AN ABSTRACT OF THE DISSERTATION OF

Jessica E. Halofsky for the degree of Doctor of Philosophy in Forest Science presented on June 14, 2007.
Title: Fire Severity and Vegetation Response to Fire in Riparian Areas of the Biscuit and B&B Complex Fires, Oregon.

Abstract approved:

David E. Hibbs

Fire is the dominant disturbance process in western U.S. forests, and although effects of fire in upland forests are relatively well-studied, there is little information about fire effects on riparian forests, critical areas of the landscape for both habitat and water quality. This dissertation examines different aspects of fire effects in riparian areas of two recent fires in Oregon, the Biscuit Fire in southwestern Oregon and the B&B Complex Fire in the Cascade Mountain Range. In the first of three studies, I compared riparian fire severity to that in uplands and investigated factors influencing riparian fire severity in both fire areas. In a second study, the relationships among ground-based indices of fire severity in riparian areas, and the relationships between ground-based and remotely-sensed indices of fire severity, were examined. In a third study, I investigated patterns in post-fire riparian plant community regeneration in the same areas.

I found that understory fire severity was significantly lower in riparian areas compared to adjacent uplands, suggesting a decoupling of understory fire effects in riparian areas versus uplands. However, there were no differences in overstory fire severity between riparian areas and uplands in either fire. Understory and overstory fire severity indices were found to be weakly related, suggesting that there are limitations in the use of both types of fire severity indices. However, both overstory and understory fire severity in riparian areas were most strongly predicted by upland fire severity. Riparian fuel properties were also strong predictors of riparian fire severity. Patterns in post-fire riparian regeneration were influenced, at a coarse spatial scale, by factors associated with position in a watershed (headwater versus main stem channels) in the Biscuit Fire and by elevation/plant association in the B&B Complex Fire. At a finer spatial scale, differences in species composition and microsite conditions between deciduous hardwood- and conifer-dominated communities, and understory fire severity, influenced patterns of post-fire regeneration. Results of these studies suggest that management practices that reduce upland fire severity may also reduce riparian fire severity. Results also suggest that post-fire riparian regeneration efforts be tailored to site-specific vegetation conditions of complex riparian environments.

Fire Severity and Vegetation Response to Fire in Riparian Areas of the Biscuit and B&B Complex Fires, Oregon

by
Jessica E. Halofsky

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APPROVED:

Major Professor, representing Forest Science

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

Jessica E. Halofsky, Author

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CONTRIBUTION OF AUTHORS

Dr. David Hibbs assisted in the study design, implementation, analysis, writing, and interpretation in Chapters 1 through 5.

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DEDICATION

To my family, who gives me unwavering support and encouragement. And to Josh, for enriching my life in so many ways.

CHAPTER 1 – INTRODUCTION

Disturbance is inherent in the dynamics of all ecosystems. Disturbances such as wind, floods, insects, and fire play a vital role in shaping landscape patterns and influencing ecosystem processes. Fire is the dominant disturbance process in western U.S. landscapes, and its role in influencing species composition and age structure of present-day western forests is well documented. Very little is known, however, about fire severity and post-fire vegetation regeneration in riparian areas, critical areas of the landscape for both habitat and water quality.

Riparian areas can be defined as "three dimensional zones of direct physical and biotic interactions between terrestrial and aquatic ecosystems, with boundaries extending outward to the limits of flooding and upward into the canopy of streamside vegetation" (Gregory et al. 1991). Riparian areas have unique physical characteristics and unique vegetation structure and composition, which have the potential to influence fire behavior and, in turn, be influenced by it. Many attributes of riparian areas would be expected to result in lower fire intensity and severity in riparian areas than uplands. The topographic position of riparian areas, along with the presence of surface water and saturated soils, results in a characteristically moist microclimate in riparian areas (Dwire and Kauffman 2003). During fire events, lower wind speed in riparian areas sheltered by adjacent slopes may prevent them from burning as severely as the surrounding uplands (Dwire and Kauffman 2003). Continuity of the stream channel and/or the presence of unvegetated gravel bars may result in riparian areas acting as natural fire breaks (Heinselman 1973, Dwire and Kauffman 2003). In addition, vegetation structure and composition are often unique in riparian areas compared to uplands; hardwoods are often dominant over conifers immediately adjacent to streams (Baker 1989, Bradley et al. 1992, Pabst and Spies 1999, Nierenberg and Hibbs 2000, Wimberly and Spies 2001), and the abundance of herbaceous fuels is often higher in riparian areas (Romme and Knight 1981). High soil moisture, along with high fuel moisture in hardwood species and herbaceous vegetation in riparian areas, could reduce intensity and resulting severity of fire in riparian areas. However, high soil moisture could also lead to high biomass production and relatively high fuel loads in riparian areas. Thus, if fuels are sufficiently dry in riparian areas, they have the potential to sustain fires of high intensity and severity, especially in extreme weather conditions (Romme and Knight 1981, Camp et al. 1997, Williamson 1999).

Despite the potential for differences in fire behavior in riparian areas versus adjacent uplands, very few studies have focused on fire severity and the role of fire in riparian systems. In the studies that have addressed fire in riparian areas, there is a lack of consensus on fire effects in riparian areas compared to uplands. Some researchers have found cases where fire is less severe in riparian areas compared to uplands (Agee 1994, Skinner 2003), while others have found cases where fire is more severe in riparian areas (Romme and Knight 1981, Segura and Snook 1992, Camp et al. 1997, Agee 1998, Williamson 1999, Everett et al. 2003, Tollefson et al. 2004). Discrepancies in findings concerning how fire severity in riparian areas compares to that in uplands are likely due to variation in riparian attributes that influence fire severity, such as fuel characteristics, local topography, and microclimate. The factors leading to the variation in fire behavior in riparian areas need further investigation in order to determine the role of fire in riparian areas with varied attributes. Chapter 2 of this dissertation explores fire severity in riparian areas versus adjacent uplands and the factors influencing riparian fire severity in two recent fires in Oregon.

The answer to the question of how fire severity in riparian areas compares to that in uplands may also be dependent on which fire severity index is used. Although there are many common remotely-sensed and ground-based indices of fire severity, there is no single universally preferred quantitative measure of fire severity (Cocke et al. 2005, Key and Benson 2005, Hammill and Bradstock 2006, Lentile et al. 2006, Jain and Graham 2007), and there is little information on relationships among many of the various fire severity indices. Chapter 3 explores the relationships among several ground-based and remotely-sensed indices of fire severity in riparian areas.

Riparian areas are some of the most diverse, complex, and dynamic terrestrial habitats (Gregory et al. 1991, Naiman et al. 1993, Naiman and Decamps 1997). Riparian areas not only provide critical habitat to a diverse array of species, but also influence water quality throughout the stream system. Some of the ecological functions provided to streams by riparian vegetation include shade, stream bank stability, and input of organic matter and large wood. Sustainable management of these critical areas of the landscape requires an understanding of how disturbance processes affect them. Fire in riparian areas has the potential to influence riparian vegetation functions by altering plant community structure and composition, and the regeneration of riparian vegetation after a fire likely dictates the magnitude and duration of fire effects on stream systems (Minshall 2003). The study described in Chapter 4 addresses the effects of fire on riparian vegetation and investigates controls on patterns of post-fire riparian vegetation regeneration. Potential impacts of fire on ecological functions provided by riparian vegetation to adjacent streams are explored.

Overall, this dissertation explores the effects of fire in riparian areas and riparian forest response to fire. Studies were conducted in two recent fires in Oregon, the Biscuit Fire in southwestern Oregon and the B&B Complex Fire in the Cascade Mountains of Oregon. Results of these studies provide information on the role of fire in riparian areas in conifer-dominated forests in the western U.S. This knowledge can be used to evaluate current riparian forest conditions and develop achievable goals and strategies for managing riparian area structure and function.

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CHAPTER 2 - FIRE SEVERITY IN RIPARIAN AREAS OF THE BISCUIT AND B&B COMPLEX FIRES, OREGON

ABSTRACT

Fuels, topography, and microclimate may be distinct in riparian areas compared to uplands, and among different riparian areas, thus leading to variable fire behavior and effects. However, there is little information on fire severity in riparian areas. The present study compared riparian fire severity to that in adjacent uplands and investigated the factors influencing riparian fire severity in two recent fires in Oregon, the Biscuit Fire in southwestern Oregon and the B&B Complex Fire in the Cascade Mountain Range of Oregon.

A stratified random sampling design was used to select points in a range of fire severity classes, stand ages, and stream sizes in areas of each fire. At each selected point, plots were sampled in riparian areas and in adjacent uplands. Fire severity was assessed in each plot, and measurements were made of vegetation characteristics and local topography. Differences in fire severity in riparian areas versus adjacent uplands were assessed with t-tests, and model selection with Akaike's Information Criterion (AIC) was used to determine what factors were most strongly associated with riparian fire severity.

Understory fire severity (exposed mineral soil and scorch height) was significantly lower in riparian areas compared to adjacent uplands in both fires, suggesting a decoupling in understory fire effects in riparian areas versus uplands. However, overstory fire severity (crown scorch and basal area mortality) was similar in riparian areas and adjacent uplands in both fires. Of all explanatory variables considered in the analyses, fire severity in riparian areas was most strongly associated with upland fire severity, reflecting an expected spatial autocorrelation in fire behavior and effects between riparian areas and adjacent uplands. In addition, fuel variables, particularly those describing the riparian fine fuel component and species composition, were strong predictors of riparian fire severity. Slope variables were also strong predictors of exposed mineral soil, suggesting that slope in and around riparian areas be considered in predicting post-fire riparian soil conditions. Despite differences in species composition and topography between the two fire areas, I found consistency in fire severity and the

factors controlling fire severity in the Biscuit and B&B Complex Fires, suggesting that factors controlling fire severity in riparian areas may be similar across fire-prone regions of Oregon. In particular, the strong relationship between riparian and upland fire severity suggests that management practices that reduce upland fire severity may also reduce riparian fire severity.

INTRODUCTION

Disturbance is inherent in the dynamics of all ecosystems and plays a vital role in shaping landscape patterns and influencing ecosystem processes. Fire is the dominant disturbance process in the western US landscape, and its profound effects on species composition and age structure of upland forests are well documented (Agee 1993, Pyne et al. 1996). However, little is known about the role of fire in riparian zones (Dwire and Kauffman 2003), areas critical for both habitat and water quality in western landscapes.

Fire behavior is controlled by factors in three main categories: fuels, topography, and weather (Agee 1993, Pyne et al. 1996). Characteristics of all three of these categories may be distinct in riparian areas compared to uplands, and between different riparian zones, thus leading to distinct fire behavior and effects. However, there is little information on fire behavior and effects in riparian areas. For example, the relationship between upland fire severity and fire severity in adjacent riparian areas is uncertain; some researchers have found evidence that riparian areas burn less severely than uplands (Agee 1994, Skinner 2003), while others have found evidence that riparian areas burn more severely than adjacent uplands (Romme and Knight 1981, Segura and Snook 1992, Camp et al. 1997, Agee 1998, Williamson 1999, Everett et al. 2003, Tollefson et al. 2004).

Riparian fire severity is likely controlled by fuel characteristics (quantity, composition, and structure), local topography (slope, valley floor width, and elevation), and microclimate. Environmental conditions and related fuel characteristics can vary widely among riparian areas. Plant association surrounding a riparian area, size and age of trees in the riparian forest, and stream size can all influence fuel composition and structure, and consequently, fire behavior and severity. For example, deciduous hardwoods may be more dominant along larger streams due to high water availability and flooding regime (Baker 1989, Bradley et al. 1992, Pabst and Spies 1999, Nierenberg and

Hibbs 2000, Wimberly and Spies 2001), while conifers are often dominant along smaller streams. Riparian vegetation composition also influences the riparian plant community's susceptibility to fire; deciduous hardwood species dominant in many riparian zones are generally more susceptible to fire damage than conifer species (Flint 1925). In addition to differences in fuel composition and structure, fuel quantity differs among riparian areas. Increased water availability along some streams results in increased biomass, and therefore, greater fuel quantity. Tree basal area and density also vary within regions due to forest stand age (Naiman and Decamps 1997), flooding regime (Russell and McBride 2001), and species composition (conifer versus hardwood dominance).

Riparian topographic settings are also highly variable (Gregory et al. 1991), and this variability can lead to differences in fire behavior and fire severity among riparian zones. Topography changes with stream size; larger streams are generally found at lower elevations than smaller streams. Increased stream gradient, a factor that also tends to be associated with increasing elevation and decreasing stream size, likely leads to greater fire severity; slope angles flames closer to the unburned areas ahead of a fire, leading to increased preheating, fireline intensity and surface fire rate of spread (Rothermel 1983, Taylor and Skinner 1998). In addition, steep narrow valleys sometimes act as chutes or chimneys by channeling fire in the direction of wind (Agee 1993, 1994, Pyne et al. 1996, Skinner 2003).

The topographic setting in which riparian areas are found influence microclimatic conditions that also influence fire behavior. The topographic position of riparian areas, along with the presence of surface water and saturated soils, results in the characteristically moist microclimate of riparian areas (Dwire and Kauffman 2003). The low position of riparian areas in the landscape leads to nighttime cold air drainage and reduced solar insolation in riparian zones, thus making riparian areas generally cooler and moister than adjacent uplands (Agee 1994). Cooler temperatures and higher moisture in riparian zones likely result in reduced fire intensity and resulting severity in these areas.

Although microclimate in riparian zones is often distinct from that in uplands, similarities in climatic conditions that riparian areas and adjacent uplands experience during a fire may result in similarities in fire behavior and resulting severity. For example, riparian zones and adjacent uplands often burn at the same time of day, and at similar levels of ambient humidity. Thus, in addition to the influence of riparian fuels and topographic setting on fire behavior and resulting severity, fire behavior in adjacent upland forests influences, and is influenced by, that in riparian forests. High fire intensity in an upland forest can lead to greater preheating and thus higher fire severity in nearby riparian areas, and vice versa.

Fire severity can be thought of as recorded fire behavior and is the primary way to assess the impacts of a fire event on various ecosystem components. However, there is no universally preferred quantitative measure of fire severity (Cocke et al. 2005, Key and Benson 2005, Hammill and Bradstock 2006, Lentile et al. 2006). For the purposes of this study, fire severity was defined as the effects of fire on vegetation and soil and was assessed using four different common measures of fire severity, including two measures of overstory fire effects (crown scorch and basal area mortality), and two measures of understory fire effects (scorch height and exposed mineral soil).

This study investigated riparian fire severity and the factors influencing riparian fire severity in recent fires of two fire-prone regions in Oregon: the Klamath-Siskiyou region of southwestern Oregon and the east slope of the Cascade Range (Figure 2.1). The objectives of this study were to 1) compare riparian fire severity with that of adjacent uplands and 2) determine what factors are associated with riparian fire severity. Both study regions are characterized by forests dominated by Douglas-fir and mixed-severity fire regimes, where single fire events create a relatively fine-scale (10’s to 100’s of m) mosaic of patches of varied fire severity, including low, moderate, and severe burn patches (Agee 1993). However, there are differences in species composition, topography, and hydrology between these regions, and there is potential for distinct patterns in riparian fire severity given these regional differences.

METHODS

Site Descriptions

Biscuit Fire

The Biscuit Fire occurred in the Siskiyou Mountains of southwestern Oregon (Figure 2.1). The fire was a result of four separate lightning-ignited fires merging together in early July, 2002 and covered an area of approximately 200,000 ha before it was extinguished by rain in early November, 2002. The fire burned mainly in the Siskiyou National Forest, although some of the area burned is managed by the Bureau of Land Management (BLM). The pattern of the burn was a mosaic of burn severities; 29% of the area remained unburned or burned at low severity (up to 25% canopy mortality), 27% of the area burned with moderate severity (25-75% canopy mortality), and 44% of the area burned with high severity (>75% canopy mortality) (USDA Forest Service 2004).

Climate in the study area is characterized by cool, wet winters and warm, dry summers. Mean annual precipitation in the study area ranges from 250 to 300 cm (Daly et al. 2002), with higher precipitation levels on the western (coastal) side of the study area due to an orographic effect. Most precipitation falls between the months of November and April. The mean temperature in January ranges from two to five degrees, and the mean temperature in July ranges from 18 to 20ºC.

Terrain in the Biscuit Fire region is highly dissected with steep slopes. Elevation of study sites ranged from 200 to 1200 m in elevation. Streams in the region are fed primarily from groundwater and surface runoff. Parent material in the study area is primarily schist-phyllite, metamorphic/volcanic, metasedimentary/conglomerate, and metasandstone/siltstone. Major soil subgroups include Typic Dystrochrepts and Typic Hapludults.

Anthropological evidence suggests that, prior to Euro-American settlement, American Indians had been burning in the Siskiyou Mountains for many thousands of years (USDA Forest Service 2004). Although the fire history is not well-studied in the region, estimates of historical fire frequencies have ranged from 10 to 40 years (Atzet and Martin 1992, Sensenig 2002) with evidence of low to moderate severity fires (USDA Forest Service 2004). High severity fires also occurred during the pre-Euro-American settlement period (Agee 1993). Gold mining and related settlement began in the region in 1850. Early settlers used many of the same burning practices as the American Indians had used in the area to clear and maintain certain vegetation communities (USDA Forest Service 2004). Fire suppression activities began in the region in the early part of the twentieth century. Logging activities also occurred in the fire area throughout the twentieth century. The 39,000 ha Silver Fire occurred in 1987 in the Siskiyou National Forest, and the Biscuit Fire burned over the entire area of the Silver Fire and beyond the Silver Fire boundary. The Biscuit Fire was the largest fire in Oregon's recorded history. Although the fire occurred during a period of record-breaking drought, there is also question as to whether fire suppression activities starting in the early part of the twentieth century led to greater quantities of understory fuels and contributed to increased size and severity of the Biscuit Fire (USDA Forest Service 2004).

B&B Complex Fire

The B&B Complex Fire was the result of the merging of two lightning-caused fires, the Bear Butte and the Booth Fires, on the east slope of the Cascade Range in Oregon (Figure 2.1). From mid-August through late September of 2003, the B&B Complex Fire burned over approximately 37,000 ha. The fire burned mainly within the Deschutes and Willamette National Forests. Within the B&B Complex fire area, 38% of the area was unburned or burned with low severity (up to 25% mortality), 18% burned with moderate severity (25-75% mortality), and 44% of the area burned with high severity (>75% mortality) (USDA Forest Service 2005).

Climate in the B&B Complex Fire area is moderate with cool, wet winters and warm, dry summers. Annual precipitation in the fire area ranges from 50 cm at the lower elevations to 140 cm at the upper elevations (USDA Forest Service 2005). Most of the precipitation occurs from November to March. Precipitation above 1,000 m falls mainly as snow in the winter.

The B&B Complex fire area is characterized by gentle to moderately steep topography. Slope aspects within the fire area are generally easterly with north and south facing valley slopes. Elevation of sample areas ranged from 800 to 1500 m. The east slope of the Cascades where the B&B Complex Fire burned is a geologically young and complex volcanic region. Due to the high porosity of the volcanic soils, stream density is low, most streams in the area are spring-fed, and stream flow is stable.

Although little is known about pre-Euro-American fire history in the B&B Complex Fire area, estimates of mean fire return interval for the ponderosa pine sites in the Pacific Northwest range from approximately 11-16 years (Agee 1993). Evidence suggests that fires were low severity in ponderosa pine forests. However, more severe fires may have also occurred in these forests. Fire return intervals in the mixed conifer forest types likely ranged between 30 and 100 years (Agee 1993). Higher severity fires were likely more common in the mixed conifer forest types, particularly in the wet mixed conifer forest type of the B&B Complex Fire. Forests in the B&B Complex area were heavily grazed by domestic livestock, mostly cattle, in the late nineteenth century (Agee 1993). Fire suppression activities began in the fire area in the early twentieth century, and logging activities also occurred in the fire area throughout the twentieth century. As for the Biscuit Fire area, there is question as to whether fire suppression activities resulted in greater quantities of understory fuels in the B&B Complex Fire area, thus leading to increased fire size and severity (USDA Forest Service 2005). Potential fire suppression effects are of particular concern in the ponderosa pine forest type, since this forest type were historically characterized by a relatively frequent, low severity fire regime (USDA Forest Service 2005).

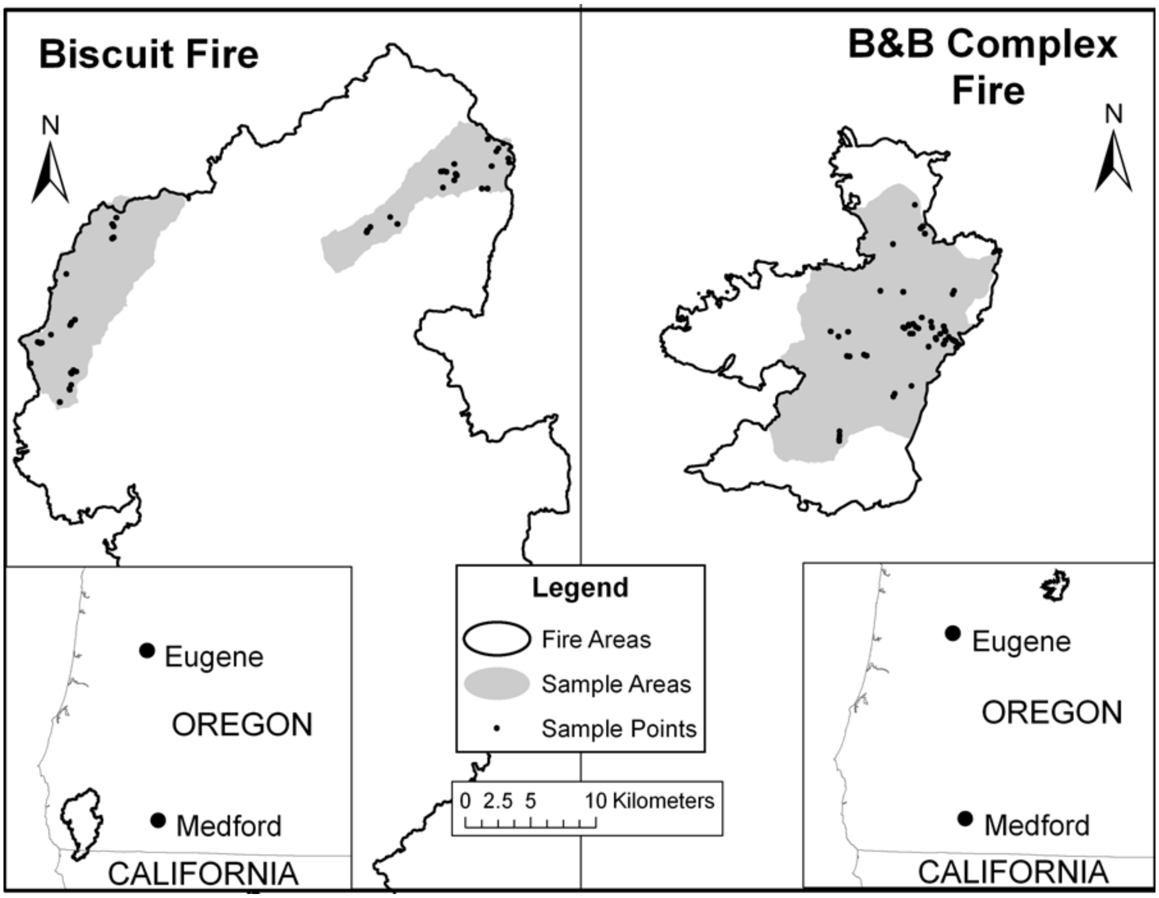

Figure 2.1. Locations of the Biscuit and B&B Complex Fires and study sites within fires. Sampling area in the two fires was similar (16,000 ha in the Biscuit Fire and 13,600 ha in the B&B Complex Fire).

Site Selection

Biscuit Fire

Two sixth-field sub-watersheds in the Biscuit Fire area were selected for sampling (Figure 2.1) based on differences in precipitation levels and plant associations between the watersheds, and variation in fire severity within each watershed. The first watershed on the east side of the fire (east watershed) is characterized by relatively low precipitation and forest productivity, is dominated by the dry tanoak plant association, and is approximately 6,000 ha in size. The second watershed on the west side of the fire (west watershed) is characterized by relatively high precipitation and forest productivity, is dominated by the wet tanoak plant association, and is approximately 10,000 ha in size. A stratified random sampling design was used to select points in each watershed that represented a range of broad fire severity classes, pre-fire tree size classes, and stream sizes, as described below.

Within a geographic information system (GIS), a fire severity map was used to separate each watershed into three broad fire severity categories (fire severity class 1, 2, and 3). The remotely-sensed fire severity map was created by the Forest Service with Landsat 7 ETM+ imagery of the burned areas acquired in August 2001 (pre-fire) and August 2002 (post-fire). Images were converted to reflectance values and were co-registered to each other. Both pre- and post-fire imagery was converted to Normalized Difference Vegetation Index (NDVI) values and then differenced (dNDVI). NDVI, an indicator of vegetation greenness, is derived by taking the difference between the near-infrared (Landsat ETM+ band 4) and red (Landsat ETM+ band 3) reflectance values and dividing by their sum (NDVI = (near infrared - red) / (near infrared + red)). Areas that showed little or no change in the NDVI in the Biscuit Fire (fire severity class 1) generally experienced low intensity underburn that consumed understory vegetation but had little influence on the overstory (<25% overstory mortality) (USDA Forest Service 2004). In areas with moderate change in NDVI (fire severity class 2), vegetation less than 21 inches in diameter at breast height (DBH) experienced close to 100% mortality, but overstory mortality remained low (25-50%). Areas that had high change in NDVI (fire severity class 3) had high vegetation mortality from high intensity fire (100% overstory mortality) (USDA Forest Service 2004).

For a given watershed and fire severity class, all existing first-, second-, and third-class stream segments were identified in a GIS. Class 1 streams are fish-bearing streams with a steady flow (stream orders 5-7), class 2 streams are also fish-bearing with moderate flow (stream orders 3-4), and class 3 streams have few fish and low flow (stream orders 1-2). Once stream segments were identified in each watershed and fire severity class, points on the stream segments were randomly selected in a GIS to represent a range of adjacent tree size classes (small, medium, and large size classes). The size class layer was created by the Forest Service based on aerial photographs, with size class 1 being the smallest size class (0-14.9” or 0-37.9 cm DBH), followed by size class 2 (15.0-19.9" or 40.0-50.7 cm DBH), and size class 3 (20.0" + or 50.8 cm + DBH) being the largest.

We attempted to sample each fire severity class/stream class/tree size class combination in each of the watersheds. This sampling strategy would have resulted in 27 points being sampled in each watershed, with number of points in the two watersheds totaling 54. However, only about 23 points were sampled in each watershed, because not all combinations for each watershed were found in the landscape. With the missing combinations, number of points in the two watersheds totaled 47. All of the missing combinations in the east and west watersheds involved moderate or high severity fire levels and stream class 1, the largest stream class (Appendix A). Four of the seven missing combinations involved tree size class 3. It is possible that many of the larger streams in these watersheds did not burn with high severity, especially when the larger streams were surrounded by forests dominated by larger trees. It is also possible that shadows in steep valleys prevented satellite detection of vegetation change.

B&B Complex Fire

The site selection procedure for the B&B Complex Fire closely followed that in the Biscuit Fire. However, for site selection in the B&B Complex Fire, only certain plant associations within five sixth-field sub-watersheds were chosen for sampling (plant associations did not separate by watershed as they did in the Biscuit Fire) (Figure 2.1). The study area was approximately 13,600 ha in size. Three plant associations were sampled, including ponderosa pine (*Pinus ponderosa*), dry mixed conifer, and wet mixed conifer. The ponderosa pine sites represent the driest sites in the study area, followed by dry mixed conifer and then the wet mixed conifer.

As in the Biscuit Fire, a stratified random sampling design was used to select points in each plant association that represented a range of broad fire severity classes, tree size classes, and stream sizes. The tree size class map used for the B&B Complex Fire was created by the Forest Service using aerial photographs and was comparable to that used for the Biscuit. The fire severity map used for the B&B Complex Fire was also created in a similar way to that for the Biscuit Fire. For the B&B Complex Fire, Landsat ETM+ imagery of the fire area was acquired from October 2002 (pre-fire) and October

2003 (post-fire). Both images were converted to reflectance values and were co-registered to each other. Both pre- and post-fire imagery was converted to Normalized Burn Ratio (NBR) values and then differenced. NBR is an index formulated from Landsat ETM+ band 7 (short wave infrared) and band 4 (near infrared) reflectance (NBR = (near infrared – short wave infrared) / (near infrared + short wave infrared)). Areas with little or no change in NBR in the B&B Complex (fire severity class 1) generally had low intensity to severe underburn that resulted in less than 25% mortality of overstory trees (USDA Forest Service 2005). Areas with moderate change in NBR (fire severity class 2) generally experienced mixed mortality, with the overstory tree mortality ranging from 25% to 75% (USDA Forest Service 2005). Areas with high change in NBR (fire severity class 3) experienced high intensity fire that resulted in 100% vegetation mortality (USDA Forest Service 2005).

We attempted to sample each fire severity class/stream class/tree size class combination in each of the three plant associations. This sampling strategy would have resulted in 27 points being sampled in each plant association, with number of points in the three plant associations totaling 81. However, only about 18 points were sampled in each plant association because not all combinations for each plant association were found in the landscape. With the missing combinations, number of points in the three plant associations totaled 54. All but one of the 27 missing combinations was in the dry and wet mixed conifer plant associations (Appendix A). Fifteen of the 27 missing combinations included tree size class 3, which represents the largest and likely oldest forests in the landscape. The size class 3 forests are rare compared to the younger size classes in the fire area, and this rarity of large size class forests could be due to past fires and/or harvesting activities in the forest. The missing combinations were evenly distributed among fire severity classes and stream classes.

Sampling Methodology

Biscuit Fire

Sampling was conducted in the summer of 2004, two years after the Biscuit Fire. At each randomly selected point, one 10- x 25-m (slope-corrected) plot was established in the riparian area. Half of the plot (5- x 25-m) was in the riparian area on one side of the stream, and the other half of the plot (5- x 25-m) was in the riparian area on the other side of the stream. The half-plots on each side of the stream were directly adjacent to and parallel with the stream. In addition to the riparian plots, one slope-corrected 10- x 25-m upland plot was placed 25 m in elevation above the riparian area on each side of the stream. This elevation change ensured that the upland plot would not be as directly influenced by the presence of a stream.

In each plot, an assessment of fire severity was done that included measurements of understory fire severity (scorch height and exposed mineral soil), and overstory fire severity (percent crown scorch and percent basal area mortality). Cover of exposed mineral soil was visually estimated to the nearest 5% in each plot. This assessment was conducted by the same two individuals throughout data collection, and an average of the estimates for each individual was used for each plot in order to reduce bias. Scorch height was measured as the height of char on the six tallest trees in each riparian plot and the three tallest trees in each upland plot. Crown scorch was measured with a hypsometer as the percent of the pre-fire live crown that was scorched by the fire. Crown scorch was also measured on the six tallest trees in each riparian plot and the three tallest trees in each upland plot. Basal area mortality and live basal area were approximated in each plot by measuring the diameter at breast height (DBH) of all trees greater than 5 cm DBH, and the species and live/dead status of each tree was recorded. All individual tree and shrub stems less than 5 cm DBH were counted by species. Dead shrub stems were also counted by species, and the percent cover of all live shrub species was visually assessed.

In riparian plots, further measurements were taken, including stream gradient (degrees slope) within plots, percent slope to each of the two upland plots, bank-full width, and valley floor width. Information such as plant association and tree size class for each sampling point was extracted from GIS layers created by the Forest Service.

B&B Complex Fire

Sampling in the B&B Complex Fire was conducted in the summer of 2005, two years after the B&B Complex Fire. The sampling strategy in the B&B Complex Fire was very similar to that in the Biscuit Fire, with some exceptions. In the B&B Complex Fire, instead of placing upland plots 25 m in elevation above the riparian area, upland plots were placed 150 m in slope-corrected distance from the riparian area. Slope-corrected distance was used in the B&B Complex Fire because there is only moderate elevation change between riparian areas and uplands in the B&B Complex Fire. Placing the upland plot 150 m away from the riparian plot ensured that the upland plot would not be as directly influenced by the presence of a stream as the riparian plot. All measurements taken in plots in the B&B Complex Fire were the same as those taken in the Biscuit Fire. Plant association and tree size class was extracted from GIS layers created by the Forest Service.

Data Analysis

Vegetation and Topographic Patterns

Indicator species analysis (Dufrêne and Legendre 1997) was conducted with an approximation of pre-fire vegetation (stem number) in study plots in order to identify species that were more consistently found in riparian areas or uplands and to identify species that were more consistently found in one plant association/watershed versus another. Pre-fire vegetation was approximated by including stems of all species that were thought to have been alive prior to the fire; stems that were dead before the fire showed a greater amount of bole damage than stems that were alive before the fire. Indicator species analysis produces indicator values for each species in each group based on information on species abundance in a particular group and the faithfulness of a species to a particular group (McCune and Grace 2002). Indicator values are tested for statistical significance using Monte Carlo randomization techniques. Indicator species analysis was performed using PC-ORD v5.0 (McCune and Mefford 1999) with 1000 Monte Carlo simulations. Species with p-values less than 0.05 were considered indicators of a particular group.

Analysis of variance (ANOVA) was used to compare mean levels of various topographic and vegetation-related variables, including bank-full width, valley floor width, stream gradient, slope to uplands, elevation, percent deciduous hardwood basal area, total basal area, and small stem number, among plots along different stream classes (two fires analyzed separately). PROC MIXED in SAS v9.1 (SAS Institute, Cary, NC, USA) was used to fit a mixed effects model to the data. Assumptions of normality and constant variance were checked prior to interpreting results of the analysis. Log-transformations were used when necessary to improve constant variance for a given variable. LSMEANS with a Bonferroni adjustment (SAS v9.1) was used for multiple comparisons of means.

