GEOMORPHOLOGY, HYDROLOGY AND BIOLOGY OF FLOODPLAIN VEGETATION IN THE SPRAGUE BASIN, OR: HISTORY AND POTENTIAL FOR NATURAL RECOVERY

by

CHRISTINE GAIL RASMUSSEN

A DISSERTATION

Presented to the Department of Geography
and the Graduate School of the University of Oregon
in partial fulfillment of the requirements
for the degree of
Doctor of Philosophy

December 2011

DISSERTATION APPROVAL PAGE

Student: Christine G. Rasmussen

Title: Geomorphology, Hydrology and Biology of Floodplain Vegetation in the Sprague Basin, OR: History and Potential for Natural Recovery

This dissertation has been accepted and approved in partial fulfillment of the requirements for the Doctor of Philosophy degree in the Department of Geography by:

Patricia F. McDowell	Chairperson
W. Andrew Marcus	Member
Patrick Bartlein	Member
Scott Bridgham	Outside Member

and

Kimberly Andrews Espy	Vice President for Research & Innovation/Dean of the Graduate School

Original approval signatures are on file with the University of Oregon Graduate School

Degree awarded December 2011

DISSERTATION ABSTRACT

Christine G. Rasmussen

Doctor of Philosophy

Department of Geography

December 2011

Title: Geomorphology, Hydrology and Biology of Floodplain Vegetation in the Sprague Basin, OR: History and Potential for Natural Recovery.

Restoration of riparian ecosystems in semi-arid riparian ecosystems requires an understanding of geomorphic, hydrologic and biologic factors and how they relate to vegetation. Such an understanding allows prioritization of restoration projects and avoidance of activities that are either unnecessary or likely to fail. In this dissertation I examined a suite of factors controlling distribution of vegetation types in the Sprague Basin, OR, and used those factors to predict potential for natural recovery. Factors ranged from basin-wide (e.g. floodplain width and slope) to local (e.g. topography, hydrology and soil texture). Results of historical analysis and photographic mapping showed that basin-wide vegetation types have remained generally stable since the early 1940s and that wide floodplains have been without woody vegetation since the late 1800s. The most prevalent changes in floodplain vegetation due to land use included reduction of shrub cover in moderately wide floodplains and associated increases in herbaceous vegetation.

Soil moisture conditions were studied using piezometers and nested clusters of soil moisture tension meters. The interrelations among soil texture, elevation and distance from the channel, and vegetation (herbaceous and woody) characteristics in the riparian zone were examined along 75 transects using a generalized additive model for non linear factors and Hurdle analysis for abundance data.

On the Sprague mainstem, fine soils with high recession rates supported abundant shrubs, while on the Sycan (Sprague tributary) coarse soils with readily available moisture and greater subsurface water movements supported abundant shrubs. Habitats in the Sycan were well colonized with new shrub seedlings though long term persistence was unlikely.

Results show that riparian shrubs are unlikely to influence stream shade or bank stability on the mainstem Sprague whether they germinate naturally or are planted through restoration efforts, as shrubs near the channel are unlikely to persist long term. In the Sycan, germination and persistence are more likely than on the Sprague, though risks of predation, trampling from grazers, and fluvial action will be constant threats to near-channel shrubs. Results emphasize the need to understand factors controlling vegetation prior to restoration in any basin or stream segment.

CURRICULUM VITAE

NAME OF AUTHOR: Christine G. Rasmussen

GRADUATE AND UNDERGRADUATE SCHOOLS ATTENDED:

University of Oregon, Eugene
Oregon State University, Corvallis
Weber State University, Ogden, Utah

DEGREES AWARDED:

Doctor of Philosophy, 2011, University of Oregon. Geography
Master of Science, 1996, Oregon State University. Rangeland Resources
Bachelor of Science, 1992, Weber State University, Ogden. Botany and Zoology

AREAS OF SPECIAL INTEREST

River restoration ecology
Fluvial geomorphology
Non-linear system dynamics and theory in fluvial systems

PROFESSIONAL EXPERIENCE

Independent Contractor/Consultant, owner of Mainstream Contracting, operating in Colorado, Oregon, New Mexico, and Utah. 1996 to 2011.

Research Associate. Department of Geography, University of Oregon. 2006 to 2008.

Teaching Associate. Department of Geography, University of Oregon. Physical Geography, Fluvial Geomorphology.

Course Instructor, Department of Geography, University of Oregon. River and Riparian Field Studies. Summer 2007 and Summer 2008.

Project Manager, Environmental Studies, Environmental Leadership Program. Environmental Stewardship. 2006 and 2007.

Natural Resources Specialist, Oregon Department of Fish and Wildlife – Fisheries Research. March 1995 to June 1997.

Resarch and Teaching Associate, Oregon State University, Department of Rangeland Resources. June 1994 to June 1996.

Experimental Biologist Aide for the Oregon Department of Fish and Wildlife – Fisheries Research. June 1992 to June 1994.

Biologist Aid for the Utah Division of Wildlife – Fisheries. August 1988 to September 1991, intermittent.

GRANTS, AWARDS AND HONORS

Certificate of Honor - "A Year of Vigor" South Coast/Lower Rogue Watersheds (2002)

Outstanding Field Student, Zoology Department, Weber State University (1992)

Evolution-Ecology Award, Zoology Department, Weber State University (1992)

Departmental Honors in Botany, Weber State University (1992)

Outstanding Botany Student, Weber State University (1992)

Botany Scholarship Award, Weber State University (1990-1991)

Honors-at-Entrance Scholarship, Weber State University (1988)

Early College Program while attending Roy High School (1987-1988)

PUBLICATIONS:

Massingill, C. 2010. Dolores River Restoration Plan. Dolores, Colorado. Dolores Public Lands Office.

Massingill, C. 2003. Oregon Riparian Silviculture Guide. Charleston, Oregon; Coos Watershed Association. 100 p.

Massingill, C. and H. Hoogesteger, 2002. Curry Action Plan. Gold Beach, Oregon; South Coast Watershed Council.

Massingill, C. 2001. Individual Watershed Action Plans for each of: Chetco River, Elk River, Euchre Creek, Floras Creek, Hunter Creek, Pistol River, Port Orford, Sixes River, and Winchuck River. Gold Beach, Oregon; South Coast Watershed Council.

Borman, M., C. Massingill, and E. W. Elmore. 1999. Riparian Area Responses to Changes in Management. Rangelands 21(3): 3-7.

Borman, M. and C. Massingill 1997. Responses of Selected Eastern Oregon Streams to Changes in Grazing Management. Riparian Use, Ecology and Management Workshop. May 27, 1997. Oregon State University - Corvallis, Oregon.

Rasmussen, C. G. 1996. Results and Review of a Riparian Survey Method Used in Eastern Oregon. Masters Thesis. Oregon State University.

Harley, S. M., and C. Rasmussen. 1993. Staining for Ribonuclease Activity in Polyacrilamide Gels. The American Biology Teacher. 55(6):366-368.

ACKNOWLEDGMENTS

This document could not have come to fruition without the dedicated and patient support of my committee: Pat McDowell as front line for advice, critique and motivation; Andrew Marcus for encouragement and fabulous teaching; Pat 'Bart' Bartlein for help navigating the wonderful world of statistics programming and experimental design; and Scott Bridgham for thoughtful input on shrub metrics that greatly improved the ultimate conclusions.

A sincere thank you to my family who has supported me unfailingly, to all of the hardworking students who helped me collect and compile field data, and Eric Barkemeyer for thoughtful input on drafts and enduring patience. Clara Rasmussen edited several of the chapters, created Figure 4.2 from a transect photo, and helped with graphic design of many of the figures. Thank-you, Mom.

The work could not have happened without Larry Dunsmoor of the Klamath Tribes and Pat McDowell shepherding grant proposals. This research was funded by a grant from the Natural Resources Conservation Service, Conservation Effects Assessment Project in the Upper Klamath Basin, grant number: 68-3A75-4-101, and a grant from The Klamath Tribes Natural Resources Department, contract number 1-991-07. Both grants were awarded to Professor Patricia McDowell of the University of Oregon, Department of Geography.

DEDICATION

Dedicated as the first Ph.D. of our Williams Clan and the first female Ph.D. of our Rasmussen Clan. May there be many more of each.

TABLE OF CONTENTS

Chapter Page

LIST OF FIGURES

Figure Page

LIST OF TABLES

CHAPTER I

INTRODUCTION

Distribution of riparian vegetation types in the semi-arid West is dependent on a suite of characteristics that vary by basin and local factors. These factors are typically related to: saturation (Nakai *et al*., 2009; Castelli *et al*., 2000; Li *et al*., 2006; Rodriguez-Gonzales *et al*., 2010), or drought (Mahoney and Rood, 1998; Amlin and Rood, 2002; Castelli *et al*., 2000; Chapin *et al.*, 2002; Stella and Battles, 2010); soil characteristics such as texture (Nakai, *et al.,* 2009; Mahooney and Rood, 1998); stream scour and burial (Loheide and Booth, 2011); or a combination of several factors (Hupp and Osterkamp, 1996; Osterkamp and Hupp 2010; and Bornette *et al.*, 2008). Basin level factors (Merrill *et al*., 2006; Lina *et al*., 2011; Jaquette *et al.*, 2005; Cordes *et al.*, 1997; Fotherby 2009; Cooper *et al*., 2003) are observable at broad spatial scales and with investigations of historic conditions. However, local factors may vary considerably with small changes in distance from the channel and fluvial processes (Hupp and Osterkamp, 1996; Cordes *et al*., 1997) and variations in land uses such as livestock grazing (Green and Kauffman, 1995; Holland *et al.*, 2005; Shultz and Leininger, 1990).

Improvement of habitat for at-risk fish species, such as those found in the Sprague Basin, often includes restoration of woody vegetation and especially streamside shrubs. Shrub cover is valued for stream shading and bank stabilization (Green and Kauffman, 1995). Successful restoration depends on an understanding of controlling factors (Lake *et al*., 2008) and how those factors may have changed through time (Wohl 2005; Palmer, 2008).

In Chapter II, I show how vegetation cover types (herbaceous, bare, short woody and tall woody) vary by river segment and through time using: aerial photographs from the 1940s, 1968 and 2000; Government Land Office records of cadastral surveys from the late 1800s; and herbarium notes from the early 1900s. I compare percentages of cover types of basin segments between years and relate the percentage cover of woody vegetation to floodplain width. A transition matrix is used to document all possible cover transitions experienced by any given point on the floodplain. Those transitions are then associated with common fluvial processes and land uses in the basin. In the chapter summary, I propose recovery potentials of vegetation types in the three floodplain width categories. Recovery potentials are generated from segment characteristics, deviations from historic cover conditions, and general vegetation trends.

In Chapter III, I show how variations in soil moisture, topography and soil texture control shrub abundance. Season-long soil moisture is measured directly with continuous reading tensiometers, rather than indirectly with piezometers, and resulting recession rates are compared to shrub abundance and existing literature. I evaluate the importance of soil texture, critical to moderating movement of soil moisture and subsequent gas exchange, on soil moisture values and recession rates. Topography, or height above the channel, is examined relative to both soil moisture values and soil texture and is used to describe potential for both restoration and natural recovery of shrubs.

In Chapter IV, I use extensive data from 75 riparian transects to investigate relationships between vegetation characteristics and local conditions such as: topography, soil textures, hydrology and land use. The initial evaluation compares basin and transect level characteristics to shrub values totaled for each transect. The second evaluation, based on individual points on transects, investigates how shrub values, totaled per point, are impacted by topographic, soils, hydrologic and basin characteristics. The third evaluation documents the preferred habitats of individual shrubs based on their genera, age class and stem class. All point and transect level factors are synthesized to predict the restoration and natural recovery potential of shrubs on a local level.

This dissertation shows the importance of a suite of factors in controlling vegetation patterns and shrub distributions in the Sprague Basin and how those factors vary by segment, position on a transect, and over time. With this understanding of dominant factors operating at different spatial scales, it is possible to prioritize restoration efforts in a way that maximizes potential for success and avoids projects that are either unnecessary or likely to fail.

CHAPTER II

VEGETATION CHANGE IN THE SPRAGUE RIVER VALLEY: AN HISTORICAL PERSPECTIVE FOR RESTORATION GUIDANCE

Introduction

Distribution of vegetation types within a basin is controlled by geomorphic character, hydrologic processes and prevailing land uses. Favorable conditions for floodplain vegetation in Western, semi-arid basins are largely determined by flooding and drought (Chapin *et al*,. 2002; Hupp and Osterkamp, 1996; Bendix, 1997; Bornette and Amoros, 1996; Li *et al.*, 2006; Bornett *et al.*, 2008; Castelli *et al.*, 2000; Amlin and Rood, 2002), basin characteristics such as floodplain width and slope (Merrill *et al.*, 2006; Jaquette *et al.*, 2005; Cordes *et al.*, 1997; Fotherby 2009; Cooper *et al.*, 2003), and use for livestock production (Green and Kauffman, 1995; Holland *et al.*, 2005; Shultz and Leininger, 1990). Successful restoration of riparian and floodplain environments requires an understanding of river and vegetation processes as they exist currently, (Jaquette *et al.*, 2005) and as they have been altered historically (Wohl, 2005).

Processes controlling floodplain vegetation differ spatially relative to the channel. Near-channel environments experience more disturbance from flooding, scour and burial (Hupp and Osterkamp, 1996; Cordes *et al.*, 1997), but also have more opportunities for establishment of typical riparian species (Gurnell *et al.*, 2008; Karrenberg *et al.*, 2002). Distal floodplain surfaces are more often modified for grazing, hay production or other agricultural practices.

If it can be shown how vegetation types relate to basin geomorphology (specifically floodplain width), and how the proportion of types have changed over time with land use, then it should be possible to predict the best habitats for vegetation types. It should also be possible to predict habitats to be avoided such as those where certain vegetation types are unlikely to survive or where natural recovery is likely without intervention. Results from this historical analysis will help practitioners understand the general vegetation trends in the basin and variations in trends for different floodplain widths and will provide a basis for future restoration planning.

This chapter documents the nature and extent of variations in vegetation cover types on the Sprague Valley floodplain, where riparian restoration has generally included efforts to restore woody vegetation with the goal of improving fish habitat through stream shading and increased bank stability (Green and Kauffman, 1995). Efforts to establish shrubs and trees on wide floodplains have been largely unsuccessful, though herbaceous recovery has been robust. In order to understand why restoration strategies sometimes fail in the Sprague, I examine variations due to geomorphic character and prevailing land uses using aerial photos from the 1940s, 1968 and 2000. Historic records are also examined, incorporating vegetation notes from government surveys conducted in the late 1800s and botanical surveys from the early 1900s. Primary questions are: 1) how do general vegetation patterns relate to floodplain width, 2) how have those general patterns changed over time, and 3) how do changes relate to land use history. Answers to these questions are used to recommend general restoration strategies for floodplain vegetation types.

Methods

Site Description

The Sprague River is an important source of water for the Upper Klamath Lake, home to several endangered fish species and focus of the Klamath Basin water crisis of 2001. Extensive restoration efforts have been implemented in the Sprague Valley, often in wide valley segments, and range from changing cattle grazing to channel and wetland reconstruction. Most projects include efforts to establish woody vegetation, especially in near-channel zones, where it is most likely to benefit fish habitat and water quality. These near-channel zones are more dynamic than surrounding floodplains, making them more challenging for restoration efforts and more sensitive to land use changes and flood events.

The Sprague Basin has several distinct features that impact biogeomorphic relationships. First, mainstem channel gradients are very low, even in the narrower floodplain areas. Second, soils are dominated by pumice released from former Mt. Mazama—currently Crater Lake. Lastly, unlike many semi-arid alluvial channels, the mainstem channel is not incised and maintains frequent connections with the surrounding floodplain.

The Sprague floodplain is divided into twelve mapped segments (Figure 2.1; Table 2.1) based on channel gradient, floodplain width, and influence of major tributaries in a related study of geomorphic history (O'Connor *et al.*, in progress). Three segments represent tributaries: the lower Sycan River segment entering from the north, near Beatty, the North Fork Sprague, and the South Fork Sprague, near Bly. Floodplain segments are grouped into narrow, moderate and wide categories based on their average floodplain width. Floodplain segments are used as a structure for analysis of vegetation because valley width can influence geomorphic and hydrologic conditions that influence vegetation patterns and land use. In general, narrow valleys are expected to have higher energy streamflow and coarser channel and floodplain sediments than wide valley floodplains. Narrow valleys also have more topographic shading. Wide valleys have space for development of channel meanders and more floodplain wetlands.

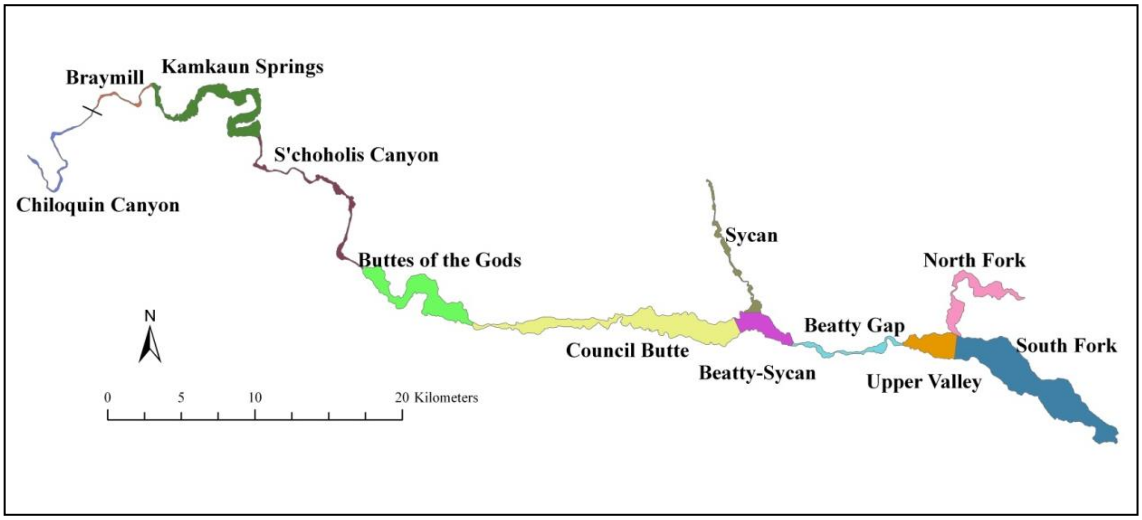


Figure 2.1. Segments of the Sprague floodplain that were examined as part of this study. Flow direction is from right to left.

Narrow floodplain segments in the Sprague basin have a high percent cover of woody species including willow (*Salix* sp.), ponderosa pine (*Pinus ponderosa)*, and limited cover of cottonwood (*Populus* sp.) and quaking aspen (*Populus tremuloides*). Both narrow floodplain segments (Chiloquin Canyon and Braymill) are low in the basin and are predominantly managed by the US Forest Service. Land uses in these segments have historically been related to the timber industry (harvest and transport of timber), with limited haying or modification for pasture use. Recreation use (roads and campsites) is very common.

Table 2.1. Characteristics of mainstream floodplain segments in 2000 arranged from downstream to upstream, and tributaries (North Fork, South Fork and Lower Sycan)

River Segment	Avg. Floodplain Width (m)	Width Category*	Woody Vegetation Types
Chiloquin Canyon (CC)	100	Narrow	Ponderosa prevalent with many shrubs, occasional aspen and cottonwood
Braymill (BR)	105	Narrow	Ponderosa prevalent with many shrubs, occasional aspen and cottonwood
Kamkaun Sp. (KS)	540	Wide	Shrubs-including some tree form Salix
S'choholis Canyon (SC)	175	Moderate	Mixed dominance. Ponderosa, shrubs, occasional aspen
Buttes o/t Gods (BGD)	945	Wide	Few shrubs. No trees.
Council Butte (CB)	850	Wide	Few shrubs. No trees.
Beatty-Sycan (BSY)	965	Wide	Few shrubs. No trees.
Beatty Gap (BGP)	250	Moderate	Many shrubs, some aspen and ponderosa.
Upper Valley (UV)	1245	Wide	Few shrubs. No trees.
South Fork (SF)	1645	Wide	Few shrubs. No trees.
North Fork (NF)	525	Wide	Few shrubs. No trees.
Lower Sycan (SY)	225	Moderate	Many shrubs. Some ponderosa at uppermost extent.

*Narrow floodplains widths average less than 150m wide, moderate widths between 150m and 300m, and wide floodplains greater than 300m

Vegetation in wide segments is strongly dominated by herbaceous cover. The invasive species, reed canary grass (*Phalaris arundicea),* is common in mid and lower basin segments and spreading. Nearly all portions of the wide valleys are privately owned and intensively managed for livestock grazing and hay production. Common floodplain and channel alterations include ditches, levees, field leveling and several types of irrigation.

The three moderately wide floodplain segments are different. S’choholis Canyon has mixed ownership by the US Forest Service, private timber companies and rural residential development. Beatty Gap is privately owned, but has not been as intensively managed as any of the other upper basin segments. The Sycan segment is privately owned with a mix of heavy, moderate and light grazing pressure and considerable floodplain alteration. While the active floodplain of the Sycan is narrow, it is situated within a broad, dry terrace that is not accessible by the stream channel. Vegetation in moderately wide segments is a mix of shrub, herbaceous species and some tree cover, with small patches of aspen in both Beatty Gap and S'choholis Canyon.

Land Use History

Up until the late 1950s, most of the Sprague Valley was contained within the Klamath Indian Reservation, extending from near Bly, Oregon, westward to Chiloquin. According to Stern (1966, pg. 148), by the early 1920s, tribal "…allottees had disposed of valuable haylands and grazing tracts in Sycan Marsh, the valleys of the Williamson, Sprague, and Wood rivers, and at Modoc Point. Klamath Marsh tracts were soon to follow." Timber was of greater value to the Tribe than grazing, with timber harvest beginning in the 1870s and continuing until termination of the Tribe in 1954. Although intensive agriculture was attempted in the early days of the reservation, the area was deemed unsuitable due to drought, cold and a short growing season. By the mid 20th century, there was little agriculture in the basin other than haying and grazing.

Off-reservation lands near Bly and the forested upper basin were reported as very heavily grazed as early as 1907 (Connelly and Lyons, 2007). Floodplains in these off reservation areas came under intensive use considerably earlier than reservation lands, with establishment of mills, a greater amount of mechanical alteration (levees, ditches and roads), and more intensive grazing and hay production. Portions of the North Fork and South Fork Sprague river channels were re-configured for drainage and flood control by the US Army Corps of Engineers starting in the 1950s, likely in response to floods (Connelly and Lyons, 2007).

In 1940, the floodplain was relatively free from major mechanical alteration, with the exception of forestry and urban development in the most western and eastern segments. Hay production and grazing were occurring, however, and flood irrigation was recorded on one portion of the Council Butte segment in the 1940s photographs.

Development of ditches, levees, dams and irrigation ponds greatly accelerated between 1940 and 1968, as did the intensity of grazing and hay production, leaving considerable bare ground and encouraging conversion of shrub cover to herbaceous pasture. The channel was straightened and "cleaned" by the Army Corps of Engineers for an unspecified length of the mainstem and tributaries, an operation that actively removed woody cover from stream banks (Rabe and Colonje, 2009). The winter of 1964 brought a large flood event that inundated the valley, leaving several feet of water on lowland properties, sometimes for weeks (USACE records, 1964-1990). Grazing pressure was high on both public and private lands. Efforts to improve pasture, combined with high disturbance, likely led to greater occurrence of introduced species (mostly grasses) in the riparian areas. Forestry pressure lessened during the 1940 to1968 period somewhat, with the closure of many mills after World War II (Rabe and Colonje, 2009).

The time between the 1968 and 2000 photo sets, concerns about endangered species, water quality and quantity and tribal relations had eased the demands placed on floodplain vegetation cover. Both habitat degradation and increased concern about sensitive species in the basin were reflected in the federal endangered listing of two fish species (Lost River and short nosed suckers - listed 1988), as well as concern over bull trout (listed as threatened in 1998), redband trout, and large scale sucker (Rabe and Colonje, 2009). Some private landowners began restoration efforts and more sustainable forms of grazing management, though in this time period, others continued traditional practices. Since 2000, a multitude of restoration projects have been undertaken by a wide variety of organizations and private landowners (Rabe and Colonje, 2009).

