

AN ABSTRACT OF THE THESIS OF

Griffith J. Gilbert for the degree of Master of Science in Rangeland Ecology and Management presented on September 8, 2006.

Title: Habitat Parameters Associated With the Distribution of Seven Willow Species on a Stream in Southeastern Oregon.

Abstract approved:

Tamzen K. Stringham

Thirteen different habitat parameters were measured either quantitatively or qualitatively around seven different *Salix* (willow) species on a defined reach of stream on the southwestern slope of Steens Mountain in southeastern Oregon in order to both broaden the current information base of riparian ecology and inform future willow plantings aimed at improving riparian habitat. Willow species included in the research were: *S. lemmonii* (Lemmon willow), *S. scouleriana* (Scouler willow), *S. boothii* (Booth willow), *S. geyeriana* (Geyer willow), *S. exigua* (coyote willow), *S. lasiandra* (whiplash willow), and *S. lutea* (yellow willow). The habitat parameters measured were: height and distance of willow individual from stream channel bankfull elevation, stream channel slope, entrenchment ratio, width-to-depth ratio, watershed elevation, valley azimuth, valley width, soil rock size distribution, soil texture, and winter air temperature. Logistic regression models were built to describe probabilities of occurrence for five out of the seven willow species based on the habitat data collected. Multi-response permutation procedures were performed to describe differences between respective willow habitats.

Booth and Geyer willow habitats were best described by watershed elevation as these species dominated the research stream channel's upper reaches. Whiplash willow habitat was best described by stream channel entrenchment and width-to-depth ratio as this species occurred, on average, in habitats with high stream channel entrenchment and width-to-depth ratios. Specifically, the odds of whiplash willow occurrence are expected to increase by 17% with a unit increase in width-to-depth ratio. Yellow willow habitat was best described by watershed elevation and stream channel width-to-depth ratio as this species occurred only on the lower reaches of the research stream channel. Lemmon willow habitat was best described by interactions between watershed elevation and valley azimuth and between stream channel slope and width-to-depth ratio as the first of these interactions worked to create air temperatures favorable for species occurrence. Coyote willow habitat was best described by stream channel slope, entrenchment, and width-to-depth ratio as this species occurred, on average, in habitats with combinations of stream channel slopes, entrenchment, and width-to-depth ratios able to promote frequent streambank rejuvenation. Scouler willow habitat was best described by stream channel entrenchment ratio, as well as interactions between watershed elevation and valley azimuth and between stream channel slope and width-to-depth ratio. Specifically, the odds of Scouler willow occurrence are expected to decrease by 89% with a unit increase in entrenchment ratio. Scouler willow, on average, occurs in habitats with air temperature dynamics similar to those described above for Lemmon willow, and on hydraulically efficient stream channels with low entrenchment and width-to-depth ratios.

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Habitat Parameters Associated With the Distribution of Seven Willow Species on a
Stream in Southeastern Oregon

by
Griffith J. Gilbert

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

Griffith J. Gilbert, Author

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Habitat Parameters Associated With the Distribution of Seven Willow Species on a Stream in Southeastern Oregon

CHAPTER 1

Introduction

Context of the Research

Riparian Ecology

Riparian plant communities occupy a relatively small amount of the total area of western rangelands in the United States (Elmore and Beschta 1987, Malanson 1993, Naiman and Decamps 1997, Crowe et al. 2004). The ecological, economic, and social value of these communities, however, is relatively large and makes them essential components of their respective landscapes. Riparian zones support disproportionately high amounts of biomass per unit area of land (Brinson 1990, Crowe et al. 2004). This high primary productivity translates into valuable forage and habitat resources for many different animal species (Malanson 1993, Naiman and Decamps 1997). One of the most important functions of a riparian plant community is its significant contribution to a stream's structural stability (Naiman and Decamps 1997). In buffering stream banks from erosion, riparian plants actually promote channel aggradation and, over time, widening of the riparian zone itself. Riparian vegetation can also serve to substantially improve water quality by reducing nonpoint source pollution inputs to streams. Other important economic and social benefits provided by riparian ecosystems include recreational use, aesthetic enjoyment, and surface water supplies (Malanson 1993).

Anthropogenic alterations of riparian zones have impacted streamside vegetation communities across much of the western United States (Naiman and Decamps 1997). A loss of riparian plants can lead to a loss of many of the riparian zone functions and benefits described above. Therefore, the compositional and functional restoration of

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degraded riparian areas is being actively employed or sought after by both public land managers and private landowners (Naiman and Decamps 1997, Crowe et al. 2004). To be successful in rehabilitating a degraded system in a given setting, restoration efforts require a working knowledge of that setting (Beschta and Kauffman 2000). As Malanson (1993) claims, “One problem with the assessment of changes in the riparian landscape is knowledge of previous, or in some cases present, conditions” (p. 22). More recently, in 2004, Chambers et al. stated that riparian restoration and management “require an understanding of...the relationships among riparian vegetation and geomorphic and hydrologic processes” (p. 196). In other words, to increase the success rate of restoration efforts, it is imperative to know more about how riparian systems function, not just in a geomorphic or hydrologic sense, but ecologically as well. Riparian ecology can be defined as the active exchange between riparian plants and their environment that directs the evolution of both.

Topics of research meant to broaden the knowledge base of riparian ecology range from seed dispersal (Densmore and Zasada 1983) to soil waterlogging (Dionigi et al. 1985). More specifically, much of the research has focused on understanding riparian plant distributional patterns as related to environmental and physical influences. This body of literature centers largely on the role of flood dynamics and/or fluvial geomorphology in shaping plant communities (Teversham and Slaymaker 1976, Hupp 1983, Hupp and Osterkamp 1985, Harris 1988, Hudak and Ketcheson 1991, Stromberg et al. 1991). Vegetation distribution has also been examined in the light of other environmental and physical factors such as, elevation (Brunsfeld and Johnson 1985), several different edaphic features (Frye and Quinn 1979, Roelle and Gladwin 1999), and

even light availability (Hansen 1977). Each of these topics will be reviewed further in Chapter 2.

Willow Ecology

Relatively few of the topics mentioned above have been studied on riparian landscapes of eastern Oregon rangelands. Nonetheless, this arid region's watersheds support riparian vegetation that exhibits all of the vital riparian functions listed earlier. In 1987, Elmore and Beschta qualitatively described the region's watersheds as existing in a "far less productive state than their natural potential" (p. 261). In 2004, Crowe et al. echoed this perception in stating their opinion that "Decades of intensive use of riparian areas and other wetlands in central and eastern Oregon have caused substantial degradation of their ecological structure, composition and function" (p. 1). Elmore and Beschta (1987) also illuminated the crucial role of willow (*Salix* spp.) in eastern Oregon riparian systems, as it can (in combination with sedge and rush species) very competently perform the ecological services expected of riparian vegetation. However, twenty years later, the literature regarding the detailed ecology of this important riparian plant species in eastern Oregon is still somewhat limited.

Currently, the most detailed description of eastern Oregon willows is provided by Crowe et al. (2004) within their key (and accompanying descriptions) of riparian plant associations of central and eastern Oregon. This extensive document aids its user in classifying a riparian area's various vegetation communities by allowing for comparisons within a key of riparian plant associations (e.g., *Salix geyeriana/Calamagrostis canadensis* Association). The authors derived their classifications of plant associations by conducting field surveys of riparian plant stands that ranged in ecological status from

those in a mostly late seral successional stage down to some in a mid-seral successional stage. These surveys were not exhaustive and excluded most early successional communities in an attempt to characterize vegetation potential. Nevertheless, several plant associations (some willows included) of central and eastern Oregon were broadly described and assigned ranges within various classes of physical and environmental characteristics such as elevation, valley width, and soil type.

To gain a more detailed understanding of willow ecology (defined as the active exchange between plant and environment directing the evolution of both), one must measure the dynamic environmental and physical variables surrounding naturally occurring willow species (Karrenberg et al. 2002). Although in reality such measurable parameters certainly exert influence over one another, on paper each can be isolated, enabling one to infer associations of one or many of these parameters with individual willow occurrences. The environmental and physical habitat features one measures can range widely from temperature to physical landform. Ultimately, such an analysis results in habitat descriptions of the focal species and, overall, a more detailed understanding of willow ecology.

Objectives of the Research

The goal of this research was to reveal and describe the associations between a suite of environmental and physical characteristics and the occurrences of willow species on a watershed scale. The primary research question can be phrased in the following manner: “Does the environment influence willow occurrence?” The research then required a definition of “environment” in order to synthesize an answer. This definition included the most biologically important yet obtainable willow habitat descriptors on the research

watershed and focused on the potential effects of landform, geomorphology, elevation, aspect, soil, and temperature on willow species occurrence. In greater detail, the research objectives were to collect the following information at established willow individuals:

1. Height of willow individual from nearest stream channel bankfull elevation
2. Distance of willow individual from nearest stream channel bankfull elevation
3. Water surface slope of stream channel reach nearest to willow individual
4. Entrenchment ratio of stream channel reach nearest to willow individual
5. Width-to-depth ratio of stream channel reach nearest to willow individual
6. Elevation of willow individual
7. Azimuth of valley immediately surrounding willow individual
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9. Rock size distribution of soil sample taken from the first gravel layer contacted directly below willow individual
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11. Range of winter air temperatures for each willow species
12. Age class of willow individual
13. Species list of major upland and riparian plant species occurring near willow individual

Significance of the Research

The need for broadening the information base of riparian ecology was mentioned above as it pertained to riparian restoration work. This research aimed to provide some of that new information through habitat descriptions of several different willow species

distributed across the research watershed. This knowledge could then presumably be utilized by individuals or groups working to restore degraded riparian systems.

In particular, the research findings were expected to increase the success and efficiency of willow plantings aimed at improving riparian habitat. In their interdisciplinary technical guide McCluskey et al. (1983) refer to willow planting as “a valuable tool for restoring riparian habitat condition” (p. 2). These authors stress the importance, when undertaking such projects, of matching “the site characteristics to the species planted” (p. 7). They state that it is “critical that the willow species being planted match their environmental requirements” (p. 6). Before this step, however, the stream’s “potential for willow production (willow stands or remnants that are visible and identifiable to species at or near the project site)” must be understood (p. 4). McCluskey et al. realize that in some cases willow populations “have been totally eliminated” from the project area making both project initiation and species selection extremely difficult (p. 6). It was hoped that the research described here could assist planting projects by providing specific habitat descriptions and predictive statistical models for several different willow species. If one determined that the measurable habitat parameters at a project site matched the habitat parameters of a species described within this research, then perhaps one could use that species for a restoration planting.

Limitations of the Research

It is important to mention how far the results of this research can be extended into real-world scenarios, so as to ensure the clarification of observable ecological relationships. The predictive statistical models produced with this research’s data hold true only for the 107 research willow individuals included for observation on the research

watershed. It is possible that these models are applicable on other ecologically and climatically similar watersheds, but extreme caution should always be exercised when drawing comparisons.

CHAPTER 2

Literature Review

A Brief Life History of *Salix*

Willow shrubs and trees comprise what is known botanically as the genus *Salix*. The Latin *Salix* originates from the Celtic “sallis” – sal “near” and lis “water” (Newsholme 2002). *Salix* species are most often found in moist environments, but the genus exhibits a wide range of adaptability with some tree species thriving in river channels and other dwarf species surviving on mountain tops. Occurring mostly in the Northern Hemisphere, *Salix* contains roughly 450 species worldwide (Argus 1997). The genus appears in the tropics as well as the arctic, but is generally most prevalent in mainland North America, Europe, and Asia (Newsholme 2002). The peoples of these continents have found many uses for *Salix* species including basketry, medicine, fuel, and even the production of bats for the British-derived sport of cricket.

The willow’s ecological uses are as equally important as its anthropological ones. In riparian restoration work, willow “transplants are recommended because they are usually locally available, native, easily established, relatively inexpensive to plant, provide more stability to the site than many other woody plants, and grow rapidly” (Conroy and Svejcar 1991, p. 59), not to mention their great importance as wildlife habitat (Newsholme 2002). Overall, species of the genus *Salix* are recognized for their resiliency in dynamic riparian environments and their ability to buffer these systems against powerful physical forces.

Forces That Shape Willow Habitat

Distribution by Disturbance

The riparian environment shapes willow ecology through several forces, and one of the most characteristic of these is natural disturbance (Hupp 1983, Malanson 1993, Hughes 1997, Karrenberg et al. 2002). Specifically, this disturbance is the result of erosion and deposition of channel and floodplain sediment, which increase and decrease in rates according to fluctuations in stream discharge. The resulting disturbance regime is thought to heavily influence plant establishment and distribution throughout the riparian zone as it can frequently reorganize channel morphology, sediment composition, and moisture gradients (Hupp 1983, Stromberg et al. 1991, Hughes 1997, Karrenburg 2002, Dixon 2003). Vegetation distribution patterns are also affected by other biotic and abiotic factors mentioned below such as geomorphology, soil organic matter, elevation, and temperature.

The Role of Geomorphology

Flooding is the force that links riparian plant distribution with surrounding landforms, as it subjects both plant and land to constant change through space and time. Therefore, an examination of a riparian area's morphology and vegetation should, by association, implicate that area's characteristic flooding dynamics (Sigafos 1961, Teversham and Slaymaker 1976). Similarly, the response of vegetation to various geomorphological arrangements, which are largely resultant of flooding dynamics, can be deduced by observing riparian vegetation distribution within the context of its surrounding geomorphology (Frye and Quinn 1979, Hupp 1983, Hupp and Osterkamp 1985, Harris 1988, Hudak and Ketcheson 1991, Gregory et al. 1991, Hughes 1997). Numerous studies

have implicated the influence of channel and floodplain geomorphology on organizational patterns exhibited by the vegetation distributed throughout riparian zones.

Hupp and Osterkamp (1985) investigated the relationship between landform and woody plant species distribution. They also correlated flow duration and flooding frequency data with the species-landform association data, since these hydrological processes influenced by landforms are the variables that actually shape species patterns across landforms. Approximately one-third of the species they sampled were associated with landforms. *Salix nigra*, for example, occurred frequently on depositional bars and the channel shelf, but was rarely found on the floodplain or terraces. The authors concluded that “certain bottomland species of woody vegetation have predictable distribution patterns that correspond to observable fluvial landforms,” and that such patterns could indicate an area’s unique “hydrogeomorphic condition” (p. 677).

Furthermore, Tabacchi et al. (1998), citing Malanson (1993) and Naiman and Decamps (1997), warn that the use of a geomorphological model to generally analyze the relationship between vegetation and hydrology cannot substitute for a “particular system-specific study explaining stream-vegetation relationships, particularly if regional constraints on streams (e.g., desert climate) are strong” (p. 498). In other words, every stream system has evolved its own characteristic geomorphology according to the local hydrology and plant species present. Therefore, important contributions to the general understanding of distributional processes of vegetation can be offered by every individual stream system study.

The Role of Flood Magnitude and Frequency

Many factors dictate the hydrology exhibited by a particular watershed (Hughes 1997). Geomorphology both influences and is influenced by flooding, as it to some degree directs the path that floodwaters must take, but also experiences change as floodwaters reconfigure sediment throughout that same path. The local climate pattern also affects flood dynamics as it influences the annual hydrograph.

Discharge that causes a stream's stage to surpass its bankfull elevation creates what is termed a flood. A flood's magnitude is measured in volume, and flooding frequency describes how often a stream's discharge equals that volume measured. Illustrating discharge with hydrographs can allow for comparisons of various flood magnitudes over time, thus describing the frequency of each flood magnitude.

Both flood magnitude and frequency heavily influence distributional patterns of vegetation in the riparian zone (Brinson 1990, Hughes 1997, Naiman and Decamps 1997). The patterns eventually expressed by riparian vegetation in response to flooding events depend also on an area's geomorphology and species composition. Hughes (1997), citing Wolman and Miller (1960) points out that "In general, infrequent, high-magnitude floods are the most important geomorphic agents in determining channel form and have longer-lasting effects in semi-arid regions..." (p. 510), but a flood's influence on geomorphology may also be largely determined by a channel's geologic constraints. Both low and high-magnitude floods affect riparian ecosystem structure through either destructive (e.g., erosion and plant mortality) or constructive (e.g., sediment deposition) processes. Flood magnitudes and frequencies are channel-specific and can be related to observable spatial patterns in a channel's riparian plant community.

By linking streamgage data with a stream's stage readings and cross-sectional profile data, Chapin et al. (2000) were able to quantify flood frequencies for events of various magnitudes on multiple streams within the same basin. Then, the presence or absence of various plant species community types (e.g., willow-sedge community type) were recorded with their floodplain elevations relative to a benchmark used in channel cross-sections. A high correlation was found between plant distribution and floodplain elevation as well as between peak stream flows and upper limits of the riparian zone. The peak stream flow required to flood the riparian zone (i.e., reach the upper limits) was estimated as having a return interval of roughly 3 to 7 years throughout the basin. Return intervals could then be estimated for various plant community types based upon the associated floodplain elevations. For example, community types dominated by willow were associated with floodplain elevations exhibiting an average return interval of 3.5 years, indicating that distributional mechanisms of willow dominated community types were controlled by less frequent floods than species at the channel edge exhibiting return intervals of 2 years or less. The authors suggest that this relationship reflects the balance willow communities require between flooding for recruitment (via the creation of bare soils and/or dispersal of broken twigs) and a long enough return interval for establishment purposes.

In support of this idea are the results of a study by Hupp (1983) who associated vegetation patterns across a floodplain with plant age, flood-damaged plant parts, and flood frequencies. He observed that flood tolerance increased closer to the channel edge as woody plant occurrence decreased. The destructive forces of flooding strongly limited plant survival and heavily influenced vegetation patterns observed.

The Role of Fluvial Morphology

The interaction between flooding and geomorphology can be understood within the context of important factors controlling the interaction's outcome. For example, stream grade (Hupp 1982), channel width-to-depth ratio (Baker 1989, Danzer 1996), and valley type (Irvine and West 1979, Harris 1988) are variables that can be measured to provide a basis for understanding the fluvial and morphological processes influencing riparian vegetation distribution.

More specifically, discharge, which is a function of channel area and flow velocity, is affected by a stream's grade or slope. As Hupp (1982) states "Given a relatively constant discharge, variation in stream grade changes the proportion each factor [width, depth, and velocity] contributes to discharge" (p. 488). A shift in the way these factors interact can lead to changes in the channel's hydrology and/or morphology, which can then pattern vegetation distribution. Stream power (i.e. slope times discharge) is the vehicle driving this change. Hupp (1982) illustrated this in a study that compared the stream grade and vegetation of six reaches on the same stream. Upper reaches of the stream were low grade and slow-moving with cut banks that isolated the channel from the floodplain. The grade increased in lower reaches and the banks were not as steep or defined. The stream's morphology was thought to result primarily from a soft shale underlying the upper reaches and a relatively resistant sandstone in the lower reaches. Vegetation differed in composition and diversity between these two different sets of conditions. Vegetation of the lower reaches was believed to have been influenced by more frequent disturbance brought on by the increase in stream power. Reaches above exhibited less power, so vegetation there was more stable and mature, but less diverse. The area's

underlying geology played an important role here as it affected the degree to which hydrology influenced streambank morphology.

Fluvial morphology on a broader scale, as it relates to a stream channel's valley, is also heavily influenced by geology. Harris (1988) conducted a study associating stream valley type with riparian vegetation. He segmented streams into units of homogeneous geomorphology and attributed a valley type (e.g., U-shaped glaciated bedrock, V-shaped incised in till, etc.) to each segment. He then sampled vegetation within segments and described the associations he found between plant occurrence and valley geomorphology. For instance, the *Salix* spp.-*Glyceria striata* vegetation type was associated with U-shaped bedrock valleys.

Additional Habitat Features

Soil

Among the many requirements riparian vegetation has for establishment on stream banks or the floodplain, available moisture is unquestionably one of the most important (Hansen 1977, Sacchi and Price 1992, Kranjcec et al. 1998). Some of the major physical agents that dictate how well this requirement is met include the various properties of soil in the riparian zone. Soil texture, sediment size, and soil depth all control the moisture regime of riparian vegetation communities. While these relationships between soil factors and soil moisture have been demonstrated (Wolfe and Pittillo 1977, Frye and Quinn 1979, McBride and Strahan 1984, Dionigi et al. 1985, Sacchi and Price 1992), Hughes (1997) points out that a stream's hydroperiod still has the most direct influence on vegetation distribution. Nonetheless, water movement and/or retention in soil, as

directed by soil physical factors per se, exert strong distributional forces on riparian vegetation.

Frye and Quinn (1979) conducted a thorough investigation of a floodplain's soils to make correlations between the soil and the floodplain's vegetation. After comprehensive sampling of the riparian vegetation, they measured height of the water table, surface soil moisture content, soil texture, soil pH and cation exchange capacity (CEC). Differences in the position of the water table were the measurements that best described vegetation differences across the floodplain. Specifically, the lower floodplain was poorly drained while higher floodplain elevations were well-aerated allowing for a better root area distribution and greater plant species richness, diversity, and total cover farther from the channel. Surface soil moisture may have also been important with lower areas exhibiting higher surface moisture content.

Tolerance to anoxia in two co-occurring willow species was studied by Dionigi et al. (1985). They conducted a field survey as well as greenhouse experiments to investigate the relative tolerances to soil waterlogging of *Salix exigua* and *Salix nigra*. First, vegetation measurements, including floodplain elevations, were associated with stream stage data to illustrate the preference by each species for either lower, wetter sites or higher, drier sites. Leaf energy status (expressed as adenylate energy charge) was measured in randomly sampled individuals across the floodplain and used as an indication of sublethal stress from soil waterlogging. Measurements in the field and from greenhouse experiments suggest that while both willow species prefer open, moist areas, *S. nigra* better tolerates anoxic soil conditions and can be found in longer inundated areas of the floodplain.

Inundation duration in any given portion of the riparian zone depends not only on hydrology, but also upon the soil textures and sediment sizes present (Johnson et al. 1976, Wolfe and Pittillo 1977, McBride and Strahan 1984). Soil texture and organic matter content were measured within stands of sampled riparian vegetation on the Missouri River floodplain by Johnson et al. (1976). They found that cottonwood stands were correlated with soils high in percent sand and low in organic matter content. Elm stands, on the other hand, were associated with finer textured soils higher in organic matter content. These relationships are reflective of the relative floodplain elevations associated with each species. That is, young cottonwoods, a pioneer tree species, formed stands lower down in the path of floodwaters, whereas mature well-established elm stands were found in upper floodplain areas.

When comparing substrate preferences of two pioneer species, willow and cottonwood, McBride and Strahan (1984) found that willow species established in areas with sediment less than 0.2 cm in diameter, while cottonwoods established in areas with larger sediment sizes. They attribute this pattern to the differential seed dispersals and subsequent requirements for germination and seedling growth of each species. Willow dispersal occurred later than that of cottonwood, so only sandy areas could support willow establishment in the drier conditions of early summer, whereas cottonwood dispersed earlier in late spring and was therefore able to establish in gravels.

Elevation

As a stream flows from its headwaters to its confluence with a larger channel it progressively descends from higher to lower elevations. This change in elevation is accompanied by changes in the environmental and physical factors affecting streamside

vegetation, and a concomitant shift in vegetation patterns can be observed (Campbell and Green 1968, Whittaker and Niering 1975, Brunsfeld and Johnson 1985, Harris 1988, Danzer 1996). Species distribution can be described then in terms of an elevation gradient.

Along several drainages in Idaho, Brunsfeld and Johnson (1985) described the relative ranges of elevation in which they observed several different willow species. For example, they recorded *Salix exigua* in environments from 3,000 to about 5,000 feet, while *Salix lemmonii* occurred from about 7,000 to 9,000 feet on average across sampled drainages.

Light

Solar radiation varies in duration and intensity throughout a given watershed as sunlight interacts with topography to create areas of exposure ranging from zero to full, and intensities ranging from low to high. The interception of incoming solar radiation is of vital importance to the success of *Salix* species, just as it is with most autotrophic organisms (Raven 1992). However, the influences of aspect and subsequent light intensities on riparian vegetation distribution are not well documented or understood.

Hansen (1977) measured the amount of direct sunlight at sites along a stream in Utah where he also sampled vegetation. He concluded that the effects of shading from adjacent topography on vegetation distribution are subtle overall and more pronounced in the understory species. Danzer (1996) mentions the importance of aspect in affecting plant community composition through its influence on a site's solar irradiation, soil moisture, and evaporative potential. Citing McLaughlin's (1992) reanalysis of data from Shreve (1924), Danzer explains that at elevations above 2,134 meters aspect plays a

larger role than elevational change in explaining variation in plant community composition.

Temperature

Both elevation and solar irradiation are two of several factors that combine to determine local air and soil temperatures associated with a given vegetation community. Whether through freezing tolerance or control of evapotranspiration, temperature significantly influences a plant's physiology, in turn affecting growth and subsequent distributional patterns (Woodward 1988, Hastings and Turner 2003). Riparian vegetation communities have been described as exhibiting amplitudes of minimum to maximum temperatures that correspond with both elevational ranges and moisture requirements (Campbell and Green 1968, Hansen 1977, Brunsfeld and Johnson 1985, Raven 1992, Danzer 1996). The relationship between air temperature and elevation along streams can be deceptive as cold-air drainage (i.e., the flood of cold dense air down slope via canyons and valleys) occurs in areas at night. Hastings and Turner (2003) note that in the Sonoran Desert due to cold-air drainage "trees may descend along streams as much as 3,000 feet below their lowest occurrence on north slopes" (p. 15).

Temperature of the soil can also be correlated to changes in elevation with a general decline being noted as elevation increases. Brunsfeld and Johnson (1985) mention the importance of soil temperatures as related to moisture and plant stand differentiation as they observed that "...at an elevation of 8575 feet, for example, the wet sandy stream edge soil dominated by *Salix drummondiana* was 2.8 °C colder at 30 cm on July 14 than the drier, silty soil of the immediately adjacent bench totally occupied by *S. wolfii*" (p. 9).

Soil temperature plays an important role in the germination of willow seeds, and thus their establishment and observed distributional patterns (Raven 1992).

In summary, many of the above parameters inherently influence one another on the landscape, but most can be measured independently, enabling research to view associations between one or many of these factors and subsequent patterns of plant distribution. By performing such research in the context of willow habitats, conclusions might be reached that expand the current understanding of willow ecology. It is perhaps research's primary tenet that new information can lead to the solutions of both old and new problems.

CHAPTER 3

Materials and Methods

The Research Area

The research watershed is located on Steens Mountain in southeastern Oregon at the northernmost extent of the vast interior area of the United States known as the Great Basin. Volcanism, faulting, and glaciation have directed the geologic history of Steens Mountain and left its present elevation at 2,950 meters above sea level (Mansfield 2000). On a topographic map it is evident that the research stream heads just above 2000 meters on the southwestern slope of Steens Mountain. It falls 920 meters in elevation as it flows southwest and then due west through approximately 25 kilometers of canyons and meadows eventually into the Catlow Valley. The research reach is confined to the uppermost elevations of the research stream and extends from 2000 meters elevation down to a fence line roughly 8 kilometers away and 460 meters below the headwater spring.

As described by Anderson et al. (1998) the High Desert Ecological Province (which includes Steens Mountain) exhibits a dry climate with cold and hot extremes. Average annual precipitation at Frenchglen (at the base of Steens Mountain) is 30 centimeters, falling mostly in the winter and much of it as snow. The area's average maximum and minimum temperatures for April to June are 68 °F and 35 °F, respectively (Anderson et al. 1998).

According to Mansfield (2000), *Salix* comprises one of the largest floristic genera on Steens Mountain with 20 of its species represented. Mansfield observed that "Trees and shrubs in the cottonwood and willow genera predominate in every riparian area in the

region” (p. 301). While not all riparian areas of the region have been surveyed, this statement nonetheless demonstrates the local importance of these two genera, as Mansfield’s publication is by far the most thorough floristic record of Steens Mountain and the surrounding area. Riparian zones extend throughout the Steens Mountain landscape supporting not only *Populus* and *Salix* species, but also *Alnus*, *Prunus*, and many herbaceous species. Adjacent uplands are dominated by the various subspecies of *Artemisia tridentata* and several species of native bunchgrasses.

Livestock use on Steens Mountain has been historically intensive (Petersen 2004 citing Griffiths 1902). The research reach, however, has not been grazed by livestock since 2001, excepting occasional visitation while moving cattle to higher ground. Currently, many different species of wildlife such as mule deer, red-tailed hawks, pronghorn antelope, and bushy-tailed woodrats use the area’s habitat and food resources.

Data Collection

Reconnaissance

Visits to the research area began in the spring of 2005 to explore the research reach and identify the willow species present. Several samples having pistillate aments (i.e., female flowers) from willow individuals were collected for species identification under magnification offsite using the published dichotomous key “Field guide to the willows of east-central Idaho” by Brunfeld and Johnson (1985). This key was developed relatively close to the research area and offered an impressive level of detail for both the vegetative and reproductive anatomy of several local willow species. Individuals sampled were given a number and flagged to enable future visits. Their position on the landscape was marked using a Trimble Pathfinder Pro© Global Positioning System (GPS) unit with sub-

meter resolution. Willow species identification became progressively easier with practice, which facilitated the recording of the locations of hundreds of willow individuals along the research reach using the GPS unit.

These points of willow individuals were overlaid with aerial photographs of the research watershed using GIS software tools. Together, these maps comprised a good representation of willow species occurrences both within and across all willow stands on the research reach. The maps aided in the process of selecting research individuals by visually depicting the geospatial range of each willow species and revealing patterns of willow species distributions. The decision to select a given willow individual for research was based on a combination of the maps explained above with the field-based methods described below. (A map of the research watershed illustrating the relative position of each research clump was drawn to scale and is included in Appendix A).

