two nearby locations. Cove (884 m elevation), situated at the foot of the mountains 24 km northwest of Catherine Creek Meadow, averaged 55 cm annual precipitation over a twenty-year record. Moss Spring (1768 m elevation), 8 km north-northwest of Catherine Creek Meadow, averaged 127 cm precipitation from 1985 to 1995 (weather data on file at USDA National Water and Climate Service).

The headwaters flow through a series of permanently saturated small meadows formed behind erosion-resistant basalt obstructions. Downstream from the basalt obstructions the stream has incised into glacial till in the slopes of the upper basin (stream gradient of 2 to 39%). At 1825 m the valley widens out into Catherine Creek Meadow, a large mesic flat of fine alluvial fill, which also formed behind a large erosion-resistant basalt obstruction. The creek then descends through a deep, glaciated canyon where the stream gradient is moderately steep (gradient of 2 to 7%). The flat canyon floor consists of poorly sorted glacial till and moraines (Mark Ferns, Geologist, State of Oregon, Baker

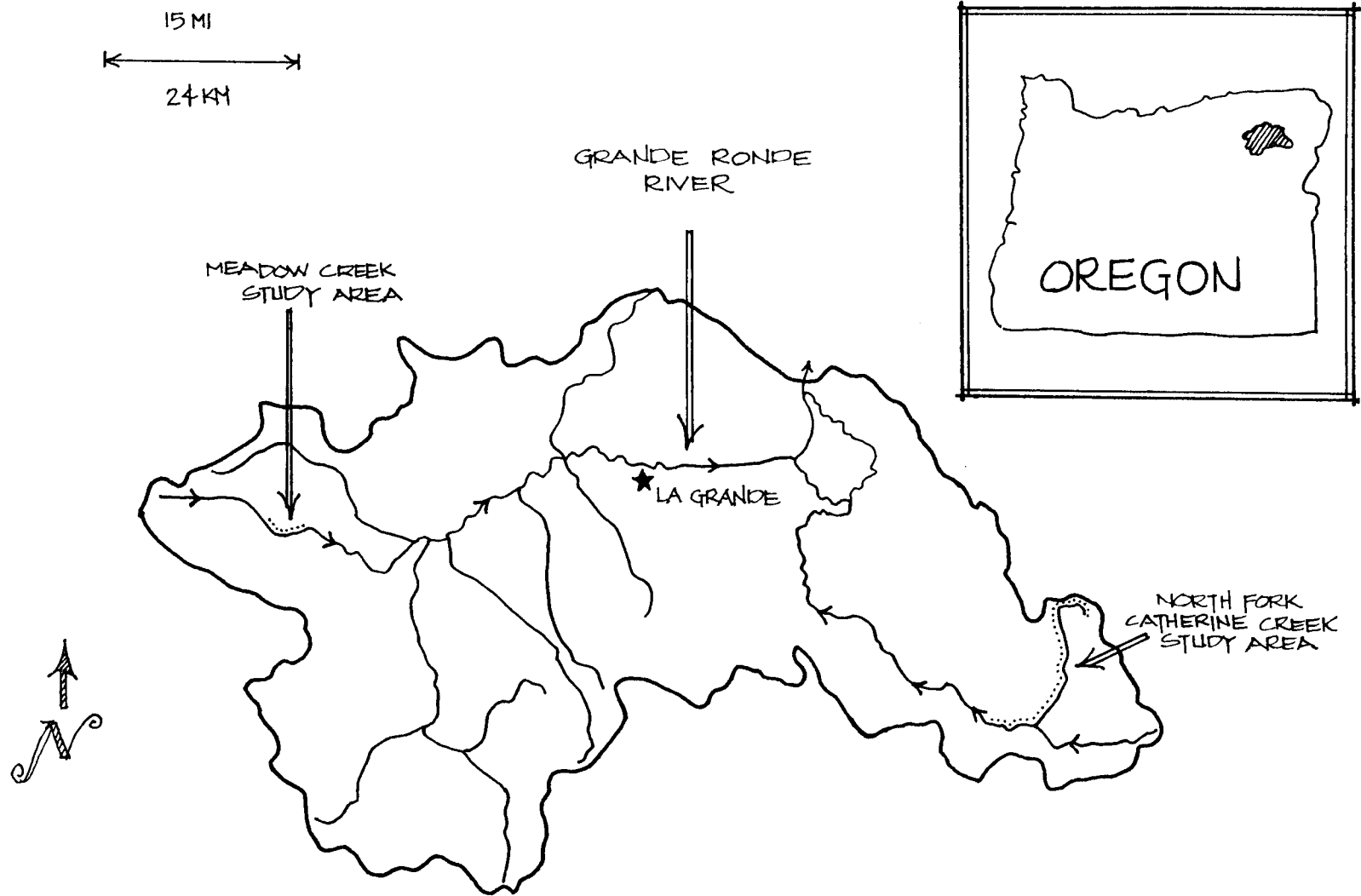


Figure 2.1. Map of Catherine Creek and Meadow Creek study area locations, Upper Grande Ronde River basin, Oregon.

City, personal communication). Channel substrates are coarse boulders, cobbles, and gravels. Dynamic high flow events are evidenced in the canyon by newly cut channels and piling of large cobbles and boulders. Unlike the headwater reach which has a stable, somewhat entrenched channel, multiple channels often occur in the canyon. Near the mouth of the canyon, the valley floor consists of recently deposited poorly sorted alluvial deposits (Walker and MacLeod 1991). The lowermost portion of the study area is a broad depositional reach within foothills at the edge of the Grande Ronde Valley (gradient of 0.5 to 3.5%). Parts of the stream were channelized in the 1970's but some sinuosity is returning to the reach. Downstream of the study area, Catherine Creek winds northward through agricultural lands until it joins the Grande Ronde River.

Most of the forested area in the upper part of the watershed is publicly owned: the upper 13 km of stream are within the Eagle Cap Wilderness and the rest is within the Wallowa-Whitman National Forest. Catherine Creek Meadow at 1720 m is a private inholding of 65 ha surrounded by wilderness. The low elevation portion of the study area in the lower end of the canyon (below 1100 m) and Grande Ronde Valley is privately owned. Hall Ranch, administered by Oregon State University, lies in a foothill valley where the creek emerges from the canyon.

Riparian vegetation in the headwaters (2300 m to 1700 m) generally consists of narrow bands of herbaceous plants on saturated stream margins, low narrow floodplains, and occasional wet meadows. Other near-stream vegetation is mostly high elevation conifer with little understory. Mid-elevation canyon riparian vegetation (1700 to 1200 m) is conifer with riparian and woodland shrubs. The lower elevation reaches at the canyon mouth and in the valley (1100 to 1000 m) have cottonwood and conifer with abundant riparian deciduous shrubs. The surrounding upland conifer forests in the basin consist of *Abies lasiocarpa*, *Pinus contorta*, and *Picea engelmannii* in the upper elevations, from approximately 2300 down to 1700 m, and *Abies grandis*, *Pseudotsuga menziesii*, *Larix occidentalis*, and *Pinus ponderosa* through from approximately 1700 m down to 1000 m.

Historically the Catherine Creek Allotment was grazed by sheep, cattle, and horses. Heavily overgrazed areas in high elevations were reported in 1924 (allotment history on file at La Grande Ranger District). Currently, cattle grazing occurs yearly,

season long (16 June-30 September) in Catherine Creek Meadow and the headwater meadows. The middle and lower elevations are lightly grazed or are not grazed, which appears to allow for development of shrub communities near the stream. Little logging has occurred in the North Fork which is roadless over the uppermost 15 km of stream (above 1280 m). Logging has been extensive in the other three major tributaries (Middle Fork, Buck Creek, and South Fork) which join the main stem (North Fork) at the 1280 m, 1160 m, and 1125 m elevations respectively.

Field sampling methods

During the summers of 1994 and 1995, I established 29 plots adjacent to and on alternating sides of the stream channel at intervals of 50 m elevation, from stream origin in the headwaters to the valley foothills. An extra plot was taken when the distance between plots exceeded 1.6 km (1 mile). Plot coordinates were predetermined from USGS 7.5 minute topographic quad maps. A global positioning system (Magellan Nav 5000 DX) was then used to locate the plots on the ground. I used a nested plot design with a more intensive survey of vegetation closest to the stream. A 25×25 m plot was laid against the stream margin with “belts” of 10×25 m and 2×25 m laid at the stream edge within the larger plot (Figure 2.2). Vascular plant nomenclature follows the Jepson Manual, Higher Plants of California (Hickman 1993) for the genera *Populus*, *Salix* and *Alnus*, and Flora of the Pacific Northwest (Hitchcock and Cronquist 1973) for all other taxa (nomenclature synonymy between the floras is listed in Appendix 1).

Measurements were made at each plot as follows:

1. The 25×25 m plot included all trees >10 cm diameter at breast height (dbh). Breast height equals 1.37 m (4.5 feet). Species, height, and diameter were recorded.
2. Within the 10×25 m belt all woody plants >1.37 m in height but <10 cm dbh were recorded for species, and measured for height (H), width of canopy at its widest point (W1), width of the canopy perpendicular to the first width (W2). The elliptical crown area for each plant was computed as $(\pi \times W1 \times W2)/4$.

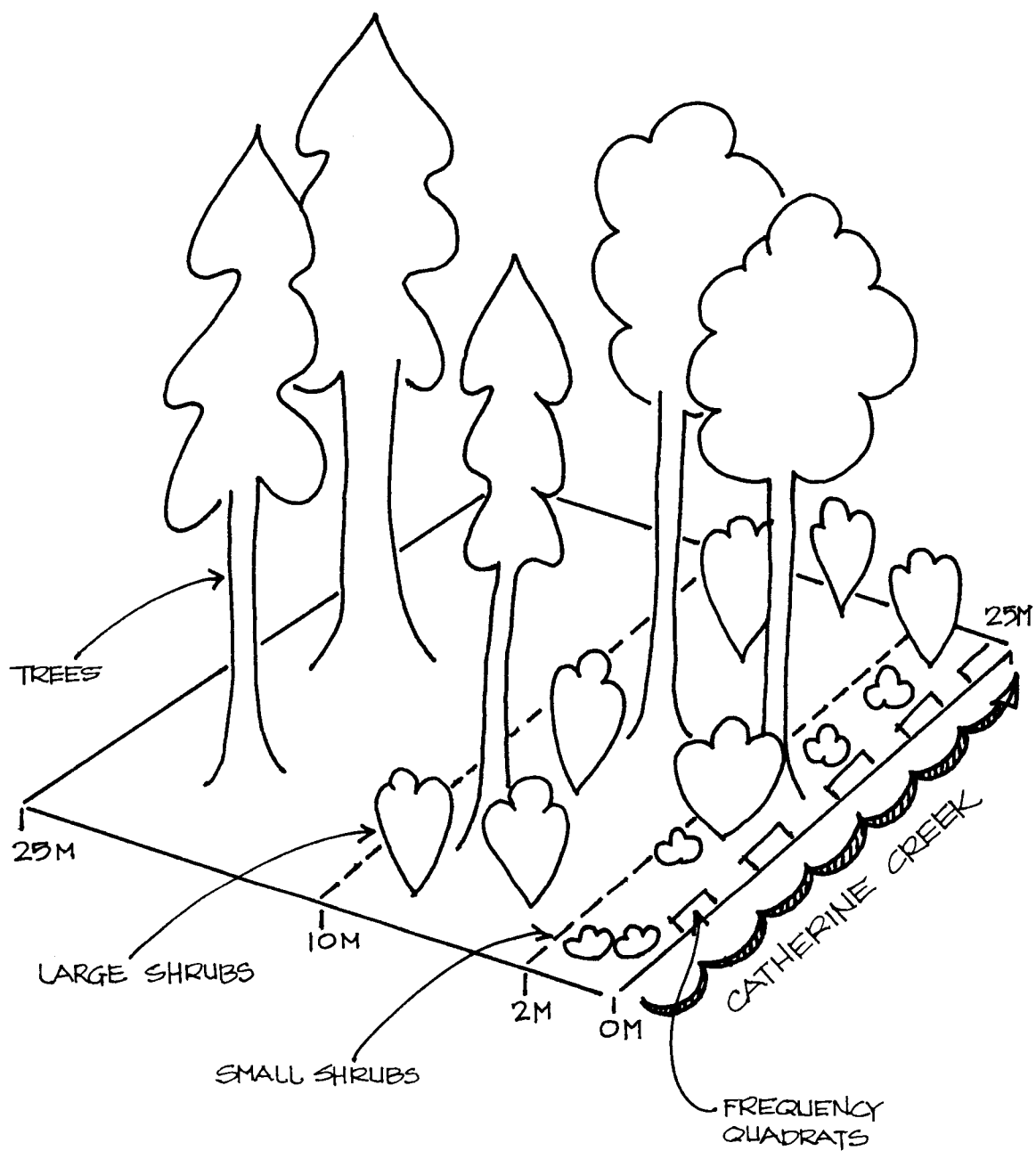


Figure 2.2. Schematic of sample plot used for gradient analysis on Catherine Creek, Oregon.

3. Within the 2×25 m belt all woody plants >0.5 cm basal diameter and <1.37 m in height were measured in the same manner as those in the 10×25 m belt.

4. At the stream edge presence only was recorded for all species (including graminoids and forbs) on five quadrats (0.5×1 m) spaced 5 m apart.

5. Geomorphic surface was recorded for all plants >0.5 cm basal diameter.

6. The following hydrogeomorphic characters were recorded for each plot: stream gradient, stream aspect, stream width, and valley width. Stream gradient was measured with a clinometer, aspect with a compass, and stream width and valley width were visually estimated.

7. Edaphic information was recorded for all plants >0.5 cm basal diameter. Substrates at the base of each plant were classified as follows: boulder (>20 cm), cobble (7.5 cm to 20 cm), gravel (2 mm to 7.5 cm), fines (<2 mm).

8. Solar insolation was measured using a Solar Pathfinder at the stream edge on the center (meter 12.5) of the plot border. The observer uses the instrument to trace onto a graph the image of riparian and topographic features that cast shade. The energy inputs over a selected period of time are then calculated for the portion of the sky not blocked by shade. Insolation was expressed in this study as megajoules per square meter (Mj/m²) for the months of June, July, and August (Li et al. 1994). Calculations were made for the total potential insolation without adjustment for cloudy days.

9. Geomorphic surfaces were mapped and the area of each feature was estimated. Terminology for geomorphic surfaces follows that commonly used by geomorphologists and stream ecologists (Morisawa 1968, Hupp and Osterkamp 1985). Bar and floodplain categories were subdivided to fit the specific geomorphology of Catherine Creek. Each plot was sketch-mapped with a plan view and a cross-sectional view. Definitions of geomorphic surfaces as used in this study are as follows:

- *Channel*: the stream bed below the lower limits of herbaceous vegetation.
- *Cutbank*: vertically oriented surface produced by active fluvial erosion cutting into floodplains, terraces, and uplands.
- *New bar*: convex coarse sediment (cobble and boulder) deposit of recent deposition as evidenced by smaller seedlings, a barren surface devoid of

herbaceous vegetation and litter; generally at a low elevation with respect to the stream.

- *Old bar*: older convex coarse sediment (boulder) deposits with less evidence of recent scouring or secondary deposition, generally lacking fine sediments; possessing larger woody plants and a surface layer of litter and herbaceous plants; generally higher in elevation with respect to the stream than new bars.
- *Annual floodplain*: low lying flat surfaces of sandy loam; inferred flood recurrence of approximately 1-3 years.
- *Five to ten year floodplain*: flat surfaces at higher elevation than annual floodplain; sandy to loamy surface; inferred flood recurrence of approximately 5-10 years.
- *Swale*: concave depressions, troughs or side channels, often with sandy and silty sediments but little herbaceous vegetation; generally containing water during high flow or bankfull events.
- *Terrace*: a flat fluvial surface (formerly a floodplain) that no longer floods or floods only during the most extreme events, generally >1 m higher than summer base flow level.
- *Upland*: higher elevation non-riparian surfaces not influenced by fluvial processes.