Historic Vegetation Conditions

The three primary sources of vegetation information in the Sprague River corridor were: 1) plat maps that occasionally showed generalized cover (e.g. forest, bottomland, marshes), 2) notes from Government Land Office (GLO) section line surveys (e.g. prairie, timber pine) (USDI, http://www.blm.gov/or/landrecords/index.php) , and 3) presence or absence and nature of trees used to document corners of section and ¼ section lines (witness trees). Most of the mid and upper basin was surveyed in 1866, with parts of Braymill, Chiloquin Canyon and Upper Sycan surveyed between 1869 and 1872. Parts of the Upper Sycan and Bramill were not surveyed until 1892 or 1895. Vegetation notes collected in this effort were compared to mapping done by Oregon Institute of Technology in Klamath Falls (Klamath Water Library, accessed 4-1-2011).

Historical notes from botanist William E. Lawrence were also reviewed (Lawrence, 1922, 1934). Lawrence described vegetation types and species occurring in Beatty-Sycan, Beatty Gap and South Fork Sprague segments in 1922 and 1934 as he travelled from Klamath Falls to Lakeview.

GIS Mapping

General vegetation trends in the basin were determined by reviewing historical documents (Government Land Survey and botanist notes) as well as mapping the floodplain surface from aerial photos. Relationships between floodplain width and woody vegetation were also investigated.

Using black and white aerial photographs, I mapped vegetation, water and bare ground surfaces on the floodplains of the Sprague River basin including the mainstem Sprague, South Fork Sprague, North Fork Sprague and Sycan Rivers. Photographs from three separate year sets were used. Images for 2000 were digital orthophoto quadrangles from the USGS (2000). Images for 1968 (USDA, 1968) and the 1940s (USDA, 1940) were rectified from aerial photographs from the US Department of Agriculture. The 1940s set was taken at different times over the summer, included photos from more than one year (1940, 1941 and 1942), and covered a smaller area than in 1968 and 2000. In particular, the North Fork and South Fork had limited coverage in the 1940s photographic set and are therefore included in some analysis results and not others. All photo sets used were black and white, though a high resolution, true-color set taken in 2005 (NAIP, 2005) was used for double checking type and position of vegetation stands. Vegetation types were also field checked against current photographs to verify characteristics.

Table 2.2. Cover types for mapping and typical cover.

Cover Class	**Typical surface or cover**
Tall Woody (>6m tall)	Trees: Ponderosa pine, aspen
Short Woody (<6m tall)	Shrubs or small trees: Willow, rose, currant, Spirea
Herbaceous	Riparian and upland non-woody vegetation
Water	Primary and secondary water features, ditches, ponds, etc
Bare	Exposed channel sediment or soil

All vegetation, water and bare/built features were mapped within the active floodplain. The extent of the active floodplain was determined by the presence of fluvial geomorphic features (such as oxbows and scroll bars) and low-lying position adjacent to the channel system. Mapping consisted of drawing digital polygons around patches of woody vegetation, water, built features and bare soils, typically at the scale of 1:2000. Patches had to be larger than 20 square meters, and/or comprised of more than 5 individuals separated by fewer than 20 meters. Single, large, isolated ponderosa trees were often excluded from polygons. These vegetation classes (Table 2.2) are consistent with National Wetland Inventory (NWI) methods which divide Forested and Scrub-Shrub wetland types at the 6-meter height threshold (NWI classification in Cowardin *et al.*, 1979). As in the NWI method, immature trees are classified as short woody.

Tall woody vegetation, generally ponderosa pine, quaking aspen or cottonwood, typically had accompanying shadows and predictable shapes on the aerial photos. Pines were very dark on the photos and sometimes nearly indistinguishable from the accompanying shadows. Quaking aspen had round crowns for individual trees; larger stands had a mottled texture. Aspen color was typically darker than the shorter, more patchy willow and lighter than adjacent pine. Portions of the 1968 photo set were taken prior to leaf-out for the aspen trees, making crown identification difficult. Shadows of tree crowns were very distinctive, however, making mapping possible. The same problem existed for willows, though to a lesser extent, and contrast between crowns and surrounding herbaceous vegetation was high.

Once all woody vegetation was mapped, areas without any vegetation were delineated and classified as bare. Houses, roads and bridges were assumed to be bare. All surfaces that were not mapped as water, tall woody, short woody or bare were assumed to be covered with herbaceous vegetation. All areas within the floodplain boundary were assigned one of the five classifications: bare, water, herbaceous, short woody or tall woody. With the entire floodplain mapped for all three photo sets, the nature and extent of cover changes between the year sets were investigated both in general terms (i.e. hectares of short woody vegetation lost per segment), and in detail.

Analysis

Analysis was conducted in ArcGIS, within a geodatabase designed for the project by Pollyanna Lind of the University of Oregon. Near-channel zones were delineated using a 20-meter buffer extending from each side of the primary channel into the floodplain area.

Analysis of changes from one cover type to another was done using a transition matrix. A transition matrix identifies all of the possible changes in land cover classes, allowing determination of transitions that are most prevalent during different time periods. Individual transitions can then be related to human and natural processes and translated into ecological trends. Transition matrix analysis has been used in landscape scale investigations of land use (Petit *et al.*, 2001), grassland and woodland interactions (Hibbard *et al.*, 2003), and dune and delta environments (Shaunmugam and Barnsley, 2002; Biondini and Kandus, 2006). Pairs of transitions (e.g. water to bare or bare to water) were combined for each imagery set and each segment for clarity in reporting.

The 1968 photographs were taken early in the season and at higher water than either the 1940 or 2000 sets. All photos from 1968 were taken in the same year, but include photos from early spring and summer.

During the mapping of vegetation, water features were the overriding cover type. For example, water overlapped by vegetation was mapped as water. In most cases this makes only small differences in overall percentages, and as it was done consistently across years, it should not interfere with interpretation of vegetation change over time.

Results

Current Spatial Distribution of Vegetation (2000 photos)

The purpose of this section is to: 1) describe vegetation patterns as they exist in 2000, 2) show links between vegetation patterns and floodplain width, and 3) examine differences in vegetation patterns between the floodplain and near-channel zones. Vegetation patterns appear to be closely related to variations in floodplain width.

Water covers nearly 40% of the total floodplain widths in narrow segments, between 18 and 12% in moderate widths and between 1 and 13% in wide segments. All values in this section reflect the proportion of vegetation cover only (i.e. vegetation classes plus bare ground, no water). Bare ground is a very minor component of the total floodplain cover, though considerably higher in the near-channel zone. Values for bare ground areas are included here as they have the potential to be occupied by vegetation.

Narrow and moderately wide floodplains have a much higher proportion of woody vegetation on the floodplain than wide floodplains (Figure 2.2). The Sycan segment, while currently resembling wide floodplain segments in woody cover, had 26% woody cover in the 1940s and has lost considerable shrub cover through grazing and modification of the floodplain surface. Woody cover is mainly short woody cover (Figure 2.3). Wide floodplain segments are all strongly dominated by herbaceous cover (>92% herbaceous cover).

Cover values in near-channel zones are different than those on the floodplain as a whole in several ways (Figure 2.3). First, bare ground is a larger component of surface cover in the near-channel zone than on the floodplain, reflecting the presence of active bar surfaces along the channel. Second, tall woody vegetation has a stronger presence in the floodplain composition than in the near-channel zone, likely due to intolerance of both aspen and ponderosa to the higher levels of soil saturation near the channel. Third, there is a slightly higher proportion of short woody vegetation in the near-channel zone than in the whole floodplain in most segments. However, the differences in percentage are not great, suggesting that water is not limiting for shrubs on broader floodplain surfaces. In most semi-arid regions, the near-channel zone contains most of the floodplain shrubs, because of increased water availability near the channel, as well as higher availability of seeds and germination sites (Karrenberg et al. 2002). The slightly greater cover of shrubs in the near-channel zones is most pronounced in the narrow segments, though this can be seen to some degree in all segments. This difference is possibly due to microsites made available by lateral channel movements or seed dispersal processes.

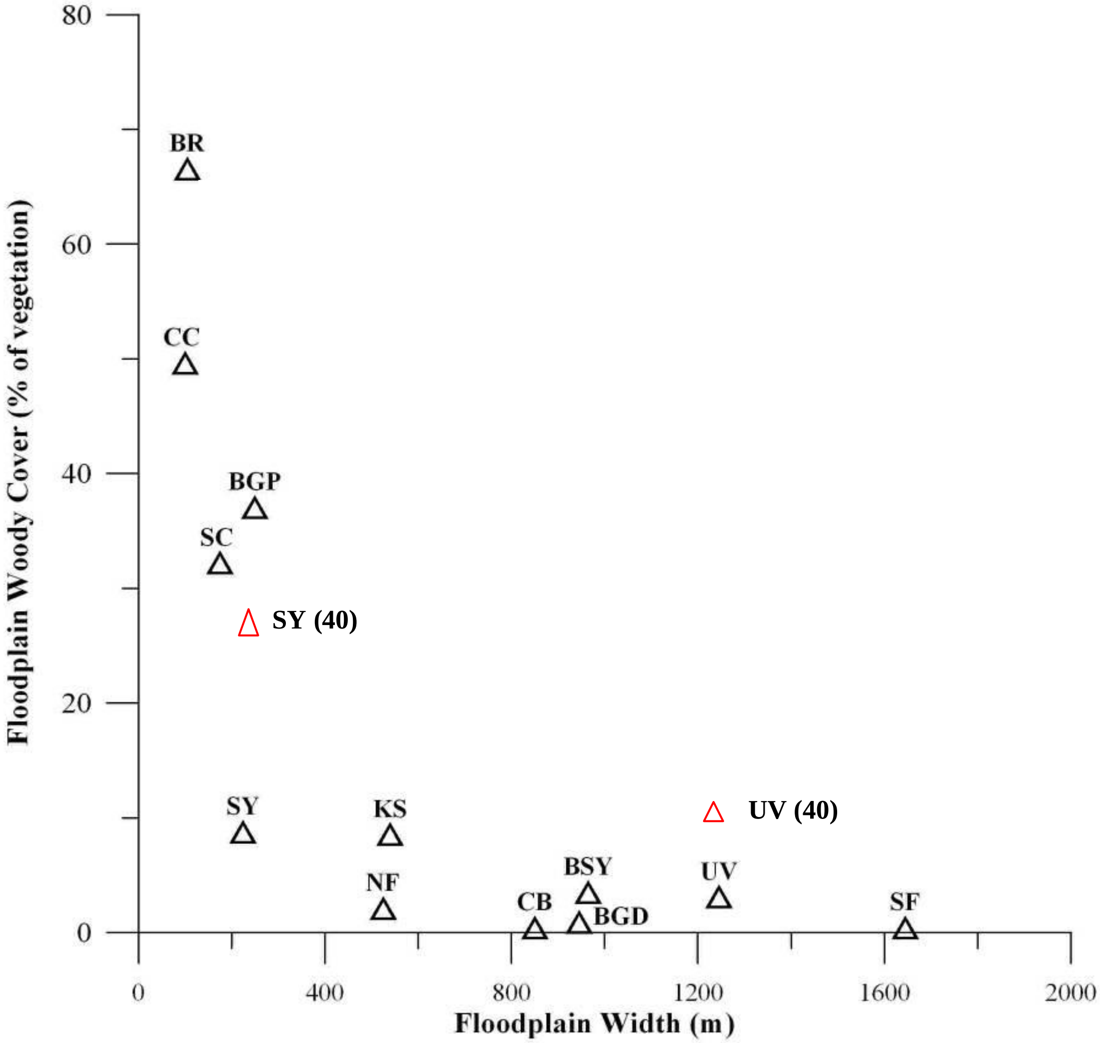


Figure 2.2. A summary of the relationship between the average floodplain width and the percent of woody vegetation (short and tall woody) mapped in each segment for the year 2000. Woody cover in 2000 had changed less than 5 percent from 1940 values for all segments except the two shown (Sycan and Upper Valley).

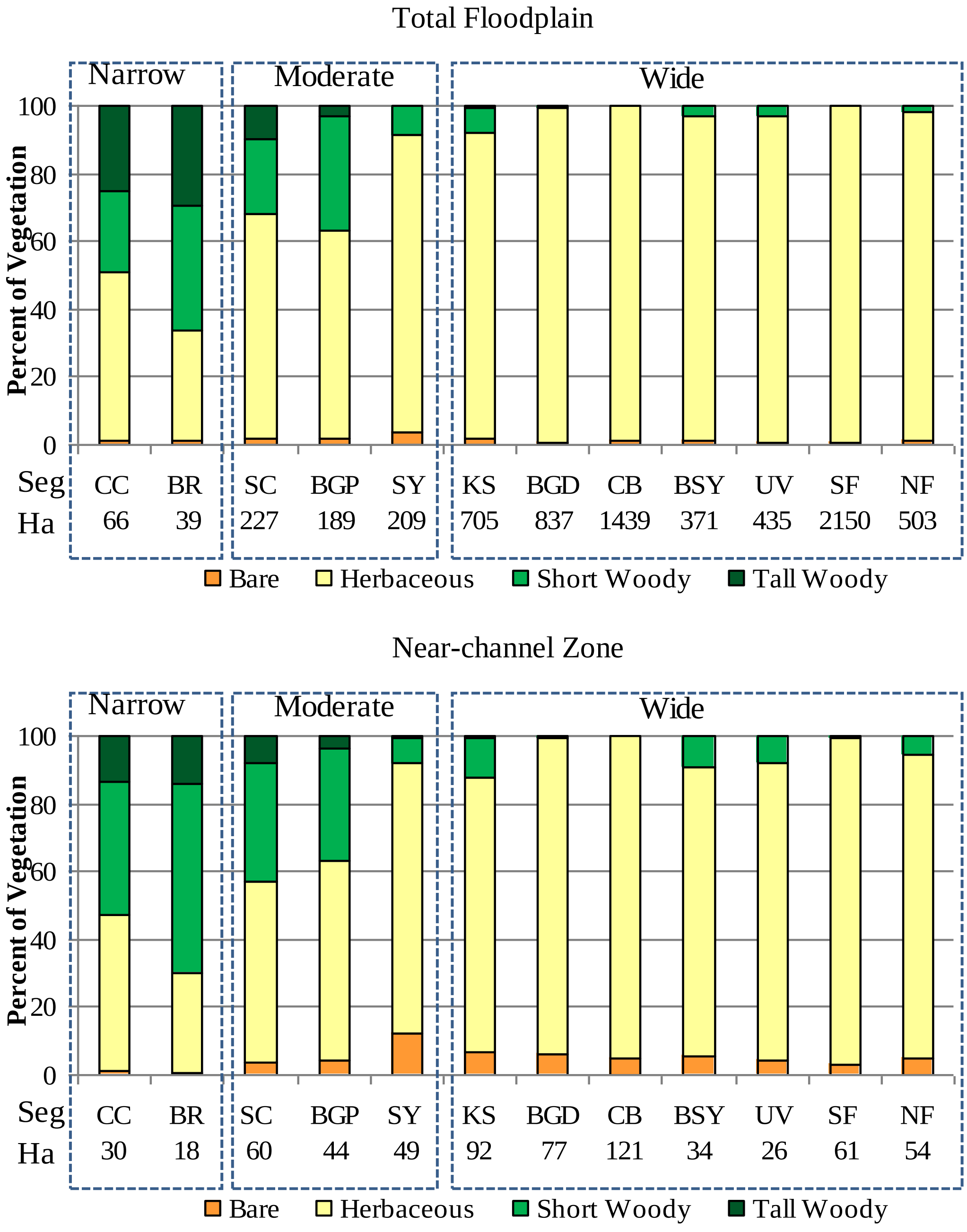


Figure 2.3. Summary of vegetation cover (non-water cover) on floodplain and near-channel (within 20m of the channel) surfaces for each segment in 2000, arranged by relative floodplain width and position downstream to upstream (left to right within each grouping). The number of hectares mapped for each segment surface is listed below the segment symbol. Average floodplain widths per segment are: CC – 100m, BR – 105m, SC – 175m, BGP – 250m , SY – 225m, KS – 540m, BGD – 945m, CB – 850m, BSY – 965m, , UV – 1245m, SF – 1645m, NF – 525m.

Vegetation Cover Change

General Land Office Surveys and Botanist Notes

General vegetation patterns have changed little since the late 1800s, based on review of Government Land Office (GLO) surveys (USDI, http://www.blm.gov/or/landrecords/index.php). Wide floodplains that are currently dominated by herbaceous cover now had no tree cover then. Narrow floodplain segments were described as forested and moderately wide segments as a mix of herbaceous and timber. In narrow and moderate floodplains, the proportion of the survey line on the active floodplain is small, generating fewer notes on floodplain vegetation. For that reason, the narrowest segments are excluded from Table 2.3, but appear to have been heavily forested at that time.

GLO surveys were made on section lines, documenting very general conditions on both floodplain and upland surfaces. Surveyors often noted transitions between forest and prairie with statements such as ‘leaving river bottom’ or ‘entering timber’. Surveys tended to focus on timber and prairie resources, likely for the promotion of agriculture and timber harvest. No direct mention of riparian shrubs is made on any section line survey, except in two cases (Beatty Gap and Upper Valley) where large willows were used as witness trees. Surveyors often commented on topography and soil conditions without direct mention of vegetation cover. Comments such as ‘land level’ or ‘soil first rate’ were not considered to be indicators of vegetation types. No aspen stands were mentioned in Beatty Gap, S’choholis Canyon or the narrow valley segments, though some aspen patches exist currently and were present in the 1940s

Table 2.3. Vegetation notes extracted from GLO surveys

Segment *	Data from plat maps	Floodplain notes from section line survey	Floodplain witness trees	Notes:
Kamkaun Springs.	Lower Kamkaun drawn as non-forested in bottom, timber upland. 34S 8E	13 lines total 2 'Prairie'	12 points total 2 with pine 10 with no trees	Mix of timber and prairie on both uplands and floodplain. Open river bottom interpreted as prairie.
S'choholis Canyon	N. D.**	11 lines total 1 'Prairie'	5 points total 3 with pine 2 with no trees	The one mention of prairie was near the boundary with Buttes of the Gods segment.
Buttes of the Gods	N. D.**	6 lines total 1 'Prairie' 5 'No timber'	15 points total 15 with no trees	
Council Butte	Described as 'level prairie' on upper 1/3 of plat map of 35S 10E.	9 lines total 2 'Prairie' 8 'No Timber'	22 points total 22 with no trees	Many mentions of 'land level', but not vegetation type on floodplain surface.
Beatty-Sycan	N. D.**	4 lines total 2 'No timber'	5 points total 5 with no trees	
Beatty Gap	N. D.**	8 lines total 4 'No timber'	5 points total 1 with willow 4 with no trees	2 willows used as witness trees, 3" and 8" diameters.
Upper Valley	N. D.**	4 lines total 1 'No timber'	5 points total 1 with willow 4 with no trees	2 willows used as witness trees, both 4" in diameter.
South Fork	Area of wetland vegetation drawn on plat map. No timber on downstream end of segment. 36S 14E	11 lines total 4 'No timber'	26 points total 26 with no trees	Swampy soil mentioned on two segment line.
North Fork	N. D.**	9 lines total 3 'No timber'	5 points total 5 with no trees	
Lower Sycan	N. D.**	8 lines total 3 'Prairie'	4 points total 2 with pine 2 with no trees	

* Segments arranged downstream to upstream. **N.D. means no data available

The locations of markers (section corners and section line mid-points) were related to as many as three nearby 'witness trees'. The surveyor recorded the species and diameter of each witness tree, and its direction and distance from the marker. The absence of witness trees indicates a lack of nearby trees and is interpreted as non-forested cover for purposes here (Table 2.3). Smaller shrubs or willows without single stems were likely present but are not mentioned. Pine trees were recorded on floodplain surfaces only in Kamkaun Springs, S'choholis Canyon and the Lower Sycan segments. Notes mention a single aspen witness tree in the Braymill segment.

A botanist traveling through the area in 1922 and again in 1934, documented vegetative conditions in Southern Oregon, with comments relative to the Sprague Valley highlighted below (Lawrence, 1922, 1934). Lawrence primarily saw the Beatty Flat area, near the confluence of the Sycan and Sprague, upstream through Beatty Gap and into Bly. Segments viewed were Beatty-Sycan, Beatty Gap and the South Fork Sprague.

Lawrence notes on his trip on July 1, 1922 from Klamath Falls to Lakeview, Oregon, via Hillebrand, Bly: "No trees are to be found in the Beattie flat. The kind of sage was not noted", "*Ribes aureum* grew very luxuriantly along the creek in Beattie valley. *Salix* was very abundant along the stream and *Rumex* along the dry roadside, where there is some subsoil moisture.", "The road after rising over a ridge soon came to border the Sprague River. *Ribes aureum* was very abundant along this river even leaving it and creeping a short way out on the drier slopes now and then.", "*Salix*, *Ribes aureum*, *Amelanchier*, *Prunus demissa*, *Populus*, *Urtica*, *Rosa* sp. were seen abundantly along the Sprague river.", "In brief it was *Populus*, etc. and *Ribes aureum* along the river. *Kunzia tridentate* then *Artemesia tridentat* and a little *Ribes cereum* with yellow pine farther up.", "Hay farming characterizes the productive areas here.", "…cattle get water hemlock along the river. The rootstock stick up and are bitten off by the cattle and sometimes by the sheep."

From July 3, 1922 he notes: “The currents grow in quantity along the creek bottoms. This is *Ribes aureum*. It is along the Sprague River in quantity. It extends from above Bly at Sec. 10T 37R 16 down the river in abundance for 8 miles. It grows here in thick bodies. Below here it extends scattering with the willows down into the Reservation.”

On a repeat trip on July 30, 1934 Lawrence notes: “Sprague River junction…..There is an extensive natural meadow flat here which extends along the river bordered with Salix.”, “Over this ridge and we turn into a large valley mostly covered with sage. A small area of natural pasture is seen.”, “From here the Sprague River is seen to the left (north) with natural meadow pasture on bottom and bordered by willows."

Vegetation Trends 1940-2000

In this section, mapping from the 1940s, 1968 and 2000 photos (Figure 2.5 shows example of mapping) is used to describe the nature of changes in floodplain cover to address the following questions: 1) what is the aggregate change in floodplain cover for the Sprague floodplain by segment, segment type and basin total; and 2) what is the extent of change both in terms of percent cover and hectares. All cover types (vegetation classes, bare and water) are considered in this analysis, as losses in one type are reflected in gains in another.

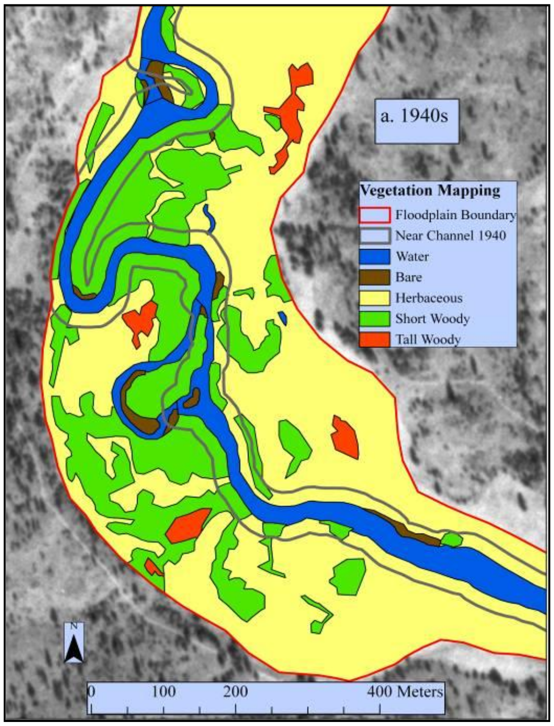
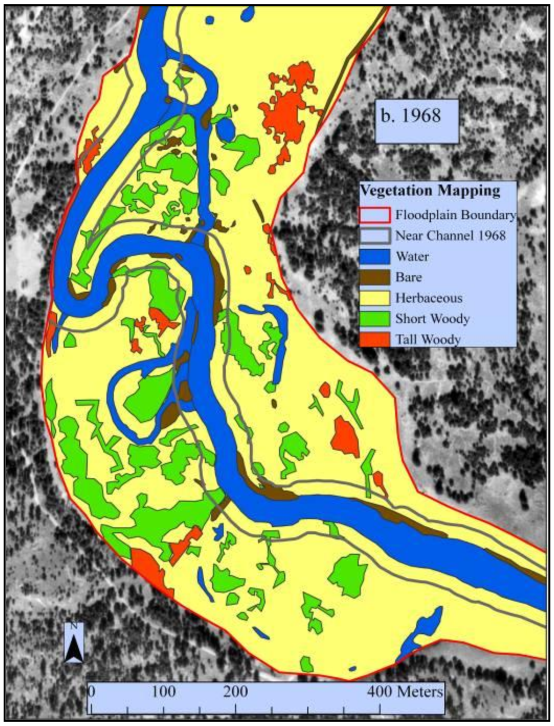
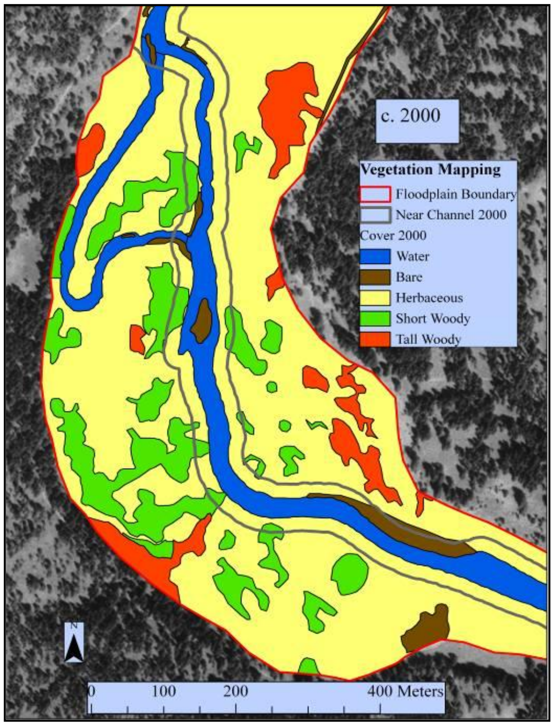


Figure 2.4. Examples of the vegetation floodplain mapping on a small upstream portion of S’choholis Canyon for (a) 1940s, (b) 1968, and (c) 2000.