Selection of Research Willows

In order to capably describe the physical habitats of each willow species on the research reach it was critical to account for the maximum possible variation within each of the habitat parameters measured among all of the willow species encountered. Thus, from the outset of field work, the overarching goal of describing the full range of habitat variability directed the selection of research willows. To begin accomplishing this at the broadest possible scale, changes in valley morphology were assessed throughout the research watershed following the methods of a Rosgen (1996) Level I stream classification.

In his book *Applied River Morphology* (1996), Rosgen explains four assessment levels of stream classification, starting with that at the broadest scale and moving down to

a very detailed final description. Level 1 is known as a Geomorphic Characterization of the stream and includes making associations between surrounding valley morphology and the major stream types, “A” through “G”. Rosgen describes eleven different valley types (e.g. “u-shaped”, “v-shaped”, “fault-line”, etc.) and the stream types expected to be observed within them. These descriptive data were used to observe the distribution of differing valley and stream characteristics over the entire research reach. Combining these descriptive data with the willow occurrence maps began to reveal certain willow individuals as potential research individuals due to their location in relation to the different valley types present.

The Level 1 classification also supported a Level 2 stream classification by roughly outlining the potential major stream types present on the research reach. Level 2 is known as a Morphological Description of the stream and includes a direct assessment of five major stream channel characteristics (entrenchment ratio, width/depth ratio, sinuosity, slope, and dominant channel materials) on a length of stream equal to 20 – 30 times its width. This assessment results in finer-detailed stream classifications down to sub-divisions of the major stream types A through G. (A classification key for these stream types can be found in Appendix B). After establishing the research reach’s predominant stream types willow selection began by ensuring that the research individuals selected represented each valley and stream type present on the research watershed, since not all willow individuals present could be selected for research. That is, it was a goal of willow selection to include species habitat descriptions from each valley and stream type on the research reach, if possible.

Willow individuals were then selected for research starting at the lowest elevation and working towards the top of the research reach. Each willow individual was considered for inclusion in the research dataset based on the goal to maximize the variation within each of the habitat parameters to be measured, as mentioned above. Once neighboring willow individuals were selected for research they were incorporated into units named “clumps”. A clump’s dimensions were defined by the length of stream measured to produce a clump’s stream channel slope value (i.e., 30 times the stream channel width) and the width of valley bottom measured to produce a clump’s valley width value (i.e., from toe-slope to toe-slope) plus any distance extending beyond that resulting from the occurrence of a willow individual. Thus, clumps were not uniform across the research reach. The new term “clump reach” will be used hereafter to define the section of the research reach used to obtain measurements of habitat parameters.

Six quantitative habitat parameters were measured at the level of the clump, while seven other quantitative habitat parameters were measured at the level of the willow individual. The goal of describing the full range of possibilities for each of these parameters within each willow species directed the decision to select or not select a willow individual for research. In terms of a given species, coyote willow (*Salix exigua*) for example, it was necessary to include the coyote willow individual of the lowest elevation, as well as that of the highest; the individual furthest from the channel, as well as the closest; the individual of the steepest stream channel slope and that of the flattest, and so-on for each quantitative habitat parameter measured. After being selected, a willow individual was given an identity according to its four letter species code (e.g., SAEX for *Salix exigua*) and a number (e.g., SAEX 1 for the first *Salix exigua*

encountered). This alphanumeric identity was marked on a write-on aluminum tag and fastened to a branch of the research willow individual with wire.

Measurement of Habitat Parameters

1. Height of willow individual from nearest stream channel bankfull elevation. In the research's first objective the question was asked, "Do the relative heights above or below a stream channel's bankfull elevation of the individuals of a given willow species significantly differ from those of the individuals of another species?" To answer this question, the height of each research individual relative to the nearest clump reach channel bankfull elevation was measured. For an understanding of bankfull elevation refer to Rosgen (1996).

First, after willow individuals were selected, bankfull elevations were marked with pinflags at several locations (at least four) along the clump reach channel. The height value was obtained by using a surveyor's level mounted on a tripod in concert with a surveyor's rod held both at the center of the base of the research willow individual and at the bankfull elevation of the point on the clump reach channel bank nearest the willow individual. This resulted in a rod reading in meters for both locations. The willow rod reading was then subtracted from the bankfull elevation rod reading to produce the height of the willow individual from the nearest stream channel bankfull elevation.

2. Distance of willow individual from nearest stream channel bankfull elevation. The second objective asked the question, "Do the relative distances from a stream channel's bankfull elevation of the individuals of a given willow species significantly differ from those of the individuals of another willow species?" To answer this question, the distance of each research individual from the nearest clump reach channel bankfull

elevation was measured. Specifically, for a given research individual, the same bankfull point used in the height measurement above was used for the distance measurement.

First, a straight, 1.5 m-long PVC pole was held perpendicular to the ground with its base directly at the bankfull elevation. Another person then extended meter tape from the center of the base of the research individual towards the PVC pole at bankfull. The intersection of the tape and the pole revealed the distance of the willow individual from the nearest stream channel bankfull elevation.

3. Water surface slope of stream channel reach nearest to willow individual. The third objective asked the question, “Does a relationship exist between a stream channel’s slope and the occurrence of a willow species in, on, or near that channel?” To answer this question, the water surface slope (%) of the nearest clump reach channel was measured following the methods of Rosgen (1996).

4. Entrenchment ratio of stream channel reach nearest to willow individual. The fourth objective asked the question, “Does a relationship exist between a stream channel’s entrenchment ratio (ER) and the occurrence of a willow species in, on, or near that channel?” To answer this question, the ER of the nearest clump reach channel was measured in channel cross-section following the methods of Rosgen (1996). Rosgen describes ER as “the vertical containment of the river” (p. 5-19). Specifically, it “is the ratio of the width of the flood-prone area to the surface width of the bankfull channel” (p. 5-19). It was measured using a surveyor’s level and rod along the most representative clump reach channel cross-section. “Representative” is defined here as exhibiting the dominant geomorphology of the surrounding channel and excluding obvious artificially disturbed sections.

5. Width-to-depth ratio of stream channel reach nearest to willow individual. The fifth objective asked the question, “Does a relationship exist between a stream channel’s width-to-depth ratio (W/D) and the occurrence of a willow species in, on, or near that channel?” To answer this question, the W/D of the nearest clump reach channel was measured following the methods of Rosgen (1996). Rosgen defines W/D as “the ratio of the bankfull surface width to the mean depth of the bankfull channel” (p. 5-21). For each clump reach, the exact same rod readings (10 readings from one bankfull mark to the other) achieved in the cross-section for ER were used to calculate the W/D.

6. Elevation of willow individual. The sixth objective asked the question, “Does a relationship exist between elevation and the occurrence of a willow species?” To answer this question, the elevation of each clump was measured using a handheld altimeter. The elevation measurements took place over the course of one hour after the altimeter was calibrated at a known elevation using a topographic map. The altimeter was read at each clump’s central most willow individual.

7. Azimuth of valley immediately surrounding willow individual. The seventh objective asked the question, “Does a relationship exist between valley azimuth and the occurrence of a willow species?” To answer this question, the valley azimuth of each clump was measured using a handheld compass. Central to the clump, the user found a point at which the view facing downvalley and also up either valley sideslope was unencumbered. The user then selected an object far downvalley that was aligned visually with the valley azimuth. Finally, the user pointed the compass at this object to measure the downvalley azimuth in degrees true north.

8. Width of valley bottom immediately surrounding willow individual. The eighth objective asked the question, “Does a relationship exist between valley bottom width and the occurrence of a willow species?” To answer this question, the valley bottom width of each clump was measured using the Trimble Pathfinder Pro© GPS unit. The valley bottom was defined as the area between the opposing valley toe slopes. The toe slope was a consistent observable boundary as change in slope was always apparent there.

Central to the clump and directly over one valley side’s toe slope, the GPS was used to record the user’s geospatial location. The user then moved the GPS unit directly across the valley bottom, perpendicular to the valley azimuth described above, to record the geospatial location of the opposing toe slope. The GPS unit then calculated the distance between these two points to reveal the valley bottom width value.

9. Rock size distribution of soil sample taken from the first gravel layer contacted directly below willow individual. The ninth objective asked the question, “Do the rock size distributions in the soil around the individuals of a given willow species significantly differ from those in the soil around the individuals of another species?” To answer this question, the rock size distribution of a soil sample taken from the first gravel layer encountered beneath each willow individual was calculated. The soil sample was obtained through the use of a soil auger. Thus, the volume extracted for each sample remained consistent. One sample was taken from beneath each of the research individuals within a 1 m radius of the base of the individual. The first sample to contact a gravel presence in the soil profile was bagged and taken back to a lab for sieving.

Five different sieves were used, each corresponding to the five major size class divisions within the category of “Gravels” under Rosgen’s (1996) pebble count

procedure. These size classes are as follows: 1.25 inches (32 mm) or greater in diameter = Very Coarse, 0.625 – 1.25 inches (16 – 32 mm) = Coarse, 0.3125 – 0.625 inches (8 – 16 mm) = Medium, 0.1575 – 0.3125 inches (4 – 8 mm) = Fine, and 0.0787 – 0.1575 inches (2 – 4 mm) = Very Fine. The samples were dried overnight at 110 °C, weighed with a bucket and hanging scale, and then sieved. Each sample underwent the same sieving procedure in which all five sieves were stacked on top of one another with the Very Coarse sieve on top and the Very Fine sieve on the bottom. The sample was then poured onto the top sieve and all five sieves were shook by hand both forward and backward and side-to-side for two minutes over a large bowl. The materials retained on each sieve were then weighed respectively with the same bucket and hanging scale and divided by the sample's total weight to produce a percent value of each size class for each sample.

10. Texture of soil sample taken from the first gravel layer contacted directly below willow individual. The fine materials in each soil sample were analyzed by hand to measure soil texture. Hand analysis followed the texture classes outlined by the Natural Resources Conservation Service (Schoeneberger et al. 2002). First, soil was placed in the palm of the hand and wetted. Wet soil was then worked into a ball. (If no ball was possible, then soil texture was sand). The ball of soil was then pinched between the thumb and index finger to squeeze out a ribbon of soil. (If no ribbon was possible, then soil texture was loamy sand). If a weak ribbon less than 2.5 cm long was achieved, then soil texture was sandy loam, silt loam, or loam. If a ribbon 2.5 – 5.0 cm long was achieved, then soil texture was sandy clay loam, silty clay loam, or clay loam. If a strong ribbon more than 5.0 cm long was achieved, then soil texture was sandy clay, silty clay,

or clay. Final soil texture was defined by excessively wetting additional soil in the palm of the hand and rubbing it with the tip of the index finger. If soil felt very gritty, then it was sandy loam, sandy clay loam, or sandy clay depending on the result of the ribbon test. If soil felt very smooth, then it was silt loam, silty clay loam, or silty clay depending on the result of the ribbon test. If neither grittiness nor smoothness predominated, then it was loam, clay loam, or clay depending on the result of the ribbon test.

11. Range of winter air temperatures for each willow species. Temperature recorders were placed on the research watershed from September through April to capture winter air temperature data. Specifically, 18 TipTemp Temp101© temperature recorders were placed in protective solar shields made by the Onset Corporation and attached to different willow individuals using steel wire. Selection criteria for temperature recorder locations were designed to cover the range of each willow species' distribution as much as equipment costs would allow. Thus, one temperature recorder was placed at both the lowest elevation and highest elevation research individuals of each willow species. The temperature recorders were programmed to log the ambient air temperature every 10 minutes for a total of 227 days. They were removed in May and their data was offloaded for analysis onto a desktop computer.

Descriptive Data

12. Age class of willow individual. The age class of each research individual was recorded following the methods of Winward (2000). These methods account for the two different primary growth forms exhibited by willow species – multi-stemmed trees or single-stemmed trees. The latter growth form was expressed only in coyote willow and

whiplash willow on the research watershed, while the remaining five willow species grew multi-stemmed.

The single-stemmed coyote and whiplash willows were fitted into one of three possible age classes: Sprout, Young, and Mature. The decision for coyote willow was based upon growth rings and relative tree height, while age of the much less common whiplash willow was assessed using only the non-destructive tree height method. A Sprout possessed 1 – 2 annual rings and was one-quarter the height of a full tree. A Young coyote willow had 3 – 10 rings and was half the height of a full tree, while a full tree with more than 10 rings was considered Mature. Annual rings were not counted in trees of the Young and Mature age classes; instead, rings were inferred from relative tree heights after an initial understanding was made of the approximate height of Sprouts, or trees with 1 – 2 annual rings.

The multi-stemmed willow species were fitted into one of five possible age classes: Sprout, Young, Mature, Decadent, and Dead. The decision was based upon the number of living stems present. A Sprout possessed a single living stem at ground-level, while a Young tree had 2 – 10 live stems. With more than 10 stems, a Mature tree had over half of these stems alive, while a Decadent tree had less than half alive. Dead trees possessed no living stems.

13. Species list of major upland and riparian plant species occurring near willow individual. The dominant, subdominant, and several co-dominant and co-subdominant species of upland and riparian plants (besides the willow species) occurring in and/or adjacent to each clump were recorded. This was done through quick visual estimation of the vegetation's aerial cover across the landscape. Several published dichotomous keys

and plant guides were used to aid in plant identification (Hitchcock and Cronquist 1973, Cooke 1997, Hurd et al. 1998, Mansfield 2000).

Data Analysis

Box Plots

Raw data were graphed in a box plot format in order to give clear visual representations of the distribution of values for each willow species within each parameter measured. The “box” in these box plots represents the middle 50% of the group of values. The line and point within this box is the median value of the group. The maximum and minimum values that are no more than 1.5 box-lengths away from the box are represented by brackets above and below the box. The lines that connect these brackets to the box, therefore, represent all of the values that lie within a range of 1.5 times the middle 50% of all values. “Outliers” are represented by points beyond these maximum and minimum boundaries. Box plots comparing the seven research willow species were produced for the parameters numbered above as 1 – 9 (Appendix C).

Logistic Regression

One dataset for each of the seven research willow species was constructed for model building using multivariable logistic regression analysis for a total of seven different datasets. Each species dataset included the data for *Elevation*, *Slope*, *Valley Width*, *Valley Azimuth*, *Entrenchment Ratio*, and *Width-to-Depth Ratio* on a clump-by-clump basis for all 40 research clumps. The status of the willow species was listed as present or absent according to the clumps that it was included or not included in, respectively. This data structure lent itself naturally to logistic regression analysis.

Logistic regression follows many of the same rules found in linear regression, with at least one important difference – it builds regression models that describe a function of a binary response (i.e., either 0 or 1) known as the logarithm of the odds (Ramsey and Schafer 2002). A normal linear regression approach to binary data permits probabilities less than zero and greater than one, so is not suitable for these types of datasets. The normal regression structure is linear ($\beta_0 + \beta_1 X_1 + \dots + \beta_p X_p$) with an intercept term (β_0) and one or multiple slope terms ($\beta_p X_p$). It is then set equal to some function of the mean referred to as a “link” function in order to build a regression equation. Instead of using the identity link, $g(\mu)$, common to normal linear regression (population mean denoted as “ μ ”), a binary response requires a nonlinear proportion or probability known as the logit or log-odds and defined as $\log[\pi/(1-\pi)]$ (population mean denoted as “ π ” to represent a proportion) in order to keep the same structure of the β 's above. All of the model terms together yield a value for the logit, which can then be exponentiated through the logistic function ($\pi = \exp(\text{logit})/[1+\exp(\text{logit})]$) and ultimately reveal the odds of observing a “1” response. If individual model coefficient estimates test significantly different from zero, they can be exponentiated as well, and described as having a specific multiplicative effect on the odds of a “1” response.

A suitable model was built for each of the seven research willow species using the datasets described above. First, each of the six environmental variables served as the lone independent variable in six different univariable logistic regression analyses using S-PLUS 7.0 (Anonymous 2005). A multivariable analysis then followed, including those variables from each univariable analysis with p-value < 0.50. These p-values were obtained through a drop-in-deviance test (often referred to as the likelihood ratio test) in

which the deviance (similar to the sum-of-squared residuals in linear regression) of the full model (i.e., intercept term, or constant, plus one independent environmental variable in this case) was compared with that of the null model (i.e., just the constant) (Ramsey and Schafer 2002). The p-value is the proportion of a chi-squared distribution that is greater than the difference between full and reduced deviances on x degrees of freedom (x being equal to the difference between full and reduced degrees of freedom). Hosmer and Lemeshow (2000) suggest using the variables with $p\text{-value} < 0.25$ and any others of “known clinical importance” in final model building (p. 95). These authors go on to explain that a univariable approach may overlook the potential collective influence multiple variables can have both on each other and the response, and that larger significance levels may be used to mitigate for this, which is why $p\text{-value} < 0.50$ was used here instead. The multivariable logistic regression model was then subjected to a drop-in-deviance test comparing the full and null models to ascertain whether or not "environment" at all, as measured in this research, influenced the model outcome. Full models were favored to null models at a $p\text{-value} < 0.05$.

Subsequent models were then tested on a variable-by-variable basis using Akaike's Information Criterion (AIC) (Gittleman, personal communication, May 2006). The AIC measures a model's lack of fit while adding a penalty for the number of terms included (Ramsey and Schafer 2002). The smaller a model's AIC, the more suitable the model is considered. Using the “dropterm” function in the S-PLUS commands window, an output was given listing the AIC for each model minus one of the variables. The variable dropped from the model with the lowest AIC could then be eliminated and AIC's could be recalculated. Each time a variable was eliminated the resulting full model was

compared to the null model in a drop-in-deviance test as explained above. Reduced models were also compared to richer models through the same test. Likewise, different models with the same number of variables could be compared to each other by comparing their respective AIC values, with the lower AIC indicating the better model.

Finally, potentially relevant interaction terms along with variables not included in the original model because of their high p-values were added to the existing models and subjected to the same tests. Ultimately, the final model was produced and its goodness-of-fit was checked following the advice of Ramsey and Schafer (2002) who state that “model checking is based largely on fitting models that include extra terms (such as squared terms or interaction terms) whose significance would indicate shortcomings of the ‘target’ model” (p. 601). Each coefficient in the final model was exponentiated to yield its odds ratio effect on the response and a confidence interval was constructed for this odds ratio. The significance of individual coefficients was determined by a p-value < 0.05 using a Wald’s test in which each coefficient estimate yields a z-statistic that can be compared to a standard normal distribution (Ramsey and Schafer 2002). There is no application for t-distributions in logistic regression as these can only be used for normally distributed response variables. A confidence interval can be built around the coefficient estimate by subtracting and adding to it the product of the estimate’s standard error times a z-multiplier from the standard normal distribution. A 95% confidence interval requires the use of the z-multiplier in the 97.5th percentile of the standard normal distribution.

Multi-response Permutation Procedure

A separate dataset not based on the presence or absence of species in clumps was constructed for use in a multi-response permutation procedure (MRPP) analysis. The

primary goal of this analysis was to include the seven habitat parameters measured at the level of the individual willows, which could not be used in the logistic regression analysis due to the fact that absence data could not be generated for them. These are *Height from bankfull*, *Distance from bankfull*, and the five rock size distribution categories – % *Very Coarse*, % *Coarse*, % *Medium*, % *Fine*, % *Very Fine*.

MRPP achieves a comparison between two or more a priori groups of values and tests how likely it is that observed differences between groups are due to chance (McCune and Grace 2002). The advantage in ecological datasets that MRPP has over tools like multivariate analysis of variance (MANOVA) is that it need not meet distributional assumptions. Thus, it is a nonparametric procedure well-suited for analyzing the non-linear relationships commonly found in ecological data.

The seven different willow species constituted the seven different a priori groups to be compared by the MRPP. The environmental values for two or more research individuals of the same species in a given clump were averaged to ensure independence among members within groups. Otherwise, the values for habitat parameters measured at the level of the clump would repeat within a given group if two or more individuals of the same species occurred in that clump together. This reduced the dataset from 107 research willow individuals to 67 research willow individuals-clump combinations. Habitat parameter values were then relativized by their standard deviates to eliminate any problems posed by the vastly different scales of measurement used across all habitat parameters.

The actual MRPP, carried out using PC-ORD Version 4 (McCune and Mefford 1999), then measured the Euclidean distances among values within groups to calculate an

average distance value within each group (McCune and Grace 2002). Next, a value called *delta* (δ), which describes the degree of separation between groups, was calculated by weighting the average within-group distance of each group according to the number of items in each group and summing. A smaller δ indicated closely related groups, while a larger δ indicated a greater separation between groups (Biondini et al. 1985). The probability of arriving at a δ of equal size or smaller through all the different possible distance measures was then approximated from a continuous distribution to yield a p-value. The test statistic for this, “*T*” as computed by PC-ORD, describes how strongly separated the groups are with a more negative *T* indicating stronger separation. A p-value < 0.05 implies that groups are significantly different from one another. A standard Bonferroni adjustment procedure, however, was applied to each set of tests described below in order to reduce the risk of making a type one error. That is, statistical significance was assigned to tests with $p < 0.002381$, instead of the usual $p < 0.05$. This adjusted p-value was calculated by dividing 0.05 by the number of tests (i.e., 21) in each set of tests described below. Finally, PC-ORD calculated within-group agreement, “*A*”, to describe the homogeneity of individual groups. McCune and Grace (2002) also call this the “effect size”. If $A = 1$, then all the items are identical within groups. If $A = 0$, then the heterogeneity within groups is what would be expected by chance. If *A* is negative, then items are more heterogeneous within groups than would be expected by chance.

Both univariable and multivariable MRPP analyses were performed using data from the 67 research willow individuals-clump combinations described above. Univariable MRPP included one analysis including all possible pair-wise comparisons across species

for each of the seven habitat parameters measured at the level of the willow individual. Again, these were *Height from Bankfull Elevation*, *Distance from Bankfull Elevation*, and the five soil parameters *% Very Coarse Gravel*, *% Coarse Gravel*, *% Medium Gravel*, *% Fine Gravel*, and *% Very Fine Gravel*. The multivariable MRPP's facilitated an observation of a change in p-values between an analysis including all possible pair-wise comparisons across species with all thirteen habitat parameters compared with an analysis including all possible pair-wise comparisons across species with all parameters except one of the seven habitat parameters measured at the level of the willow individual for each of these seven parameters. This was meant to clarify the role of each of the seven different habitat parameters observed at the level of the willow individual within the context of the measured environment as a whole, and potentially indicate environmental drivers of the ecosystem. Each analysis generated a value for T , p , and A .

CHAPTER 4

Results

Reconnaissance

Seven different willow species occurred on the research watershed. A total of 107 willow individuals were selected for inclusion as research willows. The numbers of individuals selected for research are organized by species in Table 1 along with the numbers of clumps, 40 total, in which each willow species was found. Note that several clumps supported more than one species, thus the number of clumps in the table sums to more than 40.

Table 1. Willow species and their respective numbers of individuals selected for research.

Willow Species	Common Name	Number of Individuals	Number of Clumps
<i>Salix lemmonii</i>	Lemmon willow	40	24
<i>Salix scouleriana</i>	Scouler willow	26	16
<i>Salix boothii</i>	Booth willow	11	6
<i>Salix geyeriana</i>	Geyer willow	9	5
<i>Salix exigua</i>	coyote willow	8	6
<i>Salix lasiandra</i>	whiplash willow	7	6
<i>Salix lutea</i>	yellow willow	6	4

Two major valley types comprised the research watershed at varying elevations. A Type I valley was found dominating the middle to upper elevations of the research watershed while Type II valleys extended both above and below it (Rosgen 1996). Type I valleys are described as V-shaped and confined, supporting predominantly A type stream channels. Type II valleys exhibit more gradual side slopes and valley floor slopes than Type I valleys and most commonly support B type stream channels. Most of the research reach classified as a B4a stream type. The “B” indicates moderate entrenchment (entrenchment ratio = 1.4 – 2.2), a moderate width-to-depth ratio (>12), and moderate

sinuosity (>1.2), while the “4” means that gravel was the dominant channel material, and the “a” represents steep stream slopes ranging from 4 to 9.9%. In parts of the Type I valley the research reach switched to an A4 stream type indicating overall lower entrenchment ratio, and width-to-depth ratio values.

Graphical Analysis

Box Plots

Box plots of data for the five willow species analyzed using logistic regression analysis can be found in Appendix C. These species are *Salix lemmonii*, *Salix scouleriana*, *Salix exigua*, *Salix lasiandra*, and *Salix lutea*. Data for *Salix boothii* and *Salix geyeriana* contained values that eliminated the need for and, to some degree, precluded a logistic regression analysis approach. Therefore, these data are represented in the box plots below.

Salix boothii – Booth Willow

One set of box plots for each of the six habitat parameters used in logistic regression displayed data from research willow clumps in which Booth willow was present side-by-side with data from clumps in which Booth willow was absent. These six habitat parameters were *Elevation*, *Slope*, *Valley Width*, *Valley Azimuth*, *Entrenchment Ratio*, and *Width-to-Depth Ratio*. This procedure was performed only after attempts at logistic regression model building with Booth willow data failed.

Varying degrees of separation between presence and absence datasets within each habitat parameter were made apparent through this technique. In the *Elevation* box plot, there was a strong visual pattern of separation between the *Elevation* values of clumps with Booth willow present compared to the clumps without Booth willow (Figure 1).

This visual separation did not occur across the other five habitat parameters (Figures 2 – 6).

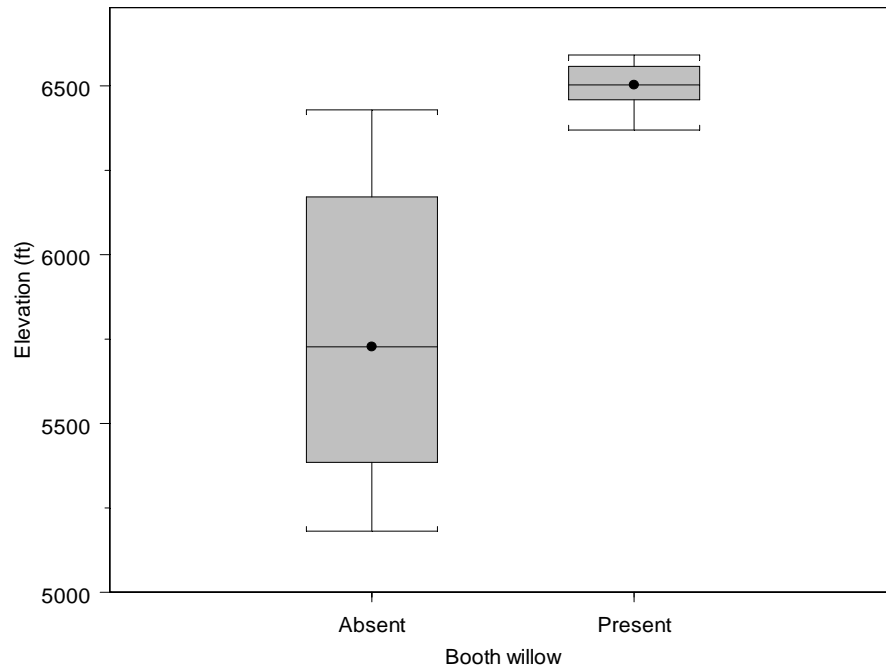


Figure 1. Elevation in feet of all research willow clumps with Booth willow absent versus all clumps with Booth willow present.

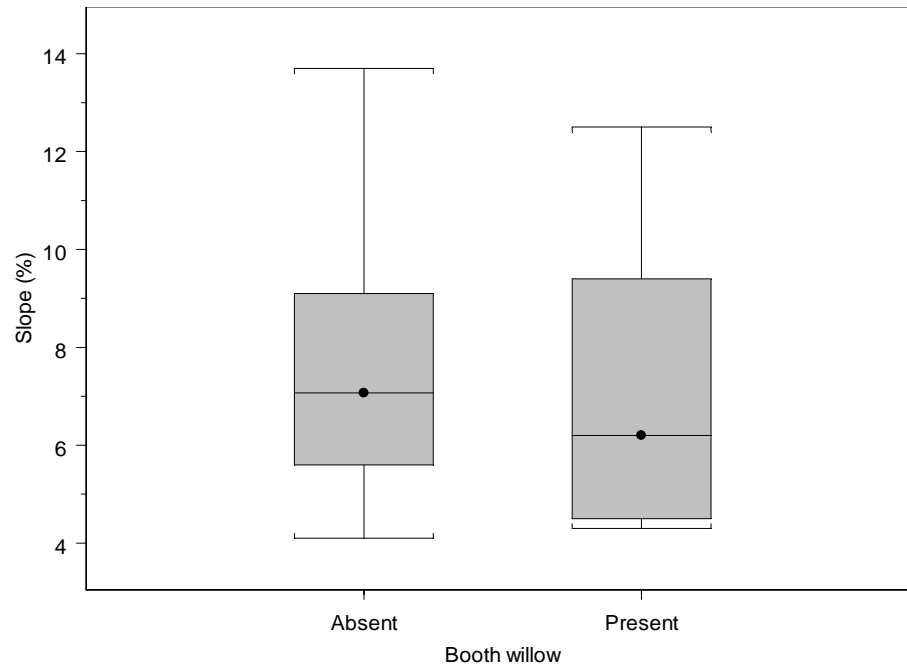


Figure 2. Percent stream slope in all research willow clumps with Booth willow absent versus all clumps with Booth willow present.