Data analysis

Data were first analyzed by use of multivariate ordinations to correlate species distribution with environmental variables and vegetation attributes. Secondly, the relationships of species with geomorphic surfaces within the plots was tested using Chi-square methods. For facilitation of comparisons, results were often interpreted in terms of three reaches of the stream: the first and second order headwater reach, the second and third order canyon reach, and the fourth order valley reach. Plot 18, which fell in Catherine Creek Meadow, a large grazed pasture at 1720 m lacking woody vegetation, was eliminated from all analyses because of its extreme dissimilarity to all other plots.

Diversity

Species richness per plot (alpha diversity) was calculated as the average number of species occurring over all 28 plots (total species divided by total plots). Landscape level species richness (gamma diversity) was simply the total number of species on all the plots. Heterogeneity, the change in species composition over the set of samples (beta diversity) was calculated by dividing alpha by gamma (the total number of species over all plots) (Whittaker 1972).

Vegetation and environmental variables (longitudinal gradient)

Multivariate analysis was used to describe correlations of plant community composition with physical environmental variables (elevation, stream gradient, stream width, valley width) and vegetation attributes (basal area of trees, solar insolation, and insolation intercepted by deciduous vegetation). Ordinations were performed using the PCORD program (McCune and Mefford 1997). The original species matrix of 31 species and 29 plots consisted of data from the 10×25 m belt (plants >breast height and < 10 cm dbh). Eleven rare species (those occurring in 2 or fewer plots) were eliminated and the data were converted to presence-absence. I discarded Plot 18 (3.0 standard deviations from the mean) which was in a large, heavily grazed, open pasture in Catherine Creek Meadow lacking woody vegetation, and Plot 3 (2.6 standard deviations) which was a terrace lacking many of the species common to the reach. Eliminating the two outlier plots produced a final matrix of 27 plots × 20 species. A separate matrix of plots × environmental variables was constructed. All environmental variables were log transformed except elevation.

I used a Bray-Curtis analysis with three ordination axes. The distance measure was Sorenson, a city block measure written as $1-2W/(A+B)$, where W is the sum of shared abundances and A and B are the sums of abundances in individual sample units. The endpoint selection method was variance-regression (Beals 1984), and axis progression geometry was Euclidean (Bray and Curtis 1957).

Physical structure was summarized with descriptive statistics for the three reaches of the stream. Differences in solar insolation between plots having deciduous vegetation and those without were tested using the Mann-Whitney U test. These analyses included 28 plots (excluding only plot 18).

Vegetation and geomorphology (lateral mosaic)

The topographic analysis was limited to the valley and canyon reaches (plots 1-17, 988-1671 m elevation) because most woody deciduous species did not range into the headwater reach (plots 18-29, above 1720 m elevation). For each plot, the areal extent of each geomorphic surface was estimated from plot maps for the 10×25 m belt. The area of each surface type was pooled over the 17 plots. Only plants meeting the criteria for the 10×25 m belt were included in the analysis.

Each recorded plant was assigned to one of the nine geomorphic surfaces. Six of the more common genera, three coniferous and three deciduous, were analyzed for association with geomorphic surfaces: *Abies (grandis)*, *Pinus (ponderosa)*, *Picea (engelmannii)*, *Alnus (incana and viridis)*, *Populus (balsamifera)*, and *Salix (bebbiana, boothii, exigua, lucida, melanopsis, prolixa, and sitchensis)*. *Salix scouleriana*, an upland willow, was not included in the analysis. Additionally, analyses of tree species were limited to plots within their upper or lower range limit (i.e., *Populus* on plots 1-13, *Pinus* on plots 1-7, *Picea* on plots 5-17, *Abies* on plots 4-17).

Chi-square analysis was used to test association of major plant taxa with topographic features within the plots. Assuming a random pattern of distribution, the null hypothesis was that the frequency of occurrence of plants of a given taxon occurring on a geomorphic surface was proportionate to the percentage of the total area that surface represents. For each category of topography upon which it was reasonable to expect to find the taxon in question, the chi-square statistic was computed as follows:

$$\chi^2 = \sum((\text{observed \#} - \text{expected \#})^2 / \text{expected \#})$$

where the observed number is of the total number of plants of a given taxon tallied on a given topographic surface, and the expected number is of the total number of plants of

that taxon on the plots multiplied by the percentage of the pooled plot area represented by the geomorphic surface. Chi-square was not calculated for surfaces where a taxon would not be expected (e.g., riparian obligate willows on uplands). The cumulative chi-square statistic for a taxon on all possible surfaces was used to answer the general question of whether the taxon had affinity for some surfaces over others. Individual chi-square tests for taxa with surfaces revealed which specific surfaces were associated with each taxon.

RESULTS

Plant species distribution on Catherine Creek was strongly associated with the 1219 meters of elevation change along the longitudinal gradient. Species distribution was also associated with stream width, valley width, and topographic position. Streamside plant communities gradually shifted from predominantly high-elevation conifers bordering narrow riparian strips in the first and second order headwater reach, through mid-elevation conifer/shrub communities in the second and third order canyon reach, to an increasingly broader band of low-elevation deciduous tree/shrub communities in the fourth order valley reach. Flood-prone area (excluding terraces and uplands) in plots on the headwater reach comprised 27% of the area within 10 m of the stream, 60% in the canyon, and 84% in the valley. There was, however, local variation within the reaches. For example, there were numerous low gradient meadows and fens in the headwaters, and in the canyon the stream varied between single and multiple channels.

Diversity and elevational range of riparian plant species

Forty woody species (11 tree species and 29 shrub species), and 159 herbaceous species were tallied on plots (Appendix 2). Woody species richness (alpha) was high in valley and canyon reaches but low in the headwaters (Table 2.1). Beta diversity was high for woody species on the study area, reflecting the changes from high elevation conifer communities to an abundance of deciduous species in low elevation reaches. Low

beta diversity for the three reaches indicates that each of the reaches was fairly homogeneous in woody species composition.

Table 2.1. Woody species diversity on Catherine Creek, Oregon. Species richness (alpha) is average number of woody species on the plots. Heterogeneity, or change in species composition over the set of samples (beta) is calculated by dividing gamma (the total number of species on all plots) by alpha.

	Diversity measure			
	n	alpha	beta	gamma
Valley	6	8.1	2.4	19
Canyon	11	8.4	2.6	22
Headwater	11	2.6	2.3	6
All plots	28	5.5	7.3	40

Of the 159 herbaceous species occurring on the streambanks, 61 species occurred on only one plot, 113 species occurred on three or fewer plots, and 11 species occurred on more than nine plots. Composition of the streambank forb and graminoid community was very heterogeneous: beta diversity over all samples was 8.6 and beta diversity within reaches was 4.0 to 4.9 (Table 2.2). The valley plots had less than half as many species as either the canyon or the headwater reach.

Few tree species were strictly associated with low elevation (*Pinus ponderosa*, *Betula occidentalis*) or high elevation (*Tsuga mertensiana*, *Pinus albicaulis*) (Figure 2.3). Most ranged from low to middle elevation (e.g., *Abies grandis*) or from middle to high elevation (e.g., *Pinus contorta*). The species with the widest range was *Picea engelmannii* found from 1085 m to 2110 m.

Shrubs ranged primarily from low through middle elevation, approximately 1000 to 1600 meters (Figure 2.4). Four *Salix* species occurred only in the valley below 1050 m even though they are common at elevations up to 1300 to 1700 m elsewhere in the Blue Mountains (Crowe and Clausnitzer 1997). *Salix sitchensis* and *S. scouleriana* were common through the large canyon at middle elevation to approximately 1700 m. Heavily

Table 2.2. Forb and graminoid diversity on Catherine Creek, Oregon. Species richness (alpha) is average number of forb and graminoid species on the plots. Heterogeneity, or the change in species composition (beta) is calculated by dividing gamma (the total number of species) by alpha.

	n	Diversity measure		
		alpha	beta	gamma
Valley	6	8	4.0	32
Canyon	11	20	4.1	82
Headwater	11	22	4.7	104
Study area	28	18	8.6	159

browsed *S. sitchensis* and another unidentifiable *Salix* species were observed outside of plots from upper Catherine Creek Meadow (1730 m) to about 1800 m. Above 1800 m understory vegetation throughout the plot was almost exclusively *Vaccinium scoparium*, a dwarf upland huckleberry.

Environment and community composition

The Bray-Curtis ordination grouped plots according to similarity woody species on the 10×25 m plots (Figure 2.5). The headwater plots were positively associated with Axis 1 and negatively associated with Axis 3. The valley plots were negatively associated with both with both Axis 1 and Axis 3. The canyon plots were spread out on both axes, but were much more positively associated with axis 3 than with plots on the other two reaches.

The variables elevation, stream width, stream gradient, crown volume, and percent deciduous shade were correlated with the ordination axes (Table 2.3). Elevation was the dominant environmental variable associated with Axes 1 and 2. Stream width varied inversely and fairly consistently with elevation, while stream gradient was more irregular and was weakly correlated with Axis 1. Stream gradient was 0.5 to 3.5 % on valley and lower canyon plots, 2 to 7 % on middle to upper canyon plots, and 2 to 39 % on

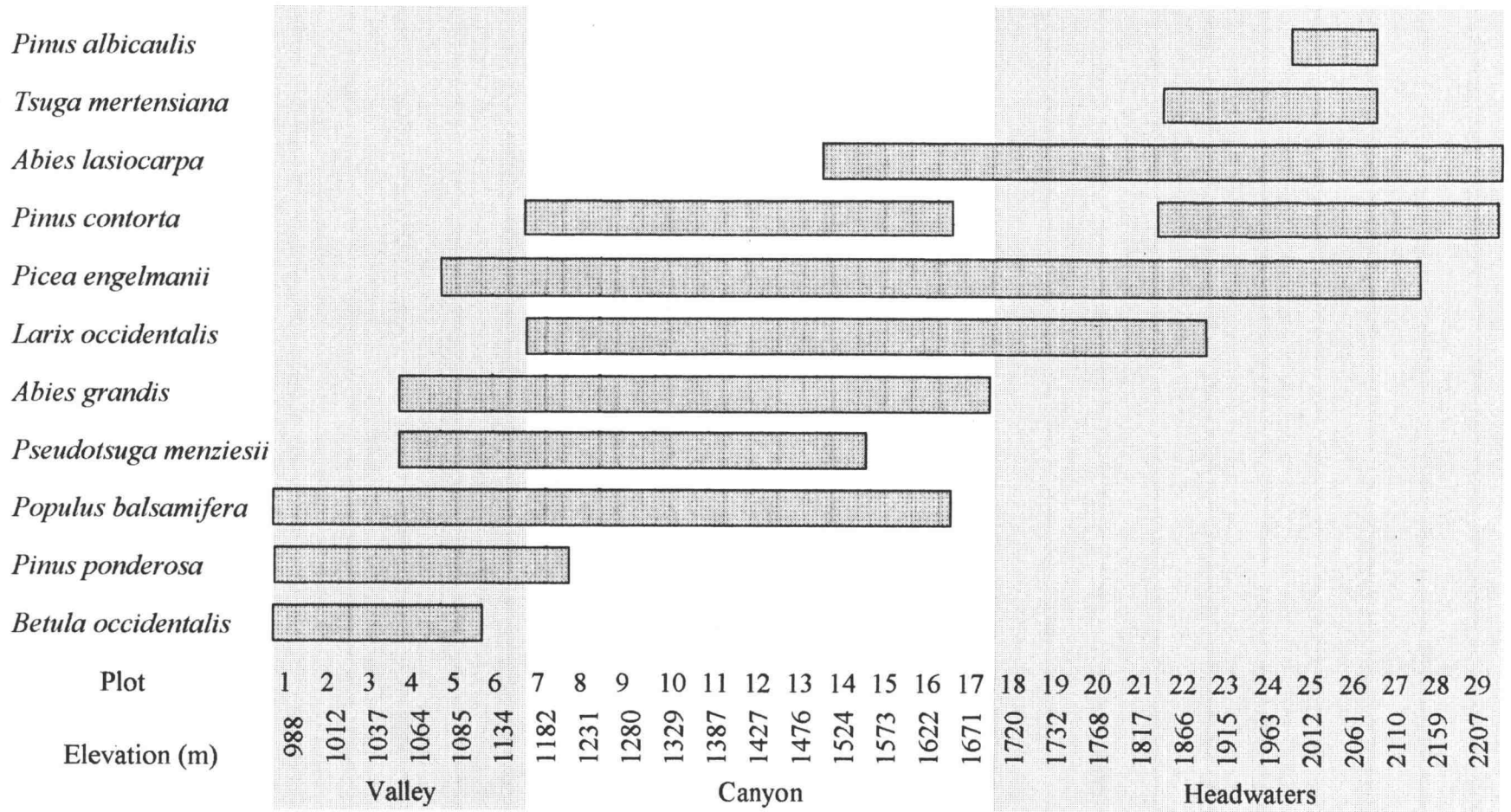


Figure 2.3. Elevation range of tree species observed on or adjacent to plots at Catherine Creek, Oregon. Gaps of more than two plots are not graphed.

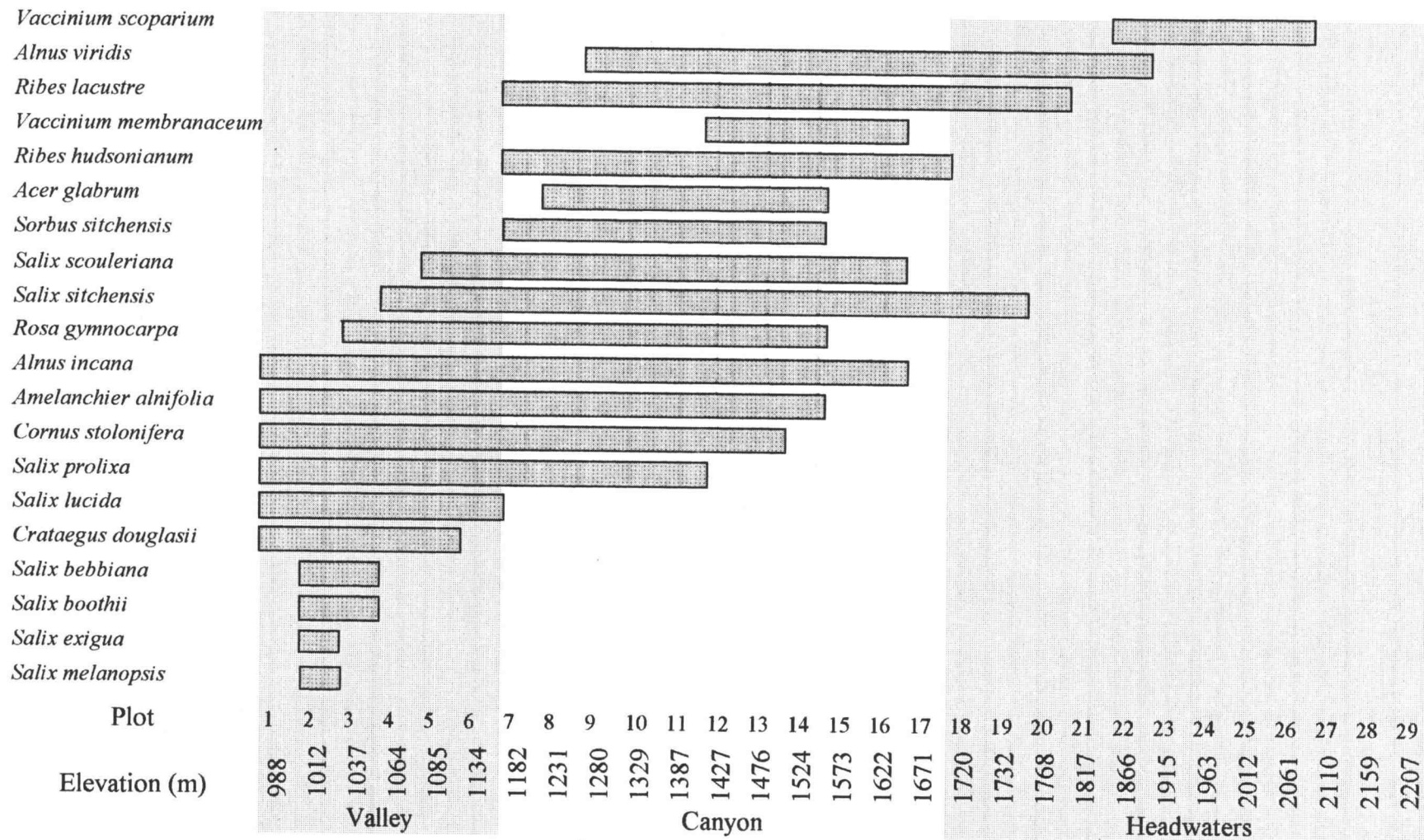


Figure 2.4. Elevation range of shrub species observed on or adjacent to plots at Catherine Creek, Oregon.