Basin wide totals from 1940 to 2000 (Table 2.4) show a distinct loss of short woody cover, a smaller loss of water surface, and a gain of herbaceous cover. Bare ground and tall woody cover increased slightly. Water cover decreased nearly 50 hectares, possibly representing the loss of secondary channel features such as ponds and oxbows to pasture development and channel straightening efforts by the USACE.

Table 2.4. Basin-wide (excluding NF and SF) change from 1940 to 2000.

	Hectares	**% Floodplain Area**
Water	-47.9	-0.9
Bare	13.0	0.3
Herbaceous	165.8	3.3
Short Woody	-144.2	-2.8
Tall Woody	13.4	0.3

Over the two time periods (1940-1968 and 1968-2000), and across all segments, the largest vegetation changes were a loss of short woody vegetation and a gain in herbaceous cover (Table 2.5). Short woody cover had a large decrease between 1940 and 1968, and had a slight further decrease from 1968 to 2000. Herbaceous cover increased during both periods, as did tall woody cover, though by a much smaller extent than herbaceous. Water cover and bare ground had a similar trend, increasing from 1940-1968 and decreasing from 1968-2000.

Most of the short woody vegetation lost in the earlier period was in moderate and wide floodplains (Table 2.5), with slight increases in short woody cover in moderate and narrow floodplains during the later period. The greatest increase in herbaceous cover

Table 2.5. Cover change in hectares and percent area of floodplain by floodplain width category.

Cover Type	**Narrow *, ha (%)**	**Moderate*, ha (%)**	**Wide*, ha (%)**	**Total (ha)**	**All Segs (%)**
		1968 minus 1940			
Water	2.1 (1.2)	24.8 (3.4)	4.3 (0.1)	**31.2**	**0.6**
Bare	0.2 (0.1)	17.7 (2.4)	47.5 (1.1)	**65.4**	**1.3**
Herbaceous	-0.1 (-0.1)	20.6 (2.8)	16.1 (0.4)	**36.6**	**0.7**
Short Woody	-9.4 (5.4)	-60.0 (-8.2)	-68.1 (-1.6)	**-137.6**	**-2.7**
Tall Woody	7.4 (4.2)	-3.1 (-0.4)	0.2 (0.0)	**4.5**	**0.1**
		2000 minus 1968			
Water	-2.4 (-1.4)	-24.9 (-3.4)	-51.8 (-1.2)	**-79.1**	**-1.6**
Bare	-1.7 (-0.9)	-12.1 (-1.7)	-38.6 (-0.9)	**-52.3**	**-1.0**
Herbaceous	-0.9 (-0.5)	27.5 (3.8)	102.5 (2.4)	**129.2**	**2.5**
Short Woody	3.4 (2.0)	1.9 (0.3)	-11.9 (-0.3)	**-6.6**	**-0.1**
Tall Woody	1.5 (0.8)	7.7 (1.1)	-0.3 (0.0)	**8.9**	**0.2**

*Narrow sections total 174 ha, moderate 730 ha and wide 4194 ha. Basin total 5098 ha.

occurred in wide floodplain segments during the later period. During 1940 to1968, tall woody cover (predominantly ponderosa) increased by more than seven hectares in narrow floodplains, while more than three hectares of tall woody cover (likely aspen) was lost in moderate floodplain widths. The same data expressed as a percentage of floodplain area (Table 2.5) show that changes in each category affected only a small portion of the floodplain. The most pronounced changes in total percentages were losses of short woody cover between 1940 and 1968 and gains of herbaceous cover between 1968 and 2000, though each of those was less than 3 percent of the floodplain total. Segments with moderate widths experienced the greatest changes in terms of percent of the floodplain, with losses of short woody cover marking the most extreme value of 8.2 percent. Changes in the percentage of water are likely due mostly to the high water captured in the 1968 photos.

With totals broken down by segment, major trends are still consistent, with a few discrepancies (Table 2.6). Council Butte segment, for example, shows a loss of water cover (possibly due to channelization) while all other segments increased in water cover. Chiloquin Canyon had a decrease in bare ground cover in the early period when all others increased, likely due to closing of mills that had been operating on the floodplain.

Loss of short woody cover was unevenly distributed, with much greater losses in the upper basin segments. The Upper Valley and Sycan segments experienced the greatest drops in short woody cover, with both declines continuing into the later time period. The North Fork and South Fork segments showed decreases in bare ground cover and increases in herbaceous cover between 1968 and 2000. In the same period, the North Fork segment had a large loss of short woody cover and a considerable decrease in bare area. Beatty Gap, an upper basin segment, gained considerable area in short woody during the later period, opposite the trend of all segments surrounding it.

The greatest changes were in loss of short woody vegetation to herbaceous cover, with the greatest acreage lost in wide floodplain segments but the largest percentage lost in moderate floodplain segments. Segments in the upper basin were the most impacted through both time periods, except Beatty Gap during the later period. The drivers of these changes are examined in the next section, detailing individual transitions and relating them to land uses and riparian processes.

Table 2.6. Floodplain cover change by segment (ha).

1940 – 1968												
	Narrow		**Moderate**			**Wide**						
	CC	**BR**	**SC**	**BGP**	**SY**	**KS**	**BGD**	**CB**	**BSY**	**UV**	**SF***	**NF***
Total Ha	**113**	**61**	**277**	**214**	**238**	**817**	**928**	**1596**	**405**	**447**	**260**	**292**
Water	1.38	0.71	**9.66**	**9.57**	**5.58**	**18.44**	**4.63**	**-22.37**	1.62	1.94		
Bare	-0.95	1.12	**5.61**	**3.81**	**8.29**	**8.17**	2.98	**31.10**	**3.02**	2.22		
Herb	0.24	-0.33	-1.17	**5.48**	**16.32**	**-8.58**	-2.70	1.03	-1.06	**27.39**		
Short Woody	**-5.62**	**-3.81**	**-15.95**	**-14.71**	**-29.39**	**-18.79**	**-4.93**	**-9.23**	**-3.59**	**-31.55**		
Tall Woody	**5.03**	2.33	1.84	**-4.15**	-0.80	0.75	0.02	-0.53	0.00	0.00		
1968 – 2000												
	CC	**BR**	**SC**	**BGP**	**SY**	**KS**	**BGD**	**CB**	**BSY**	**UV**	**SF**	**NF**
Total Ha	**113**	**61**	**277**	**214**	**238**	**817**	**928**	**1596**	**405**	**447**	**2174**	**524**
Water	-2.61	0.25	**-13.96**	**-7.06**	**-3.90**	**-4.54**	**-16.46**	**-21.43**	**-8.69**	-0.66	**-4.88**	-1.95
Bare	-0.61	-1.04	**-4.11**	**-3.22**	**-4.77**	-1.10	**-9.08**	**-24.53**	-2.03	-1.83	**-5.94**	**-22.79**
Herb	-0.86	0.01	**10.19**	1.42	**15.86**	**11.95**	**25.08**	**47.83**	**9.93**	**7.75**	**16.53**	**37.50**
Short Woody	**3.03**	0.37	0.85	**8.38**	**-7.34**	**-6.03**	0.48	-1.87	0.79	**-5.26**	**-5.82**	**-12.95**
Tall Woody	1.05	0.42	**7.03**	0.48	0.16	-0.25	-0.02	0.00	0.00	0.00	0.11	0.20

Values in blue represent a greater than 3 hectare increase in that cover type and values in red a greater than 3 hectare decrease. *Values excluded from analysis due to differences in mapping areas.

Transition Analysis

Structure of Analysis

The preceding sections of this work described general characteristics and summarized changes at different scales. This section examines those trends from the perspective of ecosystem processes that may be driving the changes, identifying possible natural or human controls of these changes.

This analysis looks specifically at the transitions experienced by each pixel from 1940-1968 and 1968-1940. For any given pixel, cover changes were recorded as one of a possible 21 transitions (Table 2.7), including 20 transitions of one cover type to another plus that of ‘No Change’. Transitions below the diagonal line of No Change represent a loss of structural complexity. Transitions above the diagonal line of ‘No Change’ show increases in structural complexity. Greater vegetation height is interpreted as greater structural complexity because greater height generally means more potential surface area or variety of surfaces available for use by dependent organisms. For example, bare ground becoming herbaceous cover (Bare→Herbaceous) shows an upward trend in complexity as herbaceous cover offers more structural complexity than bare soil. A transition from herbaceous to short woody also shows increasing complexity with a greater surface area, greater vertical height, variety of surfaces, etc. for supporting

Table 2.7. Possible transitions of cover classes in change analysis.

	Water (W)	**Bare (B)**	**Herbaceous (H)**	**Short Woody (SW)**	**Tall Woody (TW)**
W	**No Change**	W→B	W→H	W→SW	W→TW
B	B→W	**No Change**	B→H	B→SW	B→TW
H	H→W	H→B	**No Change**	H→SW	H→TW
SW	SW→W	SW→B	SW→H	**No Change**	SW→TW
TW	TW→W	TW→B	TW→H	TW→SW	**No Change**

biological processes. Similarly, short woody to water, possibly a loss of bank vegetation to erosion, shows a declining trend in structural complexity of vegetation cover.

Magnitude of Change

In all segments for both time periods, the majority of the floodplain surface experienced No Change (Table 2.8). The earlier time period was more dynamic (lower values for no change), as are near-channel areas. Segments with moderately wide floodplains typically showed the lowest No Change values, followed by narrow floodplains.

Table 2.8. Percent area with no change in cover by segment.

				Floodplain									
	CC	**BR**	**KS**	**SC**	**BGD**	**CB**	**BSY**	**BGP**	**UV**	**SF**	**NF**	**SY**	**Avg.**
’40-68	75.8	72.6	88.0	74.2	92.6	91.0	91.6	74.7	89.6	-	-	77.1	**82.7**
’68-00	80.6	80.8	89.1	76.5	92.9	92.4	92.0	76.1	94.8	98.2	88.1	78.0	**86.6**
				Near-Channel									
’40-68	76.8	74.5	77.5	68.3	81.9	75.0	76.8	64.5	61.2	-	-	60.0	**71.7**
’68-00	80.7	83.3	79.5	70.2	80.7	77.8	76.0	65.9	74.3	76.7	58.9	60.8	**73.7**

Transition Pairs

Pairs of transitions were combined for a net change value for any one pairing. For example, if 2% of cover changed from water to bare and 0.5% changed from bare to water, the net change for the Water – Bare (W – B) pairing would be 1.5% water to bare. Figure 2.5 shows the nature and extent of vegetation transitions in the segments experiencing the most change.

With the large number of possible transitions, it was necessary to simplify the data somewhat for graphing and reporting. Transitions with low values were excluded, including Water – Tall Woody (W – TW) and Bare – Tall Woody (B – TW) and

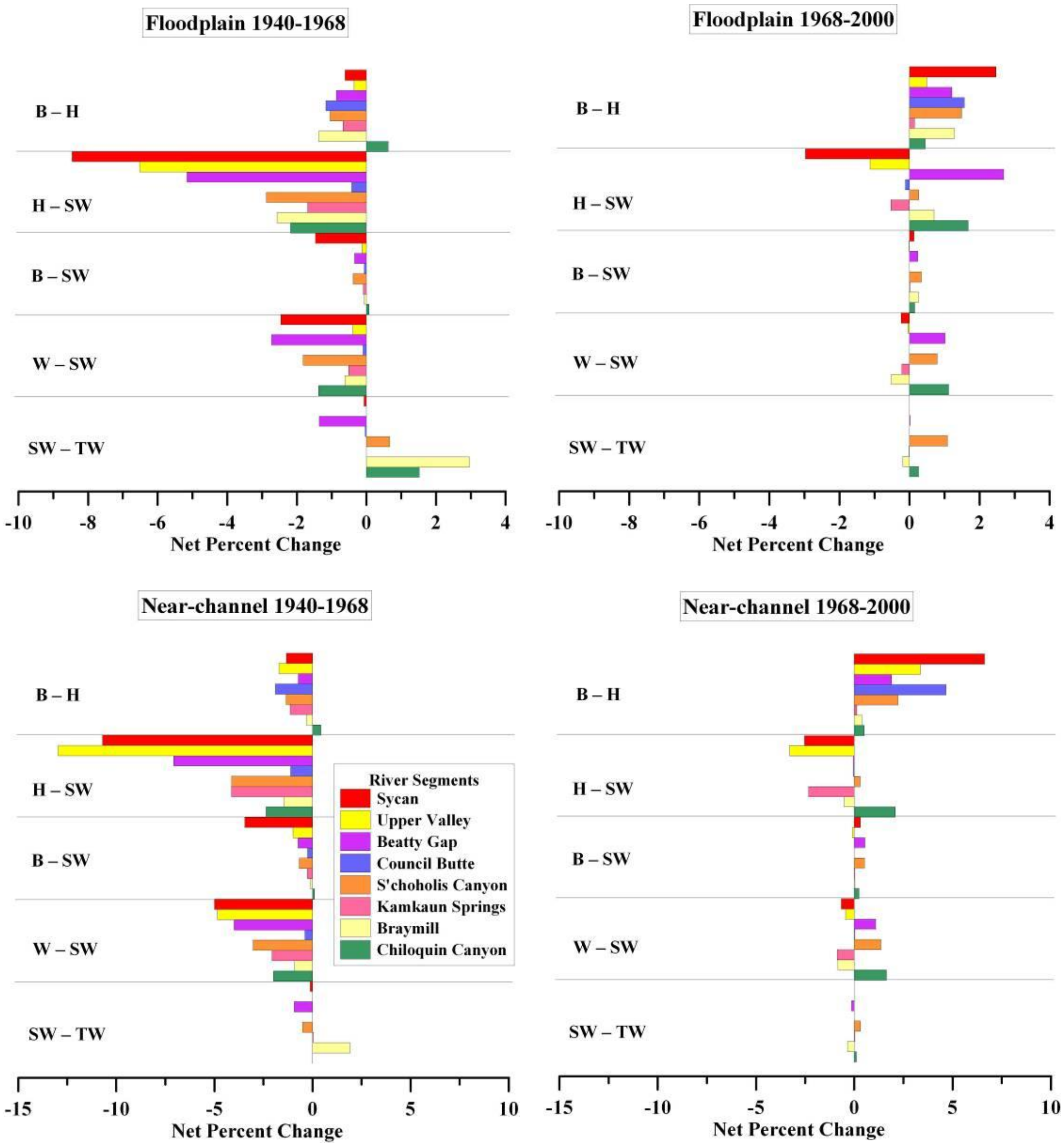


Figure 2.5. Cover type transition. Percent changes in type 1 area and type 2 area and 2 to 1 are summed to get net percent change in area. Bars to left indicate transitions to simpler vegetation structure, and bars to right indicate the reverse. Note the difference in scale of the x-axes between total floodplain near-channel zones graph pairs. Segments are arranged in spatial order from upstream (top) to downstream (bottom).

Herbaceous – Tall Woody (H – TW). Transitions between W – B and B – H, though substantial, were more a reflection of water level changes than ecologically significant indicators and were also excluded.

Some segments were excluded also. The North Fork and South Fork segments were not shown because large portions were not mapped in the 1940s. Buttes of the Gods and Beatty Sycan segments were excluded as their prominent transitions were those related to changing water levels.

Transitions and Riparian Processes

Transitions between bare and herbaceous (B – H) cover reflect colonization/denudation of floodplain surfaces by vegetation that is capable of stabilizing soils. In 1940 - 1968, there was a shift from herbaceous to bare cover, both in near-channel zones and the larger floodplain area (Figure 2.4). In 1968-2000, bare areas tended to shift to herbaceous cover. Bare areas near the channel indicate potential for short woody regeneration, but when exposed to high and sustained grazing pressure, successful colonization by short woody vegetation is unlikely and colonization by herbaceous plants will be slow. Herbaceous communities are dominant in the Sprague basin, and in the absence of heavy grazing or other intensive land use, will aggressively colonize bare surfaces. Increasing herbaceous cover in Lower Chiloquin Canyon 1940-1968 was likely related to the closing of lumber mills that were operating on the floodplain around the time of the 1940s photos.

Transitions between herbaceous (H) and short woody (SW), especially short woody to herbaceous, are common in floodplains used for agriculture. Cattle grazing is known to favor herbaceous over shrub cover, as does active removal of shrubs through mechanical or chemical means. Floods may remove short woody vegetation, but short woody losses are almost as large on the whole floodplain as in the near-channel zone where erosion occurs. This short woody to herbaceous transition showed the greatest change, both on floodplain surfaces and near-channel zones. All segments experienced change from short woody to herbaceous from 1940 to 1968, with a mix of transitions for the later period. The Sycan, Upper Valley and Kamkaun Springs segments continued to lose short woody to herbaceous cover during the later period, on both floodplain and near-channel zones.

Some segments reversed this trend from 1968-2000. Beatty Gap showed the greatest recruitment or expansion of short woody cover on its floodplain, though not in the near-channel zone. The Braymill segment showed expansion of short woody cover on the floodplain but retraction near the channel. Chiloquin Canyon gained considerable area of short woody cover from 1968 to 2000, both on the floodplain and in the near-channel zone.

All segments lost short woody cover (SW) to water (W) during 1940 to 1968. The Sycan, Upper Valley and Kamkaun Springs segments continued to lose short woody to water cover through the 1968 – 2000. Conversion of short woody to water reflects erosion of channel banks and bars, but also, to a smaller but unknown extent, higher water levels in the 1968 photos compared to the 1940 and 2000 photos. Floods that occurred in 1964 and 1997 (discussed below) likely contributed to the loss of short woody cover to water.

During 1968 to 2000, Beatty Gap, S'choholis Canyon and Chiloquin Canyon gained short woody cover from water cover, both on the larger floodplain surfaces and in near-channel zones. Water to short woody transitions were greatest in the moderately wide floodplain segments which tended to have active lateral mobility, channel diversity and prevalent short woody cover. Conversion of water to short woody cover may occur at the primary channel margin in the form of narrowing channels or retreating extent of water, and may also occur on the floodplain within or near other water features such as oxbows, floodplain wetlands or secondary channels.

Transitions between bare (B) and short woody (SW) can indicate a variety of processes. Short woody cover can be removed through stream scour and/or deposition, or through concentrated cattle grazing, road building or other high impact land use. Transitions from bare to short woody occur primarily through recruitment on exposed surfaces or expansion of existing short woody cover into bare areas. The Sycan experienced a moderate loss of short woody to bare (-1.5% of its floodplain area) in 1940-1968. For all other segments and time periods, percentages of transitions with this pairing were minimal.

Short woody (SW) to tall woody transitions (TW) typically represent areas where young trees have grown enough to cross the 6 meter height threshold, though they may also be through stand replacement (e.g. willow to aspen). Short woody to tall woody transitions were most common in Braymill, Chiloquin Canyon and S'choholis Canyon segments for the floodplain surfaces in the earlier period, where tall woody cover was consistently more common. Tall woody to short woody likely reflects a loss of tall woody cover to surrounding shrubs. This has occurred in quaking aspen stands in both

S'choholis Canyon and Beatty Gap that were surrounded by willow. As aspen patches declined, willows expanded, both during the 1940-1968 and 1968 to 2000 intervals.

The greatest transitions seen in this analysis were losses of short woody cover to herbaceous and bare, and changes in bare and herbaceous cover. As in the previous section, changes were greatest in moderately wide segments.

In December of 1964, the Sprague basin experienced a peak flow event (14,900 cfs) that is the highest on record for the Sprague River gauge at Chiloquin, with another high peak flow (10,800 cfs) in January of 1997. These floods had great potential to change many of the transition pairs, especially in the near channel environment. Photographs were taken 4 years and 3 years, respectively, after these large flows, giving ample time for recovery of herbaceous vegetation. That said, vegetative recovery after flood impacts might have been hampered by ongoing cattle grazing.

Discussion and Conclusion

General spatial patterns of vegetation in the Sprague floodplain in 2000 are clearly influenced by basin characteristics and have been the same since government surveys in the 1800s. These patterns of vegetation cover are strongly tied to floodplain width. Woody species prefer narrow floodplains; wide floodplains are strongly dominated by herbaceous cover and have experienced little vegetative change over time. Moderately wide floodplains have a mixed cover of woody and herbaceous cover. Changes to those general patterns over time have likely been driven by livestock use in the basin, similar to other riparian areas in the Intermountain West (Green and Kauffman, 1995; Holland *et al.,*. 2005; Schulz and Leininger, 1990). Conclusions about grazing are not based on numerical grazing data. While grazing is recognized as the primary land use in the basin (Connelly and Lyons, 2007), and was noted as very heavy as early as 1907, detailed records of number of animals and distribution of animals on the floodplain surface were not available. Patches of short woody vegetation (Figure 2.4) became smaller and more fragmented between 1940 and 1968, a pattern consistent with changes due to livestock use. Patches were only rarely cleared wholesale, as would be the case for clearing for haying operations. Fluvial action was not likely a dominant cause of reduction, as patches both near the channel and far from the channel were altered. Short woody cover was lost to herbaceous cover-not to roads, houses, forest or impounded water, and only a small degree to bare ground. Negative impacts of natural events and processes are magnified due to these land uses, and have manifested most strongly in moderately wide floodplains.

Vegetation trended toward less structural complexity between 1940 and 1968 and toward greater structural complexity from 1968 and 2000, though not achieving the level that existed in 1940. Tall woody and herbaceous cover increased from 1940 to 2000. Patches of tall woody cover tended to expand, with herbaceous cover and sometimes short woody cover transitioning to tall woody cover. Short woody cover generally declined from 1940 to 2000. Short woody cover in the 1940s (Figure 2.5) tended to occur in large patches, with no apparent preference for near-channel zones. Patches were considerably smaller and much more fragmented in1968, with many patches disappearing before the 2000 photos. Cover lost to short woody was matched by large increases in herbaceous area.

Broad trends in water cover from 1940 to 2000 show an overall decrease, possibly due to loss of secondary channel features to pasture development, loss of channel length to straightening activities, or water withdrawals for agriculture. Water cover peaks in 1968 due to high water at the time of the 1968 photos as can be seen in Figure 2.5 both as a slightly wider primary channel as well as activated secondary channel features that are either absent (2000) or very small (1940s) in other images. Higher water in 1968 likely covered active bars, essentially masking areas that would have increased already high values for bare ground.

Trends in bare ground reflect grazing pressures and other land uses, as well as fluvial geomorphic processes. Bare ground cover was highest in 1968, four years after the highest event (December 1964), while bare ground cover was considerably less in 2000, only 3 years after the 1997 (January) high flow. Differences in vegetation response following these two large floods may be due to several possible factors: 1) the magnitude of the 1964 flood was great enough to disrupt vegetation cover regardless of its condition prior to the flood; 2) grazing pressure prior to the 1964 flood made channels more susceptible to flood impacts, or; 3) continued grazing pressures after the 1964 flood greatly increased recovery time.