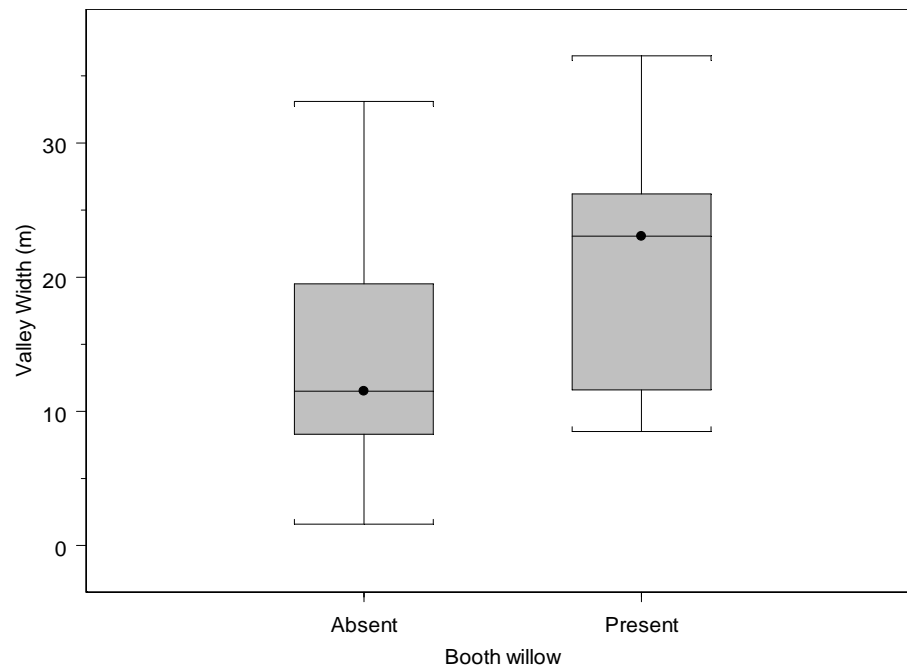


Figure 3. Valley width in meters of all research willow clumps with Booth willow absent versus all clumps with Booth willow present.

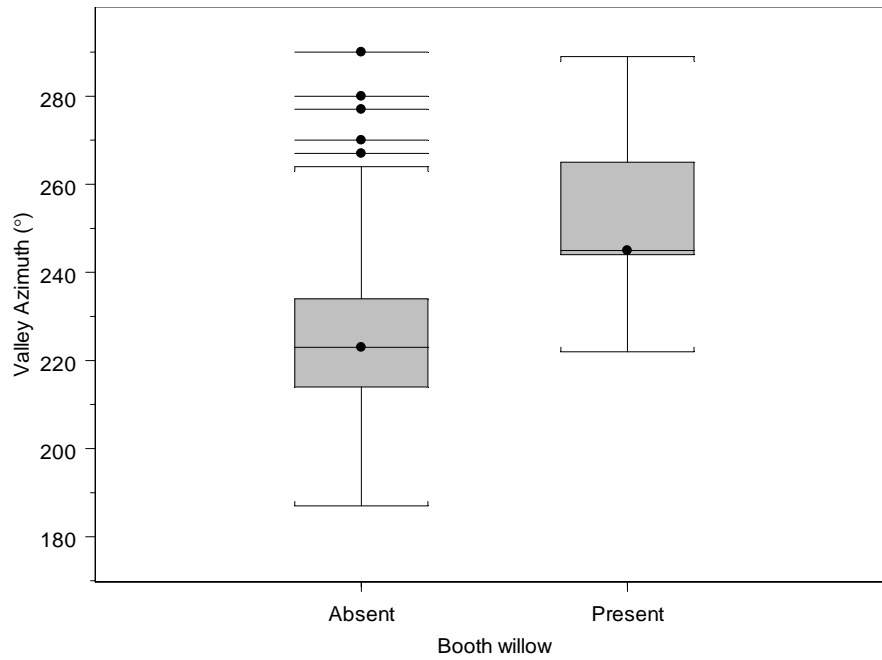


Figure 4. Downslope valley azimuth in degrees true north of all research willow clumps with Booth willow absent versus all clumps with Booth willow present.

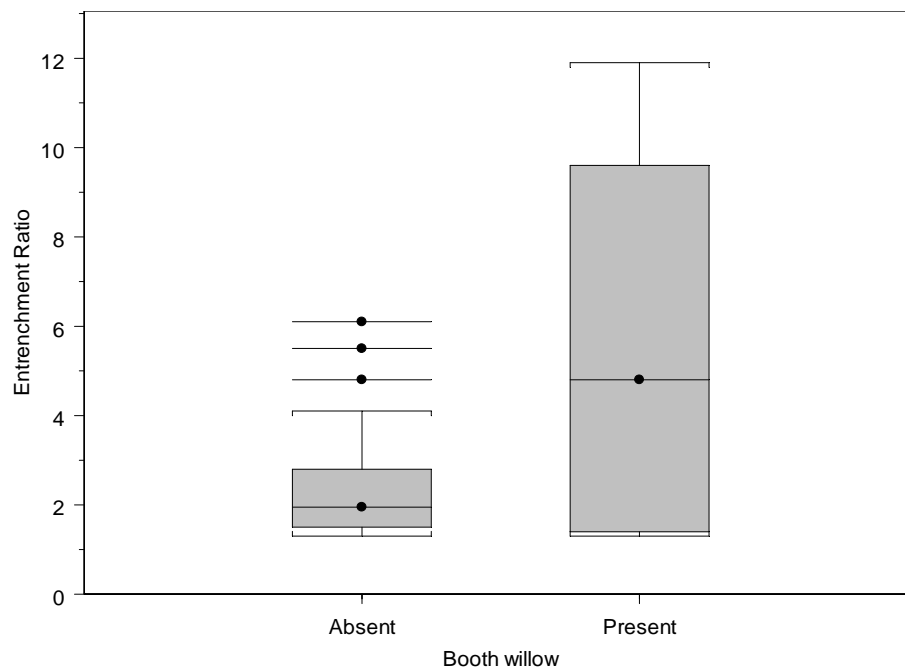


Figure 5. Stream entrenchment ratio in all research willow clumps with Booth willow absent versus all clumps with Booth willow present.

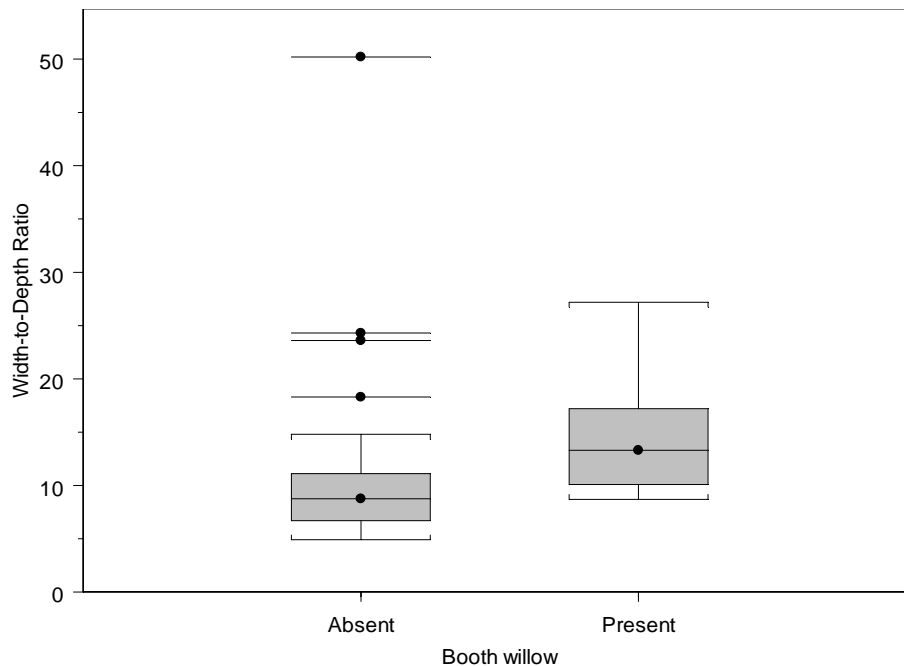


Figure 6. Stream width-to-depth ratio in all research willow clumps with Booth willow absent versus all clumps with Booth willow present.

Salix geyeriana – Geyer Willow

The Geyer willow data displayed a pattern similar to that observed across Booth willow box plots using the same graphical techniques. Specifically, data for *Elevation* exhibited a clear separation of values for clumps with Geyer willow present compared to clumps without Geyer willow (Figure 7). As with Booth willow, all other habitat parameters seemed not to exert the same influence; rather, much overlap occurred between the presence and absence datasets (Figures 8-12).

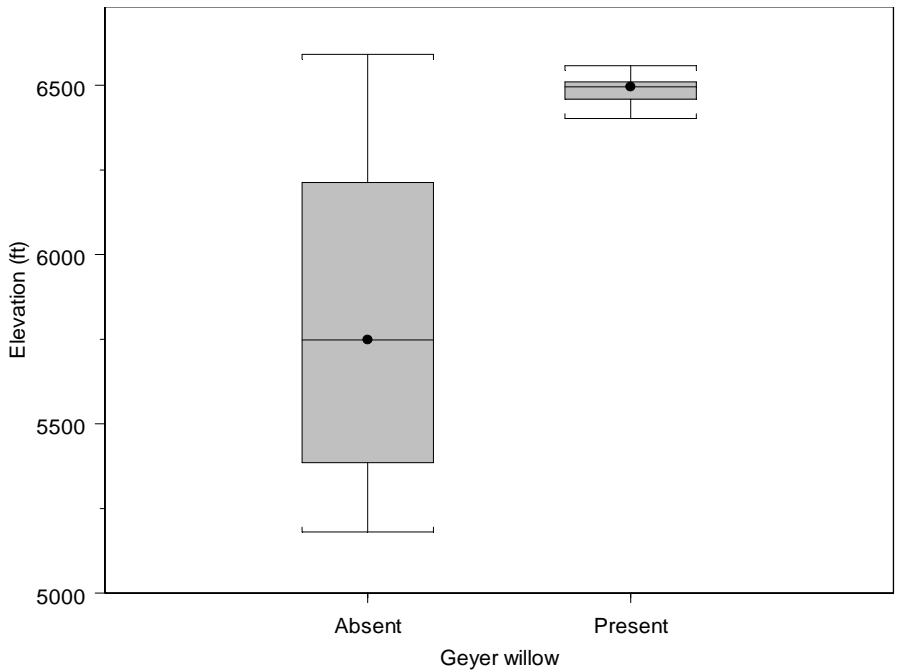


Figure 7. Elevation in feet of all research willow clumps with Geyer willow absent versus all clumps with Geyer willow present.

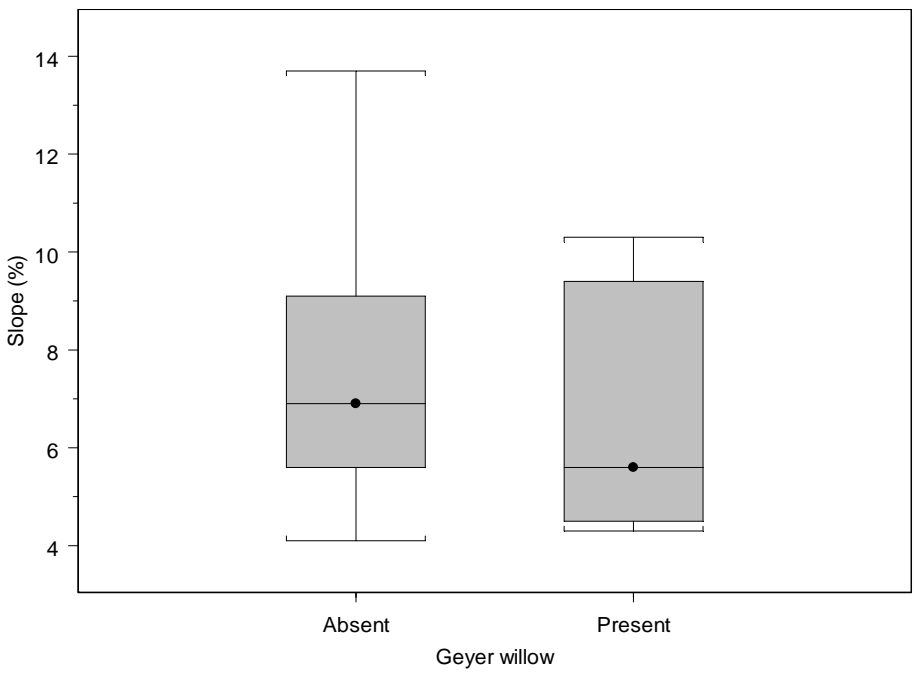


Figure 8. Percent stream slope in all research willow clumps with Geyer willow absent versus all clumps with Geyer willow present.

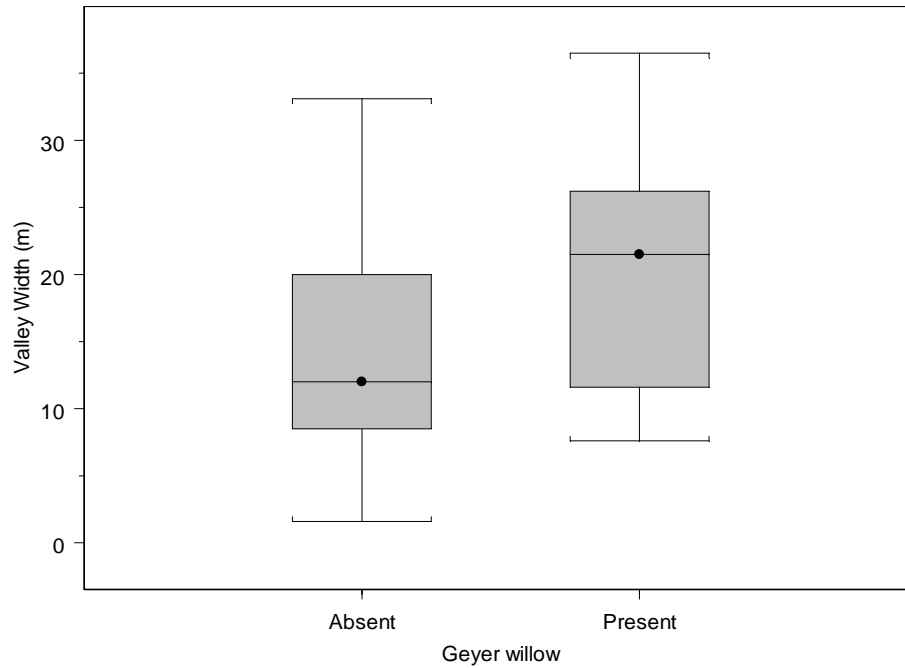


Figure 9. Valley width in meters of all research willow clumps with Geyer willow absent versus all clumps with Geyer willow present.

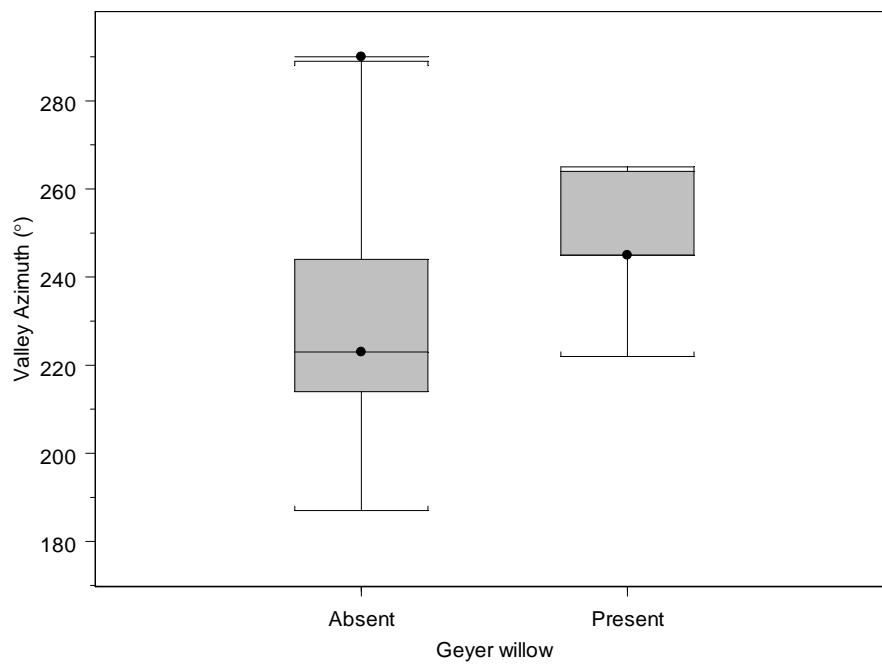


Figure 10. Downslope valley azimuth in degrees true north of all research willow clumps with Geyer willow absent versus all clumps with Geyer willow present.

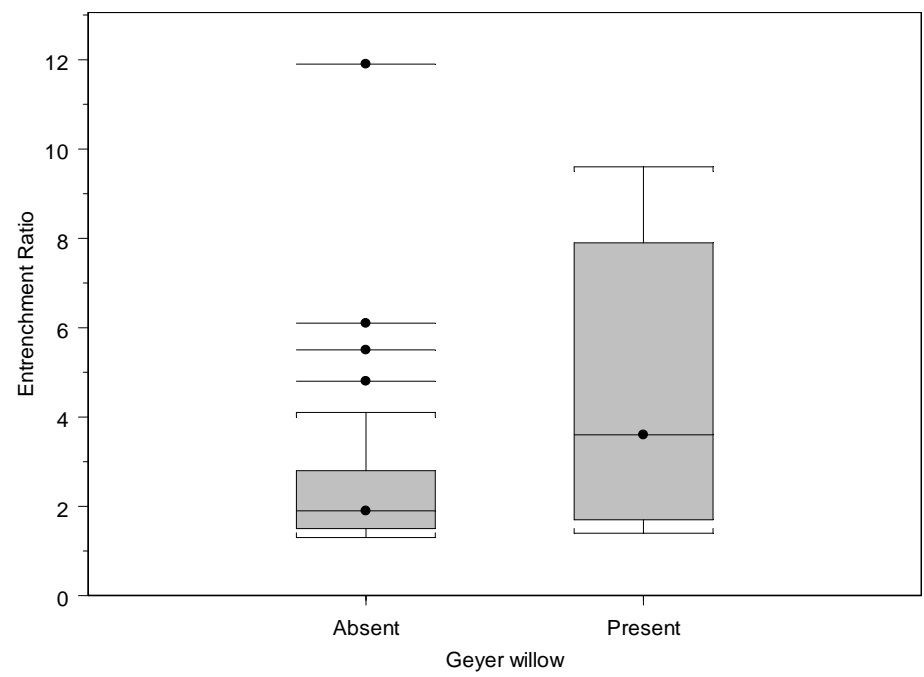


Figure 11. Stream entrenchment ratio in all research willow clumps with Geyer willow absent versus all clumps with Geyer willow present.

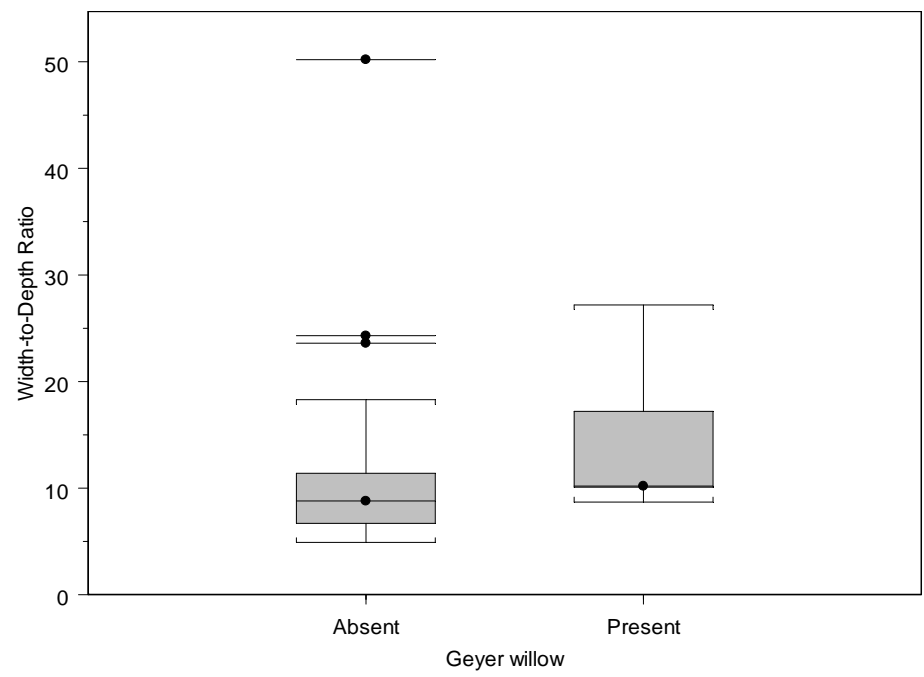


Figure 12. Stream width-to-depth ratio in all research willow clumps with Geyer willow absent versus all clumps with Geyer willow present.

Logistic Regression Models

In General

Models varied widely across the seven willow species researched in terms of the final variables selected for inclusion, as well as the respective levels of significance for those variables. The only habitat parameter not included in any of the final models was *Valley Width*. The only habitat parameter included in all of the final models was *Width-to-Depth Ratio*.

Ultimately, five final models were built; one for each of five of the seven total different willow species present. As illustrated above, data for Booth and Geyer willow eluded any practical application of logistic regression. A graphical display of these data, instead, proved sufficient for illustrating relationships between the environment and these two willow species. Each of the five final logistic regression models is presented below.

Salix lasiandra – Whiplash Willow

The following logistic regression model:

$$Y = -3.6579 - (0.0432 \text{Entrenchment Ratio}) + (0.1535 \text{Width-to-Depth Ratio})$$

was selected as the model best suited to describe the probability of whiplash willow occurrence. A drop-in-deviance test comparing this model to the null model (i.e., the model containing only the intercept term, or constant, and no environmental variables) significantly rejected the null hypothesis, which favored the null model ($p = 0.027324$). The coefficient of *Width-to-Depth Ratio* was found to be significantly different from zero using a Wald's test that yielded $p = 0.047$. Table 2 presents the model coefficients' standard error values, z-values, odds ratios, 95% confidence intervals, and p-values.

Table 2. Variables of the logistic regression model for *Salix lasiandra* and their associated statistics.

Variable	Coefficient	Standard Error	z-value	Odds Ratio	95% Confidence Interval	p-value
(Constant)	-3.6579	1.1536	-3.17	-	-	0.0015244
<i>Entrenchment Ratio</i>	-0.0432	0.2041	-0.21	0.96	0.64 to 1.43	0.8336677
<i>Width-to-Depth Ratio</i>	0.1535	0.0772	1.99	1.17	1.00 to 1.36	0.0468486

Salix lutea – Yellow Willow

The following logistic regression model:

$$Y = 32.3210 - (0.0065\textit{Elevation}) + (0.1451\textit{Width-to-Depth Ratio})$$

was selected as the model best suited to describe the probability of yellow willow occurrence. A drop-in-deviance test comparing this model to the null model significantly rejected the null hypothesis that favored the null model ($p = 0.020080$). None of the coefficients were found to be significantly different from zero. Table 3 presents the model coefficients' standard error values, z-values, odds ratios, 95% confidence intervals, and p-values.

Table 3. Variables of the logistic regression model for *Salix lutea* and their associated statistics.

Variable	Coefficient	Standard Error	z-value	Odds Ratio	95% Confidence Interval	p-value
(Constant)	32.3210	20.4295	1.58	-	-	0.1141069
<i>Elevation</i>	-0.0065	0.0040	-1.64	0.99	0.99 to 1.00	0.1010052
<i>Width-to-Depth Ratio</i>	0.1451	0.1142	1.27	1.16	0.92 to 1.45	0.2040846

Salix lemmonii – Lemmon Willow

The following logistic regression model:

$$Y = -182.4385 + (0.0266\textit{Elevation}) + (1.7523\textit{Slope}) + (0.8270\textit{Valley Azimuth}) + (1.1374\textit{Width-to-Depth Ratio}) - (0.0001\textit{Elevation} \times \textit{Valley Azimuth}) - (0.2065\textit{Slope} \times \textit{Width-to-Depth Ratio})$$

was selected as the model best suited to describe the probability of Lemmon willow occurrence. A drop-in-deviance test comparing this model to the null model significantly rejected the null hypothesis that favored the null model ($p = 0.002963$). The coefficient of the interaction term *Slope x Width-to-Depth Ratio* ($p = 0.044$) was found to be significantly different from zero. Table 4 presents the model coefficients' standard error values, z-values, odds ratios, 95% confidence intervals, and p-values.

Table 4. Variables of the logistic regression model for *Salix lemmonii* and their associated statistics.

Variable	Coefficient	Standard Error	z-value	Odds Ratio	95% Confidence Interval	p-value
(Constant)	-182.4385	113.3992	-1.61	-	-	0.1073979
<i>Elevation</i>	0.0266	0.0181	1.47	1.03	0.99 to 1.06	0.1420724
<i>Slope</i>	1.7523	0.9404	1.86	5.77	0.91 to 36.43	0.0624015
<i>Valley Azimuth</i>	0.8270	0.5053	1.64	2.29	0.85 to 6.16	0.1017337
<i>Width-to-Depth Ratio</i>	1.1374	0.5890	1.93	3.12	0.98 to 9.89	0.0534754
<i>Elevation x Valley Azimuth</i>	-0.0001	0.0001	-1.57	1.00	1.00 to 1.00	0.1152791
<i>Slope x Width-to-Depth Ratio</i>	-0.2065	0.1026	-2.01	0.81	0.67 to 0.99	0.0441294

Salix exigua – Coyote Willow

The following logistic regression model:

$$Y = 17.2933 - (3.9751Slope) + (1.3443Entrenchment Ratio) - (1.2812Width-to-Depth Ratio) + (0.2701Slope x Width-to-Depth Ratio) - (0.1159Entrenchment Ratio x Width-to-Depth Ratio)$$

was selected as the model best suited to describe the probability of coyote willow occurrence. A drop-in-deviance test comparing this model to the null model significantly rejected the null hypothesis that favored the null model ($p = 0.011772$). The coefficients of the following three variables were found to be significantly different from zero: *Slope* ($p = 0.033$), *Width-to-Depth Ratio* ($p = 0.044$), and the interaction term *Slope x Width-to-*

Depth Ratio ($p = 0.037$). Table 5 presents the model coefficients' standard error values, z-values, odds ratios, 95% confidence intervals, and p-values.

Table 5. Variables of the logistic regression model for *Salix exigua* and their associated statistics.

Variable	Coefficient	Standard Error	z-value	Odds Ratio	95% Confidence Interval	p-value
(Constant)	17.2933	8.8505	1.95	-	-	0.0511761
<i>Slope</i>	-3.9751	1.8670	-2.13	0.02	0.00 to 0.73	0.0332443
<i>Entrenchment Ratio</i>	1.3443	0.9225	1.46	3.84	0.63 to 23.39	0.1450598
<i>Width-to-Depth Ratio</i>	-1.2812	0.6360	-2.01	0.28	0.08 to 0.97	0.0439688
<i>Slope x Width-to-Depth Ratio</i>	0.2701	0.1296	2.08	1.31	1.02 to 1.69	0.0371420
<i>Entrenchment Ratio x Width-to-Depth Ratio</i>	-0.1159	0.0668	-1.74	0.89	0.78 to 1.02	0.0825628

Salix scouleriana – Scouler Willow

The following logistic regression model:

$$Y = -466.4712 + (0.0757Elevation) + (1.3928Slope + (2.0393Valley Azimuth) - (2.2042Entrenchment Ratio) + (0.5534Width-to-Depth Ratio) - (0.0003Elevation x Valley Azimuth) - (0.1000Slope x Width-to-Depth Ratio)$$

was selected as the model best suited to describe the probability of Scouler willow occurrence. A drop-in-deviance test comparing this model to the null model significantly rejected the null hypothesis that favored the null model ($p = 0.000134$). The coefficients of the following four variables were found to be significantly different from zero: *Elevation* ($p = 0.020$), *Valley Azimuth* ($p = 0.023$), *Entrenchment Ratio* ($p = 0.042$), and the interaction term *Elevation x Valley Azimuth* ($p = 0.020$). Table 6 presents the model coefficients' standard error values, z-values, odds ratios, 95% confidence intervals, and p-values.

Table 6. Variables of the logistic regression model for *Salix scouleriana* and their associated statistics.

Variable	Coefficient	Standard Error	z-value	Odds Ratio	95% Confidence Interval	p-value
(Constant)	-466.4712	200.7665	-2.32	-	-	0.0203409
<i>Elevation</i>	0.0757	0.0325	2.33	1.08	1.01 to 1.15	0.0198062
<i>Slope</i>	1.3928	0.7570	1.84	4.03	0.91 to 17.75	0.0657682
<i>Valley Azimuth</i>	2.0393	0.8931	2.28	7.69	1.33 to 44.25	0.0226077
<i>Entrenchment Ratio</i>	-2.2042	1.0843	-2.03	0.11	0.01 to 0.92	0.0423565
<i>Width-to-Depth Ratio</i>	0.5534	0.3694	1.49	1.74	0.84 to 3.59	0.1362242
<i>Elevation x Valley Azimuth</i>	-0.0003	0.0001	-2.32	1.00	1.00 to 1.00	0.0203409
<i>Slope x Width-to-Depth Ratio</i>	-0.1000	0.0581	-1.72	0.90	0.81 to 1.01	0.0854324

Multi-response Permutation Procedures

There were several significant differences among both the univariable and multivariable pair-wise species comparisons at the 0.05 level. This changed greatly after adjusting the p-value to 0.002381 using the Bonferroni procedure, as suggested by McCune and Grace (2002). In univariable testing, there were 27 (out of a possible 147 across all variables) significantly different willow species pairs, in which values for one species tested significantly different from values for another species at the 0.05 level. At the 0.002381 significance level, there were only 3 significantly different willow species pairs (Table 7). Specifically, these were comparisons between Booth willow and Scouler willow for the variables *Distance from Bankfull Elevation*, *% Fine Gravel*, and *% Very Fine Gravel*.

Table 7. Significant univariable MRPP comparisons and their associated statistics.

Species Compared	Variable Tested	<i>T</i>	<i>p</i>	<i>A</i>
Booth vs. Scouler	<i>Distance from Bankfull Elevation</i>	-8.48	0.000074	0.311
Booth vs. Scouler	<i>% Fine Gravel</i>	-7.10	0.000348	0.274
Booth vs. Scouler	<i>% Very Fine Gravel</i>	-5.09	0.002323	0.190

In multivariable testing at the 0.05 level there were 11, out of a possible 21, significantly different willow species pairs when all thirteen habitat parameters were included. At the 0.002381 significance level, there were 4 significantly different willow species pairs (Table 8).