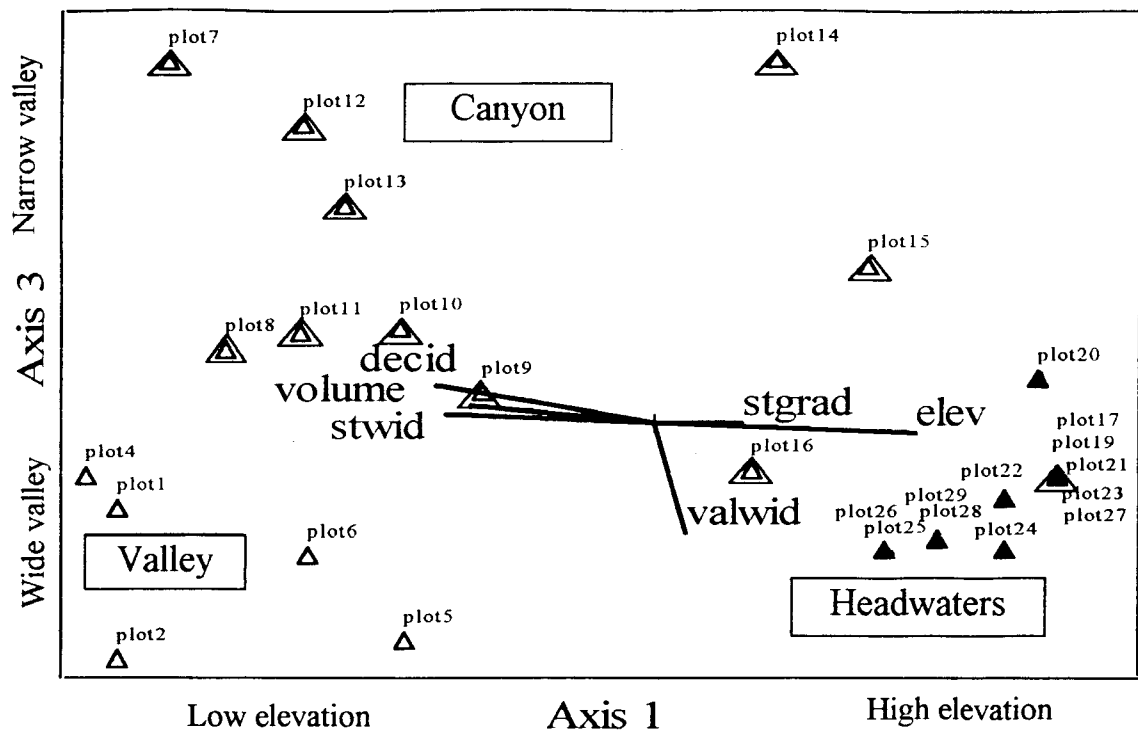


Figure 2.5. Bray-Curtis ordination diagram of plots on Catherine Creek, Oregon. Joint plot lines represent the correlation of environmental variables with the axes. elev=elevation, valwid=valley width, stwid=stream width, stgrad=stream gradient, decid=crown volume of riparian shrubs.

headwater plots. Most deciduous vegetation occurred in the two lower elevation reaches (<1700 meters) and consequently the amount of deciduous shade was greater on low and middle elevation plots where shrubs were more abundant. The total summer-long insolation and basal area of trees did not show correlations with the ordination axes.

The close association of many species with elevation observed in the direct gradient analysis also dominated the ordination, particularly on Axis 1 (Table 2.3). Conifers that occurred above 1700 meters were associated with Axis 2. Of these, *Picea* and *Pinus* tended not to occur together, possibly because of differing responses to soil moisture or past fire events. Environmental variables measured in this study did not explain the relative distribution of the two species. Axis 3 represented valley width and to a lesser degree crown volume. The middle elevation canyon plots were separated on this axis from plots located in wider valleys, mostly at the upper and lower elevations. The

Table 2.3. Pearson correlations with Bray Curtis ordination axes, Catherine Creek, Oregon.

	Regression coefficients (r^2)		
	Axis		
	1	2	3
Environmental variables:			
elevation	0.78	0.34	0.04
stream gradient	0.26	0.12	0.00
stream width	0.62	0.18	0.04
valley width	0.01	0.21	0.47
basal area	0.00	0.04	0.00
solar insolation	0.00	0.01	0.03
crown volume	0.46	0.15	0.23
deciduous shade	0.65	0.23	0.16
Species:			
<i>Abies grandis</i>	0.44	0.22	0.17
<i>Abies lasiocarpa</i>	0.76	0.36	0.02
<i>Picea engelmannii</i>	0.11	0.36	0.04
<i>Pinus contorta</i>	0.07	0.68	0.07
<i>Pinus ponderosa</i>	0.19	0.03	0.16
<i>Populus balsamifera</i>	0.65	0.10	0.02
<i>Tsuga mertensiana</i>	0.07	0.38	0.06
<i>Acer glabrum</i>	0.15	0.05	0.41
<i>Alnus incana</i>	0.86	0.23	0.03
<i>Alnus viridis</i>	0.03	0.09	0.44
<i>Amelanchier alnifolia</i>	0.23	0.01	0.28
<i>Cornus stolonifera</i>	0.61	0.11	0.13
<i>Crataegus douglasii</i>	0.30	0.03	0.15
<i>Holodiscus discolor</i>	0.19	0.03	0.40
<i>Ribes lacustre</i>	0.03	0.03	0.43
<i>Rosa</i> sp.	0.02	0.00	0.42
<i>Salix lucida</i>	0.23	0.03	0.10
<i>Salix prolixa</i>	0.41	0.06	0.13
<i>Salix sitchensis</i>	0.36	0.06	0.19
<i>Sorbus sitchensis</i>	0.05	0.01	0.58

valley of the middle elevation canyon reach was generally narrow (20-134 m), while the lower elevation reach and the headwater reach had broader valleys (100-1000 m and 200-800 m respectively). The species associated with the Axis 3 were riparian and woodland shrubs (*Alnus viridis*, *Acer glabrum*, *Holodiscus discolor*, *Ribes lacustre*, *Rosa* sp., and *Sorbus sitchensis*) abundant in the canyon.

Influence of riparian plant community structure on stream environment

Overstory composition was increasingly deciduous at lower elevations. Deciduous species (*Populus balsamifera*, *Alnus incana*, and *Betula occidentalis*) which were absent from the headwater reach, made up 15% of total basal area in the canyon reach and 43% of the total basal area in the valley reach. However, tree height, density, and basal area of trees over 10 cm dbh did not differ substantially from the headwaters to the valley. Stem density of trees within 10 m of the stream was nearly the same for all three reaches (0.033-0.035 stems/m²).

Within the 10 x 25 m belt, crown volume in the understory shrub-sapling layer was much greater in the valley and canyon reaches (2.66 m³/m² and 1.78 m³/m² respectively) than in the headwater reach (0.37 m³/m²) (Figure 2.6). Understory crown volume was dominated by deciduous species (74 % of measured crown volume). Composition of the understory changed from coniferous (71% of total volume) in the headwater reach to predominantly deciduous (76% of total volume) in the lower two reaches. *Alnus incana* and *A. viridis* were the two most abundant shrubs. On the low to mid-elevation plots where *A. incana* occurred, its median total plot crown volume (10×25 m plot, plants >dbh) was 163 m³. *Alnus viridis*, which partially overlapped *A. incana* in range but was more abundant in middle elevations, had a median total plot crown volume of 137 m³ on plots where it occurred. The median total plot crown volume of all *Salix* species on plots where they occurred was 35 m³.

Within the frequency quadrats placed at the edge of the channel, 20 shrub species, 5 tree species, and 159 herbaceous species were recorded. At lower elevations, the most common tree on quadrats was *Populus balsamifera* which was rooted at the stream edge

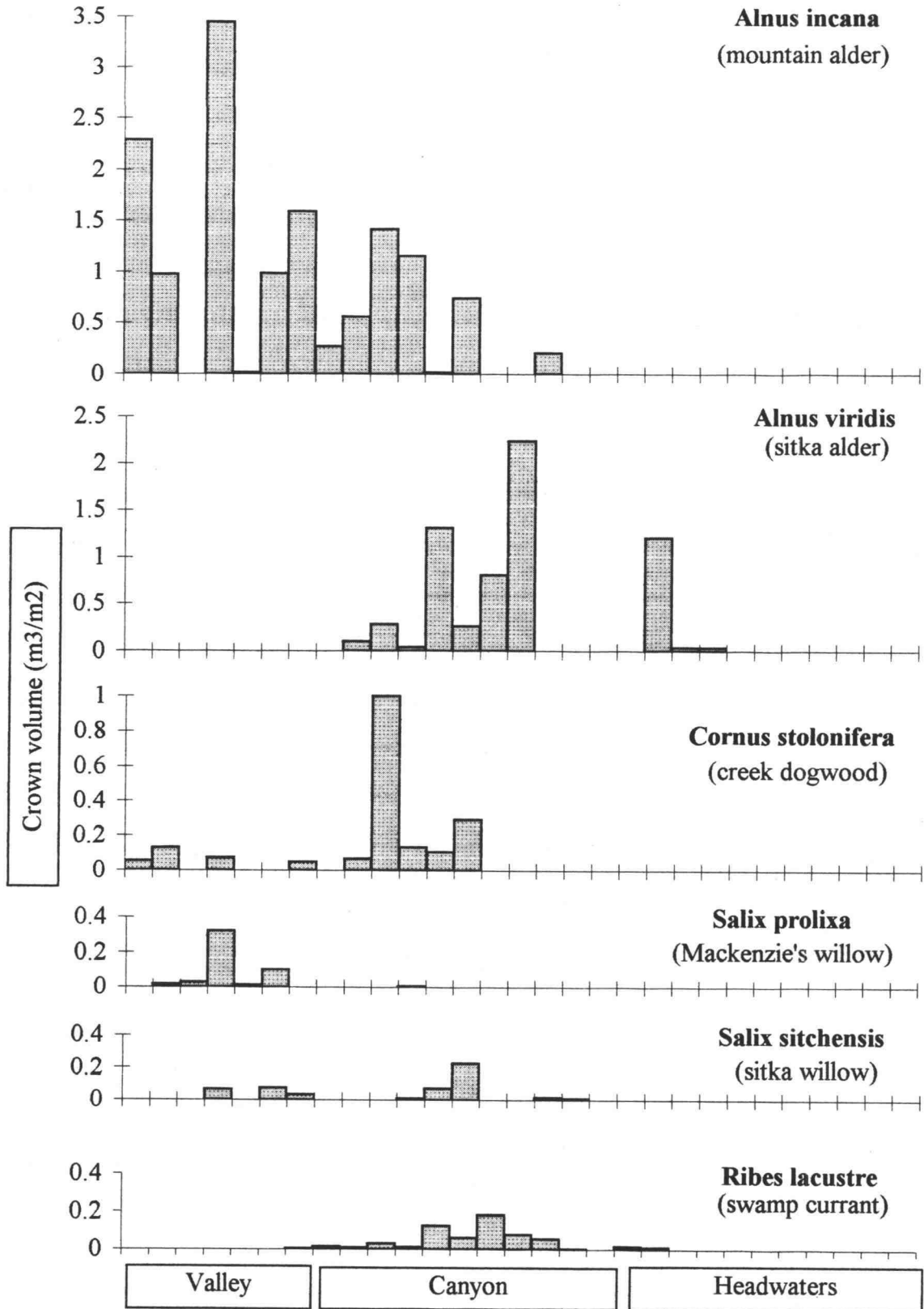


Figure 2.6. Shrub crown volume (m3/m2) on 10X25 m plots, Catherine Creek, Oregon.

on 9 of the lower 13 plots. Conifers were rarely present on quadrats below 1400 m. *Abies grandis* occurred on the quadrats of all five plots in the upper portion of the canyon between 1400 and 1600 m. In the 11 headwater plots, *Abies lasiocarpa* occurred on streambank quadrats in 10 plots, and *Picea engelmannii* occurred on quadrats in 7 plots. The most common shrubs rooted at stream bank were *Alnus incana* and *Cornus stolonifera* at lower elevations, and *Alnus viridis*, *Ribes lacustre*, and *R. hudsonianum* at middle elevations. Stream banks on the headwaters were dominated by conifers and forbs, and had almost no shrubs.

Average solar insolation reaching the stream edge for all plots for the summer months of June, July, and August was 500 megajoules per square meter (assuming no cloudy days). Deciduous cover accounted for 33% of insolation blocked on all plots and 53% of insolation blocked on the 15 lower elevation plots (Figure 2.7). Plots having deciduous shade in addition to or instead of conifer shade averaged less than half as much direct insolation as plots shaded only by conifers (340 Mj/m^2 versus 686 Mj/m^2).

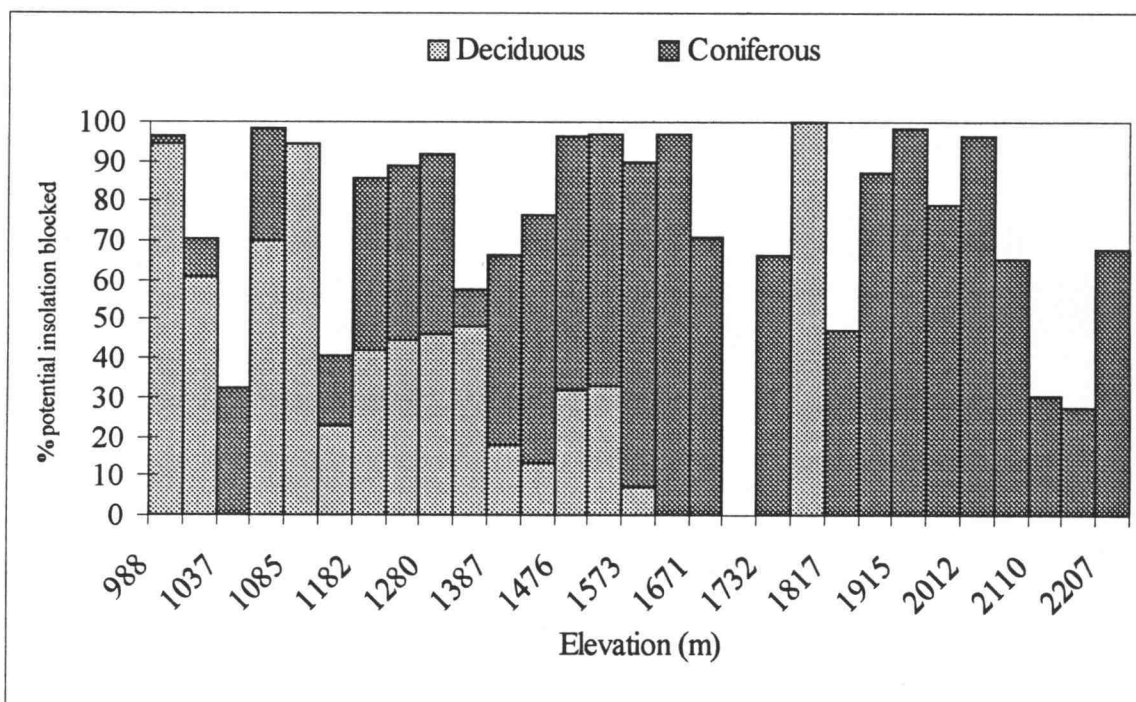


Figure 2.7. Effective blocking of insolation at the stream edge, Catherine Creek, Oregon.

