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## Effect of Hydrologic, Geomorphic, and Vegetative Conditions on Avian Communities in the Middle Rio Grande of New Mexico

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EFFECT OF HYDROLOGIC, GEOMORPHIC, AND VEGETATIVE  
CONDITIONS ON AVIAN COMMUNITIES IN THE MIDDLE RIO GRANDE  
OF NEW MEXICO

A Thesis

Submitted to the Graduate Faculty of the  
Louisiana State University and  
Agricultural and Mechanical College  
in partial fulfillment of the  
requirements for the degree of  
Master of Science

In

The School of Renewable Natural Resources

by  
Sarah G. Hamilton  
B.S., Auburn University, 2009  
August 2014

This work is dedicated to the memory of my grandfather and hero, Doil Newton Parker. His love for and connection with the land was apparent to me at a young age, and has greatly impacted my life. Were it not for the countless hours spent riding through the pastures in his lap, playing outside where wildlife and farm animals abounded, and exploring the wide open spaces of his beloved farm, I may never have realized my own connection with the land and deeply-rooted passion for conservation. It is because of the wonderful experiences I had with him on his farm that I found my calling as a wildlife biologist. It is my sincere hope that his example of resiliency, perseverance, work ethic, and dedication is apparent in this work and all my future endeavors.

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## ABSTRACT

Anthropogenic regulation of the Middle Rio Grande (MRG) of New Mexico has altered the hydrogeomorphology of the system and led to a rapid decline in breeding riparian-obligate birds as native riparian forests are replaced by exotic tamarisk stands. In this study, I evaluated the relationships among hydrogeomorphology, vegetation structure and composition, and avian communities of the San Acacia Reach (SAR) of the MRG. I conducted avian point count surveys and collected habitat data to determine avian community structure and abundance, geomorphic feature, surface flooding, and vegetation structure and composition along 44 transects throughout the SAR. A total of 999 point count surveys and 1,801 vegetation plots were completed throughout the 2012 and 2013 breeding season. Sixty-nine land bird species were detected over the two breeding seasons. Avian guilds responded differently to various hydrogeomorphic conditions. Ground-nesting birds and low shrub-nesting birds were insensitive to hydrogeomorphic changes as they do not rely on native understory, but can use exotic understory or woody debris. In contrast, canopy-nesting birds required native overstory; therefore, they were sensitive to hydrogeomorphic changes as native overstory species, such as cottonwood (*Populus deltoides*) and Goodding's willow (*Salix gooddingii*), require surface floods to germinate and establish. Similarly, water-obligate species were also sensitive to hydrogeomorphic changes as they require close proximity to surface water. I also evaluated hydrogeomorphic relationships with the habitat of the Western Yellow-billed Cuckoo (*Coccyzus americanus occidentalis*), a candidate species under the Endangered Species Act, using cuckoo presence/absence survey data, spatial statistics in ArcGIS 10, and vegetation and hydrology data. Results indicated that management of riparian forests that promotes overbank floods and regeneration and survival of cottonwood and Goodding's willow overstory, with a mixed

understory of Goodding's willow, coyote willow (*Salix exigua*), and New Mexico olive (*Forestiera pubescens*) would provide long-term habitat for Western Yellow-billed Cuckoos. I also quantified the amount of variability within Hink and Ohmart vegetation structure classes, a vegetation classification scheme widely used throughout the MRG. Results indicated that including woody stem density classes in conjunction with the current Hink and Ohmart classification methodology will better inform songbird habitat management prescriptions.

# CHAPTER 1

## INTRODUCTION

### 1.1 INTRODUCTION

Riparian ecosystems in the semiarid and arid southwestern United States support some of the highest avian species richness and density in temperate North America (Brand et al. 2008). However, these biodiverse ecosystems are threatened by a lack of legal protection coupled with human population growth and subsequent increasing demands for groundwater and surface water (Stromberg et al. 1996; Brand et al. 2011). Groundwater and stream withdrawals have contributed to the loss and alteration of wetland and riparian ecosystems throughout the Southwest (Levine and Stromberg 2001). Water control structures such as diversions, levees, and dams modify flood frequency and duration, surface flow rates, and sediment and nutrient transport (Scott et al. 2000; Levine and Stromberg 2001; Merritt et al. 2010). Additionally, channelization of rivers has led to channel incision, further altering the depth, timing, duration, and frequency of flooding (Scott et al. 2000; Merritt et al. 2010). Such changes in the hydrogeomorphology of rivers have led to the degradation of riparian habitats as the native biota has evolved to cope with the dynamic flows of rivers (Stromberg et al. 1996; Scott et al. 2000; Merritt et al. 2010).

These hydrologic and geomorphic changes have impacted vegetation communities of southwestern riparian systems. For example, recruitment of native plants, like Goodding's willow (*Salix gooddingii*) and Rio Grande cottonwood (*Populus deltoides* ssp. *wislizeni*), has declined as the hydrologic conditions needed for seedling establishment, such as spring floods and shallow water tables, have been altered

(Stromberg et al. 1996; Johnson 2000; Levine and Stromberg 2001, Brand et al. 2008). Thus, riparian corridors along controlled rivers become ideal colonization sites for more stress-tolerant, opportunistic, or xerophytic plants like exotic tamarisk (*Tamarix* spp.) or Russian olive (*Elaeagnus angustifolia*), allowing for extensive replacement of native, biodiverse riparian forests by homogenous stands of exotic species (Johnson 2000; Levine and Stromberg 2001).

Anthropogenic regulation of the Middle Rio Grande (MRG) of New Mexico has altered the hydrogeomorphology of the system and led to a severe degradation of riparian habitat as the channel has become narrow and incised, flood pulses have been lost, depth to groundwater has increased, and native forests are replaced by exotic species (Levine and Stromberg 2001; Ellis 2007; Schmidt-Petersen 2007). Currently along the MRG, breeding riparian-obligate birds, such as the Western Yellow-billed Cuckoo (*Coccyzus americanus occidentalis*) and the endangered Southwestern Willow Flycatcher (*Empidonax traillii extimus*), are rapidly declining as native riparian forests are replaced by exotic tamarisk stands due to hydrologic alterations (Yong and Finch 1997; Levine and Stromberg 2001; Pruett et al. 2001; Wiggins 2005; Schmidt-Petersen 2007; Sechrist et al. 2009). The impacts of hydrologic alterations are projected to increase as a result of growing urban, commercial, and agricultural demands on the Middle Rio Grande, placing greater pressure on limited water resources and further depleting an already water-stressed system (Jackson et al. 2001; Robert 2007). Projected climate change patterns are expected to intensify water scarcity in the region and potentially increase conflicts among water users and wildlife, including endangered species (Hurd and Coonrod 2007).



Many avian species markedly respond to alterations in riparian vegetation composition and structure (Hunter et al. 1987; Van Riper et al. 2008). For example, Anderson et al. (1977) and Ellis (1995) found higher avian species richness in cottonwood-willow than mesquite (*Prosopis* spp.) or tamarisk on the MRG and lower Colorado. Brand et al. (2011) found that canopy-nesting birds are dependent on mature cottonwood/willow stands; therefore, when depth to groundwater increased, the density of canopy-nesting birds decreased as mature cottonwoods and willows were lost due to groundwater declines. In contrast, groundwater declines led to denser midstories because of increased tamarisk coverage and the density of midstory-nesting birds and some understory-nesting species increased (Brand et al. 2011). Hydrologic regime has also been found to influence nest survival (Brand et al. 2010). Brand et al. (2010) found that nest survival for Yellow-breasted Chats and Abert's Towhee was lower in tamarisk stands with intermittent flow (surface water was present < 92% but > 40% of the season) than in tamarisk stands with ephemeral flow (surface water was present < 40% of the season). Because birds are sensitive to changes in riparian vegetation, they are often used as indicators of ecological conditions of the riparian and wetland systems and are frequently the aim of conservation and restoration efforts (Sogge et al. 2008; Brand et al. 2011).

Despite the increasing understanding of the effects of altered hydrology on riparian vegetation, few studies have examined the effects of hydrology and vegetation on avian communities (Brand et al. 2011). Therefore, questions remain as to what hydrogeomorphic conditions are needed along the MRG to achieve certain ecological outcomes, such as the conservation of avian populations and communities. In this study,

I evaluate the relationships among geomorphology, hydrology, vegetation structure and composition, and avian relative abundance and community structure within the San Acacia Reach of the MRG. The San Acacia Reach is 87 km (54 miles) long and encompasses three physically different subreaches (Massong et al. 2006; Holste 2013; personal observation); the San Acacia diversion to Socorro, NM (degrading); Socorro to mid-Bosque del Apache National Wildlife Refuge (aggrading); and mid- Bosque del Apache National Wildlife Refuge to Elephant Butte Reservoir pool boundary (degrading). I place particular focus on evaluating the effects of geomorphology, hydrology, and vegetation structure and composition on the Western Yellow-billed Cuckoo because it is a candidate species for listing under the Endangered Species Act (Sechrist et al. 2009). I also evaluate the ability of the Hink and Ohmart (1984) vegetation classification scheme, the current vegetation classification scheme used on the MRG, to describe the structure of songbird habitat.

## **1.2 STUDY OBJECTIVES**

The objective of Chapter 2 is to evaluate the effects of surface hydrologic environments, geomorphic setting, and vegetation community structure and composition on avian relative abundance and community structure. The objective of Chapter 3 is to evaluate the effects of surface hydrologic environments, geomorphic setting, and vegetation community structure and composition on the candidate species, the Western Yellow-billed Cuckoo. Finally, the objective of Chapter 4 is to evaluate the ability of the Hink and Ohmart (1984) vegetation structure classes to describe the structure of songbird habitat. This research will increase our understanding of songbird responses to vegetation and the limitations of hydrology and geomorphology on avian communities,

thus aiding managers in delineating the range of restoration possibilities within given hydrogeomorphic conditions. Chapters 2–4 are organized as separate manuscripts to be submitted to scientific journals; therefore, some duplication of text and information occurs.

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## **CHAPTER 2**

# **EFFECT OF HYDROLOGIC, GEOMORPHIC, AND VEGETATIVE CONDITIONS ON AVIAN COMMUNITIES IN THE MIDDLE RIO GRANDE OF NEW MEXICO**

### **2.1 INTRODUCTION**

Riparian ecosystems in the semiarid and arid southwestern United States support some of the highest avian species richness and density in temperate North America (Brand et al. 2008). However, these biodiverse ecosystems are threatened by a lack of legal protection coupled with human population growth and subsequent increasing demands for groundwater and surface water (Stromberg et al. 1996; Brand et al. 2011). Groundwater and stream withdrawals have contributed to the loss and alteration of wetland and riparian ecosystems throughout the Southwest (Levine and Stromberg 2001). Water control structures such as diversions, levees, and dams modify flood frequency and duration, surface flow rates, and sediment and nutrient transport (Scott et al. 2000; Levine and Stromberg 2001; Merritt et al. 2010). Additionally, channelization of rivers has led to channel incision, further altering the depth, timing, duration, and frequency of flooding (Scott et al. 2000; Merritt et al. 2010). Such changes in the hydrogeomorphology of rivers have led to the degradation of riparian habitats as the native biota has evolved to cope with the dynamic flows of rivers (Stromberg et al. 1996; Scott et al. 2000; Merritt et al. 2010).

These hydrologic and geomorphic changes have impacted vegetation communities of southwestern riparian systems. For example, the recruitment of native plants, like Goodding's willow (*Salix gooddingii*), Rio Grande cottonwood (*Populus deltoides* ssp. *wislizeni*), and coyote willow (*Salix exigua*), has declined as the hydrologic

conditions needed for seedling establishment, such as spring floods and shallow water tables, have been altered (Stromberg et al. 1996; Johnson 2000; Levine and Stromberg 2001, Brand et al. 2008; Hultine et al. 2010; Caplan et al. 2013). Thus, riparian corridors along controlled rivers become ideal colonization sites for more stress-tolerant, opportunistic, or xerophytic plants like exotic tamarisk (*Tamarix* spp.) or Russian olive (*Elaeagnus angustifolia*), allowing for extensive replacement of native, biodiverse riparian forests by homogenous stands of exotic species (Johnson 2000; Levine and Stromberg 2001).

Anthropogenic regulation of the Middle Rio Grande (MRG) of New Mexico, the reach of the Rio Grande that extends from Chochiti Dam to Elephant Butte Reservoir in New Mexico, has altered the hydrogeomorphology of the system and led to a severe degradation of riparian habitat as the channel has become narrow and incised, flood pulses have been lost, depth to groundwater has increased, and native forests have been replaced by exotic species (Levine and Stromberg 2001; Ellis 2007; Schmidt-Petersen 2007). Currently along the MRG, breeding riparian-obligate birds, such as the Western Yellow-billed Cuckoo (*Coccyzus americanus occidentalis*) and the endangered Southwestern Willow Flycatcher (*Empidonax traillii extimus*), are rapidly declining as native riparian forests are replaced by exotic tamarisk stands due to hydrologic alterations (Levine and Stromberg 2001; Yong and Finch 1997; Pruett et al. 2001; Wiggins 2005; Schmidt-Petersen 2007; Sechrist et al. 2009). The impacts of hydrologic alterations are projected to increase as a result of growing urban, commercial, and agricultural demands on the Middle Rio Grande, placing greater pressure on limited water resources and further depleting an already water-stressed system (Jackson et al. 2001; Robert 2007).

Projected climate change patterns are expected to intensify water scarcity in the region and potentially increase conflicts among water users and wildlife, including endangered species (Hurd and Coonrod 2007).

Many avian species markedly respond to alterations in riparian vegetation composition and structure (Hunter et al. 1987; Van Riper et al. 2008). For example, Anderson et al. (1977) and Ellis (1995) found higher avian species richness in cottonwood-willow than mesquite (*Prosopis* spp.) or tamarisk on the MRG and lower Colorado. Brand et al. (2011) found that canopy-nesting birds are dependent on mature cottonwood/willow stands; therefore, when depth to groundwater increased, the density of canopy-nesting birds decreased as mature cottonwoods and willows were lost due to groundwater declines. However, density of midstory-nesting birds and some understory-nesting species increased as depth to groundwater increased, causing tamarisk coverage to increase (Brand et al. 2011). Hydrologic regime has also been found to influence nest survival (Brand et al. 2010). Brand et al. (2010) found that nest survival for Yellow-breasted Chats and Abert's Towhee was lower in tamarisk stands with intermittent flow than in tamarisk stands with ephemeral flow. Because birds are sensitive to changes in riparian vegetation, they are often used as indicators of ecological conditions of riparian and wetland systems and are frequently the aim of conservation and restoration efforts (Sogge et al. 2008; Brand et al. 2011).