Table 8. Significant multivariable MRPP comparisons (with all thirteen habitat parameters) and their associated statistics.

Species Compared	Variables Tested	<i>T</i>	<i>p</i>	<i>A</i>
Booth vs. Lemmon	All	-5.85	0.000142	0.057
Booth vs. Scouler	All	-8.05	0.000004	0.109
Booth vs. Yellow	All	-4.45	0.001835	0.180
Geyer vs. Scouler	All	-4.81	0.000478	0.063

When each one of the seven habitat parameters measured at the level of the willow individual were removed from testing there were no changes in significance at the 0.002381 level compared with testing that included all thirteen habitat parameters. That is, the 4 willow species pairs that were significantly different when all thirteen habitat parameters were included were still significantly different when each of the seven habitat parameters measured at the level of the willow individual were individually removed (Table 9). Moreover, no new willow species pairs tested significantly different following the removal of each of the seven habitat parameters measured at the level of the willow individual. Although no changes in significance occurred, fluctuation in p-values was observed. For example, by removing *Distance from Bankfull Elevation* in the Booth willow vs. Yellow willow comparison the p-value changed from 0.001835 prior to removal to a nearly non-significant 0.002171 after removal.

Table 9. Significant multivariable MRPP comparisons (with each of the seven habitat parameters measured at the level of the willow individual removed one-at-a-time) and their associated statistics.

Species Compared	Variables Tested	<i>T</i>	<i>P</i>	<i>A</i>
Booth vs. Lemmon	All except <i>Height from Bankfull Elevation</i>	-5.86	0.000155	0.060
Booth vs. Scouler	All except <i>Height from Bankfull Elevation</i>	-8.01	0.000004	0.111
Booth vs. Yellow	All except <i>Height from Bankfull Elevation</i>	-4.46	0.001824	0.183
Geyer vs. Scouler	All except <i>Height from Bankfull Elevation</i>	-4.78	0.000512	0.065
Booth vs. Lemmon	All except <i>Distance from Bankfull Elevation</i>	-5.59	0.000176	0.055
Booth vs. Scouler	All except <i>Distance from Bankfull Elevation</i>	-7.45	0.000008	0.099
Booth vs. Yellow	All except <i>Distance from Bankfull Elevation</i>	-4.23	0.002171	0.172
Geyer vs. Scouler	All except <i>Distance from Bankfull Elevation</i>	-4.70	0.000577	0.062
Booth vs. Lemmon	All except % <i>Very Coarse Gravel</i>	-5.83	0.000147	0.058
Booth vs. Scouler	All except % <i>Very Coarse Gravel</i>	-8.64	0.000004	0.126
Booth vs. Yellow	All except % <i>Very Coarse Gravel</i>	-4.56	0.001661	0.189
Geyer vs. Scouler	All except % <i>Very Coarse Gravel</i>	-5.34	0.000235	0.073
Booth vs. Lemmon	All except % <i>Coarse Gravel</i>	-6.04	0.000118	0.061
Booth vs. Scouler	All except % <i>Coarse Gravel</i>	-8.03	0.000005	0.112
Booth vs. Yellow	All except % <i>Coarse Gravel</i>	-4.46	0.001838	0.182
Geyer vs. Scouler	All except % <i>Coarse Gravel</i>	-4.83	0.000519	0.065
Booth vs. Lemmon	All except % <i>Medium Gravel</i>	-6.33	0.000071	0.063
Booth vs. Scouler	All except % <i>Medium Gravel</i>	-8.31	0.000003	0.114
Booth vs. Yellow	All except % <i>Medium Gravel</i>	-4.49	0.001916	0.183
Geyer vs. Scouler	All except % <i>Medium Gravel</i>	-5.22	0.000256	0.069
Booth vs. Lemmon	All except % <i>Fine Gravel</i>	-5.18	0.000470	0.052
Booth vs. Scouler	All except % <i>Fine Gravel</i>	-7.30	0.000010	0.096
Booth vs. Yellow	All except % <i>Fine Gravel</i>	-4.20	0.002062	0.159
Geyer vs. Scouler	All except % <i>Fine Gravel</i>	-4.87	0.000386	0.063
Booth vs. Lemmon	All except % <i>Very Fine Gravel</i>	-5.55	0.000263	0.057
Booth vs. Scouler	All except % <i>Very Fine Gravel</i>	-7.68	0.000005	0.104
Booth vs. Yellow	All except % <i>Very Fine Gravel</i>	-4.30	0.001836	0.172
Geyer vs. Scouler	All except % <i>Very Fine Gravel</i>	-4.10	0.001362	0.053

Descriptive Data

Soil Texture

A silty clay loam soil texture was dominant throughout the majority of the soil sampled. Also commonly found was sand. The soil textures sampled are tallied by species in Table 10.

Table 10. Number of soil samples in each soil texture category encountered around each willow species.

Willow Species	Silty Clay		Clay		Silty	Sandy
	Loam	Sand	Loam	Loam	Loam	Loam
Coyote	5	2	1	0	0	0
Yellow	2	1	0	2	0	0
Lemmon	17	12	2	1	6	1
Scouler	17	5	0	0	3	0
Whiplash	4	2	0	0	1	0
Geyer	7	1	1	0	0	0
Booth	10	0	1	0	0	0
Total	62	23	5	3	10	1

Winter Air Temperatures

A total of 9, out of the 18 temperature recorders launched, logged readings every 10 minutes for 227 days. The remaining 9 temperature recorders experienced either battery troubles or unidentifiable malfunctions and logged readings over varying time periods less than 227 days. The number of days logged along with the elevation of each temperature recorder is given in Table 11. The loss of data to seriously errant temperature recording devices was mitigated by extrapolating data from other nearby operative devices.

Table 11. Data logging duration and associated elevation of each temperature recorder.

Device #	Elevation (ft)	Days Logged
1	5181	131
2	5202	227
3	5289	227
4	5364	227
5	5406	227
6	5436	227
7	5529	227
8	6006	227
9	6171	178
10	6309	54
11	6351	1
12	6363	227
13	6369	115
14	6402	54
15	6459	227
16	6510	100
17	6558	176
18	6591	141

The winter air temperature ranges of each willow species are displayed in the graphs below, which follow the monthly average winter air temperatures at both the low and high elevation extents of each species (Figure 13 – 19). An additional set of graphs displays the monthly minimum winter air temperatures at both the low and high elevation extents of each species to aid in identifying possible low temperature thresholds of each willow species (Figure 20 – 26). Overall, temperature data exhibited frequent vacillation and did not reflect any definable periods of consistently low temperatures.

Figure 13. Monthly average winter air temperatures at coyote willow low and high elevation extents.

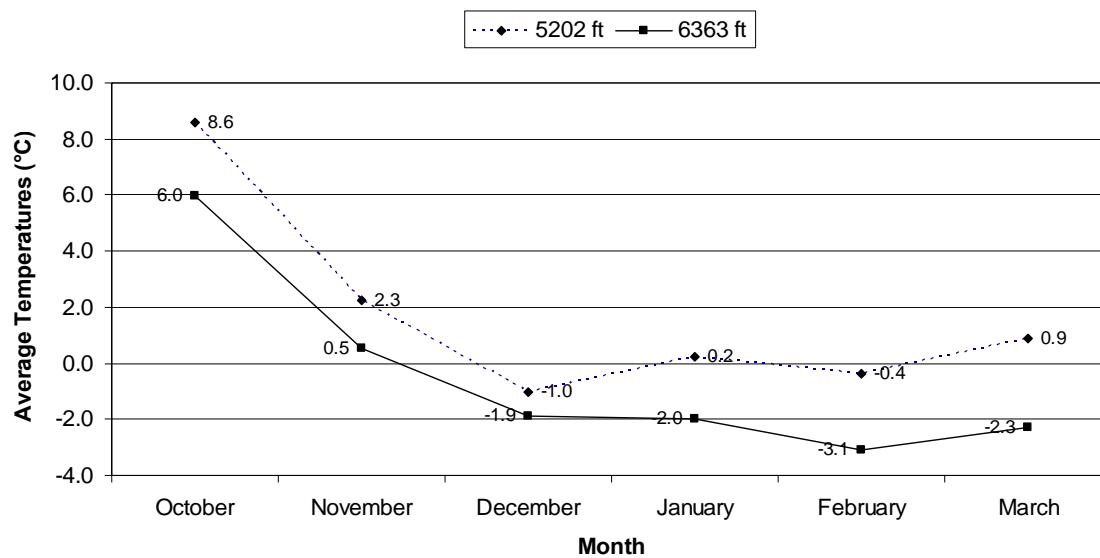


Figure 14. Monthly average winter air temperatures at yellow willow low and high elevation extents.

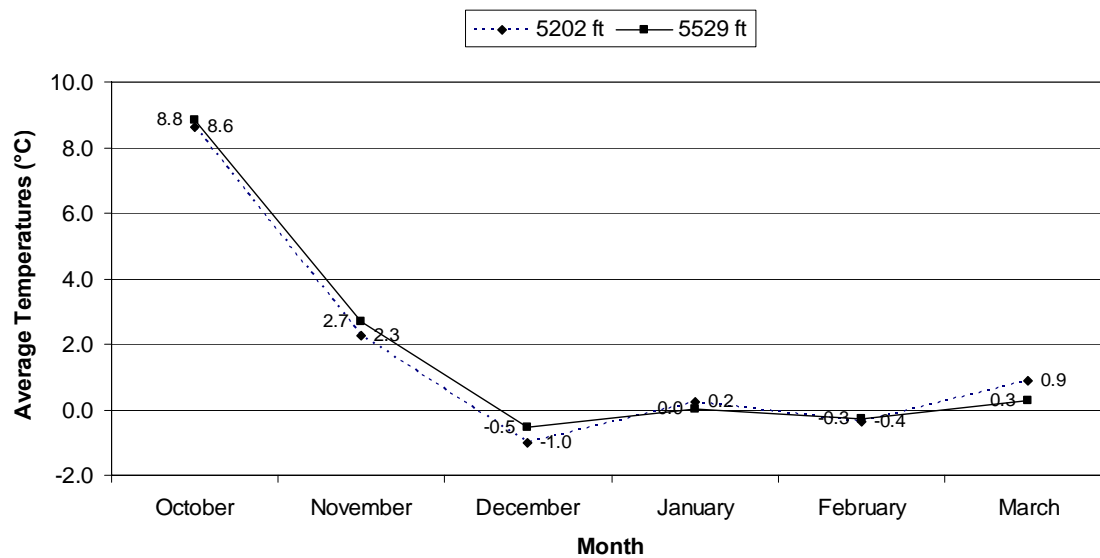


Figure 15. Monthly average winter air temperatures at Lemmon willow low and high elevation extents.

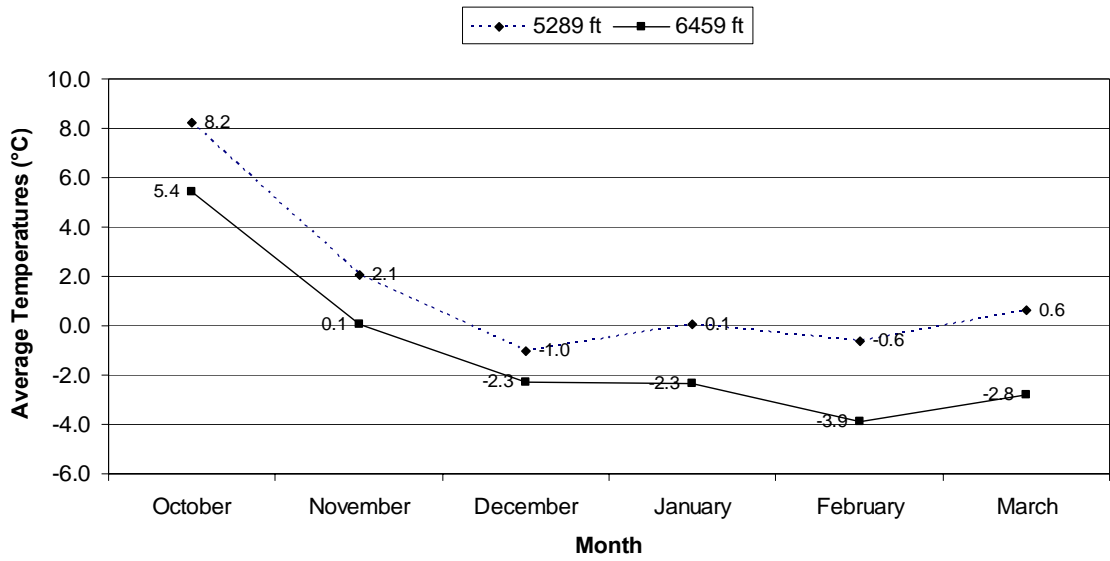


Figure 16. Monthly average winter air temperatures at Scouler willow low and high elevation extents.

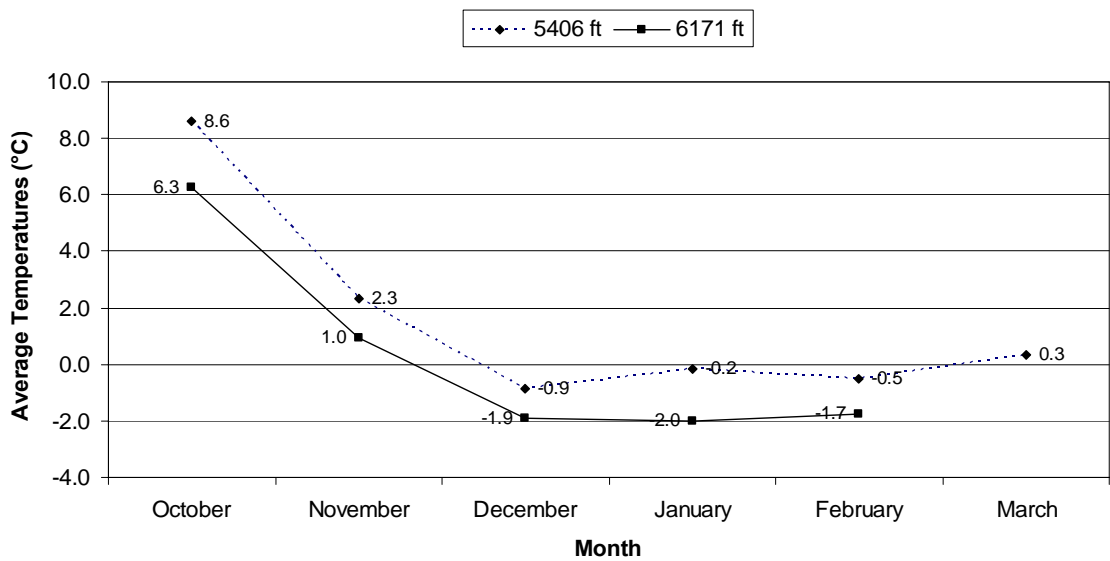


Figure 17. Monthly average winter air temperatures at whiplash willow low and high elevation extents.

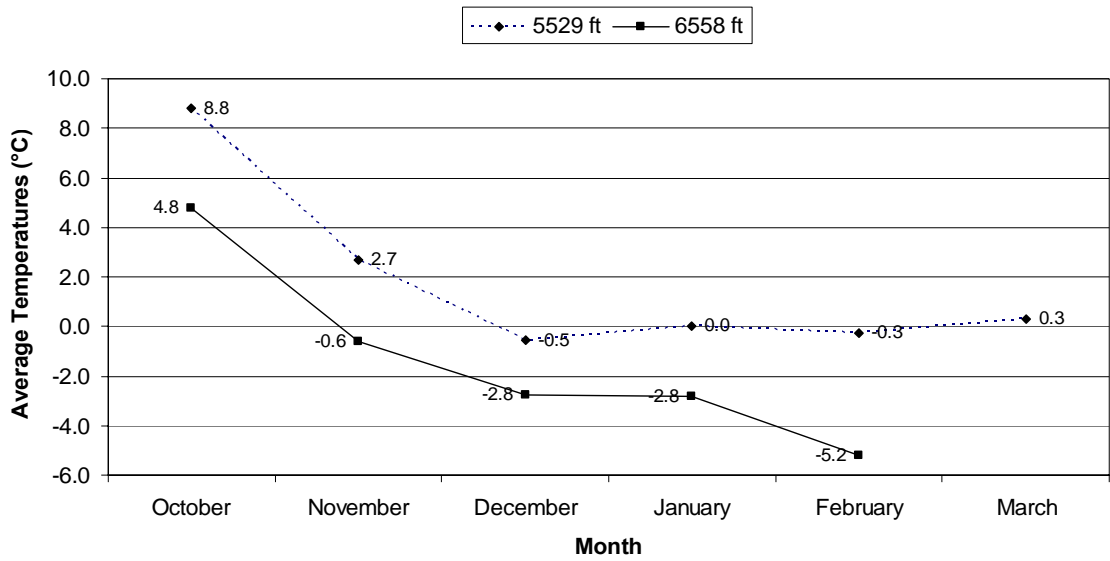


Figure 18. Monthly average winter air temperatures at Geyer willow low and high elevation extents.

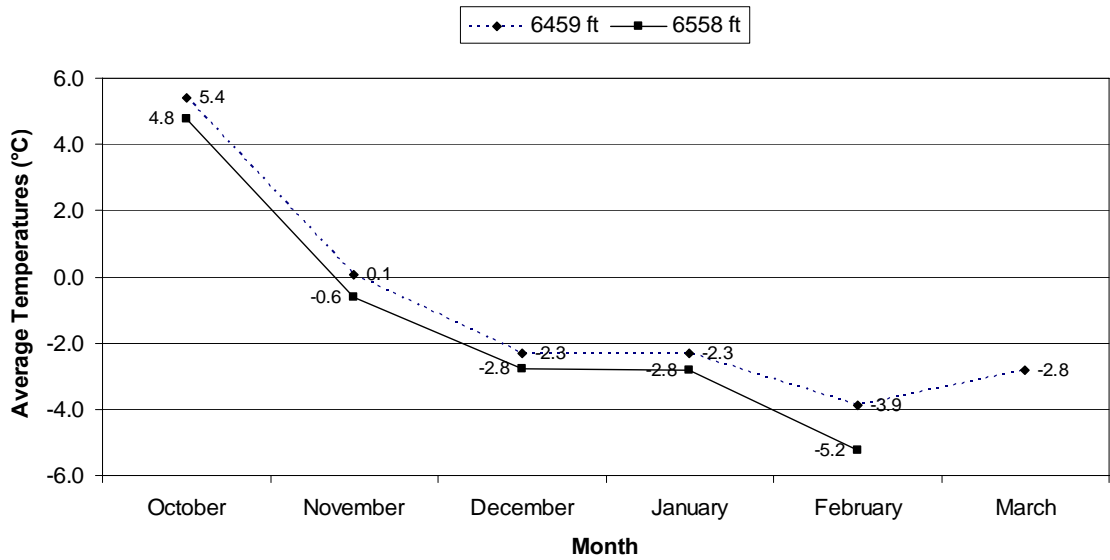


Figure 19. Monthly average winter air temperatures at Booth willow low and high elevation extents.

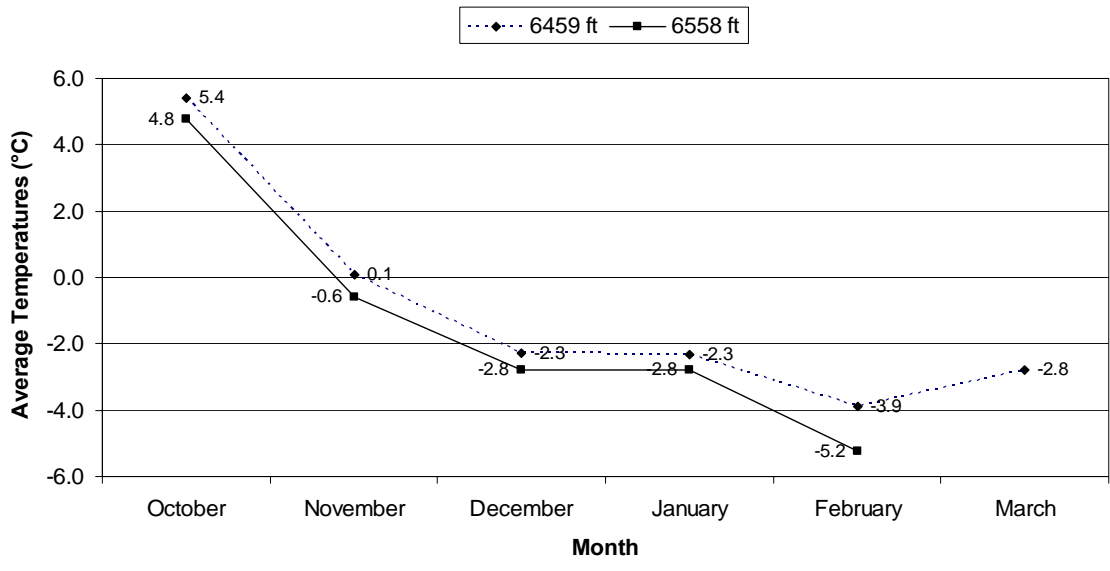


Figure 20. Monthly minimum winter air temperatures at coyote willow low and high elevation extents.

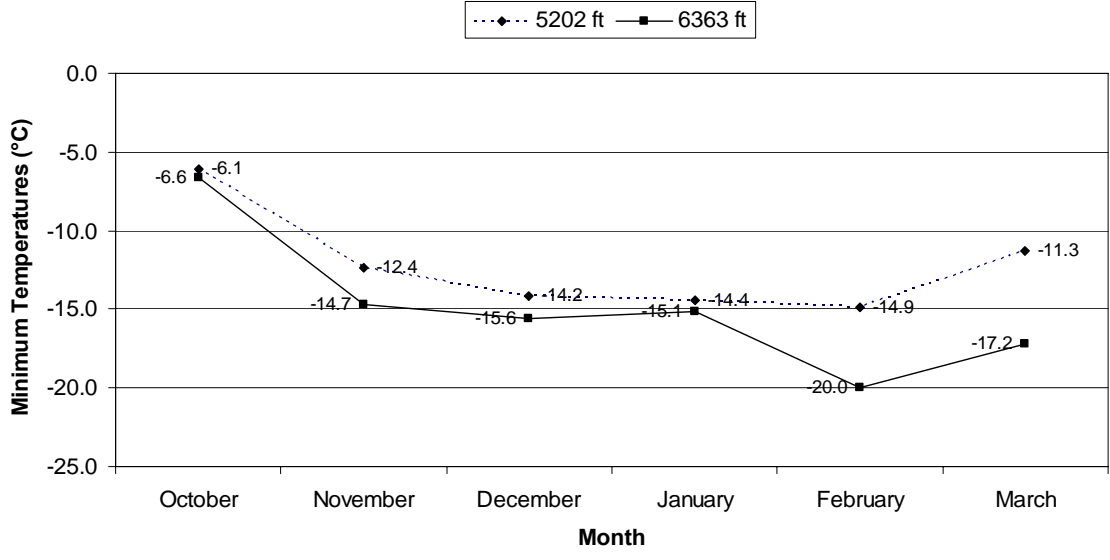


Figure 21. Monthly minimum winter air temperatures at yellow willow low and high elevation extents.

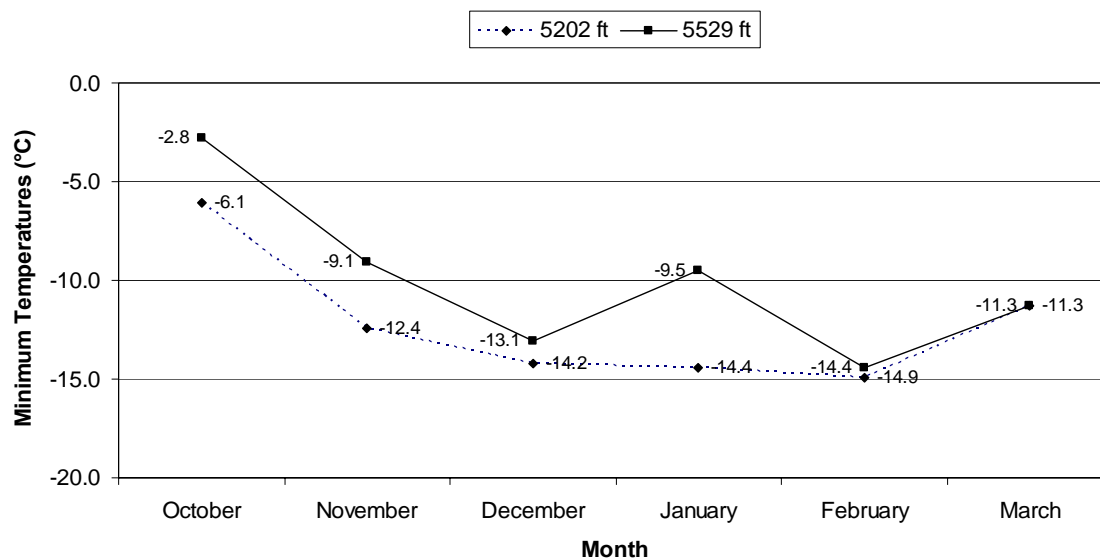


Figure 22. Monthly minimum winter air temperatures at Lemmon willow low and high elevation extents.

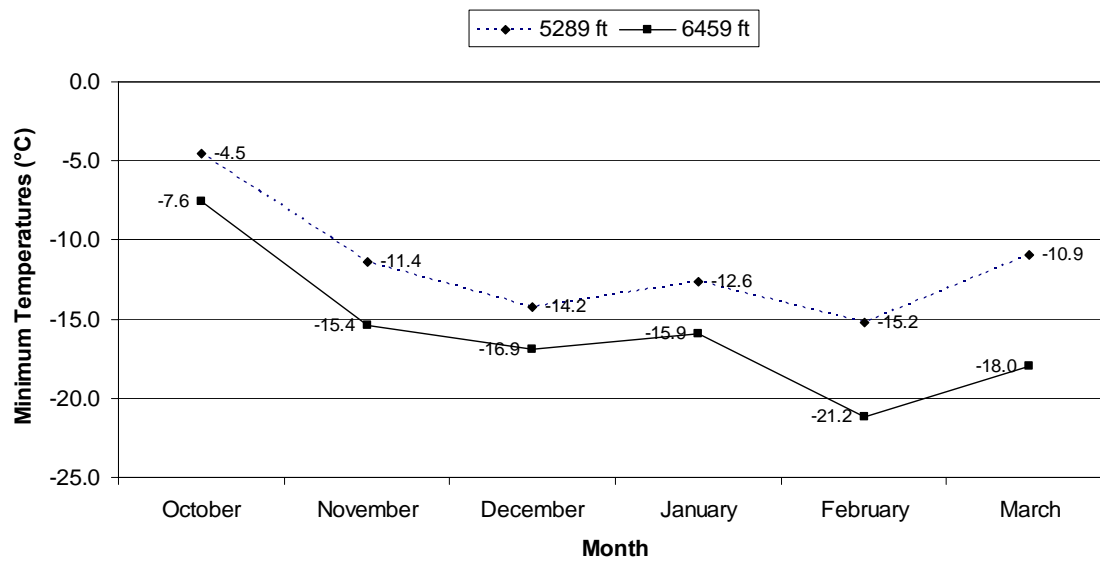


Figure 23. Monthly minimum winter air temperatures at Scouler willow low and high elevation extents.

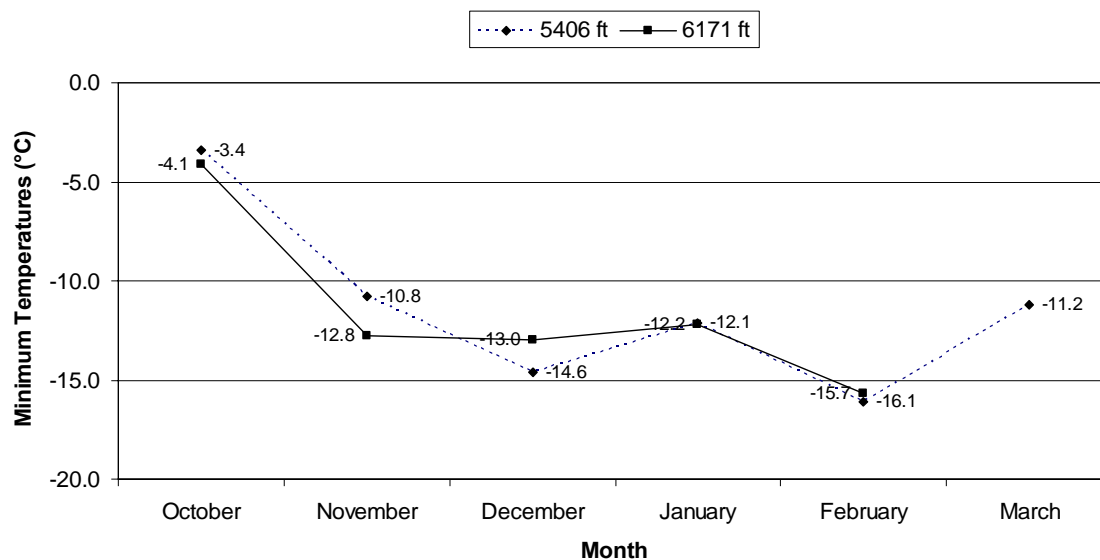


Figure 24. Monthly minimum winter air temperatures at whiplash willow low and high elevation extents.