Disease, insects and predation by wildlife occur in the basin. After sustained high water in the spring of 2006, yellow willow stands across much of the basin were infected with a rust fungus during the following growing season. Leaves yellowed and fell mid-season, though re-foliated normally the following spring. A land owner in the upper basin recalled a fungal outbreak following a similar sustained high flow in the previous decade. Predation by beaver and muskrat is prevalent throughout the basin, though highest in patches in the near-channel zone. Isolated shrubs, such as small, occasional patches in the wide floodplain sections, can be very hard hit by beaver predation as use is very concentrated. Over time, these local pressures on shrub growth likely manifest at the level mapped in this effort though the extent is unknown.

The near-channel zone was consistently more dynamic than the larger floodplain surface, and while showing greater variability in cover of water and bare ground, had similar trends in vegetative cover change to the floodplain surface as a whole. The most prominent exceptions to this similarity were the much greater loss of near-channel zone short woody cover in the Upper Valley segment and the lack of increases in tall woody cover in the near-channel zone in the Chiloquin Canyon segment. Slight increases in short woody cover tended to occur due to expansion of existing patches on floodplain surfaces rather than colonization of near-channel zones (Figure 2.5). This lack of colonization of the near-channel zones may be due to higher stresses of soil saturation on lower banks (Chapter III), especially when combined with predation by wildlife, continued grazing pressure and strong occupation by herbaceous species.

The similarity of near-channel and floodplain characteristics and the relative stability of vegetation cover over time suggest that the river is geomorphically and hydrologically stable. Specifically, the active floodplain and vegetated area has not been dewatered by an incised channel, as often happens in wide, alluvial river valleys in the West. Channel dimensions and low values for bare ground in 2000, relative to 1940, suggest that the channel is relatively stable and is not widening, unlike common conditions in degrading, wide-valley channels. Bare ground data from 1968 suggests that while flow events and land uses can negatively impact floodplain and vegetation structural complexity, processes supporting vegetation recovery are intact and exposed soil surfaces will eventually be re-colonized.

This project illustrates the need for an understanding of both basin and land use controls on vegetation patterns prior to implementing restoration projects. The consistent lack of woody vegetation in wide segments and the clear pattern of woody preference for moderate and narrow floodplains should caution against restoration practices that focus on planting woody vegetation in wide floodplain segments. Related research suggests that high ground water may be a factor in discouraging woody germination and persistence (Chapter III). Grazing does not appear to be a primary inhibitor of shrub populations on wide floodplain segments. In wide segments, areas excluded from grazing are aggressively colonized by herbaceous vegetation, not shrubs, and woody stock planted in concert with restoration projects has largely failed. Chances for successful shrub colonization of wide floodplains are low. Shrubs have not been prevalent on wide floodplains since at least the late 1800s and have not aggressively colonized surfaces after disturbances. Projects designed to restore herbaceous cover will be working in concert with the general trends of wide floodplain cover.

Floodplain segments with moderate widths are probably the best candidates for woody vegetation restoration as many hectares have been lost since the 1940s and short woody cover is presently increasing, but at a slower rate than desired. Restoration efforts in moderately wide floodplains should include adoption of grazing strategies that encourage vigorous shrub recruitment and growth.

A review of similar mapping studies of Western rivers shows that the small magnitude of floodplain change in the Sprague basin was novel. Other stream systems experienced much more variation over time due to natural channel movement with flood events, but also urban development, dams, levees, water diversion and invasive species (Tetra Tech, 2004; Thatcher *et al.*, 2008; Stillwater Sciences, 2007).

This study has shown the general patterns of vegetation cover changes in the Sprague Basin. Restoration of riparian areas in any basin is about capitalizing on ecological momentum by recognizing, encouraging and mimicking trends that are already occurring. Projects that take advantage of intact biogeomorphic processes and favorable environmental settings have a greater chance of success.

CHAPTER III

SOIL MOISTURE, TEXTURE AND TOPOGRAPHY AS CONTROLS OF SHRUB DISTRIBUTION IN THE SPRAGUE BASIN

Introduction

In semi-arid ecosystems, distribution of riparian vegetation between the water's edge and upland communities is primarily controlled by processes related to the presence, absence and movement of water. Degree of drought tolerance determines the upper spatial boundaries of species in riparian areas (Castelli *et al*., 2000; Stella and Battles, 2010), often through high rates of ground water recession (Mahoney and Rood, 1998; Amlin and Rood, 2002). The lower boundaries of shrub distributions may be defined by soil saturation and oxygen stress (Nakai *et al*., 2009; Castelli *et al*., 2000; Li *et al*., 2006; Rodriguez-Gonzales *et al*., 2010), though that stress may be moderated by movement of water through coarser textured soils (Nakai *et al*., 2009). Movement of water through coarser soil textures refreshes oxygen supplies to plant roots. Vegetation can also be removed or excluded through scour and burial (Loheide and Booth, 2011), or a by combination of factors (Hupp and Osterkamp, 1996; Bornette *et al*., 2008; Hughes, 1997; Karrenberg *et al.*, 2002).

Most research on riparian shrubs and soil moisture has focused on the upper boundaries (local elevation above the channel or water table) of shrub tolerance using the measurement of water table recession (increasing depth to ground water). It is possible to formulate a general view of water table dynamics over the growing season using shallow monitoring wells or piezometers in any soil texture. However, the relationship between water table depth and moisture available to plants will be considerably different in coarse and fine soils. The capillary zone in riparian soils can range from 5 to 130 cm above the water table depending on soil texture (Mahoney and Rood, 1998). In riparian areas with a mixture of coarse and fine textured soils, such as the Sprague Basin, investigations based solely on water table depth are less reliable for predicting shrub survival than direct measurements of soil moisture.

This study focuses on changes in soil moisture over the course of the summer and the saturation tolerance of shrubs. Direct measurement of soil moisture provides greater accuracy than piezometer studies in predicting favorable habitat for restoration and recovery of shrubs. This level of resolution requires an understanding of soil moisture, texture and topographic characteristics that are known to affect germination and persistence of riparian shrubs (Karrenberg *et al.*, 2002). Specific questions addressed are: 1) how does soil moisture in the Sprague relate to soil texture and the height above the water table, and 2) how does shrub abundance relate to soil moisture, texture, and recession rates?

Literature on willows suggests that recession rates greater than 2 cm per day (Amlin and Rood, 2002) may be problematic for survival of seedlings, exceeding growth rates of roots and depriving plants of needed moisture during the summer dry season. These results show that shrub populations prefer greater recession rates in fine soils. Soil coarseness, a dominant control of water movement in the soil, varies considerably with local topography (Chapter IV). Thus, local topography controls soil texture and access to moisture. Texture controls shrub distribution by moderating water and oxygen movement through soil grains (Nakai *et al.,* 2009; Li *et al*., 2006).

Methods

Soil moisture data were collected on a subset of transects (Chapter IV) on the Sycan and Sprague Rivers (Figure 3.1) during summer seasons of 2007 and 2008 to document the amount of moisture available to vegetation and to determine if rapidly declining water tables were responsible for the scarcity of shrubs in certain segments.

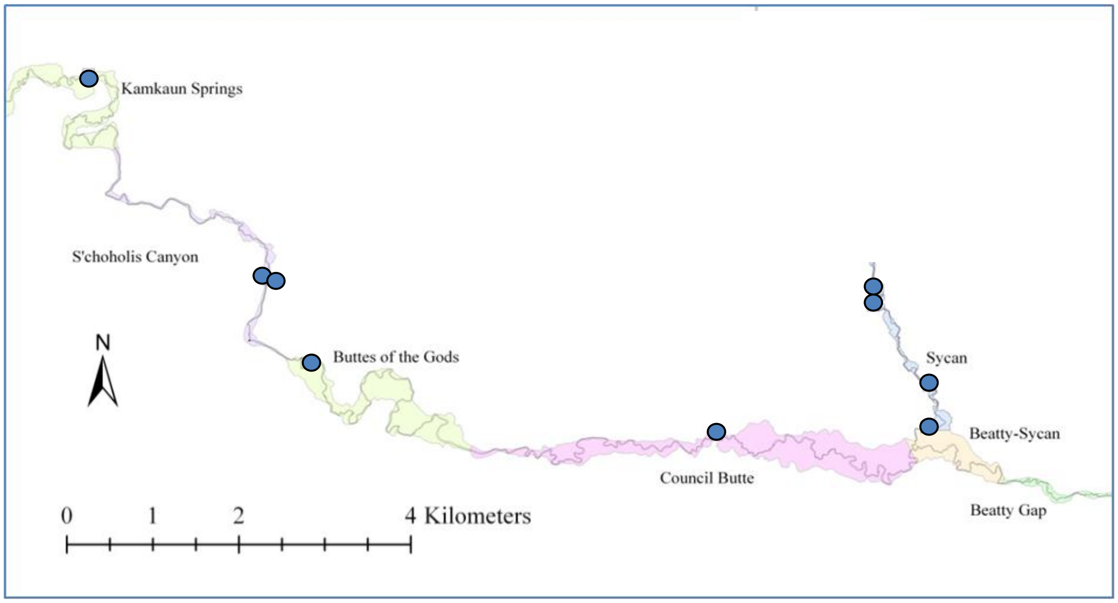


Figure 3.1. Locations of soil moisture transects

Watermark Soil Moisture Sensors (Model 200SS) provided season-long measurement of soil moisture. Each 2.5 x 4.5 cm sensor consisted of a granular matrix wrapped in perforated stainless steel with wires extending between a recording meter and electrodes embedded in the sensor. Moisture within the granular matrix equilibrated with surrounding soil, slowly dissolving a gypsum wafer near the electrodes. Electrical resistance between the electrodes increased with decreasing moisture. Sensors functioned in the soil for several years before degrading, unlike similar solid gypsum block sensors.

Granular matrix sensors can provide continuous readings at several depths simultaneously and for an extended time (Shock *et al.*, 2005).

Fourteen clusters of sensors (Figure 3.2) were placed on nine riparian transects (Chapter IV). A maximum of four sensors made up each cluster at depths of 20, 40, 70 and 110 cm. Associated ground water changes were monitored with piezometers placed within 1 meter of each cluster. Clusters placed near the channel in a very shallow water table had only two sensors (20 and 40 cm depth). Resistant substrate occasionally determined the depth of the deepest sensor. Each data logger was housed in an irrigation valve box set into the ground. Watermark Monitor (Model 900M) data loggers recorded soil moisture tension twice daily from mid-June to mid-September.

Piezometers were read manually once per month. During the 2007 season, 47 sensors produced data from 14 clusters. The 2008 season had only 31 successful sensor records from 9 clusters due to data logger failures, retrieval issues and removal of one cluster due to an impending bank stabilization project. Piezometers, with perforations only on the bottom of pipe length, were appropriate for nearly all of the clusters measured as there was no evidence of artesian flow or aquacludes that modified ground water pressure. Shallow wells with perforations along the entire pipe length might have been more appropriate for one cluster on the Sycan where lateral ground movements saturated high banks for the width of the site with water weeping from the whole bank (Richardson *et al*., 2001). Soil moisture sensors in this cluster were saturated at every depth for the duration of the season, so impacts to results were minimal.

The soil moisture measurement equipment used in the study is most often employed in irrigated agricultural settings to maintain sufficient, but not excessive, moisture. Soil sensors read soil moisture tension (SMT), or the negative pressure required to pull moisture away from soil particles, expressed in kilopascals. SMT thresholds from the manufacturer (Table 3.1) and a research group from Oregon State University (Shock *et al*., 2005) were used in analysis of SMT values.

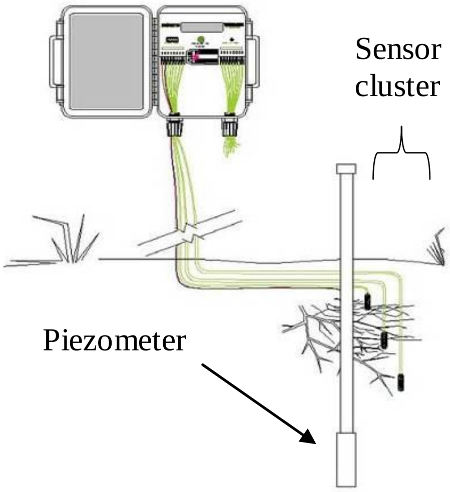


Figure 3.2. Illustration of soil moisture cluster with data logger (top) and piezometer. Image from the manufacturer, (www.irrometer.com, accessed 2-18-09)

Table 3.1. Manufacturer's soil moisture thresholds (Irrometer.com)

Soil Water Tension (kPa)	**Moisture threshold**
Less than -100	Dry
-30 to -60	Usual range for irrigation (most soils)
-10 to -30	Adequately wet for most soils (coarse sand soils beginning to lose water)
-0 to -10	Soil saturation

Analysis

The program "R" was used for linear regression and/or analysis of variance to analyze dryness and shrub data. The absolute values of soil dryness were square root transformed to increase normality, as were the number of shrubs per cluster. Variables are described below.

1) SMT daily values were averaged for 30-day increments: mid-June to mid-July (days 0-30, early summer); mid-July to mid-August (days 30-60, midsummer); mid-August to mid-September (days 60-90, late summer). SMT from midsummer was compared to shrub abundance, as that period represents a critical time for germinating seedlings. SMT values at the 40 cm depth are used for several comparisons as they are below the quick-drying surface soils and typically above the influence of ground water. The higher the SMT value, the drier the soil, with a maximum instrument reading in this study of 240 cb.
2) Number of individual shrubs were counted (abundance) within two meters of a sensor cluster. Each cluster has only one associated shrub count used for both 2007 and 2008 SMT values.
3) Soil texture, as it is used here, is a generalization of soil texture classes derived from hand texture analysis performed in the field (Huddleston and Kling, 1996). Texture classes were grouped into categories of coarse or fine, depending on the relative dominance of sand observed in the sample. Texture classes that specify sand were considered coarse (e.g. sandy loam or sandy silt). Texture classes of loam and finer, with no specified sandy component, were considered fine (e.g. loamy silt, silt, loam). The small sample size of

sensors and the diversity of texture classes made grouping into coarse and fine soils necessary. Soil texture data for the 110 cm depths were not available, as they were beyond the reach of the probe auger used.

4) Water table depth is the distance between the surface of the soil and standing water in each piezometer, as measured monthly during the 2007 and 2008 seasons. Piezometer levels fluctuated with natural flow recession, precipitation events, and irrigation activities, and they were averaged for each season.

5) Height above water table (HTWT) is the distance between each soil moisture probe and the average water table depth for the season. HTWT is a surrogate for topography, and does not account for horizontal distance to the channel. R-value (correlation coefficient) of a comparison between HTWT and height over the interior riparian vegetation edge (description in Chapter IV) was 0.93, after excluding one cluster with strong sub-irrigation effects (with sub-irrigation cluster, R-squared value was 0.75).

6) Recession rate, the rate of downward movement of soil moisture in the profile as the summer progresses, is measured in centimeters per day. It is calculated from the time difference in drying out of one sensor and the next deeper sensor in the cluster. Recession rate is based on a SMT threshold of -20 kPa, which is drier than saturation but with abundant available moisture (Irrometer, Co., Riverside, CA). The ground water recession rate was calculated by dividing the vertical distance between sensors (20 cm) by the number of day's difference between the -20 kPa thresholds of sensors. Recession rate based on

> a saturation value (0 to -10 kPa) would have been more consistent with research using water table recession, but many sensors at 20 cm depths were not saturated at the beginning of measurements, making that comparison difficult.

Results

Soil Moisture, Texture, and Relation to Water Table (HTWT)

Sensors, set at four different depths in the soil profile, detected drying effects from the surface and wetting effects of ground water (Figure 3.3). The shallowest sensors (20 cm) were the first to dry out in response to evaporation and transpiration. They were also the first to respond to significant precipitation events. Sensors at 70 and 110 cm experienced slower drying with many maintaining saturation for the duration of the season. In a combined model (HTWT and texture), late summer SMT values are strongly related to HTWT (p-value <0.000), but not to soil texture (p-value = 0.15, linear regression and analysis of variance). However, a model with texture alone (Figure 3.4) shows that finer soils experienced considerably greater drying (p-value <0.001, linear regression) than coarse soils. This disparity of significance between the two models shows that topographic position controls HTWT, SMT and soil texture. Height above water table (HTWT) and soil texture controls soil moisture.

The shallowest sensors (20 cm) recorded the broadest range of SMT values and were occasionally rewetted by irrigation effects or precipitation. By late summer, SMT values from 12 of 23 sensors at 20 cm depth had crossed the threshold of dry (-100 cb), while nine showed available moisture. Of the sensors at 40 cm depth, five of 23 were dry in late summer and seven were saturated. Nearly all deeper sensors (70 and 110 cm) showed available moisture in the late summer. Most clusters with saturation at 20 cm depth were on the Sycan River where sub-irrigation from both agricultural activities and floodplain springs was common. The single Sprague mainstem cluster with saturation at 20 cm depth was on the wide floodplain reach of the Council Butte segment. Only three of the 29 sensors in coarse soils had SMT values lower than -30 kPa (Figure 3.4), despite their greater potential for drying.

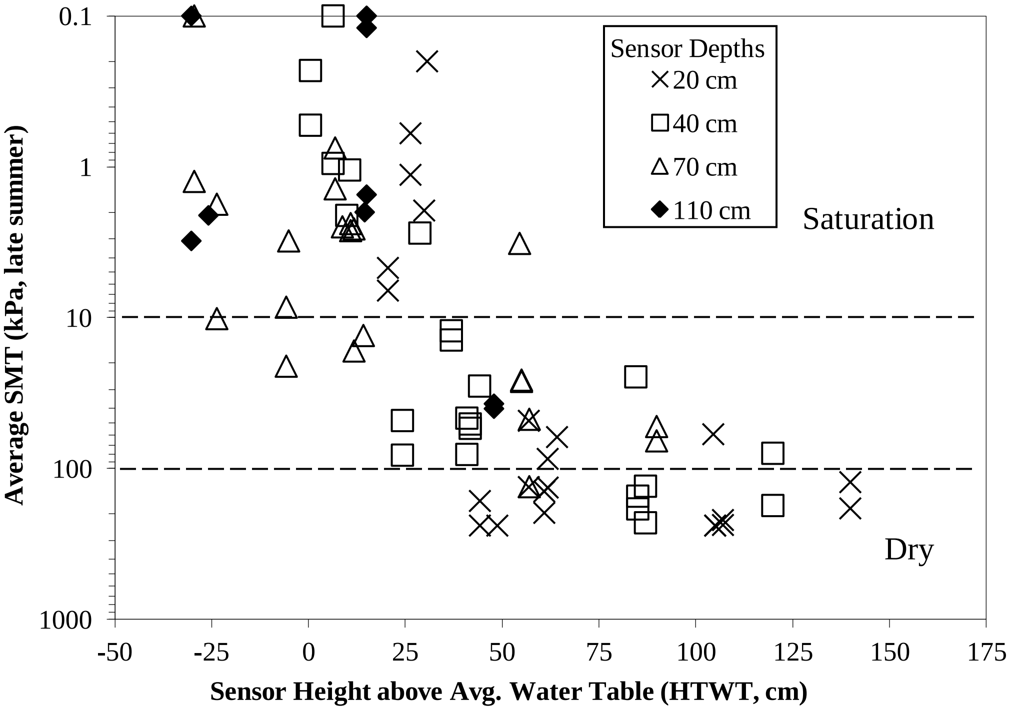


Figure 3.3. Average SMT (kPa) in late summer and HTWT (cm) by sensor depth, with thresholds from the manufacturer (Irrometer.com). SMT values are plotted as absolute values plus a constant of -0.10 kPa to allow for log scale graphing. For 2007, piezometer readings changed between 23 and 31 cm. The 2008 season was more dynamic, with differences in readings ranging from 20 to 57 cm.

Water was available in all sensors in the early summer, with all sensors reading greater than -100 kPa. During midsummer, many of the shallower sensors were dry (SMT less than -100 kPa), but water was generally available at the deeper sensors. Coarse soils experienced little drying throughout the season, due to their proximity to the water table and influence of sub-irrigation.

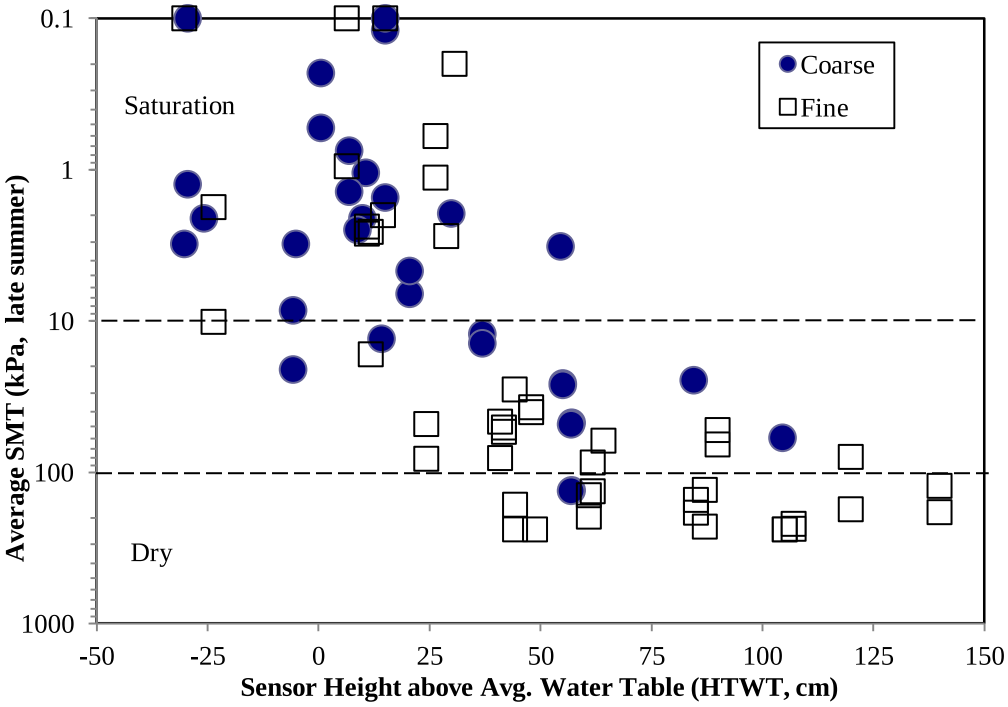


Figure 3.4. Average SMT (cb) during late summer and HTWT (cm) by soil texture. SMT values are plotted as absolute values plus a constant of -0.10 kPa to allow for log scale graphing. Deepest sensors (110 cm) did not have texture data are not included on the graph.

Shrub Abundance, Soil Moisture Tension (SMT), and Texture at 40 cm

As seen in the previous section, sensors at 40 cm depth were less exposed to surface drying and re-wetting and less affected by ground water fluctuations than deeper sensors. In this section, shrub abundance was compared to SMT values at 40 cm during midsummer when seedlings are most vulnerable to declining water availability (Figure 3.5).

Analysis of variance shows soil texture at 40 cm to be a significant control on shrubs (p-value of 0.05), though average SMT values of coarse and fine soils at either midsummer or late summer were not significant. Clusters with fine soils at 40 cm depth typically had lower shrub numbers than coarse soils, especially where moisture values show very wet or saturated conditions. Fine soils at 40 cm are generally found on the Sprague, while most coarse soils at 40 cm are found on the Sycan. Coarse soils, especially those near the channel edge, are assumed to have a greater exposure to deposition and scour. Fine soils, indicating less dynamic fluvial processes, are expected to be less susceptible to scour and burial. Within the range of SMT values and soil textures encountered in sampled riparian areas, soil texture appeared to control shrub abundance while availability of soil moisture did not. There was available soil moisture within or close to the shrub root zone throughout the summer. This analysis reflects the number of shrubs near a cluster (sometimes very small and unlikely to persist), and may show a different relationship with biomass rather than shrub abundance.