Despite the increased understanding of the effects of altered hydrology on riparian vegetation, few studies have examined the effects of hydrology and vegetation on avian communities (Brand et al. 2011). Therefore, questions remain as to what hydrogeomorphic conditions are needed along the MRG to achieve certain ecological



outcomes, such as the conservation of avian populations and communities. The specific objective of this study is to evaluate the effects of surface hydrologic environments, geomorphic setting, and vegetation community structure and composition on avian relative abundance and community structure. I predict that there will be more native vegetation at sites with frequent surface flooding than at sites that rarely flood. Furthermore, I predict that relative abundance of ground-nesting species and low shrub-nesting species will be correlated with a wide range of hydrogeomorphic and vegetative conditions. I also predict that relative abundance of high shrub-nesting species will be correlated with occasional surface flooding and native overstory and exotic understory, while I predict that relative abundance of canopy-nesting species will be correlated with occasional flooding and native overstory. Finally, I predict that water-obligate species will be correlated with surface water, frequent surface flooding, and native understory vegetation (Table 2.1). This research will increase understanding of songbird responses to vegetation and the limitations of hydrology and geomorphology on avian communities, thus aiding managers in delineating the range of restoration possibilities within given hydrogeomorphic conditions.

## **2.2 METHODS**

### **2.2.1 Study Area**

This study was conducted in the San Acacia Reach of the MRG within the active floodplain of the Rio Grande from the San Acacia Diversion (river mile 116) to the full pool boundary of Elephant Butte Reservoir (river mile 62) (Figure 1). The San Acacia

Table 2.1. List of species in each guild (Poole 2005).

<b>Ground-nesting Guild</b>	<b>Low Shrub-nesting Guild</b>	<b>High Shrub-nesting Guild</b>	<b>Canopy-nesting Guild</b>	<b>Other Nesting Guild</b>	<b>Water-obligate Species</b>
Gambel's Quail	Bell's Vireo	White-winged Dove	Northern Flicker	Mourning Dove	Western Yellow-billed Cuckoo
Common Yellowthroat	Bewick's Wren	Western Yellow-billed Cuckoo	Western Wood-Pewee	Bushtit	Bell's Vireo
Yellow-breasted Chat	House Finch	Black-chinned Hummingbird	Western Kingbird	Northern Mockingbird	Common Yellowthroat
Spotted Towhee		Ladder-backed Woodpecker	Lucy's Warbler	Blue Grosbeak	
Western Meadowlark		Ash-throated Flycatcher	Summer Tanager	Brown-headed Cowbird	
		Black-headed Grosbeak	Lesser Goldfinch		

Reach is unique because, although altered by valley infrastructure, there are two uncontrolled tributaries that input sediment and water during summer monsoon storm events (Crawford et al. 1993; Ellis 2007). In addition, the spring hydrograph maintains the historic timing although magnitude and duration of flows have been altered (Crawford et al. 1993). These processes result in a dynamic river (in certain subreaches) that supports one of the largest continuous stretches of native riparian habitat, specifically cottonwood, Goodding's willow, and coyote willow, and associated wildlife (Ahlers et al. 2010b). The reach supports the federally endangered Rio Grande silvery minnow (*Hybognathus amarus*) and Southwestern Willow Flycatcher, and two candidate species, the Western Yellow-billed Cuckoo and the New Mexico meadow jumping mouse (*Zapus*

*hudsonius luteus*) (U.S. Fish and Wildlife Service 2003; Ahlers et al. 2010a; Ahlers et al. 2010b; U.S. Fish and Wildlife Service 2013). Land management in the reach includes two National Wildlife Refuges (Sevilleta National Wildlife Refuge and Bosque del Apache National Wildlife Refuge), U.S. Bureau of Reclamation river maintenance, and numerous private lands with opportunities for habitat protection and improvement partnerships. The water control infrastructure of the reach adds to the complexity of hydrologic connection in the area. Throughout the San Acacia Reach, a low-flow conveyance channel is located on the western side of the Rio Grande and runs parallel to the channel at a lower elevation than the channel, thus acting as a drain for the valley (Towne 2007).

In 2011-2012, all appropriate hydrologic, geomorphic (topography), and vegetative (community, structure, composition) datasets were reviewed and incorporated into a GIS geodatabase to stratify abiotic and biotic components of the San Acacia Reach (Table 2.2). From February to May 2012, ground-truthing was conducted throughout the San Acacia Reach to validate stratification. Based on the most current channel geomorphology data (Massong et al. 2006; Holste 2013) and ground-truthing, the San Acacia Reach was divided into three subreaches. Subreach 1 is a degrading channel that extends from San Acacia Diversion (river mile 116) to Escondida (river mile 102).

Table 2.2. List of data sets and references used for site stratification.

<b>Data Type</b>	<b>Reference</b>
Hydrology Data	Makar and AuBuchon 2012; Tetra Tech 2002
Geomorphology Data	Lettis & Associates 2003
Vegetation Data	Moore and Ahlers 2008

Subreach 2 is an aggrading channel that stretches from Escondida (river mile 102) to north of the southern boundary of Bosque del Apache National Wildlife Refuge (river mile 76). Due to headcutting north of Elephant Butte Reservoir (Holste et al. 2011; Holste 2013), Subreach 3 is a degrading channel that extends from north of the southern boundary of Bosque del Apache National Wildlife Refuge (river mile 76) to the full pool boundary of Elephant Butte Reservoir (river mile 62) (Figure 2.1).

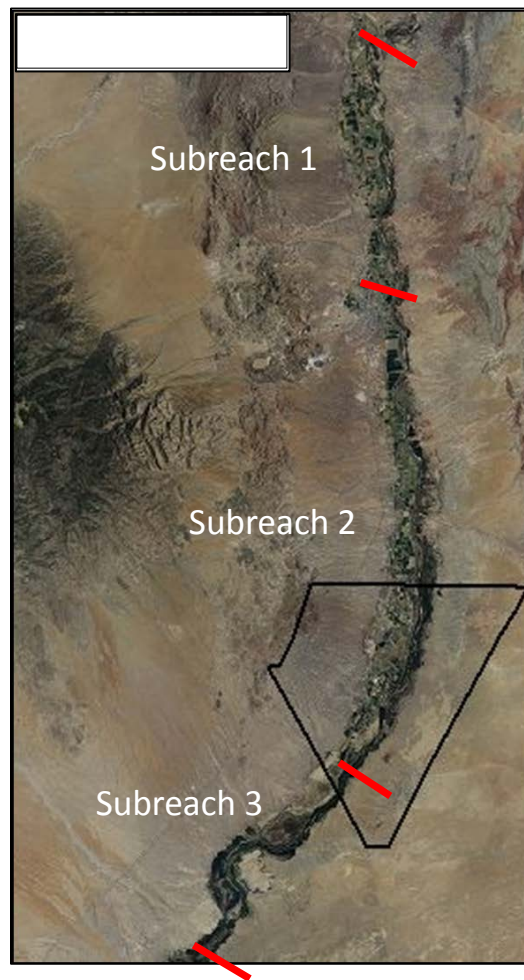


Figure 2.1. Map of the San Acacia Reach of the Middle Rio Grande, located about 66 miles south of Albuquerque, New Mexico. The San Acacia Reach encompasses 54 miles of river. The black trapezoid indicates the boundary of Bosque Del Apache National Wildlife Refuge. I divided the San Acacia Reach into 3 subreaches based on channel morphology. Subreach 1 and Subreach 3 are incised channels, while Subreach 2 is aggraded channel. Subreach 1 has been incised for decades, while Subreach 3 has recently begun incising, most notably since 2004 (Holste 2013).

### 2.2.2 Site Selection

Forty four transects of variable length based on floodplain width were placed perpendicular to the river at stratified random locations. Sites were stratified by subreach (11 transects in Subreach 1; 22 transects in Subreach 2; 11 transects in Subreach 3) and vegetation type using coarse vegetation data from Moore and Ahlers (2008) so that all dominant vegetation types found along the San Acacia Reach occurred along selected transects (Table 2.3 & 2.4). Sites were stratified by subreach to test for the effects of different geomorphic settings (degraded channel or aggraded channel) on avian relative abundance and community composition. Transects were placed on the east and west side of the river to test for the effects of the low flow conveyance channel. Transects were located  $\geq 1$  km apart to insure independence among transects.

Table 2.3. Hink and Ohmart (1984) vegetation structure classes.

Structure Class	Description
1	Vegetation in all foliage layers, with trees reaching 50 to 60 ft. Mature to mixed age class stands. 25% or greater of understory is vegetated.
2	Mature stands of trees up to 50 to 60 ft tall, with most of the foliage in the canopy layer > 30 ft. Sparse, patchy understory and little herbaceous growth.
3	Intermediate age stand with a thick understory. Dense vegetation up through about 30 ft, but little above 30 ft. 25% or greater of understory is vegetated.
4	Relatively open stands of intermediate-age stands. Most of the foliage was between 20 and 40 ft. Shrubs widely spaced and herbaceous growth is sparse.
5	Dense vegetation at about 10 or 15 ft high, often including a thick layer of grass and annuals. Some taller trees scattered throughout.
6	Low and relatively sparse herbaceous and/or shrubby vegetation, with most foliage below 5 ft.

Table 2.4. Dominant vegetation types along the San Acacia Reach; based on 2002 vegetation data from Bureau of Reclamation (Moore and Ahlers 2008). Canopy and understory layers are separated by a slash (/). The number indicates the Hink and Ohmart (1984) structure class (Table 2.3).

<b>Vegetation Type</b>	<b>Area (ha)</b>
Tamarisk 5	1,591.5
Cottonwood / Tamarisk 3	439.6
Cottonwood / Tamarisk 1	194.7
Cottonwood 4	119.3
Cottonwood 2	0.09
Cottonwood 5	0.08
Goodding's Willow / Tamarisk 3	0.07
Coyote Willow 5	0.07

### 2.2.3 Hydrology Data

Hydrology data was derived from the 2006 Rio Grande channel planform mapping data (Makar and AuBuchon 2012) and the FLO2D modeling output from the Upper Rio Grande Water Operations Model (Tetra Tech 2002). FLO2D model outputs were composites of actual historic run-offs from the period of record (1958 – 2012) (Terta Tech 2002). Four peak flow levels out of Cochiti Dam (River Mile 232.6) were used to represent 4 different spring run-off flood events: inundation of active bars at 57 m<sup>3</sup>/s (cms), a low flood event at 101 cms, a moderate flood event at 152 cms, and a high flood event at 213 cms (Remshardt and Tashjian 2005). These discharge rates were selected from a suite of FLO2D model runs representing a low to moderate spring run-off, a moderate spring run-off, and a high spring run-off (Tetra Tech 2002). A flow of 57 cms has a 2 year occurrence, while a low flood event at 101 cms has a 2.5 year occurrence. A moderate flood event at 152 cms has a 5 year occurrence, and a high flood

event at 213 cms has a 40 year occurrence. Areas inundated at each flow level were depicted in an ArcGIS shape file. Area ( $\text{m}^2$ ) inundated at each site was calculated in ArcGIS 10 by calculating the area of each site that was inundated at each flow level. Area ( $\text{m}^2$ ) inundated at each site at each flow level was then used in analysis as the hydrologic variables.

#### **2.2.4 Vegetation Sampling**

Existing vegetation data for the San Acacia Reach was generated at a coarse scale using 2002 aerial photography and ground-truthing/classification using the Hink and Ohmart (1984) vegetation classification scheme (Moore and Ahlers 2008). This study required vegetation data at a finer scale to adequately describe songbird habitat (MacArthur and MacArthur 1961; Willson 1974; Rotenberry and Wiens 1980; Schemske and Brokaw 1981; Rotenberry 1985; Faccio 2003; Zurtia and Zuleta 2009); therefore, data from Moore and Ahlers (2008) were used only for stratification of sites. Finer scale habitat data were collected along all 44 belt transects to determine species composition, stand structure, stem density, and visual obstruction of the vegetative community. Plots were placed every 50 m along the transect (east to west), and then every 20 m or 50 m and 100 m north and south of the transect, depending on distance from river (Figure 2.2). At each plot, observers estimated the percent cover of the four most dominant overstory ( $> 4.5$  m) species and the four most dominant understory (0.6 m to 4.5 m) species within a 10 m radius circle of the data point. Observers also estimated percent of total stems alive of each species (hereafter referred to as “percent live”). Percent cover and percent live were estimated in increments of five. Stand structure was classified using Hink and Ohmart (1984) structure classes (Table 2.3). Hink and Ohmart (1984) structure classes

categorize communities into six broad structure types, allowing for high structural variability within a given classification. Therefore, observers also recorded stem density and visual obstruction data to further refine the broad Hink and Ohmart classifications (see Chapter 4). The number of woody stems and *Kochia* > 1.37 m tall was recorded in four classes: Class 1 is 0 – 500 woody stems; class 2 is 500 – 1,000 woody stems; class 3 is 1,000 – 3,500 woody stems; class 4 is over 3,500 woody stems. Visual obstruction was measured using a modified method of Robel et al. (1970). We positioned a piece of letter-sized paper 1.68 m above the ground and estimated the percent of the paper that was obstructed by vegetation when viewed from 5 m away. Visual obstruction measurements were taken in each cardinal direction. As there were four visual obstruction measurements per plot, the median of the four numbers was used as the visual obstruction measurement of the plot.

Figure 2.2. Plot layout along a belt transect. Transects were oriented perpendicular to the river and vegetation composition and stand structure were qualitatively assessed at each plot.



### **2.2.5 Avian Surveys**

Bird data were collected at all 44 transects during the 2012 and 2013 breeding seasons (21 May to 10 Aug). One to six point count survey locations were placed on each transect for a total of 69 point count survey locations. Survey locations marked the center of a 100 m radius variable circular plot and were positioned along transects beginning 100 m from the bank of the Rio Grande and spaced 250 m apart to increase likelihood of sample independence. Survey locations were placed  $\geq 130$  m from the upland transition (east side) or the eastern toe of the spoil levee (west side) to avoid sampling birds outside of the floodplain.

Survey methods were based on adaptations of Hamel et al. (1996). Each survey location was visited 4 to 8 times per breeding season, with a minimum of 7 days between visits to increase temporal independence. The order in which survey locations were visited was reversed with each visit to reduce potential bias of time of day. Surveys were not conducted during heavy rains or high winds as these conditions reduce bird activity and detectability. Point count surveys were conducted from sunrise to 10 AM. After an initial wait period of 5 minutes, the observer recorded all birds seen or heard during a 10 minute period. The 10 minute period was divided into 3 time intervals: 0 – 3 minutes, 3 – 6 minutes, and 6 – 10 minutes. For each detection, the observer recorded species, sex, age, distance and direction from survey location, time interval of detection, and behavior indicative of breeding, such as male/female pairs or birds carrying nesting material or food. At each survey, wind strength was recorded using the Beaufort scale and sky conditions were recorded using the Weather Bureau codes (Hamel et al. 1996). A total of seven observers conducted surveys during the two year study. At the

beginning of each field season, every observer completed a minimum of 1.5 weeks of training on survey techniques, including distance estimation and identification of species by sight and sound, before data collection began. Observers were rotated between survey locations so that each observer surveyed every location approximately the same number of times.