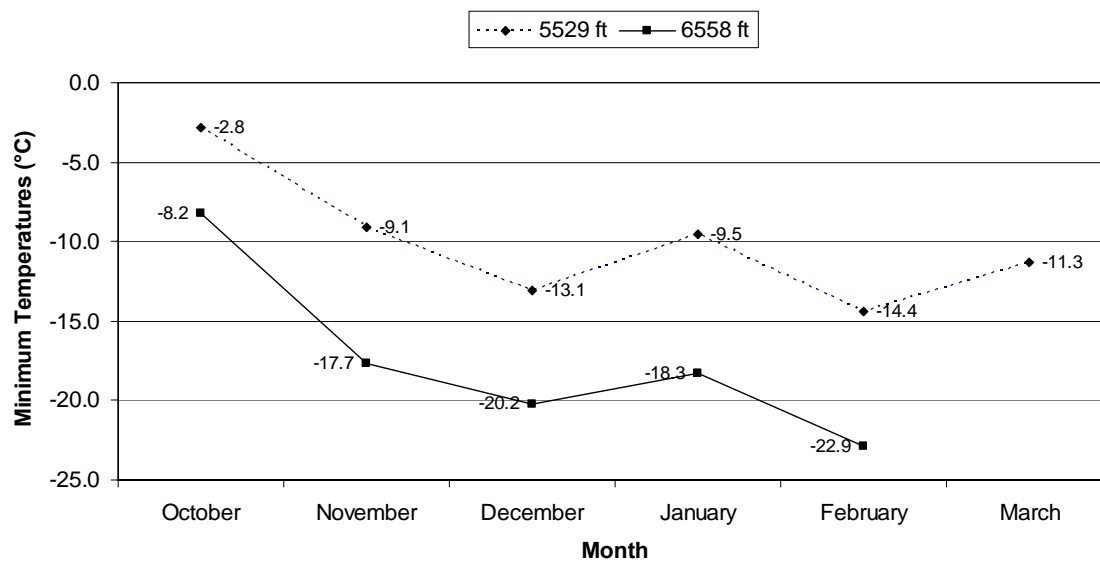


Figure 25. Monthly minimum winter air temperatures at Geyer willow low and high elevation extents.

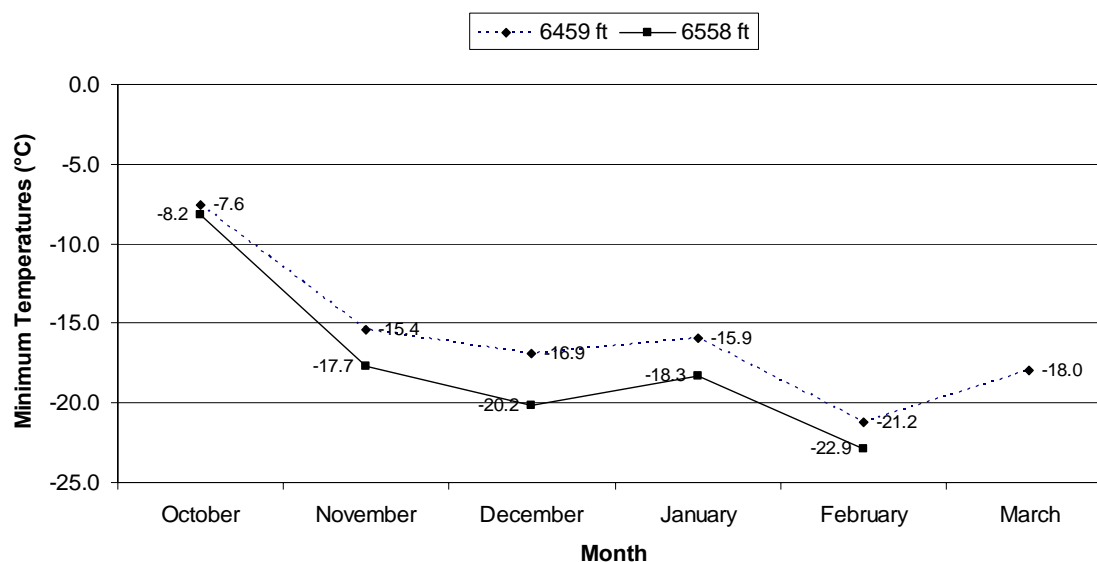
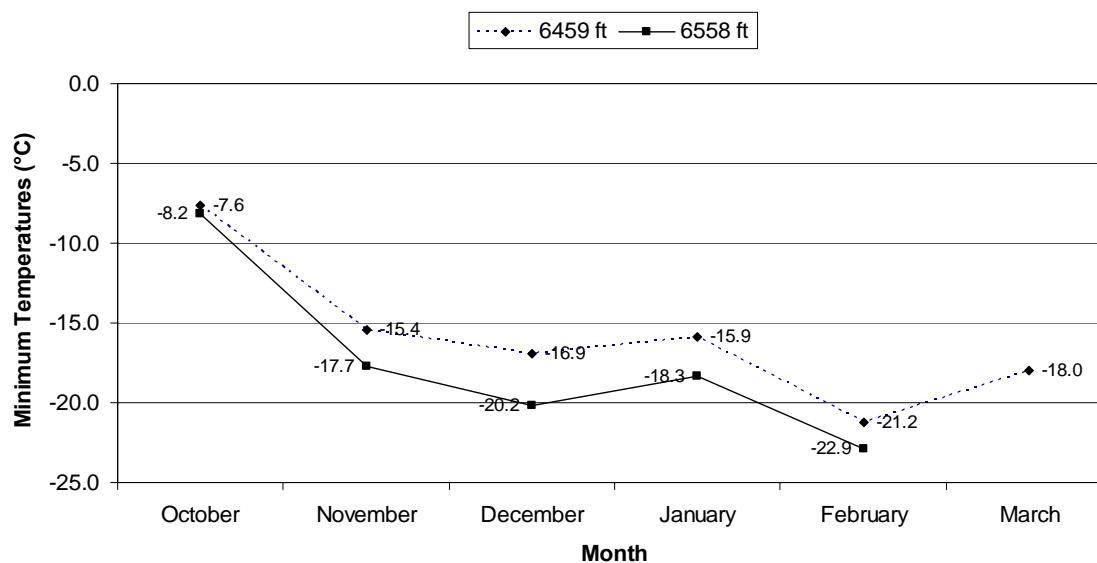


Figure 26. Monthly minimum winter air temperatures at Booth willow low and high elevation extents.



Air temperature data for graphs above were extrapolated from nearby operative temperature recording devices in the following cases: low elevation extent for coyote willow, low and high elevation extents for Lemmon willow, low and high elevation extents for Scouler willow, low elevation extent for Geyer willow, low and high elevation extents for Booth willow (Table 12).

Table 12. Actual elevational ranges of each willow species compared with the elevational ranges covered by the operative temperature recording devices.

Willow Species	Actual Low Elevation Extent (ft)	Actual High Elevation Extent (ft)	Elevation of Temperature Recorder at Low Extent (ft)	Elevation of Temperature Recorder at High Extent (ft)
Coyote	5181	6363	5202	6363
Yellow	5202	5529	5202	5529
Lemmon	5262	6510	5289	6459
Scouler	5385	6351	5406	6171
Whiplash	5529	6558	5529	6558
Geyer	6402	6558	6459	6558
Booth	6369	6591	6459	6558

Therefore, the phrase “low and high elevation extents” actually refers to the extents of the operative temperature recording devices. All elevational ranges of the temperature data used, however, fell within actual elevational ranges of species occurrence. As seen in the Figures 16 – 19 above, there were no temperature data in the month of March for Scouler, whiplash, Geyer, or Booth willow.

Age Classes

Overall, willow individuals in the Mature age class dominated the research group with a total of 53. Research willow individuals numbered 25 total in both the Young and the Decadent age classes, and there were only 4 willow individuals in the Sprout age class. The totals of all four age classes are arranged in Table 13 according to species.

Table 13. Number of willow individuals in each age class for each willow species.

Willow Species	# of Individuals			
	Sprout	Young	Mature	Decadent
Coyote	1	5	2	0
Yellow	0	1	4	1
Lemmon	2	12	21	5
Scouler	0	5	13	8
Whiplash	1	2	3	1
Geyer	0	0	6	3
Booth	0	0	4	7
Total	4	25	53	25

Species Lists

In or adjacent to every research willow clump were stands of *Artemisia tridentata* ssp. *wyomingensis*, making it the dominant shrub on the research watershed. Another prevalent woody plant was *Populus tremuloides*, especially at middle to higher elevations, which occurred both in the riparian zone and in the adjacent uplands. The grass *Poa pratensis* was common throughout the research watershed both in the riparian zone and on hillsides. In the riparian zone itself, the dominant graminoid species were *Juncus balticus* and *Carex nebraskensis*.

Raw Averages

Table 14 presents the average values of each habitat parameter by species.

Table 14. Averages of each habitat parameter measured for each willow species on the research watershed.

Willow Species	Elevation (ft)	Slope (%)	Valley Width (m)	Valley Azimuth (°downslope)	Entrenchment Ratio	Width-to-Depth Ratio	Height from Bankfull Elevation (m)
Coyote	5635	6.5	17.9	239	2.6	13.5	0.639
Yellow	5371	5.5	16.6	220	3.4	10.6	0.116
Lemmon	5719	6.8	14.1	229	2.6	9.6	0.316
Scouler	5927	8.4	10.9	225	1.8	9.1	0.557
Whiplash	6237	7.1	14.2	252	2.9	25.1	0.080
Geyer	6494	6.4	22.1	246	5.0	15.2	0.325
Booth	6509	6.7	22.7	248	6.0	15.0	0.192

Willow Species	Distance from Bankfull Elevation (m)	% Very Coarse	% Coarse	% Medium	% Fine	% Very Fine
Coyote	2.186	4.8	9.5	12.6	13.2	13.3
Yellow	1.190	2.5	4.6	7.2	7.2	8.7
Lemmon	3.562	2.4	9.5	12.4	11.0	12.0
Scouler	2.191	5.9	8.9	9.9	9.0	10.3
Whiplash	1.960	0.5	3.9	10.9	13.3	12.8
Geyer	6.950	0.0	4.9	10.9	12.7	16.8
Booth	9.704	1.1	4.5	10.9	16.9	17.0

CHAPTER 5

Discussion

Salix boothii (Booth Willow) and *Salix geyeriana* (Geyer Willow)Overview

The data for both Booth and Geyer willow failed to produce any meaningful regression output. Thus, a more basic examination of these data was used to elucidate why logistic regression analysis was not applicable (Gittleman, pers. comm.). Box plots, this so-called “basic” approach, compared presence versus absence data for Booth and Geyer willow and pointed to the factor responsible for confounding the attempts at regression (Figures 1 – 12, p. 41 – 47).

It was made apparent in viewing these box plots that among the habitat parameters available for use in logistic regression, *Elevation* distinctly accounts for the presence or absence of both Booth and Geyer willow in a given willow clump on the research watershed (Figures 1 and 7, p. 41 and 45). That is, the five habitat parameters other than *Elevation* do not exhibit such clearly separated values between the presence and the absence datasets as does *Elevation*, and can thus be interpreted as exerting much less influence over the occurrence of both willow species (Figures 2 – 6 and 8 – 12, p. 41 – 44 and 45 – 47). It would be difficult, and probably unwise, to call these five other habitat parameters completely unimportant in relation to Booth and Geyer willow distribution. *Elevation*, however, clearly plays a stronger role in shaping the local distribution of Booth and Geyer research individuals. Thus, before even attempting to understand the roles of each of the other five habitat parameters in question it must first be understood that upon reaching a certain elevation on the research watershed Booth and Geyer willow

individuals are not encountered, but after reaching that elevation they are always encountered. This fact alone, more than any other fact relating to the measurement of Booth and Geyer willow habitat, clarifies exactly what about this habitat is important in determining the distribution of these two species on the research watershed – specifically, this is an elevation above about 6360 feet.

The winter air temperature ranges for Booth and Geyer willow are reported as being identical in Table 12 (p. 64). The actual elevation ranges for each species, however, are different from one another (Table 12, p. 64). This is because winter air temperature data for both Booth and Geyer willow had to be extrapolated from nearby operative temperature recording devices due to malfunctions of temperature recording devices placed specifically at the elevation extents of these two species. The low elevation temperature data for Booth willow was recorded 122 feet above the actual low elevation extent of the species. Similarly, the low elevation temperature data for Geyer willow was recorded 56 feet above the actual low elevation extent of the species. The high elevation temperature data for Booth willow was recorded 33 feet below the actual high elevation extent of the species.

Figures 18 and 19 (p. 59 and 60) show that at the reported low elevation extents, both willow species tolerate monthly average air temperatures of -2.3°C for December and January, -3.9°C for February, and -2.8°C for March. These low elevation extent data also describe the high elevation extent of Lemmon willow (Figure 15, p. 58) and are colder than all, but one (whiplash willow), of the remaining species' high elevation extent temperatures. Thus, four of the other five research willow species do not occur within the winter air temperature ranges of Geyer and Booth willow, with whiplash willow

being the exception. This is evident in the monthly minimum temperature data, as well (Figure 25 and 26, p. 63). Perhaps the Booth and Geyer willow habitats are too cold for the other willow species, thus further explaining why elevation (through its relationship to temperature) so aptly defines Booth and Geyer willow distribution.

Co-occurrence

Upon viewing the MRPP test results, Booth and Geyer willow continue to exhibit habitat preferences divergent from the other willow species. Univariable testing that compared the *Distance from Bankfull Elevation*, *% Fine Gravel*, and *% Very Fine Gravel* data between different pairs of willow species found that Booth willow and Scouler willow habitats differed significantly from each other on these three parameters (Table 9, p. 54). Of these three parameters, it is *Distance from Bankfull Elevation* that provided the most negative value for T , indicating that the measured Booth and Scouler willow habitats are most strongly separated from each other on this parameter. Testing on this parameter also provided the largest value for within-group agreement or A , implying that the values of *Distance from Bankfull Elevation* are highly similar within both the Booth and the Scouler willow habitats, respectively. The MRPP analysis reveals that these two willow species occur at significantly different distances from the research reach channel (Table 9, p. 54). In Table 14 (p. 65) it is apparent that Booth willow occurs, on average, more than 7 m further from the bankfull edge of the research reach channel than does Scouler willow.

Noting the means of *Valley Width* in Table 14 (p. 65) for Booth and Scouler willow reveals an interesting comparison. Booth willow occurs in valleys that average 22.7 m wide, while valleys supporting Scouler willow average less than half this width. Using

MRPP to compare these values produces a significant difference ($p = 0.03$) between Booth and Scouler valley widths at the 0.05 level (no Bonferroni adjustment was made as only one test was conducted). Perhaps this explains why Booth willow occurs so much further from the stream channel than does Scouler willow – simply, it can. That is, a wider valley bottom implies a wider floodplain on which to establish. Scouler willow, occurring predominantly in the narrow canyons of the research watershed's middle to higher elevations, does not have the broad landforms enjoyed by Booth willow on which to establish. Thus, a Booth willow individual is less confined in horizontal space and able to occur much further from the bankfull edge of the stream channel than is Scouler willow. Crowe et al. (2004) found a similar comparison across much of central and eastern Oregon as valleys that supported Booth and Geyer willow mixes measured more than three times the width, on average, of valleys that supported Scouler willow. These narrower valleys that are seemingly associated with Scouler willow could also tend to limit incoming solar radiation. Scouler willow is thus thought to be a more shade tolerant willow species relative to the other willow species of the research watershed. Such an assessment cannot be quantified at this point, however, as incoming sunlight was not directly measured.

The multivariable MRPP analysis involving all thirteen habitat parameters showed that Booth and Scouler willow's overall habitats were significantly different from each other ($p = 0.000004$), as well as the most strongly separated pair of willows on the research watershed ($T = -8.05$) in terms of the measured habitat as a whole (Table 8). This helps to explain why no mix of Booth and Scouler willow is observable on the research reach. The same is true for a Geyer and Scouler willow pairing, and a Booth

and yellow willow pairing, as these species pairs also differed significantly in their overall habitats ($p = 0.000478$ and 0.001835 , respectively) (Table 8, p. 53). Brunsfeld and Johnson (1985), however, found that all three of these unassociated species pairs co-occurred on their sites in east-central Idaho. Unfortunately, Brunsfeld and Johnson report only elevation in their field guide to willows of east-central Idaho. They collected no other quantitative data.

Booth and Lemmon willow habitats also tested significantly different from each other on the research watershed despite an observed co-occurrence of these two species (Table 8, p. 53). The reason for this might be found in any one or more features of the environment. Winter air temperature ranges, for example, overlap in the co-occurring Booth and Lemmon willow, but not in the mutually exclusive Geyer and Scouler willow or Booth and Yellow willow. Most likely, it is the combined effect from all habitat parameters that actually determines species co-occurrence. Brunsfeld and Johnson (1985) found that, in east-central Idaho, Booth willow rarely occurred higher in elevation than Lemmon willow while Geyer willow never occurred above Lemmon willow. Practically the opposite is true on the research watershed as Booth and Geyer willow replaces Lemmon willow at the higher elevations. Perhaps the thermal environments (dependent on incoming solar radiation, cold-air drainage, etc.) of the research watershed and Brunsfeld's and Johnson's sites differ so as to affect Lemmon willow's elevational extent differently. Also, their sites are about 3 °N in latitude from the research watershed. As temperature, in general, tends to decrease with more northerly latitudes in the Northern Hemisphere, then it could be suggested that their sites experience colder temperatures at lower elevations than the research watershed due to the more northern

latitude. Only hypotheses can be offered here as Brunsfeld and Johnson provide no other data than the reported elevational ranges. Additionally, a difference between the research watershed and Brunsfeld's and Johnson's sites on any one of the habitat parameters measured (e.g., stream slope) could lead to differences in Lemmon willow's realized elevational ranges at each location. The same can be said for the findings of Crowe et al. (2004), which suggest that associations between Lemmon, Booth, and Geyer willow occur at elevations much lower than observed on the research reach. Similar to Brunsfeld's and Johnson's sites, the sites of Crowe et al. are north of the research watershed by a few degrees latitude.

The conflicting findings between this research and Brunsfeld's and Johnson's study highlight the importance of considering habitat as more than one parameter. The relative elevational ranges of the research watershed's willow species differ from Brunsfeld's and Johnson's elevational ranges as the result of an entire ecosystem effect. Stream channel morphology, air temperature, soil, and many other factors all apply different pressures on the odds of occurrence for each willow species.

Salix lasiandra (Whiplash Willow)

Overview

The final logistic regression model for whiplash willow is unique among the five final models that were selected to describe probabilities of species occurrence. It is interesting because it contains a significant coefficient, but no interaction terms with which to confound it (Table 2, p. 49). Therefore, the odds ratio calculated by exponentiating the coefficient estimate can be used to describe a probabilistic relationship. This holds true for only one other significant coefficient produced in the results – that of the

Entrenchment Ratio term in the Scouler willow model (Table 6, p. 52). It cannot be done in the remaining models with significant coefficients as the individual main effects terms are also included in interaction terms in the models, and the nature of the probabilistic relationship requires that all other model terms remain fixed.

The significant coefficient of interest here is that of the term *Width-to-Depth Ratio*. The coefficient estimate is 0.1535, which exponentiated produces an odds ratio of 1.17. Thus, it can be said that a unit increase in *Width-to-Depth Ratio* is associated with a 17% increase in the odds of whiplash willow presence. This interpretation, however, must be kept within the confines of the 95% confidence interval, which was reported as 1.00 to 1.36. The interpretation now follows that a unit increase in *Width-to-Depth Ratio* is associated with anywhere from a 0 to 36% increase in the odds of whiplash willow presence. In other words, a relative increase in the research reach channel's width-to-depth ratio likely increases the chance of finding whiplash willow. Implications of this are explored below.

The Interpretation of Model Terms

The coefficient estimate for *Entrenchment Ratio* in the whiplash willow model cannot be discussed as being different from zero as it is accompanied by a p-value greater than 0.05 (Table 2, p. 49). The inclusion of the *Entrenchment Ratio* term, however, is still of interest ecologically, as well as that of the *Width-to-Depth Ratio* term. More specifically, it is important to understand why these two terms, out of the six terms possible, built the best fitting model for describing the odds of whiplash willow presence.

Rosgen (1996) discusses the importance of the entrenchment ratio (ER) as representing flood-prone areas that are associated with flood events less than fifty years

apart, which he considers to be relatively frequent. The lower the ER becomes the more deeply entrenched the stream channel becomes. Streamflows greater than the channel's bankfull elevation often do not overflow the tops of the banks of a deeply entrenched stream, as they tend to do if the stream is only slightly entrenched. Thus, energy from flood waters that would normally be dissipated across floodplains on a slightly entrenched stream contribute instead, to increased rates of streambank erosion on more deeply entrenched channels. Whiplash willows occur on research clump reach channels with an average ER of 2.9, and are therefore considered only slightly entrenched by Rosgen's standards (Table 14, p. 65). The average floodplain, then, is accessible to relatively frequent floods. Perhaps *Entrenchment Ratio* was included in the whiplash willow model because the floodplains on which the species occurs are unique (relative to floodplains not supporting the species) in their range of values of flood-prone areas accessed by relatively frequent flooding. The *Entrenchment Ratio* term only makes sense, however, in the context of the model and not independent of the *Width-to-Depth Ratio* term.

The two terms are closely related to each other through the hydrology of the stream channels by which they are both affected and which they both affect. Rosgen (1996) relates the width-to-depth ratio (W/D) to the distribution of energy within stream channels and suggests that it can help indicate changing degrees of channel stability. This is because the shape of the channel dictates how energy is distributed within the channel. The higher the W/D becomes, the wider and shallower the stream channel becomes. Generally, this means a decrease in stream velocity and power, but in the presence of increased stream channel slope, high W/D values can translate into

accelerated bank erosion through the increased bank stress of wide, shallow channels. Sediment deposition follows bank erosion and the channel continues to become wider and shallower. As demonstrated above, the odds ratio of the *Width-to-Depth Ratio* coefficient suggests that as the W/D increases, so to do the odds of whiplash willow presence. Data suggest then, that on wide and shallow (high W/D) research reach channels with accessible floodplains (high ER) the average whiplash willow might find a favorable habitat in which to occur on the research reach.

It should be noted that Rosgen actually reserves $ER > 2.2$ for “C” and “E” stream types, which begs the question of how a B stream (i.e., the research reach) produced ER values for whiplash willow habitat (e.g., 2.9) that are typically found on these other stream types. Two explanations for this exist. First, the ranges of typical values provided by Rosgen for each stream type are only approximations, not absolutes; thus, leeway must be granted to each stream type for crossing above or below its expected range of values for ER or any of Rosgen’s parameters. Second, parts of the research reach do not conform to Rosgen’s idealized stream types and their respective ranges of typical values because they tend not to support permanent, well-defined stream channels. Hillside seeps exhibit influence over the system’s hydrology as does a fluvial morphology in parts (especially of upper elevations) that creates an environment that might be more aptly described as an intermittent wetland than a permanent riparian zone. Just one Rosgen stream type cannot be superimposed onto the environments of these fluvial wetlands which often exhibit multiple, small defined channels at baseflow during spring runoff; rather, data must be collected parameter-by-parameter to describe the system’s structure free from notions of individual stream types.

Co-occurrence

In regards to whiplash willow and potential co-occurring research willow species, there are no data that reject any of the possible species mixes. In fact, whiplash willow exhibits the widest winter air temperature range of any research willow species, with high elevation average (Figure 17, p. 59) and minimum (Figure 24, p. 62) temperatures equal to those of Booth and Geyer willow at the top of the research reach. It should also be noted that the most diverse research willow clump encountered supported whiplash willow, yellow willow, coyote willow, Lemmon willow, and Scouler willow.

An Example of Logistic Regression Model Application

Overall, each of the five logistic regression models provides a formula with which to help examine the probability of species presence. Thus, to determine the chances of finding whiplash willow on a stream channel with an entrenchment ratio of 2 and a width-to-depth ratio of 10, for example, these values can be inserted into the model and the odds then calculated:

$$\text{logit}(\pi_i) = -3.6579 - 0.0432 \text{Entrenchment Ratio} + 0.1535 \text{Width-to-Depth Ratio}$$

$$= \text{logit}(\pi_i) = -3.6579 - 0.0432(2) + 0.1535(10)$$

$$= \text{logit}(\pi_i) = -2.2093$$

$$\pi_i = \frac{e^{-2.2093}}{1 + e^{-2.2093}}$$

$$\pi_i = 0.10$$

Therefore, according to the whiplash willow model that was built using data from the research watershed, there is a 10% chance (" π_i ") of whiplash willow being present on a stream channel with an entrenchment ratio of 2 and a width-to-depth ratio of 10. It is

recommended that conclusions about the odds of a given species presence be extended beyond the research watershed only at the discretion of the model user. This research has not been tested for application outside of the research willow individuals used herein, and consequently should only be applied beyond this scope with extreme caution and prior knowledge of the risk of misapplication.

Salix lutea (Yellow Willow)

Overview

Like the whiplash willow model, the final logistic regression model selected to describe the odds of yellow willow occurrence contains two terms (Table 3, p. 49). Neither of these terms, however, produced coefficient estimates significantly different from zero, and therefore no application of an odds ratio can be made as it was made above using the whiplash willow model. As demonstrated above with the whiplash willow model, and which holds true for all logistic regression models, one can calculate the odds of yellow willow presence using the equation provided in the yellow willow model. The important question still remains of why *Elevation* and *Width-to-Depth Ratio* together, out of the six terms possible, built the best fitting model for describing the odds of yellow willow presence.

The Interpretation of Model Terms

The elevational range of yellow willow is unique among research willow species in that it is limited to the lower 350 feet of the research reach's 1400 total vertical feet. Yellow willow's average winter air temperature range is congruently the narrowest of all the research willow species (Figure 14, p. 57). Yellow willow's minimum monthly winter air temperatures are interesting in that the low elevation minimums are

consistently colder than those at the high elevation extent (Figure 21, p. 61). This serves as a reminder that elevation's effect on temperature can sometimes be overridden by other local factors, such as strong cold-air drainage networks. Nonetheless, *Elevation*, and its relationship with temperature, is potentially an important determinant of the odds of yellow willow occurrence as the species does not occur in elevations above about 5550 feet or in temperatures below about -15 °C.

Width-to-Depth Ratio is also a potentially important determinant of the odds of yellow willow occurrence. The average W/D on research clump reach channels supporting yellow willow is 10.6, which being less than 12, is considered low (Table 14, p. 65). A deeper and more narrow channel such as this, according to Rosgen (1996), exhibits much more stability (i.e., experiencing less significant aggradation/degradation processes) and hydraulic efficiency than the relatively shallow and wide channels discussed earlier. It appears that deeper, narrower channels persist on the research watershed at the lower elevations common of yellow willow habitat. Perhaps the few, mostly older yellow willow individuals remaining on the research reach require increased channel stability, either throughout their lifespan or only in order to persist long-term. The higher elevations of the research reach do not offer such stable channels, and possibly for this reason do not support yellow willow.

It should be noted that research clump reach stream channels that support yellow willow individuals fall predominantly into one of two stream types. These are a shallower, wider, more entrenched stream type (B) and a deeper, narrower, less entrenched one (E). All yellow willow clump reach channels are steeper than would be expected of an E type stream, thus it is thought that B is the dominant stream type overall

and that the lower W/D values (seen above) more characteristic of an E type stream result from necessary adjustments for increased slope and stream power.

Co-occurrence

In regards to yellow willow and potential co-occurring research willow species, there are data that reject some of the possible species mixes. Specifically, yellow willow did not, and is not expected to occur with Booth willow as evidenced by the significant difference in the multivariable MRPP comparison of their respective habitats (Table 8, p. 53). It is likely that differences in elevation (and temperature by association) play a large role in this species separation. Brunfeld and Johnson (1985) found that these two species did, in fact, co-occur in their east-central Idaho study sites due to a comparatively lower elevational range of Booth willow, but a similar elevational range of yellow willow compared with findings on the research watershed. Yellow willow also does not occur with Geyer willow on the research watershed, but does occur with whiplash willow, coyote willow, Lemmon willow, and Scouler willow

Salix lemmonii (Lemmon Willow)

Overview

Like the yellow willow model, the final logistic regression model selected to describe the odds of Lemmon willow occurrence contains no coefficient of individual main effects terms that are significantly different from zero (Table 4, p. 50). Unlike the yellow willow model (and the whiplash willow model), however, the Lemmon willow model contains interaction terms and the coefficient of one of these is significantly different from zero. Unfortunately, an interaction between two dynamic ecological habitat properties is too abstract of a concept on which to superimpose simple arithmetic relationships such as the

odds ratio. Though it may not make sense mathematically, the significant interaction may be discussed in terms of ecology.

The Interpretation of Model Terms

Interactions, like those in the Lemmon willow model – *Elevation x Valley Azimuth* and *Slope x Width-to-Depth Ratio* – imply that reality is more complex than a collection of mere additive effects. This conclusion is to be expected from the dynamic ecology of the riparian zone, in which changing physical properties continually affect one another with varying degrees of influence. Stream channel slope and stream channel W/D are two such physical properties. As stated earlier, streambank erosion rates depend upon the relationship between stream channel slope and W/D (Rosgen 1996). Stream channels with steeper slopes and higher W/D values experience accelerated bank erosion, but bank erosion slows down as the values of both decrease. The average slope value of research clump reach channels supporting Lemmon willow is a relatively steep 6.8% (Table 14, p. 65). Similarly, the Lemmon willow associations sampled by Crowe et al. (2004) throughout central and eastern Oregon appear to consistently exhibit steep average valley slopes relative to those of other willow species associations. The average W/D value of research clump reach channels supporting Lemmon willow is a relatively low 9.6 (Table 14, p. 65). Crowe et al. did not measure average W/D values, but did find Lemmon willow occurring on both “A” and “E” type streams, among others, which typically exhibit W/D values lower than 12, as seen here on the research watershed. Based on the relationship between slope and W/D, then, it might be suggested that the average research clump reach channel supporting Lemmon willow is stable with its deep, narrow channel and, at the same time, efficient with its steep slope. This relationship, of course, is very

dynamic as differing values for both slope and W/D simultaneously change the other's influence on channel function and subsequently the odds of Lemmon willow presence. Increasing the W/D applies more stress to streambanks, while decreasing the slope can mitigate for this through a decrease in stream velocity and power. The data suggest that this might be the precise interaction that effects the odds of Lemmon willow presence on the research reach. That is, in the low to middle elevations that are dominated by Lemmon willow, W/D values are higher and stream slopes are lower, while upstream at middle to higher elevations, W/D values decrease with increasing stream slopes and Lemmon willow still occurs. Perhaps Lemmon willow presence, then, requires an overall stable channel, to a degree, through this give and take between the channel's slope and W/D.