Fire Severity in Riparian Areas versus Uplands

Paired t-tests were used to determine whether there were significant differences in fire severity measures between riparian areas and adjacent uplands in both the Biscuit and B&B Complex Fires (each fire analyzed separately). Statistical analyses were conducted using PROC TTEST in SAS v9.1 (SAS Institute, Cary, NC, USA). Analyses for riparian basal area mortality, crown scorch, scorch height, and exposed mineral soil were also run separately for each fire. Upland fire severity levels in the two upland plots at each point were averaged for the paired analysis. Model assumptions were checked and found to be adequately met prior to examining results of the analysis.

Factors Associated with Riparian Fire Severity

Model selection based on Akaike's Information Criteria (AIC_c) was used to identify site and vegetation factors that were strongly associated with riparian fire severity (response variable) in both the Biscuit Fire and B&B Complex Fires. Model selection with AIC provides an objective procedure for choosing a parsimonious model that is representative of the data. AIC_c, an adjustment of AIC when sample size is small in relation to the number of parameters in the candidate models (Burnham and Anderson 2002), was used in the model selection procedure to account for bias introduced by small sample sizes.

A priori hypotheses were generated (Table 2.1) and used to develop a set of biologically reasonable one-, two- and three-factor candidate regression models explaining riparian fire severity (riparian basal area mortality and exposed mineral soil, measures overstory and understory fire severity, respectively). The hypotheses focused on the three main factors most likely to explain riparian fire severity. These three main factors were fuel characteristics and environmental conditions in the riparian area and surrounding forest, local topography, and upland fire severity.

Explanatory variables included in the candidate models are described in Table 2.2a (Biscuit Fire) and Table 2.2b (B&B Complex Fire). These explanatory variables were put into categories according to what fire behavior factor they were thought to explain in the context of this study ("Category" in Table 2.2). No two variables in the same category were put into the same candidate model, since variables in the same category explain an aspect of the same factor of interest. With this restriction, a set of 38 one-, two-, and three-variable candidate models was developed for analysis for the Biscuit Fire (Table 2.3a), and a set of 32 candidate models was developed for analysis for the B&B Complex Fire (Table 2.3b). There were fewer candidate models for the B&B Complex Fire analysis because valley floor width was not included as an explanatory variable in this analysis; narrow valley floors were insufficiently represented in the B&B Complex Fire area for a valid statistical test of valley floor width effects. In addition, riparian percent hardwood stems was used in place of riparian hardwood basal area for the B&B Complex Fire because basal area of hardwoods was generally very low and similar among riparian plots; the majority of hardwood species in the B&B Complex Fire area were smaller than 5 cm DBH and so would not be included in the basal area calculation. Thus, a percentage of total stems that were hardwoods gave a better indication of hardwood abundance in riparian plots in the B&B Complex Fire. All Biscuit Fire candidate models included watershed as a blocking factor.

Elevation, a factor that would be included in the local topography category, was considered for inclusion as an explanatory variable of riparian fire severity in the AIC_c analyses for both fires. However, it was determined that other variables in the candidate models would account for elevation in relation to riparian fire severity. For example, plant association was highly correlated with elevation in the B&B Complex Fire, and in the Biscuit Fire, stream gradient, slope to uplands, and bank-full width were all highly correlated with elevation. Valley aspect, another factor that would be included in the local topography category, was also considered as an explanatory variable in the AIC_c analyses. However, there was not sufficient variation in valley aspect in sampled areas of either fire for a valid statistical test. Thus, although aspect and elevation are often included in models explaining fire behavior and severity, these variables were not included in this analysis.

Table 2.1. Hypotheses used to develop models for AICc analysis of factors associated with riparian fire severity in the Biscuit and B&B Complex Fires. Specific variable names are included in hypotheses or found in parentheses following the variable description.

	Fuel and Environmental Indicator Hypotheses
Hypothesis 1	Fire severity in riparian zones decreases with increasing hardwood composition (riparian deciduous hardwood basal area or riparian percent hardwood stems).
Hypothesis 2	Fire severity in riparian zones decreases with increasing forest tree size (tree size).
Hypothesis 3	Fire severity in riparian zones varies by plant association, with the highest riparian fire severity occurring in the plant association with the lowest fuel moisture (dry tanoak or ponderosa pine) and the lowest riparian fire severity occurring in the plant association with the highest fuel moisture (moist tanoak or wet mixed conifer).
Hypothesis 4	Riparian fire severity increases with an increase in the fine fuels component of riparian forests (riparian small stem number).
	Local Topography Hypotheses
Hypothesis 5	Fire severity in riparian zones decreases as the channel and valley floor widen (bank-full width and valley floor width).
Hypothesis 6	Riparian fire severity increases with increasing slope in riparian zones (stream gradient) and with increasing slope to uplands.
	Upland Fire Severity Hypothesis
Hypothesis 7	Fire severity in riparian zones increases with increasing fire severity in upland forests (upland fire severity), and vice versa.

Table 2.2. Explanatory variables for riparian fire severity included in candidate models for AICc analysis for the Biscuit Fire (a) and B&B Complex Fire (b). In the category column, 'F' stands for fuel and environment, 'T' stands for local topography, and 'U' stands for upland fire severity. Valley floor width was not included as an explanatory variable in the B&B Complex Fire analysis because narrow valley floors were insufficiently represented in the B&B Complex Fire area for a valid statistical test of valley floor width effects. In addition, riparian percent hardwood stems was used in place of riparian hardwood basal area in the B&B Complex Fire because basal area of hardwoods was generally very low and similar among riparian plots; the majority of hardwood species in the B&B Complex Fire area were smaller than 5 cm DBH and so were not be included in the basal area calculation. Thus, a percentage of total stems that were hardwoods gave a better indication of hardwood abundance in riparian plots in the B&B Complex Fire.

(a)

Variable Name	Variable Description	Variable Type, Units and Range	Category
Tree size	Mean tree size, including (1) Seed/Sap/Pole (12.7 cm), (2) Small (31.8 cm DBH), (3) Medium (44.5 cm DBH), and (4) Large (63.5 cm DBH)	Numeric, centimeters, 12.7-63.5	F
Riparian small stem number	Total number of woody stems less than 5 cm DBH in the riparian area (pre-fire)	Numeric, count, 440-29,480 per ha	F
Riparian deciduous hardwood basal area	Basal area of riparian-associated deciduous hardwood species in the riparian area (pre-fire)	Numeric, square meters, 0-56.4 per ha	F
Plant association	Plant association, including (1) moist tanoak, (2) white fir/Douglas-fir, (3) tanoak/oak, and (4) Port Orford cedar	Indicator, 4 levels	F
Bank-full width	Mean bank-full width of the stream over the length of a riparian plot	Numeric, meters, 0.6-13.0	T
Slope to uplands	Mean degrees slope from the stream to the upland plots	Numeric, degrees, 9-54	T
Stream gradient	Stream gradient, or degrees slope of the stream, over the length of a riparian plot	Numeric, degrees, 0-33	T
Valley Floor Width	Width of the valley floor at sample point	Numeric, meters, 5.4-110.0	T
Upland fire severity	Percent of total basal area of upland plot that was killed in the fire (highest of two upland plots)	Numeric, %, 5-100	U

(b)

Variable Name	Variable Description	Variable Type, Units and Range	Category
Tree size	Mean tree size, including (1) small single story (19.1 cm DBH), (2) small multistory with larger overstory (25.4 cm DBH), (3) small multistory with extra large overstory (35.6 cm DBH), (4) medium multistory with smaller understory (40.6 cm DBH), (5) medium multistory with larger overstory (48.3 cm DBH), and (6) large multistory with smaller understory (63.5 cm DBH)	Numeric, centimeters, 19.1-63.5	F
Riparian small stem number	Total number of woody stems less than 5 cm DBH in the riparian area (pre-fire)	Numeric, count, 3480-66,200 per ha	F
Riparian percent hardwood stems	Percent of total woody stems in the riparian area that were hardwoods (pre-fire)	Numeric, %, 26-100	F
Plant association	Plant association, including (1) ponderosa pine, (2) dry mixed conifer, and (3) wet mixed conifer	Indicator, 3 levels	F
Bank-full width	Mean bank-full width of a stream over the length of a riparian plot	Numeric, meters, 0.5-21	T
Slope to uplands	Mean degrees slope from the stream to the upland plots	Numeric, degrees, 1-29	T
Stream gradient	Stream gradient, or degrees slope of the stream, over the length of a riparian plot	Numeric, degrees, 1-13	T
Upland fire severity	Percent of total basal area of upland plot that was killed in the fire (highest of two upland plots)	Numeric, %, 0-100	U

Table 2.3. Candidate models developed to explain riparian fire severity in the Biscuit Fire (a) and B&B Complex Fire (b). All models for the Biscuit Fire included the base model blocking factor (watershed). For the B&B Complex Fire, the base model was essentially a null model with no explanatory factors.

(a)

Base Model:
1) Watershed
Fuel/Environmental Indicator Models:
2) Base + Tree size
3) Base + Riparian small stem number
4) Base + Riparian deciduous hardwood basal area
5) Base + Plant association
Local Topography Models:
6) Base + Bank-full width
7) Base + Slope to uplands
8) Base + Stream gradient
9) Base + Valley floor width
Upland Fire Severity Models:
10) Base + Upland fire severity
Fuel/Environmental Indicator and Local Topography Models:
11) Base + Tree size + Bank-full width
12) Base + Tree size + Slope to uplands
13) Base + Tree size + Stream gradient
14) Base + Tree size + Valley floor width
15) Base + Riparian small stem number + Bank-full width
16) Base + Riparian small stem number + Slope to uplands
17) Base + Riparian small stem number + Stream gradient
18) Base + Riparian small stem number + Valley floor width
19) Base + Riparian deciduous hardwood basal area + Bank-full width
20) Base + Riparian deciduous hardwood basal area + Slope to uplands
21) Base + Riparian deciduous hardwood basal area + Stream gradient
22) Base + Riparian deciduous hardwood basal area + Valley floor width
23) Base + Plant association + Bank-full width
24) Base + Plant association + Slope to uplands
25) Base + Plant association + Stream gradient
26) Base + Plant association + Valley floor width
Fuel/Environmental Indicator, and Upland Fire Severity Models:
27) Base + Tree size + Upland fire severity
28) Base + Riparian small stem number + Upland fire severity
29) Base + Riparian deciduous hardwood basal area + Upland fire severity
30) Base + Plant association + Upland fire severity
Local Topography and Upland Fire Severity Models:
31) Base + Bank-full width + Upland fire severity
32) Base + Slope to uplands + Upland fire severity
33) Base + Stream gradient + Upland fire severity
34) Base + Valley floor width + Upland fire severity

(a) (Continued)

Fuel/Environmental Indicator, Local Topography, and Upland Fire Severity Models:
35) Base + Plant association + Bank-full width + Upland fire severity
36) Base + Riparian deciduous hardwood basal area + Stream gradient + Upland fire
37) Base + Tree size + Slope to uplands + Upland fire severity
38) Base + Riparian small stem number + Stream gradient + Upland fire severity

(b)

Base Model:
1)
Fuel/Environmental Indicator Models:
2) Base + Tree size
3) Base + Riparian small stem number
4) Base + Riparian percent hardwood stems
5) Base + Plant association
Local Topography Models:
6) Base + Bank-full width
7) Base + Slope to uplands
8) Base + Stream gradient
Upland Fire Severity Models:
9) Base + Upland fire severity
Fuel/Environmental Indicator and Local Topography Models:
10) Base + Tree size + Bank-full width
11) Base + Tree size + Slope to uplands
12) Base + Tree size + Stream gradient
13) Base + Riparian small stem number + Bank-full width
14) Base + Riparian small stem number + Slope to uplands
15) Base + Riparian small stem number + Stream gradient
16) Base + Riparian percent hardwood stems + Bank-full width
17) Base + Riparian percent hardwood stems + Slope to uplands
18) Base + Riparian percent hardwood stems + Stream gradient
19) Base + Plant association + Bank-full width
20) Base + Plant association + Slope to uplands
21) Base + Plant association + Stream gradient
Fuel/Environmental Indicator and Upland Fire Severity Models:
22) Base + Tree size + Upland fire severity
23) Base + Riparian small stem number + Upland fire severity
24) Base + Riparian percent hardwood stems + Upland fire severity
25) Base + Plant association + Upland fire severity
Local Topography and Upland Fire Severity Models:
26) Base + Bank-full width + Upland fire severity
27) Base + Slope to uplands + Upland fire severity
28) Base + Stream gradient + Upland fire severity
Fuel/Environmental Indicator, Local Topography, and Upland Fire Severity Models:
29) Base + Plant association + Bank-full width + Upland fire severity
30) Base + Riparian percent hardwood stems + Stream gradient + Upland fire severity
31) Base + Tree size + Slope to uplands + Upland fire severity
32) Base + Riparian small stem number + Stream gradient + Upland fire severity

Regression analyses for model selection were conducted using PROC MIXED with maximum likelihood estimation methods in SAS v9.1 (SAS Institute, Cary, NC, USA). Analyses for riparian basal area mortality and exposed mineral soil, two different measures of fire severity, were run separately for each fire. The candidate models were ranked using AIC_c values.

To determine the set of best models for each analysis, several metrics were considered. The difference in AIC_c value between any given model (*i*) and the model with the lowest AIC_c, or the Δ_i, was considered; Δ_i from 0 to 2 indicated strong support for the model being the best approximating model, Δ_i from 2 to 4 indicated moderate support. Δ_i greater than 4 indicated weak support for the model being the best approximating model (Burnham and Anderson 2002), and thus these models were not included in the set of best models. The negative two log-likelihood was also considered in choosing the set of best models. Negative two log-likelihood can be thought of as the lack of model fit, or the relative strength of evidence against each model, given the data and given that the data is normal and the sample size is large. To further interpret the relative likelihood of a model, Akaike weights (ω_i), or the weight of evidence in favor of a certain model being the best model given a specific set of candidate models (Burnham and Anderson 2002), were considered. Akaike weights are likelihoods normalized to be a set of positive weights that sum to one. Only models with relatively low Δ_i, relatively low negative two log-likelihoods, and relatively high ω_i values were considered for the final set of best models.

The set of best models includes some explanatory variables and not others. However, inclusion in the set of best models by itself does not indicate the importance of a variable in explaining the response compared to other variables. Thus, in addition to determining the set of best models, the importance of any one explanatory variable compared to others was assessed using relative variable importance (Burnham and Anderson 2002). Relative variable importance (RVI) is calculated as the sum of the Akaike weights of all models in a set that include the explanatory variable of interest.

RVI values range from zero to one, and the larger the RVI value for a variable of interest, the more important that variable is relative to the other explanatory variables.

Model assumptions were checked prior to examining results of the analysis. The assumptions of linearity and constant variance were checked by visually examining residual plots for each model and scatter plots of the response against all explanatory variables. Log-transformations were used when necessary to improve linearity and/or constant variance for a given variable. Residual plots and scatter plots were examined to detect outliers and influential observations. In addition, PROC CORR in SAS v9.1 (SAS Institute, Cary, NC, USA) was used to examine correlation between all of the explanatory variables. All pairs of explanatory variables had correlation coefficients below 0.5, and thus, none of the explanatory variables had high enough correlation to cause variance inflation if they were put in the same model (Burnham and Anderson 2002).

The site selection in this study was designed so that the sampled sites were representative of riparian areas burned in the watersheds (Biscuit Fire) and plant associations (B&B Complex Fire) sampled. Thus, the scope of inference for this portion of the study is riparian forests in the sampled watersheds and plant associations in the Biscuit and B&B Complex Fires. However, the sampling strategy for this study was also designed to encompass a broad range of conditions, including a range of moisture levels, vegetation types, stream sizes, stand sizes/ages, and fire severity, in order to make this study more relevant to the entire area of the fires and to other fires and regions. This was an observational study, and thus causality between the explanatory variables and the response cannot be inferred.

RESULTS

Vegetation and Topographic Patterns

Biscuit Fire

Prior to the Biscuit Fire, upland forests in the fire area were dominated by *Pseudotsuga menziesii* (Douglas-fir), *Abies concolor* (white fir), *Pinus lambertiana* (sugar pine), *Chamaecyparis lawsoniana* (Port-Orford-cedar), *Thuja plicata* (western redcedar), and *Tsuga heterophylla* (western hemlock) (Table 2.4a). Forest midcanopies were dominated by hardwood species, such as *Lithocarpus densiflorus* (tanoak), *Chrysolepis chrysophylla* (golden chinquapin), *Arbutus menziesii* (Pacific madrone), and *Quercus chrysolepis* (canyon live oak) (Table 2.4a). Understories were characterized by *Rhododendron macrophyllum* (Pacific rhododendron), *Mahonia nervosa* (dwarf Oregon-grape), *Gaultheria shallon* (salal), and *Vaccinium* spp. (huckleberries).

Riparian forests in the Biscuit Fire study area were dominated by *Alnus rubra* (red alder), *Chamaecyparis lawsoniana*, *Pseudotsuga menziesii, Tsuga heterophylla,* and *Thuja plicata* (Table 2.4a). Common midstory species in riparian areas included *Alnus rubra*, *Acer circinatum* (vine maple), *Lithocarpus densiflorus*, and *Salix* spp. (willow species). Common riparian understory species included *Rubus ursinus* (wild blackberry), *Gaultheria shallon*, *Rhododendron macrophyllum, Mahonia nervosa*, *Rhododendron occidentale* (western azalea), and *Vaccinium* spp. (Table 2.4b).

In addition to differences in species composition between riparian areas and uplands, structural differences in pre-fire vegetation between these areas could have influenced fire severity. The mean height to live crown of measured riparian hardwood species (3.20 m, range 0.1 – 13.8 m) was an average of 5.67 m lower than that of upland conifers in the Biscuit Fire (at 8.86 m, range 0.1 – 37.3 m).

Vegetation composition differed between the two study watersheds in the Biscuit Fire area. Indicator species analysis of pre-fire vegetation (stem number) in study plots showed that some species were more consistently found in one watershed than the other. Similarly, some species were found more commonly in riparian areas than uplands. Indicator species for uplands in the east watershed (lower precipitation) included *Pinus lambertiana*, *Chrysolepis chrysophylla,* and *Quercus sadleriana* (Sadler oak). Indicator species for riparian areas in the east watershed included *Abies concolor*, *Cornus nuttallii* (Pacific dogwood), *Leucothoe davisiae* (Sierra laurel), *Thuja plicata*, and *Tsuga heterophylla* (Table 2.4). In the west watershed (higher precipitation), *Pseudotsuga menziesii* was an upland indicator species. Indicator species for riparian areas in the west watershed included *Chamaecyparis lawsoniana*, *Holodiscus discolor* (ocean spray), *Gaultheria shallon*, and *Vaccinium parvifolium* (red huckleberry) (Table 2.4).

Riparian areas along streams of different sizes also had distinct topography and vegetation composition in the Biscuit Fire area (Table 2.5a). Class 1 streams were generally wider (larger bank-full widths) with lower gradient and greater slope to the uplands (more incised valleys), and were found at lower elevations than class 2 and 3 streams. Valley floors were most narrow for the smallest streams. The number of stems less than 5 cm DBH was significantly lower along the larger class 1 and 2 streams than along the smaller class 3 streams. Total pre-fire basal area was lowest for the larger streams (Table 2.5a). However, the proportion of deciduous hardwoods was highest for the larger streams and decreased with decreasing stream size (Table 2.5a).

Table 2.4. Mean live basal area (range) of common overstory and midstory species in sampled riparian and upland areas (a), and mean live stem number (range) of common understory species in sampled riparian areas (b) before the Biscuit Fire. The east watershed is characterized by lower precipitation, while the west watershed is characterized by higher precipitation.

(a)

	Mean Basal Area (m^2/ha)			
	Upland East Watershed	Riparian East Watershed	Upland West Watershed	Riparian West Watershed
Abies concolor	6.41 (0-53.23)	1.31 (0-10.21)	0 (0)	0 (0)
Alnus rubra	0 (0)	4.31 (0-36.48)	0 (0)	6.48 (0-56.32)
Arbutus menziesii	0.41 (0-6.36)	0 (0)	1.57 (0-19.84)	0.17 (0-2.82)
Chrysolepis chrysophylla	0.97 (0-13.24)	0.79 (0-15.39)	1.54 (0-16.18)	0.33 (0-4.66)
Chamaecyparis lawsoniana	2.50 (0-40.38)	4.96 (0-74.70)	6.29 (0-48.75)	19.68 (0-68.94)
Lithocarpus densiflorus	3.27 (0-38.39)	0.83 (0-10.23)	4.32 (0-35.91)	0.86 (0-12.71)
Pinus lambertiana	5.47 (0-58.32)	0.60 (0-10.94)	1.92 (0-33.98)	0.15 (0-3.63)
Pseudotsuga menziesii	29.98 (0-146.79)	9.24 (0-84.71)	39.36 (0-185.86)	22.22 (0-125.84)
Quercus chrysolepis	1.17 (0-14.24)	0.01 (0-0.11))	2.99 (0-38.22)	0 (0)
Thuja plicata	0.53 (0-21.67)	6.32 (0-102.95)	1.62 (0-47.17)	0 (0)
Tsuga heterophylla	6.67 (0-59.37)	4.63 (0-64.35)	0.61 (0-15.38)	0 (0)
All Species	57.65 (0-166.67)	58.32 (3.82-211.79)	61.41 (1.33-217.09)	53.26 (2.05-186.62)

(b)

	Stems < 5 cm DBH (number/ha)	
	Riparian East Watershed	Riparian West Watershed
Acer circinatum	315 (0-3560)	272 (0-2920)
Alnus rubra	366 (0-1440)	375 (0-4560)
Cornus nuttallii	69 (0-760)	0 (0)
Gaultheria shallon	3293 (0-14400)	1110 (0-7040)
Holodiscus discolor	6 (0-120)	343 (0-2440)
Leucothoe davisiae	1053 (0-5960)	0 (0)
Lithocarpus densiflorus	309 (0-2120)	475 (0-3840)
Mahonia nervosa	1066 (0-8320)	302 (0-2280)
Quercus sadleriana	435 (0-3600)	8 (0-160)
Rhododendron macrophyllum	456 (0-2400)	612 (0-5680)
Rhododendron occidentale	240 (0-2360)	618 (0-6640)
Vaccinium ovatum	16 (0-320)	743 (0-13040)
Vaccinium parvifolium	289 (0-3520)	228 (0-1200)
All Species	9844 (1400-29480)	6693 (1000-15400)

B&B Complex Fire

The ponderosa pine plant association is located in the eastern portion of the B&B Complex Fire area, primarily at lower elevations (below 1,100 m). The dominant forest overstory species in the ponderosa pine plant association was *Pinus ponderosa* (ponderosa pine), with *Pseudotsuga menziesii*, and *Larix occidentalis* (western larch) in more mesic areas (Table 2.6a). Understories in the ponderosa pine plant association were dominated by grasses and shrub species, such as *Purshia tridentata* (antelope bitterbrush). In riparian zones, dominant overstory species included *Pinus ponderosa*, *Larix occidentalis*, and *Picea engelmanii* (Engelman spruce) (Table 2.6a). Indicator species in riparian areas of the ponderosa pine plant association included *Alnus incana* (thinleaf alder), *Amelanchier alnifolia* (Pacific serviceberry), *Larix occidentalis*, *Lonicera involucrata* (twinberry), *Physocarpus capitatus* (Pacific ninebark), *Pinus ponderosa*, *Spiraea betulifolia* (white spiraea), and *Symphoricarpos albus* (snowberry) (Table 2.6b).

The dry and wet mixed conifer plant associations in the B&B Complex Fire area are found between 1,000 and 1,500 m in elevation. Dominant forest overstory species in the mixed conifer plant associations included *Pinus ponderosa*, *Pseudotsuga menziesii*, and *Abies grandis/Abies concolor* (grand fir and white fir hybrid) (Table 2.6a). The forest understory was characterized by species such as *Ceanothus velutinus* (snowbrush), *Mahonia nervosa*, and *Rubus ursinus*.

Dominant overstory species in riparian areas of the dry mixed conifer plant association included *Abies grandis/Abies concolor*, *Pseudotsuga menziesii,* and *Picea engelmanii* (Table 2.6a). Indicator species in these riparian areas included *Abies grandis/Abies concolor*, *Acer circinatum*, *Holodiscus discolor*, *Pinus contorta* (lodgepole pine), and *Pseudotsuga menziesii* (Table 2.6b). Dominant overstory species in riparian areas of the wet mixed conifer plant association included *Abies grandis/Abies concolor*, *Pseudotsuga menziesii, Picea engelmanii*, *Tsuga heterophylla*, and *Thuja plicata* (Table 2.6a). Indicator species in riparian areas of the wet mixed conifer plant association included *Pachistima myrsinites* (boxwood), *Picea engelmanii, Rubus parviflorus* (thimbleberry), *Taxus brevifolia* (Pacific yew), *Tsuga heterophylla,* and *Thuja plicata* (Table 2.6b).

Differences in pre-fire vegetation structure between riparian areas and uplands in the B&B Complex Fire area may have influenced fire severity. The mean height to live crown of measured riparian hardwood species (1.59 m, range 0.1–15.4 m) was an average of 7.98 m lower than that of upland conifers (at 9.57 m, range 0.5–30.7 m) in the B&B Complex Fire.

Riparian areas along streams of different sizes had somewhat distinct topography and forest attributes in the B&B Complex Fire area (Table 2.5b). However, these patterns were not as distinct as those in the Biscuit Fire area. Class 1 streams were wider (larger bank-full widths) than class 2 and 3 streams. Class 1 streams also had higher total pre-fire basal area than smaller class 2 streams.

Differences in Vegetation and Topography between Fires

In addition to differences in vegetation composition and topographic patterns *within* the Biscuit and B&B Complex Fire areas, important differences in vegetation and topography *between* the two fire areas could have influenced patterns in riparian fire behavior and severity (Table 2.5). Riparian areas in the B&B Complex Fire area generally had a greater conifer component than riparian areas in the Biscuit Fire, particularly along larger streams. Total basal area along larger streams in B&B Complex Fire riparian areas was also generally higher than that in the Biscuit Fire, indicating that there were more large trees in riparian areas of large streams in the B&B Complex Fire. Stems less than 5 cm in DBH were generally more numerous in riparian areas of the B&B Complex Fire. Large and mid-sized (class 1 and 2) streams in the Biscuit Fire generally had larger bank-full widths than those in the B&B Complex Fire area. On average, small and mid-sized (class 3 and 2) streams in the Biscuit Fire had a higher stream gradient than those in the B&B Complex Fire, and slope to uplands from riparian zones was generally higher in the Biscuit Fire than it was in the B&B Complex Fire, indicating that valleys were generally more incised in the Biscuit Fire and that the terrain in the Biscuit Fire was steeper and more complex than that in the B&B Complex Fire.

Table 2.5. Mean values (range) for topographic and vegetation variables by stream class in the Biscuit Fire (a) and B&B Complex Fire (b). Class 1 streams are fish-bearing streams with a steady flow. Class 2 streams are also fish-bearing with moderate flow, and class 3 streams have few fish and low flow. For a given variable, means followed by the same letter are not significantly different (p-values > 0.05). Results of some tests are based on transformed data.

(a)

Stream Class	Bank-full width (m)	Valley Floor Width (m)	Stream Gradient (º)	Slope to Uplands (º)	Elevation (m)	% Deciduous Hardwood Basal Area	Total Basal Area (m^2/ha)	Stems < 5 cm DBH (per ha)
1	8.6 a (5.5-10.5)	29.0 a (19.0-50.5)	2 a (0-5)	43 a (29-54)	467 a (268-597)	73.7 a (2.8-100.0)	21.45 a (3.82-63.41)	3736 a (440-7120)
2	4.3 b (1.2-13.0)	32.8 a (7.3-75.0)	4 a (0-14)	29 b (13-41)	816 b (413-1002)	27.2 b (0.0-100.0)	72.85 b (14.06-211.40)	5162 a (1120-14600)
3	1.7 c (0.6-4.1)	21.8 b (5.4-110.0)	14 b (1-33)	27 b (9-42)	921 c (427-1151)	9.5 c (0.0-97.0)	56.01 b (7.89-186.65)	13431 b (1000-29480)

(b)

Stream Class	Bank-full width (m)	Valley Floor Width (m)	Stream Gradient (º)	Slope to Uplands (º)	Elevation (m)	% Deciduous Hardwood Basal Area	Total Basal Area (m^2/ha)	Stems < 5 cm DBH (per ha)
1	5.9 a (1.6-21.0)	107.3 a (20-525)	3 ab (1-6)	10 a (3-27)	3312 a (2681-4111)	13.9 a (0.0-100.0)	72.08 a (4.47-134.99)	23407 a (2920-52640)
2	1.7 b (0.5-3.1)	145.2 a (15-1000)	2 a (0-9)	8 a (1-30)	3483 a (2933-4607)	10.6 a (0.0-79.5)	45.58 b (1.00-103.93)	18455 a (2040-65920)
3	1.7 b (0.6-4.1)	151.0 a (20-1000)	4 b (1-13)	7 a (1-24)	3272 a (3035-3698)	4.0 a (0.0-17.2)	58.46 ab (19.38-122.53)	14991 a (2680-32400)

Table 2.6. Mean live basal area (range) of common overstory and midstory species in sampled riparian and upland areas (a), and mean live stem number (range) of common understory species in sampled riparian areas (b) before the B&B Complex Fire. Upland and riparian plots were sampled in the ponderosa pine, dry mixed conifer, and wet mixed conifer plant associations.

(a)

	Mean Basal Area (m^2/ha)					
	Upland Ponderosa Pine	Upland Dry Mixed Conifer	Upland Wet Mixed Conifer	Riparian Ponderosa Pine	Riparian Dry Mixed Conifer	Riparian Wet Mixed Conifer
Abies grandis/concolor	4.50 (0-41.97)	14.89 (0-86.55)	12.80 (0-73.63)	1.48 (0-15.04)	17.55 (0-61.78)	7.16 (0-48.98)
Alnus incana	0 (0)	0 (0)	0 (0)	3.23 (0-11.88)	1.14 (0-4.22)	0.99 (0-4.84)
Larix occidentalis	2.57 (0-21.58)	0.12 (0-2.79)	2.25 (0-14.70)	4.89 (0-21.98)	1.26 (0-15.61)	1.20 (0-21.64)
Pinus contorta	0 (0)	2.19 (0-30.47)	0.71 (0-14.23)	0 (0)	2.15 (0-31.97)	0 (0)
Picea engelmanii	1.34 (0-19.84)	2.09 (0-36.64)	5.76 (0-48.91)	14.04 (0-60.17)	10.53 (0-31.98)	19.85 (0-73.28)
Pinus ponderosa	29.54 (0-96.41)	8.95 (0-50.71)	7.94 (0-60.70)	11.74 (0-55.49)	5.16 (0-39.22)	2.08 (0-24.09)
Pseudotsuga menziesii	2.63 (0-23.87)	15.53 (0-81.21)	26.83 (0-116.02)	3.03 (0-44.79)	18.88 (0-88.97)	20.67 (0-99.30)
Thuja plicata	0.22 (0-6.36)	0.07 (0-1.58)	3.20 (0-76.28)	0.22 (0-3.74	1.44 (0-27.35)	8.85 (0-97.01)
Tsuga heterophylla	0 (0)	0 (0)	2.46 (0-37.02)	0 (0)	3.21 (0-25.34)	10.46 (0-77.78)
All Species	41.88 (6.73-88.27)	47.89 (3.04-100.81)	63.85 (4.30-123.99)	38.75 (1.01-124.19)	66.90 (19.38-134.99)	74.50 (26.56-131.77)

(b)

	Stems < 5 cm DBH (number/ha)		
	Riparian Ponderosa Pine	Riparian Dry Mixed Conifer	Riparian Wet Mixed Conifer
Abies grandis/concolor	327 (0-1720)	914 (0-5000)	504 (0-3760)
Acer circinatum	0 (0)	634 (0-4280)	273 (0-1280)
Alnus incana	4522 (0-13320)	2564 (0-7680)	1489 (0-7880)
Amelanchier alnifolia	828 (0-4880)	225 (0-2120)	49 (0-200)
Cornus sericea	1271 (0-16840)	181 (0-1600)	180 (0-920)
Holodiscus discolor	0 (0)	537 (0-3640)	22 (0-360)
Lonicera involucrata	802 (0-3720)	301 (0-2120)	216 (0-1320)
Mahonia nervosa	1461 (0-5600)	1347 (0-13080)	2973 (0-13520)
Pachistima myrsinites	0 (0)	541 (0-5000)	567 (0-3400)
Physocarpus capitatus	2612 (0-6040)	135 (0-2400)	218 (0-2000)
Ribes spp.	257 (0-2240)	1524 (0-10800)	1549 (0-7440)
Rosa gymnocarpa	4080 (840-12440)	2512 (0-6640)	2636 (0-8920)
Rubus parviflorus	5 (0-40)	566 (0-3040)	953 (0-4840)
Spiraea betulifolia	3593 (40-16600)	303 (0-3400)	1173 (0-9640)
Symphoricarpos albus	3167 (240-12480)	766 (0-4080)	1253 (0-7240)
Taxus brevifolia	0 (0)	126 (0-1080)	642 (0-5600)
Tsuga heterophylla	0 (0)	152 (0-2120)	296 (0-1480)
Vaccinium membranaceum	642 (0-7040)	547 (0-5880)	553 (0-4760)
All Species	25207 (6840-65920)	15975 (2680-31480)	17118 (2040-32400)

Fire Severity in Riparian Areas versus Uplands

Percent exposed mineral soil and scorch height on trees in riparian areas were significantly lower than that of adjacent uplands in both the Biscuit and B&B Complex Fires ($p < 0.01$ for all tests) (Figure 2.2). However, no significant differences between percent crown scorch and dead basal area mortality in the riparian and adjacent upland plots were found in either fire ($p > 0.2$ for all tests). These results show consistency in overstory fire effects between riparian areas and uplands, since crown scorch and basal area mortality were not significantly different in riparian areas versus uplands. However, these results suggest that understory fire effects in riparian zones are decoupled from understory fire effects in uplands, since fire severity in the understory of riparian areas (scorch height and exposed mineral soil) was significantly lower than that in uplands.