Plot 18, within Catherine Creek Meadow was an outlier not included in the analyses. There was no woody vegetation in the lower half of the heavily grazed meadow where the plot was located. Signs of previous long-term soil saturation were evident near the terrace surface in the form of plates of oxidized iron and other redoxymorphic features. The stream had incised 1-1.5 m into the former wet meadow and the banks, composed of fine sediments, were eroding and collapsing. Except where springs and small tributaries were present, most of the meadow surface in the lower meadow was now occupied by dry land species including *Stipa occidentalis*, *Antennaria microphylla*, *Rumex acetosella*, and *Achillea millefolium*. Insolation measured in Catherine Creek Meadow was 1994 Mj/m² for the months of June, July, and August compared to averages of 624, 388, 547 and Mj/m² for the headwater, canyon, and valley reaches respectively.

Distribution of species on geomorphic surfaces

There were highly significant relationships for 5 of 6 taxa tested for association with geomorphic surfaces (significant at $p=0.001$, chi-square test) (Table 2.4). *Abies grandis*, while present on all surfaces except the channel, was significantly associated only with uplands (χ^2 significant at $p=0.001$). *Pinus ponderosa* was restricted to old bars within the 10 m zone near the stream (χ^2 significant at $p=0.001$), even though it was sometimes common on uplands away from the stream. Although the two *Alnus* species were associated with annual floodplains (χ^2 significant at $p=0.001$), they were also present on other surfaces and were not found on uplands and terraces. *Populus balsamifera* was associated with new and old bars (χ^2 significant at $p=0.001$ for each) and with the channel (χ^2 significant at $p=0.005$). It was present in very low numbers on the floodplains and was absent from cutbanks, swales, terraces, and uplands. *Salix* species were associated with the channel and annual floodplains (χ^2 significant at $p=0.001$ for each). Only *Picea engelmannii* had no significant association with specific geomorphic features. This species was evenly distributed over all features except channels, cutbanks, and new bars where it was absent.

Table 2.4. Results of chi-square test of association of plant taxa with geomorphic surfaces, Catherine Creek, Oregon.

	df	cumulative χ^2	χ^2 for specific surfaces	% of plants
<i>Abies grandis</i>	7	41*	upland 28*	45
<i>Pinus ponderosa</i>	6	167*	old bar 148*	91
<i>Picea engelmannii</i>	7	13	(no significant association)	
<i>Alnus species</i>	7	50*	annual floodplain 45*	37
<i>Populus balsamifera</i>	8	115*	channel 10*	5
			new bar 38*	30
			old bar 29*	55
<i>Salix species</i>	7	59*	channel 28*	9
			annual floodplain 19*	32

* exceeds χ^2 critical value for $p=0.01$

Of the nine near-stream topographic habitats, old bars covered the most surface area (24% of the map area on the pooled plots) and supported 35% of the of all individual shrubs and trees sampled in the pooled plot area (Figure 2.8). Old bars were particularly important to *Pinus ponderosa* (91% of total individuals) and *Populus balsamifera* (55% of total individuals). The other four taxa were present in proportion to the area that old bars covered. *P. balsamifera* and *Salix* spp. were the most important taxa on new bars. In the channel the only vascular plants present were a few *P. balsamifera* and *Salix* species. Thirty seven percent of *Alnus* spp. and 32% of *Salix* spp. occurred on annual floodplains which comprised 14% of the total area. Other species were present on annual floodplains in very low numbers. On 4-10 year floodplains *Alnus* spp., *Abies grandis*, and *Picea engelmannii* were present in amounts proportionate to the area, but other taxa were scarce. In swales *Alnus* spp. were more than twice as common as the other three taxa

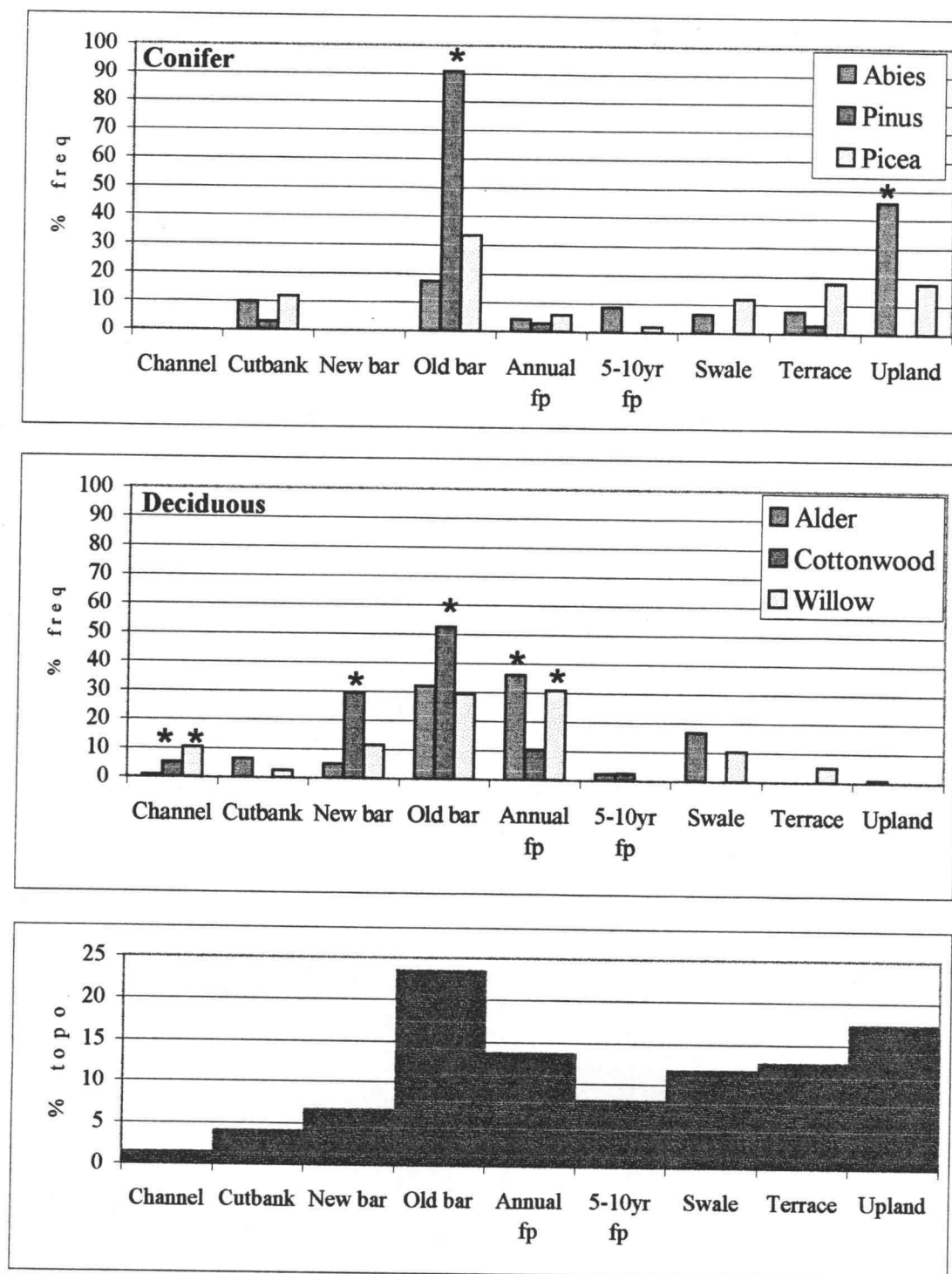


Figure 2.8. Conifer and deciduous taxa distribution on geomorphic surfaces at Catherine Creek, Oregon. * Denotes significant associations ($p < 0.01$). % freq = frequency of occurrence of taxa on surfaces, % topo = relative cover of surfaces.

present (*Abies grandis*, *P. engelmannii*, and *Salix* spp). Terraces and uplands were occupied almost exclusively by the conifers *Abies grandis* and *P. engelmannii*.

Four riparian taxa were associated with surface particle size. The substrates underlying 78% of the two *Alnus* species were sand to sandy loam, often overlying cobbles and boulders. Eighty percent of *Pinus ponderosa* were on cobble substrates. *Populus balsamifera* was found on boulders (40%), cobbles (22%) and sand (31%). Other woody taxa had no substrate pattern, were present in low numbers, or were upland species.

DISCUSSION

Longitudinal and lateral gradients influencing species distribution

Elevation was the dominant environmental variable affecting riparian plant species distribution along the longitudinal gradient at Catherine Creek. Secondly, at middle and lower elevations, there was an increasing lateral gradient of geomorphic surfaces resulting from floods. These lateral influences increased with declining elevation as channel gradient lessened, the stream enlarged as tributaries joined together, and the flood-prone area increased. Whittaker (1970) termed the influence of elevation on plant species distribution a “complex-gradient” including factors such as precipitation, temperature, and wind. Along streams, fluvial disturbance and geomorphology are equally important influences on species distribution (Hupp and Osterkamp 1985). Floods remove or bury vegetation, scouring near-stream surfaces and depositing sediments (Everitt 1968, Morisawa 1968). Fluvial surfaces are colonized differentially according to surface elevation, particle sizes, and the stochastic nature of plant propagule dispersal and weather (Mcbride and Strahan 1984, Bradley and Smith 1986, Baker 1990).

Johnson and Lowe (1985) noted that classic studies involving the influence of physical gradients on plant species distribution had ignored riparian communities. Besides the longitudinal, elevational, or “intrariparian” continuum, they proposed a “transriparian”

continuum, extending along a soil moisture gradient from the aquatic system across the riparian zone and into the uplands. This transverse gradient is particularly pronounced in the arid West. In a study of woody vegetation on streams in Utah, Webb and Brotherson (1988) found a direct association between woody riparian species and elevation. They also noted the second, transriparian gradient, most apparent at lower elevations where true riparian species were more abundant and tended to segregate out along an assumed soil moisture gradient from the stream to the uplands. The findings of this study support both gradient concepts. Elevation, stream width, and to a lesser degree stream gradient were associated with community composition on the longitudinal or intrariarian gradient. At Catherine Creek, as in the Utah study, at low elevations more riparian-associated species were found near the stream and the width of the zone containing riparian associated species was greater than at high elevations.

This study differs, however, in focusing on the complex topography of bars, floodplains, swales, and terraces which formed discontinuous and abrupt ecotones within 10 m of the stream at middle and lower elevations. Plant distribution on these surfaces is likely attributable to a combination of flood disturbance and moisture regimes associated with elevation above the stream and particle size of the surfaces. Hupp and Osterkamp (1985) studied the association of 43 woody riparian species to fluvial landforms in Virginia. Species presence was correlated with fluvial landform in 22 species and with sediment size in 11 species. Even though elevation gradients, landforms, and species differ substantially between the eastern and western United States, this study found similar associations of species occurrence on geomorphic surfaces. The authors of the Virginia study suggested that landforms play a greater role in species distribution than does sediment size. In a study of geomorphic surfaces and vegetation in a northern California riparian system, Harris (1987) suggested that because of high magnitude short duration flooding, the dominant gradient was flood disturbance (i.e., scour and sediment deposition) rather than flood duration (i.e., anaerobic conditions) as suggested by earlier researchers in bottomlands of forests of the eastern United States. This is likely also the case in Catherine Creek, where stream gradient is moderate to high, and high flows are associated with a brief period of spring snow melt. Thus, contrary to the idea that

organisms in low order systems are less adapted to aquatic/terrestrial transition environments (Junk et al. 1989), in western North America riparian vegetation and other organisms may be adapted to a different type of flood pulse than is bottomland or large river floodplain vegetation (Meffe 1984, Resh 1988, Poff and Ward 1989).

The character of the physical template varied with elevation. The headwaters of Catherine Creek were comprised of many small streams, springs, and wet meadows within a wide basin, converging into one stream at 1800 to 1900 m. Fire-killed stands of trees, snow avalanche chutes, and snowmelt channels observed within the headwater basin indicating that fire, snow avalanche, and snowmelt have an important influence geomorphic surfaces and vegetation distribution in the headwater reach. *Alnus viridis*, which was present up to 1950 m elevation, is often dominant on high elevation meadows and avalanche chutes in the Wallowa Mountains. In Alaska, *A. viridis* forms extensive stands in sub-alpine glaciated valleys and moist mountain valleys where its extensive root network and decumbent stems are important for influencing patterns and impacts of snowmelt (Mitchell 1968). At lower elevations, the stream sometimes had multiple channels and there were high boulder bars aligned parallel with the creek giving indication of past extreme floods. *Populus balsamifera* and *Pinus ponderosa* probably established on the bars shortly after they formed. Reasons for this distribution likely include high magnitude flood disturbances that provided new substrates for seedling establishment, favorable climate within the canyon, and lack of heavy browsing by livestock or wild ungulates during the seedling and sapling stage.

Because of periodic flooding, riparian zones are geomorphic mosaics in both a spatial and a temporal sense. The results of this study highlight the importance of dynamic heterogeneity in the physical environment to the diversity and abundance of riparian woody plant species. Disturbances, such as floods, blowdown, snow avalanches, and fire periodically reshape components of the physical habitat in Catherine Creek. Because riparian species are adapted to these disturbances, their communities are rejuvenated and maintained in a dynamic shifting mosaic. The presence of riparian vegetation adds further structural complexity to the physical environment and buffers the physical extremes of weather and erosion.

Management impacts

Historical land use may be an important determiner of plant community structure and composition. Shrub presence and abundance quantified in this study may have been affected by historical and present day cattle grazing, particularly in the headwater reach which is currently grazed yearly, season long. Headwater meadows and riparian zones were trampled by cattle in the summers of 1994 and 1995 stunted, heavily browsed willows were present outside of plots up to 1800 m. Solar insolation warms the water in reaches lacking vegetation (Brown 1985, Beschta et al. 1987, Li et al. 1994). Li et al. (1994) compared solar insolation values on vegetated and unvegetated reaches with stream temperatures in a study of fish habitat quality in the John Day River Basin in the central Blue mountains. They found that shaded reaches were cooler than exposed reaches and the water temperatures in some unshaded reaches approached lethal levels for rainbow trout.

With modified grazing practices or total exclusion from grazing, Catherine Creek Meadow would have potential for bank stabilization through the expansion of sedge clones and colonization by riparian shrubs. Both *Alnus* and *Salix* might be more abundant in high elevation areas if not affected by heavy browsing. A greater abundance of woody shrubs would add structural diversity in the headwaters, and might contribute to species diversity by providing more structural diversity along the reach. Ecological impact of grazing in the headwaters upon the habitat of resident bull trout in the upper reaches, and spring chinook salmon and summer steelhead in lower reaches has become a significant concern.

Conservation and restoration efforts should focus on removing land uses that are adversely affecting riparian vegetation, and allowing natural fluctuations in hydrographs to influence vegetation establishment and maintenance of channel systems. Each restoration project should be based on the best knowledge possible of the fluvial processes, geomorphology, and existing vegetation of that subbasin. Passive restoration involving protection and promotion of existing populations of native vegetation may be

more successful and cost effective than planting or engineering stream channels and riparian landscapes (Kauffman et al. 1997).