### **2.2.6 Statistical Analysis**

#### *Hydrogeomorphology and Vegetation*

Generalized linear mixed (categorical and continuous variables) models were used to test for differences at the plot level in vegetation species composition (mean percent cover of native and exotic overstory and understory) along longitudinal hydrologic gradients (among subreaches) and lateral hydrologic gradients (distance from river) (PROC GLIMMIX in SAS 9.3). Models with a cumulative logit link and a multinomial distribution were used for vegetation structure variables. Models with logit and log links and binomial (logistic), Poisson, negative binomial, and gamma distributions were compared for each vegetation species composition variable. The best fitting combination of link and distribution ( $\hat{c}$  closet to 1) in the generalized linear model were used for inference for that variable. For longitudinal hydrologic gradient analyses, the model of best fit for percent cover of native overstory, exotic overstory, and exotic understory had a log link and a gamma distribution, while the model of best fit for percent cover of native understory had a log link and a negative binomial distribution. For lateral hydrologic gradient analyses, the model of best fit for percent cover of native and exotic overstory and understory had a log link and a gamma distribution.

### *Hydrogeomorphology, Vegetation, and Birds*

Avian relative abundances were estimated for each species that had  $\geq 30$  individuals detected over both seasons. Flyovers, migrants, and detections greater than 100 m were not used in analyses. Relative abundances were estimated using Royle's (2004) N-mixture models (RStudio 0.98.501, Package Unmarked) (Schmidt et al. 2013). In sampling, measurement errors occur, including imperfect detection. Royle's (2004) N-mixture models are designed to estimate the number of individuals that were present but not detected by estimating detection and occupancy probabilities for each species based on observed species count data. Following the determination of species detection and occupancy probabilities, a Bayesian bootstrapping procedure estimated the probabilities of birds present. The upper limit for the number of birds present during bootstrapping was set based on the maximum number of individuals of each species detected during a survey. Royle's (2004) N-mixture models estimate number of individuals that use a point count site, rather than true point count site density (Joseph et al. 2009). Therefore, the abundance estimates reported are relative abundance estimates of the number of birds present at the site throughout the sample period. A two level visibility parameter (high or low visibility) at each site was included as a site-level covariate in relative abundance analyses. A site was deemed visible if the observer could see for at least 25 m for greater than 90% of the plot. Visit-level, categorical covariates included in the relative abundance analyses were wind strength, sky conditions, and time of survey. Akaike Information Criterion was used to determine the model of best fit for each species.

Bird species were then grouped in to nesting-height guilds and water-obligate species (Brand et al. 2010) (Table 2.1). Species were categorized as ground nesters (0 – 1 m), low shrub nesters (1 – 2 m), high shrub nesters (2 – 4 m), canopy nesters (> 4 m), and others (species that

nest at highly variable heights) based on data from Poole (2005) (Brand et al. 2010). Songbirds dependent on surface water in southwestern riparian ecosystems were classified as water-obligate species (Brand et al. 2010).

I then used six separate general linear mixed (categorical and continuous variables) models to correlate relative abundance of songbird nesting-height guilds and water-obligate species with the hydrologic (area inundated at each site at the 4 different flow levels), geomorphic (subreach), and vegetation variables (mean percent cover of native and exotic overstory and understory) at each point count site (PROC MIXED in SAS 9.3). To estimate total relative abundance of each guild, I summed the species-specific, detection-adjusted estimates of the guild member species (Table 2.1); this accounted for heterogeneous detection probabilities among species. Because there were 21 vegetation plots within a 100 m radius bird point count site, I calculated the mean of the 21 vegetation plots to get a composite description of the vegetation communities in each bird point count site. Residuals of each model were assessed to evaluate the assumptions of general linear mixed models. Examination of the residuals indicated heteroscedasticity among subreaches in vegetation characteristics (i.e., ranges of vegetation showed limited overlap among subreaches), resulting in an inability to estimate variance components. Therefore, vegetation variables were nested within subreach so that variance components could be estimated.

#### *Avian Species Assessment Scores*

New Mexico Partners in Flight Species Assessment Scores were used to indicate songbird species of conservation concern (New Mexico Partners in Flight 2007). Scientific credibility of the species assessment scores has been acknowledged in peer-reviewed journals (Beissinger et al. 2000). Assessment scores are derived from 5 vulnerability factors: distribution

(global breeding distribution and global non-breeding distribution), threats (breeding season threats in North America, non-breeding season threats, and breeding season threats in New Mexico), global population size, local population trend, and importance of New Mexico to breeding (New Mexico Partners in Flight 2007). Scores from all five vulnerability factors are totaled to create a combined score ranging from 5 – 25 (New Mexico Partners in Flight 2007).

General linear mixed (categorical and continuous variables) models were then used to correlate relative abundance of songbird species of conservation concern with the hydrologic (area inundated at each site at the 4 different flow levels), geomorphic (subreach), and vegetation variables (mean percent cover of native and exotic overstory and understory) at each point count site (PROC MIXED in SAS 9.3). Residuals of each model were assessed to evaluate the assumptions of general linear mixed models. Examination of the residuals indicated heteroscedasticity among subreaches in vegetation characteristics (i.e., ranges of vegetation showed limited overlap among subreaches), resulting in an inability to estimate variance components. Therefore, vegetation variables were nested within subreach so that variance components could be estimated.

## **2.3 RESULTS**

### **2.3.1 Hydrogeomorphology**

Overall, the total flooded area was much smaller in subreaches with incised channels (Subreaches 1 and 3) than in the subreach with an aggraded channel (Subreach 2; Table 2.5). At a discharge rate of 57 cms, inundated areas were limited to active bars within the channel along the incised Subreaches 1 and 3. However, at the same discharge rate on the non-incised channel, Subreach 2, inundated areas were active bars within the floodplain. Along Subreaches 2 and 3, inundated area increased when flows increased. However, along Subreach 1, inundated area did

not increase when flows increased from 57 cms to 101 cms or from 101 cms to 152 cms due to the steep banks along the incised channel. In summary, Subreach 2, the non-incised channel, had the largest inundated area at each flow level, ranging from 4 to 15 times more flooded habitat than Subreaches 1 and 3. Subreach 1 had the second highest inundated area at flows of 57 cms and 101 cms; however, Subreach 3 had the second highest inundated area at flows of 152 and 213 cms.

Table 2.5. Total area (ha) of sites inundated along each subreach at all four flow levels of interest.

Subreach	57 cms	101 cms	152 cms	213 cms	Total Area
1	3.4	3.4	3.4	3.9	1,392.4
2	14.7	32.2	62.0	93.6	3,801.8
3	0.95	3.1	4.0	7.2	2,541.3

### 2.3.2 Hydrogeomorphology and Vegetation

A total of 1,801 vegetation plots were completed. Excluding the communities that comprised less than 1% of the data set, 14 vegetation communities were documented in our surveys (Table 2.6). Along the downstream hydrologic gradient, dense monotypic stands of tamarisk (Hink and Ohmart class: Salt Cedar 5) occurred most frequently in all subreaches (Table 2.6 and Figure 2.3). In Subreach 1, dense early succession Russian olive (*Elaeagnus angustifolia*) (Hink and Ohmart class: Russian Olive 5) was the second most dominant vegetation community, while early succession cottonwood (Hink and Ohmart class: Cottonwood 5) was the third most dominant vegetation community (Table 2.6 and Figure 2.3). Young cottonwoods were recently planted at a site on the west side of Subreach 1 as a restoration effort, thus explaining this finding. However, in Subreach 2, dense coyote willow (Hink and Ohmart class: Coyote Willow 5) was the second most dominant vegetation community, and intermediate

aged cottonwood with a dense tamarisk understory (Hink and Ohmart class: Cottonwood / Salt Cedar 3) was the third most dominant vegetation community (Table 2.6 and Figure 2.3). In Subreach 3, intermediate aged cottonwood with a dense tamarisk understory (Hink and Ohmart class: Cottonwood / Salt Cedar 3) was the second most dominant vegetation community, while intermediate aged cottonwood with dense woody debris in the understory (Hink and Ohmart class: Cottonwood / Woody Debris 3) was the third most dominant vegetation community (Table 2.6 and Figure 2.3).

Table 2.6. Percent occurrence of dominant vegetation communities recorded in vegetation survey. Communities that comprised less than 1% of the data set are not included; therefore, percentages per subreach do not total 100. Canopy and understory layers are separated by a slash (/). The number indicates the Hink and Ohmart (1984) structure class (Table 2.3). Salt Grass (*Distichlis spicata*); New Mexico olive (*Forestiera pubescens*).

<b>Vegetation Community</b>	<b>Subreach 1</b>	<b>Subreach 2</b>	<b>Subreach 3</b>
Cottonwood 5	5	3	0
Coyote Willow 5	5	13	6
<i>Kochia</i> 5	0	4	0
<i>Kochia</i> 6	1	3	0
Russian Olive 5	6	4	0
Tamarisk 5	48	37	49
Salt Grass 6	0	2	0
Cottonwood / Cottonwood 3	4	2	0
Cottonwood /Coyote Willow 3	2	2	5
New Mexico Olive 5	1	2	0
Cottonwood / Russian Olive 3	5	2	0
Cottonwood / Tamarisk 1	5	3	4
Cottonwood / Tamarisk 3	1	6	14
Cottonwood / Woody Debris 3	0	1	9

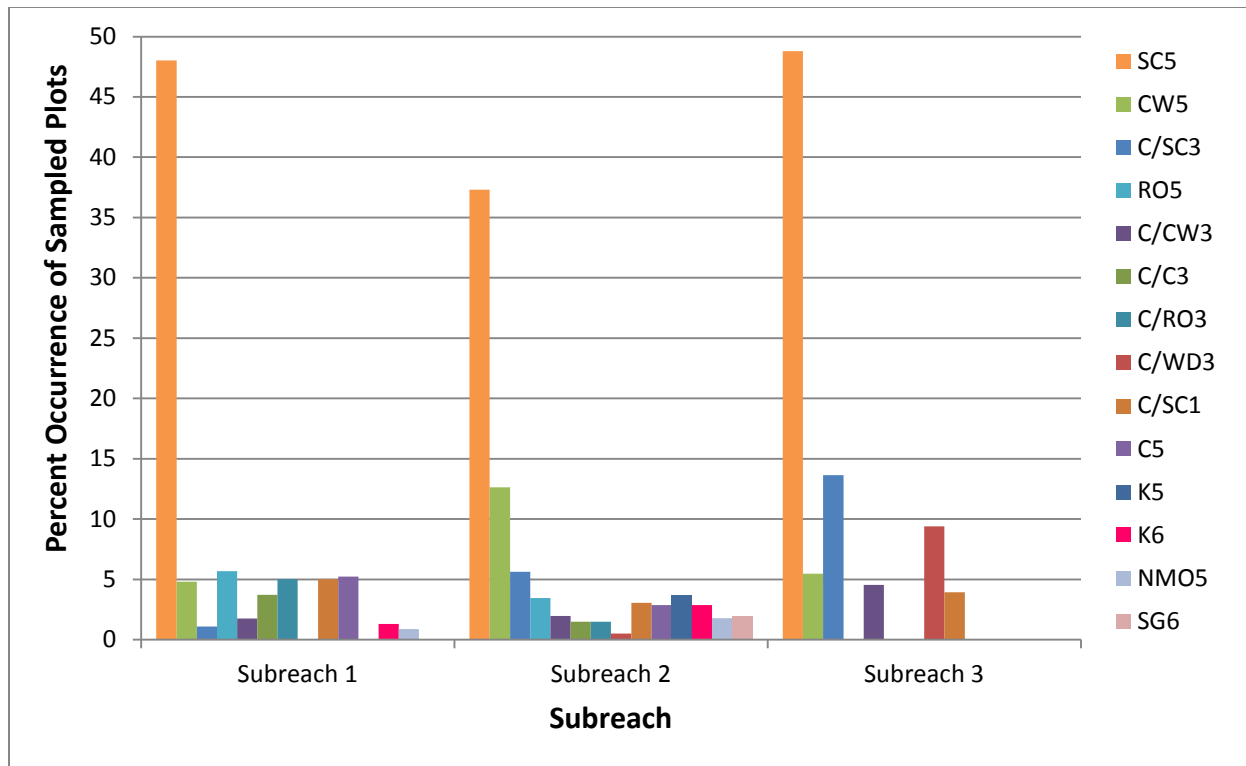


Figure 2.3. Percent occurrence of vegetation communities of each subreach. Vegetation community types are denoted using Hink and Ohmart notation. SG6: sparse salt grass; NMO5: dense New Mexico olive; K6: sparse *Kochia*; K5: dense *Kochia*; C5: dense early succession cottonwood; C/SC1: mature aged cottonwood overstory with dense tamarisk understory; C/WD3: intermediate aged cottonwood overstory with dense woody debris in the understory; C/RO3: intermediate aged cottonwood overstory with dense Russian olive understory; C/C3: intermediate aged cottonwood overstory with dense cottonwood understory; C/CW3: intermediate aged cottonwood overstory with dense coyote willow understory; RO5: dense early succession Russian olive; C/SC3: intermediate aged cottonwood overstory with dense tamarisk understory; CW5: dense coyote willow; SC5: dense tamarisk.

There were significant differences in vegetation species composition along a longitudinal hydrologic gradient (among subreaches) (Table 2.7); however, these findings did not fully support the prediction that there would be more native vegetation at sites with frequent surface flooding than at sites that rarely flood. While mean percent cover of native understory (DF = 2, 66;  $F = 2.23$ ;  $p = 0.12$ ) and exotic understory (DF = 2, 66;  $F = 0.82$ ;  $p = 0.45$ ) did not statistically differ among subreaches, the mean percent cover of native overstory and exotic overstory did statistically differ among subreaches. Specifically, mean percent cover of native overstory was



greater in Subreach 3 than Subreach 1 ( $\beta = 0.41$ ; DF = 1, 61;  $t = -2.33$ ;  $p = 0.02$ ) and Subreach 2 ( $\beta = 0.42$ ; DF = 1, 61;  $t = -2.51$ ;  $p = 0.01$ ), but did not statistically differ between Subreaches 1 and 2 ( $\beta = 0.97$ ; DF = 1, 61;  $t = -0.12$ ;  $p = 0.90$ ). Mean percent cover of exotic overstory was greater in Subreach 1 than Subreach 2 ( $\beta = 1.22$ ; DF = 1, 66;  $t = 2.15$ ;  $p = 0.04$ ) and Subreach 3 ( $\beta = 1.54$ ; DF = 1, 66;  $t = 3.42$ ;  $p < 0.01$ ), and greater in Subreach 2 than Subreach 3 ( $\beta = 1.26$ ; DF = 1, 66;  $t = 2.07$ ;  $p = 0.04$ ). However, the exotic overstory statistical model exhibited very poor fit and showed evidence of uncorrectable overdispersion. Therefore, the statistical significance may over-inflate the biological meaning of this variable.