Shrub Abundance, Recession Rate and Fine Soils

It was possible to calculate soil moisture recession rates between sensors at 20 and 40 cm depths and occasionally between 40 and 70 cm depths in the drier clusters. Many of the clusters with coarser soils were located near the channel (high water table) or on the Sycan River (frequent sub-irrigation) and maintained saturated conditions near the surface of the soil. For that reason, ground water recession rates were calculable only

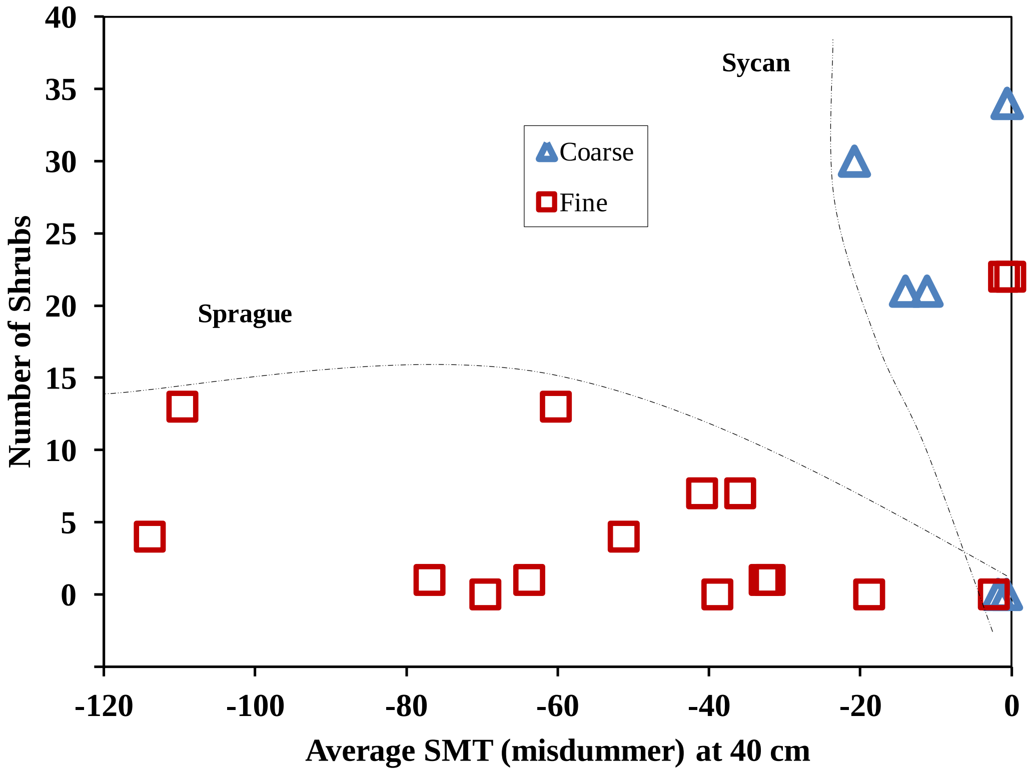


Figure 3.5. Average SMT values (cb, at 40 cm) in midsummer and number of shrubs (within 2 m of a cluster) by soil texture. Dashed lines represent envelopes of Sprague and Sycan sampling clusters. Water table depths and SMT values were taken for each piezometer and sensor during each monitoring season and have unique values for 2007 and 2008. Each cluster had one shrub count that was used for 2007 and 2008.

on eight of the fourteen clusters, all of which were located on the Sprague mainstem and had fine soils at 40 cm depth.

Recession rates ranged from 0.4 to 2.5 cm per day between sensors at 20 and 40 cm depths. Five clusters had calculable recession rates on sensors at 40 and 70 cm depths. Ground water recession rates in the deeper sensors were uniformly slower than rates of adjacent 20-40 cm rates, and none exceeded 1.5 cm per day.

Shrub abundance in fine soils of the Sprague was favored on sites with higher recession rates (Figure 3.6), contrary to the recession literature (Amlin and Rood, 2002), though the small sample size (n = 9) prohibits drawing a strong conclusion. Lack of soil water recession, rather than soil drying, may be limiting shrub abundance in these habitats. However, saturated coarse soils in the Sycan clearly support large numbers of shrubs (Figure 3.5). This suggests that soil texture controls shrub abundance.

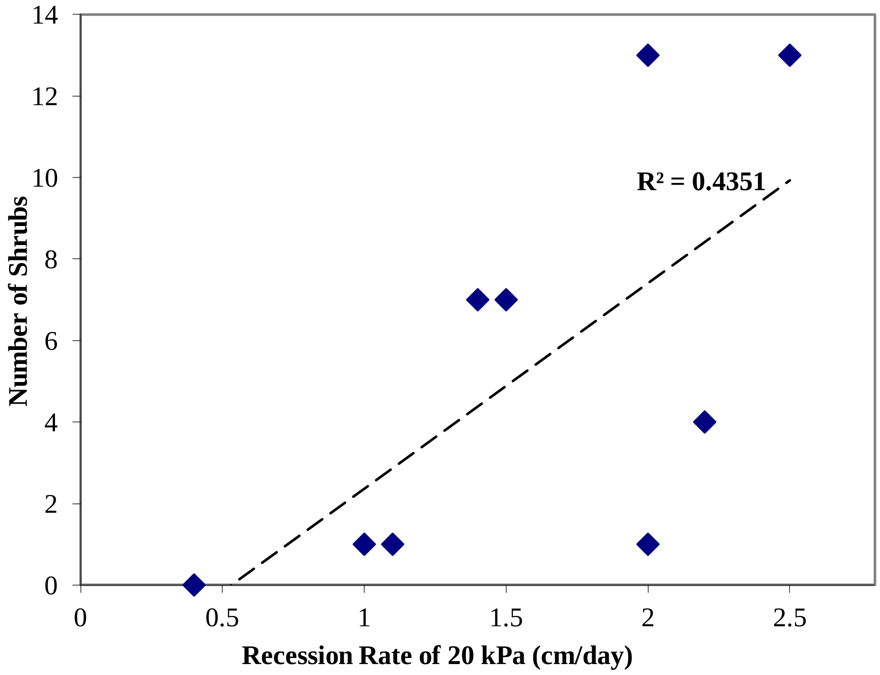


Figure 3.6. Centimeter per day recession rates of 20 kPa threshold and the number of shrubs within 2 meters of the cluster. All values shown are from fine sediment clusters on the Sprague mainstem. Clusters not shown had no ground water recession between 20 and 40cm depths.

Conclusions

In the Sprague basin, topographic position controls soil coarseness and access to soil moisture. Soil coarseness appears to control shrub abundance in habitats with readily available moisture or saturated soils; in saturated conditions, shrubs prefer coarse textures. Data suggest that faster rates of ground water recession encourage shrub abundance in fine soils. Lack of moisture is not a limiting factor for shrub distribution within the Sprague basin riparian areas, in contrast to the results from other studies in the western U.S. Coarse soils near the channel maintain moisture due to topographic position; fine soils farther from the channel have a greater capacity to hold moisture and sustain shrub growth.

These results suggest that availability of oxygen is a fundamental control of shrub abundance in the Sprague Basin, as moderated by soil coarseness and soil moisture (Li *et al*., 2006; Karrenberg *et al*., 2002; Nakai *et al*., 2009; Castelli *et al*., 2000). In coarse moist soils, more rapid flow of soil moisture tends to keep oxygen levels higher than in fine moist soils. Coarseness and moisture, as they vary across riparian habitats, determine potential for shrub recruitment and persistence.

These findings have implications to natural recovery of shrubs in the Sprague Basin. Habitats with coarse soils and readily available moisture represent the best opportunity for germination and initial survival of shrub seedlings. Coarse soils suggest higher fluvial activity and availability of sites free from competing vegetation, but also higher exposure to scour and burial. Potential for recruitment is high, but combination of hazards suggests lower potential for long term persistence. Sub-irrigated, high-bank habitats on portions of the Sycan are more favorable due to abundant moisture and oxygen, without the channel related hazards, and are more likely to support shrubs long term.

Habitats with fine soils and abundant moisture (low recession rates) represent poor potential for shrub recruitment and persistence due to oxygen stress. These habitats are found in the majority of the Sprague mainstem having wide floodplains. Shrub recruitment may occur in these habitats, but long term persistence is unlikely.

Habitats with coarse soils and low available moisture are also likely to have poor potential for shrubs, mainly due to very high recession rates and of mobility of soil. Coarse soils with low water availability are typically somewhat removed from the channel either in horizontal or vertical distance, often on such features (in the Sprague basin and other rivers) such as high sand bars or coarse-grained terraces. Such habitats were not sampled in this effort and are typically occupied by early seral upland vegetation.

Habitats with fine soils and lower available moisture (higher recession rates) have the best potential for long-lived shrub populations, if in somewhat lower numbers. These habitats are typically higher above the channel and more isolated from channel related hazards of scour, burial and saturation. Opportunities for germination are more limited because of reduced hydrochory (placement of seedlings by water; Stella *et al*., 2006) and density of existing vegetation. However, successful seedlings are more likely to persist.

Direct measurement of soil moisture offers an advantage over traditional means of assessing ground water recession rates by accounting for variability in soil coarseness often found in riparian zones. Soils with finer textures are likely to have lower recession rates than soils with coarser textures, making comparisons across soil types difficult.

While this approach has promise, more resolution is needed on actual wilting points for riparian shrubs in common soil texture classes and more distinct thresholds for water availability.

Topography, and its relation to moisture availability, control other influences on shrubs such as competing vegetation on seedling sites (Bendix and Hupp, 2000) or potential for predation by rodents (Barnes and Mallick, 2001). Both of these factors have considerable impacts on shrubs in the Sprague Basin and warrant further study. Also, the frequency of compatible timing of surface moisture and shrub seedling dispersal (Stella *et al*., 2006; Merritt and Wohl, 2002; Cooper *et al*., 2003) is fundamental for recovering riparian areas and is unknown for the Sprague Basin. The following chapter explores a variety of factors that may influence the distribution and abundance of shrubs in addition to those discussed in this chapter.

CHAPTER IV

FACTORS CONTROLLING DISTRIBUTION OF SHRUBS IN THE SPRAGUE BASIN: PREDICTING NATURAL RECOVERY POTENTIAL AND SUITABILITY FOR SHRUB RESTORATION

Introduction

Shrub distribution in riparian communities is influenced by a variety of factors, some varying at the basin scale and others locally. Favorable sites for shrubs and enduring shrub communities are often influenced by stream scour and deposition (Gurnell *et al.,* 2008), saturation and drought (Chapin *et al.*, 2002; Cordes *et al.*, 1997; Leyer, 2005; Pezeshki *et al.,* 2007; Amlin and Rood 2002; van Eck *et al.*, 2006), movement of soil water (Nakai *et al.,* 2009), soil texture (Pezeshki *et al.,* 2007; Bhattacharjee *et al.,* 2008), timing of seed release (Stella *et al.,* 2006), or grazing (Shultz and Leininger, 1990; Holland *et al.,* 2005; and Green and Kauffman, 1995). Basin characteristics such as floodplain width and channel slope also play a role (Merrill *et al.,* 2006; Hupp and Osterkamp, 1996), with a different hierarchy of factors for different locations.

If it can be clearly shown which factors influence shrub distribution, then it should be possible to determine the most favorable areas for shrub habitat, and utilize that information, as well as historic conditions, to guide restoration activities. It is also critical to know where *not* to plant, because of unfavorable conditions (van Eck, 2006; Chapin *et al.,* 2002), or high potential for natural recovery.

Herbaceous vegetation often appears as a distinct band that runs parallel to the stream bank in response to these upper and lower tolerances for flooding and drought (van Eck *et al.*, 2006; Leyer, 2005; Pezeshki *et al.*, 2007), especially when flooding occurs during the summer season (Henszey *et al.*,2004). Inundation from irrigation water and natural sources mimics flooding from precipitation events and occurs at the summer peak of vegetation growth (van Eck, 2006). Saturation presents a challenge for many species depending on soil texture and movement of water (Nakai *et al.*, 2009).

Shrubs moderate water quality for threatened and endangered fish in the Upper Klamath Basin with shade and stream bank stability (Green and Kauffman, 1995). Wider floodplains have had historically low shrub populations (Chapter 2 of this dissertation), and are currently the focus of restoration activities due to endangered fish habitat concerns (Connelly and Lyons, 2005).

In narrow and moderately wide floodplains of the Sprague Basin, on the other hand, shrub populations are lower than they were historically (Chapter II), primarily due to grazing (Shultz and Leininger, 1990; Holland *et al.*, 2005; and Green and Kauffman, 1995), and agricultural activities that disfavor or actively remove shrubs from stream banks and floodplains (Stern, 1965; Connolly and Lyons, 2005).

There are few studies involving the Sprague Basin that link vegetation preferences to field conditions for guiding restoration projects, especially riparian shrubs. An exception is the work of Chapin *et al.*, (2002) on flood frequencies, i.e. the rate of occurrence and height of seasonal overbank flooding that supports the upper extent of riparian communities.

This study evaluates the relative importance of factors controlling shrub distributions on 74 riparian transects surveyed in the Sprague Basin. Recommendations are made for identification of habitats in the Sprague Basin that are more likely to recover naturally and those where germination or persistence is unlikely.

First, basin level factors and those that vary by transect are examined, followed by factors within transects, both from the perspective of points on transects and individual shrubs. And finally, a synthesis of factors shows how those factors may determine natural recovery potential for shrubs and suitability for the planting of woody species.

Methods

Field Surveys

Basin Geography

Floodplain width was measured from ArcGIS coverage used in Chapter II. Floodplain slope of river segments was derived from the same coverage. Floodplain width, often varying with floodplain slope, is a strong control of vegetation patterns (Chapter II). Channel slopes, as opposed to floodplain slopes, were not used due to irregularities in the topographic coverage near the channel.

Transects

Transect sites were chosen based on restoration projects sponsored by the Natural Resources Conservation Service, the US Fish and Wildlife Service, the Upper Klamath Watershed council, or through landowner connections related to an ongoing University of

Oregon geomorphology study. Additional sites were added on public property (US Forest Service, Klamath County).

All transects surveyed (Figure 4.1) were on the main valley floor of the Sprague and Sycan Rivers. Seventy-four transects were surveyed on 17 separate properties, with measurements taken from late-July to mid-August. Transects were placed adjacent to the primary channel and on depositional banks having gentle to moderate slopes. Cutbanks and very narrow riparian areas were avoided as they support very few shrubs and did not clearly display the soil differentiation and hydrologic gradients needed for this study. Transects were placed to represent typical community structure and abundance of shrubs.

Transect data were collected during the summer seasons of 2006 and 2007. Transect surveys included assessment of riparian topography, soil characteristics, hydrology, and general characteristics of the riparian plant community. Locations were recorded by Geographic Positioning System (GPS) using a Trimble Geoexplorer, and GPS data were post-processed to achieve accuracy of ±0.5 m. Transects were placed perpendicular to the channel (Figure 4.2), beginning at the inner edge of riparian vegetation (often within the wetted channel) and extending to communities occupied by dry upland grasses and/or sage brush. An auto-level was used to measure elevation at 1 meter increments along each transect, at gradient breaks, and the edge of the wetted channel. All elevations were recorded as meters above the ground or channel bed at the lowest rooted, vascular, riparian vegetation present at the time of survey (height above vegetation edge). Basing measurement at the vegetation edge was judged to be a more stable basis for local elevation than channel stage height, as stage height varied considerably over the course of the summer season due to precipitation and irrigation.

Figure 4.1. Locations of transects.

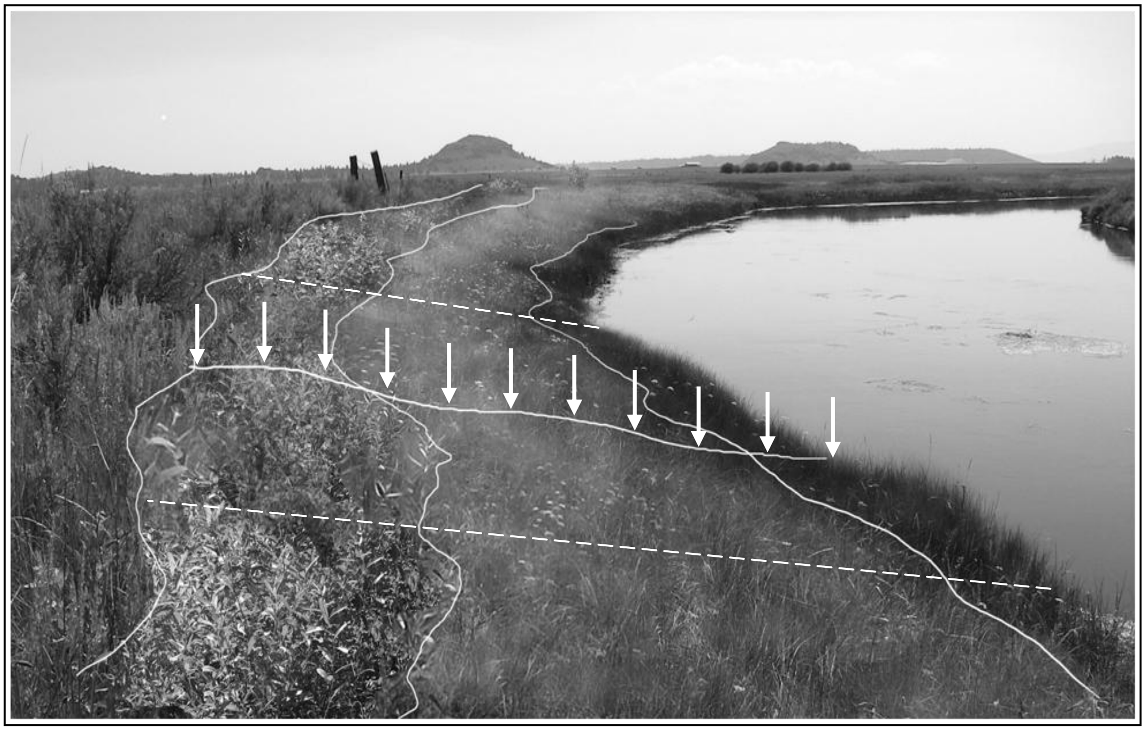


Figure 4.2. Schematic of transect survey. Vertical arrows mark topographic and soil survey points. Lines parallel to the channel delineate vegetation bands. Any shrubs within the dashed lines were inventoried. (Photo art by Clara Rasmussen)

Herbaceous Vegetation – Bands and Vegetation Moisture Class

Herbaceous vegetation community types were divided into bands based on dominant species and ground cover, moving outward from the channel and within 0.5 meter from the transect line. Dominant species were recorded in declining order by ocular estimate, indicating when dominance was shared. Bands were categorized as to their vegetation moisture class:

- **hydric** (supporting mostly riparian obligate, saturated vegetation [Cowardin, 1979]),
- **mesic** (supporting a mix of facultative wet riparian species), or,

- **xeric** (facultative riparian species - often a mix of upland herbaceous species, still-green pasture grasses with greater access to water).

Reed canary grass (*Phalaris arundinacea*, RCG), a common, aggressive species, was specifically reported wherever it was observed. RCG influence was categorized for each riparian band as: 'not present', 'present but not dominating', or 'dominating'. To be called dominating, RCG had to be listed either first or second on the vegetative band description.

Shrubs

Woody species were recorded in a belt transect, 6 meters wide, centered on the herbaceous transect (Figure 4.2). Any woody species found within 3 meters upstream or downstream of the transect line were identified as to genus, measured for elevation and distance from the inner vegetation edge, classified as to age class and height (Table 4.1), and inspected for condition (e.g. evidence of browse, insect damage, disease, etc.).

Table 4.1. Stem classes used (Winward, 2000).

Sprout	1 stem
Young	2-10 stems
Mature	10+ stems, >½ of stems alive
Decadent	10+ stems, < ½ of stems alive

Height classes were: <1m, 1-2m, 2-4m, 4-6m and >6m. Several species of willow, currant, rose and spirea were inventoried on transects (Table 4.2). Aspen, cottonwood (*Populus* sp.) and ponderosa pine (*Pinus ponderosa*) occurred occasionally on floodplains in moderately wide and narrow valleys, but were beyond the outside boundary of all transects.

Table 4.2. Riparian woody species encountered on floodplain or riparian surfaces.

Species	**Common name**
Salix lasiandra	Pacific, whiplash willow
Salix geyeriana	Geyer’s willow
Salix boothii	Booth willow
Salix exigua	Coyote willow
Salix lutea	Yellow
Rosa woodsii	Wild Rose
Ribes sp.	Currant
Spirea	Spirea, hardhack

Soils

Soils immediately adjacent to the water’s edge, as measured here, often bear little resemblance to the characteristics of the larger mapped floodplain extent. Features that would have reflected floodplain soils (cutbanks and banks on outside curves) were actively avoided during site selection for transect surveys. Transects were typically placed on recent stream deposits with moderate slopes either on inside bends or relatively straight segments of stream.

Soil characteristics were assessed along the transect line, typically at one meter increments. Cores 2.5 cm in diameter were taken to 70 cm maximum depth with each layer documented for depth in the profile, thickness, texture class, layering and moisture (Huddleson and Kling, 1996).

Land Use

Land uses were documented on each transect for both the riparian area and adjacent pastures. The most common uses were grazing and irrigated agriculture. Also documented were the type of irrigation in adjacent fields and nearby water features such as floodplain springs or ponds that could potentially influence the riparian transects through subsurface water flow. Current grazing evidence was categorized as follows:

- NE – no evidence of current grazing pressure. No evidence of grazing (herbaceous or woody) by cattle, and no trampling damage or trails. A few dung piles and individual hoof prints were sometimes observed. This category often included pastures that were dormant season grazed, i.e. browsing and grazing was masked by current year's growth.
- LM – light to moderate grazing pressure. Vegetation is grazed, but the majority of the plant remains. No (or minimal) trampling damage to banks is observed and no cattle trails.
- MH – moderate to heavy grazing pressure. Vegetation is grazed, with the majority of palatable plants heavily grazed. Trampling damage is considerable and cattle trails within the riparian area are obvious.
- H – heavy grazing pressure. Vegetation is heavily grazed, broken and/or trampled. Banks and riparian surfaces are heavily damaged by hoof action.

Sub-irrigation

Many transects were sub-irrigated either from water features on the floodplain (springs, wetlands or irrigation ponds) or from irrigation activities in adjacent pastures (sprinklers, flood irrigation). Sub-irrigation was coded as present or absent for the purposes of this study. Areas impacted by sub-irrigation were sometimes saturated, other times just wet, and were not regularly distributed over transects. Sub-irrigation due to agricultural uses was also variable over time, as water was routed from pasture to pasture.

Analysis

The goal of the data analysis was to relate vegetation characteristics to controlling factors such as moisture conditions, soil texture, topography, management, etc. Data were analyzed in three formats: 1) at the level of transects, 2) on the basis of individual points on the transect, and 3) from the perspective of individual shrubs and groups of shrubs (genus, height class, stem class). Factors that were autogenic (based on biotic interactions), allogenic (based on abiotic interactions) and those due to management were not separated (Francis 2006) during analysis. The analysis was not based on the species of individual plants, but the physiognomy or structure and function of groups of plants. Factors documented in this effort can be arranged hierarchically, beginning with the broadest basin controls and moving to finer local controls. Table 4.3 shows the list of measured and calculated variables grouped by spatial scale.

Basin and Transect Level Data Set

Summary data for each transect (i.e. total shrubs, total height, transect length, bare ground, dominant soil type, river distance, floodplain width, etc.) were analyzed with a generalized additive model (GAM) to determine the strongest basin and transect scale controls on shrub distributions (Hastie, 2011). GAM was appropriate due to non-linear relationships of predictor variables and interrelationships between variables. The 'R' statistical package was used (R Development Core Team, 2011). The response variable for this analysis was shrub biomass density which was calculated by multiplying shrub height and shrub stem class for each shrub, summing the values for each area

Table 4.3. Variables used in analysis. See text for explanation of variables and scales of analysis.

Between transects	**Varies by:**
Basin (River)	
Segment	
Segment slope*	Segment
Floodplain width	Transect
Transect	
Dominant soil texture of transect	Transect
Soil category of transect (fine or coarse)	Transect
Grazing	Transect
Sub-irrigation	Transect
Average bare ground	Transect
Average reed canary grass presence	Transect
Number of bands	Transect
Total number of shrubs	Transect
Total shrub biomass*	Transect
Total shrub biomass density*	Transect
Within transect	
Vegetation moisture class	Band
Bare ground	Band
Reed canary grass presence code	Band
Height above vegetation edge (and %*)	Point
Distance above vegetation edge (and %*)	Point
Dominant soil texture of point	Point
Soil category of point (fine or coarse)	Point
Number of shrubs w/in 0.5m tape distance	Point
Shrub biomass w/in 0.5m tape distance*	Point
Average biomass per shrub per point*	Point
Individual shrubs	
Genus	Shrub
Height above vegetation edge	Shrub
Distance from vegetation edge	Shrub
Height class	Shrub
Stem class	Shrub
Biomass*	Shrub

* Variables calculated.

sampled to get biomass, and dividing biomass by the area sampled. Biomass density values were square root transformed prior to analysis. Non-linear relationships were used for floodplain width and segment slope.