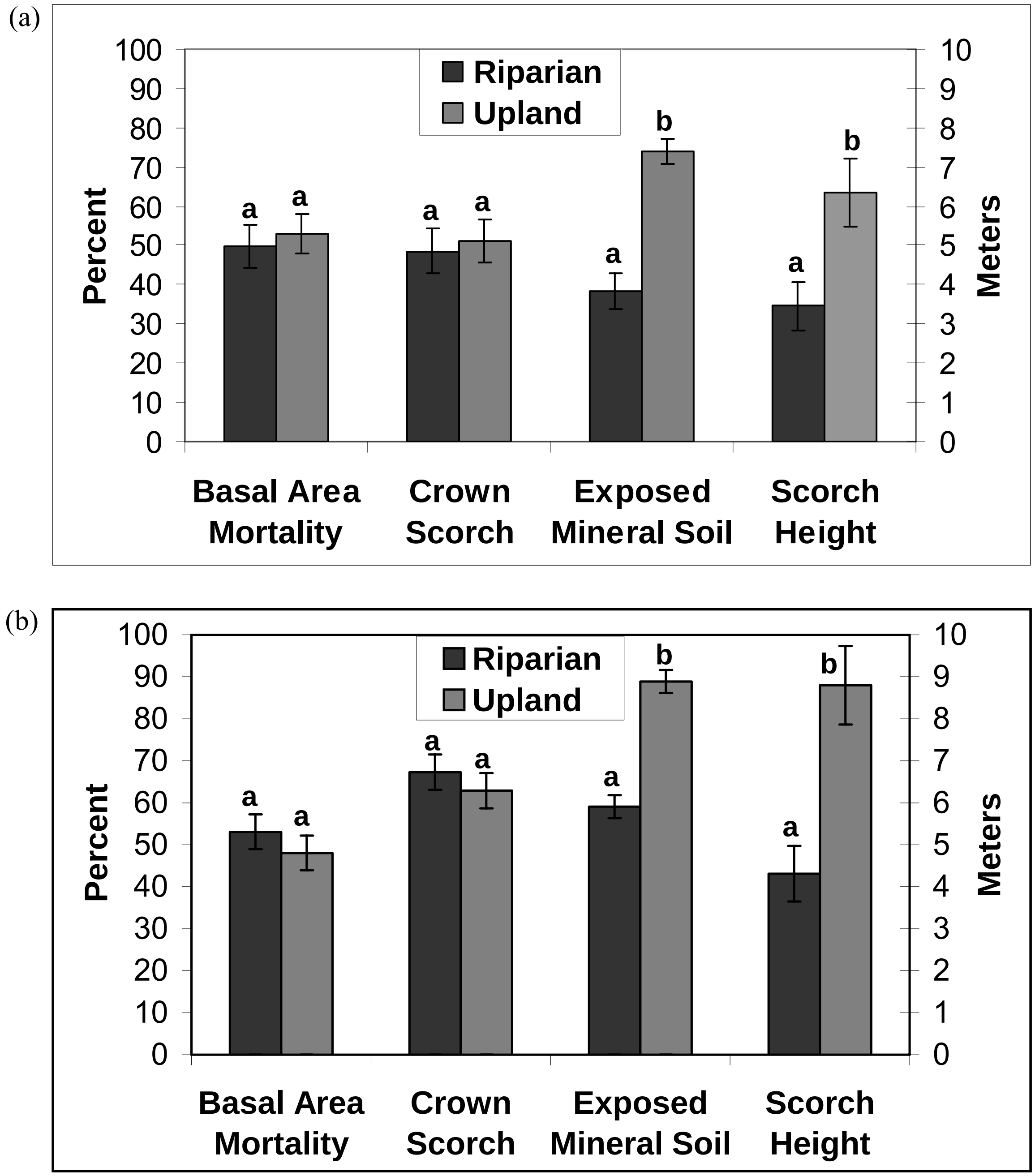

Figure 2.2. Mean fire severity levels in riparian areas versus adjacent uplands in the Biscuit Fire (a) and B&B Complex Fire (b). Of the fire severity variables on the x-axis, exposed mineral soil, crown scorch, and dead basal area are on a percentage scale (left-hand y-axis). Scorch height is shown in meters (right-hand y-axis). Standard errors are shown for each mean value. For a given fire severity measure, significant difference between riparian areas and uplands ($p < 0.05$) is indicated with a difference in letters between riparian areas and uplands; means with the same letter are not significantly different ($p > 0.05$).

Factors Associated with Riparian Fire Severity

To determine what factors were most strongly associated with riparian fire severity, a set of best models was chosen for each of the four analyses based on the negative 2 log-likelihood (-2LogL), AIC_c, Δ_i, and ω_i of the candidate models (Table 2.7). The predictive strength of different explanatory variables was further evaluated based on RVI (Table 2.8). Overall, upland fire severity and a riparian fuels/environmental indicator variable were the strongest predictors of overstory fire severity (basal area mortality) in the Biscuit and B&B Complex Fires (Tables 2.7 and 2.8). A local topography variable and a riparian fuels/environmental indicator variable were the strongest predictors of understory fire severity (exposed mineral soil) in the Biscuit Fire (Tables 2.7 and 2.8). Upland fire severity and variables in the local topography and riparian fuels/environmental indicator categories were all found to be strong predictors of understory fire severity in the B&B Complex Fire (Tables 2.7 and 2.8).

<u>Upland Fire Severity</u>

Upland fire severity (basal area mortality) was a relatively weak predictor of riparian understory fire severity (exposed mineral soil) in the Biscuit Fire (Table 2.8). However, upland fire severity was found to be a strong predictor of overstory fire severity (basal area mortality) in riparian areas of the Biscuit Fire, and of both understory fire severity (exposed mineral soil) and overstory fire severity (basal area mortality) in riparian areas of the B&B Complex Fire (Tables 2.7a, 2.7c, 2.7d, and 2.8). Evidence indicated that upland fire severity explained more variation in riparian overstory fire severity in the Biscuit Fire than any other explanatory variable; the RVI value for upland fire severity was 0.9798, indicating that almost 98% of the weight in favor of any of the 38 candidate models was for the models including upland fire severity (Table 2.8). The RVI for upland fire severity was also high in both the overstory and understory fire severity analyses for the B&B Complex Fire (0.6681 and 0.7577, respectively) (Table 2.8). In contrast, the RVI value for upland fire severity was comparatively low (0.3219) in the understory fire severity analysis for the Biscuit Fire (Table 2.8).

In all analyses, upland fire severity was positively associated with riparian fire severity, suggesting that when fire is severe in the uplands, it will also be severe in riparian areas (or vice versa), but when fire is of moderate or low severity in the uplands, fire will burn with moderate or low severity in the riparian zone. Upland fire severity is influenced by the same general weather conditions, such as ambient humidity, that influence fire in riparian areas, potentially resulting in similar fire behavior and severity in adjacent areas (spatial autocorrelation). Upland fire intensity can also have a direct effect, through pre-heating and drying of fuels, on riparian fire intensity and resulting severity, and vice versa, thus resulting in similar fire intensity and severity in the two adjacent areas.

Table 2.7. Results of AICc analysis of models explaining riparian overstory fire severity (basal area mortality) in the Biscuit Fire (a) and B&B Complex Fire (c) and for models explaining understory fire severity (exposed mineral soil) in the Biscuit Fire (b) and B&B Complex Fire (d). Number of parameters estimated in the model (K), negative 2 log-likelihood (-2LogL), AIC_c, difference in AIC_c values between any given model and the model with the lowest AIC_c (Δ_i), and Akaike weight (ω_i) are listed for each candidate model. Only models with Δ_i less than four and the null (base) model are shown. Models determined to be in the set of best models based on the listed criteria are shown in bold. Negative relationships between explanatory variables and the response are indicated by a (-), and positive relationships are indicated by a (+).

(a) Results of AICc analysis for models explaining riparian overstory fire severity in the Biscuit Fire.

Model	K	-2LogL	AIC_c	Δ_i	ω_i
Riparian small stem number (+), Upland fire severity (+)	4	19.00	28.00	0.00	0.35
Riparian small stem number (+), Bank-full width (-), Upland fire severity (+)	5	18.43	29.97	1.97	0.13
Riparian deciduous hardwood basal area (-), Upland fire severity (+)	4	21.59	30.59	2.59	0.10
Upland fire severity (+)	3	24.28	30.86	2.87	0.08
Bank-full width (-), Upland fire severity (+)	4	22.01	31.01	3.01	0.08
Stream gradient (+), Upland fire severity (+)	4	22.68	31.68	3.68	0.06
.	.	.	.	.	.
Null Model	2	36.02	40.31	12.31	0.00

(b) Results of AICc analysis for models explaining riparian understory fire severity in the Biscuit Fire.

Model	K	-2LogL	AIC_c	Δ_i	ω_i
Riparian deciduous hardwood basal area (-), Stream gradient (+)	4	-5.54	3.46	0.00	0.28
Riparian small stem number (+), Stream gradient (+)	4	-4.18	4.82	1.36	0.14
Riparian deciduous hardwood basal area (-), Bank-full width (-)	4	-3.64	5.36	1.91	0.11
Stream gradient (+), Upland fire severity (+)	5	-6.17	5.37	1.91	0.11
Riparian deciduous hardwood basal area (-), Bank-full width (-), Upland fire severity (+)	6	-8.69	5.52	2.06	0.10
Riparian deciduous hardwood basal area (-), Upland fire severity (+)	4	-2.09	6.91	3.45	0.05
Riparian small stem number (+), Bank-full width (-), Upland fire severity (+)	6	-6.81	7.40	3.94	0.04
.	.	.	.	.	.
Null Model	2	20.04	24.33	20.87	0.00

(c) Results of AICc analysis for models explaining riparian overstory fire severity in the B&B Complex Fire.

Model	K	-2LogL	AIC_c	Δ_i	ω_i
Plant association, Upland fire severity (+)	5	14.77	26.02	0.00	0.46
Plant association, Bank-full width (-), Upland fire severity (+)	6	14.09	27.87	1.85	0.18
Plant association	4	19.92	28.73	2.71	0.12
Plant association, Bank-full width (-)	5	18.10	29.35	3.33	0.09
.	.	.	.	.	.
Null Model	2	31.38	35.62	9.60	0.00

(d) Results of AICc analysis for models explaining riparian understory fire severity in the B&B Complex Fire.

Model	K	-2LogL	AIC_c	Δ_i	ω_i
Slope to uplands (+), Upland fire severity (+)	4	-0.31	8.51	0.00	0.76
Riparian small stem number (-), Slope to uplands (+)	4	2.15	10.97	2.46	0.22
.	.	.	.	.	.
Null Model	2	22.07	26.31	17.80	0.00

Table 2.8. Relative variable importance (RVI) for variables explaining riparian overstory fire severity (basal area mortality) and understory fire severity (exposed mineral soil) in the Biscuit and B&B Complex Fires. Variables are listed from highest to lowest RVI, and only variables with RVI greater than 0.10 are shown. RVI is the evidence of the importance of variables in explaining the response (fire severity), across all models considered. Values of RVI range from zero to one, with values closer to one indicating greater evidence for the importance of a variable. Negative relationships between explanatory variables and the response are indicated by a (-), and positive relationships are indicated by a (+). Explanatory variables were put into categories according to what fire behavior factor they were thought to explain in the context of this study. Categories included upland fire severity (U), fuels/environmental indicators (F), and local topography (T).

	Explanatory Variable	RVI	Category
Biscuit Fire Basal Area Mortality	Upland fire severity (+)	0.9798	U
	Riparian small stem number (+)	0.4963	F
	Bank-full width (-)	0.2830	T
	Riparian deciduous hardwood basal area (-)	0.1415	F
Biscuit Fire Exposed Mineral Soil	Riparian deciduous hardwood basal area (-)	0.6082	F
	Stream gradient (+)	0.5828	T
	Upland fire severity (+)	0.3219	U
	Bank-full width (-)	0.2890	T
	Riparian small stem number (+)	0.2173	F
B&B Complex Fire Basal Area Mortality	Plant association (ponderosa pine > dry mixed conifer > wet mixed conifer)	0.7900	F
	Upland fire severity (+)	0.6681	U
	Bank-full width (-)	0.2705	T
	Tree size (+)	0.1470	F
B&B Complex Fire Exposed Mineral Soil	Slope to uplands (+)	0.9951	T
	Upland fire severity (+)	0.7577	U
	Riparian small stem number (-)	0.2229	F

Riparian Fuels

Overstory Fire Severity

After accounting for upland fire severity, riparian fuels/environmental indicator variables were strong predictors of riparian overstory fire severity (basal area mortality) in both fires. Riparian small stem number (stems less than 5 cm DBH) was included in the top two models explaining riparian overstory fire severity in the Biscuit Fire (Table 2.7a and 2.7c), and the RVI for riparian small stem number was 0.4963 (Table 2.8), meaning that almost 50% of the weight in favor of any of the models was for models including riparian small stem number. Overstory fire severity was higher in riparian areas with a greater number of small stems. Small stems (fine fuels) ignite and sustain combustion more easily than large fuels, leading to greater fire intensity and severity (Pyne et al. 1996). The number of small stems in a riparian area could also reflect other environmental factors, such as moisture levels, which may also influence fire behavior.

Evidence showed that plant association explained the most variation in riparian overstory fire severity of any of the included explanatory variables in the B&B Complex Fire; the RVI of plant association was 0.7900 (Table 2.8), indicating that almost 79% of the weight in favor of any of the candidate models was for the six models containing plant association. There was also strong evidence that the model including plant association and upland fire severity explained the most variation in riparian overstory fire severity (lowest AICc value and high ω_i) (Table 2.7c). The equation for this "best" approximating model for riparian overstory fire severity in the B&B Complex Fire is as follows (standard errors shown in parentheses below the parameter estimates):

$$\text{Riparian overstory fire severity} = \underset{(0.10)}{0.23} + \underset{(0.09)}{0.33}\text{*ponderosa pine} + \underset{(0.09)}{0.10}\text{*dry mixed conifer} + \underset{(0.11)}{0.26}\text{*upland fire severity (\% basal area mortality)}$$

According to this model, after accounting for the effect of upland fire severity, riparian overstory fire severity was 33 percentage units higher (95% CI: 15, 51) in ponderosa pine forests compared to wet mixed conifer forests. Riparian overstory fire severity was not significantly higher in dry mixed conifer forests compared to wet mixed conifer forests (estimated difference was 10 percentage units higher, 95% CI: -9, 28).

Compositional differences between riparian plots in the ponderosa pine and wet mixed conifer plant associations could account for differences in overstory fire severity between these plots. Ponderosa pine plots had a greater mean percentage of fire-sensitive deciduous hardwood stems (96%) than wet mixed conifer plots (81%). Ponderosa pine riparian plots also had more than twice the mean basal area and small stem number of the fire-sensitive *Alnus incana* compared to wet mixed conifer riparian plots (Table 2.6). Dead *Alnus incana* made up an average of 33% of the total dead basal area in ponderosa pine riparian plots but made up only an average of 1% of total dead basal area in wet mixed conifer riparian plots. Thus, greater hardwood composition, particularly *Alnus incana* composition, in ponderosa pine riparian plots accounts for the greater proportion of dead basal area in ponderosa pine riparian plots compared to those in the wet mixed conifer plant association. This reflects a difference in fire effects because of compositional differences between riparian plots in the ponderosa pine and wet mixed conifer plant associations rather than in a difference in fire behavior in riparian areas in these two plant associations.

Understory Fire Severity

Riparian understory fire severity was associated with riparian fuels/environmental indicator variables in both fires (Table 2.7b and 2.7d). Riparian deciduous hardwood basal area (RVI = 0.6082) was strongly negatively associated with riparian understory fire severity in the Biscuit Fire, suggesting that riparian understory fire severity was lower in areas with greater riparian deciduous hardwood basal area. Deciduous hardwoods serve as a microsite indicator in the Siskiyou region in that their presence indicates generally mesic soil conditions. Deciduous hardwoods also have higher fuel moisture than conifers (Pyne et al. 1996). The high fuel and soil moisture levels in location where deciduous hardwoods grow likely lead to decreased fire intensity and resulting understory fire severity.

Although it was included in the set of best models for understory fire severity in the Biscuit Fire, riparian small stem number had a relatively low RVI of 0.2173. The number of small stems in riparian areas was positively associated with riparian exposed mineral soil in the Biscuit Fire. Small stems ignite and sustain combustion more easily than large fuels (Pyne et al. 1996), leading to greater fire intensity and resulting severity.

Riparian small stem number was a weak predictor of riparian understory fire severity in the B&B Complex Fire. Riparian small stem number was in the set of best models explaining riparian understory fire severity (Table 2.7d). However, the RVI was 0.2229 for riparian small stem number (Table 2.8). This result suggests that, in the B&B Complex Fire, combustion of small fuels did not lead to increased fire severity. Small stems in riparian areas of the B&B Complex Fire were mostly riparian-associated deciduous hardwoods (Table 2.6b), as opposed to a mix of riparian and upland associated species such as that found in riparian areas of the Biscuit Fire (Table 2.4b). A greater number of small stems in riparian areas of the B&B Complex Fire could indicate generally wet conditions that lead to decreased fire intensity and resulting severity.

Local Topography

Overstory Fire Severity

Bank-full width was weakly negatively related to riparian overstory fire severity in both fires (Table 2.7a and 2.7c), indicating that basal area mortality was lower along larger streams. Although bank-full width was included in the second best model explaining riparian overstory fire severity for both fires, and the Δ_i for this model was less than four in both cases, these models were almost two Δ_i units from the top models, and the ω_i values for these models were less than half that of the top models (Table 2.7a and 2.7c). In addition, for models explaining riparian overstory fire severity, the RVI for bank-full width was less 0.30 for both fires (Table 2.8). Thus, it seems that bank-full width has less explanatory power than measures of riparian fuels and upland fire severity in explaining riparian overstory fire severity in both the Biscuit and B&B Complex Fires, suggesting that fuel conditions and adjacent fire behavior are more important in predicting local fire behavior than the presence of a watercourse. However, the weak negative relationship between overstory fire severity and bank-full width suggests that fire severity is lower along larger streams. Larger streams are wider, and thus have greater potential to act as fire breaks. Cold air drainage may be greater in the larger streams because they are generally at lower elevations. The gradient of larger streams is lower than that of smaller streams, resulting in less pre-heating of fuels ahead of the flaming front and less heat-generated wind, and thus lower fire severity. Larger streams also generally have a greater deciduous hardwood component than smaller streams, which likely leads to lower fire severity along larger streams because of the high fuel moisture of deciduous hardwood species.

Understory Fire Severity

Riparian understory fire severity was strongly associated with topography in both fires, particularly slope (Table 2.7b and 2.7d). In the Biscuit Fire, stream gradient was in three of the top four models explaining riparian understory fire severity (Table 2.7b). Stream gradient had the second highest importance value (0.5828) of any variable explaining riparian understory fire severity in the Biscuit Fire (Table 2.8). Stream gradient was strongly positively associated with Biscuit Fire riparian understory fire severity, suggesting that riparian areas along streams with higher gradients had higher fire severity than those along streams with lower gradients. Higher gradient streams burn more severely because greater slope steepness leads to greater pre-heating of fuels ahead of the flaming front and more heat-generated wind, leading to increased flame length and surface fire rate of spread and thus higher fire severity.

In the B&B Complex Fire, riparian understory fire severity was strongly positively associated with slope to uplands. Slope to uplands was included in both of the top models explaining riparian exposed mineral soil in the B&B Complex Fire (Table 2.7d). RVI for slope to uplands was very high at 0.9951, meaning that almost all of the weight in favor of any of the candidate models was for models including slope to uplands (Table 2.8). Slope to uplands, or percent slope from the riparian plot to the upland plots, was found to be strongly positively associated with riparian understory fire severity, indicating that riparian locations in steeper valleys experience higher fire severity. Slope angles flames closer to the unburned areas ahead of the fire. Thus, fuels ahead of the fire front reach ignition temperatures more quickly than if flames were perpendicular to the ground surface. This increases flame length and surface fire rate of spread (Rothermel 1983).

DISCUSSION

Fire Severity in Riparian Areas versus Uplands

Despite distinct differences in vegetation composition and topography between the two study regions, fire severity levels in riparian areas versus uplands were largely consistent between the Biscuit and B&B Complex Fires; riparian areas in both fires had lower understory fire severity (exposed mineral soil and scorch height) but similar levels of overstory fire severity (crown scorch and basal area mortality) compared to uplands. Other studies of fire severity in riparian areas versus uplands have quantified fire severity as overstory mortality (Segura and Snook 1992, Agee 1998, Tollefson et al. 2004) or crown scorch from aerial photographs (Williamson 1999). These studies found that fire severity in riparian areas was similar to or higher than that in the uplands, consistent with the riparian versus upland crown scorch and basal area mortality results in this study. However, these studies did not compare scorch height or effects of fire on soils in riparian areas versus adjacent uplands. Results of this and other studies suggest that the answer to the question of how fire severity in riparian areas compares to that in uplands depends on the fire severity measure used; overstory measures of fire severity show similarity in riparian and upland fire severity levels, but understory measures of fire severity show that fire severity is lower in riparian areas compared to uplands. Lower levels of understory fire severity but similar levels of overstory fire severity in riparian areas compared to uplands suggest a decoupling of understory fire effects in riparian areas versus adjacent uplands.

While surface and crown fires result in the combustion of aboveground biomass and the litter layer, smoldering combustion in ground fires is responsible for the combustion of the organic soil layers (Kasischke et al. 1995, Pyne et al. 1996). The biomass consumption (fire severity) resulting from one of these burning processes can be independent of biomass consumption resulting from the other, particularly when soil moisture is high (Kasischke et al. 1995, Pyne et al. 1996).

The lower understory fire severity in riparian areas versus adjacent uplands is likely due to a combination of factors related to high moisture levels and cooler microclimate in riparian areas. Higher moisture availability in riparian zones compared to uplands results in changed species composition, mainly increased abundance of deciduous hardwoods. Deciduous hardwoods generally have higher fuel moisture than conifers (Pyne et al. 1996). Understory shrubs and herbaceous vegetation in riparian zones also tend to have higher moisture content than that in uplands (Agee et al. 2002), most likely due to the cooler microclimate and higher relative humidity in riparian zones (Danehy and Kirpes 2000). Moisture acts as a heat sink, since it must be boiled away before fuels reach ignition temperature (Agee 1993, Pyne et al. 1996). When moisture content is high, fires do not easily ignite and burn poorly, if at all (Pyne et al. 1996). Thus, the cool riparian microclimate, saturated riparian soils, and high moisture content of riparian fuels likely combine to result in reduced fire intensity and consequent severity in the understories of riparian zones.

Pre-fire differences in the thickness of the organic matter layer in riparian areas compared to uplands could also contribute to the lower levels of post-fire exposed mineral soil in riparian zones. However, lower scorch height in riparian areas compared to uplands, combined with lower exposed mineral soil, indicates that understory fire severity was lower in riparian zones.

Despite lower understory fire severity in riparian areas, levels of overstory fire severity were similar in riparian areas compared to uplands. The level of overstory fire severity in riparian areas may be explained by the fire susceptibility of species commonly found in riparian areas. Riparian areas of forested western North America are dominated by species that are competitive in high moisture, flood-prone environments, often deciduous hardwoods (Baker 1989, Bradley et al. 1992, Pabst and Spies 1999, Nierenberg and Hibbs 2000, Wimberly and Spies 2001). Species with higher moisture requirements tend to have thinner bark, making them more susceptible to girdling, and retain lower branches (lower height to live crown), making torching of the foliage more likely (Flint 1925, Agee 1993).

Lower live branches can carry a fire into the crown of a tree, resulting in greater crown scorch and mortality. This and another study (Williamson 1999) showed that riparian hardwoods have lower height to live crown than upland conifers. In conifer dominated forests of west-central Idaho, height to live crown of riparian trees was below the critical level required for crowning activity, while that of upland trees was above the critical level (Williamson 1999). Thus, even though scorch height on trees in riparian areas of the Biscuit and B&B Complex Fires was generally lower than that in uplands, the crown scorch and morality was relatively high for riparian trees, likely because of lower height to live crown.

Factors Associated with Riparian Fire Severity

Of the potential factors influencing riparian fire severity, including fuel characteristics/environmental indicators, local topography, and upland fire severity, upland fire severity was the most consistently strong predictor of riparian fire severity in the Biscuit and B&B Complex Fires. The relationship between fire severity in riparian areas and adjacent uplands reflects expected spatial autocorrelation, whereby a process in an adjacent area affects that process locally. Fire intensity in uplands can have a direct effect on riparian fire intensity and resulting severity (and vice versa) through pre-heating and drying of fuels. In addition, weather conditions that control fire behavior are likely very similar in riparian areas and adjacent uplands during fire events, thus leading to similarities in fire behavior and resulting severity.

After accounting for upland fire severity, riparian fuels/environmental indicators were found to influence riparian fire severity, particularly overstory fire severity (basal area mortality). Among different riparian fuels/environmental indicator variables, plant association was the strongest predictor of overstory fire severity in the B&B Complex Fire, and small stem number was a strong predictor of overstory fire severity in the Biscuit Fire. The influence of plant association on riparian overstory fire severity (basal area mortality) likely reflects varied abundance of species with high susceptibility to fire, while the influence of small stem number reflects the increased fire intensity and severity resulting from a greater fine fuel component in riparian zones.

Overstory riparian fire severity was significantly higher in the ponderosa pine plant association than it was in the wet mixed conifer plant association of the B&B

Complex Fire. This is opposite the hypothesized relationship between plant association and riparian fire severity, and the results of this study indicated that the plant association hypothesis did not include a number of factors related to plant association that could influence riparian fire behavior, mainly species composition and species susceptibility to fire. Increased overstory fire severity in ponderosa pine forests compared to wet mixed conifer forests is likely due to differences in species composition in ponderosa pine riparian forests compared to wet mixed conifer riparian forests; ponderosa pine riparian plots had a greater component of the fire-sensitive *Alnus incana* (thinleaf alder), which made up a large portion of dead basal area in ponderosa pine riparian plots. The wet mixed conifer plant association had a lower mean proportion of fire-sensitive deciduous hardwoods. Thus, measured fire severity varied with vegetation composition in addition to fire behavior.

As hypothesized, overstory fire severity was higher in locations with a greater number of small stems in the Biscuit Fire. This is likely due to the elevated ability of small fuels to ignite and sustain combustion compared to large fuels (Pyne et al. 1996). However, in the B&B Complex Fire, understory fire severity was lower in locations with a greater number of small stems. It is possible that locations with a high number of small stems are also locations with high soil moisture and fuel moisture in the B&B Complex Fire. Despite the relatively large fine fuel component, high moisture levels in these locations would result in reduced fire severity, particularly understory fire severity. High small stem number in the Biscuit Fire would not necessarily be indicative of high moisture availability due to the high number of drought-tolerant evergreen hardwood species. Thus, it is likely differences in species composition between the two fire areas resulted in varied relationships between small stem number and riparian fire severity.

Riparian fuels/environmental indicators were also found to predict understory fire severity in the Biscuit Fire. As hypothesized, riparian deciduous hardwood basal area was strongly negatively associated with riparian understory fire severity in Biscuit Fire riparian areas, indicating that understory fire severity was lower in riparian areas with a greater deciduous hardwood component. The presence of deciduous hardwoods in the

Siskiyou region where the Biscuit Fire took place is generally indicative of high soil moisture levels. High soil moisture levels in areas with a relatively large deciduous hardwood component likely contribute to lower fire intensity and resulting understory fire severity in riparian zones. However, when fire reaches greater intensity in riparian zones, the deciduous hardwoods seem to be highly susceptible to fire damage.

While fuels/environmental indicators were strong predictors of overstory fire severity, local topography variables were some of the strongest predictors of understory fire severity. As hypothesized, understory fire severity in both fires increased as measures of topographic steepness increased. In the Biscuit Fire, stream gradient was strongly positively associated with riparian understory fire severity. In the B&B Complex Fire, riparian understory fire severity was strongly positively associated with slope to uplands, indicating that riparian locations in steeper, more incised valleys experience higher fire severity. Kobziar and McBride (2006) also found a positive association between steeper slopes and the severity and extent of riparian zone burns along two Sierra Nevada streams. Increased slope results in increased preheating and surface fire rate of spread, thus leading to increased understory fire severity.

The relationship between exposed mineral soil and slope in both fires could also be due to factors that are not related to fire. It is possible that riparian areas with steeper slopes in the Biscuit and B&B Complex Fires had thinner organic matter layers before the fire events or lost organic matter after the fire events due to increased erosion potential on steeper slopes (Brady and Weil 2002). We did not measure pre-fire differences in organic layer thickness and thus cannot account for any effect on post-fire differences.

Management Implications and Conclusions

In spite of differences in the species composition and topography between the two study areas, the factors controlling fire severity were consistent between the Biscuit and B&B Complex Fires, suggesting that factors controlling fire severity in riparian areas may be similar in other parts of Oregon with comparable vegetation types. Overstory fire severity in riparian areas of these regions is primarily associated with upland fire severity and riparian fuel characteristics/environmental indicators. Understory fire severity in riparian areas of these regions is mainly associated with slope steepness, with upland fire severity and riparian fuels/environmental conditions also having an influence.

Assessing riparian fire severity after a fire is difficult with remote-sensing due to shadows from riparian sideslopes. However, because upland fire severity was most consistently associated with riparian fire severity, a measure of upland fire severity may be the most useful post-fire indicator of riparian fire severity from a management perspective. Because riparian areas adjacent to uplands that burned with high severity (>75% basal area mortality) are more likely to have burned at high severity themselves, they may be at greatest risk for stream bank instability and increased stream temperatures due to the loss of shade over the stream after a fire. However, some riparian areas may have burned with high severity historically and so the vegetation may be adapted to high severity fire. If riparian vegetation is adapted to high severity fire, and high severity fire is necessary to maintain historic processes and conditions (which may include erosion), then post-fire rehabilitation activities may not be necessary to maintain historic riparian conditions.

Predicting future riparian fire severity could be accomplished by using factors found to be strongly associated with riparian fire severity in this study, such as small stem number. These factors could be used to predict which riparian areas would be likely to burn with high severity in future fires. High severity fire may not be desirable in riparian areas that were historically characterized by lower severity fire, but as a result of fire suppression and subsequent fuel buildup, are burning with higher fire severity in present-day fires. Thus, pre-fire predictors of riparian fire severity may be useful in targeting areas for fuels reduction treatments. However, although methods to treat fuels in more upland-like riparian forests along smaller streams may be similar to those in uplands, it is not clear how fuels treatments in riparian areas would be conducted along larger streams with a greater deciduous hardwood component. Thinnings in upland forests are often accomplished by removing smaller understory stems and ladder fuels. But in many riparian forests along larger streams, smaller understory stems are primarily deciduous hardwood species that play important roles in the functioning of some riparian forests by providing stream shade, stream bank stabilization, wildlife habitat, and allochthonous inputs to streams. Thus, removing deciduous hardwood stems in riparian fuels treatments may have ecological costs. In addition, most hardwoods and many shrub species resprout after cutting, which would result in more fine fuels after a thinning in riparian areas, potentially increasing future fire severity. Thus, it is not clear if fuels treatments would effectively reduce riparian fire severity, particularly in extreme weather conditions, or how frequently riparian fuels treatments would have to be conducted to reduce riparian fire severity.

Reducing riparian fire severity may be possible through reduction of upland fire severity. The strong relationship between upland fire severity and riparian fire severity found in this study suggests that, if a reduction in riparian fire severity is desired, pre-fire fuels treatments in uplands may be effective in reducing riparian fire severity (assuming that upland fire behavior influences riparian fire behavior, as opposed to riparian fire behavior influencing upland fire behavior). Fuels treatments in upland forests have been shown to effectively reduce fire severity (Finney et al. 2005, Raymond and Peterson 2005), and United States federal policies, including the Healthy Forest Restoration Act of 2003 (Bill H.R.1904), mandates the reduction of fire hazard through fuels reductions in forests of the western United States. Fuels treatments in upland forests and a resulting reduction in upland fire severity may move upland forests toward a more historic fire regime, and in doing so, potentially move riparian areas to a more historic fire regime. Upland fuels treatments may be particularly important in forests types that historically experienced more frequent, low intensity fire, such as ponderosa pine forests.

Currently, both state and federal land management agencies in the Pacific Northwest place buffers around streams. Limited or no logging is permitted within these buffers in order to maintain riparian conditions. This current practice of placing buffers around streams may be counterproductive, however, if the buffers are allowing for compositional and structural changes in riparian forests that lead to increased fire severity when fires occur. More severe fires in riparian areas as a result of fire suppression and global warming could result in more severe impacts on riparian organisms and aquatic systems. Further study of the historic frequency and severity of fire in riparian areas will help to determine appropriate management actions in these sensitive portions of the landscape.