Table 2.7. Mean (SD) percent cover of vegetation categories per subreach. Averages followed by the same letter within a column did not statistically differ; averages followed by different letters within a column did statistically differ.

Subreach	Native Overstory	Exotic Overstory	Native Understory	Exotic Understory
1	12 (10) A	3 (4) A	18 (13) A	39 (20) A
2	11 (13) A	2 (3) B	26 (21) A	40 (20) A
3	30 (15) B	0 (0) C	14 (13) A	49 (23) A

Along a lateral hydrologic gradient, native overstory ( $\beta = 0.10$ ; DF = 1, 1777;  $t = -12.70$ ;  $p < 0.01$ ), exotic overstory ( $\beta = 0.10$ ; DF = 1, 1777;  $t = -12.24$ ;  $p < 0.01$ ), and native understory ( $\beta = 0.10$ ; DF = 1, 1777;  $t = -4.18$ ;  $p < 0.01$ ) were negatively associated with distance from the river, while exotic understory was not associated with distance from the river ( $\beta = 1.00$ ; DF = 1, 1777;  $t = 0.66$ ;  $p = 0.51$ ). Dense coyote willow occurred most frequently on the banks of the river throughout the San Acacia Reach; however, at  $\geq 50$  m from the river bank, dense tamarisk occurred most frequently (Figure 2.4).

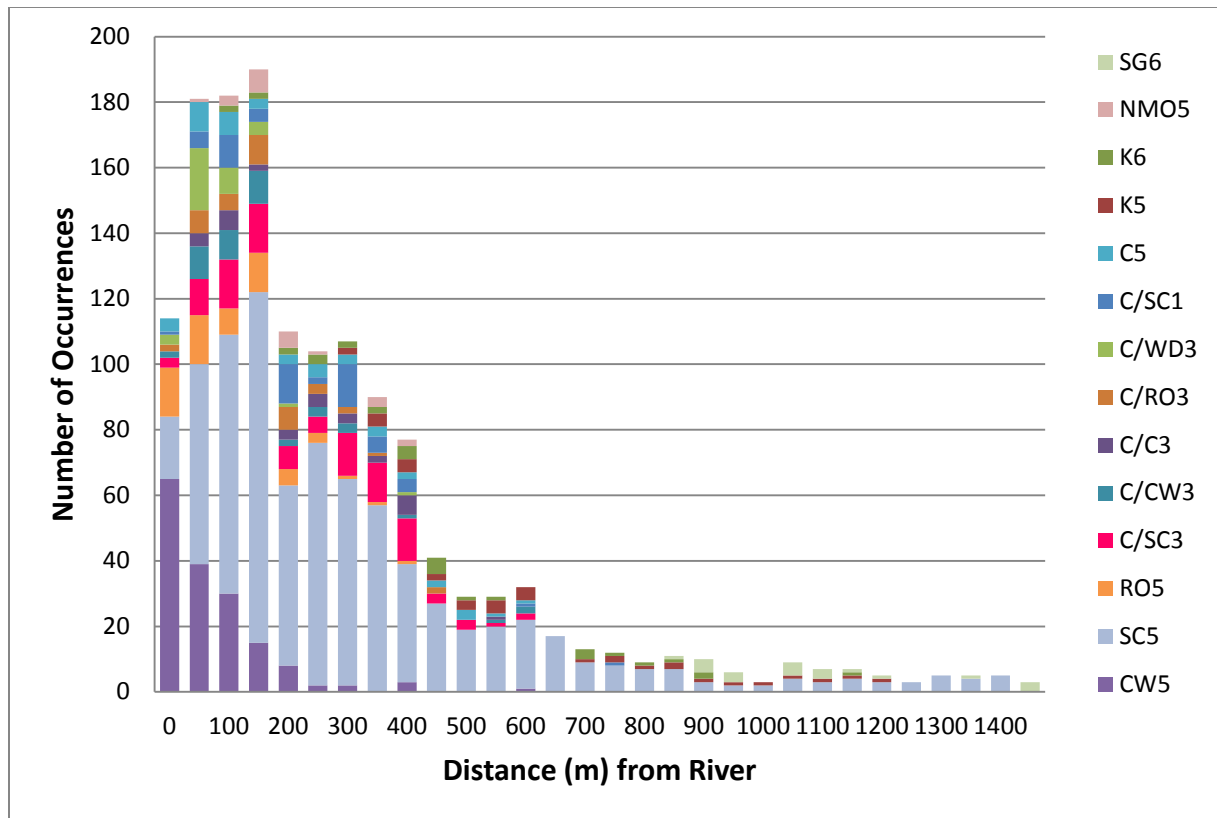


Figure 2.4. Vegetation communities types along a lateral hydrologic gradient. Floodplain width varies across transects from 250 m to 1,450 m. Vegetation community types are denoted using Hink and Ohmart notation. CW5: dense coyote willow; SC5: dense tamarisk; RO5: dense early succession Russian olive; C/SC3: intermediate aged cottonwood overstory with dense tamarisk understory; C/CW3: intermediate aged cottonwood overstory with dense coyote willow understory; C/C3: intermediate aged cottonwood overstory with dense cottonwood understory; C/RO3: intermediate aged cottonwood overstory with dense Russian olive understory; C/WD3: intermediate aged cottonwood overstory with dense woody debris in the understory; C/SC1: mature aged cottonwood overstory with dense tamarisk understory; C5: dense early succession cottonwood; K5: dense *Kochia*; K6: sparse *Kochia*; NMO5: dense New Mexico olive; SG6: sparse salt grass.

The low flow conveyance channel does not appear to have much of an effect on vegetation composition as the most dominant communities are the same on the east and west side of each subreach as listed above (Figure 2.5). However, along Subreach 1, the second most dominant community type on the west side is early succession cottonwood (Hink and Ohmart class: Cottonwood 5; 10% of sampled plots), while the second most dominant community type

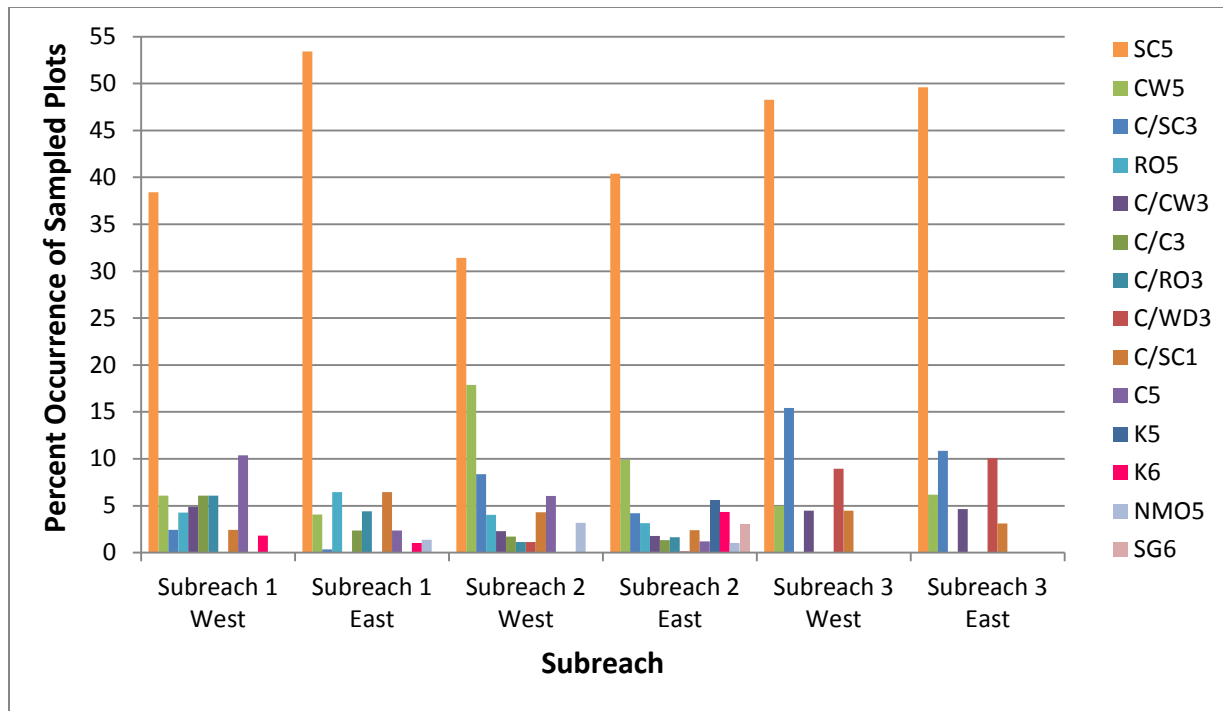


Figure 2.5. Percent occurrence of vegetation communities on east and west side of each subreach. Vegetation community types are denoted using Hink and Ohmart notation. SG6: sparse salt grass; NMO5: dense New Mexico olive; K6: sparse *Kochia*; K5: dense *Kochia*; C5: dense early succession cottonwood; C/SC1: mature aged cottonwood overstory with dense tamarisk understory; C/WD3: intermediate aged cottonwood overstory with dense woody debris in the understory; C/RO3: intermediate aged cottonwood overstory with dense Russian olive understory; C/C3: intermediate aged cottonwood overstory with dense cottonwood understory; C/CW3: intermediate aged cottonwood overstory with dense coyote willow understory; RO5: dense early succession Russian olive; C/SC3: intermediate aged cottonwood overstory with dense tamarisk understory; CW5: dense coyote willow; SC5: dense tamarisk.

on the east side is dense early succession Russian olive (Hink and Ohmart class: Russian olive 5; 6% of sampled plots) and mature cottonwood with a dense tamarisk understory (Hink and Ohmart class: Cottonwood / Salt Cedar 1; 6% of sampled plots) (Figure 2.5). As stated above, young cottonwoods were recently planted at a site on the west side of Subreach 1 as a restoration effort, thus explaining this finding. Additionally, along Subreach 2, the first and second most dominant communities are the same on the east and west side of the subreach as listed above (Figure 2.5). However, on the west side of Subreach 2, the third most dominant community is intermediate aged cottonwood with a dense tamarisk understory (Hink and Ohmart class:

Cottonwood / Salt Cedar 3), while on the east side the third most dominant community is dense *Kochia* (Hink and Ohmart class: *Kochia* 5; Figure 2.5). Eleven sites on the east side of Subreach 2 have recently been restored to early succession grassland habitat and *Kochia* is found throughout these two sites, thus explaining this finding.

### **2.3.3 Avian Data**

A total of 999 point count surveys were completed throughout the 2012 and 2013 breeding season. Sixty-nine land bird species were detected over the two breeding seasons (Appendix A). However, only 25 species were detected  $\geq 30$  times over the two breeding seasons, and these were the species used in analyses (Table 2.8). Yellow-breasted Chat was the most commonly detected bird (2,007 detections) and occurred at 67 sites. Spotted Towhee was the second most commonly detected bird (1,405 detections) and occurred at 66 sites; Mourning Dove was the third most frequently detected bird (1,053 detections) and occurred at 68 sites. Because the mode of relative abundance estimates produced from Royle's (2004) N-mixture models sometimes overestimated the maximum number of individuals detected at a site as compared to other southwestern avian studies (Rumble and Gobeille 2004; Mcfarland et al. 2012), the more conservative first quartile of relative abundance estimates was used in analyses (Kéry and Schaub 2012). Different combinations of covariates were required for each species to achieve the model of best fit.

#### *Species Assessment Scores*

Using New Mexico Partner in Flight Species Assessment scores, 5 species qualify as species of concern. Bell's Vireo and Lucy's Warbler are prioritized at Species Conservation Level 1; Black-chinned Hummingbird is prioritized at Species Conservation Level 2 (New Mexico Partners in Flight 2007). Western Yellow-billed Cuckoo is prioritized at Biodiversity

Conservation Level 1, and Summer Tanager is prioritized at Biodiversity Conservation Level 2 (New Mexico Partners in Flight 2007).

Table 2.8. Number of detections of each species that was detected  $\geq 30$  times.

<b>Species</b>	<b>Total Number of Detections</b>
Yellow-breasted Chat	2,007
Spotted Towhee	1,405
Mourning Dove	1,053
Brown-headed Cowbird	694
Common Yellowthroat	612
White-winged Dove	579
Black-headed Grosbeak	555
Black-chinned Hummingbird	497
Northern Mockingbird	473
Ash-throated Flycatcher	446
Blue Grosbeak	397
Bewick's Wren	387
Summer Tanager	307
House Finch	241
Bell's Vireo	159
Western Kingbird	134
Lucy's Warbler	111
Gambel's Quail	90
Ladder-backed Woodpecker	86
Northern Flicker	64
Bushtit	53
Western Wood-Pewee	47
Western Meadowlark	42
Lesser Goldfinch	30
Western Yellow-billed Cuckoo	30

### **2.3.4 Hydrogeomorphology, Vegetation, and Birds**

#### *Nest Height Guilds*

Results presented are specific to the nested subreach; however, where these hydrogeomorphic and vegetative conditions existed at the point count site level in other subreaches, these correlations likely existed. The prediction that relative abundance of ground-nesting species and low shrub-nesting species would be correlated with a wide range of hydrogeomorphic and vegetative conditions was supported. Ground nesters were positively correlated with areas that flooded at 101 cms, exotic overstory on Subreach 2, native understory on Subreach 2, and exotic understory on Subreach 1 and Subreach 2 (Table 2.9). Low shrub nesters were positively correlated with areas that flooded at 57 cms, native overstory on Subreach 1, and woody debris in the understory on Subreach 1, while this guild was negatively correlated with rare woody understory species on Subreach 1 (Table 2.10).

The prediction that relative abundance of high shrub-nesting species would be correlated with occasional surface flooding, native overstory, and exotic understory was partially supported as high shrub nesters were positively correlated with areas that inundated at 101 cms (Table 2.11). The prediction that relative abundance of canopy-nesting species would be correlated with occasional flooding and native overstory was supported. Canopy nesters were positively correlated with areas that flooded at 152 cms and native overstory on Subreach 1, while this guild was negatively correlated with exotic overstory on Subreach 1 and areas that inundated at 101 cms (Table 2.12). It is likely that canopy nesters were negatively correlated with areas that inundated at 101 cms as these areas were inundated too frequently to allow for survival of native trees to grow to overstory heights. The other nest height guild was negatively correlated with native overstory on Subreach 2 (Table 2.13). The prediction that water-obligate species would

be correlated with surface water, frequent surface flooding, and native understory vegetation was partially supported. Water-obligate species were positively correlated with native understory on Subreach 2 and exotic understory on Subreach 2, while they were marginally negatively correlated with increased distance from the river (Table 2.14).

Table 2.9. Results of the general linear mixed model correlating ground-nesting species to environmental variables. All effects were fixed. The degrees of freedom for the denominator were 108 for each variable.