Values for bare ground and reed canary grass (collected at band level) were analyzed using two methods. They were averaged for each transect (discussed above), and also added to point data (following section). Vegetation moisture class (hydric, mesic or xeric) was attached to points but not included in the transect dataset.

Point Level Data Set

Each transect was translated into a series of points (typically collected at 1-meter increments) that were populated with vegetative, geomorphic, hydrologic, soils, basin and management characteristics. The 74 transects produced a table of 1464 data points. Data from shrubs growing within 3 meters upstream or downstream of the line transect were attached to the nearest point. Soil texture classes were also assigned to points, representing texture classes at depths of 0, 0.2, 0.4, and 0.7 m and dominant soil texture class for the whole profile. Dominant soil texture classes for points were further generalized as fine or coarse, depending on the amount of sand in the texture class.

Most elements of the analysis used heights and distances above the vegetation edge expressed in meters. In some cases, heights and distances were expressed as a percent of the total in order to normalize transects, given that transects began and ended at defined edges of the riparian area.

Point data were used to determine transect level preference of shrubs based on combined hydrologic, geomorphic and vegetation information. Hurdle analysis, using the number of shrubs per point, accommodated the very high percentage of points with no shrubs (Jackman, 2011). An initial presence/absence analysis compared 'zero' data with 'non-zero' data, identifying factors that may have been be keeping shrubs from growing. The second level of analysis looked only at 'non-zero' or count data, analyzing the influence of individual factors on shrub abundance. The count portion of the analysis used a truncated negative binary distribution with a log link. The presence/absence analysis used a binomial distribution with a logit link. An inherently nested analysis structure such as in Merrill *et al.*, (2006) would have been appropriate for this data set and would be recommended for similar or subsequent studies. Analysis of variance (ANOVA) was used for several comparisons of factors within the point level data set.

Individual Shrub Data Set

Biomass values, species present, and number of shrubs were summed per point and assigned to the point level data. Differences between preferences of shrub genera or size classes were analyzed with multivariate analysis of variance (MANOVA), after transformation of some variables (e.g. log transformation of height above vegetation edge, square root transformation of distance from vegetation edge). MANOVA results were similar with transformed and untransformed data, but the analysis of transformed data was used to minimize violating assumptions of normality.

Results

Basin and Transect Level Soils

Sycan transects were dominated by coarser sediments (Table 4.4). Sprague transects included a greater range of soil textures classes but were dominated by finer sediments.

Point Level Soils

Soils near the vegetation edge typically had a greater sandy component with textures fining with increasing height and distance from the vegetation edge (Table 4.4).

Table 4.4. Number of points by dominant soil texture classes and heights above vegetation edge (m).

	Height above Vegetation Edge (m)											
Texture*	**0.00**	**0.25**	**0.50**	**0.75**	**1.00**	**1.25**	**1.50**	**1.75**	**2.00**	**2.25**	**2.50**	**Total**
						Sprague						
VGSd	3		1									**4**
GSd	17											**17**
Sd	14	13	5	5								**37**
LSd	20	4	12	11	20	2	2					**71**
SdCL	4	8	16	6	5	15	16	19	3			**92**
SdL	19	14	18	10	13	6	7		1			**88**
CL	1	2	2	3	1	2		2	1			**14**
L	9	16	22	36	37	26	16	13	4			**179**
StCL	3	3	7	7	17	9	7	3	1	2	1	**60**
StL	12	33	61	63	39	28	21	18	13	10	2	**300**
StC	14	42	34	11	11	6	5	3	1			**127**
St	9	7	15	19	10	9	4	4	2	7		**86**
StOM	2	13	8					1				**24**
Total	**127**	**155**	**201**	**171**	**153**	**103**	**78**	**63**	**26**	**19**	**3**	**1099**
Texture*	**0.00**	**0.25**	**0.50**	**0.75**	**1.00**	**1.25**	**1.50**	**1.75**	**2.00**	**2.25**	**2.50**	**Total**
						Sycan						
VGSd	6	3	2									**11**
GSd	2	2										**4**
Sd	4	3	14	7	3							**31**
LSd	13	20	16	14	9	2	3	2				**79**
SdL	10	9	8	10	10	4		1	1	1		**54**
L	2	5	12	5	11	3	2	3	2		1	**46**
StL		2	2	2	4	3	5	13	3	1	2	**37**
St	3		2		1					2	1	**9**
Total	**40**	**44**	**56**	**38**	**38**	**12**	**10**	**19**	**6**	**4**	**4**	**271**

***VG – very gravelly, G – gravelly, Sd – sand, L – loam, C – clay, St – silt, OM – organic matter**

Basin and Transect Factors

The suite of factors that vary by river, segment and transect were examined with the following generalized additive model for influences on shrub biomass density.

Shrub biomass density ~ river (Sprague or Sycan) + floodplain width (log 10) + floodplain slope + sub-irrigation + grazing + general texture (fine or coarse)

Floodplain width and segment slope showed the most control (p-value less than 0.00 for each), with biomass density increasing with segment slope and decreasing with floodplain width. Segment slopes are very low, ranging from 0.0148 to 0.0276 percent. Floodplain width and slope control sediment size and access to water (Merrill *et al.,* 2006), and also the movement of water through soil grains (Nakai *et al.,* 2009).

Grazing, sub-irrigation, average reed canary grass dominance and general soil texture (coarse vs. fine) showed no impact on shrub biomass density at the transect level (all p-values >0.10). The River variable also was not significant (p-value of 0.53). Biomass density was greatly impacted by the size of plants, which were consistently smaller (younger) in the Sycan than on the Sprague. Count of shrubs, rather than biomass density, accentuated differences between factors on the Sycan versus the Sprague in the point level analysis (below).

The significance of floodplain width to biomass density was supported by data in Chapter II which showed that wider floodplains had lower shrub biomass densities. River segments of different slopes and widths have had consistent potential for shrubs over time (Chapter II), though land uses between narrow and wide valleys differ considerably.

The lower Sycan segment (wide and flat) historically had very high numbers and density of shrubs, but now has only small and young shrubs on a limited portion of its length.

Reed canary grass was absent from transects in the Sycan. In the Sprague, it often grows at lower portions of transects than most shrubs. Sub-irrigation tended to be an influence at higher portions of transects and often in areas with few shrubs.

Point Level Factors

Individual points on transects reflected local conditions as well as factors at basin and vegetative band levels. Segment slope and floodplain width were included in the points analysis, as they were shown to exert significant control over shrub biomass. Band level characteristics were bare ground and vegetation moisture class. Both bare ground and vegetation moisture class were response variables to basin and transect level characteristics, but control variables to point level characteristics. Response variables at the point level were all related to shrubs: presence or absence, abundance, biomass within 0.5m of a point, and average biomass at a point. In this section, Hurdle analysis shows how all factors relate, followed by comparisons of individual factors.

Hurdle Analysis of Point Data

Hurdle analysis, using the number of shrubs per point, showed the overall influence of all factors on both the presence/absence and abundance of shrubs (Table 4.5). The model, stated below, resulted in an r-squared value of 0.15.

Number of shrubs ~ river + ht over vegetation edge + floodplain width (log 10) + vegetation moisture class + grazing + reed canary grass + dominant texture class

Height above the vegetation edge, floodplain width, vegetation moisture class and grazing were strongly significant controls on the presence/absence of shrubs. Reed canary grass exerted the strongest control on abundance. Factors with no significance at the point level were segment slope, bare ground, sub-irrigation, distance from the vegetation edge, and soil texture class. The very low r-squared value may reflect factors not measured or accounted for within the analysis, or may be due to the complex nature of the data set. While there is little predictive value shown in the model, it may still provide useful insight into relationships between variables. Analysis of biomass values (showing persistence rather than presence) would probably have stronger predictable value, but was not possible with the hurdle model that used count data, only.

Table 4.5. Results of hurdle analysis of point data.

	Factors	**Coefficient**	**P-value**
Presence/absence	Grazing	Positive	< 0.000
	Vegetation moisture class (mesic),	Positive	< 0.000
	Height over the vegetation edge (%)	Positive	< 0.000
	Floodplain width (log transformed)	Negative	< 0.000
	Vegetation moisture class (xeric)	Positive	0.0031
	Fine soil texture	Negative	0.0354
	River (Sycan)	Positive	0.1043
	Reed canary grass	Negative	0.1963
Abundance	Reed canary grass	Negative	0.0078
	Vegetation moisture class (mesic)	Positive	0.0324
	River (Sycan)	Positive	0.0486
	Vegetation moisture class (xeric)	Positive	0.0403
	Height over the vegetation edge (%)	Negative	0.2306
	Grazing	Positive	0.2755
	Floodplain width (log transformed)	Negative	0.5160
	Fine soil texture	Negative	0.9441

Grazing Pressure

Grazing showed a significant and positive relationship with the presence of shrubs. This was unexpected at the points level analysis and likely due to one or more of the following possibilities. First, heaviest grazing pressure was seen in Sycan sites where many other factors are favorable to shrubs. Second, the grazing pressure variable reflected current evidence only – some sites with no current evidence were abusively grazed for decades and are now recovering. Third, hoof action from heavy grazing could create microsite availability, if seedlings survive browse. Fourth, the analysis used of abundance data (necessary for the Hurdle model), rather than biomass data, and biased results in favor of very small seedlings that were unlikely to survive.

Reed Canary Grass

Reed canary grass preferred the mesic portion of the riparian transects surveyed (Figure 4.3). RCG dominated most often in the mesic bands and rarely in xeric bands. RCG was most often present in hydric bands but was not dominant there.

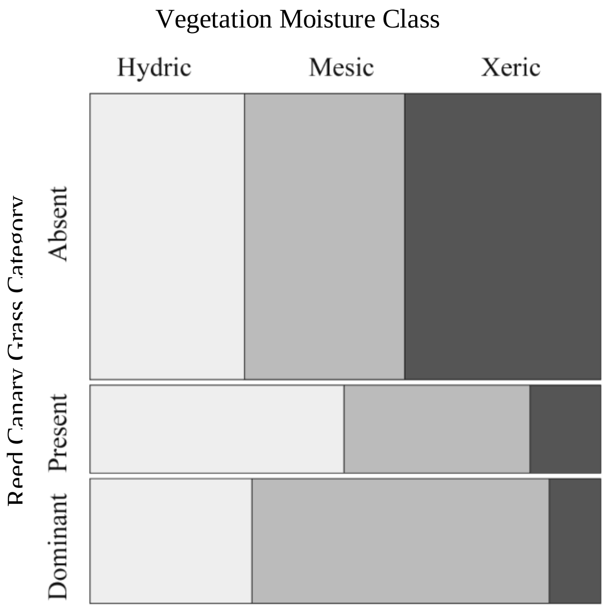


Figure 4.3. Mosaic plot of the proportion of points per reed canary grass category and vegetation moisture class. Categories on each axis sum to 100 percent.

Bare Ground

Percentage are of bare ground (quartiles: 0-25, 26-50, 51-75, 76-100%) is controlled by the general texture of the soil (higher on fine soils than on coarse; Figure 4.4) and the level of grazing (higher with heavier grazing intensity; Figure 4.5). Bare ground was not compared to the presence/absence or abundance of shrubs because ground cover (inverse of bare ground) was partly composed of shrub cover.

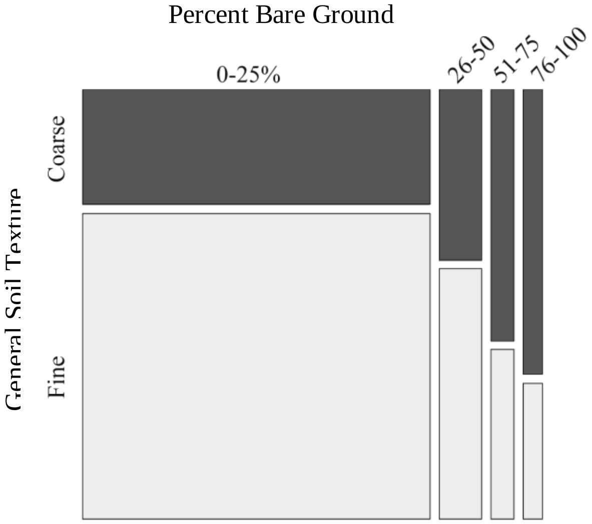


Figure 4.4. Mosaic plot of proportion of points per general texture and percent of bare ground.

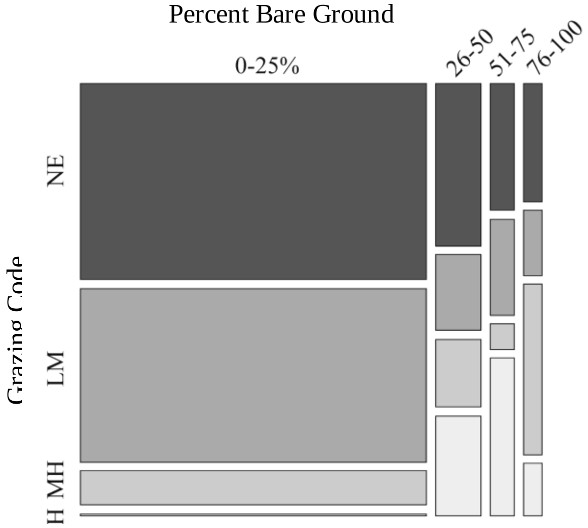


Figure 4.5. Mosaic plot of proportion of points by grazing code and percent bare ground. H – Heavy, MH – Moderate to High, LM – Low to Moderate, NE – No Evidence.

Vegetation Moisture Class and Texture

The presence/absence of shrubs on a site was sensitive to the vegetation moisture class (Figure 4.6), though with different controls for the Sprague and Sycan transects. Shrub presence increases with dryness in the Sprague. In the Sycan, shrub presence is relatively evenly distributed across vegetation moisture classes with a slight peak in the mesic vegetation moisture class. Presence/absence of shrubs on individual points shows a slight favoring toward coarse textured soils, with many fine textured soils having no shrubs at all (Figure 4.7).

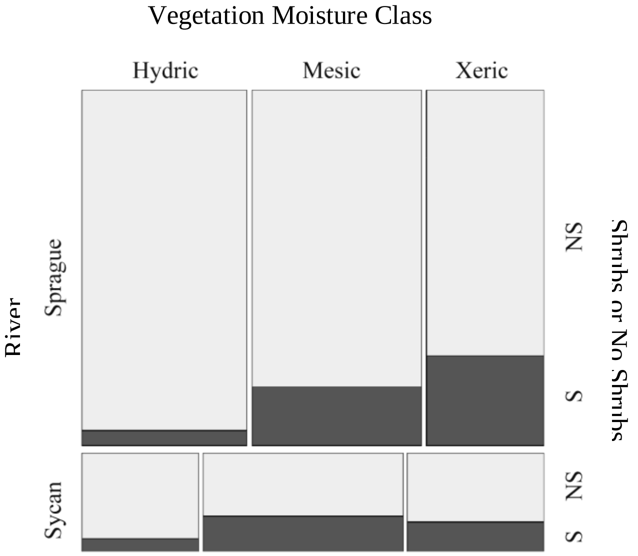


Figure 4.**6.** Mosaic plot of proportion of points by: presence and absence of shrubs (S=shrubs, NS=no shrubs), vegetation moisture class, and by river (Sprague and Sycan).

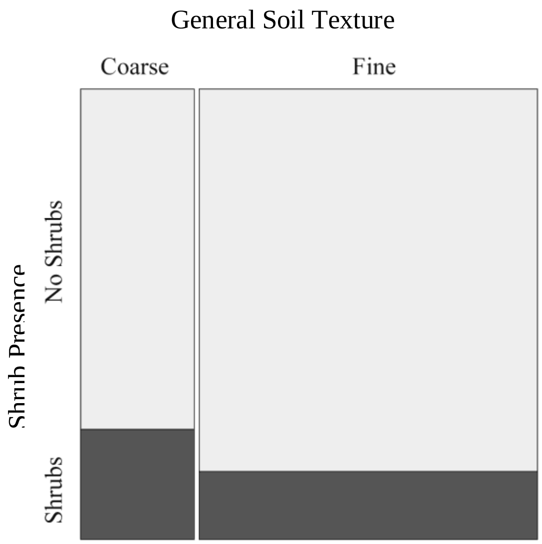


Figure 4.7. Mosaic plot of proportion of points by shrub presence and general soil texture**.**

Looking at the number of shrubs rather than presence/absence, the hydric vegetation moisture class on the Sprague supported very few shrubs (Table 4.6) in either coarse or fine soils. Highest numbers of shrubs on the Sprague were in the xeric moisture class, with a greater proportion of shrubs to points in coarse textured soils. The Sycan supported high proportions of shrubs to points in all but the hydric moisture class; the proportion of shrubs to points was moderate for hydric coarse soils. Shrubs in the Sycan favored coarse soils and shrubs in the Sprague favored fine soils (Figure 4.8). Availability of sediment textures in each river likely dominated the presence of shrubs on individual points.

Table 4.6. Ratio of number of shrubs to number of points per vegetation moisture class, river, and general texture

		Hydric			**Mesic**			**Xeric**	
Texture	**Shrubs**	**Points**	**Shbs:Pts**	**Shrubs**	**Points**	**Shbs:Pts**	**Shrubs**	**Points**	**Shbs:Pts**
					Sprague				
Coarse	10	161	**0.06**	35	77	**0.45**	20	22	**0.91**
Fine	29	256	**0.11**	124	351	**0.35**	165	265	**0.62**
					Sycan				
Coarse	20	64	**0.31**	263	99	**2.66**	64	40	**1.60**
Fine	0	17	**0.00**	37	38	**0.97**	133	50	**2.66**

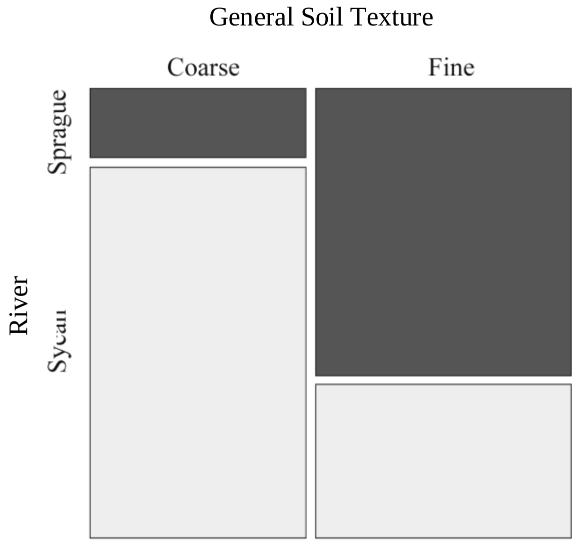


Figure 4.8. Mosaic plot of the proportion of total shrubs (n=1058) per general texture by river (Sprague and Sycan).

Sub-irrigation

Sub-irrigation from visible natural features and irrigated agriculture significantly impacted the position of transect occupied by vegetation moisture classes. Horizontal position on the transect for a given point was calculated using the horizontal distance from the vegetation edge, with 0 being at the vegetation edge (near the channel) and 100 being the outer edge of the riparian transect. The average horizontal position on transect for a given point was significantly impacted by factors of: river, vegetation moisture class and sub-irrigation (ANOVA, all p-values <0.00). Variance was not homogeneous (Bartlett's test, p-value 0.07). In a typical transect, the hydric vegetation moisture class is found close to the vegetation edge (near the channel), xeric is found near the outer edge of the riparian zone, and mesic between hydric and xeric. With sub-irrigation, hydric and mesic vegetation moisture classes are extended toward the outer and higher portion of transects and the xeric moisture class is compressed (Figure 4.9). Despite clear impacts to herbaceous vegetation (vegetation moisture class), neither the number of shrubs nor the biomass densities of shrubs showed sensitivity to sub-irrigation.

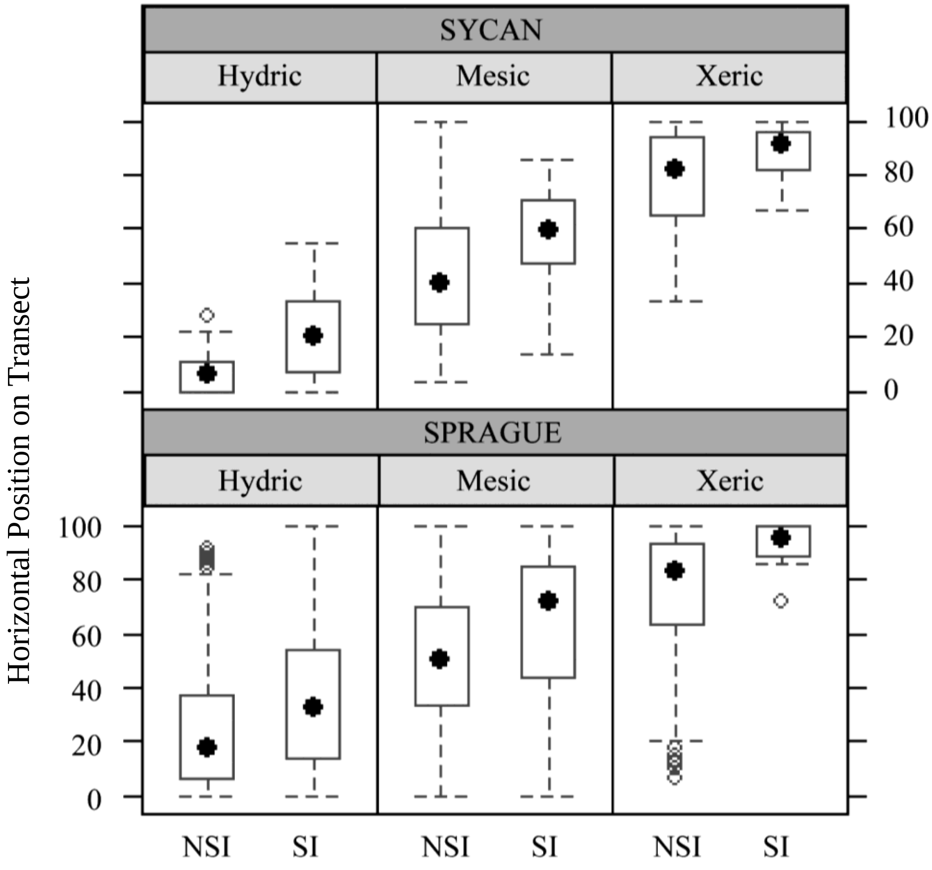


Figure 4.9**.** Sub-irrigation effects on horizontal position on transect by vegetation moisture class and river. NSI=no sub-irrigation, SI=sub-irrigation present.

Heights Above the Vegetation Edge

Shrub numbers and distribution patterns were very different for the Sprague and Sycan Rivers (Figure 4.10). The number of shrubs per point was considerably higher on the Sycan than on the Sprague and peaked near 0.5 meter above the vegetation edge. In the Sprague, the number of shrubs per point peaked near 1.25 meter above the vegetation edge.

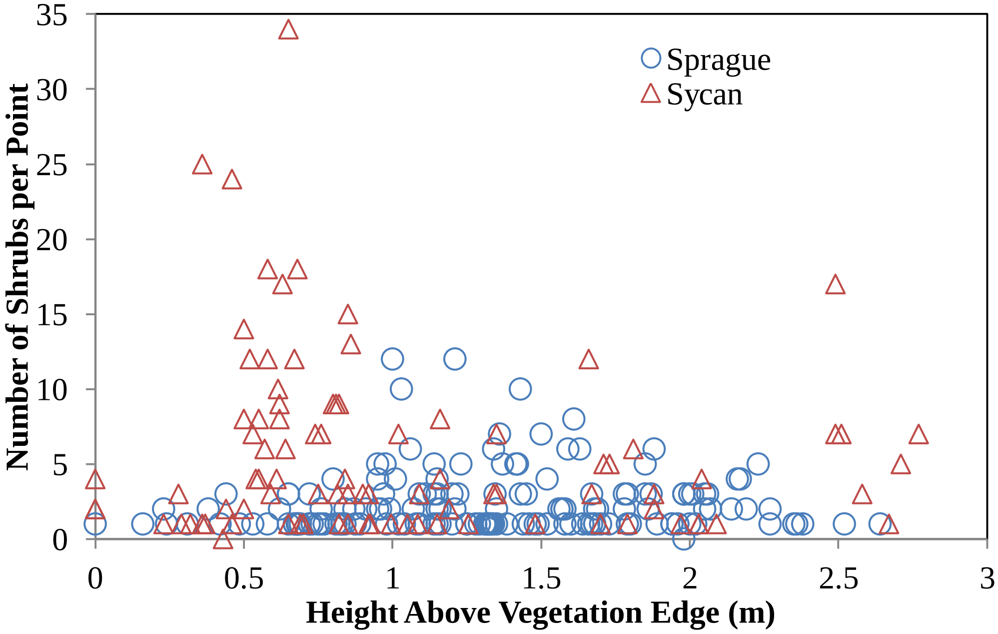


Figure 4.10. Number of shrubs per point.