Also interesting is that while many Lemmon willow habitat parameters change as elevation increases on the research watershed, Lemmon willow's soil parameters remain relatively constant. The % *Coarse* gravel in Lemmon willow soil samples decreases slightly from an average 10.1% around low to middle elevation Lemmon willows to an average 9.2% around middle to higher elevation Lemmon willows. Lemmon willow's % *Fine* gravel increases from an average 10.7% around low to middle elevation Lemmon individuals to an average 11.5% around middle to higher elevation Lemmon individuals. These small shifts in the rock sizes specific to Lemmon willow soils make sense when viewed in the context of another important parameter - *Distance from Bankfull Elevation*. Lemmon willow research individuals occur more than 2 m closer, on average, to the research channel in middle to higher elevations than in low to middle elevations. The Scouler willow associated with the middle to higher elevation Lemmon willow occurs, on

average, about half-a-meter further from the research channel than does Lemmon willow. Perhaps Lemmon willow research individuals of middle to higher elevations occur closer to the stream channel because the finer gravels they occur in further from the channel in lower elevations are confined to a thin line close to the channel by the lower ER (2.0 on average) of higher elevations. It is possible, then, that Lemmon willow occurrence is not “following” a stable channel; rather, it might be following a specific combination of soil parameters which facilitates Lemmon willow growth throughout much of the research watershed.

The interaction between *Elevation* and *Valley Azimuth* is more obvious. It is simply a fact that as one climbs upstream both the direction and the elevation of the research watershed’s valley change. Their interaction indicates that the effect of high elevations, for example, on the odds of Lemmon willow occurrence changes depending on the direction of the valley. This makes sense scientifically through these parameters’ known relationships with air temperature. Depending on the direction of the valley, the thermal effects of the sun on the landscape change dramatically due to varying lengths of time in which its radiation reaches the earth’s surface. Likewise, increasing elevations are associated with decreasing air temperatures through adiabatic cooling. Thus, certain air temperatures brought on by certain elevations become different air temperatures at certain valley azimuths.

Lemmon willow dominated the low to middle elevations of the research reach, which face predominantly due southwest. Air temperatures are increased here by the effects of both lower elevation and more solar radiation. Upstream the valley azimuth turns due west and the temperatures decrease from the effects of higher elevation and less solar

radiation. Thus, perhaps the dominant Lemmon willow stands at lower to middle elevations rely on a give and take between elevation and valley azimuth to produce air temperatures favorable for occurrence. It should be noted that Lemmon willow on the Brunsfeld and Johnson (1985) study sites did not extend nearly as low in elevation as on the research watershed perhaps due to a possibly different thermal environment as discussed earlier.

Co-occurrence

Lemmon willow was the most ubiquitous species on the research watershed. It occurred with all six other willow species, and so makes the results of the MRPP analysis that found Lemmon and Booth willow habitats significantly different from each other a bit unexpected (Table 8, p. 53). Perhaps the only two measurements left out of this analysis – winter air temperature and soil texture – play important roles in the co-occurrence of these two species. Especially intriguing in this argument is the fact that winter air temperature ranges overlap between Lemmon and Booth willow (Figure 15 and 19, p. 58 and 60), and both species occurred most often in silty clay loam soils (Table 10, p. 55).

Salix exigua – Coyote Willow

Overview

Coyote willow is as ubiquitous a species throughout the United States as Lemmon willow appears to be throughout the research watershed (Brunsfeld and Johnson 1985). At first glance the coyote willow individuals of the research reach definitely seem unselective, in terms of habitat, as they occur over a wide range of elevations and even

grow in the dirt road up the sideslope. Logistic regression, however, illuminates finer details of this species' preferences.

The Interpretation of Model Terms

The final logistic regression model selected to describe the odds of coyote willow occurrence contains three coefficient estimates that are significantly different from zero – those of the interaction *Slope x Width-to-Depth Ratio* and its component parts *Slope* and *Width-to-Depth Ratio* (Table 5, p. 51). The average slope value of research clump reach channels supporting coyote willow is a moderately steep 6.5%, while the average W/D is a high 13.5 (Table 14, p. 65). Based on earlier discussions of how the relationship of these parameters manifests itself on the stream channel (i.e., high slope with high W/D accelerates erosion), it appears that the average coyote willow individual occurs in highly rejuvenating stream reaches. The average ER (the other individual main effects term of the coyote willow model) here is a high 2.6, indicating that the average coyote willow individual occurs on channels only slightly entrenched with accessible floodplains (Table 14, p. 65).

Together, then, these three parameters describe coyote willow's strategy for persistence on the research watershed. As a clonal, disturbance-driven, pioneer species coyote willow relies on fresh depositional surfaces on which to occur (Hansen et al. 1988). The coyote willow model suggests that the habitat parameters most important in describing the odds of coyote willow presence – slope, W/D, and ER – are those that are capable of satisfying these occurrence requirements through their characterization of channel morphology and streamflow dynamics. No other parameters besides these were included in the model. Also, most of the coyote willow research individuals are in the

Young age class strengthening an interpretation of the coyote willow model as a metaphor for coyote willow's successional strategy.

Co-occurrence

In regards to coyote willow and potential co-occurring research willow species, the only data rejecting any of the possible species mixes are winter air temperature records. The highest coyote willow research individual occurred immediately below the lowest Booth and Geyer willow research individuals on the research watershed. This could suggest that coyote willow's threshold for low air temperatures prevents it from extending into these higher elevations. The coldest temperatures experienced by coyote willow (Figure 20, p. 60) are consistently about 1 °C warmer than those of Geyer and Booth willow (Figure 25 and 26, p. 63). Though it did not occur with Booth and Geyer willow, coyote willow did occur with the other four research willow species.

Scouler Willow

Overview

Scouler willow appeared to be the most habitat-selective species of the research reach. Support for this observation is provided by the final logistic regression model selected to describe the odds of its occurrence. The interaction term *Elevation x Valley Azimuth* and its component parts *Elevation* and *Valley Azimuth* are each accompanied by significant coefficients in the Scouler willow model (Table 6, p. 52). There is one coefficient estimate that is significantly different from zero belonging to the individual main effects term *Entrenchment Ratio*, which is not confounded by any interaction terms. Therefore, this coefficient's odds ratio can be used in the manner demonstrated above in the whiplash willow model.

The Interpretation of Model Terms

The coefficient estimate for the *Entrenchment Ratio* term is -2.2042, which exponentiated, produces an odds ratio of 0.11 (Table 6, p. 52). Thus, it can be said that a unit increase in *Entrenchment Ratio* is associated with an 89% decrease in the odds of Scouler willow presence. Note that the odds ratio here affects the probability negatively because the sign of the coefficient is negative, unlike the effect presented above with the whiplash willow model. The interpretation, of course, must be kept within the limits of the 95% confidence interval, which was reported as 0.01 to 0.92. The interpretation now follows that a unit increase in *Entrenchment Ratio* is associated with anywhere from an 8 to 99% decrease in the odds of Scouler willow presence. In other words, a relative increase in the research reach channel's ER decreases the chance of finding Scouler willow by at least 8% and potentially by 99%.

Thus, the odds of Scouler willow presence decrease as the research reach channel becomes less entrenched and its respective floodplains become more accessible. The average ER of Scouler willow clump reach channels is a low 1.8, which is the lowest average ER of all the research willow species (Table 14, p. 65). This places the average Scouler willow individual on a channel that is very confined by its valley with much less space for floodplain development than is possible in the habitats of most of the other research willow species. The less confined the stream channel becomes the less likely the presence of Scouler willow becomes, providing further evidence of Scouler willow's potential for increased tolerance to shade within these characteristically confined valleys. A separation of habitats between Scouler willow and many of the other research willow species is evident in simply viewing the species groupings on the research reach

(Appendix A). The narrow valley of the middle elevations are dominated by Scouler willow with Lemmon willow intermixed. According to the Scouler willow model there are four other parameters besides ER that help define this specific habitat – *Elevation*, *Slope*, *Valley Azimuth*, and *Width-to-Depth Ratio*. Of these, the coefficient estimates for both *Elevation* and *Valley Azimuth* are significantly different from zero, but the coefficient of the interaction between them, *Elevation x Valley Azimuth* is also significantly different from zero, which negates any application of probabilistic relationships within the model equation (Table 6, p. 52). Nonetheless, the inclusion of these terms in the Scouler willow model is worth examining.

Some Scouler willow research individuals occur in the lower elevations of the research reach, but the majority occur in the upper-middle 400 ft of the research reach. They occur, on average, in valleys that face approximately due southwest. Their range of winter air temperatures (Figure 16, p. 58) is narrower and generally warmer than all other research willow species, except yellow willow. Perhaps Scouler willow's relatively low tolerance for cold winter air temperatures (Figure 23, p. 62) restricts it to the increased solar radiation offered by the due southwest valleys of the upper-middle elevations on the research watershed. The valley azimuth above turns more to the west becoming cooler, but the valley azimuth below is more southerly and, in turn, warmer. Note, however, that these lower valleys contain stream channels that are much less entrenched and, therefore, much less habitable for Scouler willow. The interaction of elevation and valley azimuth seem to influence the odds of Scouler willow presence in the same manner as it did Lemmon willow discussed above; that is, both parameters might be in a give and take relationship to ultimately realize the species' tolerable air temperature range.

The average slope of Scouler willow clump reach channels is a high 8.4, which is the highest average slope of all the research willow species (Table 14, p. 65). The average W/D of Scouler willow clump reach channels is a low 9.1, which is the lowest average W/D of all the research willow species (Table 14, p. 65). This combination of a high slope and a low W/D characterize the average Scouler willow stream channel as very hydraulically efficient. Perhaps Scouler willow's methods of propagation, then, contrast the mechanisms commonly used by a species like coyote willow. Dumroese et al. (1997) reported a variable 40 – 80% rooting success in Scouler willow cuttings. Thus, Scouler willow may not rely on vegetative regeneration as heavily as some other willow species; rather, a potentially high germination of wind dispersed seed might help to explain its ability to propagate narrow, efficient valleys. In terms of the average Scouler willow research individual, slope and W/D interact in ways that increase the efficiency of the stream (i.e., steeper slopes with deeper, narrower channels). This is similar to the way this interaction influenced the average Lemmon willow research individual. Likewise, Crowe et al. (2004) described a very steep valley gradient average for Scouler willow associations throughout central and eastern Oregon. Moreover, Evenden (1989) described Scouler willow as preferring channels characterized by stable streambanks and overall habitats that generally transport materials rather than retain them.

Co-occurrence

In regards to Scouler willow and potential co-occurring research willow species there are data that reject some of the possible species mixes. Specifically, Scouler willow did not, and is not expected to, occur with Booth willow or Geyer willow as evidenced by the significant difference in the multivariable MRPP comparisons of their respective habitats

(Table 8, p. 53). As discussed above, these three willow species do co-occur on the Brunsfeld and Johnson study sites (1985). Perhaps differences in elevation (and temperature by association) play a large role in the species separation observed on the research watershed, but it is important to remember that there are twelve other parameters involved in forming the habitats of these species. Evidence of this is seen below in the significant comparisons between Scouler and Booth willow habitat parameters.

Scouler and Booth willow tested significantly different from each other in three of the univariable MRPP analyses (Table 9, p. 54). The difference of the distances of each species from the stream channel bankfull elevation was discussed earlier. The difference of the rock size distributions of soil samples from each species has not yet been discussed. Specifically, Scouler and Booth willow soils differ significantly from each other in their respective percents of fine and very fine gravels (Table 14, p. 65). The data suggest that Scouler willow occurs in soils with less of these smaller gravels than does Booth willow. A possible explanation for this could be the relative efficiencies of Scouler stream channels (described above as potentially the most efficient of the research reach) compared with Booth stream channels. Physics dictates that as stream efficiency increases, sediment transport also increases, especially with smaller sized sediments such as fine and very fine gravels (Rosgen 1996). Thus, stream channels common to Scouler willow habitat on the research reach tend to transport the fine gravels found in Booth willow habitats downstream, which might explain why these two species do not co-occur here. Scouler willow did occur with the other four research willow species.

CHAPTER 6

Conclusion

Habitat Summaries for Each Species

Booth Willow

Booth willow habitat on the research reach was best described in terms of elevation. As elevation affects air temperature, the importance of Booth willow's winter air temperature range should also be considered in describing suitable habitat. Disparate winter air temperature ranges are believed to partly account for the significant difference found between Booth and Yellow willow habitats. Booth and Lemmon willow habitats were also found to differ significantly, although both species occur together on the research reach. Winter air temperature ranges and soil textures were left out of this comparison, but are similar between Booth and Lemmon willow and, therefore, believed to potentially play an important role in the co-occurrence of these two species. The significant differences between Booth and Scouler willow habitats, especially in terms of a willow individual's *Distance from Bankfull Elevation*, highlighted the wide valley bottoms characteristic of Booth willow habitat.

Geyer Willow

Geyer willow habitat on the research reach was also best described in terms of elevation. Likewise, as elevation effects air temperature, the importance of Geyer willow's winter air temperature range should also be considered in describing suitable habitat. Geyer and Scouler willow habitats were found to differ significantly, possibly owing in part to their distinct winter air temperature ranges.

Whiplash Willow

Whiplash willow on the research reach was best described in terms of the channel's entrenchment ratio and width-to-depth ratio. Specifically, a unit increase in the parameter *Width-to-Depth Ratio* is associated with a 17% (95% confidence interval at 0 to 36%) increase in the odds of whiplash willow presence. Whiplash willow habitat is believed, on average, to consist of wide and shallow (high W/D) stream channels with accessible floodplains (high ER). A probability of whiplash willow occurrence can be calculated by inserting any given value for both *Entrenchment Ratio* and *Width-to-Depth ratio* into the final whiplash willow model.

Yellow Willow

Yellow willow on the research reach was best described in terms of elevation and the channel's width-to-depth ratio. Yellow willow habitat is believed, on average, to consist of deeper, narrower, more stable channels common at the lower elevations of the research reach. It is possible that yellow willow did not occur at high elevations because of the concomitant decrease in channel stability seemingly required by the species in the long term. A probability of yellow willow occurrence can be calculated by inserting any given value for both *Elevation* and *Width-to-Depth ratio* into the final yellow willow model.

Lemmon Willow

Lemmon willow on the research reach was best described in terms of the interactions between elevation and valley azimuth and between slope and width-to-depth ratio. Lemmon willow habitat is believed, on average, to consist of stable channels resulting from a give and take between the channel's slope and width-to-depth ratio. Lemmon willow could potentially be occurring wherever the species' preferred ratio of fine to

coarse gravels exists. Perhaps the more laterally contained the research channel becomes, the more heavily Lemmon willow depends upon finer gravels as evidenced by the shift in soil parameters from low to higher elevations. A relationship similar to that described as the give and take between slope and width-to-depth ratio is believed to exist between the habitat's elevation and valley azimuth, ultimately producing air temperatures favorable to Lemmon willow occurrence. A probability of Lemmon willow occurrence can be calculated by inserting any given value for *Elevation*, *Slope*, *Valley Azimuth*, and *Width-to-Depth ratio* into the final Lemmon willow model.

Coyote Willow

Coyote willow on the research reach was best described in terms of the channel's slope, entrenchment ratio, and width-to-depth ratio. Coyote willow habitat is believed, on average, to consist of highly rejuvenating channel reaches that support accessible floodplains. The right combination of a steep channel slope and high width-to-depth ratio, on a slightly entrenched channel (i.e., low ER) is believed to create the habitat required by the pioneering coyote willow for occurrence. A probability of coyote willow occurrence can be calculated by inserting any given value for *Slope*, *Entrenchment Ratio*, and *Width-to-Depth ratio* into the final coyote willow model.

Scouler Willow

Scouler willow on the research reach was best described in terms of the channel's entrenchment ratio, as well as the interactions between elevation and valley azimuth and between slope and width-to-depth ratio. Specifically, a unit increase in the parameter *Entrenchment Ratio* is associated with an 89% (95% confidence interval at 8 to 99%) decrease in the odds of Scouler willow presence. These decreased entrenchment ratios

translate to decreased valley widths, which are thought to describe an increased shade tolerance of Scouler willow. Scouler willow habitat is believed, on average, to consist of deeply entrenched channels, which are very efficient as a result of steep slopes and low width-to-depth ratios. The habitat's elevation and valley azimuth are believed to interact in the same manner they did to help shape the Lemmon willow habitat mentioned above. A probability of Scouler willow occurrence can be calculated by inserting any given value for *Elevation*, *Slope*, *Valley Azimuth*, *Entrenchment Ratio*, and *Width-to-Depth ratio* into the final Scouler willow model.

Limitations of the Research (Revisited)

The research limitations discussed earlier still hold true. The scope of the results are described as extending only as far as the 107 willow individuals selected for research, but could likely extend to a broader area if willow selection strategies were modified. That is, random selection of willow individuals for research would allow for an interpretation of results within the context of the entire watershed. The more watersheds included in the selection process, and in the subsequent data collection and analysis, the broader the research's scope becomes. Larger research areas, however, require more time and money, both of which were limited on this project.

Possible Future Research

All five of the logistic regression models built with this research's dataset should be tested on other watersheds, which are ecologically and climatically similar to the research watershed. Tests might consist of comparing probabilities of occurrence produced by each regression equation with actual rates of occurrence for each species on other watersheds. First, random values for each parameter would be inserted into the

regression equations. Then, actual values for each parameter would be measured following the methods described in this research. If willow species actually occur in the habitats measured under the probabilities predicted, then the logistic regression models are accurate.

Literature Cited

- Anderson, E.W., M.M. Borman, and W.C. Krueger. 1998. The ecological provinces of Oregon: a treatise on the basic ecological geography of the state. Corvallis, OR: Oregon Agricultural Experiment Station. 138 pp.
- Anonymous. 2005. S-PLUS for Windows, Version 7. Seattle, WA: Insightful Corporation.
- Argus, G.W. 1997. Infrageneric classification of *Salix* (Salicaceae) in the world. *Systematic Botany Monographs* 52:91-98.
- Baker, W.L. 1989. Macro- and micro-scale influences on riparian vegetation in western Colorado. *Annals of the Association of American Geographers* 79(1):65-78.
- Beschta, R.L., and J.B. Kauffman. 2000. Restoration of riparian systems – taking a broader view. *Proceedings of the International Conference on Riparian Ecology and Management in Multi-land Use Watersheds*, American Water Resources Association. p. 323-328.
- Biondini, M.E., C.D. Bonham, and E.F. Redente. 1985. Secondary successional patterns in a sagebrush (*Artemisia tridentata*) community as they relate to soil disturbance and soil biological activity. *Vegetatio* 60:25-36.
- Brinson, M.M. 1990. Riverine forests. In: *Forested wetlands*, ed. A.E. Lugo, M.M. Brinson, and S. Brown (Amsterdam: Elsevier Science Pub. Co., 1990). p. 87-141.
- Brunsfeld, S.J., and F.D. Johnson. 1985. *Field guide to the willows of east-central Idaho*. Moscow, Idaho: Forest, Wildlife and Range Experiment Station, University of Idaho. 95 pp.
- Campbell, C.J., and W. Green. 1968. Perpetual succession of stream-channel vegetation in a semiarid region. *Journal of the Arizona Academy of Science* 5:86-98.
- Chambers, J.C., R.J. Tausch, J.L. Korfmacher, D. Germanoski, J.R. Miller, and D. Jewett. 2004. Effects of geomorphic processes and hydrologic regimes on riparian vegetation. In: *Great Basin riparian areas : ecology, management, and restoration*, ed. J.C. Chambers and J.R. Miller (Washington, D.C.: Island Press, 2004). p. 196-232
- Chapin, D.M., R.L. Beschta, and H.W. Shen. 2000. Flood frequencies required to sustain riparian plant communities in the upper Klamath Basin, Oregon. *Proceedings of the International Conference on Riparian Ecology and Management in Multi-land Use Watersheds*, American Water Resources Association. p. 17-22.

- Conroy, S.D., and T.J. Svejcar. 1991. Willow planting success as influenced by site factors and cattle grazing in northeastern California. *Journal of Range Management* 44(1): 59-63.
- Cooke, S.S. 1997. *A Field Guide to the Common Wetland Plants of Western Washington & Northwestern Oregon*. Seattle: Seattle Audobon Society. 417.
- Crowe, E.A., B.L. Kovalchik, and M. Kerr. 2004. *Riparian and wetland vegetation of Central and Eastern Oregon* Oregon State University, Portland, OR. 473 pp.
- Danzer, S.J. 1996. *Vegetative and environmental characteristics of high elevation riparian communities in the mountains of southeastern Arizona*. Ph.D. diss., University of Arizona.
- Densmore, R., and J. Zasada. 1983. Seed dispersal and dormancy patterns in northern willows: ecological and evolutionary significance. *Canadian Journal of Botany* 61:3207-3216.
- Dionigi, C.P., I.A. Mendelssohn, and V.I. Sullivan. 1985. Effects of soil waterlogging on the energy status and distribution of *Salix nigra* and *S. exigua* (Salicaceae) in the Atchafalaya River Basin of Louisiana. *American Journal of Botany* 72(1):109-119.
- Dixon, M.D. 2003. Effects of flow pattern on riparian seedling recruitment on sandbars in the Wisconsin River, Wisconsin, USA. *Wetlands* 23(1):125-139.
- Dumroese, R.K., K.M. Hutton, and D.L. Wenny. 1997. Propagating woody riparian plants in nurseries. In: *Regeneration, reforestation, restoration: The seedling is the key*; National proceedings, forest and conservation nursery associations, ed. D.T. Landis and J.R. Thompson. Gen. Tech. Rep. PNW-GTR-419. (Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, 1997) p. 71-76.
- Elmore, W., and R.L. Beschta. 1987. Riparian Areas: Perceptions in Management. *Rangelands* 9(6):260-265.
- Evenden, A.G. 1989. *Ecology and distribution of riparian vegetation in the Trout Creek Mountains of southeastern Oregon*. Ph.D. diss., Oregon State University.
- Frye, R.J., and J.A. Quinn. 1979. Forest development in relation to topography and soils on a floodplain of the Raritan River, New Jersey. *Bulletin of the Torrey Botanical Club* 106(4):334-345.
- Gregory, S.V., F.J. Swanson, W.A. McKee, and K.W. Cummins. 1991. An ecosystem perspective of riparian zones: focus on links between land and water. *BioScience* 41(8):540-551.

- Griffiths, D. 1902. Forage conditions on the northern border of the Great Basin. Bureau of Plant Industry, U.S. Department of Agriculture, Bulletin 15.
- Hansen, D.J. 1977. Interrelations of valley vegetation, stream regimen, soils, and solar irradiation along the Rock Creek in the Uinta Mountains of Utah. Ph.D. diss., University of Michigan.
- Hansen, P., S. Chadde, R. Pfister, J. Joy, D. Svoboda, J. Pierce, and L. Myers. 1988. Riparian site types, habitat types, and community types of southwestern Montana. Missoula, MT: University of Montana, School of Forestry, Montana Riparian Association. 140 pp.
- Harris, R.R. 1988. Associations between stream valley geomorphology and riparian vegetation as a basis for landscape analysis in the Eastern Sierra Nevada, California, USA. *Environmental Management* 12(2):219-228.
- Hastings, J.R., and R.M. Turner. 2003. The changing mile revisited: an ecological study of vegetation change with time in the lower mile of an arid and semiarid region. pp. 334.
- Hitchcock, C.L., and A. Cronquist. 1973. *Flora of the Pacific Northwest*. Seattle, WA: University of Washington Press. 730 pp.
- Hosmer, D.W., and S. Lemeshow. 2000. *Applied Logistic Regression*, 2nd Edition. New York: Wiley. 373 pp.
- Hudak, H.G., and G.L. Ketcheson. 1991. Willow community types as influenced by valley bottom and stream types. *Proceedings of the Symposium on Ecology and Management of Riparian Shrub Communities*, Sun Valley, ID, May 29-31. p. 16-17.
- Hughes, F.M.R. 1997. Floodplain biogeomorphology. *Progress in Physical Geography* 21(4):501-529.
- Hupp, C.R. 1982. Stream-grade variation and riparian forest ecology along Passage Creek, Virginia. *Bulletin of the Torrey Botanical Club* 109(4):488-499.
- Hupp, C.R. 1983. Vegetation pattern on channel features in the Passage Creek Gorge, Virginia. *Castanea* 48(2):62-72.
- Hupp, C.R., and W.R. Osterkamp. 1985. Bottomland vegetation distribution along Passage Creek, Virginia, in relation to fluvial landforms. *Ecology* 66(3):670-671.
- Hurd, E.G., N.L. Shaw, J. Mastroguiseppe, L.C. Smithman, and S. Goodrich. 1998. Field guide to Intermountain sedges. Gen. Tech. Rep. RMRS-GTR-10. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 282 pp.

- Irvine, J.R., and N.E. West. 1979. Riparian tree species distribution and succession along the lower Escalante River, Utah. *The Southwestern Naturalist* 24(2):331-346.
- Johnson, W.C., R.L. Burgess, and W.R. Keammerer. 1976. Forest overstory vegetation and environment on the Missouri River floodplain in North Dakota. *Ecological Monographs* 46:59-84.
- Karrenberg, S., P.J. Edwards, and J. Kollmann. 2002. The life history of Salicaceae living in the active zone of floodplains. *Freshwater Biology* 47:733-748.
- Kranjcec, J., J.M. Mahoney, and S.B. Rood. 1998. The responses of three riparian cottonwood species to water table decline. *Forest Ecology and Management* 110:77-87.
- Malanson, G.P. 1993. *Riparian Landscapes*. Cambridge, UK: Cambridge University Press. 296 pp.
- Mansfield, D.H. 2000. *Flora of Steens Mountain*. Corvallis: Oregon State University Press. 410 pp.
- McBride, J.M., and J. Strahan. 1984. Establishment and survival of woody riparian species on gravel bars of an intermittent stream. *The American Midland Naturalist* 112(2):235-245.
- McCluskey, D.C., J. Brown, D. Bornholdt, D.A. Duff, and A.H. Winward. 1983. *Willow planting for riparian habitat management*. Denver, CO: U.S. Department of the Interior, Bureau of Land Management. 21 pp.
- McCune, B., and J.B. Grace. 2002. *Analysis of Ecological Communities*. Gleneden Beach, OR: MjM Software Design. 300 pp.
- McCune, B., and M.J. Mefford. 1999. *PC-ORD for Windows – Multivariate Analysis of Ecological Data, Version 4*. Gleneden Beach, OR: MjM Software Design.
- McLaughlin, S.L. 1992. Notes on the botany of the “Sky Islands” region of southeastern Arizona. Department of Aridlands, University of Arizona, Tucson, AZ.
- Naiman, R.J., and H. Decamps. 1997. The ecology of interfaces: riparian zones. *Annual Review of Ecological Systems* 28:621-658.
- Newsholme, C. 2002. *Willows, the Genus Salix*. London: Batsford. 224 pp.
- Petersen, S. 2004. A landscape scale assessment of plant communities, hydrologic processes, and state-and-transition theory in a western juniper dominated ecosystem. Ph.D. diss., Oregon State University.

- Ramsey, F.L., and D.W. Schafer. 2002. *The Statistical Sleuth: A Course in Methods of Data Analysis*, 2nd Edition. Pacific Grove, CA: Duxbury. 742 pp.
- Raven, J.A. 1992. The physiology of *Salix*. *Proceedings of the Royal Society of Edinburgh* 98B:49-62.
- Roelle, J.E., and D.N. Gladwin. 1999. Establishment of woody riparian species from a natural seedfall at a former gravel pit. *Restoration Ecology* 7(2):183-192.
- Rosgen, D.L. 1996. *Applied River Morphology*. Pagosa Springs, CO: Wildland Hydrology. 1 v. (various pagings).
- Sacchi, C.F., and P.W. Price. 1992. The relative roles of abiotic and biotic factors in seedling demography of arroyo willow (*Salix lasiolepis*: Salicaceae). *American Journal of Botany* 79(4):395-405.
- Schoeneberger, P.J., D.A. Wysocki, E.C. Benham, and W.D. Broderson (editors). 2002. *Field book for describing and sampling soils*, Version 2.0. Natural Resources Conservation Service, National Soil Survey Center, Lincoln, NE.
- Shreve, F. 1924. Soil temperature as influenced by altitude and slope exposure. *Ecology* 5:128-136.
- Sigafoos, R.S. 1961. Vegetation in relation to flood frequency near Washington, D.C. In: *Geological Survey Research*, 1961. Washington: U.S. Government Printing Office. (various pagings).
- Stromberg, J.C., D.T. Patten, and B.D. Richter. 1991. Flood flows and dynamics of Sonoran riparian forests. *Rivers* 2(3):221-235.
- Tabacchi, E., D.L. Correll, R. Hauer, G. Pinay, A. Planty-Tabacchi, and R.C. Wissmar. 1998. Development, maintenance and role of riparian vegetation in the river landscape. *Freshwater Biology* 40:497-516.
- Teversham, J.M., and O. Slaymaker. 1976. Vegetation composition in relation to flood frequency in Lillooet River Valley, British Columbia. *Catena* 3:191-201.
- Whittaker, R.H., and W.A. Niering. 1975. Vegetation of the Santa Catalina Mountains, Arizona: v. biomass, production, and diversity along the elevation gradient. *Ecology* 56:771-790.
- Winward, A.H. 2000. *Monitoring the vegetation resources in riparian areas*. U.S. Dept. of Agriculture, Forest Service, Rocky Mountain Research Station ; Fort Collins, CO. 49 pp.