Variable	Sub-reach	Variable Type	$\beta$	Numerator DF	t-value	p-value
Year	--	Categorical	-1.36	1	-1.33	0.19
Subreach	1	Categorical	78.11	2	0.03	0.98
Subreach	2	Categorical	-108.63	2	-0.05	0.96
Subreach	3	Categorical	< 0.01	2	.	.
Area inundated at 57 cms	--	Continuous	< 0.01	1	0.36	0.72
Area inundated at 101 cms	--	Continuous	< 0.01	1	2.62	0.01
Area inundated at 152 cms	--	Continuous	< 0.01	1	-1.37	0.17
Area inundated at 213 cms*(Subreach)	1	Continuous	< 0.01	3	0.77	0.44
Area inundated at 213 cms*(Subreach)	2	Continuous	< 0.01	3	0.88	0.38
Area inundated at 213 cms*(Subreach)	3	Continuous	< 0.01	3	0.56	0.58
Percent Cover of Native Overstory*(Subreach)	1	Continuous	0.05	3	0.46	0.64
Percent Cover of Native Overstory*(Subreach)	2	Continuous	0.02	3	0.71	0.48
Percent Cover of Native Overstory*(Subreach)	3	Continuous	-0.05	3	-1.18	0.24
Percent Cover of Exotic Overstory*(Subreach)	1	Continuous	-0.17	3	-0.67	0.50
Percent Cover of Exotic Overstory*(Subreach)	2	Continuous	0.26	3	2.06	0.04
Percent Cover of Exotic Overstory*(Subreach)	3	Continuous	2.86	3	1.97	0.05

Table 2.9 (continued). Results of the general linear mixed model correlating ground-nesting species to environmental variables. All effects were fixed. The degrees of freedom for the denominator were 108 for each variable.

<b>Variable</b>	<b>Sub-reach</b>	<b>Variable Type</b>	<b><math>\beta</math></b>	<b>Numerator DF</b>	<b>t-value</b>	<b>p-value</b>
Percent Cover of Native Understory*(Subreach)	1	Continuous	0.13	3	1.53	0.13
Percent Cover of Native Understory*(Subreach)	2	Continuous	0.04	3	2.45	0.02
Percent Cover of Native Understory*(Subreach)	3	Continuous	-0.10	3	-0.45	0.66
Percent Cover of Exotic Understory*(Subreach)	1	Continuous	0.10	3	3.28	<0.01
Percent Cover of Exotic Understory*(Subreach)	2	Continuous	0.06	3	2.8	0.01
Percent Cover of Exotic Understory*(Subreach)	3	Continuous	-0.12	3	-0.53	0.60
Percent Cover of Rare Woody Species in Understory*(Subreach)	1	Continuous	0.14	3	0.48	0.64
Percent Cover of Rare Woody Species in Understory*(Subreach)	2	Continuous	0.57	3	1.04	0.30
Percent Cover of Rare Woody Species in Understory*(Subreach)	3	Continuous	-3.36	3	-1.62	0.11
Percent Cover of Woody Debris in Understory*(Subreach)	1	Continuous	-0.01	3	-0.02	0.98
Percent Cover of Woody Debris in Understory*(Subreach)	2	Continuous	0.02	3	0.15	0.88
Percent Cover of Woody Debris in Understory*(Subreach)	3	Continuous	-0.08	3	-0.29	0.77



Table 2.10. Results of the general linear mixed model correlating low shrub-nesting species to environmental variables. All effects were fixed. The degrees of freedom for the denominator were 108 for each variable.

<b>Variable</b>	<b>Sub-reach</b>	<b>Variable Type</b>	<b><math>\beta</math></b>	<b>Numerator DF</b>	<b>t-value</b>	<b>p-value</b>
Year	--	Categorical	1.82	1	2.62	0.01
Subreach	1	Categorical	927.12	2	0.52	0.61
Subreach	2	Categorical	3057.69	2	1.94	0.05
Subreach	3	Categorical	< 0.01	2	.	.
Area inundated at 57 cms	--	Continuous	< 0.01	1	2.85	0.01
Area inundated at 101 cms	--	Continuous	< 0.01	1	-0.14	0.89
Area inundated at 152 cms	--	Continuous	< 0.01	1	0.33	0.74
Area inundated at 213 cms*(Subreach)	1	Continuous	< 0.01	3	-1.5	0.14
Area inundated at 213 cms*(Subreach)	2	Continuous	< 0.01	3	-0.67	0.50
Area inundated at 213 cms*(Subreach)	3	Continuous	< 0.01	3	0.35	0.73
Percent Cover of Native Overstory*(Subreach)	1	Continuous	0.20	3	2.56	0.01
Percent Cover of Native Overstory*(Subreach)	2	Continuous	0.02	3	0.78	0.43
Percent Cover of Native Overstory*(Subreach)	3	Continuous	-0.03	3	-0.94	0.35
Percent Cover of Exotic Overstory*(Subreach)	1	Continuous	-0.35	3	-2.06	0.04
Percent Cover of Exotic Overstory*(Subreach)	2	Continuous	-0.14	3	-1.62	0.11
Percent Cover of Exotic Overstory*(Subreach)	3	Continuous	-0.42	3	-0.42	0.67
Percent Cover of Native Understory*(Subreach)	1	Continuous	-0.09	3	-1.59	0.12
Percent Cover of Native Understory*(Subreach)	2	Continuous	0.02	3	1.79	0.08
Percent Cover of Native Understory*(Subreach)	3	Continuous	-0.13	3	-0.82	0.41

Table 2.10 (continued). Results of the general linear mixed model correlating low shrub-nesting species to environmental variables. All effects were fixed. The degrees of freedom for the denominator were 108 for each variable.

<b>Variable</b>	<b>Sub-reach</b>	<b>Variable Type</b>	<b><math>\beta</math></b>	<b>Numerator DF</b>	<b>t-value</b>	<b>p-value</b>
Percent Cover of Exotic Understory*(Subreach)	1	Continuous	-0.02	3	-0.81	0.42
Percent Cover of Exotic Understory*(Subreach)	2	Continuous	0.03	3	2.51	0.01
Percent Cover of Exotic Understory*(Subreach)	3	Continuous	-0.11	3	-0.73	0.47
Percent Cover of Rare Woody Species in Understory*(Subreach)	1	Continuous	-0.59	3	-2.87	<0.01
Percent Cover of Rare Woody Species in Understory*(Subreach)	2	Continuous	0.58	3	1.55	0.12
Percent Cover of Rare Woody Species in Understory*(Subreach)	3	Continuous	-2.06	3	-1.47	0.14
Percent Cover of Woody Debris in Understory*(Subreach)	1	Continuous	1.08	3	2.44	0.02
Percent Cover of Woody Debris in Understory*(Subreach)	2	Continuous	0.17	3	1.6	0.11
Percent Cover of Woody Debris in Understory*(Subreach)	3	Continuous	-0.05	3	-0.27	0.79

Table 2.11. Results of the general linear mixed model correlating high shrub-nesting species to environmental variables. All effects were fixed. The degrees of freedom for the denominator were 108 for each variable.

Variable	Sub-reach	Variable Type	$\beta$	Numerator DF	t-value	p-value
Year	--	Categorical	1.55	1	1.58	0.12
Subreach	1	Categorical	-1384.26	2	-0.55	0.58
Subreach	2	Categorical	904.83	2	0.41	0.68
Subreach	3	Categorical	< 0.01	2	.	.
Area inundated at 57 cms	--	Continuous	< 0.01	1	0.31	0.76
Area inundated at 101 cms	--	Continuous	< 0.01	1	2.16	0.03
Area inundated at 152 cms	--	Continuous	< 0.01	1	-1.8	0.08
Area inundated at 213 cms*(Subreach)	1	Continuous	< 0.01	3	0.5	0.62
Area inundated at 213 cms*(Subreach)	2	Continuous	< 0.01	3	0.03	0.98
Area inundated at 213 cms*(Subreach)	3	Continuous	< 0.01	3	-0.38	0.71
Percent Cover of Native Overstory*(Subreach)	1	Continuous	0.06	3	0.56	0.58
Percent Cover of Native Overstory*(Subreach)	2	Continuous	< 0.01	3	0.04	0.97
Percent Cover of Native Overstory*(Subreach)	3	Continuous	-0.02	3	-0.45	0.65
Percent Cover of Exotic Overstory*(Subreach)	1	Continuous	-0.11	3	-0.47	0.64
Percent Cover of Exotic Overstory*(Subreach)	2	Continuous	0.02	3	0.13	0.90
Percent Cover of Exotic Overstory*(Subreach)	3	Continuous	0.71	3	0.52	0.61
Percent Cover of Native Understory*(Subreach)	1	Continuous	0.02	3	0.2	0.84
Percent Cover of Native Understory*(Subreach)	2	Continuous	< 0.01	3	0.18	0.86
Percent Cover of Native Understory*(Subreach)	3	Continuous	-0.01	3	-0.05	0.96

Table 2.11 (continued). Results of the general linear mixed model correlating high shrub-nesting species to environmental variables. All effects were fixed. The degrees of freedom for the denominator were 108 for each variable.

<b>Variable</b>	<b>Sub-reach</b>	<b>Variable Type</b>	<b><math>\beta</math></b>	<b>Numerator DF</b>	<b>t-value</b>	<b>p-value</b>
Percent Cover of Exotic Understory*(Subreach)	1	Continuous	0.04	3	1.23	0.22
Percent Cover of Exotic Understory*(Subreach)	2	Continuous	< 0.01	3	-0.06	0.95
Percent Cover of Exotic Understory*(Subreach)	3	Continuous	0.06	3	0.27	0.78
Percent Cover of Rare Woody Species in Understory*(Subreach)	1	Continuous	0.14	3	0.48	0.63
Percent Cover of Rare Woody Species in Understory*(Subreach)	2	Continuous	0.40	3	0.77	0.45
Percent Cover of Rare Woody Species in Understory*(Subreach)	3	Continuous	-0.59	3	-0.3	0.76
Percent Cover of Woody Debris in Understory*(Subreach)	1	Continuous	-0.35	3	-0.56	0.58
Percent Cover of Woody Debris in Understory*(Subreach)	2	Continuous	0.36	3	2.5	0.01
Percent Cover of Woody Debris in Understory*(Subreach)	3	Continuous	0.13	3	0.51	0.61

Table 2.12. Results of the general linear mixed model correlating canopy-nesting species to environmental variables. All effects were fixed. The degrees of freedom for the denominator were 108 for each variable.

<b>Variable</b>	<b>Sub-reach</b>	<b>Variable Type</b>	<b><math>\beta</math></b>	<b>Numerator DF</b>	<b>t-value</b>	<b>p-value</b>
Year	--	Categorical	1.09	1	1.35	0.18
Subreach	1	Categorical	-302.40	2	-0.15	0.88
Subreach	2	Categorical	2183.85	2	1.2	0.23
Subreach	3	Categorical	< 0.01	2	.	.
Area inundated at 57 cms	--	Continuous	< 0.01	1	0.25	0.81
Area inundated at 101 cms	--	Continuous	< 0.01	1	-3.59	<0.01
Area inundated at 152 cms	--	Continuous	< 0.01	1	3.45	<0.01
Area inundated at 213 cms*(Subreach)	1	Continuous	< 0.01	3	2.01	0.05
Area inundated at 213 cms*(Subreach)	2	Continuous	< 0.01	3	-0.4	0.69
Area inundated at 213 cms*(Subreach)	3	Continuous	< 0.01	3	0.87	0.39
Percent Cover of Native Overstory*(Subreach)	1	Continuous	0.31	3	3.3	<0.01
Percent Cover of Native Overstory*(Subreach)	2	Continuous	-0.03	3	-1.27	0.21
Percent Cover of Native Overstory*(Subreach)	3	Continuous	0.06	3	1.68	0.10
Percent Cover of Exotic Overstory*(Subreach)	1	Continuous	-0.59	3	-2.99	<0.01
Percent Cover of Exotic Overstory*(Subreach)	2	Continuous	0.13	3	1.26	0.21
Percent Cover of Exotic Overstory*(Subreach)	3	Continuous	0.75	3	0.65	0.51
Percent Cover of Native Understory*(Subreach)	1	Continuous	-0.11	3	-1.65	0.10
Percent Cover of Native Understory*(Subreach)	2	Continuous	-0.02	3	-1.54	0.13
Percent Cover of Native Understory*(Subreach)	3	Continuous	-0.21	3	-1.16	0.25

Table 2.12 (continued). Results of the general linear mixed model correlating canopy-nesting species to environmental variables. All effects were fixed. The degrees of freedom for the denominator were 108 for each variable.

<b>Variable</b>	<b>Sub-reach</b>	<b>Variable Type</b>	<b><math>\beta</math></b>	<b>Numerator DF</b>	<b>t-value</b>	<b>p-value</b>
Percent Cover of Exotic Understory*(Subreach)	1	Continuous	-0.01	3	-0.27	0.79
Percent Cover of Exotic Understory*(Subreach)	2	Continuous	-0.02	3	-1.28	0.20
Percent Cover of Exotic Understory*(Subreach)	3	Continuous	-0.17	3	-0.98	0.33
Percent Cover of Rare Woody Species in Understory*(Subreach)	1	Continuous	-0.16	3	-0.69	0.49
Percent Cover of Rare Woody Species in Understory*(Subreach)	2	Continuous	0.36	3	0.82	0.41
Percent Cover of Rare Woody Species in Understory*(Subreach)	3	Continuous	-1.02	3	-0.63	0.53
Percent Cover of Woody Debris in Understory*(Subreach)	1	Continuous	-0.20	3	-0.39	0.70
Percent Cover of Woody Debris in Understory*(Subreach)	2	Continuous	0.29	3	2.45	0.02
Percent Cover of Woody Debris in Understory*(Subreach)	3	Continuous	-0.12	3	-0.56	0.58

Table 2.13. Results of the general linear mixed model correlating other nesting species to environmental variables. All effects were fixed. The degrees of freedom for the denominator were 108 for each variable.

Variable	Sub-reach	Variable Type	$\beta$	Numerator DF	t-value	p-value
Year	--	Categorical	-2.18	1	-1.78	0.08
Subreach	1	Categorical	-492.24	2	-0.16	0.88
Subreach	2	Categorical	-669.48	2	-0.24	0.81
Subreach	3	Categorical	< 0.01	2	.	.
Area inundated at 57 cms	--	Continuous	< 0.01	1	0.02	0.99
Area inundated at 101 cms	--	Continuous	< 0.01	1	-1.2	0.23
Area inundated at 152 cms	--	Continuous	< 0.01	1	-0.01	0.99
Area inundated at 213 cms*(Subreach)	1	Continuous	< 0.01	3	1.29	0.20
Area inundated at 213 cms*(Subreach)	2	Continuous	< 0.01	3	0.48	0.63
Area inundated at 213 cms*(Subreach)	3	Continuous	< 0.01	3	1.2	0.23
Percent Cover of Native Overstory*(Subreach)	1	Continuous	-0.05	3	-0.32	0.75
Percent Cover of Native Overstory*(Subreach)	2	Continuous	-0.10	3	-2.78	<0.01
Percent Cover of Native Overstory*(Subreach)	3	Continuous	-0.03	3	-0.6	0.55
Percent Cover of Exotic Overstory*(Subreach)	1	Continuous	-0.01	3	-0.03	0.97
Percent Cover of Exotic Overstory*(Subreach)	2	Continuous	-0.33	3	-2.15	0.03
Percent Cover of Exotic Overstory*(Subreach)	3	Continuous	1.72	3	0.99	0.32
Percent Cover of Native Understory*(Subreach)	1	Continuous	-0.13	3	-1.32	0.19
Percent Cover of Native Understory*(Subreach)	2	Continuous	-0.03	3	-1.36	0.18
Percent Cover of Native Understory*(Subreach)	3	Continuous	-0.21	3	-0.75	0.45

Table 2.13 (continued). Results of the general linear mixed model correlating other nesting species to environmental variables. All effects were fixed. The degrees of freedom for the denominator were 108 for each variable.