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CHAPTER 3 - RELATIONSHIPS AMONG INDICES OF FIRE SEVERITY IN RIPARIAN AREAS

ABSTRACT

There is currently no universally preferred quantitative measure of fire severity. Although different measures of fire severity are often assumed to be closely related, the relationships between various ground-based indices of fire severity are unknown, and information on the relationship between ground-based indices and remotely-sensed assessments of fire severity is limited. This study explores relationships among several ground-based and remotely-sensed indices of fire severity, including ground-based indices of overstory fire severity (crown scorch and basal area mortality) and indices of understory fire severity (scorch height and exposed mineral soil), in riparian areas of recent fires in Oregon.

The two overstory indices of fire severity were relatively strongly associated, and the two understory indices of fire severity were strongly associated. However, the understory fire severity indices were weakly associated with the overstory fire severity indices, suggesting that overstory fire effects are at least partially independent of understory fire effects. Results also suggested weak associations between ground-based fire severity indices and remotely-sensed fire severity assessments conducted for the two fires included in this study. Overall, this study shows limitations to the interpretation and use of all these commonly-used fire severity assessments and that fire severity indices are not necessarily interchangeable.

INTRODUCTION

Fire severity can be defined as the degree to which a fire affects organisms or ecosystems (Agee 1993). Ecological effects of fire in forested systems can be assessed using both remotely-sensed and ground–sensed indices of fire severity. A common remotely-sensed assessment of fire severity involves a measure of disturbance-caused vegetation change, frequently derived from differenced satellite imagery of the pre- and post-fire burned areas (White et al. 1996, Odion et al. 2004, Cocke et al. 2005, Finney et al. 2005, Hammill and Bradstock 2006, Lentile et al. 2006, Lutes et al. 2006). Estimating crown scorch from aerial photographs is also a common remote sensing approach to assessing fire severity (Weatherspoon and Skinner 1995, Williamson 1999, Tollefson et al. 2004). Remotely-sensed indices of fire severity are primarily assessing damage to the tallest vegetation layer, often tree canopies. In contrast, ground-based assessments of forest fire severity often include estimates of damage to the soil layers (Cocke et al. 2005, Jain and Graham), understory herbs and shrubs, and overstory trees (Chappell and Agee 1996, Pollet and Omi 2002, Cocke et al. 2005, Raymond and Peterson 2005, Jain and Graham 2007), and fire severity indices combining fire effects on these various forest layers are common (Alexander et al. 2006, Hammill and Bradstock 2006, Kobziar and McBride 2006, Lutes et al. 2006).

There are many common remotely-sensed and ground-based indices of fire severity. However, no single universally preferred quantitative measure of fire severity has been developed (Cocke et al. 2005, Key and Benson 2005, Hammill and Bradstock 2006, Lentile et al. 2006, Jain and Graham 2007), and there is little information on relationships among many of the various fire severity indices being used. Some information exists on how remotely-sensed assessments of fire severity compare to ground-based assessments (Cocke et al. 2005, Key and Benson 2005); in forested systems with closed canopies, remotely-sensed assessments of fire severity are often highly correlated with overstory mortality but have low correlations with ground or soil fire severity metrics where vegetation covers the ground (Hudak et al. 2004, Lentile et al. 2006). Although it is often assumed that various ground-based indices of fire severity are closely related, there is very little information on the relationships among different ground-based indices.

There are a number of possibilities for the nature of relationships among various ground-based fire severity indices. One possibility is that different fire severity indices are essentially an index of the same factor, and thus various fire severity indices would be linearly related to one another. Another possibility is that there are non-linear relationships between various fire severity variables. For example, mortality of overstory trees may be low at moderate fire intensities, and then increase exponentially with higher levels of fire intensity, whereas effects of fire on soils may increase exponentially at relatively low fire intensities and then level off at higher fire intensities. These potential varied relationships between fire intensity and subsequent effects on overstory trees and soil could result in an exponential relationship between indices of overstory mortality and effects on soil. A final possibility is that various fire severity indices are quantifying independent effects of fire on various ecosystem components. If this were the case, there could be essentially no relationship between various fire severity variables.

This study explores relationships among a set of ground-based and remotely-sensed indices of fire severity in riparian areas of two recent fires in Oregon. Our ground-based indices include two that are generally expected to reflect surface and ground fire characteristics (tree scorch height and exposed mineral soil) and two that are expected to reflect surface and crown fire characteristics (tree crown scorch and tree mortality). In determining the relationship between various fire severity indices, we hope to inform discussion of how well commonly used fire severity indices assess ecosystem effects of fire, and what various indices may reflect about fire characteristics. Management implications of findings are discussed.

METHODS

Site Descriptions

The study investigated fire severity indices in riparian areas of two recent fires in Oregon: the Biscuit fire in the Klamath-Siskiyou region of southwestern Oregon and the B&B Complex Fire on the east slope of the Cascade Range (Figure 3.1). These fires are located in fire-prone regions in Oregon. Both regions are characterized by mixed-severity fire regimes and forests dominated by *Pseudotsuga menziesii* (Douglas-fir) (Agee 1993).

Biscuit Fire

The Biscuit Fire was a result of four separate lightning ignited fires merging together in early July, 2002. Aided by severe drought and record-breaking heat, the fire covered an area of approximately 200,000 ha before it was extinguished by rain in early November, 2002. It was the largest fire in Oregon's recorded history. The fire burned mainly in the Siskiyou National Forest, although some of the area burned is managed by the Bureau of Land Management (BLM).

Climate in the study area is characterized by cool, wet winters and warm, dry summers. Average annual precipitation in the study area ranges from 250 to 300 cm (Daly et al. 2002, PRISM Group 2004). Most precipitation falls between the months of November and April. The mean temperature in January ranges from two to five degrees C, and the mean temperature in July ranges from 18 to 20ºC.

Terrain in the Biscuit Fire region is highly dissected with steep slopes. Elevation of study sites ranged from 200 to 1200 m in elevation. Parent material in the study area is primarily schist-phyllite, metamorphic/volcanic, metasedimentary/conglomerate, and metasandstone/siltstone. Major soil subgroups include Typic Dystrochrepts and Typic Hapludults.

Dominant forest overstory species in the Biscuit Fire study area include *Pseudotsuga menziesii*, *Abies concolor* (white fir), *Pinus lambertiana* (sugar pine), *Chamaecyparis lawsoniana* (Port-Orford-cedar), and *Tsuga heterophylla* (western hemlock). Common midcanopy species include *Lithocarpus densiflorus* (tanoak), *Quercus chrysolepis* (canyon live oak), *Chrysolepis chrysophylla* (golden chinquapin), and *Umbellularia californica* (California laurel), and the understory is characterized by *Rhododendron macrophyllum* (Pacific rhododendron), *Gaultheria shallon* (salal), *Mahonia nervosa* (dwarf Oregon-grape), and *Rubus ursinus* (wild blackberry).

<u>B&B Complex Fire</u>

The B&B Complex Fire was the result of the merging of two lightning caused fires, the Bear Butte and the Booth Fires. From mid-August through late September of 2003, the B&B Complex Fire burned over 37,000 ha. The fire burned mainly within the Deschutes and Willamette National Forests.

Climate in the B&B Complex fire area is moderate with cool, wet winters and warm, dry summers. Annual precipitation rates in the fire area range from 50 cm at the lower elevations to 140 cm at the upper elevations (USDA Forest Service 2005). Most of the precipitation occurs from November to March. Precipitation above 1,000 m falls mainly as snow in winter.

The B&B Complex fire area is characterized by gentle to moderately steep topography. Aspects within the fire area are generally easterly with north and south facing valley slopes. Elevation of sample areas ranged from 800 to 1500 m. The east slope of the Cascade Range where the B&B Complex Fire burned is a geologically young and complex volcanic region.

Dominant forest overstory species in the B&B Complex Fire area include *Pseudotsuga menziesii*, *Pinus ponderosa* (ponderosa pine), *Abies grandis/Abies concolor* (grand fir and white fir hybrid), *Picea engelmanii* (Engelman spruce), *Pinus monticola* (western white pine), and *Larix occidentalis* (western larch). The forest understory is dominated by *Ceanothus velutinus* (snowbrush), *Symphoricarpos albus* (snowberry), *Purshia tridentata* (antelope bitterbrush), *Mahonia nervosa*, *Rosa gymnocarpa* (little wood rose), and *Rubus ursinus*.

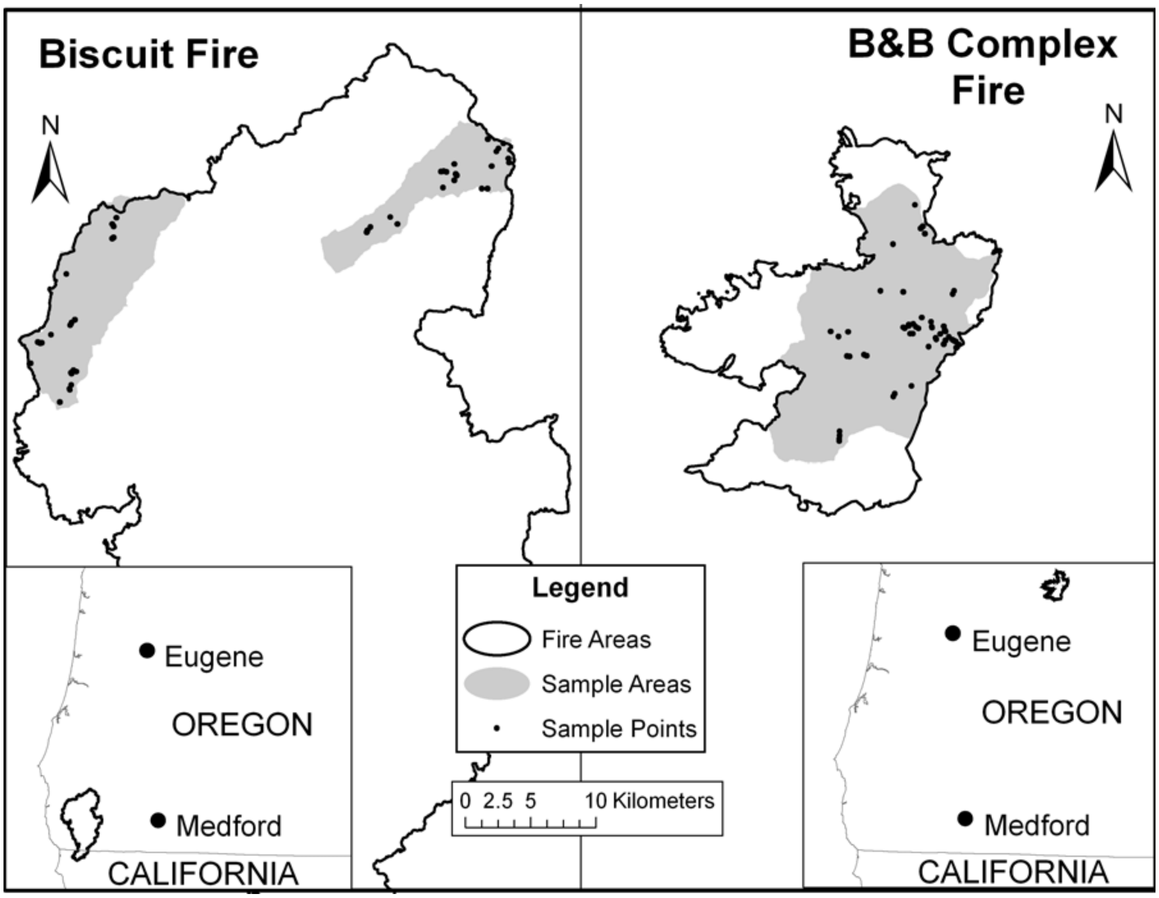

Figure 3.1. Locations of the Biscuit and B&B Complex Fires and study sites within fires. Sample points were derived from a stratified random sampling design. Sampling area in the two fires was similar (16,000 ha in the Biscuit Fire and 13,600 ha in the B&B Complex Fire).

Site Selection

A stratified random sampling design was used to select sample points that represented a range of plant associations, fire severity classes, pre-fire tree sizes, and stream sizes (details below). Two sixth-field sub-watersheds in the Biscuit Fire area were selected for sampling (Figure 3.1) based on differences in precipitation levels and dominant plant associations between watersheds and variation in fire severity within each watershed. For site selection in the B&B Complex Fire, only certain plant associations of interest within five sixth-field field sub-watersheds were chosen for study in the fire area (plant associations did not separate by watershed as they did in the Biscuit Fire) (Figure

3.1). The three plant associations included for study in the B&B Complex Fire were ponderosa pine, dry mixed conifer, and wet mixed conifer.

Within a geographic information system (GIS), fire severity maps created by the Forest Service were used to separate each watershed or plant association into three broad fire severity categories (low, moderate, and high severity). Remotely-sensed fire severity maps were created by the Forest Service by differencing pre- and post-fire Landsat 7 ETM+ imagery of the burned areas. Difference in spectral reflectance values between pre- and post-fire imagery was used as an indication of vegetation change and therefore fire severity; pixels with greater differenced values were interpreted as having greater fire severity. See data analysis section for further details on how the maps were developed for each fire.

For a given fire severity class within a watershed or plant association, all existing first-, second-, and third-class stream segments were identified in a GIS. Class 1 streams are fish-bearing streams with a steady flow (stream orders 5-7), class 2 streams are also fish-bearing with moderate flow (stream orders 3-4), and class 3 streams have few fish and low flow (stream orders 1-2). Once stream segments were identified for a fire severity class within each watershed or plant association, points on the stream segments were randomly selected within a GIS to represent a range of tree size classes (small, medium, and large size classes). The size class layer was created by the Forest Service based on aerial photographs, with size class 1 being the smallest size class (0-14.9" or 0-37.9 cm DBH), followed by size class 2 (15.0-19.9" or 40.0-50.7 cm DBH), and size class 3 (20.0" + or 50.8 cm + DBH) being the largest.

We attempted to sample one point for each fire severity class/stream class/tree size class combination in each watershed or plant association. However, not all fire severity class/stream class/tree size class combinations were found in the sample area. Number of sampled points in the Biscuit Fire totaled 47; fifty-four points were sampled in the B&B Complex Fire.

Sampling Methodology

Sampling was conducted two years after each fire event. Despite the time elapsed between the fire events and sampling, ample evidence remained in the field for a quantitative estimate of fire severity, including woody plant mortality, scorched needles, leaves, or branches in tree crowns, char on tree trunks, and exposed mineral soil.

At each randomly selected point, one 10- x 25-m (slope-corrected) plot was established in the riparian area. Half of the plot (5- x 25-m) was in the riparian area on one side of the stream, and the other half of the plot (5- x 25-m) was in the riparian area on the other side of the stream. The half-plots on each side of the stream were directly adjacent to and parallel to the stream. In addition to the riparian plots, one slope-corrected 10- x 25-m upland plot was placed 25 m in elevation above the riparian area (Biscuit Fire) or 150 m in slope-corrected distance from the stream (B&B Complex Fire) on each side of the stream. Slope-corrected distance was used in the B&B Complex Fire because there is only moderate elevation change between riparian areas and uplands in the B&B Complex Fire. Elevation change or distance from the stream ensured that the upland plot would not be as directly influenced by the presence of a stream.

In each plot, fire severity was assessed through measurements of scorch height and exposed mineral soil (understory fire effects), and percent crown scorch and percent basal area mortality (overstory fire effects). Scorch height was measured as the height of char on the six tallest trees in each plot. Percent exposed mineral soil was visually estimated to the nearest 1% in each plot. This assessment was conducted by the same two individuals throughout data collection, and an average of the estimates for each individual was used for each plot to reduce bias. Basal area mortality and live basal area were estimated in each plot by measuring the diameter at breast height (DBH) of all trees greater than 5 cm DBH, and the species and live/dead status of each tree was recorded. Crown scorch was measured with a hypsometer on the six tallest trees in each plot as the percent of the vertical pre-fire live crown that was scorched by the fire.

Data Analysis

PROC REG in SAS v9.1 (SAS Institute, Cary, NC, USA) was used to run simple linear regression analyses with exposed mineral soil as the response variable and other ground-based fire severity variables as the explanatory variables. Regression analyses were also conducted to explore other *a priori* questions regarding the relationships between basal area mortality (response) and crown scorch (explanatory variable), between basal area mortality (response) and scorch height (explanatory variable), and between crown scorch (response) and scorch height (explanatory variable). These analyses were conducted for both the Biscuit and B&B Complex Fires, and all analyses were run separately for riparian areas and uplands. As all relationships among indices of fire severity appeared to be linear, log-transformations were used in some analyses to further improve linearity. All other model assumptions were checked and found to be adequately met prior to examining results of regression analyses.

Two ground-based indices of fire severity, basal area mortality (an index of overstory fire effects) and exposed mineral soil (an index of understory fire effects), were also compared to remotely-sensed assessments of fire severity for both the Biscuit and B&B Complex Fires. These were post-hoc analyses. Quantitative accuracy assessments (Congalton and Green 1999) were not conducted because this study was not designed to formally assess the accuracy of the remotely-sensed fire severity assessments. However, the data collected for this study provide useful information on the relationships between ground-based and remotely-sensed fire severity indices, particularly because the remotely-sensed fire severity assessments done for these two fires represent information that managers are using to guide post-fire land management (USDA Forest Service 2004, USDA Forest Service 2005).

To create the remotely-sensed fire severity map for the Biscuit Fire, the Forest Service acquired Landsat 7 ETM+ imagery from August 2001 (pre-fire) and August 2002 (post-fire). The images were converted to reflectance values and were co-registered to each other. Both pre- and post-fire imagery was converted to Normalized Difference Vegetation Index (NDVI) values and then the two images were differenced (dNDVI).

dNDVI, an indicator of vegetation greenness, is derived by taking the difference between the near-infrared (Landsat ETM+ band 4) and red (Landsat ETM+ band 3) reflectance values and dividing by their sum (NDVI = (near infrared - red) / (near infrared + red)). Ground data was collected in the Biscuit Fire area to determine what levels of vegetation mortality could be expected at varied levels of dNDVI . In general, areas that showed little or no change in NDVI in the Biscuit Fire (Fire Severity Class 1) experienced low intensity underburn that consumed understory vegetation but had little influence on the overstory (< 25% overstory mortality) (USDA Forest Service 2004). In areas with low change in NDVI (Fire Severity Class 2), vegetation less than 21 inches in diameter at breast height (DBH) experienced close to 100% mortality, but overstory mortality remained low (25-50%). Areas that had moderate change in NDVI (Fire Severity Class 3) had high vegetation mortality from high intensity underburn (100% overstory mortality), but overstory trees generally retained needles and leaves. Areas that had high change in NDVI (Fire Severity Class 4) had high vegetation mortality from crown fire (100% overstory mortality). Overstory trees in this fire severity class had few needles or leaves (USDA Forest Service 2004).

For the B&B Complex Fire, Landsat 7 ETM+ imagery was acquired from October 2002 and October 2003. The images were converted to reflectance values and were co-registered to each other. Both pre- and post-fire imagery was converted to Normalized Burn Ratio (NBR) values and then differenced (dNBR). NBR is an index formulated from Landsat ETM+ band 7 (short wave infrared) and band 4 (near infrared) reflectance (NBR = (near infrared – short wave infrared) / (near infrared + short wave infrared)). Ground data was collected in the B&B Complex Fire area to determine what levels of vegetation mortality could be expected at varied levels of dNBR. Areas with little or no change in the NBR in the B&B Complex (Fire Severity Class 1) generally had low intensity to severe underburn that resulted in less than 25% mortality of overstory trees (USDA Forest Service 2005). Areas with moderate change in NBR (Fire Severity Class 2) generally experienced mixed mortality, with the overstory tree mortality ranging from 25% to 75% (USDA Forest Service 2005). Areas with high change in NBR (Fire

Severity Class 3) experienced high severity fire that resulted in 100% vegetation mortality (USDA Forest Service 2005).

Analysis of variance (ANOVA) was used to compare mean ground-based fire severity levels (basal area mortality and exposed mineral soil) in the different remotely-sensed fire severity classes for the Biscuit and B&B Complex Fires. PROC MIXED in SAS v9.1 (SAS Institute, Cary, NC, USA) was used to fit a mixed effects model to the data. Assumptions of normality and constant variance were checked prior to interpreting results of the analysis. LSMEANS with a Bonferroni adjustment (SAS v9.1) was used for multiple comparisons of means.

RESULTS

Relationships among Ground-Based Indices of Fire Severity

I found similar relationships among the ground-based indices of fire severity in the uplands compared to those in riparian areas. Ie also found similar relationships between ground-based and remotely-sensed indices of fire severity in uplands. Therefore, although fire severity data were collected and analyzed for upland plots in addition to riparian plots, only riparian data and analyses are presented here.

Scatter plots of all combinations of fire severity variables gave no indications of non-linear relationships between the various fire severity variables. Thus, potential linear relationships were explored.

Understory indices of fire severity (exposed mineral soil and scorch height) were strongly related in the Biscuit Fire ($R^2 = 0.75$) (Figure 3.2a), and overstory indices of fire severity (crown scorch and basal area mortality) were strongly related in both fires ($R^2 = 0.80$ for both the Biscuit and B&B Complex Fires) (Figures 3.3b and 3.3e). However, the relationships between understory fire severity indices and overstory fire severity indices were weaker (Figures 3.2 and 3.3). Scorch height explained less than 45% of the variation in basal area morality in both fires (Figures 3.3c and 3.3f). In addition, no more than 45% of the variation in exposed mineral soil could be explained by an overstory index of fire severity (Figure 3.2). Basal area mortality, the variable that is most strongly reflected in fire severity assessments using aerial photographs or remotely-sensed imagery (Hudak et al. 2004, Lentile et al. 2006), explained less than 38% of the variation in exposed mineral soil in both fires. The weaker relationships between overstory and understory fire severity indices than within either group suggests that overstory effects of fire are at least partially independent of understory effects of fire.

Relationships between Ground-Based and Remotely-Sensed Indices of Fire Severity

Relationships between remotely-sensed and ground-based indices of fire severity were weak (Figure 3.4). There was substantial overlap in ground-based fire severity values between remotely-sensed fire severity classes in both fires. For example, there was unexpectedly high basal area mortality and exposed mineral soil in plots that were classified as low severity in the remotely-sensed fire severity assessments. Similarly, some plots that were classified as high severity in the remotely-sensed fire severity assessments had unexpectedly low basal area mortality and exposed mineral soil.

Comparison of mean ground-based levels of fire severity in the different remotely-sensed fire severity classes in the Biscuit Fire (Table 3.1a) showed significant differences in basal area mortality between the lower classes (class 1 and 2) and higher classes (class 3 and 4), but no significant difference in basal area mortality between class 1 and 2, or between class 3 and 4. Exposed mineral soil was not significantly different among any of the four remotely-sensed fire severity classes for the Biscuit Fire (Table 3.1a), suggesting dNDVI fire severity classes did not reflect any significant variation in exposed mineral soil in the Biscuit Fire. For the B&B Complex Fire, significant differences in both basal area mortality and exposed mineral soil were found between remotely-sensed fire severity class 1 and classes 2 and 3, but ground-based fire severity indices were not significantly different between classes 2 and 3 (Table 3.1b). These results for the B&B Complex Fire suggest that remotely-sensed fire severity assessments using dNBR discriminate between low and moderate/high levels of basal area mortality and exposed mineral soil but not between moderate and high levels of basal area mortality and exposed mineral soil in riparian areas.

Overall, these results suggest weak correlation between ground-based indices of fire severity and the remotely-sensed fire severity assessments conducted for the Biscuit and B&B Complex Fires. On average, remotely-sensed fire severity assessments discriminated between relatively low and relatively high basal area mortality in both fires, and between relatively low and relatively high exposed mineral soil in the B&B Complex Fire, but the remotely-sensed fire severity assessments generally failed to detect more subtle differences in on-the-ground fire severity levels. Furthermore, the overlap in basal area mortality and exposed mineral soil between the remotely-sensed fire severity classes suggests these methods have limited accuracy in detecting differences in fire severity at fine spatial scales.

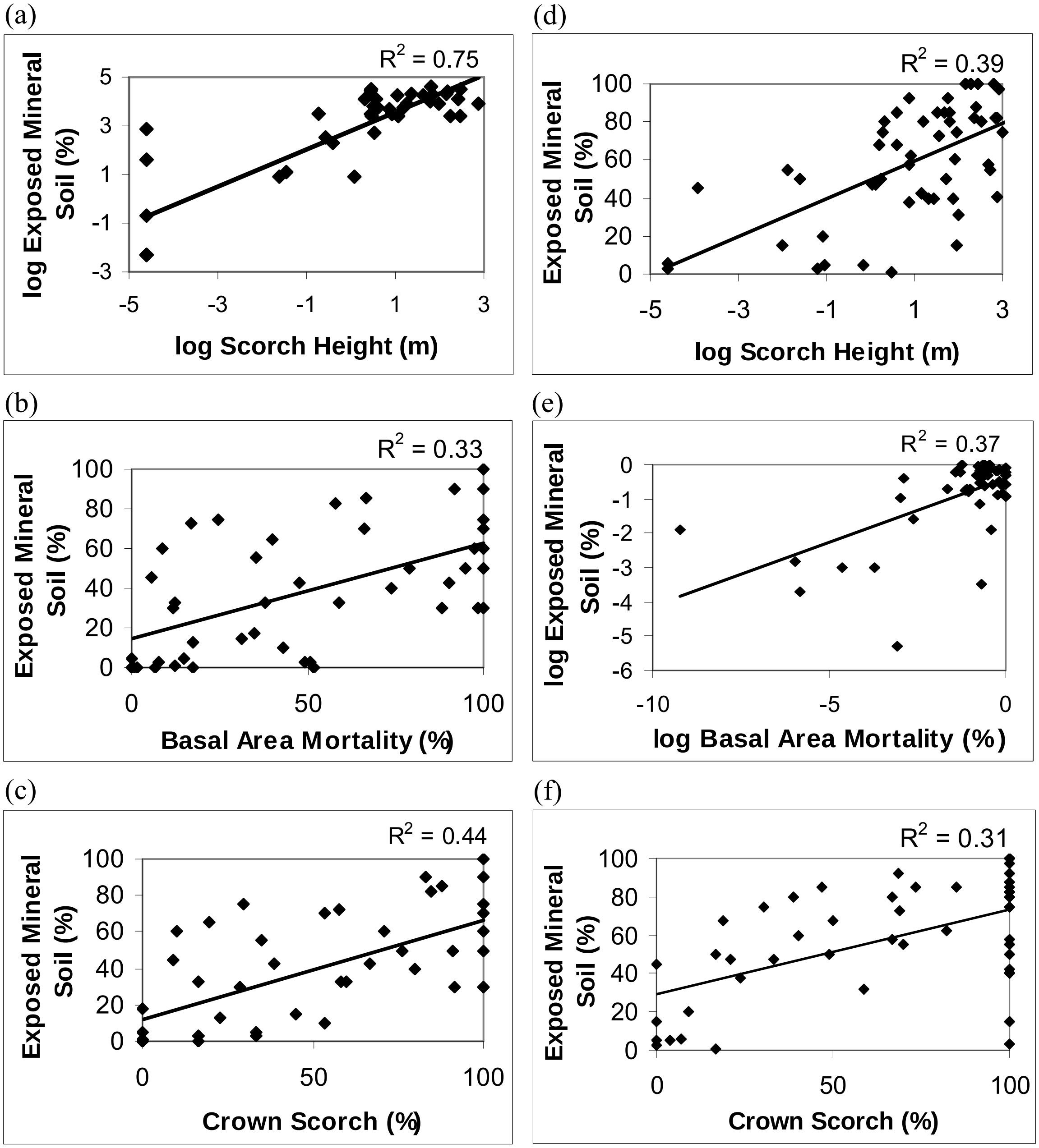

Figure 3.2. Linear regression analyses of exposed mineral soil versus other ground-sensed indices of fire severity in the Biscuit Fire (a-c) and the B&B Complex Fire (d-f). All regressions are significant (p-values for tests that slopes of regressions lines = 0 are all <0.05).

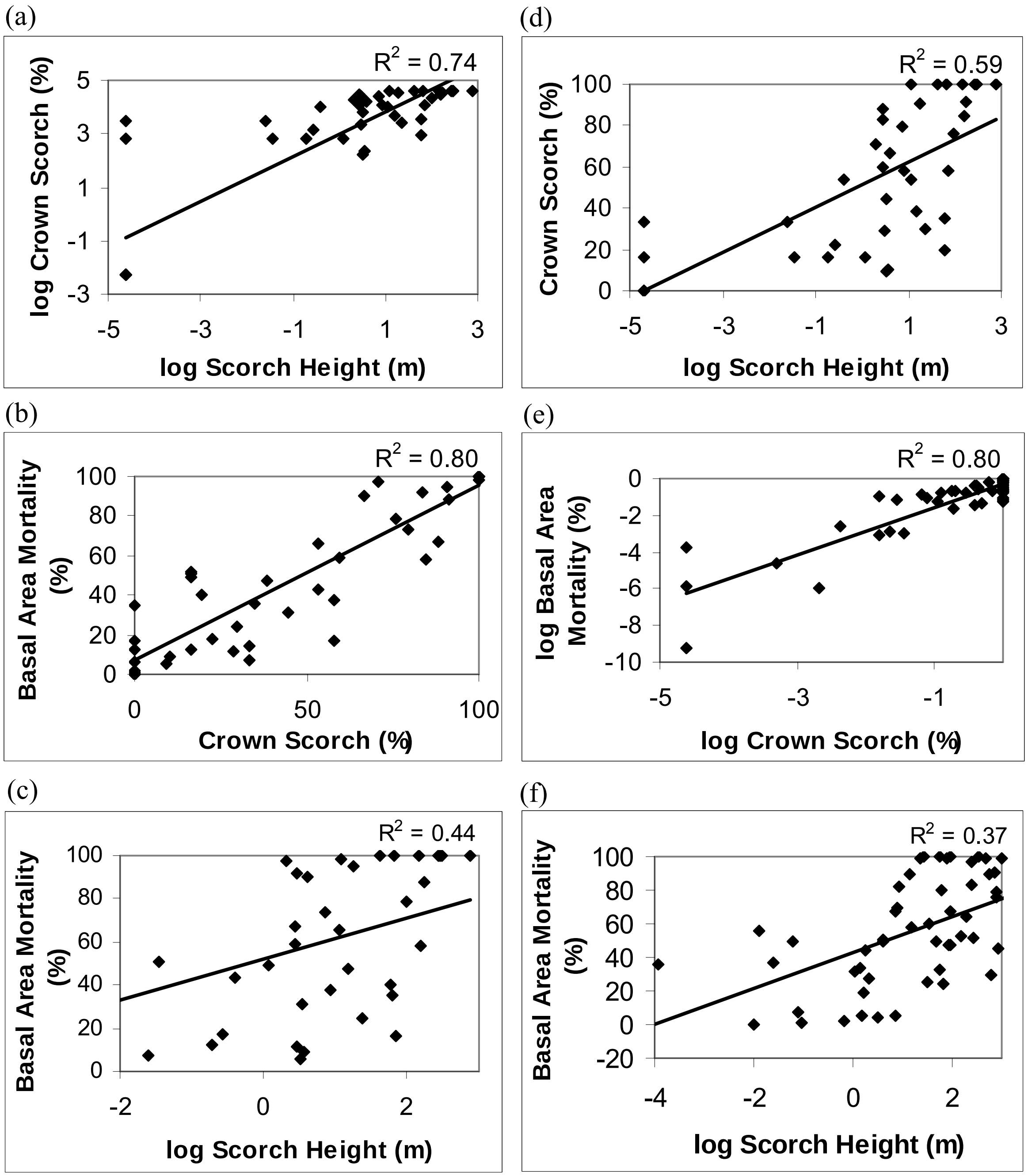

Figure 3.3. Linear regression analyses with overstory fire severity indices and scorch height in the Biscuit Fire (a-c) and B&B Complex Fire (d-f). All regressions are significant (p-values for tests that slopes of regressions lines = 0 are all <0.05).