Riparian restoration projects often include planting of shrub and tree species. This study will not serve as a guide to planting activities because environmental conditions required for establishment of many species may not be reflected in the conditions observed in the current study, which focuses on mature vegetation. Environmental changes such as sediment deposition, litter buildup, and competition from other plants inhibit new seedling establishment on currently stable surfaces. Instead, this study might serve as a basis for passive restoration approaches by demonstrating interactions of some physical and biotic components in a relatively intact stream-floodplain ecosystem.

CHAPTER 3

Response of woody riparian species to cessation of cattle grazing,
Meadow Creek, Oregon

Danna J. Lytjen

ABSTRACT

In 1991 a study was initiated of the growth dynamics of woody riparian vegetation (cottonwoods, willows, and alders) following cessation of cattle grazing on a reach of Meadow Creek, Oregon, a tributary of the Grande Ronde River in the Columbia River system. Data on 265 tagged plants were first taken in summer 1991, after which three deer and elk exclosures were built adjacent to the creek. This study quantifies the growth response (height, crown volume, and biomass) of plants during the third and fourth years following cessation of cattle grazing, and for the overall four year period from 1991 to 1995. Tagged plants were divided into four groups by growth form for analysis: cottonwoods (*Populus balsamifera*, ssp. *trichocarpa*), alder (*Alnus incana* ssp. *tenuifolia*), “non-clonal” willows (*Salix boothii*, *S. bebbiana*, *S. drummondiana*, *S. lemmonii*, *S. lucida* ssp. *caudata*, *S. prolixa*), and “clonal” willows (*S. exigua* and *S. melanopsis*) which can form new ramets from the roots. Fifty permanent 25 m transects were established to track changes in woody plant density.

In 1995 mean height of cottonwood was 73 cm outside exclosures and 94 cm inside ($p=0.17$), height of non-clonal willows was 74 cm outside and 94 cm inside ($p=0.38$), and height of clonal willows was 71 cm outside exclosures and 115 cm inside ($p=0.00$). From 1991 to 1995 mean crown volume of cottonwoods increased over 1000% both inside and outside exclosures, while that of willow groups increased 162% to 522%. As of 1995, crown volume was significantly greater inside exclosures than outside exclosures only for clonal willows ($p=0.034$). Mean alder height increased by 111% (to a mean of 162 cm), and crown volume by 603% from 1991 to 1995. 1995 differences inside versus outside exclosures in mean height and crown volume of alders were not significant ($p=0.71$ and $p=0.88$, respectively). Density on transects increased by 294 stems, 161 of which occurred within 2 large clones of *Salix exigua*. Excluding these two clones, total woody plant density increased by 72% (133 plants) from 3.7 plants per 100 m² of transect in 1991 to 6.3 plants per 100 m² of transect in 1995.

The years 1994 and 1995 marked a slowing of net growth of all plants as well as decreased differences in growth inside versus outside of exclosures. Increased beaver

activity was responsible for part of the slowed growth. Beaver herbivory had a significant effect on height growth of cottonwoods in 1994 and in 1995, and on non-clonal willow height and crown volume growth in 1995. Deer and elk repeatedly browse nearly all cottonwoods and willows outside exclosures during the growing season. Differences inside and outside exclosures were reduced because of beaver activity and deer and elk browsing inside exclosures while the fence was down at stream crossings during the winter and spring.

INTRODUCTION

Impacts of more than a century of grazing in the Blue Mountains of northeastern Oregon include alterations of riparian vegetation and stream channel morphology (Case and Kauffman 1997, McIntosh et al. 1994). Along with overfishing and river damming, degraded headwater stream habitat has contributed to the loss of native fish populations in the Columbia River Basin. Removal of streamside vegetation and trampling of banks by domestic cattle has resulted in streams that are shallow and wide (Trimble 1994). Following changes in land management, recovering vegetation may begin to provide shade to the stream and contribute to channel bank accretion, channel narrowing and geomorphic complexity (Clifton 1989, Hupp 1992).

The shrub layer in temperate montane forests is an important component of structural diversity. This layer serves as cover, nesting habitat, and food for small mammals, insects and birds (Kauffman 1982, Taylor 1986). In riparian zones, shrubs are integral components of both terrestrial and stream habitat. Shrubs supply allochthonous material in the form of terrestrial insects, leaves, and fine woody debris that serve as the energy base for the instream aquatic biota (Cummins et al. 1989). Mid-summer insect biomass in river bank willows in Siberian tundra has been measured at 850 mg/m² (Bogatschova 1972). Stems and roots trap and hold sediments, narrowing channels and contributing to channel complexity (Clifton 1989, Trimble 1994). Shade from riparian vegetation prevents temperature extremes in summer and winter (Beschta et al. 1987,

Chisolm 1987, Li et al. 1994). In these ways, the structural diversity provided by riparian shrubs is related to species diversity and ecosystem functions.

Effects of domestic livestock grazing on vegetation composition, structure and ecosystem function have been observed worldwide (Belsky and Blumenthal 1995, Fleischner 1994, Putnam 1986). Selective herbivory and grazing tolerance or intolerance of plants may lead to plant community composition change and even vegetation type conversions. Overgrazing has led to invasions of woody vegetation in savannahs of Africa (Skarpe 1990), and changes from grass to shrub steppe in Argentina (Beeskow et al. 1995). In Finland and Scandinavia, increased size of semi-domestic reindeer (*Rangifer tarandus*) herds and fenced national boundaries preventing migration have led to a shift in composition from lichens and vascular plants to bryophytes, and significant decreases in exchangeable nutrients in the soil (Vare et al. 1996).

Upland exclosure studies in the western United States have found that herbivory by wild ungulates has sizable effects on plant community composition and structure. In Rocky Mountain National Park, browsing by elk (*Cervus elaphus*) prevented regeneration of aspen (*Populus tremuloides*) suckers outside of ungulate exclosures (Baker et al. 1997). Fluctuations in elk numbers, rather than climatic conditions, were correlated with origin dates for aspen cohorts. Studies of vegetation inside and outside of ungulate exclosures in the forests of Blue Mountains (Irwin et al. 1994) and the Washington Cascades (Hanley and Taber 1980) demonstrated that suppression of the shrub layer with increased conifer sapling density and grass/forb dominance occurred in areas browsed by wild ungulates.

Studies involving riparian systems show similar effects of grazing and browsing on deciduous woody species. For example, after 30 years of cattle exclusion in Colorado, willow canopy coverage was 8.5 times greater in protected areas than in grazed areas (Schulz and Leininger 1990). At Yellowstone National Park, mean height of willows inside exclosures was 274 cm and canopy coverage was 74%, while willows subject to heavy grazing pressure by elk outside of exclosures had mean heights of 34 cm and canopy coverage of 10% (Chadde and Kay 1991). Also in Yellowstone, high levels of elk herbivory were responsible for bushy growth form and mortality in narrow leaf

cottonwood (*Populus angustifolia*) (Keigley 1997). Overbrowsing was attributed to the high elk population resulting from a lack of predators (including humans), and loss of migration patterns that historically took herds away from the area for part of the year. Riparian zones in the Blue Mountains are utilized by domestic cattle, elk, mule deer (*Odocoileus hemionus*), and beaver (*Castor canadensis*) and like the uplands, may lack deciduous woody vegetation due to heavy use. Few studies have investigated the combined effects wild and domestic herbivores on woody riparian vegetation.

This study quantified the growth dynamics of woody riparian vegetation (cottonwoods, willows, and alders) following cessation of scheduled cattle grazing on a reach of Meadow Creek, Oregon. The study is additive to the work of Case and Kauffman (1997), begun in 1991 when cattle were fenced out of a 3.7 km reach and the nearby uplands. In the summer of 1991, data on 265 tagged plants were first taken, and in fall of 1991 three deer/elk exclosures were built adjacent to the creek. In 1991, the size of plants (height, crown volume, and biomass) within the (yet unbuilt) exclosure areas and outside of exclosure areas was similar, with the exception of non-clonal willows which were significantly taller outside than inside the proposed deer/elk exclosure areas. In 1993, after the first two years of the study, Case and Kauffman (1997) found that height and crown volume increased for all cottonwoods, alders, and willows whether they were inside or outside of deer/elk exclosures. Also, height of cottonwoods and willows increased significantly more inside than outside deer/elk exclosures. Willows increased significantly more in crown volume inside than outside exclosures.

This study was concerned with woody riparian plant recovery in the third and fourth years following cessation of cattle grazing, and for the overall four-year growth period from June 1991 to June 1995 on Meadow Creek. The objectives of my study were: (1) quantify growth of woody deciduous riparian vegetation subsequent to cessation of planned cattle grazing; (2) compare rates of growth of woody riparian vegetation within deer/elk exclosure fences and on adjacent areas accessible to deer and elk; and (3) quantify rates of woody plant establishment on streambanks and gravel deposits after cessation of cattle grazing.

METHODS

Site description

Meadow Creek, a tributary of the Grande Ronde River in the Columbia River, is located in the Blue Mountains of northeastern Oregon (Figure 2.1). The mountains, underlain by Columbia River basalts, are broad plateaus out of which canyons have formed through erosion by streams. The study area is approximately 3.7 km long and lies within the Starkey Experimental Forest (T03S, R43E, S29/33/34). The reach flows generally eastward and the elevation ranges from 1143 to 1200 m. Basin area at the study site is approximately 120 km². The highest elevation in the basin is 1532 m. Mean annual precipitation at the Starkey Experimental Forest weather station (1,260 m elevation) is 54 cm (weather records on file at PNW research lab, La Grande, Oregon). Most precipitation (>80%) falls between November and June; snowmelt begins in March or April and the runoff period usually extends into May.

The site is alternately constrained and unconstrained, consisting of a series of riparian meadows and conifer stands. The valley and surrounding slopes support mule deer and Rocky Mountain elk. Valley floor vegetation is quite variable: sedges dominate old channel areas, grass communities on high gravel bars and terraces, and forested patches of Engelmann spruce (*Picea engelmannii*), western larch (*Larix occidentalis*), and Douglas fir (*Pseudotsuga menziesii*) on elevated terraces, alluvial fans, and toeslopes. Streambanks are occupied by mountain alder (*Alnus incana* ssp. *tenuifolia*), various willow species (*Salix* spp.), and communities of sedges (*Carex* spp.) and grasses alternating with less vegetated gravel bars. The steep uplands are dominated by Douglas fir and grand fir (*Abies grandis*) on north-facing slopes and by open grasslands which alternate with Douglas fir and ponderosa pine (*Pinus ponderosa*) on south-facing slopes.

Meadow Creek has undergone considerable anthropogenic disturbance in the last 150 years. Logging activities included a railroad spur on the reach and a splash dam 1 km downstream of the study area (Skovlin 1991). Grazing by cattle has been heavy since the 1870's (Irwin et al. 1994). By the 1990's deciduous hardwood riparian vegetation in the

study reach remained in depauperate condition despite replanting efforts (Beschta et al. 1991). A fisheries enhancement effort in 1990 involved the placement of large anchored instream structures. In May 1991, many of the structures failed during a large storm event, causing further damage to banks and floodplains (Beschta et al. 1991). In places, former floodplains of fine sediments are now terraces overlain with gravels. The channel is wide and shallow, with little shade from streambanks or riparian vegetation.

Field methods

In 1991, a total of 265 riparian shrubs and trees were measured, mapped and permanently tagged within areas influenced by the channel and near secondary or old channels (Case 1995). The tagged plants included all of the detectable willows and black cottonwood seedlings, and many mountain alders. Fifty permanent shrub density transects were also established within the study reach. Since 1992, the entire reach has been accessible to big game except the areas within the three high fence exclosures. For this study, in June 1994 and June 1995, data for the surviving tagged shrubs (n=241) and data from the permanent transects were collected as follows:

1. Measurements for tagged shrubs follow the methods of Case (1995): height (Ht), width through the crown center on the longest axis (W1), width through the center perpendicular to the first width measurement (W2), diameter of the largest basal stem, and the number of basal stems. These data were used to calculate comparative rates of growth reflected in heights, crown volumes, and changes in biomass.

Elliptical crown area was estimated for each tagged plant as: $A = (\pi \times W1 \times W2) / 4$. Crown volume was estimated for each tagged plant as the elliptical crown area times height. Biomass for each tagged plant was estimated differently for each of the 4 plant groups using predictive equations of Case (1995):

$$\text{Cottonwood: } \ln(y) = -5.299 + 1.25 * \ln(\text{crown area})$$

$$\text{Non-clonal willows: } \ln(y) = -5.854 + 1.307 * \ln(\text{crown area})$$

$$\text{Clonal willows: } \ln(y) = -5.748 + 1.283 * \ln(\text{crown area})$$

$$\text{Alders: } \ln(y) = -6.587 + 1.444 * \ln(\text{crown area})$$

Gender was recorded for willows that bore catkins. Herbivory that occurred on the current years growth was recorded. The two herbivory types recorded were “elk/deer”, and “beaver”. These data were used with growth data to compare effects of herbivory by ungulates and beaver on plant growth, stature, and reproductive effort.

2. In 1991, fifty permanent 25 m transects were placed parallel to the stream and marked at each end with rebar (Case 1995). Each year, height and species were recorded for all shrubs and trees within one meter of either side of the transect line. From these data, changes in density and establishment of woody species was quantified.

3. To quantify seasonal growth and herbivory patterns outside the exclosures, 50 tagged shrubs were randomly selected for remeasurement of height at midsummer (late July), late summer (early September) and post winter (mid-May). These data were used to estimate the extent and timing of seasonal browsing by deer and elk.

Analysis

A growth year was considered to be the interval between annual measurements taken in June. Thus, between time of the original measurements taken in 1991 and June 1995 there were four growth years. Analyses were performed on data from the 241 tagged plants (out of 265) that could still be found at the end of the four years. For analysis, the tagged plants were divided by growth form and taxa into four functional groups. The groups consisted of 1) black cottonwood, 2) mountain alder, 3) “non-clonal willows” (*Salix boothii*, *S. bebbiana*, *S. drummondiana*, *S. lemmonii*, *S. lucida* ssp. *caudata*, *S. prolixa*) and 4) “clonal willows” (*S. exigua* and *S. melanopsis*) (synonymy and common names are listed in Appendix 1). The willows were divided into two groups based on differing life histories, habitat requirements, and growth habits. Non-clonal willows have a bushy non-spreading form. Clonal willows spread vegetatively by sprouting new ramets from their roots and are more closely associated with the stream channel than other species. Secondly, each group was divided into those plants inside deer/elk exclosures and those outside exclosures.

Non-parametric Mann-Whitney U tests were used to compare height, crown volume, and biomass variables of the four groups between treatments and years of interest. Within each group, the overall four-year differences in height, crown volume, and biomass (1991-1995) were used as a measure of recovery following cattle grazing. For plants inside and outside of exclosures, third-year growth (1993-1994) and fourth-year growth (1994-1995) were compared as a measure of the influence of deer and elk influence on vegetation recovery. Because of lack of independence in the samples, only indirect inferences could be made as to the effects of exclusion of grazing by cattle, deer, or elk. Summary statistics were used to quantify changes in transect density, reproductive effort, beaver impacts. Seasonal growth and herbivory patterns were summarized graphically.

Vascular plant nomenclature follows the Jepson Manual, Higher Plants of California (Hickman 1993) for the genera *Salix* and *Alnus*, and Flora of the Pacific Northwest (Hitchcock and Cronquist 1979) for all other taxa (synonymy of nomenclature between the floras and a species list for the study site are listed in Appendices 1 and 2).