<b>Variable</b>	<b>Sub-reach</b>	<b>Variable Type</b>	<b><math>\beta</math></b>	<b>Numerator DF</b>	<b>t-value</b>	<b>p-value</b>
Percent Cover of Exotic Understory*(Subreach)	1	Continuous	-0.06	3	-1.47	0.15
Percent Cover of Exotic Understory*(Subreach)	2	Continuous	-0.01	3	-0.23	0.82
Percent Cover of Exotic Understory*(Subreach)	3	Continuous	-0.18	3	-0.7	0.48
Percent Cover of Rare Woody Species in Understory*(Subreach)	1	Continuous	-0.06	3	-0.15	0.88
Percent Cover of Rare Woody Species in Understory*(Subreach)	2	Continuous	-0.83	3	-1.25	0.21
Percent Cover of Rare Woody Species in Understory*(Subreach)	3	Continuous	-2.63	3	-1.06	0.29
Percent Cover of Woody Debris in Understory*(Subreach)	1	Continuous	-1.26	3	-1.61	0.11
Percent Cover of Woody Debris in Understory*(Subreach)	2	Continuous	0.08	3	0.42	0.68
Percent Cover of Woody Debris in Understory*(Subreach)	3	Continuous	-0.10	3	-0.32	0.75



Table 2.14. Results of the general linear mixed model correlating water-obligate species to environmental variables. All effects were fixed. The degrees of freedom for the denominator were 108 for each variable.

Variable	Sub-reach	Variable Type	$\beta$	Numerator DF	t-value	p-value
Year	--	Categorical	0.09	1	0.16	0.87
Subreach	1	Categorical	170.86	2	0.12	0.91
Subreach	2	Categorical	858.80	2	0.68	0.50
Subreach	3	Categorical	< 0.01	2	.	.
Area inundated at 57 cms	--	Continuous	< 0.01	1	-1.45	0.15
Area inundated at 101 cms	--	Continuous	< 0.01	1	1.67	0.10
Area inundated at 152 cms	--	Continuous	< 0.01	1	0.83	0.41
Area inundated at 213 cms*(Subreach)	1	Continuous	< 0.01	3	-0.73	0.47
Area inundated at 213 cms*(Subreach)	2	Continuous	< 0.01	3	0.26	0.80
Area inundated at 213 cms*(Subreach)	3	Continuous	< 0.01	3	-0.03	0.98
Percent Cover of Native Overstory*(Subreach)	1	Continuous	-0.07	3	-1.1	0.27
Percent Cover of Native Overstory*(Subreach)	2	Continuous	-0.03	3	-1.58	0.12
Percent Cover of Native Overstory*(Subreach)	3	Continuous	-0.04	3	-1.7	0.09
Percent Cover of Exotic Overstory*(Subreach)	1	Continuous	0.06	3	0.43	0.67
Percent Cover of Exotic Overstory*(Subreach)	2	Continuous	-0.04	3	-0.54	0.59
Percent Cover of Exotic Overstory*(Subreach)	3	Continuous	-0.04	3	-0.05	0.96
Percent Cover of Native Understory*(Subreach)	1	Continuous	0.06	3	1.28	0.20
Percent Cover of Native Understory*(Subreach)	2	Continuous	0.03	3	2.9	<0.01
Percent Cover of Native Understory*(Subreach)	3	Continuous	-0.07	3	-0.56	0.58

Table 2.14 (continued). Results of the general linear mixed model correlating water-obligate species to environmental variables. All effects were fixed. The degrees of freedom for the denominator were 108 for each variable.

<b>Variable</b>	<b>Sub-reach</b>	<b>Variable Type</b>	<b><math>\beta</math></b>	<b>Numerator DF</b>	<b>t-value</b>	<b>p-value</b>
Percent Cover of Exotic Understory*(Subreach)	1	Continuous	0.02	3	1.41	0.16
Percent Cover of Exotic Understory*(Subreach)	2	Continuous	0.04	3	3.38	<0.01
Percent Cover of Exotic Understory*(Subreach)	3	Continuous	-0.10	3	-0.83	0.41
Percent Cover of Rare Woody Species in Understory*(Subreach)	1	Continuous	0.23	3	1.41	0.16
Percent Cover of Rare Woody Species in Understory*(Subreach)	2	Continuous	0.11	3	0.35	0.72
Percent Cover of Rare Woody Species in Understory*(Subreach)	3	Continuous	-1.87	3	-1.67	0.10
Percent Cover of Woody Debris in Understory*(Subreach)	1	Continuous	0.24	3	0.68	0.50
Percent Cover of Woody Debris in Understory*(Subreach)	2	Continuous	0.11	3	1.31	0.19
Percent Cover of Woody Debris in Understory*(Subreach)	3	Continuous	-0.08	3	-0.56	0.58
Distance to River	--	Continuous	< 0.01	1	-1.8	0.07

### *Species of Concern*

New Mexico Partner in Flight Species Assessment scores prioritized Bell's vireo, Lucy's Warbler, Black-chinned Hummingbird, Western Yellow-billed Cuckoo, and Summer Tanager as species of concern (New Mexico Partners in Flight 2007). Although only tested within each nested subreach, the following correlations likely existed where these hydrogeomorphic and

vegetative conditions occurred at the point count site level in other subreaches. Bell's Vireos were positively correlated with native understory on Subreach 2 ( $\beta = 0.02$ ;  $DF = 3, 108$ ;  $t = 3.13$ ;  $p < 0.01$ ) and woody debris in the understory on Subreach 2 ( $\beta = 0.12$ ;  $DF = 3, 108$ ;  $t = 2.66$ ;  $p < 0.01$ ). Lucy's Warblers were positively correlated with areas that inundated at 152 cms ( $\beta < 0.01$ ;  $DF = 1, 108$ ;  $t = 2.15$ ;  $p = 0.03$ ), areas that inundated at 213 cms on Subreach 3 ( $\beta < 0.01$ ;  $DF = 3, 108$ ;  $t = 2.87$ ;  $p < 0.01$ ), exotic understory on Subreach 2 ( $\beta = 0.01$ ;  $DF = 3, 108$ ;  $t = 2.18$ ;  $p = 0.03$ ), and rare woody understory species on Subreach 2 ( $\beta = 0.33$ ;  $DF = 3, 108$ ;  $t = 2.30$ ;  $p = 0.02$ ); Lucy's Warblers were negatively correlated with native understory on Subreach 3 ( $\beta = -0.19$ ;  $DF = 3, 108$ ;  $t = -3.10$ ;  $p < 0.01$ ), exotic understory on Subreach 3 ( $\beta = -0.17$ ;  $DF = 3, 108$ ;  $t = -3.01$ ;  $p < 0.01$ ), rare woody understory species on Subreach 3 ( $\beta = -1.29$ ;  $DF = 3, 108$ ;  $t = -2.39$ ;  $p = 0.02$ ), and woody debris on Subreach 3 ( $\beta = -0.17$ ;  $DF = 3, 108$ ;  $t = -2.48$ ;  $p = 0.01$ ).

Black-chinned Hummingbirds were negatively correlated with areas flooded at 152 cms ( $\beta < -0.01$ ;  $DF = 1, 108$ ;  $t = -2.98$ ;  $p < 0.01$ ) and exotic understory on Subreach 2 ( $\beta = -0.03$ ;  $DF = 3, 108$ ;  $t = -4.07$ ;  $p < 0.01$ ). Western Yellow-billed Cuckoos were positively correlated with areas that flooded at 101 cms ( $\beta < 0.01$ ;  $DF = 1, 108$ ;  $t = 3.06$ ;  $p < 0.01$ ) and negatively correlated with areas that inundated at 52 cms ( $\beta < -0.01$ ;  $DF = 1, 108$ ;  $t = -3.59$ ;  $p < 0.01$ ). Summer Tanagers were positively correlated with native overstory on Subreach 1 ( $\beta = 0.13$ ;  $DF = 3, 108$ ;  $t = 3.16$ ;  $p < 0.01$ ) and Subreach 3 ( $\beta = 0.04$ ;  $DF = 3, 108$ ;  $t = 2.28$ ;  $p = 0.02$ ).

## **2.4 DISCUSSION**

### **2.4.1 Hydrogeomorphology and Vegetation**

Based on previous studies, I expected strong longitudinal and lateral patterns in vegetation species composition because of subreach differences in channel incision and lateral differences in flood frequency, respectively. I did observe differences in vegetation communities laterally and among subreaches; however, the dominant plant community type throughout all reaches was tamarisk. Furthermore, I expected native overstory to be greater in Subreach 2 as it is an aggrading reach with more frequent flooding than the incised Subreaches 1 and 3. However, native overstory did not vary as expected as Subreach 3 had more native overstory than Subreaches 1 and 2 (Table 2.7). These findings are a result of conditions necessary for establishment and survival of native species as well as temporal asynchrony between hydrogeomorphic conditions and overstory composition. Native vegetation species require overbank flooding, geomorphic disturbance, and shallow groundwater for establishment (Stromberg et al. 1996; Johnson 2000; Levine and Stromberg 2001, Brand et al. 2008), all of which are negatively affected by surface water diversions and channel incision (Stromberg et al. 1996; Scott et al. 2000; Merritt et al. 2010). This finding indicates that although hydrogeomorphic differences exist among subreaches, no subreach is unaltered and all have been affected by the hydrologic and geomorphic changes on the Middle Rio Grande (Crawford et al. 1993; Molles et al. 1998; Brand et al. 2013).

Although all subreaches were affected by hydrogeomorphic changes, vegetation was structured, to some degree, along a lateral gradient and among subreaches. Laterally, native overstory, exotic overstory, and native understory were negatively associated with distance from the river, indicating that the hydrogeomorphic conditions near the river were conducive to the

establishment and survival of these species. Sites closer to the river typically receive more frequent hydrologic and geomorphic disturbances and have higher groundwater tables, all of which are conducive to establishment of native species (Stromberg et al. 1996; Johnson 2000; Levine and Stromberg 2001, Brand et al. 2008; Hultine et al. 2010; Caplan et al. 2013). Past studies also indicate that once native species are established, they can effectively compete with exotic species provided groundwater and surface water conditions continue to be conducive for survival (Stromberg et al. 1996; Cleverly and Dello Russo 2007). In the incised Subreaches 1 and 3, the lateral distribution of native species was more compressed than in Subreach 2, but native species were still able to establish and persist along the river banks, at the more hydrogeomorphically active sites. Because Subreaches 1 and 3 have less hydrogeomorphically active sites than Subreach 2 (Table 2.5), it is not surprising that these subreaches had lower percent cover of native understory than Subreach 2 (Table 2.7). Furthermore, exotic understory was not associated with distance from the river, indicating that exotic tamarisk does not require the shallow depth to groundwater found near the banks of the river to persist (Stromberg et al. 1996; Horton et al. 2001; Stromberg et al. 2007).

I also found distinct differences in hydrologic conditions and vegetation communities among subreaches (Table 2.7 and Figure 2.3). Specifically, native overstory was statistically greater in Subreach 3 than in Subreaches 1 or 2. This finding indicates that even along incised reaches, native plants can persist, leading to temporal asynchrony of hydrogeomorphic conditions and vegetation, specifically along Subreaches 1 and 3. While hydrogeomorphic changes can be so dramatic that overstory trees quickly die off, less extreme hydrogeomorphic changes can allow for survival of native overstory and lead to a legacy effect (Katz et al. 2005; Dufour and Piégay 2008; Greene and Knox 2014). Subreaches 1 and 3 exemplify this legacy

effect as native tree species persist along these incised subreaches, reflecting hydrogeomorphic conditions approximately 20 to 80 years ago when these trees became established. For instance, the unanticipated large amount of native overstory found along Subreach 3 can be explained by past hydrogeomorphic conditions. Subreach 3 is just north of Elephant Butte Reservoir, and the area was colonized by willows in the late 1990s as the reservoir levels receded (Ahlers et al. 2010b). However, due to headcutting that noticeably began in 2004 (Holste et al. 2011; Holste 2013), the channel on this subreach is rapidly incising and areas that once supported vigorous stands of willows have begun converting to stands of exotic tamarisk (personal observation) as overbank flooding rarely occurs now (Ahlers et al. 2010b).

When compared, these three distinct subreaches provide valuable information on the various effects that hydrogeomorphic conditions have on riparian vegetation. Although all subreaches have been hydrogeomorphically affected by anthropogenic regulation and are consequently dominated by exotic tamarisk, the second and third plant communities along each subreach differ and provide valuable information on the effects that various hydrogeomorphic conditions have on riparian vegetation. Native coyote willow stands along Subreach 2 indicate that native species can establish and thrive when lateral hydrologic connectivity remains intact and the channel is not incised. Subreach 3 exhibits hydrologic conditions intermediate of Subreach 1 and 2 as this subreach continues to incise; thus, the native overstory with exotic species or woody debris (primarily dead coyote willow that could not survive groundwater declines) in the understory reflect the effects of rapid channel incision. Finally, dense Russian olive and legacy cottonwoods found along Subreach 1 indicate which vegetative species can persist along a severely incised channel.

### 2.4.2 Hydrogeomorphology, Vegetation, and Birds

At some sites, our avian relative abundance estimates were relatively high compared to some studies (Rumble and Gobeille 2004; Mcfarland et al. 2012); however, Brand et al. (2010) found similar avian densities along the San Pedro River. There are several reasons that account for the high avian relative abundances ( $> 40$  individuals) detected at some sites. First, groups of several species (House Finch, Bushtit, and Brown-headed Cowbird) were detected at these sites, thus inflating the relative abundance estimates. Second, our survey period extended in to mid-August when family groups may have been detected, thus inflating the number of individuals detected at a site. Also, observer visibility was high at these sites, thus potentially increasing number of individuals detected at these sites as compared to sites with dense vegetation and limited visibility. Therefore, a visibility covariate was included in the Royle's (2004) N-mixture models to account for sites with high visibility. Furthermore, at two of the sites where avian relative abundance was estimated at  $> 40$  individuals, there were two distinct habitat types that supported different avian species: mature cottonwood overstory with a sparse tamarisk and *Kochia* understory (Hink and Ohmart class: Cottonwood / Salt Cedar – *Kochia* 2), and dense tamarisk understory with no overstory (Hink and Ohmart class: Salt Cedar 5). Additionally, as stated above, Royle's (2004) N-mixture models estimate number of individuals that use a site, rather than true site density (Joseph et al. 2009). Therefore, the abundance estimates used are relative abundance estimates of the number of individuals present at the site throughout the sample period.