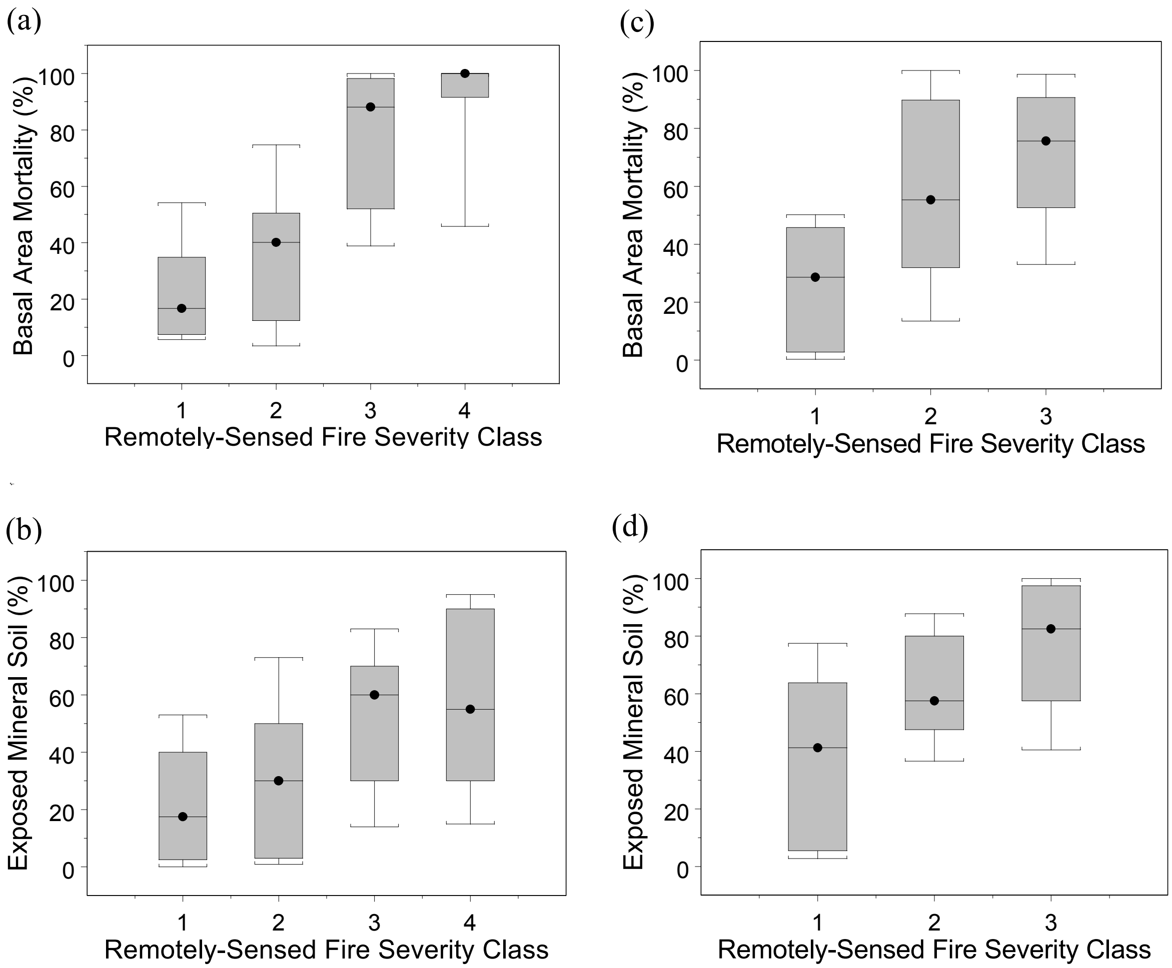

Figure 3.4. Basal area mortality (a) and exposed mineral soil (b) in four remotely-sensed fire severity classes in the Biscuit Fire, and basal area mortality (c) and exposed mineral soil (d) in three remotely-sensed fire severity classes in the B&B Complex Fire. The gray box represents the middle 50% of fire severity measurements for each remotely-sensed fire severity class; the top of the box corresponds to the 75th percentile and the bottom of the box corresponds to the 25th percentile of the data set. The black dots in the gray boxes represent the median for each remotely-sensed fire severity class. The whiskers extending from each box represent the 10th and 90th percentiles of the data set. For the Biscuit Fire, Fire Severity Class 1 = <25% overstory mortality; Class 2 = 25-50% overstory mortality and 100% understory mortality; Class 3 = 100% vegetation mortality with needles and leaves remaining in overstory trees; and Class 4 = 100% vegetation mortality with few or no needles or leaves remaining in overstory trees. For the B&B Complex Fire, Fire Severity Class 1 = < 25% overstory tree mortality; Class 2 = 25% to 75% overstory tree mortality; and Class 3 = 100% overstory tree mortality.

Table 3.1. Mean ground-based fire severity levels (basal area mortality and exposed mineral soil) in remotely-sensed fire severity classes in the Biscuit Fire (a) and the B&B Complex Fire (b). For the Biscuit Fire, Fire Severity Class 1 = <25% overstory mortality; Class 2 = 25-50% overstory mortality and 100% understory mortality; Class 3 = 100% vegetation mortality with needles and leaves remaining in overstory trees; and Class 4 = 100% vegetation mortality with few or no needles or leaves remaining in overstory trees. For the B&B Complex Fire, Fire Severity Class 1 = < 25% overstory tree mortality; Class 2 = 25% to 75% overstory tree mortality; and Class 3 = 100% overstory tree mortality. Values followed by the same letter are not significantly different (p>0.01). Mean comparisons are within and not between basal area mortality and exposed mineral soil.

(a)

	Remotely-Sensed Fire Severity Class			
	1	2	3	4
Basal Area Mortality (%)	24.3 a	37.4 a	73.0 b	81.9 b
Exposed Mineral Soil (%)	25 a	32 a	50 a	55 a

(b)

	Remotely-Sensed Fire Severity Class		
	1	2	3
Basal Area Mortality (%)	29.5 a	51.1 b	72.7 b
Exposed Mineral Soil (%)	38 a	61 b	74 b

DISCUSSION

Despite the importance of accurately assessing effects of fire in ecosystem management, there is no single standardized quantitative index of fire severity (Cocke et al. 2005, Key and Benson 2005, Hammill and Bradstock 2006, Lentile et al. 2006, Jain and Graham 2007). This study examined the relationships between commonly used indices of fire severity, including both ground-based and remotely-sensed assessments. Weak relationships between some ground-based indices of fire severity, particularly between overstory fire severity indices (basal area mortality and crown scorch) and understory fire severity indices (exposed mineral soil and scorch height), and weak relationships between ground-based and remotely-sensed assessments of fire severity, suggest that there are limitations to the interpretation and use of all these commonly-used fire severity assessments.

Weak relationships between overstory fire severity indices (basal area mortality and crown scorch) and understory fire severity indices (exposed mineral soil and scorch height) suggest that overstory effects of fire are at least partially independent from understory fire effects. Jain and Graham (2007) also found that soil burn severity and tree burn severity were independent in Rocky Mountain wildfires. While surface and crown fires result in the combustion of aboveground biomass and the litter layer, smoldering combustion is responsible for the combustion of the humus and organic soil layers (Kasischke et al. 1995, Pyne et al. 1996). The biomass consumption (fire severity) resulting from one of these burning processes can be independent of biomass consumption resulting from the other, particularly when soil moisture is high (Kasischke et al. 1995, Pyne et al. 1996). Thus, overstory fire severity indices are lacking information on understory fire severity, and vice versa. For example, if basal area mortality is used as a fire severity index, it should be understood that this index gives little information on the effects of the fire on the soil layer, including potential for erosion. In the same way, a measure of fire severity in the soil layer gives little information on overstory tree mortality. This suggests that both overstory and understory fire severity indices be included in assessments of fire severity.

In addition to weak relationships between some ground-based indices of fire severity, relationships between ground-based and remotely-sensed assessments of fire severity were weak. Although formal quantitative accuracy assessments were not conducted for the remotely-sensed fire severity maps included in this study, both of these maps were used by the Forest Service to help determine post-fire management actions in the burned areas and represent common application of remotely-sensed imagery. The poor correlation between remotely-sensed fire severity and ground-based indices of exposed mineral soil was expected, since satellite imagery generally detects changes in canopy conditions but fails to detect changes in soil conditions (Hudak et al. 2004, Lentile et al. 2006), particularly in closed-canopy forests. The inability of NBR or NDVI to detect soil conditions under a closed canopy suggests remotely-sensed fire severity assessments might also fail to detect other soil-related characteristics, such as post-fire erosion potential.

Surprisingly, there were also weak relationships between remotely-sensed fire severity classes and basal area mortality. There are several potential sources of error that could have contributed to the weak relationships between ground-based and remotely-sensed indices of fire severity. The plots on the ground were located with a GPS unit with accuracy of approximately ± 10 m. Thus, it is possible the ground-based plot did not correlate exactly with the area from which the remotely-sensed fire severity information was attained. In addition, the pixel size for the remotely-sensed imagery was 30- x 30-m, while the size of the ground-based plot was 10- x 25-m. Thus, the area from which the remotely-sensed fire severity assessment was determined was larger than the area in which the ground-based fire severity assessment was done. Furthermore, the classification of fire severity in broad categories (three or four for the assessments used in this study) may mask fine-scale variability in fire effects (Cocke et al. 2005). Remotely-sensed imagery may be useful for detecting broad differences in fire severity. However, the way remotely-sensed imagery is commonly classified, in addition to the scale of the remotely-sensed imagery commonly used (30 m resolution for both fires in this study), limit the usefulness of this imagery in detecting fine-scale patterns of fire severity (Hammill and Bradstock 2006), such as fine-scale patterns in tree mortality. Results of this study illustrate that commonly-used remotely-sensed assessments of fire severity do not always give an accurate picture of fine-scale patterns on the ground.

While this study was limited to riparian areas, it is likely that the limitations of these fire severity variables extend to other portions of the landscape. Data collected for uplands in this study but not shown support this assertion. However, the terrain in riparian areas may influence remotely-sensed fire severity assessments. Shadows in steep terrain, such as deeply incised valleys where some riparian areas are located, result in remotely-sensed fire severity misclassification, especially with low sun elevation (Hammill and Bradstock 2006). For this reason, remotely-sensed fire severity assessments may be particularly inappropriate for riparian areas.

Ground-based and remotely-sensed information on fire severity is used to guide a variety of post-fire land management activities. Rehabilitation activities and post-fire planning and monitoring are often based on fire severity maps (Cocke et al. 2005). Fire severity information frequently guides post-fire timber harvest and reforestation activities (USDA Forest Service 2004). Fire severity information is also used by researchers in exploring relationships between pre-fire conditions and fire effects, and results of such research often lead to changes in management practices aimed at reducing future fire effects. Accuracy in fire severity assessments is critical for these uses. The limitations in commonly-used fire severity indices outlined in this and other studies highlight the need for improvement in fire severity assessments. The development of quantitative assessments of fire effects that encompass effects on both the overstory and understory, particularly soil (Lentile et al. 2006), along with better integration of common ground-based and remote indices of fire severity, would greatly improve the ability to accurately assess ecosystem effects of fire. Until improved techniques to assess fire severity are developed, land managers and researchers should be aware of the limitations and potential consequences of using both ground-based and remotely-sensed fire severity information.

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CHAPTER 4 – RIPARIAN VEGETATION RESPONSE TO FIRE IN THE BISCUIT AND B&B COMPLEX FIRES, OREGON

ABSTRACT

Riparian areas provide key habitat to a diverse array of species and also provide multiple ecological functions to stream systems. Through effects on plant community structure and composition, fire in riparian areas has the potential to influence the functions riparian vegetation provides to streams and wildlife. However, there is little information on the effects of fire on riparian areas and patterns in riparian plant community regeneration after fire. The objectives of the present study were to 1) assess patterns in species abundance and composition of post-fire regenerating plant communities in riparian areas and 2) determine how these patterns relate to fire severity and other environmental variables.

The study was initiated in portions of the Biscuit Fire in southwestern Oregon and the B&B Complex Fire in the Cascade Mountain Range of west-central Oregon. We measured post-fire abundance of shrub, hardwood and conifer regeneration, and measured factors such as fire severity, valley floor width, and stream size as potential factors associated with post-fire riparian regeneration patterns. Sampling was conducted in the second year after each fire event.

At a relatively coarse spatial scale, patterns in post-fire regeneration were influenced primarily by moisture gradients represented by position within a watershed (headwater streams versus main stem stream channels) in the Biscuit Fire and by elevation/plant association in the B&B Complex Fire. At finer spatial scale, patterns in riparian regeneration were influenced by differences between deciduous hardwood- and conifer-dominated communities and by understory fire severity. Both conifer- and hardwood-dominated communities appeared to be self-replacing, suggesting that each community type tends to occur in specific ecological settings.

Overall, regeneration was abundant. Mean seedling density of all woody species in riparian areas ranged from 389 seedlings per ha along mid-sized streams to 1356 seedlings per ha along large streams in the Biscuit Fire and from 1967 seedlings per ha in the ponderosa pine plant association to 6747 seedlings per ha in the wet mixed conifer

plant association in the B&B Complex Fire. Mean sprout density of trees and shrubs ranged from 1408 sprouts per ha along large streams to 10133 per ha along small streams in the Biscuit Fire, and mean sprout density in the B&B Complex Fire ranged from 4611 in the wet mixed conifer plant association to 8233 in the ponderosa pine plant association. The abundant post-fire regeneration in riparian areas and the self-replacement of hardwood- and conifer-dominated communities in both fires is an indication of the resilience of these disturbance-adapted plant communities.

INTRODUCTION

Riparian areas are some of the most diverse, complex, and dynamic terrestrial habitats (Gregory et al. 1991, Naiman et al. 1993, Naiman and Decamps 1997). In drier forest types of the western U.S., riparian areas provide key habitat to a diverse array of species and serve as a refuge for wildlife by providing a water source, forage, and escape from predators (Naiman and Decamps 1997). Riparian areas also provide multiple ecological functions to stream systems. Root systems of riparian plants help to maintain soil structure and bank stability (Swanson et al. 1982, Minore and Weatherly 1994, Johnson 2004), and prevent erosion into streams (Naiman and Decamps 1997). Shade provided by riparian tree canopies reduces stream temperatures, improving habitat for cold-water species such as salmonids (Swanson et al. 1982, Gregory et al. 1991, Minore and Weatherly 1994, Johnson 2004). Organic matter from riparian vegetation provides food resources for aquatic organisms (Swanson et al. 1982, Gregory et al. 1991, Minore and Weatherly 1994, Naiman and Decamps 1997). Riparian areas also act as a source of large woody debris to stream systems. Large woody debris controls stream and sediment flow, shapes channel morphology, and also provides habitat for aquatic biota (Swanson and Lienkaemper 1978, Swanson et al. 1982, Minore and Weatherly 1994, DeBano and Neary 1996).

Riparian areas are a product of frequent disturbance, including flood, avalanche, wind, fire, drought, plant disease, insect outbreaks and herbivory. Fire is a dominant disturbance process in the western U. S., and although the effects of fire in upland systems are relatively well-studied, few studies have investigated the effects of fire on riparian vegetation, particularly in the Pacific Northwest. Fire in riparian areas has the potential to influence the functions riparian vegetation provides to streams by changing plant community abundance, structure, and composition, and the regeneration of post-fire riparian vegetation likely dictates the magnitude and duration of fire effects on stream systems (Minshall 2003). Determining management goals and associated management practices for these critical areas of the landscape requires an understanding of how disturbance processes affect them.

Riparian plant species are highly adapted to disturbances, such as flooding and fire, and riparian vegetation has potential for great resilience after fire due to a suite of adaptations that allow for rapid recovery (Dwire and Kauffman 2003, Reeves et al. 2006). Riparian plant species adaptations to disturbance include those that facilitate the survival of plants on site, such as sprouting and thick bark, and those that contribute to the recolonization of disturbed sites, including wind and water propagule dispersal and the capacity to establish in post-disturbance environments (seed storage in the soil or canopy) (Dwire and Kauffman 2003). Riparian areas are also characterized by high soil moisture and high water tables, which can lead to faster vegetation recovery in riparian areas compared to uplands (Konstantinidis et al. 2006, Reeves et al. 2006).

Although dendroecological studies have shown that fire historically impacted riparian areas (Everett et al. 2003, Skinner 2003, Olson and Agee 2005), fire severity in riparian areas may be higher in some present-day systems due to fire suppression and the lack of management activities to reduce fuel buildup in riparian areas. More severe fires in riparian areas as a result of fire suppression could result in greater impacts on riparian flora and fauna and aquatic systems. For example, more severe fires could result in a greater reduction in plant cover and slower recovery of riparian vegetation, resulting in increased streamflow velocity, erosion and sedimentation rates, and stream water temperatures (Reardon et al. 2005), thereby having impacts on both riparian and aquatic biota. Research on the effects of fire severity on riparian vegetation and post-fire regeneration patterns would help to determine the potential impacts of fire suppression and fuel build-up on riparian fire effects.

The objectives of the present study were: 1) to assess post-fire regeneration processes through observations of riparian plant communities two years post-fire, and 2) to determine how regeneration patterns relate to fire severity and other environmental variables. The study was initiated in two recent fires in Oregon, the Biscuit Fire in the Klamath-Siskiyou region of southwestern Oregon and the B&B Complex Fire in the Cascade Mountains of west-central Oregon. These fires are located in fire-prone regions of Oregon and therefore give an indication of the present-day effects of fire in riparian areas of fire-prone forests in the Pacific Northwest.

METHODS

Site Descriptions

Biscuit Fire

The Biscuit Fire occurred in the Siskiyou Mountains of southwestern Oregon (Figure 4.1). The fire was a result of four separate lightning-ignited fires merging together in early July, 2002, and it covered an area of approximately 200,000 ha before it was extinguished by rain in early November, 2002. The fire burned mainly in the Siskiyou National Forest, although some of the area burned is managed by the Bureau of Land Management (BLM). The pattern of the burn was a mosaic of different burn severities; 29% of the area remained unburned or burned at low severity (up to 25% canopy mortality), 27% of the area burned with moderate severity (25-75% canopy mortality), and 44% of the area burned with high severity (>75% canopy mortality) (USDA Forest Service 2004). The Biscuit Fire was the largest fire in Oregon's recorded history. Although the fire occurred during a period of record-breaking drought, there is also question as to whether fire suppression activities starting in the early part of the twentieth century led to greater quantities of understory fuels and contributed to the increased size and severity of the Biscuit Fire (USDA Forest Service 2004).

Climate in the study area is characterized by cool, wet winters and warm, dry summers. Average annual precipitation in the study area ranges from 250 to 300 cm (Daly et al. 2002, PRISM Group 2004), with higher precipitation levels on the western (coastal) side of the study area due an orographic effect. Most precipitation falls between the months of November and April. The mean temperature in January ranges from two to five degrees, and the mean temperature in July ranges from 18 to 20ºC.

Terrain in the Biscuit Fire region is highly dissected with steep slopes. Elevation of study sites ranged from 200 to 1200 m in elevation. Streams in the region are fed primarily from groundwater and surface runoff. Parent material in the study area is primarily schist-phyllite, metamorphic/volcanic, metasedimentary/conglomerate, and metasandstone/siltstone. Major soil subgroups include Typic Dystrochrepts and Typic Hapludults.

B&B Complex Fire

The B&B Complex Fire was the result of the merging of two lightning caused fires, the Bear Butte and the Booth Fires, on the east slope of the Cascade Range in Oregon (Figure 4.1). From mid-August through late September of 2003, the B&B Complex Fire burned over approximately 37,000 ha. The fire burned mainly within the Deschutes and Willamette National Forests. Within the B&B Complex fire area, 38% of the area was unburned or experienced low severity fire (up to 25% mortality), 18% experienced mixed mortality (25-75% mortality), and 44% of the area experienced high severity fire (>75% mortality) (USDA Forest Service 2005). As for the Biscuit Fire area, there is question as to whether fire suppression activities resulted in greater quantities of understory fuels in the B&B Complex Fire area, thus leading to increased fire size and severity (USDA Forest Service 2005). Potential fire suppression effects are of particular concern in the ponderosa pine and dry mixed conifer forest types, since these forest types were historically characterized by a relatively frequent, low severity fire regime (USDA Forest Service 2005).

Climate in the fire area is moderate with cool, wet winters and warm, dry summers. Annual precipitation in the fire area ranges from 50 cm at the lower elevations to 140 cm at the upper elevations (USDA Forest Service 2005). Most of the precipitation occurs from November to March. Precipitation above 1,000 m falls mainly as snow in the winter.

The B&B Complex fire area is characterized by gentle to moderately steep topography. Slope aspects within the fire area are generally easterly with north and south facing valley slopes. Elevation of sample areas ranged from 800 to 1500 m. The east slope of the Cascades where the B&B Complex Fire burned is a geologically young and complex volcanic region. Due to the high porosity of the volcanic soils, stream density is low, most streams in the area are spring-fed, and stream flow is stable.

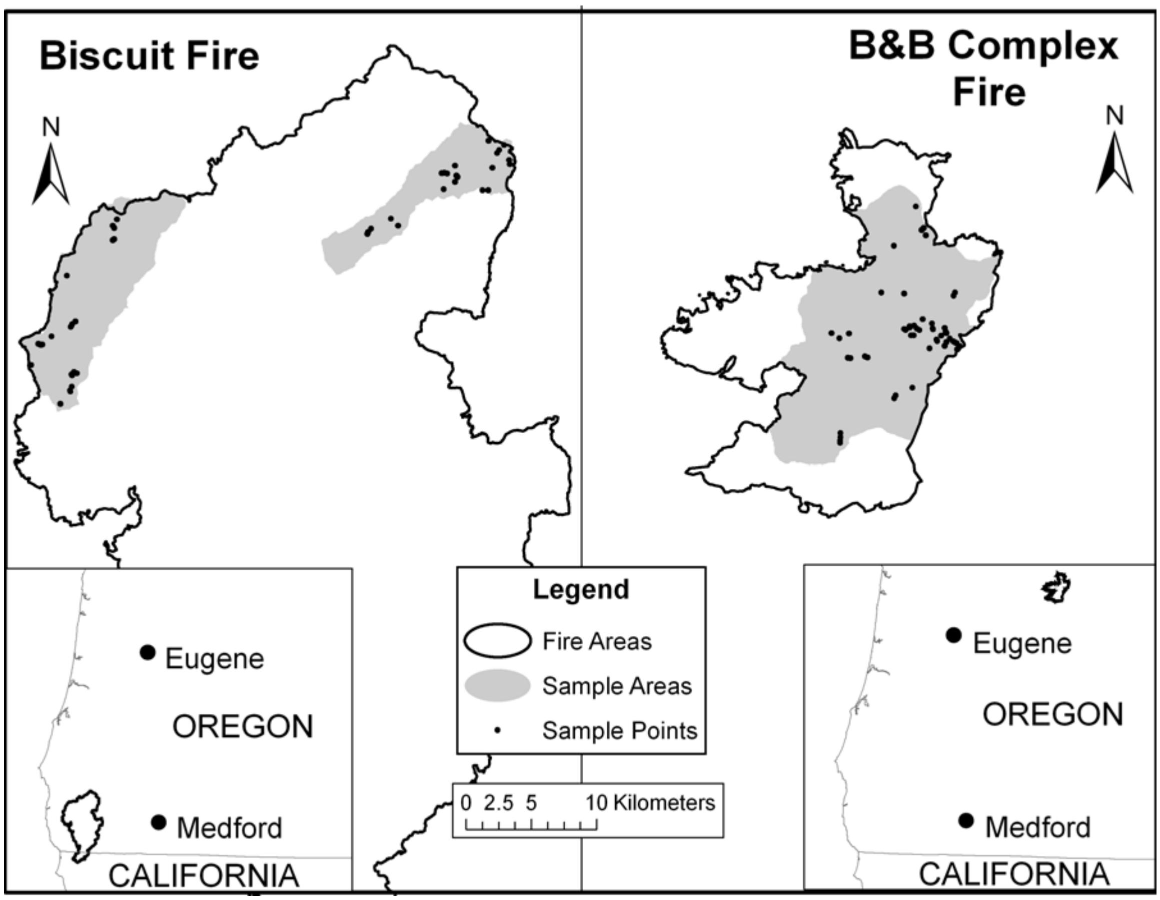


Figure 4.1. Locations of the Biscuit and B&B Complex Fires and study sites within fires. Sampling area in the two fires was similar (16,000 ha in the Biscuit Fire and 13,600 ha in the B&B Complex Fire).

Site Selection

Biscuit Fire

Two sixth-field sub-watersheds in the Biscuit Fire area were selected for sampling (Figure 4.1) based on differences in precipitation levels and plant associations between the watersheds, and variation in fire severity within each watershed. The first watershed on the east side of the fire (east watershed) is characterized by relatively low precipitation and forest productivity, is dominated by the dry tanoak plant association, and is approximately 6,000 ha in size. The second watershed on the west side of the fire (west watershed) is characterized by relatively high precipitation and forest productivity, is dominated by the wet tanoak plant association, and is approximately 10,000 ha in size. A stratified random sampling design was used to select points in each watershed that represented a range of broad fire severity classes, pre-fire tree size classes, and stream sizes as described below.

Within a geographic information system (GIS), a fire severity map created by the Forest Service was used to separate each watershed into three broad fire severity categories (fire severity class 1, 2, and 3). The remotely-sensed fire severity map was created by the Forest Service with Landsat 7 ETM+ imagery of the burned areas acquired in August 2001 (pre-fire) and August 2002 (post-fire). The images were converted to reflectance values and were co-registered to each other. Both pre- and post-fire imagery was converted to Normalized Difference Vegetation Index (NDVI) values and then differenced (dNDVI). dNDVI, an indicator of vegetation greenness, is derived by taking the difference between the near-infrared (Landsat ETM+ band 4) and red (Landsat ETM+ band 3) reflectance values and dividing by their sum (dNDVI = (near infrared - red) / (near infrared + red)). Areas that showed little or no change in the NDVI in the Biscuit Fire (fire severity class 1) generally experienced low intensity underburn that consumed understory vegetation but had little influence on the overstory (<25% overstory mortality) (USDA Forest Service 2004). In areas with moderate change in NDVI (fire severity class 2), vegetation less than 21 inches in diameter at breast height (DBH) experienced close to 100% mortality, but overstory mortality remained low (25-50%). Areas that had high change in NDVI (fire severity class 3) had high vegetation mortality from high intensity fire (100% overstory mortality) (USDA Forest Service 2004).

For a given watershed and fire severity class, all existing first-, second-, and third-class stream segments were identified in a GIS. Class 1 streams are fish-bearing streams with a steady flow (stream orders 5-7), class 2 streams are also fish-bearing with moderate flow (stream orders 3-4), and class 3 streams have few fish and low flow (stream orders 1-2). Once stream segments were identified in each watershed and fire severity class, points on the stream segments were randomly selected in a GIS to represent a range of adjacent tree size classes (small, medium, and large size classes). The size class layer was created by the Forest Service based on aerial photographs, with size class 1 being the smallest size class (0-14.9" or 0-37.9 cm DBH), followed by size class 2 (15.0-19.9" or 40.0-50.7 cm DBH), and size class 3 (20.0" + or 50.8 cm + DBH) being the largest.

We attempted to sample each fire severity class/stream class/tree size class combination in each of the watersheds, resulting in two replicates of each combination and a potential for 54 sample points. However, not all combinations for each watershed were found in the landscape (Appendix A), and thus number of sample points in the two watersheds totaled 47.

<u>B&B Complex Fire</u>

The site selection procedure for the B&B Complex Fire closely followed that in the Biscuit Fire. However, for site selection in the B&B Complex Fire, only certain plant associations of interest within five sixth-field sub-watersheds were chosen for study in the fire area (plant associations did not separate by watershed as they did in the Biscuit Fire) (Figure 4.1). The study area was approximately 13,600 ha in size. Three plant associations were sampled, including ponderosa pine, dry mixed conifer, and wet mixed conifer. The ponderosa pine sites represent the driest sites in the study area, followed by dry mixed conifer and then the wet mixed conifer.

As in the Biscuit Fire, a stratified random sampling design was used to select points in each plant association that represented a range of broad fire severity classes, tree size classes, and stream sizes. The tree size class map used for the B&B Complex Fire was created by the Forest Service using aerial photographs and was comparable to that used for the Biscuit. The fire severity map used for the B&B Complex Fire was also created in a similar way to that for the Biscuit Fire. For the B&B Complex Fire, Landsat ETM+ imagery of the fire area was acquired from October 2002 (pre-fire) and October 2003 (post-fire). The images were converted to reflectance values and were co-registered to each other. Both pre- and post-fire imagery was converted to Normalized Burn Ratio (NBR) values and then differenced (dNBR). dNBR is an index formulated from Landsat ETM+ band 7 (short wave infrared) and band 4 (near infrared) reflectance (NBR = (near infrared – short wave infrared) / (near infrared + short wave infrared)). Areas with little or no change in the NBR in the B&B Complex (fire severity class 1) generally had low intensity to severe underburn that resulted in less than 25% mortality of overstory trees (USDA Forest Service 2005). Areas with moderate change in NBR (fire severity class 2) generally experienced mixed mortality, with the overstory tree mortality ranging from 25% to 75% (USDA Forest Service 2005). Areas with high change in NBR (fire severity class 3) experienced high intensity fire that resulted in 100% vegetation mortality (USDA Forest Service 2005).

We attempted to sample each fire severity class/stream class/tree size class combination in each of the three plant associations, resulting in three replicates of each combination and a potential for 81 sample points. However, because not all combinations for each plant association were found in the landscape (Appendix A), number of points sampled in the three plant associations totaled 54.

Sampling Methodology

Sampling was conducted two years after each fire event, in the summer of 2004 in the Biscuit Fire and in the summer of 2005 in the B&B Complex Fire. To assess post-fire riparian regeneration, one slope-corrected 4- x 25-m plot was established in the riparian area at each randomly selected point. Half of the plot (2- x 25-m) was in the riparian area on one side of the stream, and the other half of the plot (2- x 25-m) was in the riparian area on the other side of the stream. The half-plots on each side of the stream were directly adjacent to and parallel with the stream.

Within established plots, stem count of all regenerating trees and shrubs was recorded by species. It was noted whether regeneration was by seed or sprout. If single dead stem had multiple basal sprouts, all sprouting stems were counted individually.

To assess fire severity at each randomly selected point, a slope-corrected 10- x 25-m plot was established in the riparian area that encompassed the 4- x 25-m regeneration plot; the 10- x 25-m plot simply extended an additional 3 m from the stream on each side of the stream. Within each 10- x 25-m plot, an assessment of fire severity was done that included measurements of percent exposed mineral soil and percent basal area mortality. Cover of exposed mineral soil was visually estimated to the nearest 1% in each plot. This assessment was conducted by the same two individuals throughout data collection, and an average of the estimates for each individual was used for each plot in order to reduce bias. Basal area mortality and live basal area were approximated in each plot by measuring the diameter at breast height (DBH) of all trees greater than 5 cm DBH, and the species and live/dead status of each tree was recorded. All live and dead tree and shrub stems less than 5 cm DBH were counted by species. Percent cover of all live shrub species was also visually assessed to approximate former shrub cover by species.

Further measurements taken at each point included stream gradient (degrees slope) within the plots, percent slope to each of the upland plots, bank-full width, and valley floor width. Plant association for each sampling point was extracted from a GIS layer created by the Forest Service.

Data Analysis

<u>Pre-Fire Vegetation and Topographic Patterns</u>

Indicator species analysis (Dufrêne and Legendre 1997) was conducted with an approximation of pre-fire vegetation (stem number) in study plots in order to identify species that were more consistently found in one plant association/watershed versus another. Pre-fire vegetation was approximated by including stems of all species that were thought to have been alive prior to the fire; stems that were dead before the fire showed a greater amount of bole damage than stems that were alive before the fire. Indicator species analysis produces indicator values for each species in each group based on information on species abundance in a particular group and the faithfulness of a species to a particular group (McCune and Grace 2002). Indicator values are tested for statistical significance using Monte Carlo randomization techniques. Indicator species analysis was performed using PC-ORD v5.0 (McCune and Mefford 1999) with 1000 Monte Carlo simulations. Species with p-values less than 0.05 were considered indicators of a particular group.

Analysis of variance (ANOVA) was used to compare mean levels of various topographic and vegetation-related variables, including bank-full width, valley floor width, stream gradient, slope to uplands, elevation, percent deciduous hardwood basal area, total basal area, and small stem number among plots along different stream classes (two fires analyzed separately). PROC MIXED in SAS v9.1 (SAS Institute, Cary, NC, USA) was used to fit a mixed effects model to the data. Assumptions of normality and constant variance were checked prior to interpreting results of the analyses. Log-transformations were used when necessary to improve constant variance for a given variable. LSMEANS with a Bonferroni adjustment (SAS v9.1) was used for multiple comparisons of means.

Fire Effects in Riparian Areas

Two sample t-tests were used to compare riparian fire severity levels in the Biscuit and B&B Complex Fires. Fire severity indices compared included percent basal area mortality, percent exposed mineral soil, percent crown scorch, and scorch height. T-tests were conducted using PROC TTEST in SAS v9.1 (SAS Institute, Cary, NC, USA). Model assumptions were checked and found to be adequately met prior to examining results of the analysis.

Vegetation Abundance in Regenerating Riparian Plant Communities

ANOVA was also used to compare post-fire percent shrub cover in riparian areas between watersheds/plant associations and along different stream classes for both fires.

PROC MIXED in SAS v9.1 (SAS Institute, Cary, NC, USA) was used to fit a mixed effects model to the data. Assumptions of normality and constant variance were checked prior to interpreting results of the analyses. LSMEANS with a Bonferroni adjustment (SAS v9.1) was used for multiple comparisons of means.

Patterns in Species Abundance and Composition of Regenerating Riparian Plant Communities

Nonmetric multidimensional scaling (NMS) (Kruskal 1964, Mather 1976) was used to examine patterns in species abundance and composition of regenerating plant communities in riparian areas of both the Biscuit and B&B Complex Fires (analyzed separately). NMS is an ordination technique that iteratively searches for the best position of entities along a determined number of axes (k dimensions) by minimizing stress (McCune and Grace 2002). McCune and Grace (2002) define stress as, "the measure of departure from monotonicity in the relationship between the dissimilarity (distance) in the original p-dimensional space and the distance in the reduced k-dimensional ordination space." This technique was chosen because it avoids the assumption of linear relationships among variables and is appropriate for nonnormal community data (McCune and Grace 2002).

The main riparian vegetation regeneration matrix for the Biscuit Fire was composed of 47 rows, or plots, and 45 columns, or species. Stem count data of all regenerating species was used in the analysis. A square root transformation was done on the data to decrease skewness, and the data were relativized by species column total to ensure that the ordination was not structured by only a few abundant species. Species that occurred in less than five percent of the plots were omitted from the analysis in order to filter out noise in the data and to aid recognition of structure in the data (McCune and Grace 2002). This resulted in the omission of 12 rare species. Omission of these species resulted in a drop in community beta diversity from 4.3 to 3.1. The resulting main regeneration matrix had 47 plots and 33 species.