Points with shrubs in the Sprague (Figure 4.11) favored higher portions of riparian transects, likely due to saturation and oxygen stress(Nakai *et al.*, 2009) on lower banks with fine soil texture dominant in this river. Points with shrubs in the Sycan were fairly evenly distributed across the transect height. Vertical position on transect (not expressed as height in meters as in Figure 4.10), was calculated from height above the vegetation edge, where 0 is at the inner vegetation edge (at channel) and 100 is at the highest position on the riparian transect.

Biomass Density and Height Above the Vegetation Edge

Biomass density patterns for Sprague and Sycan transects were remarkably similar, as they relate to height (in meters) abover the vegetation edge (Figure 4.12). In both rivers, the highest levels of shrub biomass density occurred between 0.5 and 2.0 m above the vegetation edge.

Predation by Rodents

Predation by beaver and muskrats was considerable for shrub populations on the Sycan and wide floodplain segments of the Sprague. In the Sycan, many shrubs were small, near the channel and flooded in the early spring, allowing heavy use by both beaver and muskrats. Shrubs in the moderate and narrow floodplains of the Sprague were often on higher banks, located further from the vegetation edge, and had populations that could support browse. Isolated shrubs on the sparsely populated wide floodplains often sustained very high use by beaver.

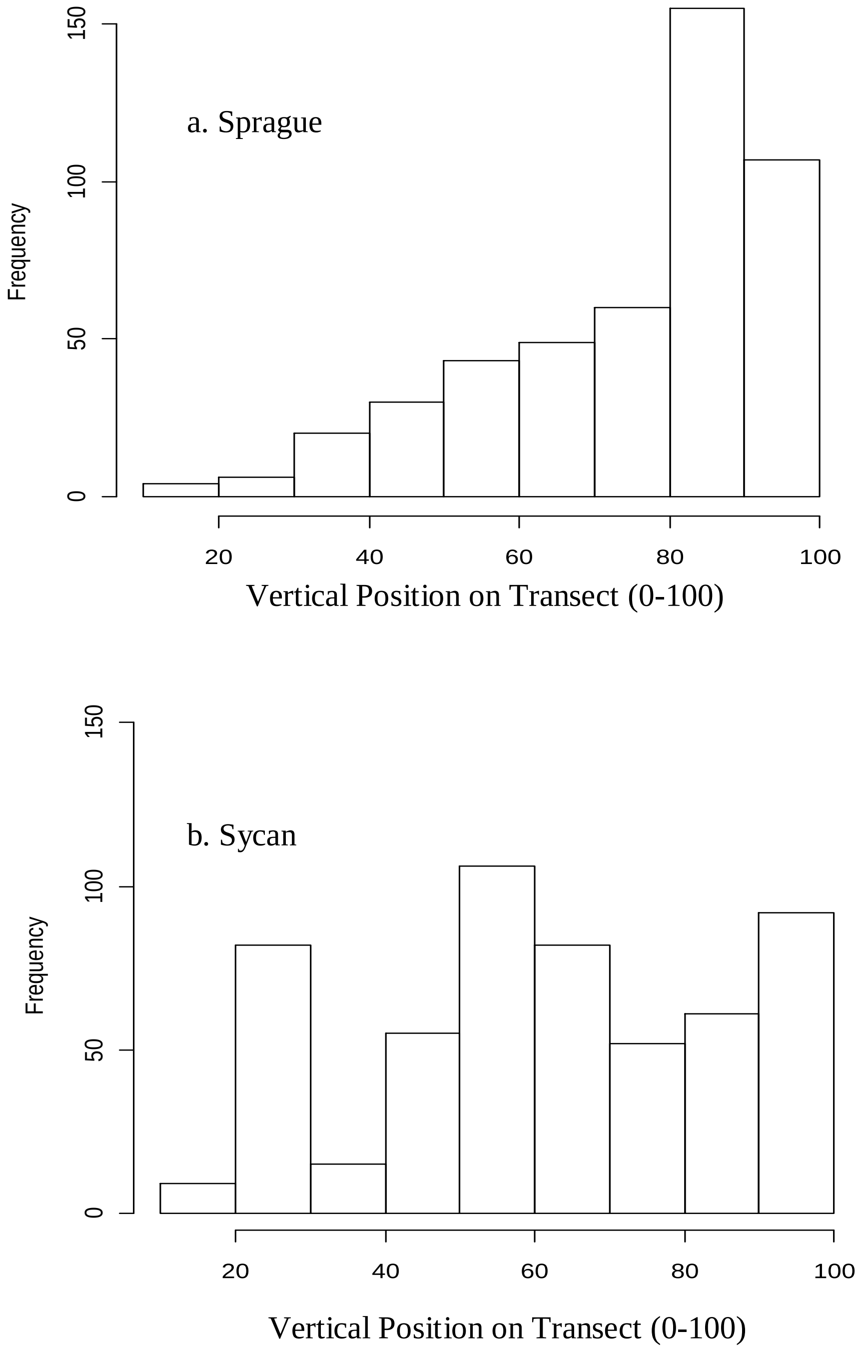


Figure 4.11. Histograms of position on transect for all shrubs on the Sprague (a) and Sycan (b) Rivers.

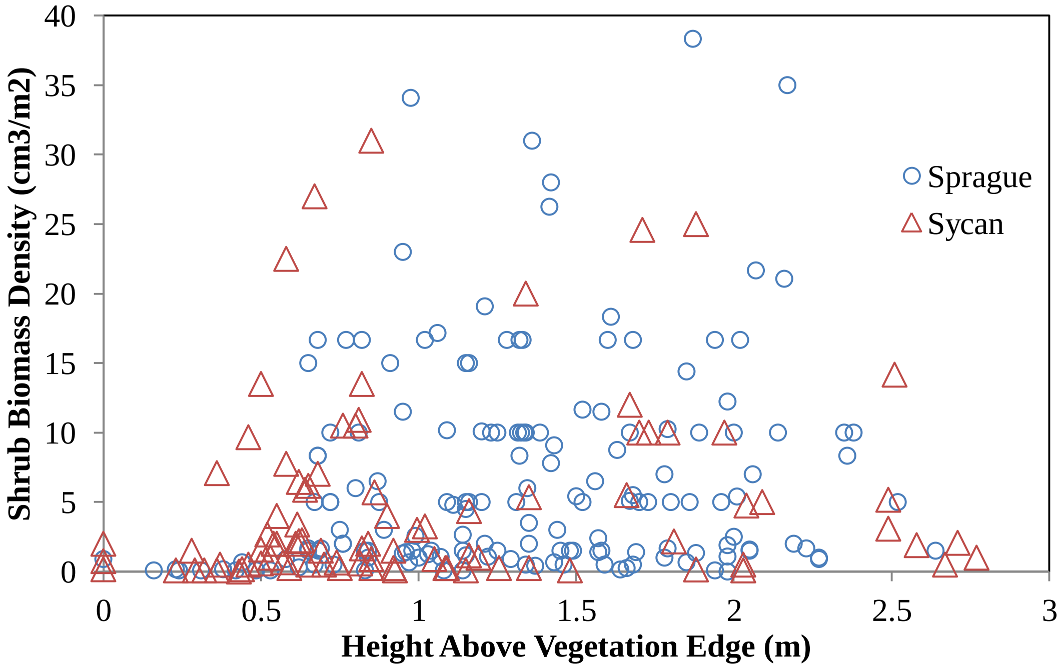


Figure 4.12. Biomass density of shrubs per point.

Points Analysis Conclusions

Shrubs preferred mesic and xeric habitats, narrower floodplain widths, higher positions above the vegetation edge, and habitats with no reed canary grass. Grazing pressure showed a positive correlation with shrub presence which may have been related to seedling microsite availability, but probably incidentally co-occurred with other preferred habitat characteristics. Vegetation moisture class responded strongly to height above vegetation edge, soil texture, and sub-irrigation. Differences in biomass density patterns likely related to differences in land use history. The Sprague retained larger, older plants, while shrubs in the Sycan were typically smaller and younger.

Individual Shrubs

Preferences of Shrub Genera

The four shrub genera encountered on riparian transects showed variable preferences for distance away from and height above the vegetation edge at the channel margin (Figure 4.13). *Salix* were least particular and most numerous at all positions on transects. Nearly all *Rosa* were found above 1.0 meter above the vegetation edge, with no apparent preference for distance away from the vegetation edge. *Ribes* occupied some of the highest positions above the vegetation edge, predominantly above 1.0 meter height. *Spirea* was found above and below 1.0 meter above the vegetation edge, with only 6 individuals encountered.

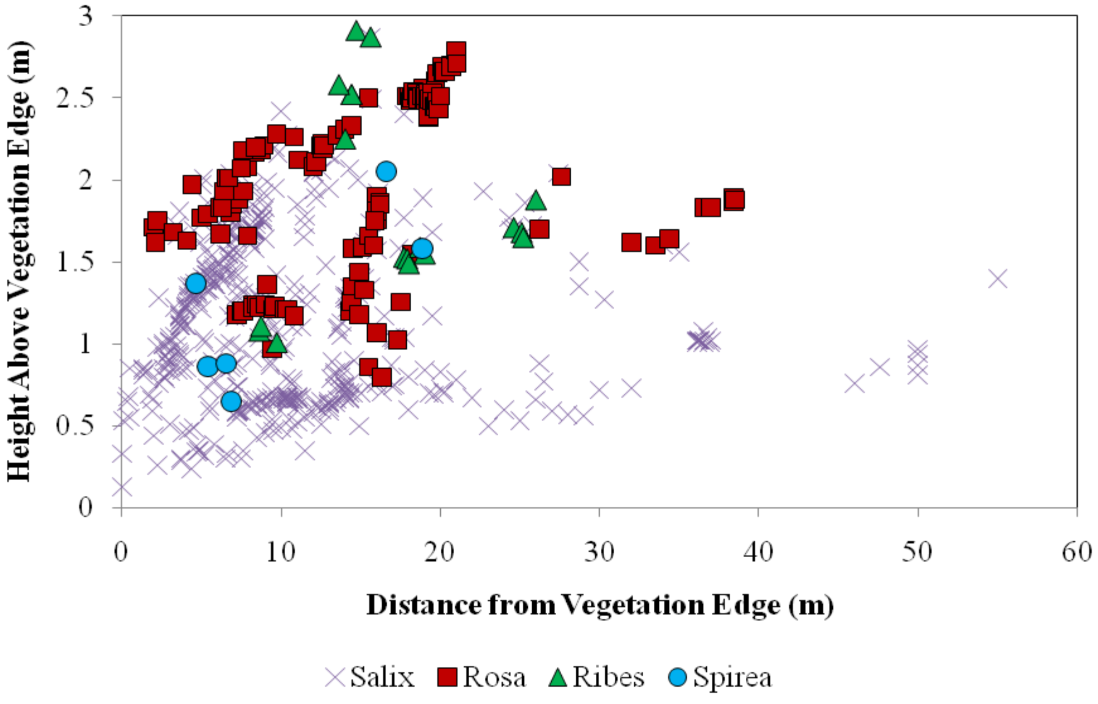


Figure 4.13. Shrub genera on transects.

MANOVA on height above vegetation edge (log-transformed) and distance from the channel (square-root transformed) showed clear differences in genera (p-value <<0.000). After transformation, variances of the groups were homogeneous for height above the vegetation edge (Bartlett test p-value <<0.000) and less so for distance from the vegetation edge (Bartlett test p-value 0.061). Sample sizes were considerably different with 664 *Salix*, 159 *Rosa*, 18 *Ribes* and 6 *Spirea*. An XY plot of transformed variables (not shown) revealed no linear relationships between height and distance from vegetation edge that would compromise MANOVA validity.

Preferences of Mature and Sprout *Salix*

Mature *Salix* plants were most commonly found in the higher and more distal positions relative to the vegetation edge, with single stem sprouts often closer to the vegetation edge, in height and horizontal distance (Figure 4.14). The lack of mature (i.e. taller) *Salix* near the vegetation edge has implications for the role of Salix as a bank stabilizer or as a modifier of stream shade for fisheries concerns. Young Salix (older than sprouts, younger than mature), not shown here, occupied all of the habitats of both mature and sprout individuals. Historically, the Sycan supported large *Salix* individuals very near the channel that have been removed over time (Chapter II). Only in the last decade have some been allowed to recover. Large *Salix* surveyed in the Sprague were most often found in federally managed stream reaches, where development for agricultural use was considerably less, though historical grazing pressure has been high (Connelly and Lyon 2007). Choice of transect locations also disfavored surveying large *Salix* near the channel (e.g. inner channel bends, gentle riparian slopes).

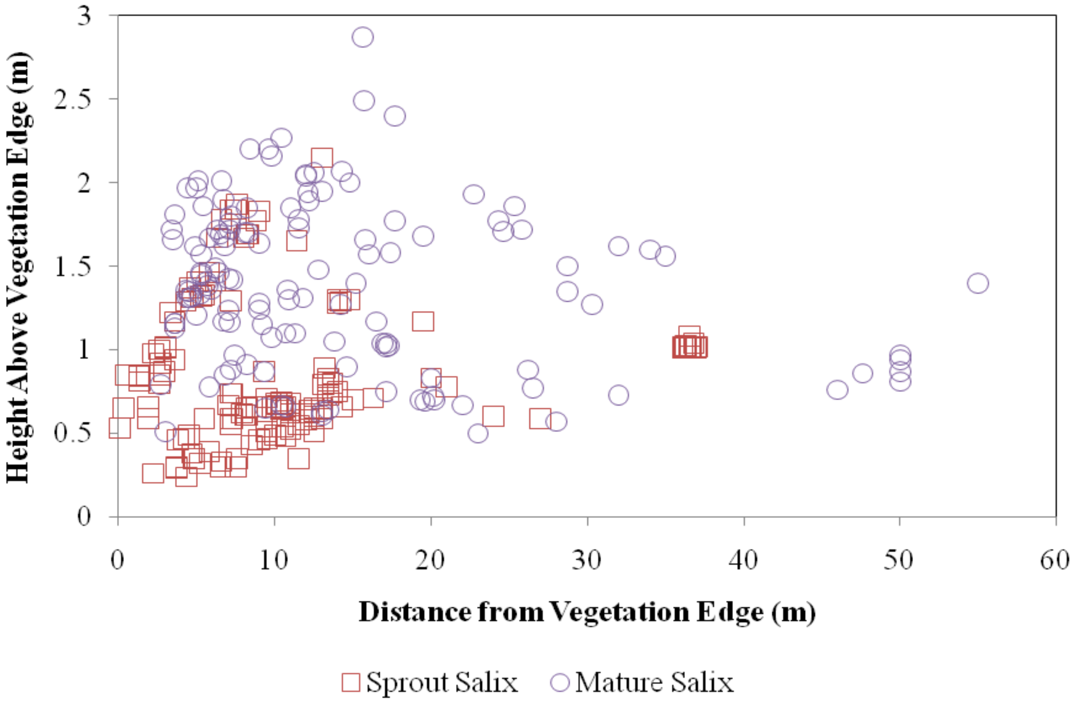


Figure 4.14. Point locations of mature and sprout *Salix*.

Natural Shrub Recovery Potential

The results indicate that, at the basin level, natural recovery potential is progressively lower in wide floodplain segments of the Sprague, especially in sites with floodplain heights lower than 1.0 meters high. Potential for natural shrub recruitment is initially based on the interactions between vegetation moisture class, which reflects bank height and hydrology, and soil texture. These fundamental factors are modified by a suite of factors, including:

- Germination (high near the channel)
- Persistence (high away from the channel)
- Fluvial action present on a site (scour and burial high near the channel)

- Likelihood of predation by rodents (high near the channel)
- Susceptibility to trampling damage by grazers (high in coarse soils)
- Oxygen stress (high near the channel in fine soils)
- Competition from existing vegetation (high in fine soils)
- Probability of seeds accessing the site (high near the channel).

Natural recovery potential also incorporates both the likelihood of shrubs germinating on a given site and the likelihood that a new seedling will persist long term.

Table 4.7 summarizes the suggested recovery potential of Sprague and Sycan shrubs (primarily willows) relative to this suite of factors. The best probability for natural recovery is in the mesic moisture class as germination is likely, persistence is moderately likely and threats are moderate. The hydric moisture class has the lowest probability of natural recovery; though germination is likely, persistence through time is not. The xeric moisture class has a moderate potential for natural recovery, as probability of germination is low. Seedlings that get established, however, are more likely to persist over time.

Table 4.7. Summary of factors influencing natural recovery potential by vegetation moisture class and soil texture. Limiting factors for each type are shown in italics.

	Coarse Texture	**Fine Texture**
Hydric	Germination: High Persistence: Low *Scour, burial, predators, trampling*	Germination: High Persistence: Low *Oxygen stress, competition, predators*
Mesic	Germination: Moderate Persistence: Moderate *Scour, burial, predators, trampling*	Germination: Moderate Persistence: Moderate *Oxygen stress, competition, predators*
Xeric	Germination: Low Persistence: High *Flow frequency, recession rate, trampling*	Germination: Low Persistence: High *Flow frequency, competition*

Suitability for Planting

The same suite of factors (Table 4.7) can be used to infer the suitability for riparian planting as a restoration tool. The hydric vegetative moisture class is the least suitable for planting as plants are unlikely to persist. The mesic moisture class is also less suitable for planting as potential for natural recovery is high and planting is unneeded. The xeric moisture class is the most suitable for planting as natural germination is infrequent, and long term persistence is likely.

Conclusions

Shrub distribution patterns were clearly impacted by a variety of factors, some basin level and others local, some environmental and others management induced. Being cognizant of the relative importance of these factors makes it possible to predict where shrubs are likely to grow naturally, where planting is needed, and where survival is unlikely. Height over vegetation edge and vegetation moisture class were dominant controls on both presence/absence of shrubs, genus of shrubs, and size of *Salix*. Conditions in the Sycan are more favorable for shrub germination than in the Sprague, though grazing pressure and predation by rodents are deterrents to shrubs reaching maturity. For the Sprague mainstem, floodplain width is a dominant control of floodplain shrubs, with moderate and narrow valleys having greater bank heights and better drained soils, and more favorable habitat for shrubs.

In the Sycan, however, shrubs grew readily on lower surfaces, including exposed portions of bankfull channel and bars very near the vegetation edge. Threats are predominantly river scour, predators and grazing pressure. The primary differences between the rivers, in terms of soils and geomorphology, are two-fold. First, soil textures in the Sycan are considerably coarser, being dominated by sands and coarse loams with gravels commonly occurring in near-channel and deep profile layers. Second, the Sycan Valley has steeper gradients, both in the longitudinal profile and valley cross-section. Though not directly studied in this effort, shallow groundwater seems to flow laterally through riparian soils of the Sycan, from both higher portions of the riparian area and water sources on the floodplain. Soil moisture measurements (Chapter III) validate this hypothesis, as saturated soils in the Sprague had very few associated shrubs while saturated soils in the Sycan had many. Neither the Sprague nor Sycan were moisture limited (Chapter III), and indeed the limitation on shrub growth is often too much soil moisture. Fine soil texture and degree of saturation ultimately determined access to oxygen and potential for shrub growth in some sites.

The preference of shrubs for narrow floodplains and higher, drier sites (Sprague) and sites with coarser sediments (Sycan) challenges the practice of planting shrubs near the channel and on wide floodplains. Shrubs in this basin are more likely to persist on positions at the far end of riparian zones where capacity to impact water quality and improve fish habitat is very limited. While planting may be worthwhile for non-fish species or other environmental services such as nutrient cycling or stabilization of off channel habitats, stream-side planting is both likely to fail and unlikely to deliver the desired changes to fish habitat through shade and water quality.

Several ideas for further research to support riparian restoration in the Sprague basin arose out of this analysis. Additional transects, especially in the wide valley segments and above Beatty Gap, would guide restoration in those areas, and identify factors that may be limiting natural shrub recovery. Further research into the timing of willow seed fly and stream flows would greatly benefit estimates of rates of recovery for woody vegetation. Determining whether favorable timing for seedling germination occurs every other year or every 10 years could change priorities for active vs. passive restoration approaches. Extrapolating vegetation moisture class to the larger floodplain surface could reveal the basin wide spatial extent most likely to support shrubs, least likely to support shrubs, or those areas that could benefit from planting efforts. Also, this type of geospatial analysis could illustrate areas most at risk of further invasion of reed canary grass.

CHAPTER V

SUMMARY

In this dissertation I have used soil textures and moisture, topographic positions relative to the channel, and historic analysis to determine the restoration potential of shrub communities in the Sprague Basin. Floodplain width exerted strong control over shrub abundance (Chapters II and IV), as did height of above the vegetation edge (Chapter IV), and texture of soil grains as they related to movement of water and oxygen (Chapter III).

Herbaceous dominated wide floodplains of the Sprague Basin, often the focus of riparian planting efforts, were the least suitable for woody vegetation. Germination and persistence of woody species in wide floodplains were limited by a combination of high water tables and fine sediments (Nakai *et al.*, 2009) – a pattern that has been maintained since the late 1800s. Habitats favorable to shrubs were either: 1) in fine sediments at the distal or higher elevation portions of riparian transects, or 2) in coarse soils that have readily available moisture and oxygen. Shrubs that occurred on high banks with fine soils (narrow and moderately wide floodplains on the Sprague mainstem) were more likely to persist long term because of a lower risk of scour, burial, and oxygen stress and also greater distance from predators. High banks have fewer opportunities for recruitment than low banks as high banks are flooded less often than low banks (reduced hydrochory) and rarely scoured free of existing vegetation (Gurnell *et al.*, 2008; Karrenberg *et al.*, 2002). Habitats with coarse soils and abundant moisture (Sycan River) were colonized aggressively but were limited by: 1) scour and burial, 2) heavy predation by rodents, and

3) sensitivity to trampling damage. While opportunities for future recruitment of shrubs are abundant on lower banks, persistence through time is less likely. Higher, sub-irrigated banks on the Sycan (farther from predators, scour and burial) may be more favorable for long term persistence, but have fewer opportunities for germination than lower banks.

Literature on willows suggests that recession rates greater than 2 cm per day (Amlin and Rood, 2002) may be problematic for survival of seedlings, exceeding growth rates of roots and depriving plants of needed moisture during the summer dry season. This model of soil dryness limiting the extent of riparian shrubs is commonly held among riparian restoration practitioners in the western U.S. In the Sprague basin however, the channel is unincised, soil moisture content in the riparian zone is relatively high throughout the summer, and recession rates are rarely above 2 cm per day. The results of this study suggest that shrubs in fine soils have a preference for higher recession rates (up to 2.5 cm/d) over fine soils with low or no recession rates. High recession rates in fine soils may be providing needed oxygen for plant metabolism (Nakai *et al*., 2009; Li *et al*., 2006). Coarser sediments in Sprague Basin riparian areas are either: 1) in the Sycan, where moisture frequently moves into riparian zones laterally from springs and irrigation return flow, or 2) at positions very near the vegetation edge and standing water. Soil coarseness, a dominant control of water movement in the soil, varies considerably with local topography (Chapter IV). Thus, local topography controls soil texture and access to moisture. Texture controls shrub distribution by moderating water and oxygen movement through soil grains (Nakai *et al.,* 2009; Li *et al*., 2006). These results may be applicable to other western rivers, or portion of rivers, that are unincised and have relatively high soil moisture content in the riparian zone. The model of dryness limiting shrub growth should not be applied without an evaluation of the local context.

These results have important implications for riparian restoration practices. Riparian shrubs are unlikely to influence stream shade or bank stability on the mainstem Sprague whether they germinate naturally or are planted through restoration efforts. Habitats best able to support shrubs long term (to large size) are at the furthest positions on riparian zones. In the Sycan, germination and persistence are somewhat more likely than on the Sprague, though risks of predation, trampling from grazers, and fluvial action will be constant pressures on near-channel shrubs. Results emphasize the need to understand controlling factors prior to restoration efforts.

Follow-up studies could expand and enhance these findings. For example, controlling factors (e.g. hydrology, soil types and topography) are unknown for the North and South Fork Sprague Rivers as surveys and aerial photos were limited or absent. In addition, availability of oxygen to plant roots was implicated but not directly addressed in this work. Associated field studies could quantify tolerance limits of shrubs and allow finer resolution in predicting favorable and unfavorable habitats. A study of this type should include a closer investigation of the role of sub-irrigation on vegetation types, specifically addressing the quality of water entering the riparian zone. Cold water from floodplain springs may have different impacts than irrigation return flow.