The results of this study indicate that avian guilds and priority conservation species responded to hydrogeomorphic conditions and resulting vegetative differences. Canopy-nesting birds require native overstory (Hunter et al. 1987; Scott et al. 2003; Brand et al. 2011); therefore,

this guild is sensitive to hydrogeomorphic changes as native overstory species, such as cottonwood and Goodding's willow, require overbank flows to germinate and establish (Stromberg et al. 1996; Brand et al. 2011). Species within the canopy-nesting guild were more abundant along Subreach 3 in plots close to the river, where native overstory percent cover was high. While vegetation clearly influenced canopy-nesting guilds along Subreaches 1 and 2, canopy nesters were occasionally detected at sites without native overstory; however, native overstory was present nearby, outside the sampling plot.

Water-obligate species are also sensitive to hydrogeomorphic conditions as they require close proximity to surface water (Brand et al. 2011) and were most abundant at sites adjacent to the river. Other guilds that utilize understory vegetation, such as ground-nesting birds and low shrub-nesting birds, are less sensitive to hydrogeomorphic changes as they do not rely on native understory, but can use exotic understory or woody debris (Brand et al. 2011). Historically, species in the ground-nesting and low shrub-nesting guilds nested in dense stands of early successional vegetation (Brown 1993, Eckerle and Thompson 2001), but where altered hydrogeomorphic conditions have led to decreased recruitment of cottonwood/willow and an increase in tamarisk, species in these guilds have been documented using tamarisk (Ellis 1995; Sogge et al. 2008). Some studies have found an increase in density of ground and shrub-nesting species with an increase in tamarisk cover (Ellis 1995; Brand et al. 2011). Species in the miscellaneous nesting height guild, such as Mourning Dove and Northern Mockingbird, are not sensitive to hydrogeomorphic changes as they are negatively correlated with native overstory. Because canopy-nesting birds and water-obligate species are sensitive to hydrogeomorphic changes, these two guilds can be used as indicators of riparian condition in southwestern river ecosystems (Rich 2002; Brand et al. 2011).



There are some species within the above guilds that have experienced population decline and are considered species of concern; these species are Bell's vireo, Lucy's Warbler, Black-chinned Hummingbird, Western Yellow-billed Cuckoo, and Summer Tanager (New Mexico Partners in Flight 2007). Results of our analysis show that, in various ways, all five of these species are sensitive to hydrogeomorphic changes. Because Bell's Vireos require native understory and Summer Tanagers need native overstory, these species are sensitive to hydrogeomorphic changes (Brand et al. 2011) as native vegetation, such as coyote willow, cottonwood, and Goodding's willow, require geomorphic disturbance and surface floods for establishment and shallow groundwater to persist (Stromberg et al. 1996; Johnson 2000; Levine and Stromberg 2001, Brand et al. 2008; Hultine et al. 2010; Caplan et al. 2013).

Lucy's Warblers and Western Yellow-billed Cuckoos are also sensitive to hydrogeomorphic changes as they require native overstory (Carothers et al. 1974; Ahlers et al. 2010b; Johnson et al. 2012) and were correlated with sites that were inundated at moderate to high flows (101 - 213 cms). Because Black-chinned Hummingbirds were negatively correlated with exotic understory, they are sensitive to hydrogeomorphic changes as anthropogenic regulation of the Middle Rio Grande has allowed for extensive replacement of native riparian vegetation by homogenous stands of exotic tamarisk (Johnson 2000; Levine and Stromberg 2001).

### **2.4.3 Conclusions**

The San Acacia Reach of the Middle Rio Grande is highly modified, resulting in vegetative shifts from native cottonwood/willow forests to exotic tamarisk stands. This is reflected as invasive tamarisk was the dominant species in all 3 subreaches (Table 2.6 and Figure

2.3). Even along Subreach 2, where surface flooding is most active, exotic understory was the most dominant plant cover (40%) (Table 2.7). The unanticipated low cover of native vegetation along Subreach 2 could be related to increased depths to groundwater and/or the presence of exotic understory that is preventing native species establishment. For instance, 31% of inundated plots at 152 cms (a 5 year flood) along Subreach 2 supported dense tamarisk (Hink and Ohmart class: Salt Cedar 5). If tamarisk was not present at these sites, native vegetation could be established during these high flow events. While Subreach 2 has the highest restoration potential as overbank flooding is most active along this subreach, dense tamarisk must be removed first to allow native species establishment. Because surface flooding is limited along incised Subreaches 1 and 3, restoration efforts must include bank modification (e.g., lowering bank height, removal of root armoring) as well as tamarisk removal prior to surface flooding to promote native vegetation recruitment.

This research has increased understanding of songbird responses to vegetation and the limitations of hydrology and geomorphology in a semi-arid system. By delineating the geomorphic and hydrologic differences among subreaches of the San Acacia Reach, I was able to compare vegetative and songbird communities in different hydrogeomorphic settings. Results suggest that maintaining or increasing overbank flows would enhance avian relative abundance, particularly in Bell's Vireos, Black-chinned Hummingbirds, Summer Tanagers, Western Yellow-billed Cuckoos, Lucy's Warblers, and other canopy-nesting species, as overbank flows promote establishment and survival of native overstory and understory (Stromberg et al. 1996; Johnson 2000; Levine and Stromberg 2001, Brand et al. 2008; Caplan et al. 2013). Even along incised subreaches, I found legacy cottonwood and Goodding's willow trees that provide suitable habitat for canopy-nesting birds now and in the near future. However, incised channels do not well

support regeneration of cottonwood and Goodding's willow as overbank flows occur less frequently along incised reaches (Stromberg et al. 1996; Katz et al. 2005; Stromberg et al. 2007). Therefore, incised subreaches with legacy trees provide suitable habitat for canopy-nesting birds now and in the near future, but these habitat conditions are not sustainable long-term. If riparian restoration is not done along incised subreaches to increase surface flooding and regeneration of native tree species, existing native overstory will eventually die-off, resulting in a decline of canopy-nesting birds and species of concern, such as the Western Yellow-billed Cuckoo and Lucy's Warbler.

Based on findings of previous studies, surface flooding alone may be insufficient to support native vegetation as depth to groundwater has a strong influence on regeneration of cottonwood and Goodding's willow and can strongly affect tree growth, stress, and survival (Stromberg et al. 1996; Horton et al. 2001; Brand et al. 2010; Brand et al. 2011). As increased depths to groundwater is a pressing issue along the Middle Rio Grande (Bowman 2007), future research should assess and integrate groundwater processes to enhance our understanding of water, vegetation, and avian community linkages.

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## **CHAPTER 3**

# **HABITAT ASSESSMENT OF THE WESTERN YELLOW-BILLED CUCKOO ALONG THE MIDDLE RIO GRANDE OF NEW MEXICO**

### **3.1 INTRODUCTION**

Riparian ecosystems in the semiarid and arid southwestern United States support some of the highest avian species richness and density in temperate North America (Brand et al. 2008). However, a lack of legal protection coupled with human population growth and subsequent increased demands for groundwater and surface water severely threaten these biodiverse ecosystems (Stromberg et al. 1996; Brand et al. 2011).

Groundwater and stream withdrawals have contributed to the loss and alteration of wetland and riparian ecosystems throughout the Southwest (Levine and Stromberg 2001). Water control structures such as diversions, levees, and dams modify flood frequency and duration, surface flow rates, and sediment and nutrient transport (Levine and Stromberg 2001; Hoover 2009). Additionally, channelization of rivers has led to channel incision, further altering the depth, timing, duration, and frequency of flooding (Scott et al. 2000; Merritt et al. 2010). Such radical changes in the hydrogeomorphology of southwestern rivers have led to the degradation of riparian corridor habitat as the native vegetation and wildlife have evolved to cope with the dynamic flows of rivers (Stromberg et al. 1996; Scott et al. 2000; Merritt et al. 2010). Thus, information on population estimates of endangered species and the factors influencing their decline are important for conservation planning and management (Salafsky et al. 2002; Battisti et al. 2008; Onmus and Siki 2013).

The Western Yellow-billed Cuckoo (*Coccyzus americanus occidentalis*) is a breeding riparian obligate species that depends on western riparian forests for breeding

(Halterman 2004). Currently, however, the species is experiencing long term population decline and extirpation throughout much of its historic distribution (British Colombia to Mexico) as native riparian forests are replaced by exotic tamarisk (*Tamarix* spp.) stands due to anthropogenic hydrologic alterations of major western rivers (Laymon and Halterman 1987; Yong and Finch 1997; Halterman et al. 2000; Johnson 2000; Levine and Stromberg 2001; Schmidt-Petersen 2007; Sechrist et al. 2009). In 2001, the western subspecies was declared a distinct population from the eastern subspecies (*Coccyzus americanus americanus*); thus, petitioning began to list the Western Yellow-billed Cuckoo under the Endangered Species Act of 1973 (USFWS 2003). While it was found that the species warranted listing, it was precluded by higher priority species (Sechrist et al. 2009).

Presently, the species is a candidate for listing under the Endangered Species Act and is listed as endangered, threatened, or sensitive by the states of Utah, New Mexico, Arizona, Colorado, and California (Sechrist et al. 2009). Reaches of major rivers in Arizona and New Mexico support some of the largest remaining tracts of contiguous native or mixed native riparian habitat in the U.S. Southwest (Sechrist et al. 2009; Ahlers et al. 2010). These areas are considered significant strongholds for Western Yellow-billed Cuckoos (Hughes 1999; Lehman and Walker 2001), with particular emphasis on the Middle Rio Grande (MRG) of New Mexico (Johanson et al. 2006, Johanson et al. 2007; Sechrist et al. 2009). As Goodding's willow (*Salix gooddingii*) and cottonwood (*Populus deltoides*) comprise the native overstory that Western Yellow-billed Cuckoos need (Hughes 1999; Sechrist et al. 2009), the decline in recruitment of these vegetation species has significant implications for the cuckoo (Ahlers et al. 2010).

Despite unfavorable conditions for native vegetation recruitment and establishment along much of the MRG, native riparian forest became established in Elephant Butte Reservoir as the reservoir water levels receded from 1995 to 2003, creating ideal conditions for native vegetation establishment (Stromberg et al. 1996; Johnson 2000; Levine and Stromberg 2001, Brand et al. 2008; Ahlers et al. 2010). In a radio telemetry study, Sechrist et al. (2009) found that native canopy with either exotic, native, or mixed understory is important to Western Yellow-billed Cuckoo nest site selection. Additionally, Sechrist et al. (2009) noted that breeding Western Yellow-billed Cuckoos need to be within 400 meters of surface water. As Elephant Butte Reservoir continues to support large stands of native Goodding's willow dominated riparian forest and has a large area of surface water, cuckoos densely populate the area north of Elephant Butte Reservoir and within the exposed conservation pool of Elephant Butte Reservoir during the breeding season (Ahlers et al. 2010; Ahlers et al. 2013). However, riparian and wetland habitats are dynamic and surface water availability varies from year to year (Kantrud and Stewart 1984); therefore, it is possible that, on a local scale, cuckoos densely populate different areas from year to year.

As the Western Yellow-billed Cuckoo is a rare and secretive species, obtaining accurate population estimates is a challenge; therefore, vocalization playback survey is the accepted method for estimating breeding population numbers (Haltermann 2002; Johanson et al. 2006; Johanson et al. 2007; Sechrist et al. 2009). The U.S. Bureau of Reclamation has conducted Western Yellow-billed Cuckoo playback surveys along the MRG of New Mexico since 2006 (Ahlers et al. 2010; Ahlers et al. 2013). The Bureau of Reclamation then compiled each year of survey data into a Geographical Information

System (GIS) shape file where each cuckoo detection is assigned spatial coordinates, thus enabling scientists to use spatial statistics to analyze the data.

The use of spatial statistics to analyze spatial data for patterns and/or the delineation of hot spots is a useful tool (Saxena et al. 2012) that may have application to Western Yellow-billed Cuckoo data in the MRG. Spatial statistics are often utilized in epidemiology studies to determine the distribution and intensity of disease occurrence (Saxena et al. 2012), but such analyses are also useful in ecology studies as they elucidate spatial patterns and distributions of species (Mueller-Warrant et al. 2008; Singh et al. 2010). Spatial autocorrelation analysis using Global Moran's I Index is used to identify spatial patterns as clustered, random, or dispersed (Saxena et al. 2012). Hot spot analysis is used to determine the intensity of spatial clusters by calculating the Getis-Ord  $G_i^*$  statistic for each feature in the data set (Mitchell 2005; Mueller-Warrant et al. 2008). Hot spot analysis has been used in wildlife roadkill studies to determine areas of intense wildlife-human conflict and recommend management strategies, such as construction of overpasses at wildlife crossings, to reduce wildlife-human conflict (Wilson 2012). Hot spot analysis has also been implemented in conservation efforts of endangered species by identifying areas of intense use and protecting these areas from disturbance (Singh et al. 2010; McFarland et al. 2013). Identification of hot spots, and cold spots, in the MRG could provide important insights into the biotic and abiotic processes that structure Western Yellow-billed Cuckoo population distributions in the region.

The objectives of this study are to: 1) determine the spatial pattern (dispersed, random, or clustered) of Western Yellow-billed Cuckoo detections within the San Acacia Reach of the MRG, 2) if the spatial pattern is clustered, identify hot spots (areas of

clustered Western Yellow-billed Cuckoo detections) and cold spots (areas of suitable habitat where Western Yellow-billed Cuckoos were not detected), and 3) determine hydrologic conditions and vegetative characteristics of hot spots versus cold spots in wet years and dry years. For this study, suitable Western Yellow-billed Cuckoo habitat was defined as mature cottonwood overstory with a dense understory, intermediate aged cottonwood overstory with a dense understory, mature Goodding's willow with a dense understory, intermediate aged Goodding's willow with a dense understory, a mixed mature cottonwood-Goodding's willow overstory with a dense understory, and a mixed intermediated aged cottonwood-Goodding's willow overstory with a dense understory (Sechrist et al. 2009). I predict that: 1) the spatial pattern of cuckoos is clustered at the annual level, 2) hot spots occur near the river channel in stands of native overstory and dense understory that are occasionally flooded, and 3) more hot spots occur in wet years than dry years.