The main riparian vegetation regeneration matrix for the B&B Complex Fire was composed of 54 rows, or plots, and 47 columns, or species. Again, stem count data of all regenerating species was used in the analysis. A square root transformation was performed on the data to decrease skewness, and the data were relativized by species column total to ensure that the ordination was not structured by only a few abundant species. There were four study plots that had no recovering vegetation. There were no signs of fire in these plots (in the first two meters from the stream), and thus there was no recovering vegetation. These four plots were omitted from further analysis since they contained no information for ordination analysis. In addition, species that occurred in less than five percent of the plots were omitted from the analysis in order to filter out noise in the data and to aid recognition of structure in the data (McCune and Grace 2002). This resulted in the omission of 7 rare species. Omission of these species resulted in a drop in community beta diversity from 2.8 to 2.3. The resulting main regeneration matrix had 50 plots and 40 species.

PC-ORD software v5.0 (McCune and Mefford 1999) was used for all NMS analyses. Variables included in the environmental matrices to explain patterns in the ordinations were watershed/plant association, stream class, bank-full width, valley floor width, stream gradient, slope to uplands, elevation, pre-fire live hardwood basal area/percent hardwood stems, pre-fire live conifer basal area, DBH of the largest tree (proxy for stand age), exposed mineral soil, basal area mortality, post-fire live conifer basal area, and post-fire live hardwood basal area. The Sørensen distance measure was used in all analyses. With random starting configurations, the Slow and Thorough NMS Autopilot mode used 250 real and 250 randomized runs of the data. Autopilot mode determined the number of dimensions that best represented the data structure. In autopilot mode, an additional dimension is included if the reduction in stress is at least five with the addition of the dimension.

Multi-response permutation procedure (MRPP) was used to test for differences in regenerating plant communities among plots along different stream classes, and in different watersheds or plant associations. MRPP is a nonparametric method used to test for differences between groups. MRPP uses weighted within-group distances and permutation tests of all possible partitions of the data to find the probability of finding an equal or smaller mean within-group distance than the observed mean within-group distance (McCune and Grace 2002). All MRPP analyses were done using PC-ORD software (McCune and Mefford 1999).

Patterns in Abundance of Regeneration Strategies in Post-Fire Riparian Plant Communities

NMS was also used to examine patterns of abundance of regeneration strategies by plot in both fires. Regeneration strategies (columns) included sprouting, seed banking (seed stored in the soil), and obligate seeding (seed stored in the canopy or dispersed to a site). For this analysis, matrix multiplication was used to develop a main matrix of abundance of regeneration strategies by plot. For the Biscuit Fire, this main matrix of abundance of regeneration strategies by plot was developed by taking the main species by plots riparian vegetation regeneration matrix used in the previous NMS analysis (with plots as rows and species as columns, before transformations, and without rare species) and multiplying the matrix by a second matrix composed of species (33 rows) by regeneration strategy (3 columns). In the second matrix of regeneration strategies, zeroes and ones were used to designate the *primary* regeneration strategy or strategies utilized by each species (Table 4.1a) (information obtained from field observations and U.S. Forest Service data – www.fs.fed.us/database/feis). For example, if a species regenerated primarily by sprouting, it would have a one in the sprouter column and zeroes in the obligate seeder and seed banker columns. The resulting product matrix, the result of multiplying the regeneration matrix by the regeneration strategy matrix, was composed of plots (47 rows) by abundance of regeneration strategies (3 columns). A square root transformation was performed on the resulting data matrix to decrease skewness.

The main matrix for the regeneration strategy analysis in the B&B Complex Fire was developed by taking the main riparian vegetation regeneration matrix (with plots as rows and species as columns, before transformations, and without rare species) and multiplying the matrix by a second matrix composed of species (40 rows) and regeneration strategies (3 columns). In the second matrix, zeroes and ones were used to designate the *primary* regeneration strategy or strategies utilized by each species (Table

4.1b) (information obtained from field observations and U.S. Forest Service data – www.fs.fed.us/database/feis). As in the Biscuit Fire, regeneration strategies included sprouting, seed banking, and seeding. The resulting product matrix was composed of plots (54 rows) and regeneration strategies (3 columns).

PC-ORD software v5.0 (McCune and Mefford 1999) was used for NMS analyses of patterns in regeneration strategies in riparian zones after fire. Again, the Slow and Thorough NMS Autopilot mode with the Sørensen distance measure was used. Variables included in the environmental matrices to explain patterns in the ordinations were the same as those used to explain patterns in abundance and composition of regenerating plant communities, and the variables included watershed/plant association, stream class, bank-full width, valley floor width, stream gradient, slope to uplands, elevation, pre-fire live hardwood basal area/percent hardwood stems, pre-fire live conifer basal area, DBH of the largest tree (proxy for stand age), exposed mineral soil, basal area mortality, post-fire live conifer basal area, and post-fire live hardwood basal area.

Table 4.1. Primary regeneration strategies of regenerating species in riparian areas of the Biscuit Fire (a) and B&B Complex Fire (b). Some species are listed in more than one category if more than one regeneration strategy is commonly used.

(a)

Sprouters	**Seed Bankers**	**Seeders**
Acer circinatum	*Arctostaphylos viscida*	*Alnus rhombifolia*
Acer macrophyllum	*Ceanothus velutinus*	*Alnus rubra*
Alnus rhombifolia	*Holodiscus discolor*	*Chamaecyparis lawsoniana*
Alnus rubra	*Ribes bracteosum*	*Pinus lambertiana*
Amelanchier alnifolia	*Rubus leucodermis*	*Pseudotsuga menziesii*
Arbutus menziesii	*Rubus parviflorus*	*Salix* spp.
Chrysolepis chrysophylla	*Rubus ursinus*	
Chimaphila umbellata		
Frangula californica		
Gaultheria shallon		
Holodiscus discolor		
Leucothoe davisiae		
Linnaea borealis		
Lithocarpus densiflorus		
Mahonia nervosa		
Quercus chrysolepis		
Quercus sadleriana		
Rhododendron macrophyllum		
Rhododendron occidentale		
Rosa gymnocarpa		
Rubus leucodermis		
Rubus parviflorus		
Rubus ursinus		
Vaccinium ovatum		
Vaccinium parvifolium		

(b)

Sprouters	Seed Bankers	Seeders
Acer circinatum	*Arctostaphylos columbiana*	*Abies concolor/grandis*
Acer glabrum	*Ceanothus velutinus*	*Pinus contorta*
Alnus incana	*Ribes bracteosum*	*Picea engelmannii*
Amelanchier alnifolia	*Ribes lacustre*	*Pinus monticola*
Chimaphila umbellata	*Ribes lobbii*	*Pinus ponderosa*
Cornus sericea	*Ribes viscosissimum*	*Pseudotsuga menziesii*
Holodiscus discolor	*Rubus leucodermis*	*Salix* spp.
Linnaea borealis	*Rubus parviflorus*	*Thuja plicata*
Lonicera involucrata	*Rubus ursinus*	*Tsuga heterophylla*
Mahonia nervosa	*Sambucus racemosa*	
Pachistima myrsinites		
Physocarpus capitatus		
Populus tremuloides		
Rosa gymnocarpa		
Rubus leucodermis		
Rubus parviflorus		
Rubus ursinus		
Sambucus racemosa		
Sorbus sitchensis		
Spiraea betulifolia		
Symphoricarpos albus		
Symphoricarpos mollis		
Taxus brevifolia		
Vaccinium membranaceum		
Viburnum edule		

RESULTS

Pre-fire Vegetation and Topographic Patterns

Biscuit Fire

Prior to the Biscuit Fire, riparian forests were dominated by *Alnus rubra* (red alder), *Chamaecyparis lawsoniana* (Port-Orford-cedar), *Pseudotsuga menziesii* (Douglas-fir), *Tsuga heterophylla* (western hemlock), and *Thuja plicata* (western redcedar) (Table 4.2a). Common midstory species in riparian areas included *Acer circinatum* (vine maple), *Alnus rubra*, *Lithocarpus densiflorus* (tanoak), and *Salix* spp. (willow species) (Table 4.2b). Common riparian understory species included *Gaultheria shallon* (salal), *Mahonia nervosa* (dwarf Oregon-grape), *Rhododendron macrophyllum* (Pacific rhododendron), *Rhododendron occidentale* (western azalea), *Rubus ursinus* (wild blackberry), and *Vaccinium* spp. (huckleberry species) (Table 4.2b).

The two study watersheds in the Biscuit Fire area had distinct vegetation composition. Indicator species analysis of pre-fire vegetation (stem number) in sampled plots showed that some species were more consistently found in riparian areas of one watershed than the other. Indicator species for riparian areas in the east watershed (lower precipitation) included *Abies concolor* (white fir), *Cornus nuttallii* (Pacific dogwood), *Leucothoe davisiae* (Sierra laurel), *Quercus sadleriana* (Sadler oak), *Thuja plicata*, and *Tsuga heterophylla* (Table 4.2). In the west watershed riparian areas (higher precipitation), indicator species included *Gaultheria shallon*, *Holodiscus discolor* (ocean spray), and *Vaccinium parvifolium* (red huckleberry) (Table 4.2).

In addition to differences in plant species composition and abundance between riparian areas in watersheds on the east and west side of the Biscuit Fire area, streams of different sized had distinct topographic and vegetation patterns (Table 4.3a). Total pre-fire basal area was lowest for the larger (class 1) streams. However, the proportion of deciduous hardwoods was highest for the larger streams and decreased with decreasing stream size. The number of stems less than 5 cm DBH was significantly lower along the larger class 1 and 2 streams than along the smaller class 3 streams. Class 1 streams were generally wider (larger bank-full widths) with lower gradient and greater slope to the uplands (more incised valleys), and were found at lower elevations than the class 2 and 3 streams. Valley floors were most narrow for the smallest streams.

Table 4.2. Pre-fire live basal area (a) and small stem number (b) (mean values and range in parentheses) of common woody species and all woody species combined in sampled riparian areas of the Biscuit Fire. Basal area values are based on stems > 5 cm DBH, while small stem number includes all stems < 5 cm DBH. The east watershed is characterized by lower precipitation, while the west watershed is characterized by higher precipitation. Asterisks denote indicator species ($p < 0.05$) for each watershed.

(a)

	Mean Basal Area (m^2/ha)	
	Riparian East Watershed	Riparian West Watershed
Abies concolor	1.31* (0-10.21)	0 (0)
Alnus rubra	4.31 (0-36.48)	6.48 (0-56.32)
Chamaecyparis lawsoniana	4.96 (0-74.70)	19.68 (0-68.94)
Pseudotsuga menziesii	9.24 (0-84.71)	22.22 (0-125.84)
Thuja plicata	6.32* (0-102.95)	0 (0)
Tsuga heterophylla	4.63* (0-64.35)	0 (0)
All Species	58.32 (3.82-211.79)	53.26 (2.05-186.62)

(b)

	Stems < 5 cm DBH (number/ha)	
	Riparian East Watershed	Riparian West Watershed
Acer circinatum	315 (0-3560)	272 (0-2920)
Alnus rubra	366 (0-1440)	375 (0-4560)
Cornus nuttallii	69* (0-760)	0 (0)
Gaultheria shallon	3293 (0-14400)	1110* (0-7040)
Holodiscus discolor	6 (0-120)	343* (0-2440)
Leucothoe davisiae	1053* (0-5960)	0 (0)
Lithocarpus densiflorus	309 (0-2120)	475 (0-3840)
Mahonia nervosa	1066 (0-8320)	302 (0-2280)
Quercus sadleriana	435* (0-3600)	8 (0-160)
Rhododendron macrophyllum	456 (0-2400)	612 (0-5680)
Rhododendron occidentale	240 (0-2360)	618 (0-6640)
Vaccinium ovatum	16 (0-320)	743 (0-13040)
Vaccinium parvifolium	289 (0-3520)	228* (0-1200)
All Species	9844 (1400-29480)	6693 (1000-15400)

B&B Complex Fire

The ponderosa pine plant association is located in the eastern portion of the B&B Complex Fire area, primarily at lower elevations (below 1,100 m). Riparian zones in the ponderosa pine plant association were dominated by *Larix occidentalis* (western larch), *Picea engelmanii* (Engelman spruce), and *Pinus ponderosa* (ponderosa pine) (Table 4.4a). Indicator species in riparian areas of the ponderosa pine plant association included

Alnus incana (thinleaf alder), *Amelanchier alnifolia* (Pacific serviceberry), *Larix occidentalis*, *Lonicera involucrata* (twinberry), *Physocarpus capitatus* (Pacific ninebark), *Pinus ponderosa*, *Spiraea betulifolia* (white spiraea), and *Symphoricarpos albus* (snowberry) (Table 4.4).

The dry and wet mixed conifer plant associations in the B&B Complex Fire area are found between 1,000 and 1,500 m in elevation. Dominant overstory species in riparian areas of the dry mixed conifer plant association included *Abies grandis/Abies concolor* (grand fir and white fir hybrid), *Picea engelmanii*, and *Pseudotsuga menziesii* (Table 4.4a). Indicator species in these riparian areas included *Abies grandis/Abies concolor*, *Acer circinatum*, *Holodiscus discolor*, *Pinus contorta* (lodgepole pine), and *Pseudotsuga menziesii* (Table 4.4). Dominant overstory species in riparian areas of the wet mixed conifer plant association included *Abies grandis/Abies concolor*, *Picea engelmanii*, *Pseudotsuga menziesii, Tsuga heterophylla*, and *Thuja plicata* (Table 4.4a). Indicator species in riparian areas of the wet mixed conifer plant association included *Pachistima myrsinites* (boxwood), *Picea engelmanii, Rubus parviflorus* (thimbleberry), *Taxus brevifolia* (Pacific yew), *Tsuga heterophylla,* and *Thuja plicata* (Table 4.4).

Different sized streams had distinct patterns in topography and forest attributes in the B&B Complex Fire area (Table 4.3b). However, these patterns were not as distinct as those in the Biscuit Fire area. In the B&B Complex Fire area, class 1 streams had higher total pre-fire basal area than smaller class 2 streams. However, percent deciduous hardwood basal area did not differ among stream classes. Class 1 streams were generally wider (larger bank-full widths) than smaller streams.

Differences in Vegetation and Topography between Fires

In addition to variation in vegetation composition and topographic patterns *within* the Biscuit and B&B Complex Fire areas, important differences in vegetation and topography *between* the two fire areas had the potential to influence patterns in fire severity and post-fire regeneration (Table 4.3). The riparian areas in the B&B Complex Fire area had a greater conifer component (% of basal area) than riparian areas in the Biscuit Fire, particularly along larger streams. Total basal area along larger streams in

B&B Complex Fire riparian areas was also higher than that in the Biscuit, indicating that there were more large trees in riparian areas of large streams in the B&B Complex Fire. Large and mid-sized (class 1 and 2) streams in the Biscuit Fire generally had larger bank-full widths than those in the B&B Complex Fire area. Small and mid-sized (class 3 and 2) streams in the Biscuit Fire had a higher stream gradient than those in the B&B Complex Fire, and slope to uplands from riparian zones was substantially higher in the Biscuit Fire than it was in the B&B Complex Fire, indicating that the terrain in the Biscuit Fire was steeper and more complex than that in the B&B Complex Fire. These patterns in vegetation composition and topography could lead to differences in riparian regeneration patterns between the two regions.

Table 4.3. Mean values (range) for topographic and vegetation variables by stream class in the Biscuit Fire (a) and B&B Complex Fire (b). Class 1 streams are fish-bearing streams with a steady flow. Class 2 streams are also fish-bearing with moderate flow, and class 3 streams have few fish and low flow. For a given variable, means followed by the same letter are not significantly different (p-values > 0.05). Results of some tests are based on transformed data.

(a)

Stream Class	Bank-full width (m)	Valley Floor Width (m)	Stream Gradient (º)	Slope to Uplands (º)	Elevation (m)	% Deciduous Hardwood Basal Area	Total Basal Area (m^2/ha)	Stems < 5 cm DBH (per ha)
1	8.6 a (5.5-10.5)	29.0 a (19.0-50.5)	2 a (0-5)	43 a (29-54)	467 a (268-597)	73.7 a (2.8-100.0)	21.45 a (3.82-63.41)	3736 a (440-7120)
2	4.3 b (1.2-13.0)	32.8 a (7.3-75.0)	4 a (0-14)	29 b (13-41)	816 b (413-1002)	27.2 b (0.0-100.0)	72.85 b (14.06-211.40)	5162 a (1120-14600)
3	1.7 c (0.6-4.1)	21.8 b (5.4-110.0)	14 b (1-33)	27 b (9-42)	921 c (427-1151)	9.5 c (0.0-97.0)	56.01 b (7.89-186.65)	13431 b (1000-29480)

(b)

Stream Class	Bank-full width (m)	Valley Floor Width (m)	Stream Gradient (º)	Slope to Uplands (º)	Elevation (m)	% Deciduous Hardwood Basal Area	Total Basal Area (m^2/ha)	Stems < 5 cm DBH (per ha)
1	5.9 a (1.6-21.0)	107.3 a (20-525)	3 ab (1-6)	10 a (3-27)	3312 a (2681-4111)	13.9 a (0.0-100.0)	72.08 a (4.47-134.99)	23407 a (2920-52640)
2	1.7 b (0.5-3.1)	145.2 a (15-1000)	2 a (0-9)	8 a (1-30)	3483 a (2933-4607)	10.6 a (0.0-79.5)	45.58 b (1.00-103.93)	18455 a (2040-65920)
3	1.7 b (0.6-4.1)	151.0 a (20-1000)	4 b (1-13)	7 a (1-24)	3272 a (3035-3698)	4.0 a (0.0-17.2)	58.46 ab (19.38-122.53)	14991 a (2680-32400)

Table 4.4. Pre-fire basal area (a) and small stem number (b) (mean values and range in parentheses) of common woody species and all woody species combined in sampled riparian areas of the B&B Complex Fire. Basal area values are based on stems > 5 cm DBH, while small stem number is based on stems < 5 cm DBH. Riparian plots were sampled in the ponderosa pine, dry mixed conifer, and wet mixed conifer plant associations. Asterisks denote indicator species ($p < 0.05$) for each plant association.

(a)

	Average Basal Area (m^2/ha)		
	Ponderosa Pine	Dry Mixed Conifer	Wet Mixed Conifer
Alnus incana	3.23* (0-11.88)	1.14 (0-4.22)	0.99 (0-4.84)
Abies grandis/concolor	1.48 (0-15.04)	17.55* (0-61.78)	7.16 (0-48.98)
Larix occidentalis	4.89* (0-21.98)	1.26 (0-15.61)	1.20 (0-21.64)
Pinus contorta	0 (0)	2.15* (0-31.97)	0 (0)
Picea engelmanii	14.04 (0-60.17)	10.53 (0-31.98)	19.85* (0-73.28)
Pinus ponderosa	11.74* (0-55.49)	5.16 (0-39.22)	2.08 (0-24.09)
Pseudotsuga menziesii	3.03 (0-44.79)	18.88* (0-88.97)	20.67 (0-99.30)
Thuja plicata	0.22 (0-3.74	1.44 (0-27.35)	8.85* (0-97.01)
Tsuga heterophylla	0 (0)	3.21 (0-25.34)	10.46* (0-77.78)
All Species	38.75 (1.01-124.19)	66.90 (19.38-134.99)	74.50 (26.56-131.77)

(b)

	Stems < 5 cm DBH (number/ha)		
	Riparian Ponderosa Pine	Riparian Dry Mixed Conifer	Riparian Wet Mixed Conifer
Abies grandis/concolor	327 (0-1720)	914* (0-5000)	504 (0-3760)
Acer circinatum	0 (0)	634* (0-4280)	273 (0-1280)
Alnus incana	4522* (0-13320)	2564 (0-7680)	1489 (0-7880)
Amelanchier alnifolia	828* (0-4880)	225 (0-2120)	49 (0-200)
Cornus sericea	1271 (0-16840)	181 (0-1600)	180 (0-920)
Holodiscus discolor	0 (0)	537* (0-3640)	22 (0-360)
Lonicera involucrata	802* (0-3720)	301 (0-2120)	216 (0-1320)
Mahonia nervosa	1461 (0-5600)	1347 (0-13080)	2973 (0-13520)
Pachistima myrsinites	0 (0)	541 (0-5000)	567* (0-3400)
Physocarpus capitatus	2612* (0-6040)	135 (0-2400)	218 (0-2000)
Ribes spp.	257 (0-2240)	1524 (0-10800)	1549 (0-7440)
Rosa gymnocarpa	4080 (840-12440)	2512 (0-6640)	2636 (0-8920)
Rubus parviflorus	5 (0-40)	566 (0-3040)	953* (0-4840)
Spiraea betulifolia	3593* (40-16600)	303 (0-3400)	1173 (0-9640)
Symphoricarpos albus	3167* (240-12480)	766 (0-4080)	1253 (0-7240)
Taxus brevifolia	0 (0)	126 (0-1080)	642* (0-5600)
Tsuga heterophylla	0 (0)	152 (0-2120)	296* (0-1480)
Vaccinium membranaceum	642 (0-7040)	547 (0-5880)	553 (0-4760)
All Species	25207 (6840-65920)	15975 (2680-31480)	17118 (2040-32400)

Fire Effects in Riparian Areas

Fire severity in riparian areas varied by stream class in the Biscuit Fire (Figure 4.2). Basal area mortality, crown scorch, exposed mineral soil, and scorch height were all significantly lower along larger class 1 streams than along class 2 or 3 streams. Fire severity levels in riparian areas along class 2 and 3 streams were generally similar; only exposed mineral soil was significantly lower along class 2 streams than along class 3 streams (Figure 4.2).

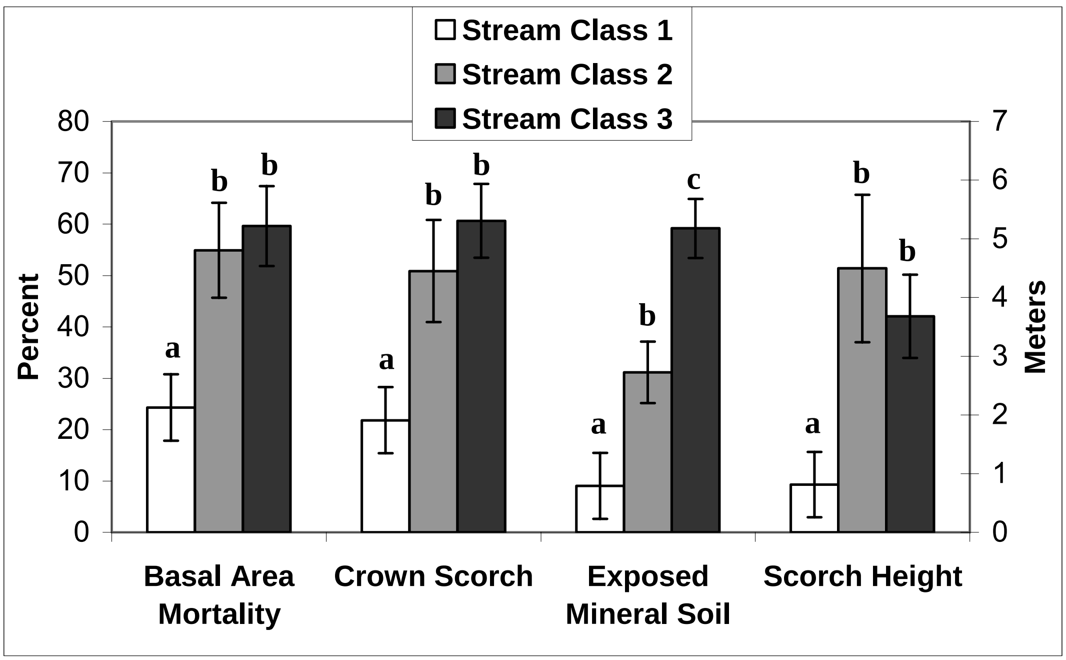


Figure 4.2. Mean riparian fire severity levels by stream class in the Biscuit Fire. Class 1 streams are fish-bearing streams with a steady flow. Class 2 streams are also fish-bearing with moderate flow, and class 3 streams have few fish and low flow. Of the fire severity variables on the x-axis, exposed mineral soil, crown scorch, and dead basal area are on a percentage scale (left-hand y-axis). Scorch height is shown in meters (right-hand y-axis). Standard errors are shown for each mean value. For a given fire severity measure, significant difference between stream classes ($p < 0.05$) is indicated with a difference in letters between stream classes; means with the same letter are not significantly different ($p > 0.05$).

There were few differences in fire severity levels among stream classes in the B&B Complex Fire; only crown scorch and scorch height were significantly lower in riparian areas along class 1 streams than along class 2 streams. The lack of a relationship between stream size and fire severity levels is likely due to the lack of variation in vegetation and topography between stream classes in the B&B Complex Fire area. However, there were significant differences in fire severity levels among plant associations in the B&B Complex Fire (Figure 4.3). Basal area mortality was significantly higher in riparian areas of the ponderosa pine plant association than in the dry and wet mixed conifer plant associations, although exposed mineral soil in riparian areas of the ponderosa pine plant association was significantly lower than that in the dry mixed conifer plant association. There were no significant differences in fire severity levels between the dry and wet mixed conifer plant associations (Figure 4.3).

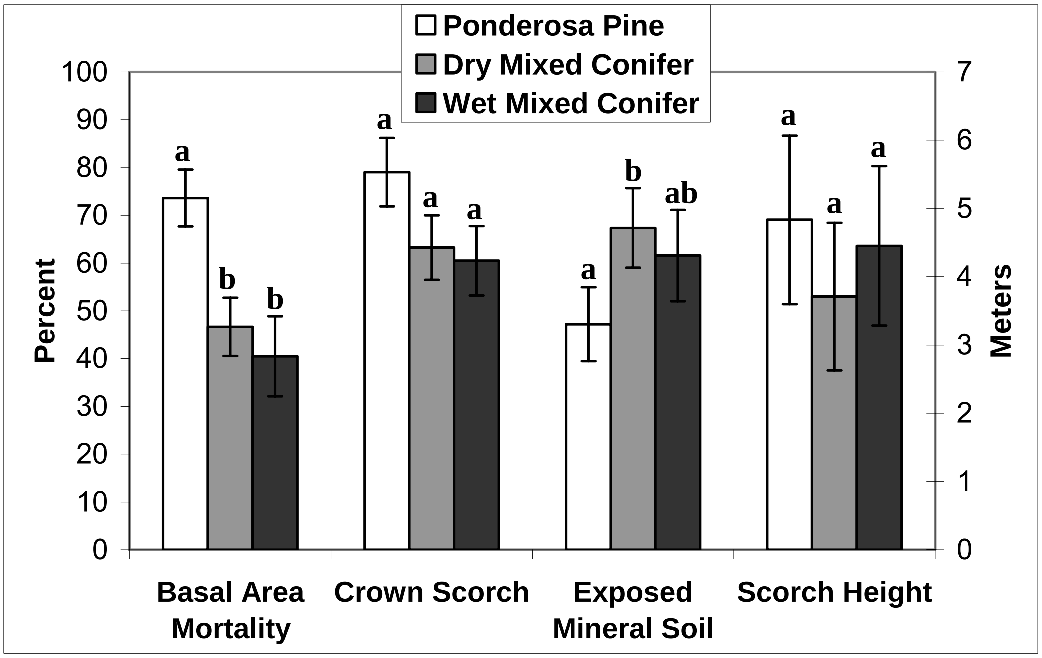


Figure 4.3. Mean riparian fire severity levels by plant association in the B&B Complex Fire. Riparian plots were sampled in the ponderosa pine, dry mixed conifer, and wet mixed conifer plant associations. Of the fire severity variables on the x-axis, exposed mineral soil, crown scorch, and dead basal area are on a percentage scale (left-hand y-axis). Scorch height is shown in meters (right-hand y-axis). Standard errors are shown for each mean value. For a given fire severity measure, significant difference between plant associations ($p < 0.05$) is indicated with a difference in letters; means with the same letter are not significantly different ($p > 0.05$).

Vegetation Abundance in Regenerating Riparian Plant Communities

Biscuit Fire

Two years post-fire, sampled riparian areas in the Biscuit Fire had a mean percent shrub cover of 11% (range 2-33%). Percent shrub cover varied somewhat by stream class; shrub cover was significantly lower in riparian areas along larger (class 1) streams than along smaller streams in both watersheds (Table 4.5a). Species providing cover also varied by stream class and watershed (Table 4.5a). Species such as *Alnus rubra, Acer circinatum, Amelanchier alnifolia, Holodiscus discolor,* and *Salix* spp. provided the most cover along larger (class 1) streams in both watersheds, reflecting the mesic site requirements of these species. *Gaultheria shallon, Lithocarpus densiflorus, Mahonia nervosa,* and *Rubus ursinus* provided a large proportion of the cover along smaller (class 2 and 3) streams (Table 4.5a), indicating these species are dominant in drier, upland-like conditions along smaller streams in the Biscuit Fire area. *Lithocarpus densiflorus,* and *Rubus ursinus* were the most consistent contributors to cover across stream classes and watersheds.

Post-fire woody species seedling density and composition varied by stream class in the Biscuit Fire, with the highest seedling density along class 1 streams (1356 seedlings per ha) and the lowest seedling density along class 2 streams (389 seedlings per ha) (Table 4.6a). *Alnus rubra* was the most common seeded species along all stream classes, with highest abundance along class 1 streams. *Salix* spp. seedlings were common along larger class 1 and 2 streams (Table 4.6a). The presence of *Alnus rubra* and *Salix* spp. along larger streams is an indication of the mesic site requirements of these species. *Arctostaphylos viscida* (white leaf manzanita) and *Ceanothus velutinus* (snowbrush) seedlings, primarily drier site species, were common along class 3 streams. Conifer seedlings were most common along class 3 streams at a density of 131 seedlings per ha and least common along class 1 streams at a density of 12 seedlings per ha (Table 4.6a). The majority of conifer seedlings were *Pseudotsuga menziesii*.

Sprout density was higher than seedling density in riparian areas along all stream classes two years after the Biscuit Fire (Table 4.7a). Sprout density was inversely related to stream size, with the highest sprout density along the smallest class 3 streams (10,133 per ha) and the lowest sprout density along the largest class 1 streams (1408 per ha) (Table 4.7a). *Alnus rubra*, *Holodiscus discolor*, and *Rosa gymnocarpa* (little wood rose), species with mesic site requirements, were the most common sprouts along class 1 streams. *Gaultheria shallon*, *Alnus rubra*, and *Acer circinatum* were the most common sprouts along class 2 streams. In riparian areas along class 3 streams, the most common sprouts were drier site species such as *Gaultheria shallon, Mahonia nervosa, Leucothoe davisiae,* and *Lithocarpus densiflorus* (Table 4.7a).

Overall, there were many differences between regeneration communities in more mesic riparian areas along larger streams and more xeric riparian areas along smaller streams. Seedlings of species with mesic site requirements, including *Alnus rubra* and *Salix* spp., were more abundant in riparian areas along larger streams. In contrast, conifer seedlings were more abundant along smaller streams. In addition, sprouts of drier site species that are more dominant in upland areas, such as *Gaultheria shallon, Mahonia nervosa* and *Lithocarpus densiflorus*, were more abundant in riparian areas along smaller streams in the Biscuit Fire area.

B&B Complex Fire

Sampled riparian areas in the B&B Complex Fire had a mean shrub cover of 18% (range 3-55%), and a mean herbaceous cover of 64% (range 2-95%). Shrub cover varied little with stream class or plant association, although shrub cover in riparian areas of stream classes 2 and 3 in the ponderosa pine plant association was significantly lower than that along stream class 3 in the wet mixed conifer plant association (Table 4.5b). Species providing cover varied by plant association and somewhat by stream class (Table 4.5b). Species such as *Alnus incana, Physocarpus capitatus,* and *Spiraea betulifolia* were more common in riparian areas of the ponderosa pine plant association, and these species were also more common along larger streams. Species such as *Acer circinatum, Ceanothus velutinus, Linnaea borealis* (twinflower), and *Rubus parviflorus* were more common in the dry and wet mixed conifer plant associations (Table 4.5b). *Mahonia nervosa, Rosa gymnocarpa, Rubus ursinus,* and *Salix* spp. were common across plant associations and stream classes.

Post-fire woody species seedling density and composition in riparian areas varied by plant association in the B&B Complex Fire (Table 4.6b). The highest seedling density was in riparian areas of the wet mixed conifer plant association (6747 seedlings per ha) and the lowest seedling density was in riparian areas of the ponderosa pine plant association (1967 seedlings per ha). Riparian conifer seedlings were more numerous two years post-fire in the B&B Complex Fire than they were in the Biscuit Fire, and conifer seedlings composed a relatively high proportion of seeded species in riparian areas of all three plant associations in the B&B Complex Fire (Table 4.6b). *Picea engelmannii* seedlings were common in riparian areas across all three plant associations. *Pinus ponderosa*, and *Abies grandis/concolor* seedlings were common in riparian areas of the ponderosa pine plant association, and *Abies grandis/concolor* seedlings were also common in the dry mixed conifer plant association. *Tsuga heterophylla* seedlings were common in both the dry and wet mixed conifer plant associations (Table 4.6b). Common deciduous seedlings included *Salix* spp., *Alnus incana*, and *Ceanothus velutinus* (in the dry and wet mixed conifer plant associations).

Sprout density also varied by plant association in the B&B Complex Fire. However, unlike seedling density, sprout density was highest in the ponderosa pine plant association (8233 sprouts per ha) and lowest in the wet mixed conifer plant association (4611 sprouts per ha) (Table 4.7b). *Alnus incana* and *Rosa gymnocarpa* were the most common sprouts in all three plant associations. *Spiraea betulifolia* and *Physocarpus capitatus* sprouts were common in riparian areas of the ponderosa pine plant association. *Mahonia nervosa* and *Ribes lacustre* (black gooseberry) were common in riparian areas of both the dry and wet mixed conifer plant associations. *Acer glabrum* (Rocky Mountain maple) and *Acer circinatum* were also common sprouts in the wet mixed conifer plant association (Table 4.7b).