- Wolfe, C.B., and J.D. Pittillo. 1977. Some ecological factors influencing the distribution of *Betula nigra* L. in western North Carolina. *Castanea* 42(1):18-30.
- Wolman, M.G., and J.P. Miller. 1960. Magnitude and frequency of forces in geomorphic processes. *Journal of Geology* 68:54-74.
- Woodward, F.I. 1988. Temperature and the distribution of plant species. In: *Plants and Temperature*, ed. S.P. Long and F.I. Woodward. (Cambridge, UK: The Company of Biologists Limited, 1988). p. 59-75.

Literature Cited

- Anderson, E.W., M.M. Borman, and W.C. Krueger. 1998. The ecological provinces of Oregon: a treatise on the basic ecological geography of the state. Corvallis, OR: Oregon Agricultural Experiment Station. 138 pp.
- Anonymous. 2005. S-PLUS for Windows, Version 7. Seattle, WA: Insightful Corporation.
- Argus, G.W. 1997. Infrageneric classification of *Salix* (Salicaceae) in the world. *Systematic Botany Monographs* 52:91-98.
- Baker, W.L. 1989. Macro- and micro-scale influences on riparian vegetation in western Colorado. *Annals of the Association of American Geographers* 79(1):65-78.
- Beschta, R.L., and J.B. Kauffman. 2000. Restoration of riparian systems – taking a broader view. *Proceedings of the International Conference on Riparian Ecology and Management in Multi-land Use Watersheds*, American Water Resources Association. p. 323-328.
- Biondini, M.E., C.D. Bonham, and E.F. Redente. 1985. Secondary successional patterns in a sagebrush (*Artemisia tridentata*) community as they relate to soil disturbance and soil biological activity. *Vegetatio* 60:25-36.
- Brinson, M.M. 1990. Riverine forests. In: *Forested wetlands*, ed. A.E. Lugo, M.M. Brinson, and S. Brown (Amsterdam: Elsevier Science Pub. Co., 1990). p. 87-141.
- Brunsfeld, S.J., and F.D. Johnson. 1985. *Field guide to the willows of east-central Idaho*. Moscow, Idaho: Forest, Wildlife and Range Experiment Station, University of Idaho. 95 pp.
- Campbell, C.J., and W. Green. 1968. Perpetual succession of stream-channel vegetation in a semiarid region. *Journal of the Arizona Academy of Science* 5:86-98.
- Chambers, J.C., R.J. Tausch, J.L. Korfmacher, D. Germanoski, J.R. Miller, and D. Jewett. 2004. Effects of geomorphic processes and hydrologic regimes on riparian vegetation. In: *Great Basin riparian areas : ecology, management, and restoration*, ed. J.C. Chambers and J.R. Miller (Washington, D.C.: Island Press, 2004). p. 196-232
- Chapin, D.M., R.L. Beschta, and H.W. Shen. 2000. Flood frequencies required to sustain riparian plant communities in the upper Klamath Basin, Oregon. *Proceedings of the International Conference on Riparian Ecology and Management in Multi-land Use Watersheds*, American Water Resources Association. p. 17-22.

- Conroy, S.D., and T.J. Svejcar. 1991. Willow planting success as influenced by site factors and cattle grazing in northeastern California. *Journal of Range Management* 44(1): 59-63.
- Cooke, S.S. 1997. *A Field Guide to the Common Wetland Plants of Western Washington & Northwestern Oregon*. Seattle: Seattle Audobon Society. 417.
- Crowe, E.A., B.L. Kovalchik, and M. Kerr. 2004. *Riparian and wetland vegetation of Central and Eastern Oregon* Oregon State University, Portland, OR. 473 pp.
- Danzer, S.J. 1996. *Vegetative and environmental characteristics of high elevation riparian communities in the mountains of southeastern Arizona*. Ph.D. diss., University of Arizona.
- Densmore, R., and J. Zasada. 1983. Seed dispersal and dormancy patterns in northern willows: ecological and evolutionary significance. *Canadian Journal of Botany* 61:3207-3216.
- Dionigi, C.P., I.A. Mendelssohn, and V.I. Sullivan. 1985. Effects of soil waterlogging on the energy status and distribution of *Salix nigra* and *S. exigua* (Salicaceae) in the Atchafalaya River Basin of Louisiana. *American Journal of Botany* 72(1):109-119.
- Dixon, M.D. 2003. Effects of flow pattern on riparian seedling recruitment on sandbars in the Wisconsin River, Wisconsin, USA. *Wetlands* 23(1):125-139.
- Dumroese, R.K., K.M. Hutton, and D.L. Wenny. 1997. Propagating woody riparian plants in nurseries. In: *Regeneration, reforestation, restoration: The seedling is the key*; National proceedings, forest and conservation nursery associations, ed. D.T. Landis and J.R. Thompson. Gen. Tech. Rep. PNW-GTR-419. (Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, 1997) p. 71-76.
- Elmore, W., and R.L. Beschta. 1987. Riparian Areas: Perceptions in Management. *Rangelands* 9(6):260-265.
- Evenden, A.G. 1989. *Ecology and distribution of riparian vegetation in the Trout Creek Mountains of southeastern Oregon*. Ph.D. diss., Oregon State University.
- Frye, R.J., and J.A. Quinn. 1979. Forest development in relation to topography and soils on a floodplain of the Raritan River, New Jersey. *Bulletin of the Torrey Botanical Club* 106(4):334-345.
- Gregory, S.V., F.J. Swanson, W.A. McKee, and K.W. Cummins. 1991. An ecosystem perspective of riparian zones: focus on links between land and water. *BioScience* 41(8):540-551.

- Griffiths, D. 1902. Forage conditions on the northern border of the Great Basin. Bureau of Plant Industry, U.S. Department of Agriculture, Bulletin 15.
- Hansen, D.J. 1977. Interrelations of valley vegetation, stream regimen, soils, and solar irradiation along the Rock Creek in the Uinta Mountains of Utah. Ph.D. diss., University of Michigan.
- Hansen, P., S. Chadde, R. Pfister, J. Joy, D. Svoboda, J. Pierce, and L. Myers. 1988. Riparian site types, habitat types, and community types of southwestern Montana. Missoula, MT: University of Montana, School of Forestry, Montana Riparian Association. 140 pp.
- Harris, R.R. 1988. Associations between stream valley geomorphology and riparian vegetation as a basis for landscape analysis in the Eastern Sierra Nevada, California, USA. *Environmental Management* 12(2):219-228.
- Hastings, J.R., and R.M. Turner. 2003. The changing mile revisited: an ecological study of vegetation change with time in the lower mile of an arid and semiarid region. pp. 334.
- Hitchcock, C.L., and A. Cronquist. 1973. *Flora of the Pacific Northwest*. Seattle, WA: University of Washington Press. 730 pp.
- Hosmer, D.W., and S. Lemeshow. 2000. *Applied Logistic Regression*, 2nd Edition. New York: Wiley. 373 pp.
- Hudak, H.G., and G.L. Ketcheson. 1991. Willow community types as influenced by valley bottom and stream types. *Proceedings of the Symposium on Ecology and Management of Riparian Shrub Communities*, Sun Valley, ID, May 29-31. p. 16-17.
- Hughes, F.M.R. 1997. Floodplain biogeomorphology. *Progress in Physical Geography* 21(4):501-529.
- Hupp, C.R. 1982. Stream-grade variation and riparian forest ecology along Passage Creek, Virginia. *Bulletin of the Torrey Botanical Club* 109(4):488-499.
- Hupp, C.R. 1983. Vegetation pattern on channel features in the Passage Creek Gorge, Virginia. *Castanea* 48(2):62-72.
- Hupp, C.R., and W.R. Osterkamp. 1985. Bottomland vegetation distribution along Passage Creek, Virginia, in relation to fluvial landforms. *Ecology* 66(3):670-671.
- Hurd, E.G., N.L. Shaw, J. Mastroguiseppe, L.C. Smithman, and S. Goodrich. 1998. Field guide to Intermountain sedges. Gen. Tech. Rep. RMRS-GTR-10. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 282 pp.

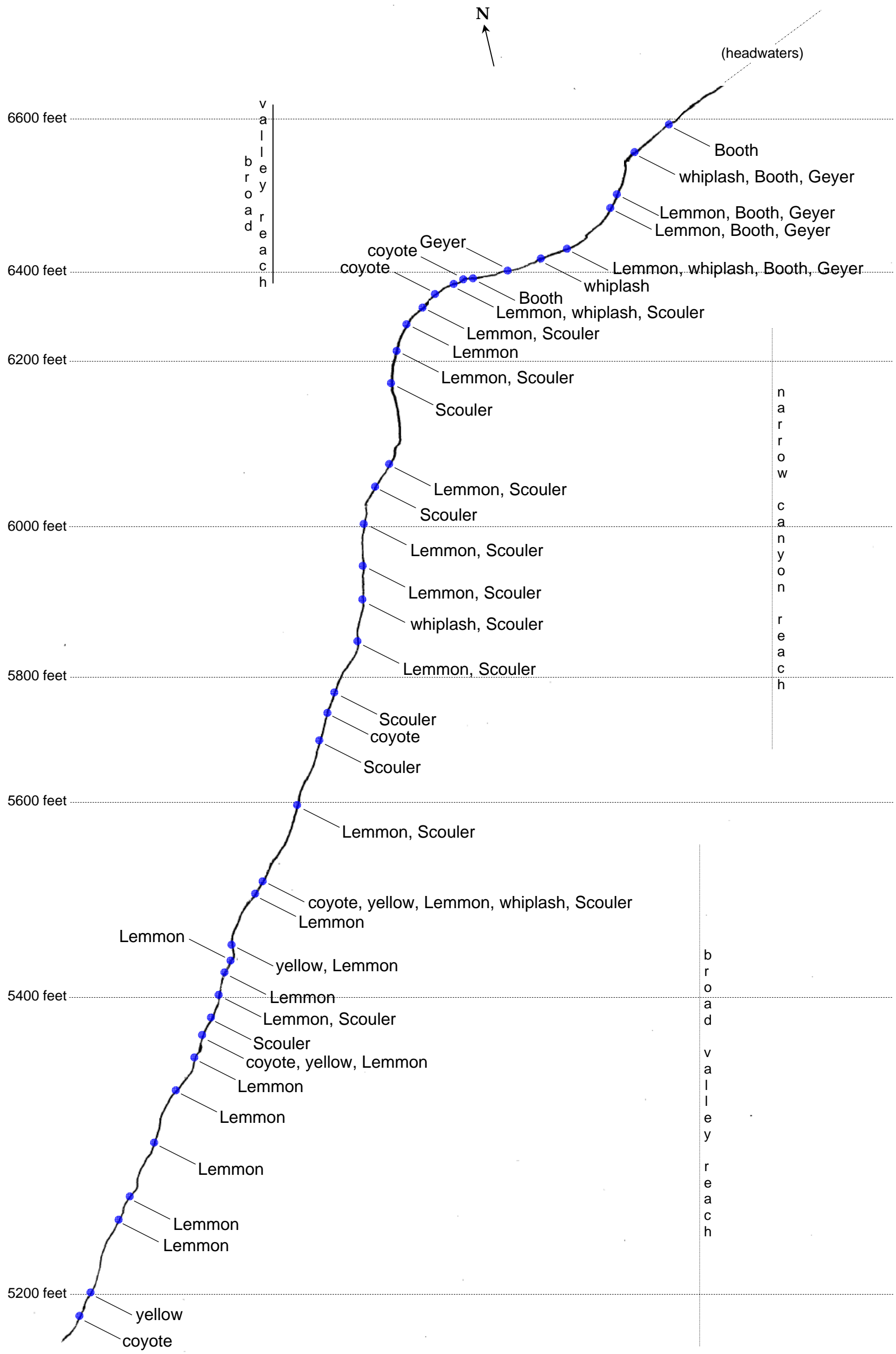
- Irvine, J.R., and N.E. West. 1979. Riparian tree species distribution and succession along the lower Escalante River, Utah. *The Southwestern Naturalist* 24(2):331-346.
- Johnson, W.C., R.L. Burgess, and W.R. Keammerer. 1976. Forest overstory vegetation and environment on the Missouri River floodplain in North Dakota. *Ecological Monographs* 46:59-84.
- Karrenberg, S., P.J. Edwards, and J. Kollmann. 2002. The life history of Salicaceae living in the active zone of floodplains. *Freshwater Biology* 47:733-748.
- Kranjcec, J., J.M. Mahoney, and S.B. Rood. 1998. The responses of three riparian cottonwood species to water table decline. *Forest Ecology and Management* 110:77-87.
- Malanson, G.P. 1993. *Riparian Landscapes*. Cambridge, UK: Cambridge University Press. 296 pp.
- Mansfield, D.H. 2000. *Flora of Steens Mountain*. Corvallis: Oregon State University Press. 410 pp.
- McBride, J.M., and J. Strahan. 1984. Establishment and survival of woody riparian species on gravel bars of an intermittent stream. *The American Midland Naturalist* 112(2):235-245.
- McCluskey, D.C., J. Brown, D. Bornholdt, D.A. Duff, and A.H. Winward. 1983. *Willow planting for riparian habitat management*. Denver, CO: U.S. Department of the Interior, Bureau of Land Management. 21 pp.
- McCune, B., and J.B. Grace. 2002. *Analysis of Ecological Communities*. Gleneden Beach, OR: MjM Software Design. 300 pp.
- McCune, B., and M.J. Mefford. 1999. *PC-ORD for Windows – Multivariate Analysis of Ecological Data, Version 4*. Gleneden Beach, OR: MjM Software Design.
- McLaughlin, S.L. 1992. Notes on the botany of the “Sky Islands” region of southeastern Arizona. Department of Aridlands, University of Arizona, Tucson, AZ.
- Naiman, R.J., and H. Decamps. 1997. The ecology of interfaces: riparian zones. *Annual Review of Ecological Systems* 28:621-658.
- Newsholme, C. 2002. *Willows, the Genus Salix*. London: Batsford. 224 pp.
- Petersen, S. 2004. A landscape scale assessment of plant communities, hydrologic processes, and state-and-transition theory in a western juniper dominated ecosystem. Ph.D. diss., Oregon State University.

- Ramsey, F.L., and D.W. Schafer. 2002. *The Statistical Sleuth: A Course in Methods of Data Analysis*, 2nd Edition. Pacific Grove, CA: Duxbury. 742 pp.
- Raven, J.A. 1992. The physiology of *Salix*. *Proceedings of the Royal Society of Edinburgh* 98B:49-62.
- Roelle, J.E., and D.N. Gladwin. 1999. Establishment of woody riparian species from a natural seedfall at a former gravel pit. *Restoration Ecology* 7(2):183-192.
- Rosgen, D.L. 1996. *Applied River Morphology*. Pagosa Springs, CO: Wildland Hydrology. 1 v. (various pagings).
- Sacchi, C.F., and P.W. Price. 1992. The relative roles of abiotic and biotic factors in seedling demography of arroyo willow (*Salix lasiolepis*: Salicaceae). *American Journal of Botany* 79(4):395-405.
- Schoeneberger, P.J., D.A. Wysocki, E.C. Benham, and W.D. Broderson (editors). 2002. *Field book for describing and sampling soils*, Version 2.0. Natural Resources Conservation Service, National Soil Survey Center, Lincoln, NE.
- Shreve, F. 1924. Soil temperature as influenced by altitude and slope exposure. *Ecology* 5:128-136.
- Sigafoos, R.S. 1961. Vegetation in relation to flood frequency near Washington, D.C. In: *Geological Survey Research*, 1961. Washington: U.S. Government Printing Office. (various pagings).
- Stromberg, J.C., D.T. Patten, and B.D. Richter. 1991. Flood flows and dynamics of Sonoran riparian forests. *Rivers* 2(3):221-235.
- Tabacchi, E., D.L. Correll, R. Hauer, G. Pinay, A. Planty-Tabacchi, and R.C. Wissmar. 1998. Development, maintenance and role of riparian vegetation in the river landscape. *Freshwater Biology* 40:497-516.
- Teversham, J.M., and O. Slaymaker. 1976. Vegetation composition in relation to flood frequency in Lillooet River Valley, British Columbia. *Catena* 3:191-201.
- Whittaker, R.H., and W.A. Niering. 1975. Vegetation of the Santa Catalina Mountains, Arizona: v. biomass, production, and diversity along the elevation gradient. *Ecology* 56:771-790.
- Winward, A.H. 2000. *Monitoring the vegetation resources in riparian areas*. U.S. Dept. of Agriculture, Forest Service, Rocky Mountain Research Station ; Fort Collins, CO. 49 pp.

- Wolfe, C.B., and J.D. Pittillo. 1977. Some ecological factors influencing the distribution of *Betula nigra* L. in western North Carolina. *Castanea* 42(1):18-30.
- Wolman, M.G., and J.P. Miller. 1960. Magnitude and frequency of forces in geomorphic processes. *Journal of Geology* 68:54-74.
- Woodward, F.I. 1988. Temperature and the distribution of plant species. In: *Plants and Temperature*, ed. S.P. Long and F.I. Woodward. (Cambridge, UK: The Company of Biologists Limited, 1988). p. 59-75.

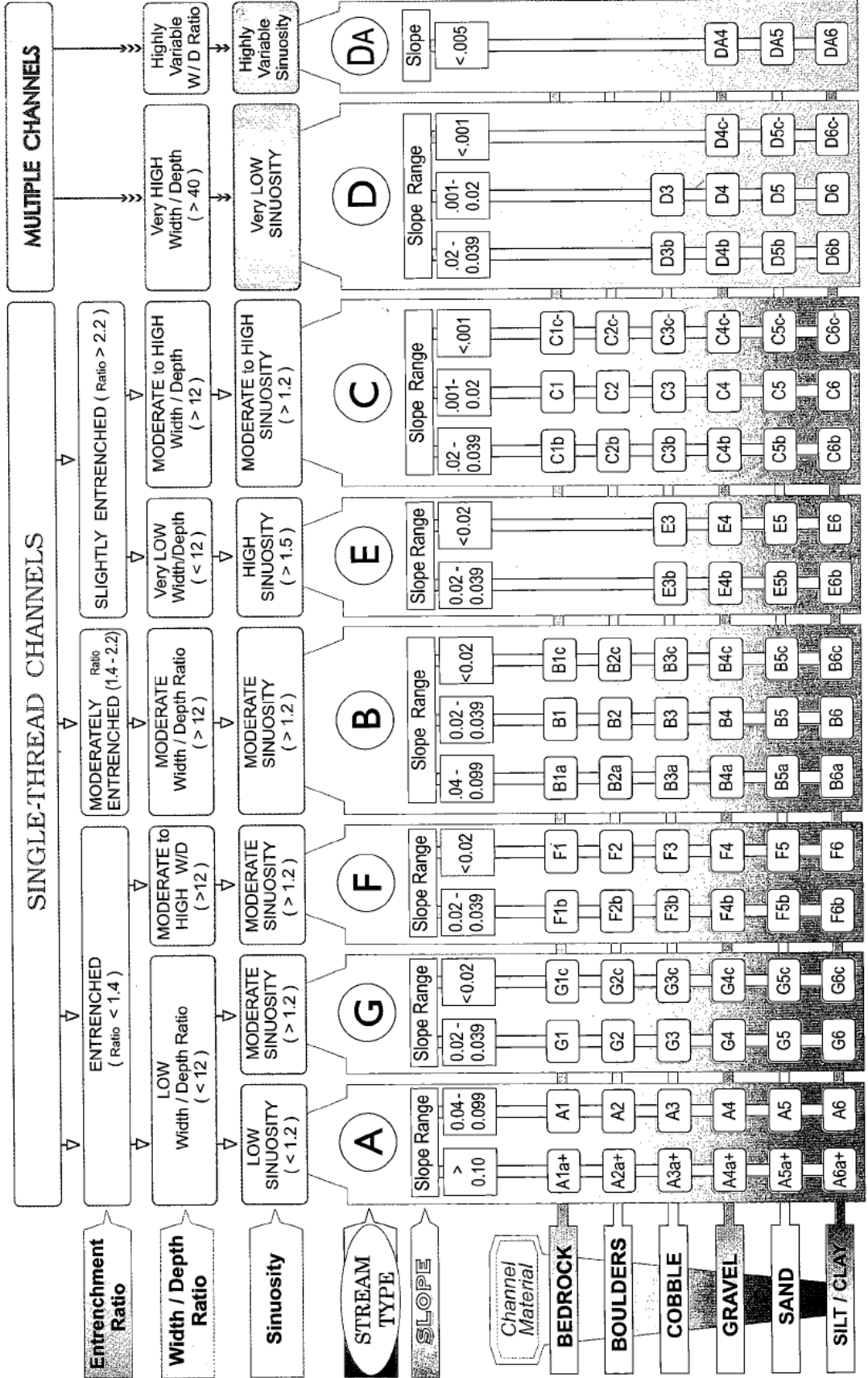
Appendix A:

The Respective Species of Each Research Willow Clump on the Research Watershed



Appendix B:

Key to Stream Types (Rosgen 1996, p. 5-6)



MULTIPLE CHANNELS

SINGLE-THREAD CHANNELS

Entrenchment Ratio

Width / Depth Ratio

Sinuosity

STREAM TYPE

SLOPE

Channel Material

BEDROCK

BOULDERS

COBBLE

GRAVEL

SAND

SILT / CLAY

ENTRENCHED (Ratio < 1.4)

MODERATELY ENTRENCHED (Ratio 1.4 - 2.2)

SLIGHTLY ENTRENCHED (Ratio > 2.2)

LOW Width / Depth Ratio (< 12)

MODERATE to HIGH W/D (> 12)

Very LOW Width / Depth (< 12)

MODERATE to HIGH Width / Depth (> 12)

LOW SINUOSITY (< 1.2)

MODERATE SINUOSITY (> 1.2)

Highly Variable Sinuosity

A

G

F

B

E

C

D

DA

Slope Range

Slope Range

Slope Range

Slope Range

Slope Range

Slope Range

Slope Range

Slope Range

Slope Range

> 0.10

0.02 - 0.039

0.02 - 0.039

0.04 - 0.099

0.02 - 0.039

0.02 - 0.039

0.02 - 0.039

0.02 - 0.039

< .005

A1a+

G1

F1b

B1a

E3b

C1b

D3b

D3b

DA4

A2a+

G2

F2

B2a

E4b

C2b

D4b

D4b

DA5

A3a+

G3

F3

B3a

E5b

C3b

D5b

D5b

DA6

A4a+

G4

F4

B4a

E6b

C4b

D6b

D6b

DA6

A5a+

G5

F5

B5a

E5

C5

D5c

D5c

DA5

A6a+

G6

F6

B6a

E6

C6

D6c

D6c

DA6

A1

G1c

F1

B1

E4

C1

D3c

D3c

DA4

A2

G2c

F2

B2

E3

C2

D4c

D4c

DA5

A3

G3c

F3

B3

E4

C3

D5c

D5c

DA6

A4

G4c

F4

B4

E5

C4

D6c

D6c

DA6

A5

G5c

F5

B5

E6

C5

D6c

D6c

DA6

A6

G6c

F6

B6

E6

C6

D6c

D6c

DA6

A1a+

G1c

F1b

B1a

E3b

C1b

D3b

D3b

DA4

A2a+

G2c

F2

B2a

E4b

C2b

D4b

D4b

DA5

A3a+

G3c

F3

B3a

E5b

C3b

D5b

D5b

DA6

A4a+

G4c

F4

B4a

E6b

C4b

D6b

D6b

DA6

A5a+

G5c

F5

B5a

E5

C5

D6c

D6c

DA6

A6a+

G6c

F6

B6a

E6

C6

D6c

D6c

DA6

Appendix C:

Box Plots Comparing Habitat Data of the Seven Research Willow Species

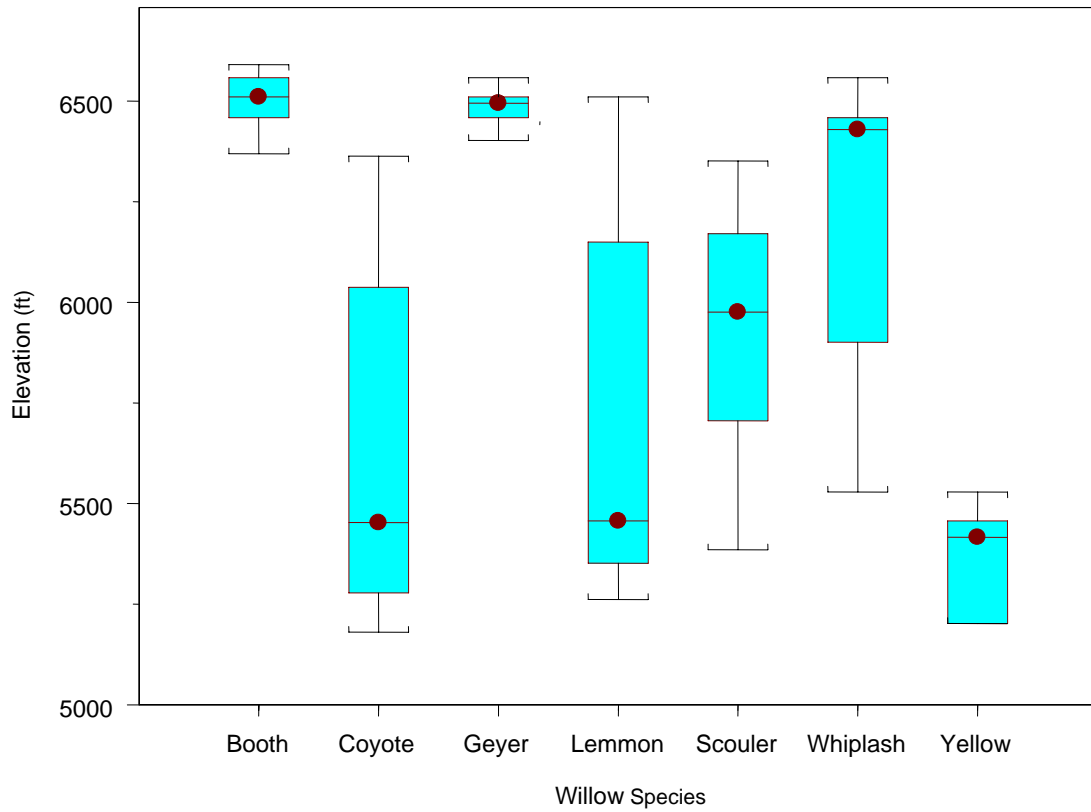


Figure 1 Elevation values, in feet, of all research willow clumps organized by species presence

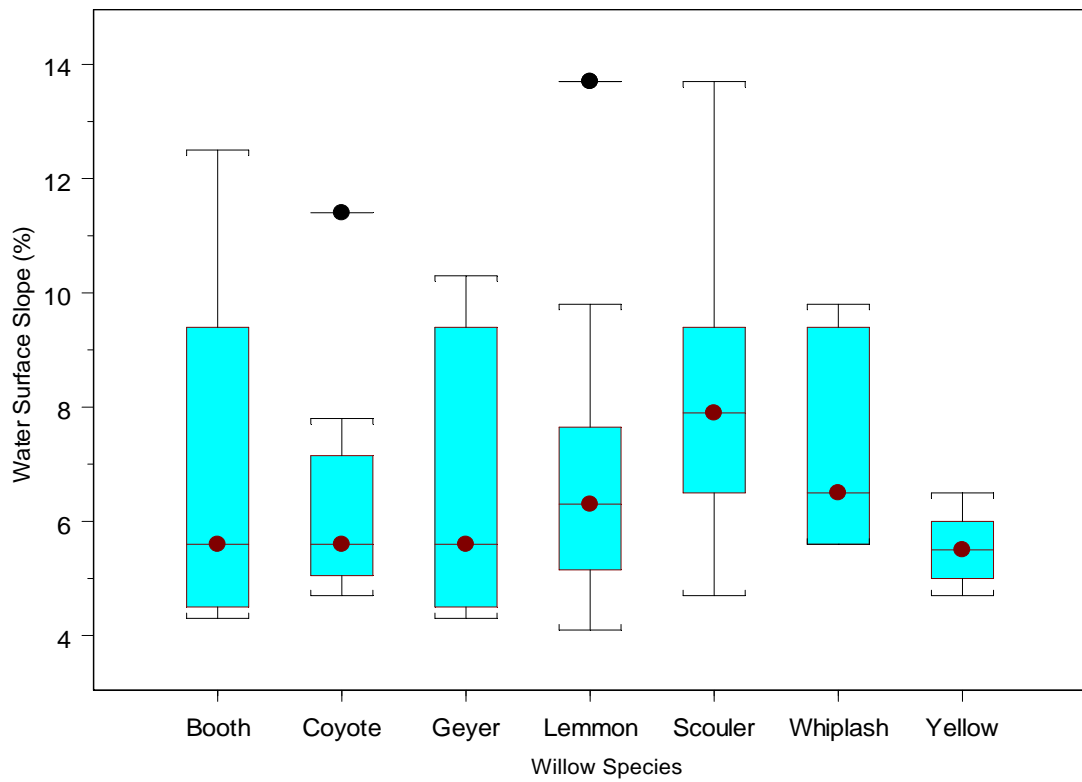


Figure 2 Percent stream slope values in all research willow clumps organized by species presence