Also, given the topographic relationships described in this work, it would be possible to map the relative shrub recovery potentials of the floodplain surface. The map could include areas hostile to shrubs and areas with high natural hazards for shrubs. Such a map, combined with flood frequencies for different basin segments and timing of seed release, could inform the relative rates of recovery possible in the basin.

REFERENCES CITED

Chapter I

Amlin, N.M. and S. B. Rood. 2002. Comparative tolerances of riparian willows and cottonwoods to water-table decline. *Wetlands* 22: 338–346.

Bornette, G., E. Tabacchi, C. Hupp, S. Puijalon, and J. C. Rostan. 2008. A model of plant strategies in fluvial hydrosystems. *Freshwater Biology* 53: 1692–1705.

Castelli, R.M., Chambers J.C. and R. J. Tausch. 2000. Soil–plant relations along a soil–water gradient in great basin riparian meadows. *Wetlands* 20: 251–266.

Chapin, D. M., R L. Beschta, and H. Wen Shen2. 2002. Relationships between flood frequencies and plant communities in the Upper Klamath Basin, Oregon. *Journal of the American Water Resources Association* 8: 603-617.

Cooper, D. J., D. J. Andersen, and R. A. Chimner. 2003. Multiple pathways for woody plant establishment on floodplains at local to regional scales. *Journal of Ecology* 91: 182-196.

Cordes, L. D., F. M. R. Hughes, and M. Getty. 1997. Factors affecting the regeneration and distribution of riparian woodlands along a northern prairie river: the Red Deer River, Alberta, Canada. *Journal of Biogeography* 24: 675-695.

Fotherby, L. M. 2009. Valley confinement as a factor of braided river pattern for the Platte River. *Geomorphology* 103: 552-576.

Green, D. M., and J. B. Kauffman. 1995. Succession and livestock grazing in a northern Oregon riparian ecosystem. *Journal of Range Management* 48:307-313.

Holland, K. A., W. C. Leininger, and M. J. Trlica. 2005. Grazing history affects willow communities in a montane riparian ecosystem. *Rangeland Ecology and Management* 58:148-154.

Hupp, C.R., and W. R. Osterkamp. 1996. Riparian vegetation and fluvial geomorphic processes. *Geomorphology* 14: 277-295.

Jaquette, C., E. Wohl, and D. Cooper. 2005. Establishing a context for river rehabilitation, North Fork Gunnison River, Colorado. *Environmental Management* 10: 593-606.

Kondolf, M. 2006. River restoration and meanders. *Ecology and Society* 11: 42-52.

Lake, P.S., N. Bond, and P. Reich. 2007. Linking ecological theory with stream restoration. *Freshwater Biology* 52: 597–615.

Li, S., S.R. Pezeshki, and F. D. Shields, Jr. 2006. Partial flooding enhances aeration in adventitious roots of black willow (*Salix nigra*) cuttings. *Journal of Plant Physiology* 163: 619-628.

Polvi, L. E., E. E. Wohl, and D. M. Merritt. 2011. Geomorphic and process domain controls on riparian zones in the Colorado Front Range. *Geomorphology* 125: 504-516.

Loheide, S P., and E. G. Booth. 2011. Effects of changing channel morphology on vegetation, groundwater, and soil moisture regimes in groundwater-dependent ecosystems. *Geomophology* 126: 364-376.

Mahoney, J. M., and S. B. Rood. 1998. Streamflow requirements for cottonwood seedling recruitment—an integrative model. *Wetlands* 18: 634-645.

Merrill, A. G., T. L. Benning, and J. A. Fites. 2006. Factors controlling structural and floristic variation of riparian zones in a mountainous landscape of the western United States. *Western North American Naturalist* 66: 137-154.

Nakai, A., Y, Yurugi, and H. Kisanuki. 2009. Growth responses of *Salix gracilistyla* cuttings to a range of substrate moisture and oxygen availability. *Ecological Research* 24: 1057-1065.

Osterkamp W. R., and C.R. Hupp. 2010. Fluvial processes and vegetation — Glimpses of the past, the present, and perhaps the future. *Geomorphology* 116: 274–285.

Rodriguez-Gonzaleza, P. A., J. C. Stella, F. Campeloc, M. T. Ferreira, and A. Albuquerquea. 2010. Subsidy or stress? Tree structure and growth in wetland forests along a hydrological gradient in Southern Europe. *Forest Ecology and Management* 259: 2015-2025.

Shultz T. T., and W. C. Leininger. 1990. Differences in riparian vegetation structure between grazed areas and exclosures. *Journal of Range Management* 43: 295-299.

Stella, J. C., and J. J. Battles. 2010. How do riparian woody seedlings survive seasonal drought? *Oecologia* 164: 579-590.

U. S. Department of Interior, Bureau of Land Management. Land status and cadastral records viewer. http://www.blm.gov/or/landrecords/index.php (accessed 2-5-2011).

Wohl, E. 2005. Virtual rivers: Understanding historical human impacts on rivers in the context of restoration. *Ecology and Society* 10, no. 2: 2. http://www.ecologyandsociety.org/col110/iss2/art2/ (accessed 12-5-2010).

Chapter II

Amlin, N. M., and S. B. Rood. 2002. Comparative tolerances of riparian willow and cottonwood to water table decline. Wetlands 22: 338-346.

Bendix, J. 1997. Flood disturbance and the distribution of riparian species diversity. *The Geographical Review* 87: 468-483.

Biondini, M. and P. Kandus. 2006. Transition matrix analysis of land-cover change in the accretion areas of the lower delta of the Parana River (Argentina) reveals two succession pathways. *Wetlands* 26: 981-991.

Bornette, G., and Amoros, C. 1996. Disturbance regimes and vegetation dynamics: role of floods in riverine wetlands. *Journal of Vegetation Science* 7: 615–622.

Bornette, G., E. Tabacchi, C. Hupp, S. Puijalon, and J. C. Rostan. 2008. A model of plant strategies in fluvial hydrosystems. *Freshwater Biology* 53: 1692–1705.

Castelli, R.M., Chambers J.C., and R. J. Tausch. 2000. Soil–plant relations along a soil–water gradient in Great Basin riparian meadows. *Wetlands* 20: 251-266.

Chapin, D. M., .R L. Beschta, and H. Wen Shen2. 2002. Relationships between flood frequencies and plant communities in the Upper Klamath Basin, Oregon. *Journal of the American Water Resources Association* 8: 603-617.

Connelly M., and L. Lyons. 2007. *Upper Sprague Watershed Assessment*. Klamath Basin Ecosystem Foundation and Oregon State University Klamath Basin Research and Extension Center. Klamath Falls, Oregon. Klamathpartnership.org/watershed_ assessments_upper_sprague.html. (accessed 2-1-2011).

Cooper, D. J., D. J. Andersen, and R. A. Chimner. 2003. Multiple pathways for woody plant establishment on floodplains at local to regional scales. *Journal of Ecology* 91: 182-196.

Cordes, L. D., F. M. R. Hughes and M. Getty. 1997. Factors affecting the regeneration and distribution of riparian woodlands along a northern prairie river: the Red Deer River, Alberta, Canada. *Journal of Biogeography* 24: 675-695.

Cowardin, L. M., V. Carter, F. C. Golet, and E. T. LaRoe. 1979. *Classification of Wetland and Deepwater Habitats of the United States*.U. S. Department of the Interior. Fish and Wildlife Service.

Fotherby, L. M. 2009. Valley confinement as a factor of braided river pattern for the Platte River. *Geomorphology* 103: 552-576.

Green, D. M., and J. B. Kauffman. 1995. Succession and livestock grazing in a northern Oregon riparian ecosystem. *Journal of Range Management* 48: 307-313.

Gurnell, A., K. Thompson, J. Goodson, and H. Moggridge. 2008. Propagule deposition along river margins: Linking hydrology and ecology. *Journal of Ecology* 96: 553-565.

Hibbard, K. A., D. S. Schimel, S. Archer. D. S. Ojima, and W. Parton. 2003. Grassland to woodland transitions: Integrating changes in landscape structure and biogeochemistry. *Ecological Applications* 13: 911-926.

Holland, K. A., W. C. Leininger, and M. J. Trlica. 2005. Grazing history affects willow communities in a montane riparian ecosystem. *Rangeland Ecology and Management* 58: 148-154.

Hupp, C. R. and Osterkamp, W. R. 1996. Riparian vegetation and fluvial geomorphic processes. *Geomorphology* 14: 277-295.

Jaquette, C., E. Wohl, and D. Cooper. Establishing a context for river rehabilitation, North Fork Gunnison River, Colorado. *Environmental Management* 10: 593-606.

Karrenberg S., Edwards P.J., and Kollmann J. 2002. The life history of *Salicaceae* living in the active zone of floodplains. *Freshwater Biology* 47: 733-748.

Klamath Waters Digital Library. *GLO survey notes, Sprague Basin quadrangle maps, Oregon – Klamath Co.* Map. United States. General Land Office; U.S. Geological Survey; United States. Forest Service, 1998. From Oregon Institute of Technology Library. http://klamathwaterlib.oit.edu/GLOSurvey/index.htm (accessed 4-1-2011).

Lawrence, W. E. 1922 and 1934. Field Journals. Oregon State University Herbarium, Corvallis, Oregon. Copies in possession of Klamath Tribes Natural Resources Office, Chiloquin, Oregon.

Li, S., S.R. Pezeshki, and F. Douglas Shields, Jr. 2006. Partial flooding enhances aeration in adventitious roots of black willow (*Salix nigra*) cuttings. *Journal of Plant Physiology* 163: 619-628.

Merrill, A. G., T. L. Benning, and J. A. Fites. 2006. Factors controlling structural and floristic variation of riparian zones in a mountainous landscape of the western United States. *Western North American Naturalist* 66: 137-154.

National Agricultural Inventory Program (NAIP). 2005. Color Digital Orthphoto Quadrangles, scale of 1:24000.

National Agriculture Imagery Program (NAIP). 2005. Oregon color half-meter Digital Orthophoto Quadrangle. U.S. Department of Agriculture and the U.S. Geological Survey.

O' Connor, J. E., P.F. McDowell, P. Lind and C. Massingill. In progress. Channel and floodplain processes of the Sprague and Sycan River, Klamath Basin, Oregon. US Geological Survey. Scientific Investigations Report.

Petit, C., T. Scudder, and E. Lambin. 2001. Quantifying processes of land-cover change by remote sensing: Resettlement and rapid land-cover changes in South-eastern Zambia. *International Journal of Remote Sensing* 22: 3435-3456.

Rabe, A., and C. Calonje. 2009. *Lower Sprague-Lower Williamson Watershed* Assessment. Klamath Watershed Partnership. Klamath Falls, Oregon. Klamathpartnership.org/watershed_assessments_lower_sprague_lower_williamson.html. (accessed 2-1-2011).

Shanmugam, S., and M. Barnsley. 2002. Quanitfying Landscape-ecological succession in a coastal dune system using sequential aerial photography and GIS. *Journal of Coastal Conservation* 8: 61-68.

Shultz T. T. and W. C. Leininger. 1990. Differences in riparian vegetation structure between grazed areas and exclosures. *Journal of Range Management* 43: 295-299.

Stern, T. 1965. *The Klamath Tribe: a people and their reservation*. University of Washington press. Seattle, USA.

Stillwater Sciences. 2007. Analysis of Riparian Vegetation Dynamics for the Lower Santa Clara River and Major Tributaries, Ventura County, California. Santa Clara River Parkway Floodplain Restoration Feasibility Study. Prepared by Stillwater Sciences for the California State Coastal Conservancy and the Santa Clara River Trustee Council. 68 p. http://www.santaclarariverparkway.org/wkb/scrbiblio/ floodplainfeasibility. Accessed 11-27-2011.

Tetra Tech, Inc. 2004. Conceptual restoration plan: Active floodplain of the Rio Grande – San Acacia to San Marcial. Volume 1 of 4. Save our Bosque Task Force, Soccorro, NM. 170 p. http://www.emnrd.state.nm.us/fd/districts/socorro/Vol_1_PhaseI_II_ Report_Final.pdf. Accessed 11-27-2011.

Thatcher, T., B. Swindell, and K. Boyd. 2008. Yellowstone River riparian vegetation mapping. Draft report prepared for Custer County Conservation District and Yellowstone River Conservation District Council. 64 p. http://nris.mt.gov/ yellowstone/Riparian_Full_River_Final_Report_082608.pdf. Accessed 11-27-2011.

U. S. Army Corps of Engineers (USACE), n.d. Documents provided by Klamath Board of Commissioners spanning 1965 to 1990. Copies in possession of U. S. Geological Survey, Oregon Water Science Center, Portland, Oregon.

U. S. Department of Agriculture (USDA). 1968. Black and white aerial photos scale of 1:20000. Project number: 1968 USDA Klamath # ASCS 8-68-DC.

U. S. Department of Agriculture (USDA), Agricultural Adjustment Administration. 1940, 1941. Black and white aerial photographs, scale of 1:20000. Project number: CNO USDA 8542.

U. S. Department of Interior (USDI), Bureau of Land Management. Land status and cadastral records viewer. http://www.blm.gov/or/landrecords/index.php (accessed 2-5-2011).

U. S. Geological Service (USGS). 2000. Black and white Digital Orthphoto Quadrangles, scale of 1:24000.

Watershed Science. 2005. *Sprague River LiDAR remote sensing and data collection*. Submitted to the Klamath Tribes, Natural Resources Department.

Wohl, E. 2005. Virtual rivers: Understanding historical human impacts on rivers in the context of restoration. *Ecology and Society* 10, no. 2: 2. http://www.ecologyandsociety.org/col110/iss2/art2/ (accessed 12-5-2010).

Chapter III

Amlin, N.M., and S. B. Rood. 2002. Comparative tolerances of riparian willows and cottonwoods to water-table decline. *Wetlands* 22: 338–346.

Baird K., Stromberg J., and T. Maddock. 2005. Linking riparian dynamics and groundwater: an eco-hydrologic approach to modeling groundwater and riparian vegetation. *Environmental Management* 36: 551–564.

Barnes, D. M., and A.U. Mallik. 2001. Effects of beaver, *Castor canadensis*, herbivory on streamside vegetation in a northern Ontario watershed. *Canadian Field-Naturalist* 115: 9 -21.

Bendix, J., and C. R. Hupp. 2000. Hydrological and geomorphological impacts on riparian plant communities. *Hydrological Processes* 14: 2977-2990.

Bornette, G., E. Tabacchi, C. Hupp, S. Puijalon, and J. C. Rostan. 2008. .A model of plant strategies in fluvial hydrosystems. *Freshwater Biology* 53: 1692–1705.

Castelli, R.M., Chambers J.C., and R. J. Tausch. 2000. Soil–plant relations along a soil–water gradient in great basin riparian meadows. *Wetlands* 20: 251-266.

Cooper, D. J., D. J. Andersen, and R. A. Chimner. 2003. Multiple pathways for woody plant establishment on floodplains at local to regional scales. *Journal of Ecology* 91: 182-196.

Hughes F.M.R. 1997. Floodplain biogeomorphology. *Progress in Physical Geography* 21: 501–529.

Huddleston, J. H., and Kling, G. F. 1996. Manual for Judging Oregon Soils. Oregon State University Extension Service Manual 6. Corvallis, Oregon: Oregon State University Extension Service.

Hupp, C.R., and W. R. Osterkamp. 1996. Riparian vegetation and fluvial geomorphic processes. *Geomorphology* 14: 277–295.

Irrometer Co., Riverside, CA. Instruction and operating manuals for soil moisture sensor (200SS). http://irrometer.com/pdf/instruction manuals/data loggers/740 900M Instruction Manual web.pdf. (accessed 9-16-11).

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.

Li, S., S.R. Pezeshki, and F. Douglas Shields, Jr. 2006. Partial flooding enhances aeration in adventitious roots of black willow (*Salix nigra*) cuttings. *Journal of Plant Physiology* 163: 619-628.

Loheide, S P. and E. G. Booth. 2011. Effects of changing channel morphology on vegetation, groundwater, and soil moisture regimes in groundwater-dependent ecosystems. *Geomophology* 126: 364-376.

Mahoney, J. M., and S. B. Rood. 1998. Streamflow requirements for cottonwood seedling recruitment—an integrative model. *Wetlands* 18: 634-645.

Nakai, A., Y. Yurugi, and H. Kisanuki. 2009. Growth responses of *Salix gracilistyla* cuttings to a range of substrate moisture and oxygen availability. *Ecological Research* 24: 1057-1065.

Merritt D.M. and E. E. Wohl. 2002. Processes governing hydrochory along rivers: hydraulics, hydrology, and dispersal phenology. *Ecological Applications* 12: 1071-1087.

Richardson J.L., J. L. Arndt, J. A. Montgomery. 2001. Hydrology of Wetlands and Related Soils. In *Wetland Soils: Genesis, Hydrology, Landscapes, and Classification* ed. J. L. Richardson and M. J. Vepraskas, 35-84. Boca Raton, FL: CRC Press.

Rodriguez-Gonzalez, P. A., J. C. Stella, F. Campeloc, M. T. Ferreira, A. Albuquerquea. 2010. Subsidy or stress? Tree structure and growth in wetland forests along a hydrological gradient in Southern Europe. *Forest Ecology and Management* 259: 2015-2025.

Shock, C. C., R. Flock, E. Fiebert, C. A. Shock, A. Pereira, and L. Jensen. 2005. Irrigation monitoring using soil water tension. Sustainable Agriculture Techniques. Oregon State Extension Service. EM8900.

Stella, J. C. and J. J. Battles. 2010. How do riparian woody seedlings survive seasonal drought? *Oecologia* 164:579-590.

Stella, J. C., J. J. Battles, B. K. Orr, and J. R. McBride. 2006. Synchrony of seed dispersal, hydrology and local climate in a semi-arid river reach in California. *Ecosystems* 9:1200-1214.

Chapter IV

Amlin, N. M., and S. B. Rood. 2002. Comparative tolerances of riparian willow and cottonwood to water table decline. *Wetlands* 22: 338-346.

Bhattacharjee, J., J. P. Taylor, Jr., L. M. Smith, and L. E. Spence. 2008. The importance of soil characteristics in determining survival of first-year cottonwood seedlings in altered riparian habitats. *Restoration Ecology* 16: 563-571.

Bornette, G. & Amoros, C. (1996) Disturbance regimes and vegetation dynamics: role of floods in riverine wetlands. *Journal of Vegetation Science* 7: 615-622.

Chapin, D. M., R. L. Beschta, and H. Wen Shen. 2002. Relationships between flood frequencies and plant communities in the Upper Klamath Basin, Oregon. *Journal of the American Water Resources Association* 8: 603-617.

Connelly M. and L. Lyons. 2007. Upper Sprague Watershed Assessment. Klamath Basin Ecosystem Foundation and Oregon State University Klamath Basin Research and Extension Center. Klamath Falls, Oregon. Klamathpartnership.org/watershed_ assessments_upper_sprague.html. (accessed 2-1-2011).

Cordes, L. D., F. M. R. Hughes, and M. Getty. 1997. Factors affecting the regeneration and distribution of riparian woodlands along a northern prairie river: The Red Deer River, Alberta, Canada. *Journal of Biogeography* 24: 675-695.

Cowardin, L. M., V. Carter, F. C. Golet and E. T. LaRoe. 1979. *Classification of Wetland and Deepwater Habitats of the United States*.U. S. Department of the Interior. Fish and Wildlife Service.

Francis, R. A. 2006. Allogenic and autogenic influences upon riparian vegetation dynamics. *Area* 38.4: 453-464.

Green, D. M., and J. B. Kauffman. 1995. Succession and livestock grazing in a northern Oregon riparian ecosystem. *Journal of Range Management* 48: 307-313.

Gurnell, A., K. Thompson, J. Goodson, and H. Moggridge. 2008. Propagule deposition along river margins: Linking hydrology and ecology. *Journal of Ecology* 96: 553-565.

Hastie, T. 2011. GAM Package for 'R''. Version 1.04.1. http://cran.r-project.org/web/packages/gam/gam.pdf. Accessed 9-23-2011.

Henszey, R. J., K. Pfeiffer, and J. R. Keough. 2004. Linking surface- and ground water levels to riparian grasslands species along the Platte River in Central Nebraska, USA. *Wetlands* 24: 665-687.

Holland, K. A., W. C. Leininger, and M. J. Trlica. 2005. Grazing history affects willow communities in a montane riparian ecosystem. *Rangeland Ecology and Management* 58: 148-154.

Hupp, C. R., and Osterkamp, W. R. 1996. Riparian vegetation and fluvial geomorphic processes. *Geomorphology* 14:277-295.

Huddleston, J. H., and Kling, G. F., 1996. Manual for Judging Oregon Soils. Oregon State University Extension Service Manual 6. Corvallis, Oregon: Oregon State University Extension Service.

Jackman, S. 2011. PSCL – Hurdle Analysis Package for 'R'. Version 1.03.10. http://cran.r-project.org/web/packages/pscl/pscl.pdf. Accessed 9-23-2011.

Klamath Waters Digital Library. GLO survey notes, Sprague Basin quadrangle maps, Oregon – Klamath Co. Map. United States. General Land Office; U.S. Geological Survey; United States. Forest Service, 1998. From Oregon Institute of Technology Library. http://klamathwaterlib.oit.edu/GLOSurvey/index.htm. Accessed 4-1-2011.

Lawrence, W. E. 1922 and 1934. Field Journals, Oregon State University Herbarium, Corvallis, Oregon. Copies of journals provided by Larry Dunsmoor of the Klamath Tribes.

Leyer, I. 2005. Predicting plant species' responses to river regulation: The role of water level fluctuations. *Journal of Applied Ecology* 42: 239–250

Mahoney, J. M., and S. B. Rood. 1992. Response of a hybrid poplar to water table decline in different substrates. *Forest Ecology and Management* 54:141-156.

Merrill, A. G., T. L. Benning, and J. A. Fites. 2006. Factors controlling structural and floristic variation of riparian zones in a mountainous landscape of the western United States. *Western North American Naturalist* 66: 137-154.

Nakai, A., Y. Yurugi, and H. Kisanuki. 2009. Growth responses of Salix gracilistyla cuttings to a range of substrate moisture and oxygen availability. *Ecological Restoration* 24:1057-1065.

Palmer, M. A. 2008. Reforming watershed restoration: science in need of application and applications in need of science. *Estuaries and Coasts*. DOI 10.1007/s12237-008-9129-5.

Pezeshki, S. R. 2001. Wetland plant responses to soil flooding. *Environmental and Experimental Botany* 46: 299-312.

R Development Core Team. 2011. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. ISBN 3-900051-07-0, URL http://www.R-project.org/.

Shultz, T. T., and W. C. Leininger. 1990. Differences in riparian vegetation structure between grazed areas and exclosures. *Journal of Range Management* 43: 295-299.

Stella, J. C., J. J. Battles, B. K. Orr, and J. R. McBride. 2006. Synchrony of seed dispersal, hydrology and local climate in a semi-arid river reach in California. *Ecosystems* 9: 1200-1214.

Stern, T. 1965. The Klamath Tribe: a people and their reservation. University of Washington Press. Seattle, USA.

Van Eck, W.H., J. P.M. Lenssen, H.M. van de Steeg, C.W.P.M. Blom, and H. de Kroon. 2006. Seasonal dependent effects of flooding on plant species survival and zonation: a comparative study of 10 terrestrial grassland species. *Hydrobiologia* 565: 59-69.

Winward, A. H., 2000. Monitoring the vegetation resources in riparian areas. Gen. Tech. Rep. RMRS-GTR-47. Ogden, UT: U. S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 49 p.

Chapter V

Amlin, N.M., and S. B. Rood. 2002. Comparative tolerances of riparian willows and cottonwoods to water-table decline. *Wetlands* 22: 338-346.

Gurnell, A., K. Thompson, J. Goodson, and H. Moggridge. 2008. Propagule deposition along river margins: linking hydrology and ecology. *Journal of Ecology* 96: 553-565.

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.

Li, S., S.R. Pezeshki, and F. D. Shields, Jr. 2006. Partial flooding enhances aeration in adventitious roots of black willow (*Salix nigra*) cuttings. *Journal of Plant Physiology* 163: 619-628.

Nakai, A., Y. Yurugi, and H. Kisanuki. 2009. Growth responses of *Salix gracilistyla* cuttings to a range of substrate moisture and oxygen availability. *Ecological Research* 24: 1057-1065.