Overall, there were many differences between the regenerating plant communities in the ponderosa pine plant association compared to those of the dry and wet mixed conifer plant associations. Sprouts of deciduous hardwood species, such as *Alnus incana, Physocarpus capitatus, Rosa gymnocarpa,* and *Spiraea betulifolia*, were more abundant in the drier and lower elevation ponderosa pine plant association. However, seedlings of conifer species and other woody species such as *Ceanothus velutinus* and *Salix* spp. were more abundant in the wetter and higher elevation dry and wet mixed conifer plant associations. These trends parallel those in the Biscuit Fire area, where species reproducing primarily by sprouting are more abundant in riparian areas in drier locations, while species reproducing primarily by seed are more abundant in riparian areas in wetter locations.

Table 4.5. Mean percent vegetative cover and proportion of total shrub cover provided by common species in riparian areas two years after the Biscuit Fire (a) and the B&B Complex Fire (b). In the Biscuit Fire, the east watershed is characterized by lower precipitation, while the west watershed is characterized by higher precipitation. In the B&B Complex Fire, riparian plots were sampled in the ponderosa pine, dry mixed conifer, and wet mixed conifer plant associations. Class 1 streams are fish-bearing streams with a steady flow. Class 2 streams are also fish-bearing with moderate flow, and class 3 streams have few fish and low flow. Mean percent vegetative cover values followed by the same letter are not significantly different (p-values > 0.05).

(a)

	Proportion of Total Cover (%)					
	East Watershed			West Watershed		
	Stream Class 1	Stream Class 2	Stream Class 3	Stream Class 1	Stream Class 2	Stream Class 3
Acer circinatum	4	12	0	2	2	7
Alnus rubra	13	9	0	10	6	2
Amelanchier alnifolia	2	<1	0	19	<1	0
Gaultheria shallon	0	19	18	2	29	6
Holodiscus discolor	0	<1	0	19	2	<1
Leucothoe davisiae	0	2	8	0	0	0
Lithocarpus densiflorus	7	6	13	1	3	18
Mahonia nervosa	0	7	4	0	3	6
Quercus sadleriana	0	2	13	0	<1	0
Rhododendron macrophyllum	0	0	15	1	3	8
Ribes bracteosum	2	2	0	2	11	<1
Rosa gymnocarpa	6	2	1	11	2	2
Rubus parviflorus	13	2	<1	4	3	1
Rubus ursinus	24	25	12	3	11	12
Salix spp.	15	1	1	10	1	1
Vaccinium ovatum	0	<1	1	1	1	12
Vaccinium parvifolium	0	1	4	4	13	2
Shrub Cover (% (range))	5 a (4-6)	14 b (2-33)	16 b (10-20)	7 a (2-16)	10 b (3-27)	9 b (4-18)

(b)

	Proportion of Total Cover (%)								
	Ponderosa Pine			Dry Mixed Conifer			Wet Mixed Conifer		
	Stream Class 1	Stream Class 2	Stream Class 3	Stream Class 1	Stream Class 2	Stream Class 3	Stream Class 1	Stream Class 2	Stream Class 3
Acer circinatum	0	0	0	1	2	13	1	5	3
Alnus incana	14	22	0	7	1	10	9	3	0
Ceanothus velutinus	1	0	0	4	8	2	4	7	2
Linnaea borealis	2	0	0	11	2	25	6	0	6
Mahonia nervosa	4	7	5	5	7	1	5	7	13
Physocarpus capitatus	13	8	0	<1	1	0	1	1	0
Rosa gymnocarpa	16	9	29	10	6	10	9	14	9
Rubus parviflorus	<1	0	0	12	9	1	6	13	10
Rubus ursinus	4	3	17	2	20	18	18	5	27
Salix spp.	1	2	15	3	20	2	11	5	0
Spiraea betulifolia	9	16	10	1	4	1	5	4	0
Symphoricarpos albus	19	17	10	7	2	2	3	1	10
Shrub Cover (% (range))	21 ab (8-43)	14 a (6-53)	5 a (4-6)	18 ab (8-48)	14 ab (3-29)	15 ab (4-51)	13 ab (3-31)	15 ab (5-34)	34 b (5-55)

Table 4.6. Seedling density and species composition of all woody species in sampled riparian areas two years after the Biscuit Fire (a) and B&B Complex Fire (b). Any regenerating woody plant determined to have germinated from seed after fire was counted as a seedling. Conifer species are shaded in gray.

(a)

	Seedling Number (per ha)					
	Stream Class 1		Stream Class 2		Stream Class 3	
	Mean	Range	Mean	Range	Mean	Range
Acer circinatum	0	0	21	0-560	0	0
Acer macrophyllum	12	0-80	0	0	40	0-1040
Alnus rhombifolia	76	0-800	0	0	0	0
Alnus rubra	584	80-7600	154	0-2240	311	0-3920
Amelanchier alnifolia	4	0-80	0	0	0	0
Arbutus menziesii	0	0	0	0	13	0-240
Arctostaphylos patula	0	0	0	0	4	0-160
Arctostaphylos viscida	0	0	4	0-160	222	0-4080
Ceanothus velutinus	0	0	11	0-160	151	0-3040
Chamaecyparis lawsoniana	0	0	4	0-80	20	0-560
Cornus sericea	0	0	17	0-480	0	0
Frangula californica	0	0	4	0-80	27	0-960
Fraxinus latifolia	28	0-320	0	0	0	0
Holodiscus discolor	4	0-80	13	0-160	0	0
Lithocarpus densiflorus	8	0-80	4	0-160	20	0-640
Pinus lambertiana	0	0	0	0	13	0-320
Pseudotsuga menziesii	0	0	21	0-720	87	0-1440
Rhododendron occidentale	0	0	2	0-80	76	0-2640
Rubus spectabilis	0	0	53	0-2000	0	0
Rubus parviflorus	8	0-160	0	0	0	0
Salix spp.	620	0-3200	65	0-1040	60	0-640
Spiraea betulifolia	0	0	0	0	22	0-800
Taxus brevifolia	4	0-80	0	0	9	0-320
Thuja plicata	8	0-160	0	0	0	0
Tsuga heterophylla	0	0	2	0-80	2	0-80
Vaccinium ovatum	0	0	0	0	2	0-80
Vaccinium parvifolium	0	0	15	0-560	7	0-240
All Species	1356	280-4320	389	0-1280	1087	0-4000

(b)

	Seedling Number (per ha)					
	Ponderosa Pine		Dry Mixed Conifer		Wet Mixed Conifer	
	Mean	Range	Mean	Range	Mean	Range
Abies grandis/concolor	148	0-2880	379	0-3920	116	0-1680
Abies lasiocarpa	0	0	46	0-1120	0	0
Acer circinatum	0	0	74	0-1280	7	0-80
Acer glabrum	5	0-160	76	0-1760	9	0-160
Alnus incana	111	0-3600	284	0-3440	331	0-5840
Amelanchier alnifolia	2	0-80	65	0-1040	2	0-80
Arctostaphylos columbiana	19	0-320	32	0-560	42	0-480
Ceanothus velutinus	64	0-1120	802	0-5680	1011	0-7360
Cornus sericea	0	0	0	0	29	0-720
Holodiscus discolor	0	0	107	0-2720	0	0
Larix occidentalis	0	0	11	0-320	0	0
Mahonia nervosa	0	0	0	0	18	0-640
Pachistima myrsinites	0	0	13	0-240	156	0-3680
Picea engelmannii	1181	0-13840	1065	0-10240	562	0-6400
Pinus contorta	0	0	78	0-1760	0	0
Pinus monticola	0	0	21	0-320	13	0-240
Pinus ponderosa	125	0-2640	29	0-320	9	0-80
Populus tremuloides	0	0	17	0-400	4	0-160
Pseudotsuga menziesii	40	0-480	160	0-2240	142	0-1360
Ribes lacustre	0	0	255	0-4880	244	0-5760
Ribes viscosissimum	0	0	116	0-2400	16	0-240
Rosa gymnocarpa	0	0	65	0-1040	0	0
Rubus parviflorus	0	0	88	0-3360	20	0-720
Salix spp.	247	0-2160	1371	0-13360	1249	0-10560
Sambucus racemosa	0	0	38	0-1040	0	0
Sorbus sitchensis	7	0-240	0	0	2	0-80
Spiraea betulifolia	19	0-640	149	0-4720	142	0-2640
Symphoricarpos albus	0	0	120	0-4080	0	0
Taxus brevifolia	0	0	6	0-240	16	0-320
Thuja plicata	0	0	86	0-3200	11	0-240
Tsuga heterophylla	0	0	352	0-8800	2596	0-40000
Tsuga mertensiana	0	0	48	0-1040	0	0
Vaccinium membranaceum	0	0	65	0-2240	0	0
All Species	1967	0-20120	6019	0-15840	6747	0-23440

Table 4.7. Species composition and density of sprouts by stream class in sampled riparian areas two years after the Biscuit Fire (a) and B&B Complex Fire (b).

(a)

	Mean Sprout Number (per ha)					
	Stream Class 1		Stream Class 2		Stream Class 3	
	Mean	Range	Mean	Range	Mean	Range
Acer circinatum	0	0	478	0-4160	362	0-4800
Acer macrophyllum	8	0-160	40	0-480	100	0-1600
Alnus rhombifolia	12	0-240	0	0	36	0-720
Alnus rubra	480	0-2160	1093	0-4960	100	0-1600
Amelanchier alnifolia	120	0-960	6	0-240	0	0
Arbutus menziesii	0	0	0	0	4	0-160
Chrysolepis chrysophylla	0	0	2	0-80	36	0-720
Chimaphila umbellata	0	0	0	0	160	0-3520
Cornus nuttallii	0	0	34	0-1200	0	0
Cornus sericea	0	0	139	0-3280	0	0
Frangula californica	0	0	11	0-320	40	0-640
Gaultheria shallon	0	0	1552	0-9840	3587	0-17280
Holodiscus discolor	296	0-2800	2	0-80	22	0-400
Leucothoe davisiae	0	0	55	0-720	1229	0-8880
Linnaea borealis	0	0	0	0	147	0-1920
Lithocarpus densiflorus	0	0	65	0-1600	678	0-7280
Mahonia nervosa	0	0	280	0-3280	1409	0-11600
Pachistima myrsinites	0	0	11	0-400	47	0-960
Quercus chrysolepis	0	0	36	0-1280	91	0-1200
Quercus sadleriana	0	0	32	0-400	249	0-1680
Rhododendron macrophyllum	0	0	0	0	338	0-2640
Rhododendron occidentale	36	0-400	69	0-800	344	0-4240
Rosa gymnocarpa	212	0-1520	223	0-4080	91	0-640
Salix spp.	120	0-1600	6	0-240	0	0
Sambucus racemosa	0	0	0	0	7	0-240
Spiraea betulifolia	0	0	0	0	222	0-8000
Symphoricarpos mollis	28	0-400	8	0-320	0	0
Umbellularia californica	20	0-400	0	0	13	0-480
Vaccinium ovatum	0	0	4	0-160	462	0-8800
Vaccinium parvifolium	76	0-880	97	0-800	358	0-4640
All Species	1408	80-5400	4244	440-13960	10133	1280-21880

(b)

	Mean Sprout Number (per ha)					
	Ponderosa Pine		Dry Mixed Conifer		Wet Mixed Conifer	
	Mean	Range	Mean	Range	Mean	Range
Acer circinatum	0	0	141	0-1520	369	0-4400
Acer glabrum	0	0	126	0-2400	498	0-8000
Alnus incana	1958	0-8160	1213	0-6480	771	0-10000
Amelanchier alnifolia	224	0-3040	328	0-3280	40	0-560
Ceanothus velutinus	0	0	15	0-560	0	0
Chimaphila menziesii	0	0	0	0	2	0-80
Chimaphila umbellata	0	0	194	0-3280	24	0-640
Cornus sericea	572	0-7440	32	0-1200	69	0-1440
Holodiscus discolor	0	0	135	0-1920	0	0
Linnaea borealis	5	0-80	25	0-80	18	0-80
Lonicera involucrata	553	0-6640	177	0-2800	84	0-1760
Mahonia nervosa	209	0-3920	387	0-12800	576	0-7520
Pachistima myrsinites	0	0	166	0-3200	131	0-1840
Physocarpus capitatus	1075	0-4880	23	0-560	109	0-2160
Populus tremuloides	0	0	0	0	2	0-80
Ribes bracteosum	14	0-480	0	0	0	0
Ribes lacustre	0	0	375	0-11040	387	0-7360
Ribes lobbii	0	0	0	0	2	0-80
Ribes viscosissimum	0	0	0	0	7	0-240
Rosa gymnocarpa	1431	0-4320	808	0-4240	716	0-2800
Rubus leucodermis	0	0	4	0-160	0	0
Rubus parviflorus	0	0	2	0-80	0	0
Salix spp.	0	0	4	0-160	29	0-800
Sambucus racemosa	0	0	4	0-160	80	0-2720
Shepherdia canadensis	0	0	15	0-480	0	0
Sorbus sitchensis	12	0-400	13	0-240	31	0-960
Spiraea betulifolia	1299	0-6400	93	0-1760	198	0-5200
Symphoricarpos albus	744	0-3920	206	0-2720	358	0-2800
Symphoricarpos mollis	21	0-640	13	0-240	9	0-240
Vaccinium membranaceum	115	0-2160	168	0-4400	102	0-2240
Viburnum edule	2	0-80	82	0-3120	0	0
All Species	8233	0-17520	4749	0-11520	4611	0-14520

Patterns in Species Composition and Abundance in Regenerating Riparian Plant Communities

Biscuit Fire

Three dimensions best represented the structure of the Biscuit Fire regeneration data (final stress = 18.12, and final instability = 0.00). A Monte Carlo test of 250 randomized runs showed the probability that a similar final stress could have been obtained by chance was 0.0040 for all three axes. Almost 29% of the variance in the data was represented by the first axis, 19.3% of the variance was explained by the second axis, and 15.8% of the variance was explained by the third axis (cumulative $R^2 = 0.636$). The ordination was rotated by bank-full width.

Percent exposed mineral soil, a measure of understory fire severity, had the highest (negative) correlation with the first axis ($r^2 = 0.51$; Figure 4.4), and elevation also had a negative correlation with axis 1 ($r^2 = 0.41$). Bank-full width had a high positive correlation with the first axis, with an r^2 value of 0.47 (Figure 4.4), and slope to uplands was also positively correlated with axis 1 ($r^2 = 0.29$). Regeneration of upland associated species, such as *Mahonia nervosa* ($r^2 = 0.37$), *Rhododendron macrophyllum* ($r^2 = 0.32$), and *Lithocarpus densiflorus* ($r^2 = 0.25$), was strongly negatively associated with axis 1 (Figure 4.4), suggesting that regeneration of upland associated species is greater at higher elevations, along smaller streams, and in riparian areas with greater exposed mineral soil. Regeneration of riparian associated species, such as *Alnus rubra* ($r^2 = 0.25$), *Salix* spp. ($r^2 = 0.32$), *Amelanchier alnifolia* ($r^2 = 0.20$), and *Rubus parviflorus* ($r^2 = 0.16$), was strongly positively related to axis 1, indicating that regeneration of riparian associated species is greater along larger streams and in more incised valleys.

Pre-fire deciduous hardwood basal area had the highest (negative) correlation with axis 2 ($r^2 = 0.20$; Figure 4.4). Post-fire live deciduous hardwood basal area was also somewhat negatively correlated with axis 2 ($r^2 = 0.14$). Regeneration of species that are abundant in wetter environments, such as *Rubus leucodermis* (whitebark raspberry) ($r^2 = 0.23$) and *Ribes bracteosum* (stink currant) ($r^2 = 0.19$), was negatively correlated with axis 2, suggesting that regeneration of species that are abundant in wetter environments was higher in locations with higher pre- and post-fire deciduous hardwood basal area. In contrast, regeneration of relatively drought-tolerant species such as *Rhododendron occidentale* ($r^2 = 0.31$), and *Linnaea borealis* ($r^2 = 0.18$) was positively associated with axis 2, suggesting that regeneration of drought tolerant species is higher in locations with lower pre- and post-fire deciduous hardwood basal area. Thus, axis 2 could represent the distinction between deciduous hardwood-dominated plant communities and drier plant community types.

Watershed, a categorical environmental variable, separated somewhat on axis 3 (Figure 4.5). Regeneration of species associated with the west watershed, such as *Frangula californica* (California buckthorn) ($r^2 = 0.17$), *Holodiscus discolor* ($r^2 = 0.13$), and *Vaccinium ovatum* (evergreen huckleberry) ($r^2 = 0.13$), was strongly negatively associated with axis 3, while regeneration of species associated with the east watershed, such as *Leucothoe davisiae* ($r^2 = 0.10$), was strongly positively associated with axis 3. All other environmental variables had $r^2 < 0.05$ for axis 3.

The test of no difference in regeneration communities between stream classes in the Biscuit Fire yielded $p < 0.0001$ and $A = 0.06$. Thus, the hypothesis of no difference between groups was rejected, and it was concluded that regeneration communities differ between stream classes. Differences in regeneration communities along different-sized streams are further illustrated by the strong correlation between bank-full width and the first axis in the ordination of recovering vegetation for the Biscuit Fire (Figure 4.4).

The test of no difference in regeneration communities between the two watersheds included in the study in the Biscuit Fire yielded $p = 0.0011$ and $A = 0.02$. Due to the relatively low A value (within-group agreement), this is weak evidence for differences in regeneration communities between watersheds. Watershed separated somewhat along axis 3 (Figure 4.5).

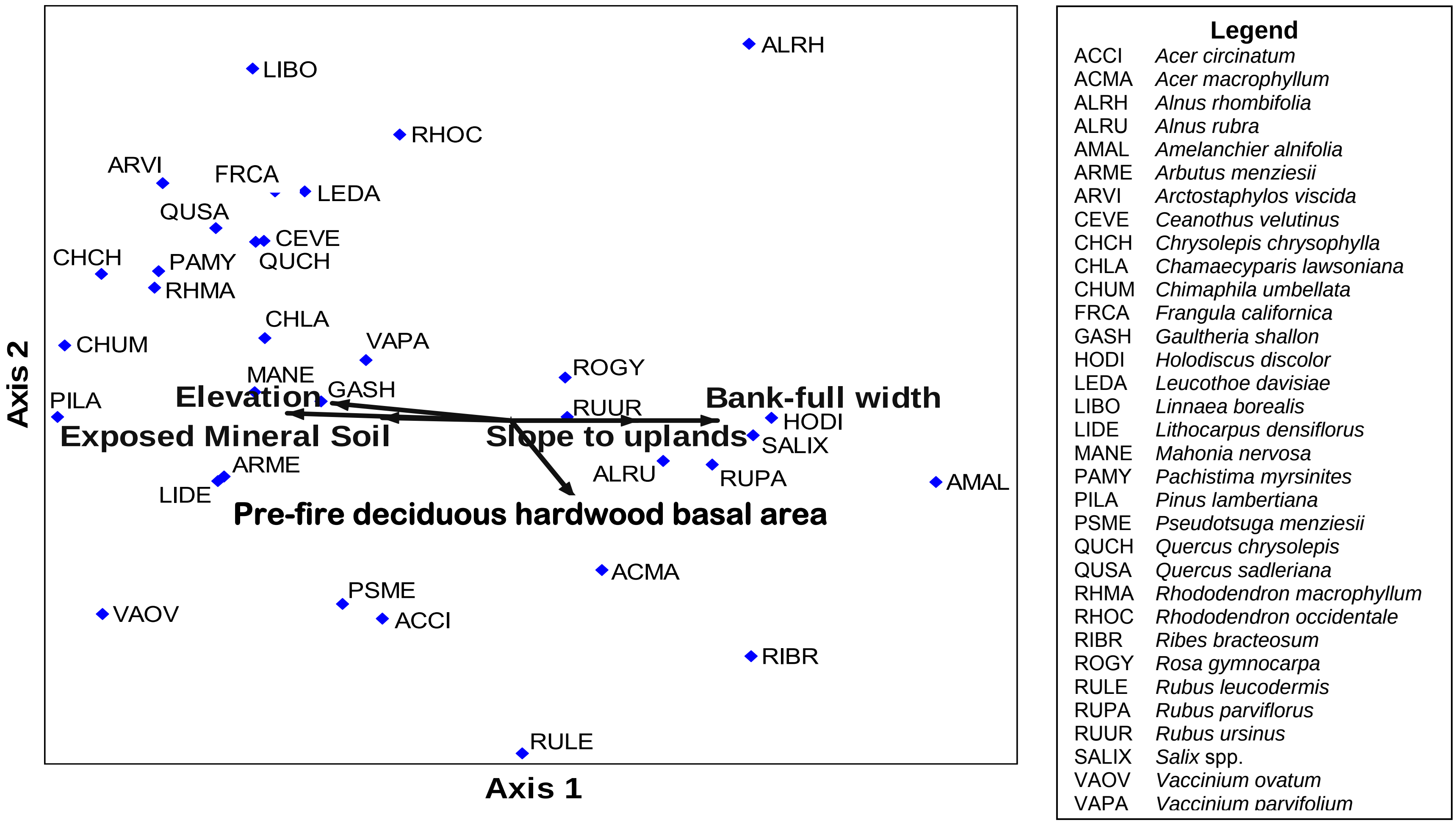


Figure 4.4. Joint plot of NMS ordination results for regenerating species in plot space for the Biscuit Fire. Angles and length of lines represent the direction and strength of relationships between variables and ordination scores. The ordination was rotated by bank-full width.

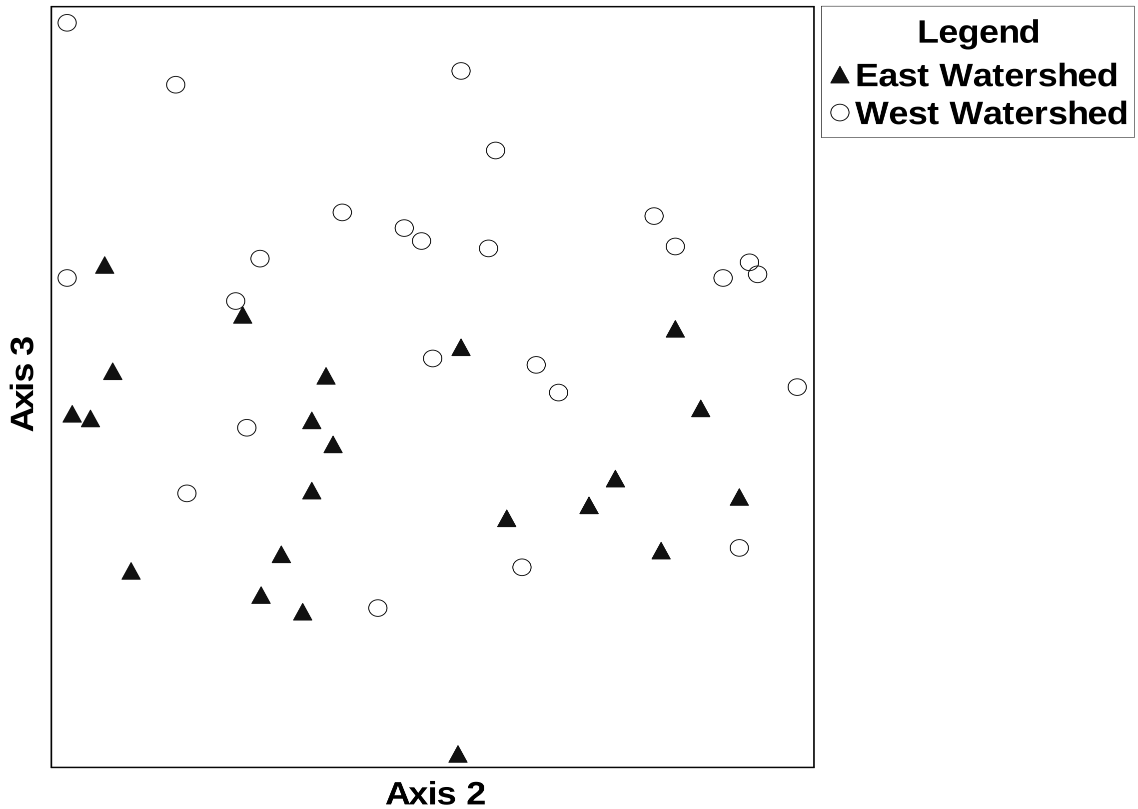


Figure 4.5. Joint plot of NMS ordination results for plots in regenerating species space for the Biscuit Fire.

B&B Complex Fire

Three dimensions best represented the structure of the B&B Complex Fire regeneration data (final stress = 15.97, and final instability = 0.00). A Monte Carlo test of 250 randomized runs showed the probability that a similar final stress could have been obtained by chance was 0.0040 for all three axes. Almost twenty-two percent of the variance in the data was represented by the first axis, 22.9% of the variance was explained by the second axis, and 29.3% of the variance was explained by the third axis (cumulative $R^2 = 0.741$). The ordination was rotated by elevation.

Pre-fire conifer basal area had the highest (positive) correlation with the first axis ($r^2 = 0.37$; Figure 4.6a), and regeneration of conifer species, such as *Pseudotsuga menziesii* ($r^2 = 0.58$), *Picea engelmannii* ($r^2 = 0.44$), *Abies grandis/Abies concolor* ($r^2 =$

0.30), and *Tsuga heterophylla* (r^2 = 0.23), was strongly positively associated with axis 1 (Figure 4.6a). This result indicates that conifer regeneration was greater in riparian areas with higher pre-fire conifer basal area. Conversely, NMS results indicated that regeneration of riparian associated hardwood species was greater in areas with lower pre-fire conifer basal area and higher pre-fire percent hardwood composition; pre-fire percent hardwood composition had a relatively high (negative) correlation with axis 1 (r^2 = 0.28), and regeneration of riparian associated hardwood species, such as *Cornus sericea* (redosier dogwood) (r^2 = 0.22), *Physocarpus capitatus* (r^2 = 0.20), and *Lonicera involucrata* (r^2 = 0.19), was strongly negatively related to axis 1. Overall, axis 1 seems to represent the distinction between conifer-dominated sites and hardwood-dominated sites, and pre-fire species composition is reflected in the post-fire regeneration patterns.

Plant association, a categorical environmental variable, separated somewhat on axis two (Figure 4.7). In particular, ponderosa pine plots separated from those in the dry and wet mixed conifer plant associations. There was not a clear separation of plots in the dry and wet mixed conifer plant associations. Regeneration of hardwood species associated with the low elevation ponderosa pine plant association, such as *Spiraea betulifolia* (r^2 = 0.40) and *Alnus incana* (r^2 = 0.20), was strongly negatively associated with axis 2, while regeneration of species associated with the higher elevation dry and wet mixed conifer plant associations, such as *Acer circinatum* (r^2 = 0.38), *Pseudotsuga menziesii* (r^2 = 0.16), and *Tsuga heterophylla* (r^2 = 0.17), as well as several other conifer species, was strongly positively associated with axis 2 (Figure 4.6b).

Elevation had the highest (positive) correlation with axis 3 (r^2 = 0.57; Figure 4.6). Regeneration of species associated with higher elevations, such as *Ceanothus velutinus* (r^2 = 0.50), *Ribes viscosissimum* (sticky currant) (r^2 = 0.47), and *Rubus parviflorus* (r^2 = 0.38), was positively associated with axis 3, while regeneration of species associated with lower elevations, such as *Physocarpus capitatus* (r^2 = 0.24), was negatively associated with axis 3. Slope to uplands (r^2 = 0.41) and exposed mineral soil (r^2 = 0.39) also had high positive correlations with axis 3.

The test of no difference in regeneration communities between plant associations yielded $p < 0.0000$ and $A = 0.07$. Thus, the hypothesis of no difference between groups was rejected and it was concluded that regeneration communities differ between plant associations. Differences in regeneration communities among plant associations are further illustrated by the separation of plant associations on axis 2 in the ordination of recovering vegetation for the B&B Complex Fire (Figure 4.7).

The test of no difference in regeneration communities between stream classes included in the study yielded $p = 0.0060$ and $A = 0.02$. Thus, there is some evidence for differences in regeneration communities in riparian areas along different stream classes in the B&B Complex Fire area. However, other factors seem to have greater influence on regenerating communities in riparian areas.

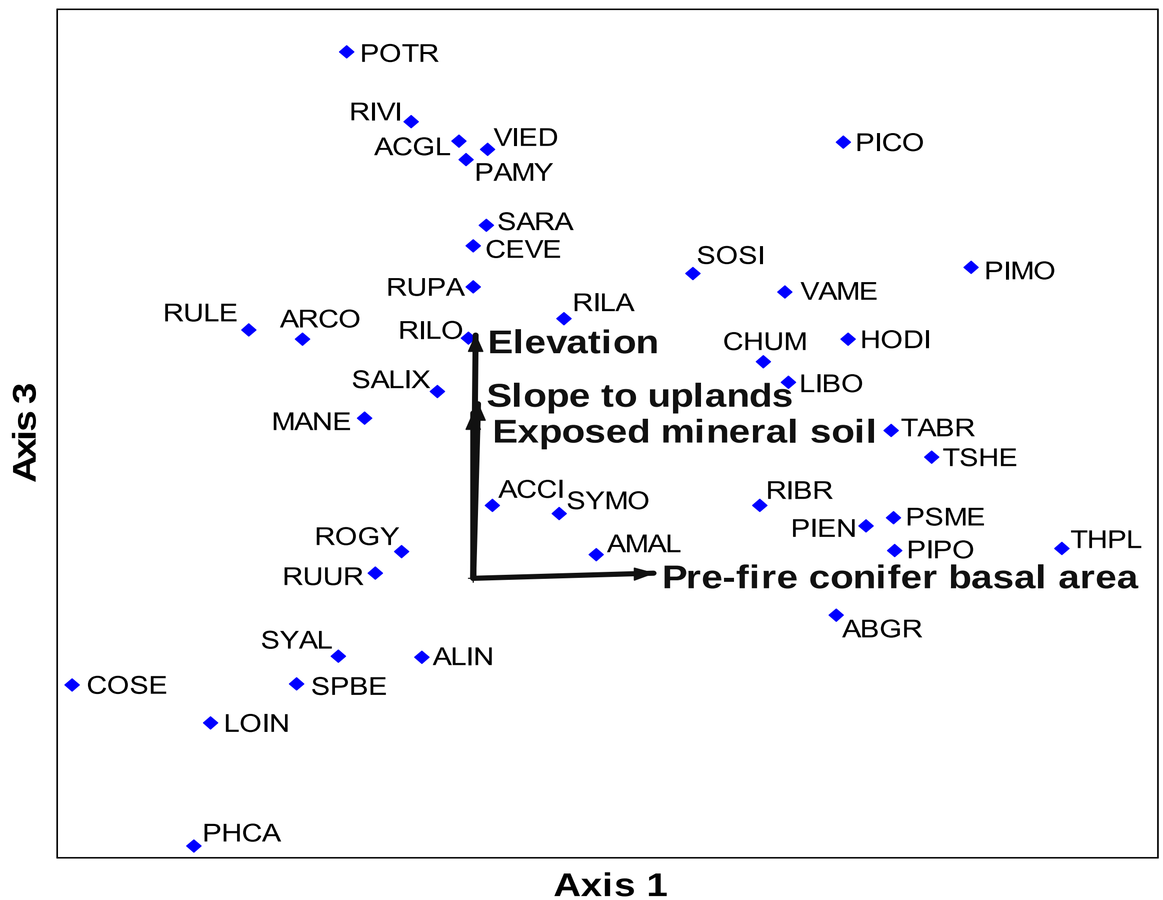
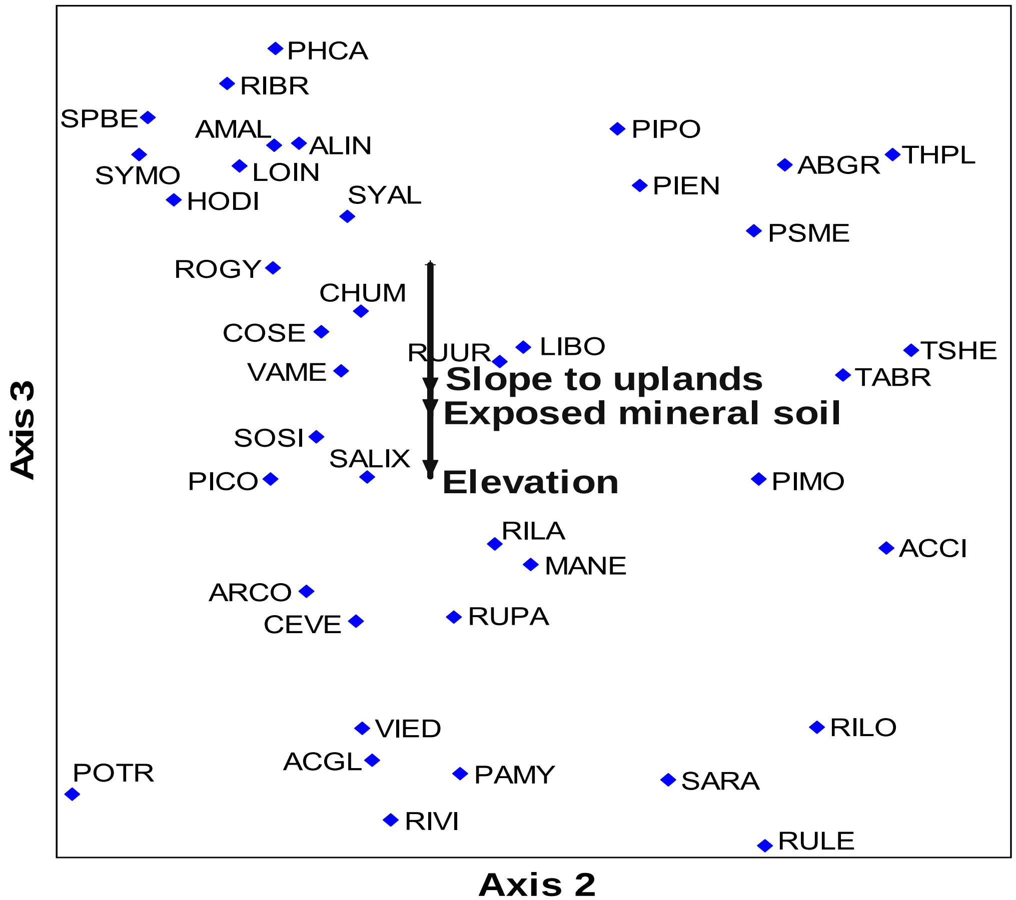


Figure 4.6a. Joint plot of NMS ordination results for regenerating species in plot space (axes 1 and 3) in the B&B Complex Fire. Angles and length of lines represent the direction and strength of relationships between variables and ordination scores. The ordination was rotated by elevation.