RESULTS

Growth response of woody vegetation

For the four years of growth after the initial 1991 measurements, all groups inside and outside of deer/elk exclosures had significant within group gains in height, crown volume, and biomass ($p < 0.05$), with the exception of clonal willows outside exclosures which showed very little change (Figures 3.1 and 3.2). At the end the four year period of 1991-1995, for both types of willows height and crown volume inside exclosures had increased significantly more than outside exclosures (non-clones height $p < 0.01$ and crown volume $p = 0.05$, clones height $p < 0.01$ and crown volume $p < 0.01$) (Table 3.1). Cottonwoods did not show significant differences between plants inside and outside of exclosures in height ($p = 0.254$) or crown volume ($p = 0.173$) for the four year period.

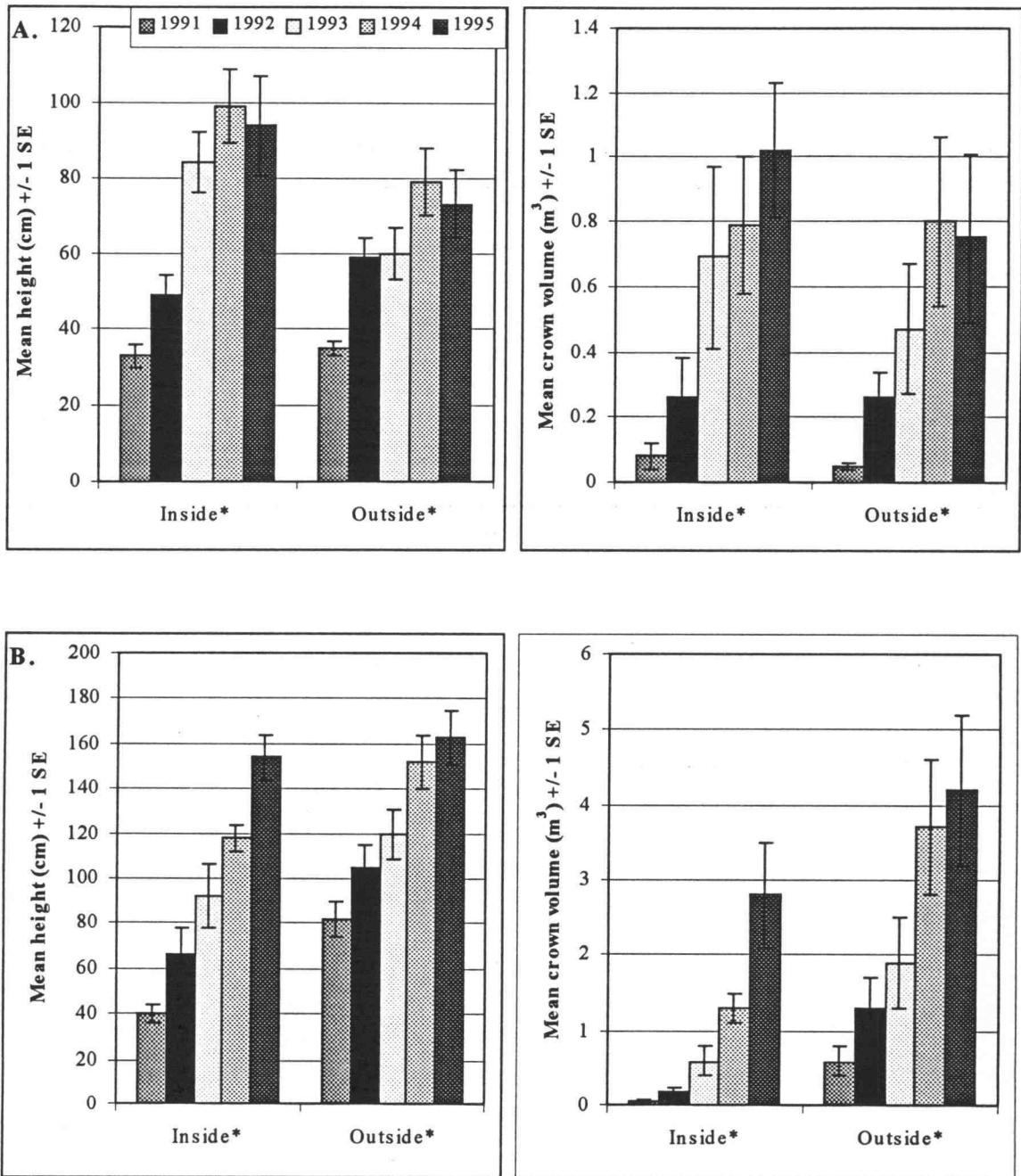


Figure 3.1. 1991 through 1995 mean height and crown volume of black cottonwoods (A) and alders (B) inside and outside of deer/elk exclosures at Meadow Creek, Oregon.

* Denotes significant within group difference between the 1991 and 1995 means.

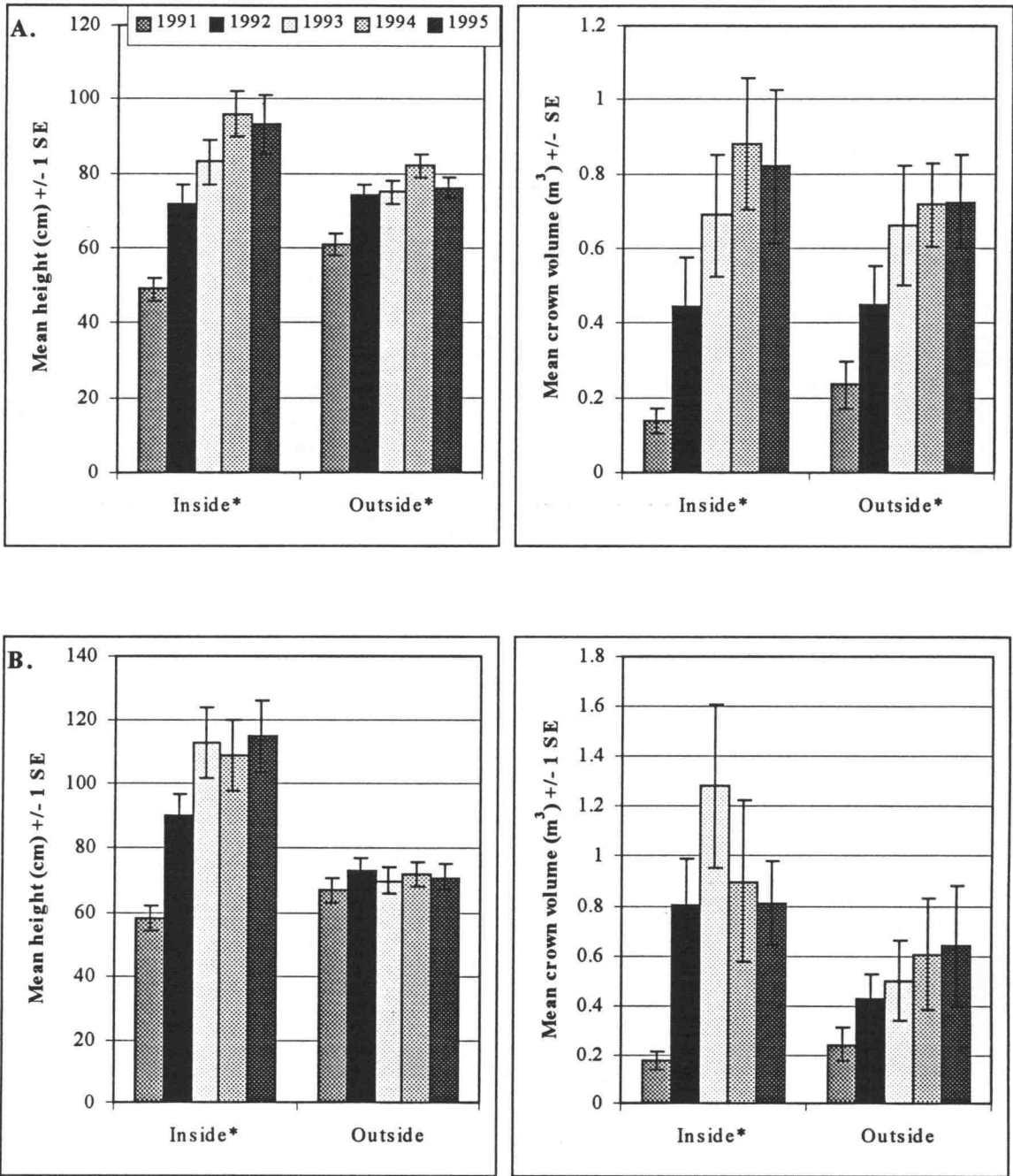


Figure 3.2. 1991 through 1995 mean height and crown volume of non-clonal willows (A) and clonal willows (B) inside and outside of deer/elk exclosures at Meadow Creek, Oregon. * Denotes significant within group difference between the 1991 and 1995 means.

Table 3.1. Mean and standard error (S.E.) of change in height and crown volume of tagged plants, inside and outside of deer/elk exclosures at Meadow Creek, Oregon, from 1991 to 1995. In=inside exclosures, Out=outside exclosures. Means that share the same subscript differ significantly ($p < 0.05$).

	n		Height (cm)				Crown volume (m ³)			
			In*		Out		In		Out	
	In	Out	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.
Cottonwoods	17	23	61	14	38	9.0	0.7	0.2	0.8	0.3
Alders	4	27	94	9.9	124	5.3	1.0	0.3	2.4	0.3
Non-clonal willows	19	95	44a	7.7	12a	3.6	0.7c	0.2	0.5c	0.1
Clonal willows	21	35	57b	11	4b	6.2	0.6d	0.2	0.4d	0.2

Over the four years, variation in height increased. Some plants grew while others remained small due to repeated herbivory. In 1991, 18 plants (7%) were over 1 meter height. In 1995, 88 plants (36%) were over 1 m height (Figure 3.3). Alders grew steadily throughout the study period and by 1995 mean height of alders had doubled to 1.6 meters, and mean crown volume had increased by 490%. In 1995, half of the 33 plants over 1.5 m height were alders, and 9 of the 12 plants over 2 m height were alders. Growth rates of the four small tagged alders inside exclosures and those outside exclosures were similar over the four year period.

Mean increase in biomass from 1991 to 1995 in tagged plants was lowest in clonal willows, and highest in alders (Table 3.2). Total biomass combined for all tagged plants increased by nearly 400% from 34.5 kg to 169.7 kg. There was no significant difference in the amount of biomass increase inside and outside exclosures for any of the groups for the four year period.

After the initial rapid growth response in the 1991-1993 period (Case 1995), the years 1994 and 1995 marked a slowing of net growth in cottonwoods and willows as well as less difference in growth between treatments (Figures 3.1, 3.2). Mean height and crown volume continued to increase for all groups through 1994, with the exception of clonal willows inside exclosures which lost crown volume and height between 1993 and

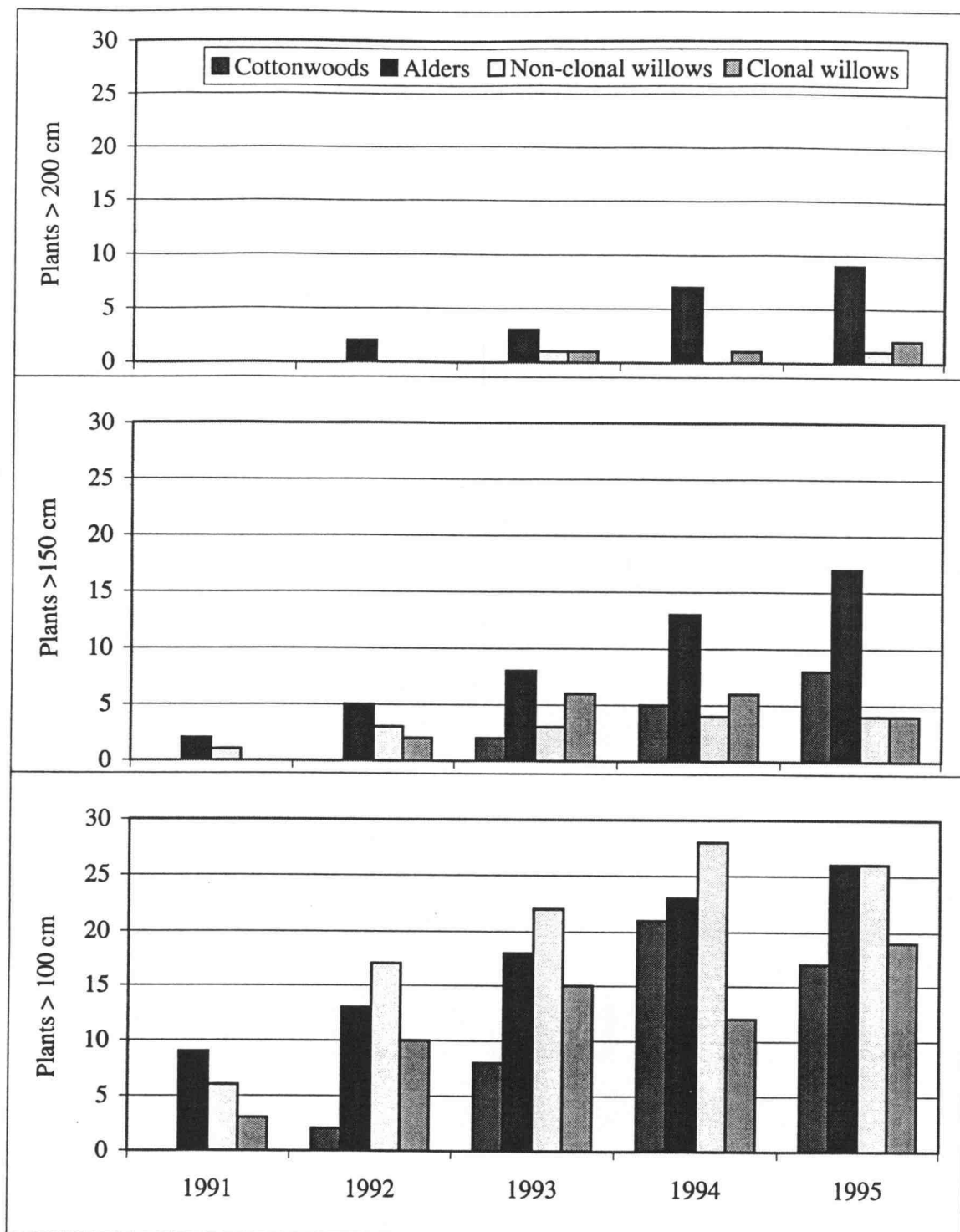


Figure 3.3. Number of plants taller than three height thresholds (100, 150, and 200 cm) at Meadow Creek, Oregon

Table 3.2. Mean biomass (g) of tagged plants on Meadow Creek, Oregon. Inside=inside exclosures, outside=outside exclosures.

Group	Treatment	n	1991	1995	Increase (%)
Cottonwoods	inside	17	71	471	570
	outside	23	43	332	670
Non-clonal willows	inside	19	91	402	370
	outside	95	110	363	230
Clonal willows	inside	21	83	254	210
	outside	35	118	411	250
Alders	inside	4	40	1905	4660
	outside	27	468	2951	540

1994. From 1994 to 1995 height, crown volume, and biomass showed no significant change for any groups except alders. The only significant difference between plants inside and outside exclosures was in clonal willows in 1994, when plants inside exclosures lost crown volume, and plants outside exclosures gained crown volume ($p < 0.05$). One dusky willow (*Salix melanopsis*) individual ("tag 13") in the outside group, had a unique form, consisting of tightly bunched ramets covering $>11 \text{ m}^2$. In 1995, this plant accounted for 33% of the crown volume, and 48% of the biomass of all tagged clonal willows outside of exclosures.

Herbivory

Mammal herbivory occurring inside and outside of the exclosures had a significant effect on plant growth. Grazing by trespass cattle occurred in the reach on numerous occasions each year. The intentional opening of exclosure fences at stream crossings during winter and spring (October to late June) as well as accidental breaches caused by floods and conifer blowdown on fences allowed browsing animals inside the largest of the exclosures. In 1995, 92% of all plants had been impacted during the previous growth year by deer, elk, trespass cattle, or beaver (Table 3.3).