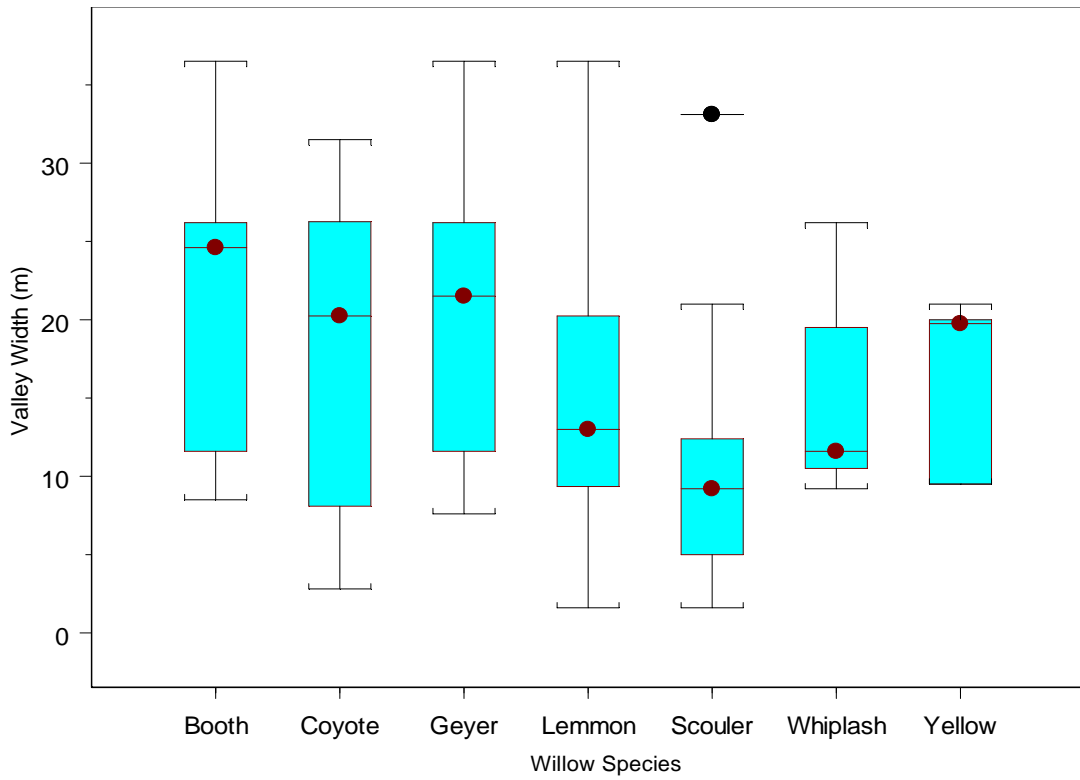


Figure 3 Valley width values, in meters, of all research willow clumps organized by species presence

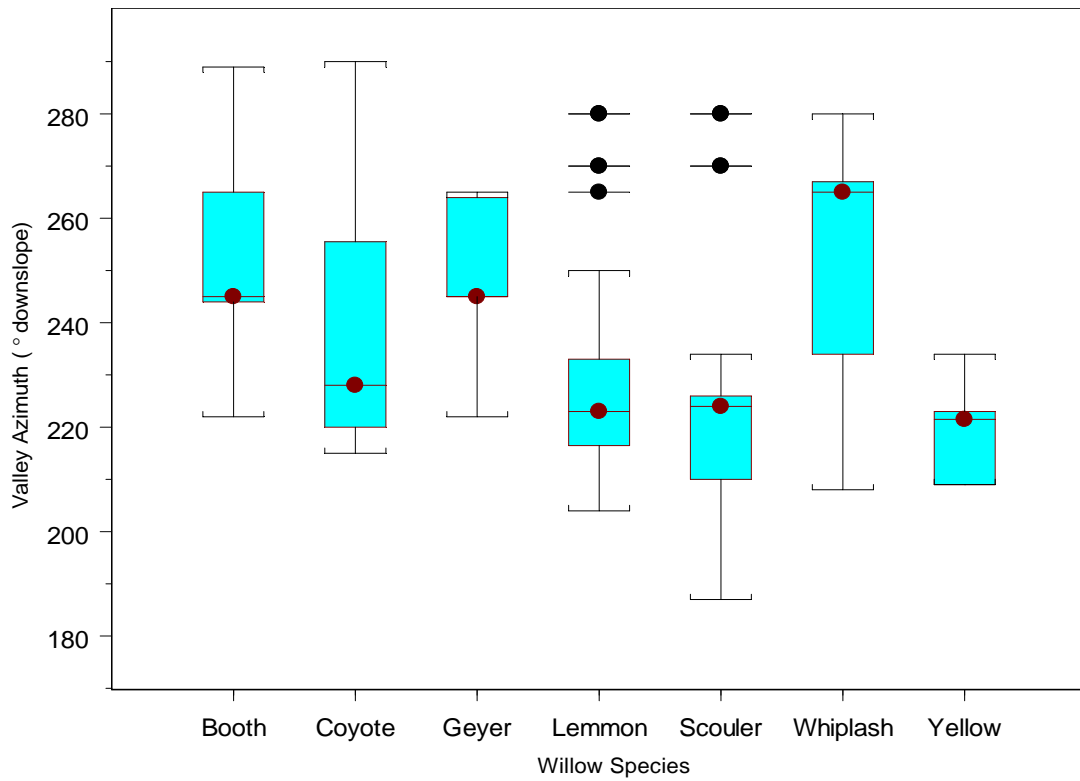


Figure 4 Downslope valley azimuth values, in degrees true north, of all research willow clumps organized by species presence

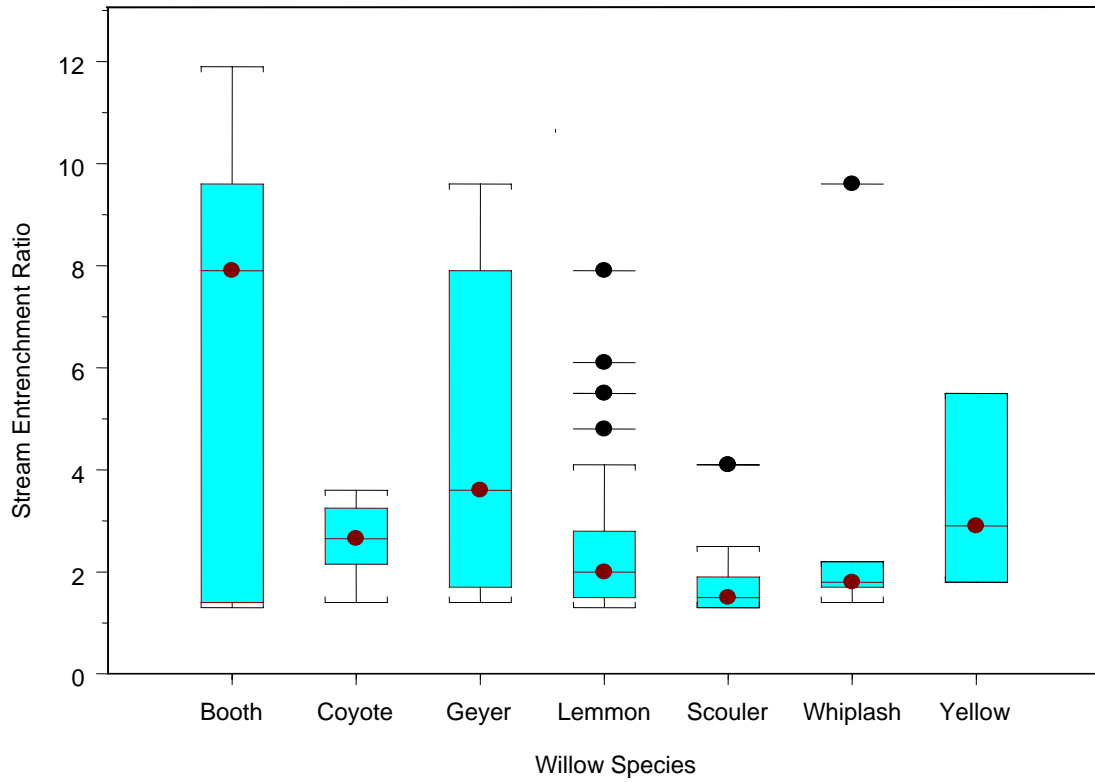


Figure 1 Stream entrenchment ratio values in all research willow clumps organized by species presence

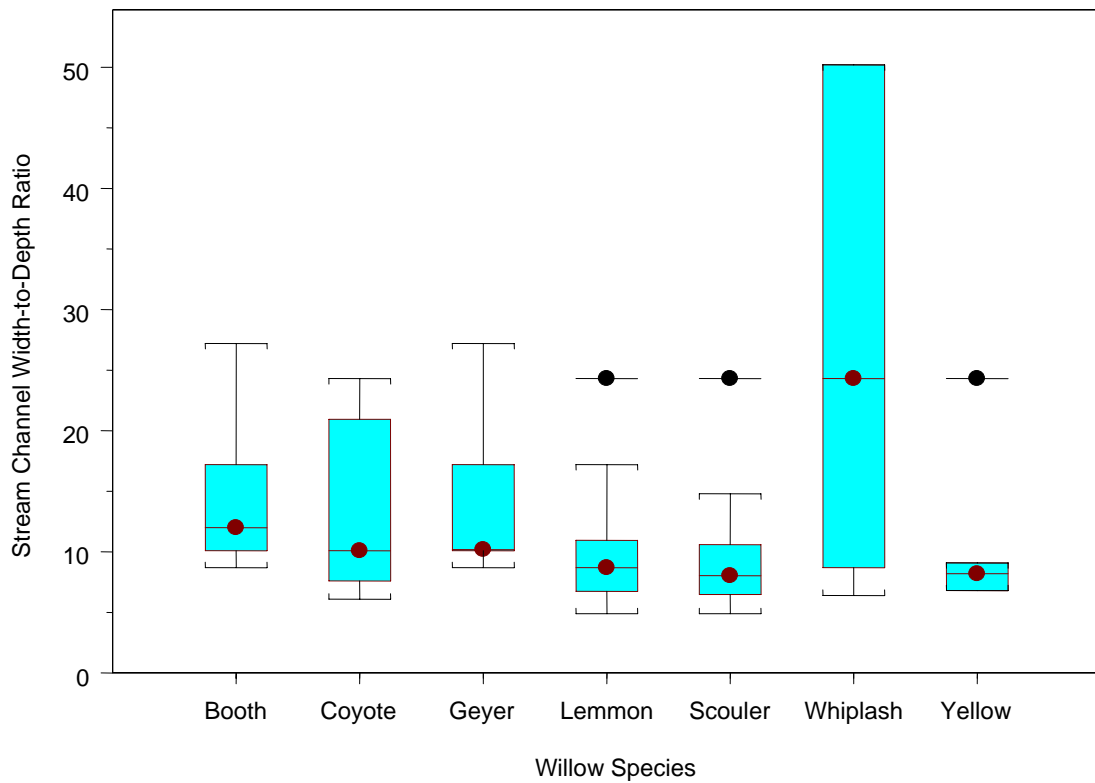


Figure 6 Stream width-to-depth ratio values in all research willow clumps organized by species presence

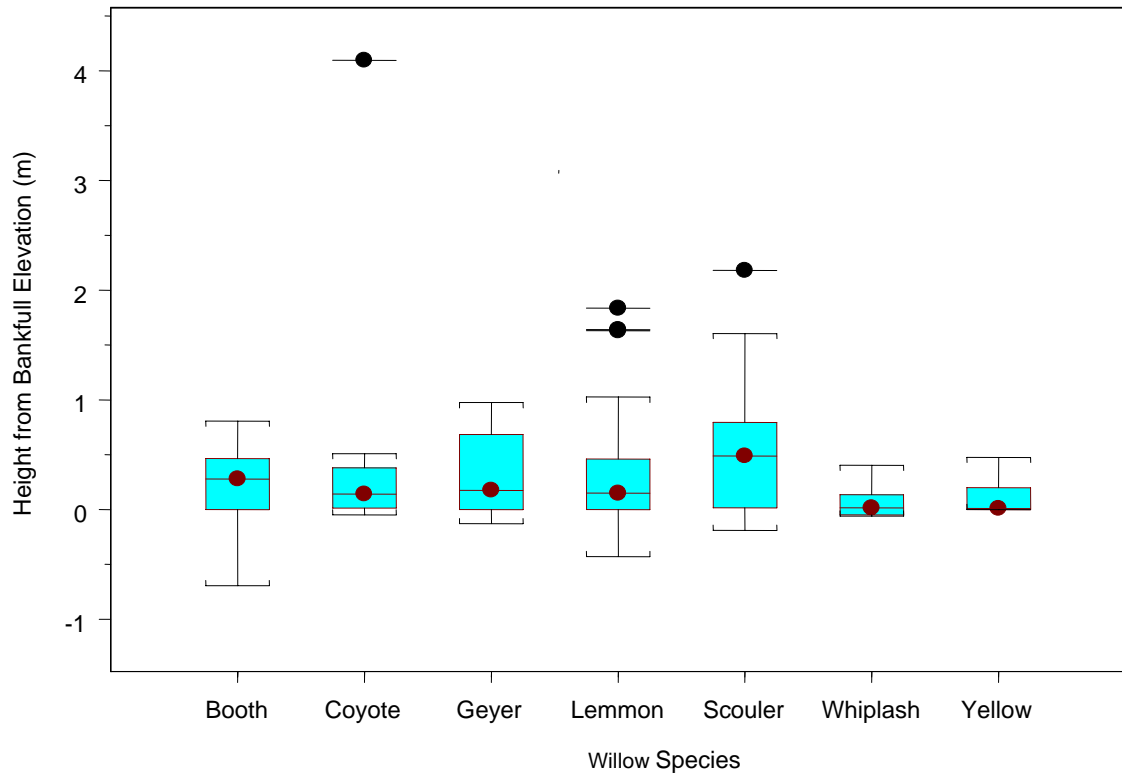


Figure 7 Height from stream bankfull elevation values, in meters, of each willow species

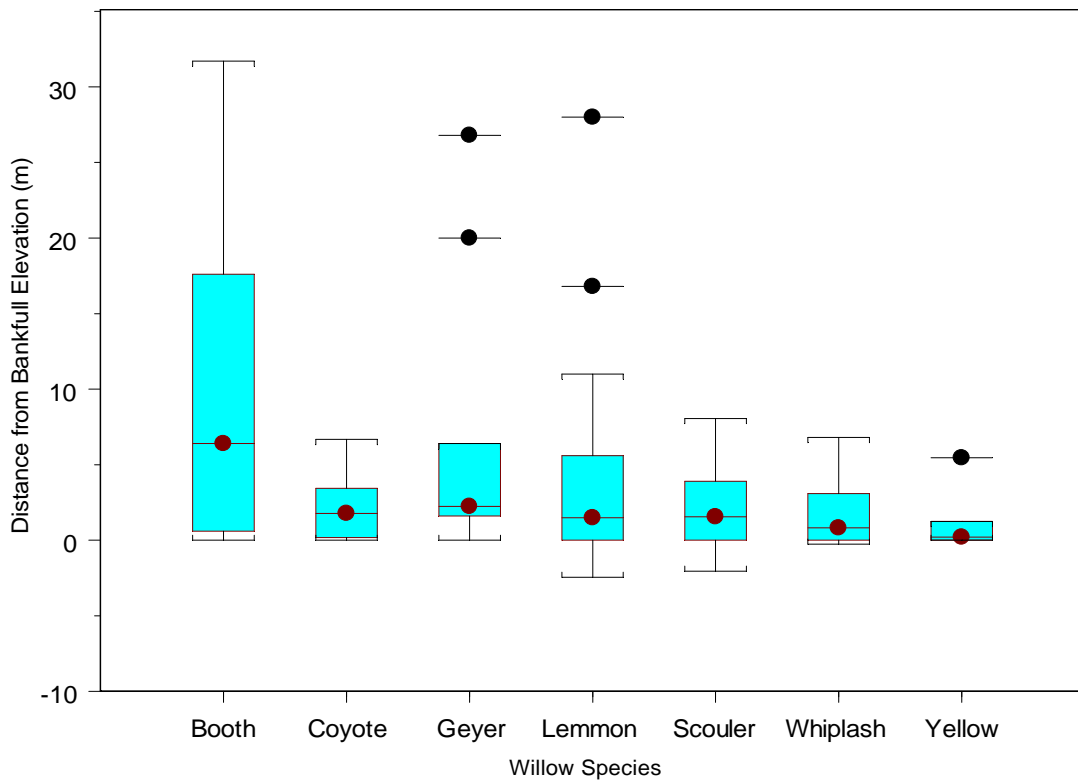


Figure 8 Distance from stream bankfull elevation values, in meters, of each willow species

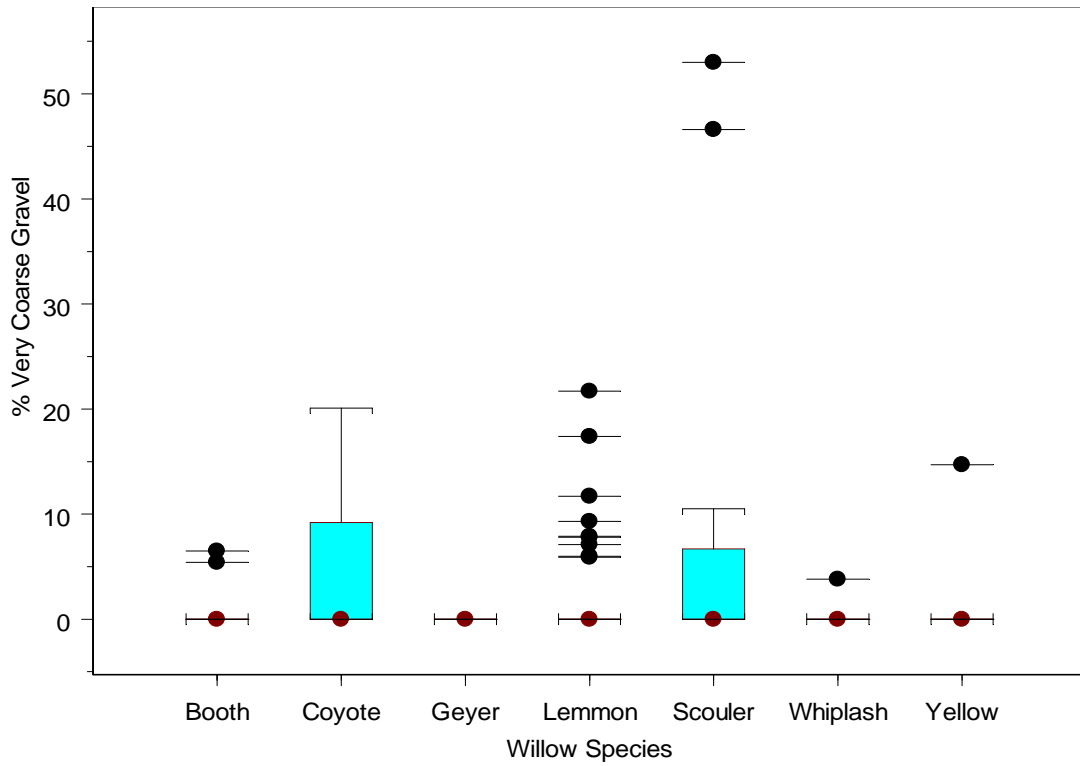


Figure 9 Percent values of gravel beneath each willow species that was 1.25 inches (32 mm) or greater in diameter

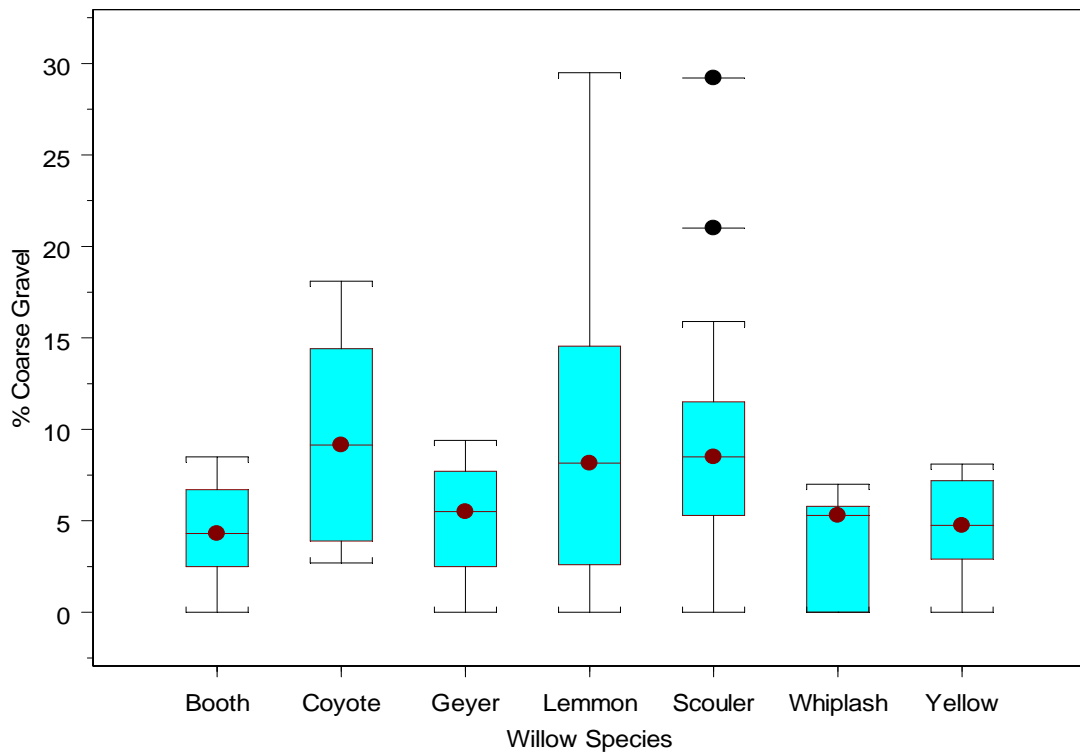


Figure 10 Percent values of gravel beneath each willow species that was between 0.625 and 1.25 inches (16 – 32 mm) in diameter

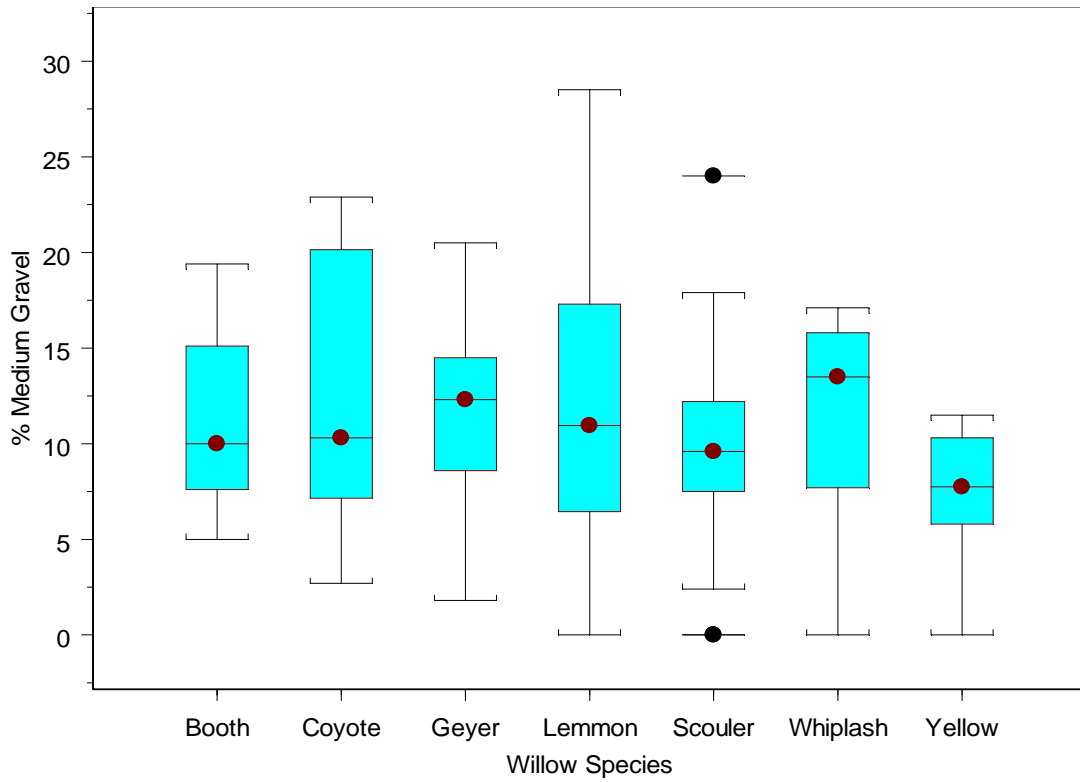


Figure 11 Percent values of gravel beneath each willow species that was between 0.3125 and 0.625 inches (8 – 16 mm) in diameter

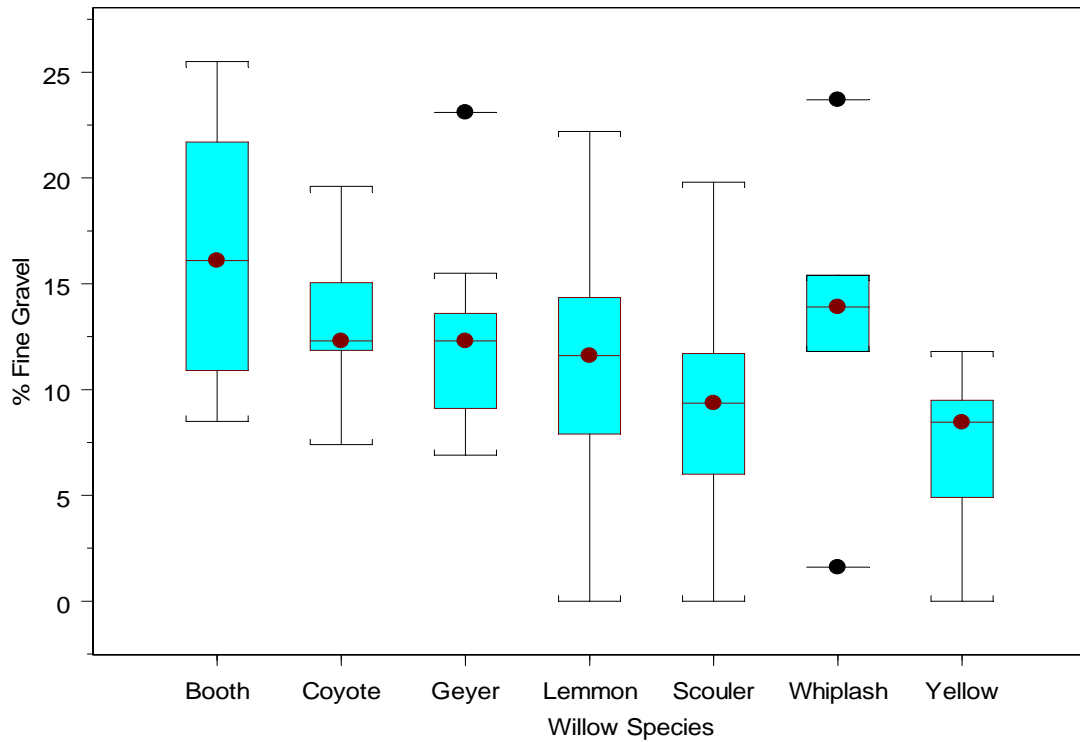


Figure 12 Percent values of gravel beneath each willow species that was between 0.1575 and 0.3125 inches (4 – 8 mm) in diameter

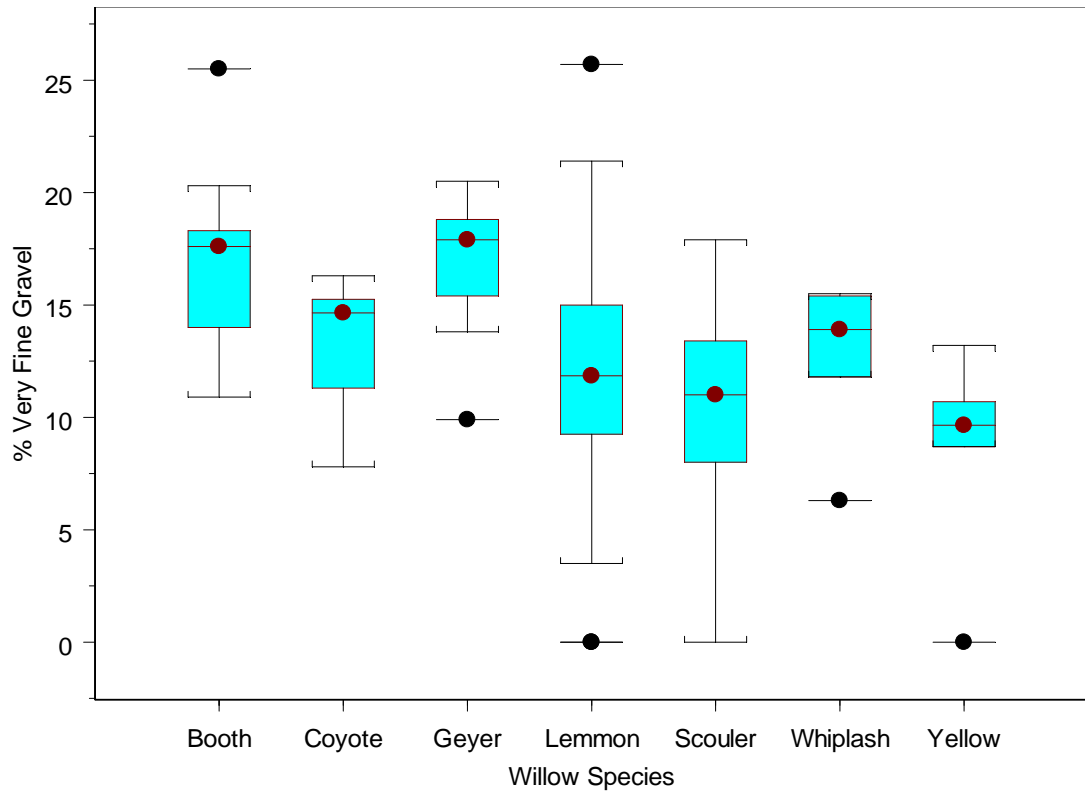


Figure 13 Percent values of gravel beneath each willow species that was between 0.0787 and 0.1575 inches (2 – 4 mm) in diameter