Legend

ABGR	*Abies grandis/concolor*
ACCI	*Acer circinatum*
ACGL	*Acer glabrum*
ALIN	*Alnus incana*
AMAL	*Amelanchier alnifolia*
ARCO	*Arctostaphylos columbiana*
CEVE	*Ceanothus velutinus*
CHUM	*Chimaphila umbellata*
COSE	*Cornus sericea*
HODI	*Holodiscus discolor*
LIBO	*Linnaea borealis*
LOIN	*Lonicera involucrata*
MANE	*Mahonia nervosa*
PAMY	*Pachistima myrsinites*
PHCA	*Physocarpus capitatus*
PICO	*Pinus contorta*
PIEN	*Picea engelmannii*
PIMO	*Pinus monticola*
PIPO	*Pinus ponderosa*
POTR	*Populus tremuloides*
PSME	*Pseudotsuga menziesii*
RIBR	*Ribes bracteosum*
RILA	*Ribes lacustre*
RILO	*Ribes lobbii*
RIVI	*Ribes viscosissimum*
ROGY	*Rosa gymnocarpa*
RULE	*Rubus leucodermis*
RUPA	*Rubus parviflorus*
RUUR	*Rubus ursinus*
SALIX	*Salix* spp.
SARA	*Sambucus racemosa*
SOSI	*Sorbus sitchensis*
SPBE	*Spiraea betulifolia*
SYAL	*Symphoricarpos albus*
SYMO	*Symphoricarpos mollis*
TABR	*Taxus brevifolia*
THPL	*Thuja plicata*
TSHE	*Tsuga heterophylla*
VAME	*Vaccinium membranaceum*
VIED	*Viburnum edule*



Legend

ABGR	*Abies grandis/concolor*
ACCI	*Acer circinatum*
ACGL	*Acer glabrum*
ALIN	*Alnus incana*
AMAL	*Amelanchier alnifolia*
ARCO	*Arctostaphylos columbiana*
CEVE	*Ceanothus velutinus*
CHUM	*Chimaphila umbellata*
COSE	*Cornus sericea*
HODI	*Holodiscus discolor*
LIBO	*Linnaea borealis*
LOIN	*Lonicera involucrata*
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PHCA	*Physocarpus capitatus*
PICO	*Pinus contorta*
PIEN	*Picea engelmannii*
PIMO	*Pinus monticola*
PIPO	*Pinus ponderosa*
POTR	*Populus tremuloides*
PSME	*Pseudotsuga menziesii*
RIBR	*Ribes bracteosum*
RILA	*Ribes lacustre*
RILO	*Ribes lobbii*
RIVI	*Ribes viscosissimum*
ROGY	*Rosa gymnocarpa*
RULE	*Rubus leucodermis*
RUPA	*Rubus parviflorus*
RUUR	*Rubus ursinus*
SALIX	*Salix* spp.
SARA	*Sambucus racemosa*
SOSI	*Sorbus sitchensis*
SPBE	*Spiraea betulifolia*
SYAL	*Symphoricarpos albus*
SYMO	*Symphoricarpos mollis*
TABR	*Taxus brevifolia*
THPL	*Thuja plicata*
TSHE	*Tsuga heterophylla*
VAME	*Vaccinium membranaceum*
VIED	*Viburnum edule*

Figure 4.6b. Joint plot of NMS ordination results for regenerating species in plot space (axes 2 and 3) in the B&B Complex Fire. Angles and length of lines represent the direction and strength of relationships between variables and ordination scores. The ordination was rotated by elevation.

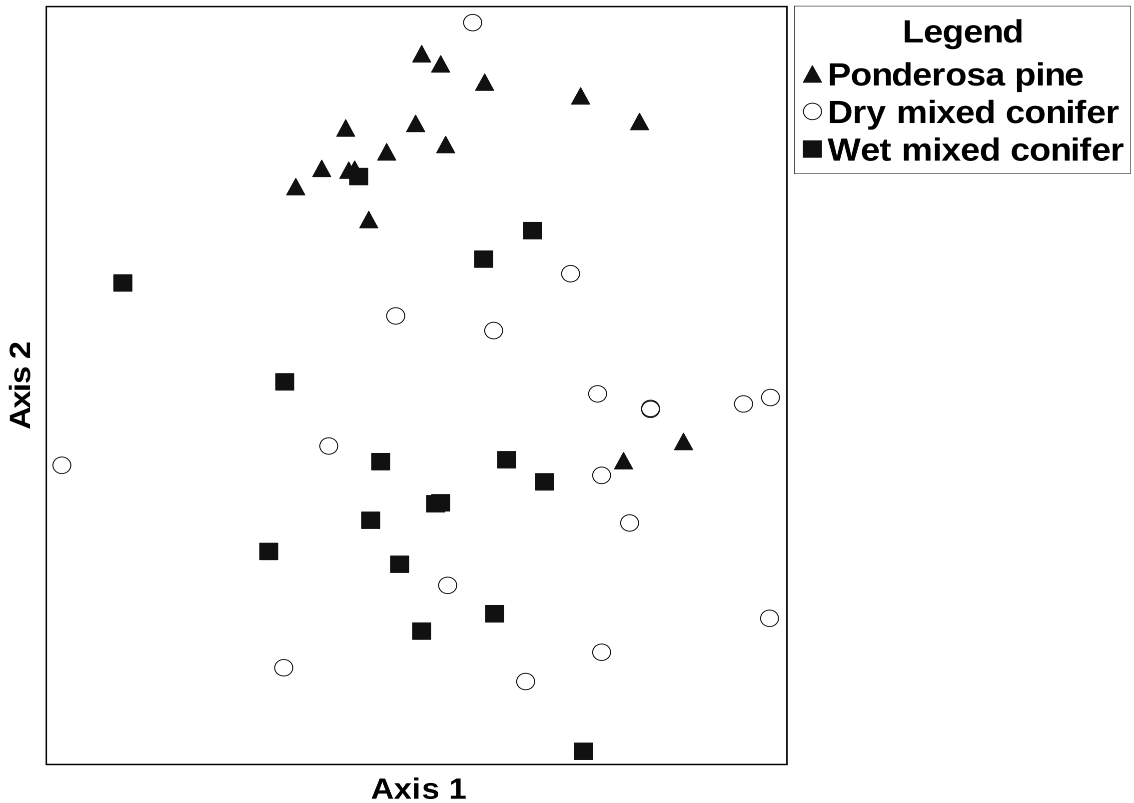

Figure 4.7. Joint plot of NMS ordination results for plots in regenerating species space for the B&B Complex Fire.

Patterns in Abundance of Regeneration Strategies in Post-Fire Riparian Plant Communities

<u>Biscuit Fire</u>

A single dimension represented the structure of the Biscuit Fire regeneration strategy data very well (final stress = 24.62, and final instability = 0.00, $R^2 = 0.79$). A Monte Carlo test of 250 randomized runs showed the probability that a similar final stress could have been obtained by chance was 0.0359. Regeneration of sprouters was very strongly positively associated with axis 1 ($r^2 = 0.90$). Regeneration of seed bank species and seeders was weakly negatively correlated with axis 1 ($r^2 = 0.02$ and 0.18, respectively). Of all environmental variables, elevation had the highest (positive) correlation with the first axis ($r^2 = 0.27$), suggesting that sprouts were more common at higher elevations. Percent exposed mineral soil also had a relatively high positive correlation with axis 1 ($r^2 = 0.24$), suggesting that sprouts and exposed mineral soil tended to co-occur at higher elevations. Sampled riparian areas at higher elevations and with higher exposed mineral soil in the Biscuit Fire were primarily along smaller streams on drier, more upland-like sites, indicating that sprouters were more abundant in these drier, upland-like riparian areas along smaller streams.

Overall, these results suggest weak structure in the Biscuit Fire regeneration strategy data. The structure in the data was primarily a positive relationship between abundance of regenerating sprouting species and elevation. The majority of regeneration in riparian areas of the Biscuit Fire was sprouting species. It is likely that the small number of regenerating seeder species (mainly conifer seedlings) and seed bank species (mainly *Ceanothus velutinus* (snowbrush), *Arctostaphylos viscida* (white leaf manzanita), and *Ribes bracteosum* (stink currant)) in riparian areas of the Biscuit Fire contributed to the weak patterns found for abundance of these regenerating strategies in sample plots.

B&B Complex Fire

Two dimensions best represented the structure of the B&B Complex Fire regeneration strategy data (final stress =11.08, and final instability = 0.00). A Monte Carlo test of 250 randomized runs showed the probability that a similar final stress could have been obtained by chance was 0.0159. Almost thirty-one percent of the variance in the data was represented by the first axis, and 60.3% of the variance was explained by the second axis (cumulative $R^2 = 0.912$).

Regeneration of both sprouters ($r^2 = 0.46$) and seed bank species ($r^2 = 0.34$) was strongly negatively correlated with axis 1 (Figure 4.8). Percent exposed mineral soil also had a relatively high negative correlation with axis 1 ($r^2 = 0.38$), suggesting that regeneration of sprouters and seed bank species was greater in riparian areas with higher exposed mineral soil. Regeneration of seeders was strongly positively correlated with axis 2 ($r^2 = 0.69$; Figure 4.8), and pre-fire conifer basal area in riparian areas also had a high positive correlation with axis 2 ($r^2 = 0.29$; Figure 4.8), suggesting that regeneration of seeders was higher in riparian areas with greater pre-fire conifer basal area. Regeneration of sprouters was negatively correlated with axis 2 ($r^2 = 0.44$; Figure 4.8), and pre-fire percent hardwood stems in riparian areas also had a high (negative) correlation with the second axis ($r^2 = 0.40$; Figure 4.8), suggesting that regeneration of sprouting species was higher in riparian areas with greater pre-fire percent hardwood stems.

The strong correlations between pre-fire conifer basal area and seeders, and between pre-fire hardwood composition and sprouters, suggest that pre-fire differences and post-fire legacies in conifer-dominated and hardwood dominated riparian plant communities influenced post-fire regeneration patterns. As all seeder species, with the exception of *Salix* spp., were conifers in the B&B Complex Fire area, it appears that conifer communities in the B&B Complex Fire area are self-replacing. The sprouting ability of hardwood species in the B&B Complex Fire area also helps ensure the self-replacement of hardwood-dominated communities. The self-replacement of these conifer- and hardwood-dominated sites suggests that there is resiliency in overstory type in both space and time, despite stand-replacing disturbance events.

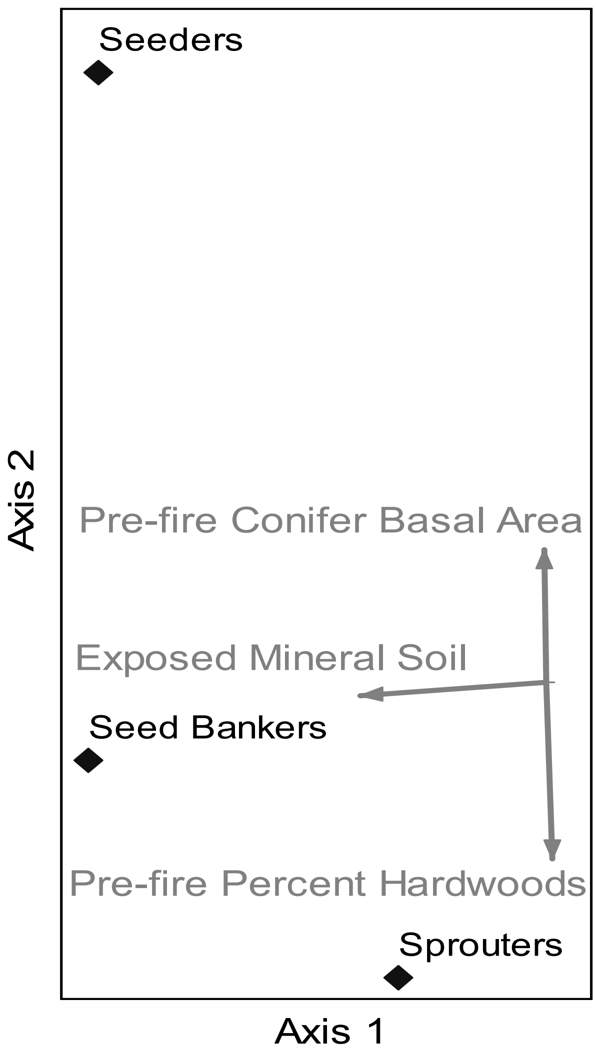

Figure 4.8. Joint plot of NMS ordination results for abundance of stems by regeneration strategy in plot space for the B&B Complex Fire. Angles and length of lines represent the direction and strength of relationships between variables and ordination scores.

DISCUSSION

Controls on Patterns of Plant Community Composition and Species Abundance in Post-Fire Riparian Areas

Post-fire riparian vegetation regeneration in the Biscuit and B&B Complex Fires was influenced by both coarse scale and fine scale factors. In the steep topography of the Biscuit Fire area, post-fire riparian regeneration was influenced primarily by the position of a stream within a watershed (headwater streams versus main stem stream channels), and to a lesser extent, the east to west gradient in moisture represented by plant association/watershed. A number of topographic and physical attributes of streams and the adjacent riparian area vary predictably with position in a watershed in the Biscuit Fire area, including elevation, slope, stream gradient, bank-full width, and valley floor width. Species composition and abundance in regenerating plant communities also varied with these factors. Riparian plant communities along smaller headwater streams (at higher elevations) more closely resembled upland communities before the fire (with higher conifer basal area and lower hardwood composition), generally experienced greater fire severity, and were characterized by greater regeneration of upland associated species, including conifers, than riparian areas along larger streams after the Biscuit Fire. Riparian plant communities along larger, main stem stream channels (at lower elevations) had greater hardwood composition before the fire, generally experienced lower fire severity and were characterized by greater regeneration of riparian-associated hardwoods, such as *Alnus rubra* (red alder) and *Salix* spp. (willow species), than riparian areas along smaller streams.

In the more gentle topography of the B&B Complex Fire, variations in moisture and topography with elevation and plant association were the primary coarse-scale controls on post-fire riparian regeneration patterns. Patterns in vegetation or topography varied little with stream size in the B&B Complex Fire area. Rather, plant community attributes and topography varied with elevation in the B&B Complex Fire area, with ponderosa pine communities occupying areas with gentle topography at lower elevations and dry and wet mixed conifer plant associations in locations with gentle to moderately steep topography at increasingly higher elevations. Riparian plant communities in the ponderosa pine plant association were characterized by relatively high basal area mortality, low exposed mineral soil, a large deciduous hardwood component before the fire, and a high density of deciduous hardwood sprouts post-fire, including species such as *Alnus incana* (thinleaf alder), *Spiraea betulifolia* (white spiraea), and *Physocarpus capitatus* (Pacific ninebark). Riparian plant communities in the dry and wet mixed conifer plant associations were characterized by lower basal area mortality but higher exposed mineral soil, high conifer basal area before the fire, and greater post-fire woody seedling regeneration, particularly of species such as *Tsuga heterophylla* (western hemlock), *Salix* spp. (willow species) and *Ceanothus velutinus* (snowbrush).

At finer spatial scales in both fires, riparian regeneration was influenced by differences in site and vegetation factors between hardwood- and conifer-dominated plant communities. In the B&B Complex fire, conifer regeneration was greater in areas with greater pre-fire conifer basal area and lower hardwood composition. Regeneration of seeder species, which were mostly conifers, was also greater in areas with greater pre-fire conifer basal area and lower hardwood composition in the B&B Complex Fire. Other studies have found greater conifer seedling numbers in riparian areas with greater conifer basal area and lower hardwood basal area (Minore and Weatherly 1994, Pabst and Spies 1999, Hibbs and Bower 2001). Greater conifer basal area increases conifer seed availability in riparian areas. In addition, communities dominated by conifer species are associated with a suite of environmental conditions that favor conifer species. In riparian areas of the Biscuit Fire, conifers are dominant along smaller streams with higher stream gradients and generally drier conditions than along larger streams. Thus, regeneration of conifer species would be expected in areas with these characteristics.

Similarly, increased pre-fire deciduous hardwood composition was associated with greater regeneration of deciduous hardwood species in both the Biscuit and B&B Complex Fires. Like conifer-dominated communities, communities dominated by deciduous hardwood species are associated with a suite of environmental conditions that favor hardwoods. Deciduous hardwood species serve as microsite indicators in the Biscuit and B&B Complex Fire areas in that their presence indicates generally mesic conditions. Thus, greater regeneration of species associated with wetter environments would be expected in areas with a greater deciduous hardwood component. In addition, sprouting automatically ensures the continued presence of pre-fire individuals in the post-fire community.

In general, conifer- and hardwood-dominated riparian areas were found to occur in identifiable ecological locations. In the Biscuit Fire, conifers were dominant along smaller streams in steeper and drier locations, while hardwoods were dominant along larger streams and in wetter locations. In the B&B Complex Fire, conifers were more dominant in riparian areas of the dry and wet mixed conifer plant associations, while hardwoods were more dominant in riparian areas of the ponderosa pine plant association. In addition, from one fire cycle to the next, conifer- and hardwood-dominated riparian communities were self-replacing, suggesting that environmental conditions and biological legacies on a site influence post-fire successional processes. These results suggest that vegetation types in the Biscuit and B&B Complex Fire areas are resilient in space and time.

A measure of understory fire severity, exposed mineral soil, was also associated with patterns in riparian regeneration in riparian areas of both the Biscuit and B&B Complex Fires. In the Biscuit Fire, greater exposed mineral soil was associated with lower regeneration of riparian associated species and greater regeneration of upland associated species. Regeneration of riparian associated species was also positively associated with bank-full width, or stream size. Lower fire severity and greater water availability may combine to result in greater regeneration of riparian associates along larger streams after fire. Alternatively, the regeneration of riparian associated species along larger streams with lower exposed mineral soil may be more a reflection of the shift in topography, hydrology, and thus plant community composition with stream size and less a relationship between fire severity and post-fire regeneration.

Exposed mineral soil was also associated with patterns in abundance of regeneration strategies in both fires. The number of riparian sprouts was positively associated with exposed mineral soil in both fires. Greater exposed mineral soil was likely associated with greater mortality of aboveground stems of sprouting species, thereby initiating a sprouting response. However, number of riparian sprouts was also positively related to elevation in the Biscuit Fire, and changes in plant community composition with elevation may be a stronger influence on abundance of sprouting species after fire than fire severity. Regeneration of seedbank species was also positively associated with exposed mineral soil in the B&B Complex Fire. Higher fire severity, particularly at the soil level, leads to stimulation of seed bank species such as *Ceanothus* (Agee 1993). Overall, the relationships between understory fire severity and post-fire riparian regeneration suggest that variation in fire severity may lead to variation in plant species establishment. However, other factors that influence fire severity, such as gradients in moisture, may exert greater control over post-fire riparian regeneration.

Potential Influence of Fire on Riparian Vegetation Functions

Both the Biscuit and B&B Complex Fires resulted in sufficient basal area mortality in riparian forests to reduce canopy cover over streams, thus leading to higher stream temperatures (USDA Forest Service 2004). This elevation in stream temperature can impact aquatic organisms in the short-term. However, fire and subsequent vegetation mortality in riparian areas initiate regeneration, and regeneration in riparian areas of both fires will provide shade to the stream in the future.

Sprouting was the dominant post-fire mode of regeneration in sampled riparian areas, particularly in the Biscuit Fire. Studies of post-fire riparian regeneration in other regions also found that a high proportion of riparian plants observed in the first several years after fire regenerated primarily by sprouting (Davis et al. 1989, Gom and Rood 1999, Ellis 2001, Kobziar and McBride 2006). Hardwood species and shrubs that sprout from established root crowns or rhizomes have a competitive advantage over conifers if nearby seed sources are lacking (Agee 1993). Sprouts also initially grow more quickly than seedlings (Bond and Midgley 2001). Sprouting reduces disturbance-related species turnover by ensuring persistence of sprouting species, as indicated by the positive relationship between pre-fire hardwood basal area and sprouters in the B&B Complex Fire, and thus helps to minimize the effects of disturbance on riparian plant composition (Bond and Midgley 2001). Abundant sprouting also helps minimize impacts of fire on riparian and aquatic systems by providing stream bank stabilization, preventing erosion, and providing shade over streams. The abundant sprouting of nitrogen-fixing *Alnus* (alder) species may further contribute to post-fire regeneration in riparian areas of both the Biscuit and B&B Complex Fires by replenishing nitrogen supplies in riparian soils.

In these ways, regeneration by sprouting plays a key role in the post-fire regeneration of both riparian forests and adjacent aquatic systems.

Conifer seedlings were also abundant in riparian areas of the B&B Complex Fire, most likely because of the timing of the fire in relation to seed maturation and seed crops of dominant species. The B&B Complex Fire occurred during a heavy seed crop year for several dominant conifer species (USDA Forest Service 2005). The fire occurred after conifer seeds had matured, but the seeds had not yet dispersed. Thus, seeds in cones were not consumed by the fire in areas that did not experience crown fire. Shortly after the fire, seed dispersal was observed over a large portion of the fire area (USDA Forest Service 2005). This phenomenon was similar to that described by Larson and Franklin (2005), in which the rapid establishment of high-density conifer seedlings after fire results from the persistence of a canopy seed bank, a type of biological legacy. This biological legacy will likely provide future shade to streams in the B&B Complex Fire area.

Conifer seedling numbers in riparian areas of the Biscuit Fire were lower than that in the B&B Complex Fire, particularly along larger streams. Even along smaller streams, observed conifer seedling densities in riparian areas of the Biscuit Fire (131 seedlings per ha) were lower than that observed along two northern Sierra Nevada streams one year after fire (500 and 317 seedlings per ha; Kobziar and McBride 2006) and that observed in uplands in other portions of the Biscuit Fire two-years post-fire (767 seedlings per ha; Donato et al. 2006). It is possible that the greater deciduous hardwood dominance and microsite conditions in riparian areas of the Biscuit Fire compared to uplands and riparian areas of the B&B Complex Fire resulted in both decreased conifer seed availability and decreased conifer seedling establishment, particularly along larger streams. Post-fire fluvial disturbance may also influence riparian conifer seedling establishment, either through direct mortality as a result of flooding or secondarily through changes in substrate availability.

Low conifer seedling numbers in riparian areas two years after the Biscuit Fire does not preclude later establishment of conifers. Conifer establishment after fire is a protracted process that can take decades (Agee 1991, Shatford et al. 2007). Due to their sprouting ability and fast growth rates, hardwoods may dominate the early stages of succession in riparian areas (Swanson et al. 1982), and low conifer seedling numbers in riparian areas of the Biscuit Fire suggests that hardwoods will dominate early post-fire successional stages. It is possible, however, that conifers will eventually overtop and suppress hardwoods in these areas, particularly along smaller streams and in drier locations, and provide future shade to the stream.

Mortality in riparian areas will lead to increased input of large woody debris (LWD) to streams (Gresswell 1999, Bragg 2000, Reeves et al. 2006). Fire in riparian zones generally results in an immediate influx of LWD to streams (Bragg 2000, USDA Forest Service 2004) and effects of riparian fire on large woody debris recruitment can continue for decades in forested drainages (Gresswell 1999), with another potential large peak in LWD recruitment several decades after a fire event (Bragg 2000). This pattern of LWD recruitment after fire in riparian areas is distinct from that of other disturbances, such as logging activities or insect outbreak, with larger peaks of LWD input due to the higher mortality of species with fire (Bragg 2000). Thus, fire-caused vegetation mortality in riparian areas is an important driver of LWD dynamics in stream systems of the western U.S. and contributes to the long-term aquatic species diversity in stream systems (Gresswell 1999).

Management Implications and Conclusions

Riparian forests of the Biscuit and B&B Complex Fires were impacted by the fire events. However, there was rapid regeneration in most sampled riparian areas. Abundant regeneration in riparian areas two years after each fire event is an indication of the resilience of these disturbance-adapted plant communities. This regeneration also ensures that riparian vegetation will continue to provide ecological functions to adjacent streams; shrub cover will provide stream bank stability and shade to adjacent streams, and tree regeneration will ensure these and other functions, such as organic matter and large woody debris input, are provided over the long term. The resilience of these riparian plant communities suggests that post-fire riparian rehabilitation activities may be unnecessary for the functioning of riparian forests after fire.

Post-fire regeneration patterns were influenced by both coarse-scale (moisture gradients associated with position in a watershed and elevation) and fine scale (microsite conditions) factors. Patterns in post-fire regeneration observed in this study suggest that, along smaller headwater streams in the Biscuit Fire area, relatively high fire severity levels, a high number of sprouts, and high conifer regeneration can be expected. In contrast, along larger streams, relatively low fire severity, high numbers of seedlings (primarily deciduous hardwoods), and greater overall regeneration of deciduous hardwood species can be expected. In the B&B Complex Fire, riparian areas in the ponderosa pine plant association can be expected to burn with high overstory fire severity and have high regeneration of deciduous hardwood species. Riparian areas in the dry and wet mixed conifer plant associations can be expected to burn with high understory fire severity and have greater regeneration of conifer species. In both fire areas, microsite variation leads to the development of distinct hardwood- and conifer-dominated vegetation types, and these communities appear to be self-replacing. This suggests that there may be difficulties in regenerating conifers on hardwood-dominated sites, and vice versa.

Results of this study show the state of riparian plant community regeneration two years after fire. Although information on this stage in regeneration is critical to the understanding of the post-fire regeneration process in riparian areas, more information on how the regeneration process progresses over time is needed for a more complete understanding of how fire influences riparian areas in these regions. For example, how do the interactions between fire and subsequent flooding influence riparian vegetation in the long term? Pre- and post-fire data would help to further define the influence of fire on riparian plant communities.

The influence of fire severity (exposed mineral soil) on regenerating riparian plant communities indicates that increases in fire severity associated with fuel buildup in riparian zones could influence riparian plant communities and associated functions.

However, high severity fire may play a distinct role in riparian areas and adjacent aquatic systems by influencing riparian forest structure and composition. The resilience of the riparian plant communities observed in this study suggests that riparian plant species adaptations to disturbance help to minimize effects of fire. Further study on the historic frequency and severity of fire in riparian areas will provide a more complete picture of the role of disturbance in riparian areas that can be used to guide management.

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CHAPTER 5 – CONCLUSION

Successful management of riparian zones requires an understanding of the disturbance processes within them. Results of this study show that riparian areas are affected by fire events, despite a number of riparian attributes that may be expected to limit fire in riparian areas. However, results showed that there are differences in how fire affects riparian areas versus adjacent uplands; riparian areas in both the Biscuit and B&B Complex Fires had lower understory fire severity (exposed mineral soil and scorch height) but similar levels of overstory fire severity (crown scorch and basal area mortality) compared to uplands. Comparison of different fire severity indices revealed that overstory and understory fire severity indices are not strongly related. The factors controlling overstory and understory fire severity were also found to differ. For example, although riparian overstory fire severity can be predicted from upland fire severity and plant association in the B&B Complex Fire, understory fire severity is best predicted from slope of riparian sideslopes. Thus, assessments of fire effects must consider both overstory and understory fire severity separately, and predictions of overstory and understory fire severity will require different information.

Results of this study show that some riparian areas in recent fires burned with high severity, particularly in the overstory. These riparian areas may have burned with high severity historically, and high severity fire may be part of the dynamics in these riparian zones. It is also possible that the role fire is currently playing in riparian areas is different from that of pre-Euro-American settlement times. Fire exclusion from riparian zones, along with a lack of management practices mimicking fire in riparian buffer zones, may result in fuel build-up and more severe fire in these areas.

To prevent more severe fires in riparian areas that burned with lower fire severity historically, management actions to reduce riparian fire severity may be desired. Because both fire severity and post-fire vegetation recovery in the Biscuit and B&B Complex Fires were controlled by factors associated with gradients in moisture, moisture gradient information could be used to target areas for pre-fire fuels reductions. However, although methods to conduct fuels treatments in more upland-like riparian forests may be straight-forward, it is not clear how thinning would be conducted in riparian forests along larger streams that have a greater deciduous hardwood component. Thinning in upland forests is often accomplished by removing smaller understory stems and ladder fuels. But in many riparian forests along larger streams, smaller understory stems are primarily deciduous hardwood species that play important roles in the functioning of riparian forests by providing stream shade, stream bank stabilization, wildlife habitat, and allochthonous inputs to streams. Thus, removing deciduous hardwood stems in riparian fuels treatments may have ecological costs.

An alternative approach to riparian fire severity reduction, if desired, may be fuels treatments in upland forests. Upland fire severity was strongly related to overstory riparian fire severity in both fires and to understory fire severity in the Biscuit Fire. The consistently strong relationship between upland and riparian fire severity in the two study regions suggests that a similar relationship could be expected in other conifer-dominated forest regions in the western U.S. The strong relationship between upland fire severity and riparian fire severity also suggests that pre-fire fuels reductions in uplands would reduce riparian fire severity (assuming that upland fire behavior influences riparian fire behavior, as opposed to the converse). Fuels treatments in upland forests and a resulting reduction in upland fire severity may move upland forests toward a more historic fire regime, and in doing so, potentially move riparian areas to a more historic fire regime. Upland fuels treatments may be particularly important in forests types that historically experienced more frequent, low intensity fire, such as ponderosa pine forests.

Results of these studies illustrated that riparian areas regenerate rapidly after fire events. Patterns in riparian regeneration varied predictably with gradients in moisture in both fire areas (position in a watershed in the Biscuit Fire and elevation/plant association in the B&B Complex Fire). Abundant regeneration and self-replacement of conifer- and deciduous hardwood-dominated communities in riparian areas two years after each fire event indicates the resilience of these disturbance-adapted plant communities. This resilience of riparian plant communities helps ensure that riparian vegetation will continue to provide ecological functions to adjacent streams. This resilience also suggests that post-fire riparian rehabilitation may not be necessary to sustain ecological functions of riparian forests.

Future studies on the historic frequency and severity of fire in riparian areas will provide more information on the historic role of fire in riparian areas that can be compared to the present-day role of fire and used to guide management. Factors found to be controllers of riparian fire severity in these studies could be further explored in the Biscuit and B&B Complex Fire areas and in other regions to develop improved predictive models of riparian fire severity. For example, at what distance from a riparian area does the relationship between riparian and upland fire severity break down? In addition, more information on how riparian vegetation regeneration progresses over time and in other regions is needed for a more complete understanding of how fire influences riparian areas. Pre- and post-fire data would further determine the influence of fire on riparian plant communities. These and future studies will lead to the improved management practices in riparian areas of conifer-dominated forest systems in the western U.S. and sustain the important ecological functions that these areas provide.

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APPENDIX

APPENDIX A. MISSING TREATMENT COMBINATIONS IN THE BISCUIT AND B&B COMPLEX FIRES.

Table A1. Missing treatment combinations in the east (1) and west (2) watersheds in the Biscuit Fire. Size class 1 is the smallest size class (0-14.9” DBH), followed by size class 2 (15.0-19.9” DBH), with size class 3 (20.0” + DBH) being the largest. Fire severity class 1 is the lowest fire severity level, fire severity class 2 represents moderate fire severity, and fire severity class 3 is the most severe level. Class 1 streams are fish-bearing streams with a steady flow. Class 2 streams are also fish-bearing with moderate flow, and class 3 streams have few fish and low flow.

Missing Observation Number	Watershed	Tree size class	Fire Severity Class	Stream Class
1	1	2	2	1
2	1	3	2	1
3	1	1	3	1
4	1	2	3	1
5	1	3	3	1
6	2	3	2	1
7	2	3	3	1

Table A2. Missing treatment combinations in the ponderosa pine (1), dry mixed conifer (2) and wet mixed conifer (3) plant associations of the B&B Complex Fire. Size class 1 is the smallest size class (0-14.9" DBH), followed by size class 2 (15.0-19.9" DBH), with size class 3 (20.0" + DBH) being the largest. Fire severity class 1 is the lowest fire severity level, fire severity class 2 represents moderate fire severity, and fire severity class 3 is the most severe level. Class 1 streams are fish-bearing streams with a steady flow. Class 2 streams are also fish-bearing with moderate flow, and class 3 streams have few fish and low flow.

Missing Observation Number	Plant Association	Tree size class	Fire Severity Class	Stream Class
1	1	1	1	3
2	2	2	1	3
3	2	2	2	2
4	2	2	2	3
5	2	2	3	2
6	2	3	1	1
7	2	3	1	2
8	2	3	2	1
9	2	3	2	2
10	2	3	3	1
11	2	3	3	2
12	2	3	3	3
13	3	1	1	2
14	3	1	1	3
15	3	1	2	3
16	3	1	3	2
17	3	2	1	3
18	3	2	2	3
19	3	2	3	3
20	3	3	1	2
21	3	3	1	3
22	3	3	2	1
23	3	3	2	2
24	3	3	2	3
25	3	3	3	1
26	3	3	3	2
27	3	3	3	3