Table 3.3. Summary of mammal herbivory in 1995 on Meadow Creek, Oregon.

	n	Number of plants			% of plants		
		None	Deer/elk	Beaver	None	Deer/elk	Beaver
Cottonwoods	40	4	27	21	10%	68%	53%
Alders	31	4	27	4	13%	87%	13%
Willows	170	12	138	49	7%	81%	29%
Outside exc.	180	2	173	43	1%	96%	24%
Inside exc.	61	12	25	31	20%	41%	51%
All plants	241	20	192	74	8%	80%	31%

Note: some plants were counted in both deer/elk and beaver columns.

The random subset of 50 tagged plants measured through the growing season (July and September) of in 1994, 1995, and 1996 showed peak height in July for willows followed by a loss in height in late summer, an even greater drop in height between September and June (Figure 3.4). On return visits during the spring and summer, the plants were often observed to have been recently browsed. Among the 50 plants alder growth rates were flat after July, and cottonwoods lost height in late summer in one year and gained in the other. Losses of height during late summer and winter counteracted some of the rapid growth that occurred in late spring and early summer. Summer losses were assumed to be from herbivory at a time when plant growth could not outpace browsing. Winter losses were from both the effects of flood scour and herbivory that occurred between mid-September and mid-June.

Beaver herbivory has increased within the reach during the course of the study. In 1991 only one plant was cut by beaver. Beaver did not substantially impact plants within exclosures until 1994 (Table 3.4). From 1992 to 1995 the number of plants impacted by beaver approximately doubled each year and cutting eventually extended throughout the study reach. In 1995, 31% of the tagged plants were impacted by beaver. In 1994 and 1995, height and crown volume growth of cottonwoods that were cut by beavers were significantly lower than those of cottonwoods not cut by beaver ($p < 0.01$). Non-clonal

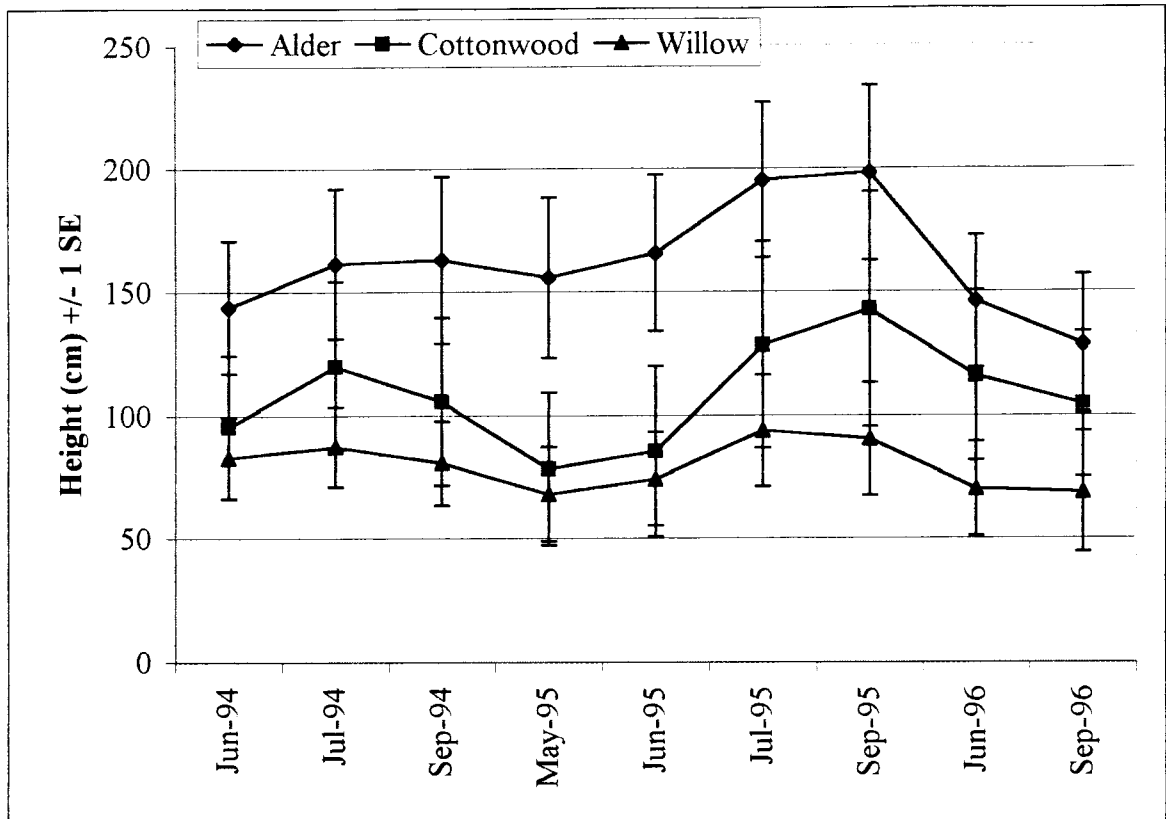


Figure 3.4. Seasonal pattern of heights of a subset of tagged plants at Meadow Creek, Oregon.

Table 3.4. Number of tagged plants cut by beaver 1991-1995 on study reach, Meadow Creek, Oregon.

Year	Inside exclosures	Outside exclosures	Total
1991	0	1	1
1992	0	11	11
1993	1	21	23
1994	22	26	48
1995	31	43	74

*total number of tagged plants = 241

willow height and crown volume were not affected by beaver cutting in 1994 ($p > 0.2$ for both), but were in 1995 ($p < 0.01$ for both). No effects of beaver cutting on height or crown volume growth were apparent for clonal willows either year. Beaver removed whole stems of willows but often left intact many catkin-bearing stems. Twenty six of 40 tagged cottonwoods were cut by beaver in 1995.

Reproductive effort and recruitment

Total catkin production in willows increased from 889 catkins in 1991 to 4044 catkins in 1995 (Table 3.5). The greatest increase in catkins was on female plants. By 1995, 64% of the tagged willows had not produced catkins. Because catkins of most species are produced near the tips of the current or previous year growth, reproductive stems of willows were often totally removed by browsing animals. Male catkins were observed in only four of the eight willow species present on the reach. The catkin ratio was strongly skewed towards females in dusky and shining willows. In species having male plants, the female:male ratio of plants was skewed towards females.

Shrub density on transects

Twenty five transects gained woody plant density, while 19 had no net change and 8 lost density (Table 3.6). The largest gain was by clonal willows on two transects which gained 161 stems, accounting for 55% of all gained stems. Excluding these two clones, total woody plant density increased by 72% (133 plants) from 3.7 plants per 100 m² of transect in 1991 to 6.3 plants per 100 m² of transect in 1995. The second largest gain was by alders which increased by 31 individuals over the transects. There were 3 fewer cottonwoods on transects in 1995 than in 1991. The frequency of all other shrub species, including red osier dogwood (*Cornus stolonifera*), hawthorn (*Crataegus douglasii*), stinking current (*Ribes hudsonianum*), Wood's rose (*Rosa woodsii*), serviceberry (*Amelanchier alnifolia*), and red raspberry (*Rubus idaeus*), doubled on transects by 1995.

Table 3.5. Sex ratios and catkin production of tagged willows on Meadow Creek, Oregon.

	Sex of plants				Number of catkins				Sex ratio of catkins 1995
	F	M	Unk.	F/M ratio	1991		1995		
					F	M	F	M	
Narrow-leaf willow <i>(Salix exigua)</i>	12	4	8	3	369	341	572	301	1.9
Dusky willow <i>(Salix melanopsis)</i>	17	7	9	2.4	121	4	1710	52	32.9
Shining willow <i>(Salix lucida)</i>	3	2	18	1.5	1	0	485	62	7.8
Mackenzie's willow <i>(Salix prolixa)</i>	7	0	28	na	49	0	710	0	na
Booth's willow <i>(Salix boothii)</i>	4	5	39	0.8	4	0	103	49	2.1
Drummond's willow <i>(Salix drummondiana)</i>	0	0	1	na	0	0	0	0	na
Lemmon's willow <i>(Salix lemmonii)</i>	0	0	4	na	0	0	0	0	na
Scouler's willow <i>(Salix scouleriana)</i>	0	0	2	na	0	0	0	0	na
Total catkins					889		4044		

Table 3.6. Number of plants of woody species (# plants/100 m²) on transects, Meadow Creek, Oregon.

Year	Cottonwood	Alder	Non-clonal	Clonal	Other	Total
			willows	willows		
1991	32	24	40	132	40	268
1995	29	55	45	351	82	562

DISCUSSION

In mountainous areas cattle prefer level riparian valley floors and avoid steep uplands (Roath and Krueger 1982). Before cattle exclusion on Meadow Creek, shrubs were heavily utilized by cattle (Case and Kauffman 1997). In a study of cattle diet on the Starkey Experimental Forest and Meadow Creek, cattle ate shrubs throughout the grazing season (approximately 20 June to 10 October) (Holechek et al. 1981). In late summer, cattle consumed 10 to 47% mature woody shrub material after succulent first year growth had been depleted. Elk diet is similar to that of cattle (Bruce Coblenz, Oregon State University, pers. com.). A study on the Starkey Forest found that elk diet consisted of 32% and 38% shrubs in consecutive years (Korfhage et al. 1980). After cattle were excluded from the Meadow Creek site, initial growth response of woody vegetation was positive (Case and Kauffman 1997). Elk and deer browsing and increasing beaver cutting apparently slowed the rate of growth between 1994 and 1995. Because of the lack of independence in the samples, only indirect inferences can be made that the cause of differences are because of the exclusion of cattle from the study reach, or of deer and elk within the exclosures.

It is probable that as woody plants recovered, deer and elk recognized a newly available food source in the Meadow Creek reach. The Meadow Creek reach is the only area not grazed by cattle in the Starkey experimental forest (Case and Kauffman 1997). Because Meadow Creek is within the Starkey Forest which is itself a large enclosure, density of elk and migratory patterns differ from those elsewhere in the Blue Mountains.

Recovery of woody species was greater inside the deer-elk exclosures on Meadow Creek over the four years of the study, but differences were probably lessened by browsing and beaver activity within the exclosures. The ridge line cattle fences around the study area were breached and cattle trespass occurred in September 1994 and again from mid-July to September 1995. The largest exclosure straddled the stream and had panels which were removed each year from October to June. Some deer and elk browsing inside the exclosure occurred in 1994 and 1995.

Increases in beaver population in Meadow Creek slowed vegetation recovery. The results of this study support other findings that beavers prefer willow and cottonwood and secondarily, alder (Hall 1960, Aleksiuik 1970). When resources are limited, beavers may deplete sources of food and then decline in numbers (Aleksiuik 1970, Bergerud and Miller 1977). On Meadow Creek, beaver use in 1995 was most apparent on cottonwoods. The <1 meter mean height of the cottonwoods belied their vigor. Many of plants were large and bushy in 1995. Mean basal stem diameter increased from 12 mm in 1991 to 28 mm in 1995, and up to 1 m of leader growth was noted on some cottonwoods in 1994 and 1995. Because of the capacity for rapid growth in young cottonwoods, protection of seedlings and saplings from beaver and large herbivores could produce a cohort of healthy trees in a short period of time.

Willow reproductive effort increased from approximately 900 catkins in 1991 to over 4000 catkins in 1995, most of the increase occurring in the two clonal willow species. Higher catkin output on the reach may be indicative of the increased stature and vigor of the plants. However, few willow seedlings were observed on the reach. The lack of seedlings may be due to the low numbers of male catkins producing pollen (Table 2.4), or that still higher seed production is needed to insure that some seed arrives at a suitable site.

Although many willows and cottonwoods grew rapidly on Meadow Creek, the upper branches were removed by repeated deer and elk browsing throughout the growing season. In willows, this pattern of browsing removed the catkin-bearing twigs, which in most species are borne on the tip branches of the current or previous years growth (Brunsfield and Johnson 1985). In Yellowstone National Park heavy browsing pressure by elk precluded seed production by willows, while inside exclosures, average willow seed production was 307,000 per m² (Chadde and Kay 1991). Suppression of sexually reproductive plant parts by either deer or elk browsing has been documented on Canada yew (*Taxus canadensis*) (Allison 1990), and upland deciduous shrubs in Yellowstone National Park (Kay 1994).

In riparian systems where mature willows and cottonwoods are abundant, large volumes of airborne seed are produced which may literally blanket the ground in the

spring (author's personal observation). Even under these conditions, recruitment and survival of willow and cottonwood seedlings occurs only occasionally (Stromberg et al. 1993, Bradley and Smith 1986, McBride and Strahan 1984). After spring floods, germinating seedlings require barren substrates and surface moisture for a few weeks until their roots contact the declining water table (Bradley and Smith 1986). The vast majority of seedlings are lost to summer drought or to inundation, scouring, and burial during later floods (McBride and Strahan 1984, Sacchi and Price 1992). High seed production enables willows and cottonwoods to persist in a shifting, disturbance-driven environment (Bradley and Smith 1986). On Meadow Creek, major floods and ice flows are common and occurred most recently in 1991. Moderate floods damaged 11 plants in 1994 and 33 plants in 1995, and by 1996 twenty-three tagged shrubs had died or washed away. Despite the availability of suitable substrates available for colonization after floods, very few willows or cottonwoods have established through sexual reproduction. Nevertheless, shrub density has doubled, mainly due to increased clonal expansion of the near-channel willow species, narrow-leaf willow (*S. exigua*) and dusky willow (*S. melanopsis*).

Alders, which are apparently much less palatable to deer and elk than to cattle, have made steady increases in height, crown volume, and biomass. Thirty one new alder seedlings appeared on transects, the greatest increase by sexual reproduction of any species. If rates of recovery continue to be substantially higher in alder than in other woody riparian species, an alder-dominated system will result. Reaches dominated by alders are not uncommon in the northern Blue Mountains (Crowe and Clausnitzer 1997).

Although large herds of domestic and wild ungulates may be desirable for meat production and for recreational hunting and viewing, their role in shaping ecosystem form and function needs to be recognized. High densities of elk, deer, and cattle exert selective browsing pressure that alters the composition and structure of vegetation in forests and riparian valleys (Alverson et al. 1988, Hanley and Taber 1980). Suppression of shrub communities by overbrowsing is symptomatic of high ungulate density. In the uplands of the Blue Mountains, Irwin et al. (1994) found that high elk density led to reduced shrub composition and structure and higher density of conifers. Lack of shrubs was in turn responsible for lowered nutritional health of the animals.

In the Blue Mountains and elsewhere in the West, a large number of stream restoration projects are being implemented with the goal of restoring fish habitat. Success of any restoration method can only be evaluated through diligent monitoring, beginning before projects are implemented and continuing for many years. Monitoring illuminates adjustments that may need to be made in project implementation and management practices. For example, impacts of such as beaver damage or cattle trespass on recovering vegetation can be addressed early if they are detected.

At Meadow Creek, high rates of shrub growth during the first two years of cattle exclusion demonstrated the apparent capacity of the vegetation to respond quickly to changes in management. However, continued monitoring revealed a reduction in woody vegetation growth rates as deer and elk keyed in on a newly available shrub resource and as beaver invaded the reach. Complete exclusion of cattle and some control over deer, elk, and beaver activity on the reach may be necessary to achieve more rapid recovery of woody riparian vegetation. Steady increases in biomass, height, and crown volume occurred for most tagged plants until 1995. If high growth rates resume, willows and cottonwoods may reach mature size providing shade and allochthonous inputs to the stream and increased structure to streambanks and floodplains.

CHAPTER 4 SUMMARY

In riparian systems of the Intermountain West, disturbances, both by fluvial processes and by herbivory, play dominant roles in shaping community composition and structure. The physical environment includes moisture, temperature, nutrient availability, and disturbance, such as removal of plants or parts of plants by flooding. Biotic influences include competition with other plants for resources, and removal of plant parts by herbivores. The two studies in this thesis, one on Catherine Creek and one on Meadow Creek of the Upper Grande Ronde River basin, quantified physical and biotic influences on woody riparian community composition and structure.

On Catherine Creek, elevation and geomorphology were the dominant factors influencing community composition and structure. From its headwaters in the Wallowa Mountains to the foothills of the Grande Ronde Valley, Catherine Creek descended 1219 m. Woody riparian plant species distributions were strongly correlated with the elevational gradient. Species ranges were assumed to be due in part to the response to orographic differences in temperature and precipitation. In the headwaters, conifers dominated and there were few shrubs. Deciduous cottonwoods, alders, and willows were common in the canyon and valley reaches between 1650 and 988 m elevation. Stream width and stream gradient were also correlated with elevation and extent of flood prone area increased with decreasing elevation.

Woody plant species were also strongly associated with geomorphic surfaces on a lateral gradient extending away from the stream. These surfaces were fluvial deposits laid down during floods and often further modified by subsequent floods. Plant species had colonized surfaces in differing patterns, apparently because of individual species' requirements for surface moisture, substrate type, access to groundwater, and tolerance of subsequent flooding. The taxa and geomorphic surfaces most important to the near-stream environment were *Salix* spp. and *Alnus* spp. on with annual floodplains, and *Populus balsamifera* on new and old gravel-cobble bars. *Pinus ponderosa*, normally a

dryland upland species was common within the riparian zone on elevated old boulder bars but was nearly absent on other surfaces.

Another major influence on composition and abundance of woody riparian species examined in this study was the biotic influence of mammal herbivory, particularly that of cattle, deer, elk, and beaver. Meadow Creek has been heavily grazed by domestic cattle for over a century. At Meadow Creek, the inability of woody riparian shrubs and trees to withstand excessive herbivory may have resulted in elimination of riparian woody vegetation from its structural role in the ecosystem. After domestic cattle grazing ended on the Meadow Creek study reach in 1991 woody deciduous vegetation responded with rapid growth in height and crown volume through 1993. In 1994 and 1995, growth slowed as herbivory by deer, elk and beaver increased.

For the overall 1991 to 1995 period all woody riparian vegetation had significant increases in height and crown volume growth except for clonal willows outside of deer and elk exclosures. For the same period cottonwoods and willows inside exclosures had significantly more height and crown volume growth than plants outside exclosures. Changes in height and crown volume during the intervals of 1993-1994 and 1994-1995 periods were not significantly different between plants inside and outside exclosures. Beaver cutting had a significant impact on height growth and crown volume growth of cottonwoods in 1994 and 1995, and on height and crown volume growth of non-clonal willows in 1995. Results indicated that reduced cattle herbivory allowed significant growth to occur in woody riparian vegetation despite the presence of deer, elk, and beaver. Excluding large ungulates resulted in significantly higher growth rates. Full and rapid recovery of woody riparian vegetation is desired on many streams in the West for improvement of stream habitat and may require increased control of large herbivores.

Riparian zones are geomorphic mosaics in both a spatial and a temporal sense. The results of this study highlight the importance of dynamic heterogeneity in the physical environment to the diversity and abundance of riparian woody plant species. Disturbances, such as floods, blowdown, snow avalanches, and fire periodically reshape the physical habitat. Riparian plant species are adapted to the effects of natural disturbances and their communities are rejuvenated and maintained by disturbance in a

dynamic shifting mosaic. Plant communities dominated by woody deciduous species are part of that environment, adding structural complexity to the physical environment and buffering streams from the physical extremes of weather and erosion.

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APPENDICES

Appendix 1. Synonymy for Betulaceae and Salicaceae encountered at Catherine Creek and Meadow Creek, Oregon. Jepson Manual = The Jepson Manual (Hickman 1993), Flora of the PNW = Flora of the Pacific Northwest (Hitchcock and Cronquist 1973).

Jepson Manual	Flora of the PNW	Common name
<i>Alnus incana</i> <i>ssp. tenuifolia</i>	<i>Alnus incana</i>	mountain alder
<i>Alnus viridis</i> <i>ssp. sinuata</i>	<i>Alnus sinuata</i>	Sitka alder
<i>Populus balsamifera</i> <i>ssp. trichocarpa</i>	<i>Populus trichocarpa</i>	black cottonwood
<i>Salix boothii</i>	<i>Salix myrtillifolia</i>	Booth's willow
<i>Salix exigua</i>	<i>Salix exigua</i> <i>ssp. exigua</i>	narrow leafed willow
<i>Salix lucida</i> <i>ssp. caudata</i>	<i>Salix lasiandra</i>	shining willow
<i>Salix melanopsis</i>	<i>Salix exigua</i> <i>ssp. melanopsis</i>	dusky willow
<i>Salix prolixa</i>	<i>Salix rigida</i> <i>var. mackenzieana</i>	Mackenzie willow

Appendix 2. Plant species identified in the study plots, Catherine Creek, Oregon.

Tree	
<i>Abies grandis</i>	<i>Salix exigua</i>
<i>Abies lasiocarpa</i>	<i>Salix lucida</i> ssp. <i>caudata</i>
<i>Betula occidentalis</i>	<i>Salix melanopsis</i>
<i>Larix occidentalis</i>	<i>Salix prolixa</i>
<i>Picea engelmannii</i>	<i>Salix scouleriana</i>
<i>Pinus contorta</i>	<i>Salix sitchensis</i>
<i>Pinus ponderosa</i>	<i>Sambucus cerulea</i>
<i>Populus balsamifera</i> ssp. <i>trichocarpa</i>	<i>Sorbus sitchensis</i>
<i>Pseudotsuga menziesii</i>	<i>Spiraea betulifolia</i>
<i>Tsuga mertensiana</i>	<i>Symphoricarpos alba</i>
<i>Salix alba</i>	<i>Vaccinium membranaceum</i>
<i>Pinus albicaulis</i>	<i>Vaccinium scoparium</i>
Shrub	Forb
<i>Acer glabrum</i>	<i>Achillea millefolium</i>
<i>Alnus incana</i> ssp. <i>tenuifolia</i>	<i>Aconitum columbianum</i>
<i>Alnus viridis</i> ssp. <i>sinuata</i>	<i>Actaea rubra</i>
<i>Amalanchier alnifolia</i>	<i>Adenocaulon bicolor</i>
<i>Ceanothus sanguineus</i>	<i>Agastache urticifolia</i>
<i>Ceanothus velutinus</i>	<i>Agoseris glauca</i>
<i>Cornus stolonifera</i>	<i>Allium validum</i>
<i>Crataegus douglasii</i>	<i>Anaphilis margaritacea</i>
<i>Holodiscus discolor</i>	<i>Anemone piperi</i>
<i>Ledum glandulosum</i>	<i>Angelica arguta</i>
<i>Lonicera involucrata</i>	<i>Antennaria microphylla</i>
<i>Lonicera utahensis</i>	<i>Arabis</i> sp.
<i>Pachistima myrsinites</i>	<i>Arenaria lateriflora</i>
<i>Philadelphus lewisii</i>	<i>Arenaria macrophylla</i>
<i>Physocarpus malvaceus</i>	<i>Arnica cordifolia</i>
<i>Ribes hudsonianum</i>	<i>Arnica diversifolia</i>
<i>Ribes lacustre</i>	<i>Arnica latifolia</i>
<i>Rosa gymnocarpa</i>	<i>Arnica longifolia</i>
<i>Rubus idaeus</i>	<i>Aster alpinus</i>
<i>Rubus parviflora</i>	<i>Aster foliaceus</i>
<i>Salix bebbiana</i>	<i>Athyrium filix-femina</i>
<i>Salix boothii</i>	<i>Cardamine cordifolia</i>
	<i>Circaea alpina</i>

Appendix 2, continued

Cirsium arvense
Clintonia uniflora
Collinsia parviflora
Corallorhiza striata
Cystopteris fragilis
Delphinium occidentale
Delphinium depauperatum
Dodecatheon alpinum
Draba crassifolia
Epilobium alpinum
Epilobium angustifolium
Epilobium glandulosum
Epilobium minutum
Equisetum arvense
Equisetum hymale
Erigeron speciosus
Fragaria virginiana
Galium aparine
Galium asperrimum
Galium bifolium
Galium trifidum
Geum macrophyllum
Gnaphalium palustre
Goodyera oblongifolia
Habenaria saccata
Hieracium albertinum
Hypericum gracile
Hypericum formosum
Lewisia triphylla
Ligusticum grayi
Linnaea borealis
Lupinus laxiflorus
Lupinus polyphyllus
Mertensia ciliata
Mimulus breweri
Mimulus guttatus
Mimulus lewisii
Mimulus moschatus
Mimulus primuloides
Mimulus tilingii
Mitella pentandra
Montia cordifolia
Montia linearis
Montia sibirica
Navarretia intertexta
Orobanche uniflora
Osmorhiza chilensis
Osmorhiza purpurea
Osmorhiza occidentale
Parnassia fimbriata
Penstemon rydbergii
Phyllodoce empetriformis
Plagiobothrys scouleri
Plantago major
Polemonium pulcherrimum
Polygonum douglasii
Polygonum kelloggii
Polygonum minimum
Potentilla flabellifolia
Prunella vulgaris
Pyrola asarifolia
Pyrola picta
Pyrola secunda
Pyrola uniflora
Ranunculus alismaefolius
Ranunculus orthorhynchus
Ranunculus populago
Ranunculus sp.
Ranunculus uncinatus
Rudbeckia occidentalis

Appendix 2, continued

Rumex acetosella
Rumex salicifolius
Sagina saginoides
Saxifraga arguta
Senecio cymbalarioides
Senecio triangularis
Silene menziesii
Smilacina stellata
Solidago canadensis
Stellaria longipes
Streptopus amplexifolius
Taraxacum officinale
Thalictrum occidentale
Trifolium longipes
Trifolium repens
Valeriana sitchensis
Veratrum viride
Veratrum californicum
Veronica americana
Veronica cusickii
Veronica serpyllifolia
Veronica wormskjoldii
Viola adunca
Viola glabella
Viola orbiculata
Viola palustris
Viola sp.

Graminoid

Agropyron caninum
Agrostis alba
Agrostis exarata
Agrostis idahoensis
Agrostis scabra
Agrostis variabilis
Bromus sp.
Bromus vulgaris

Calamagrostis rubescens
Carex aquatilis
Carex concinnoides
Carex deweyana
Carex disperma
Carex geyeri
Carex hoodii
Carex illota
Carex jonesii
Carex lanuginosa
Carex lenticularis
Carex luzulina
Carex microptera
Carex echinata
Carex neurophora
Carex nigricans
Carex scopulorum
Carex utriculata
Cinna latifolia
Deschampsia elongata
Deschampsia sp.
Eleocharis sp.
Elymus glaucus
Festuca occidentalis
Festuca rubra
Glyceria elata
Juncus drummondiana
Juncus ensifolius
Juncus mertensianus
Juncus tenuis
Luzula campestris
Muhlenbergia filiformis
Phalaris arundinacea
Phleum alpinum
Poa pratensis
Stipa occidentalis

Appendix 2, continued

Scirpus microcarpus

Trisetum canescens

Trisetum wolfii

Appendix 3. Plant species identified in the study plots, Meadow Creek, Oregon.

Tree	
<i>Populus balsamifera</i>	<i>Epilobium paniculatum</i>
Shrub	<i>Equisetum arvense</i>
<i>Alnus incana ssp. tenuifolia</i>	<i>Erigeron sp.</i>
<i>Amalanchier alnifolia</i>	<i>Euphorbia serpyllifolia</i>
<i>Cornus stolonifera</i>	<i>Fragaria vesca</i>
<i>Crataegus douglasii</i>	<i>Galium aparine</i>
<i>Ribes hudsonianum</i>	<i>Galium boreale</i>
<i>Ribes lacustre</i>	<i>Galium trifidum</i>
<i>Rosa woodsii</i>	<i>Gentiana simplex</i>
<i>Rubus idaeus</i>	<i>Geum macrophyllum</i>
<i>Salix boothii</i>	<i>Gnaphalium palustre</i>
<i>Salix exigua</i>	<i>Heterocodon rariflorum</i>
<i>Salix lemmonii</i>	<i>Hypericum anagalloides</i>
<i>Salix lucida ssp. caudata</i>	<i>Hypericum formosum</i>
<i>Salix melanopsis</i>	<i>Lactuca serriola</i>
<i>Salix prolixa</i>	<i>Lotus purshiana</i>
<i>Symphoricarpos albus</i>	<i>Madia glomerata</i>
Forb	<i>Medicago lupulina</i>
<i>Achillea millefolium</i>	<i>Mentha arvensis</i>
<i>Agastache urticifolia</i>	<i>Microseris heterophylla</i>
<i>Agoseris heterophylla</i>	<i>Microsteris gracilis</i>
<i>Antennaria microphylla</i>	<i>Mimulus guttatus</i>
<i>Arnica chamissonis</i>	<i>Mimulus moschatus</i>
<i>Artemisia ludoviciana</i>	<i>Monardella odoratissima</i>
<i>Aster foliaceus</i>	<i>Montia linearis</i>
<i>Capsella bursa-pastoris</i>	<i>Montia siberica</i>
<i>Cerastium arvense</i>	<i>Myosotis sp.</i>
<i>Cirsium arvense</i>	<i>Navarettia intertexta</i>
<i>Collinsia parviflora</i>	<i>Nemophila parviflora</i>
<i>Colomia linearis</i>	<i>Oenothera subacaulis</i>
<i>Conringia orientalis</i>	<i>Osmorhiza chilensis</i>
<i>Crypthantha sp.</i>	<i>Penstemon rydbergii</i>
<i>Descurainia pinnatifida</i>	<i>Plagiobothrys scouleri</i>
<i>Draba verna</i>	<i>Plantago major</i>
<i>Epilobium glandulosum</i>	<i>Polemonium occidentale</i>
	<i>Polygonum aviculare</i>

Appendix 3, continued

Polygonum douglasii
Portulaca oleracea
Potentilla glandulosa
Potentilla gracilis
Prunella vulgaris
Ranunculus orthorhynchus
Ranunculus uncinatus
Rorippa nasturtium-aquaticum
Rumex acetosella
Rumex crispus
Sagina saginoides
Sanguisorba minor
Sedum stenopetalum
Sidalcea oregana
Silene menziesii
Sisyrinchium angustifolium
Solidago canadensis
Stellaria longipes
Taraxacum officinale
Thermopsis montana
Tragopogon dubius
Trifolium cyathiferum
Trifolium dubium
Trifolium longipes
Trifolium repens
Trifolium wormskjoldii
Urtica dioica
Veratrum californicum
Verbascum thapsus
Veronica americana
Veronica peregrina
Veronica scutellata
Veronica serpyllifolia
Vicia americana
Viola palustris

Graminoid

Agropyron spicatum
Agrostis alba var. *stolonifera*
Agrostis thurberiana
Alopecurus pratensis
Bromus carinatus
Bromus commutatus
Bromus inermis
Bromus mollis
Bromus tectorum
Carex aquatilis
Carex arthrostachya
Carex canescens
Carex hoodii
Carex jonesii
Carex lanuginosa
Carex lenticularis
Carex microptera
Carex muricata
Danthonia californica
Danthonia intermedia
Deschampsia cespitosa
Deschampsia danthanoides
Deschampsia elongata
Eleocharis palustris
Elymus glaucus
Festuca idahoensis
Festuca rubra
Glyceria elata
Glyceria grandis
Juncus tenuis
Juncus balticus
Juncus bufonius
Juncus ensifolius
Phleum pratense
Poa compressa

Appendix 3, continued

Poa palustris

Poa pratensis

Puccinellia pauciflorus

Scirpus microcarpus

Stipa occidentalis