### **3.1.1 Study Area**

This study was conducted in the San Acacia Reach of the Middle Rio Grande of New Mexico within the active floodplain of the Rio Grande from the San Acacia Diversion (river mile 116) to the full pool boundary of Elephant Butte Reservoir (river mile 62). The San Acacia Reach is unique because, although altered by valley infrastructure, there are two uncontrolled tributaries that input sediment and water during summer monsoon storm events. In addition, the spring hydrograph maintains the historic timing although magnitude and duration of flows have been altered. These processes result in a dynamic river (in certain subreaches) that supports one of the largest continuous stretches of native riparian habitat, specifically cottonwood, Goodding's

willow, and coyote willow (*Salix exigua*), and associated wildlife (Ahlers et al. 2010). The reach is significant due to population status and occurrence of the federally endangered Rio Grande silvery minnow (*Hybognathus amarus*) and Southwestern Willow Flycatcher (*Empidonax traillii extimus*), and candidate species, the Western Yellow-billed Cuckoo and the New Mexico meadow jumping mouse (*Zapus hudsonius luteus*) (U.S. Fish and Wildlife Service 2003; Ahlers et al. 2010; U.S. Fish and Wildlife Service 2013). Land management in the reach includes two National Wildlife Refuges (Sevilleta National Wildlife Refuge and Bosque del Apache National Wildlife Refuge), U.S. Bureau of Reclamation river maintenance, and numerous private lands with opportunities for habitat protection and improvement partnerships.

### **3.2 METHODS**

From 2007 to present, the Bureau of Reclamation conducted Western Yellow-billed Cuckoo (hereafter referred to as cuckoo) surveys throughout the entire active floodplain of the San Acacia Reach with the aid of playback. Beginning in 2009, four sample periods were used: June 15<sup>th</sup> to late June; early July to mid-July; mid-July to late July; and early August to August 15<sup>th</sup>. ArcGIS shape files depicting the location of detected cuckoos for each year from 2007 to 2012 were created by the Bureau of Reclamation and made available for this study. To evaluate my hypotheses, I used cuckoo presence/absence survey data, spatial statistics in ArcGIS 10, and vegetation and hydrology data.

### **3.2.1 Determining Spatial Pattern of Cuckoo Occurrences**

#### *Aggregation of Incident Data*

For robust results, spatial autocorrelation analysis and Global Moran's I require more than zeroes and ones as responses. Therefore, ArcGIS 10 Fishnet tool was used to construct grid cells across the study area to aggregate cuckoo presence/absence data (ones and zeros) into larger numbers. I used the Fishnet Tool to create a grid that exclusively covered the study area (Figure 3.1). I then used a spatial join to join each year of cuckoo survey data to the fishnet grid. This created a new shape file that contained the number of cuckoo locations per cell, thus aggregating the incident data. Several grid sizes were tested, including 30 m X 30 m, 100 m X 100 m, 250 m X 250 m, before settling on a 500 m X 500 m grid size; smaller grid sizes contained too many zeros and ones for a robust fit. To assess the spatial pattern of cuckoo detections within a year (by sample period), I aggregated the presence/absence data at a 2,500 m X 2,500 m grid size as smaller grid sizes did not sufficiently aggregate the data.

#### *Spatial Autocorrelation*

To determine if the spatial pattern of the cuckoo locations was dispersed, random, or clustered across years and within a year, I used the spatial autocorrelation tool in ArcGIS 10 (Saxena et al. 2012). The tool calculates a Moran's I Index value and a z-score and p-value to assess statistical significance (Saxena et al. 2012). I used an 'inverse distance' with no threshold for the Conceptualization of Spatial Relationships. This method was the most ecologically sound choice due to the large variability in home ranges (5 to 282 ha) of the cuckoo (Sechrist et al. 2009), their lack of territoriality, and the paucity of published data on their movement patterns.





Figure 3.1. Clipped fishnet shape file that exclusively covers the surveyed area (the floodplain).

### **3.2.2 Hot Spot Analysis**

To identify statistically significant hot spots and cold spots of each year of data, I used hot spot analysis and Getis-Ord  $G_i^*$  statistic on the aggregated cuckoo data at the 500 m<sup>2</sup> scale (Saxena et al. 2012). However, to identify statistically significant hot spots and cold spots within a year (by sample period), I used hot spot analysis and Getis-Ord  $G_i^*$  statistic on the aggregated cuckoo data at the 2,500 m<sup>2</sup> scale (Saxena et al. 2012). I used an 'inverse distance' with no threshold for the Conceptualization of Spatial Relationships. Hot spot analysis calculates the Getis-Ord  $G_i^*$  statistic for each feature in the data set. The resultant z-scores and p-values indicate where features with low or high values cluster spatially. This tool functions by assessing each feature within the context of neighboring features. For instance, a feature with a high value is noteworthy but may not be a statistically significant hot spot. In order to be a statistically significant hot spot, a feature must have a high value and be surrounded by other features with high values. In hot spot analysis, the local sum for a feature and its neighbors is compared proportionately to the sum of all the features in the dataset. A statistically significant z-score results when the local sum is different from the expected local sum, and that difference is too large to be the result of random chance (ESRI 2012).

### **3.2.3 Site Selection**

Habitat assessment was conducted based on the 500 m<sup>2</sup> hot and cold spots found using cuckoo detections for an entire year. To assess the effects of relatively wet years and dry years on Western Yellow-billed Cuckoo habitat selection, data from the river gauge at San Marcial, the southernmost river gauge of the study site, was compiled for years 2007 – 2012. For each year, daily mean discharge values were totaled from May

15 to August 17. Although the cuckoo is present along the San Acacia Reach from late May to mid-August (Halterman et al. 2000; Ahlers et al. 2010), discharge data was used from mid-May to account for any individuals who may have arrived early. The total discharge from May 15 to August 17 of each year was then used to determine the relative wet and dry years from 2007 – 2012 (Table 3.1). The two wettest and driest years were used to determine Western Yellow-billed Cuckoo response in extreme conditions. The wettest years were 2008 and 2009, while 2011 and 2012 were the driest years. Eight 500 m<sup>2</sup> hot spots and cold spots were then selected for dry years and wet years.

The eight highest z-scores were used to determine the hot spots for wet years and dry years. Cold spots were selected by first ranking plots by greatest amount of suitable Western Yellow-billed Cuckoo habitat per 500 m<sup>2</sup> cell. Then, the z-scores of those plots were compared. Statistical cold spots were defined as cells that had negative z-scores within 0.05 of the lowest z-score in the data set. Finally, 75% of the 500 m<sup>2</sup> cell had to be in the floodplain to be selected as a cold spot. Thus, cold spots were areas of suitable but unused Western Yellow-billed Cuckoo habitat.

Table 3.1. Total mean discharge (cms) at the river gauge at San Marcial from May 15 to June 30 and from May 15 to August 17 of 2007 – 2012.

<b>Year</b>	<b>Total Mean Discharge (cms) from May 15 to June 30</b>	<b>Total Mean Discharge (cms) from May 15 to August 17</b>
2007	1,391	1,481
2008	3,261	4,399
2009	2,750	3,056
2010	1,405	1,704
2011	225	307
2012	80	161

### 3.2.4 Field Data Collection

Vegetation surveys were conducted at selected 500 m<sup>2</sup> hot spots and cold spots from wet years and dry years to determine vegetative characteristics of hot spots versus cold spots. At each hot spot and cold spot, data were collected at 36 regularly spaced points to determine species composition, stand structure, stem density, and visual obstruction of the vegetative community. At each data point, observers estimated the percent cover of the four most dominant overstory (> 4.5 m) species and the four most dominant understory (0.6 m to 4.5 m) species within a 10 m radius circle of the data point. Observers also estimated percent of total stems alive of each species (hereafter referred to as “percent live”). Percent cover and percent live were estimated in increments of five. Stand structure was classified using Hink and Ohmart (1984) structure classes (Table 3.2). Hink and Ohmart (1984) structure classes categorize communities into six broad structure types, allowing for high structural variability within a given classification. Therefore, observers also recorded stem density and visual obstruction data to further refine the broad Hink and Ohmart classifications (see Chapter 4). The number of woody stems and *Kochia* > 1.37 m tall was recorded in four classes: Class 1 is 0 – 500 woody stems; class 2 is 500 – 1,000 woody stems; class 3 is 1,000 – 3,500 woody stems; class 4 is over 3,500 woody stems. Visual obstruction was measured using a modified method of Robel et al. (1970). We positioned a piece of letter-sized paper 1.68 m above the ground and estimated the percent of the paper that was obstructed by vegetation when viewed from 5 m away. Visual obstruction measurements were taken in each cardinal direction.

Table 3.2. Hink and Ohmart (1984) vegetation structure classes.

Structure Class	Description
1	Vegetation in all foliage layers, with trees reaching 50 to 60 ft. Mature to mixed age class stands. 25% or greater of understory is vegetated.
2	Mature stands of trees up to 50 to 60 ft tall, with most of the foliage in the canopy layer > 30 ft. Sparse, patchy understory and little herbaceous growth.
3	Intermediate age stand with a thick understory. Dense vegetation up through about 30 ft, but little above 30 ft. 25% or greater of understory is vegetated.
4	Relatively open stands of intermediate-age stands. Most of the foliage was between 20 and 40 ft. Shrubs widely spaced and herbaceous growth is sparse.
5	Dense vegetation at about 10 or 15 ft high, often including a thick layer of grass and annuals. Some taller trees scattered throughout.
6	Low and relatively sparse herbaceous and/or shrubby vegetation, with most foliage below 5 ft.

### 3.2.5 Hydrology Data

To determine the surface hydrologic conditions of 500 m<sup>2</sup> hot spots and cold spots, I used hydrology data derived from the 2006 Rio Grande channel planform mapping data (Makar and AuBuchon 2012) and the FLO2D modeling output from the Upper Rio Grande Water Operations Model (Tetra Tech 2002). Four peak flow levels out of Cochiti Dam (River Mile 232.6) were used to represent different flood events: inundation of active bars at 57 m<sup>3</sup>/s (cms), a low flood event at 101 cms, a moderate flood event at 152 cms, and a high flood event at 213 cms (Remshardt and Tashjian 2005). Area (m<sup>2</sup>) inundated at each site was calculated for each flow level and used in analyses.

### **3.2.6 Analysis of Field Data**

I used logistic regression to analyze the relationship among environmental variables and the predicted occurrence of a hotspot (PROC GENMOD in SAS 9.3). Variables included: percent cover of the three most dominant overstory and understory species, percent cover of overstory and understory that is not vegetated, wet year or dry year as defined above, visual obstruction of the understory, the six existing Hink and Ohmart (1984) structure classes (Table 3.2), the four woody stem density categories defined above, and area inundated of 500 m<sup>2</sup> hot spot or cold spot at four different flows: 57 cms, 101 cms, 152 cms, and 213 cms. Thresholds were then calculated of variables that were deemed important in predicting a hot spot. Thresholds were determined by the inverse logit ( $\alpha$  hat/  $\beta$  hat) of the parameter estimate for each variable.

## **3.3 RESULTS**

### **3.3.1 Spatial Autocorrelation**

The spatial pattern of cuckoo detections within a sample period varied from clustered to random; two sample periods were highly clustered ( $p < 0.01$ ) (Table 3.3). The least clustered sample period was the first sample period (June 15 to late June) in 2010 (Moran's Index = 0.120, z-score = 3.87) and the most highly clustered sample period was the second sample period in 2010 (Moran's Index = 0.131, z-score = 3.93) (Table 3.3).

In 2007, there were 79 cuckoo detections; in 2008, there were 97 cuckoo detections. In 2009, there were 136 cuckoo detections, while in 2010 there were 49 cuckoos detected. In 2011, there were 74 cuckoos detected, and in 2012 there were 154 cuckoo detections. The number of cuckoos detected each year within a 500 m<sup>2</sup> cell is

shown in Table 3.4. All 6 years of cuckoo detection data were highly clustered ( $p < 0.01$ ) (Table 3.5). The least clustered year was 2007 (Moran's Index = 0.02, z-score = 3.66) and the most highly clustered year was 2010 (Moran's Index = 0.06, z-score = 12.20). The range of statistical variance from year to year is very small, ranging from 0.000025 to 0.000028.

Table 3.3. Summary of statistical results from spatial autocorrelation analysis of cuckoo detection data at the sample period level from 2009 to 2012.

Year	Sample Period	Moran's Index	Expected Index	Variance	z-score	p-value
2009	1	0.026	-0.017	0.0013	1.18	0.24
2009	2	-0.029	-0.017	0.0015	-0.30	0.76
2009	3	0.062	-0.017	0.0013	2.18	0.03
2009	4	0.039	-0.017	0.0014	1.49	0.14
2010	1	0.120	-0.017	0.0013	3.87	<0.01
2010	2	0.131	-0.017	0.0014	3.93	<0.01
2010	3	0.033	-0.017	0.0013	1.39	0.16
2010	4	-0.004	-0.017	0.0005	0.59	0.56
2011	1	0.010	-0.017	0.0013	0.74	0.46
2011	2	0.027	-0.017	0.0007	1.70	0.09
2011	3	0.033	-0.017	0.0013	1.37	0.17
2011	4	-0.028	-0.017	0.0012	-0.32	0.75
2012	1	-0.005	-0.017	0.0014	0.31	0.75
2012	2	-0.008	-0.017	0.0015	0.25	0.80
2012	3	0.027	-0.017	0.0015	1.14	0.25
2012	4	0.028	-0.017	0.0015	1.17	0.24

Table 3.4. Number of cuckoo detections per 500 m<sup>2</sup> cell of each year.

Number of Cuckoos per Cell	Number of Plots in 2007	Number of Plots in 2008	Number of Plots in 2009	Number of Plots in 2010	Number of Plots in 2011	Number of Plots in 2012
0	514	508	479	528	515	466
1	39	38	60	29	38	61
2	9	10	16	7	7	30
3	2	4	6	2	3	7
4	1	5	2	0	3	1
5	0	1	2	0	0	1
6	0	0	1	0	0	0
7	1	0	0	0	0	0

Table 3.5. Summary of statistical results from spatial autocorrelation analysis of cuckoo detection data at the annual level from 2007 to 2012.

Year	Moran's Index	Expected Index	Variance	z-score	p-value
2007	0.017	-0.0018	0.000025	3.66	< 0.01
2008	0.043	-0.0018	0.000027	8.48	< 0.01
2009	0.034	-0.0018	0.000028	6.77	< 0.01
2010	0.062	-0.0018	0.000027	12.20	< 0.01
2011	0.027	-0.0018	0.000027	5.51	< 0.01
2012	0.032	-0.0018	0.000028	6.28	< 0.01

### 3.3.2 Hot Spot Analysis

Although spatial autocorrelation analysis showed that cuckoo detections were highly clustered in only 2 sample periods, hot spot analysis found statistically significant hot spots in all 4 sample periods in 2009 – 2012 ( $p < 0.01$ ) (Table 3.6). These results are possible because spatial autocorrelation analysis assesses the global spatial pattern of cuckoo detections, while hot spot analysis assesses the local spatial pattern of cuckoo detections (ESRI 2012). There is considerable temporal variation in the location of hot spots within a year. Spatial statistics are sensitive to spatial resolution, and it is important



to note that cuckoo detections at the sample period level were aggregated at a much larger scale (2,500 m<sup>2</sup>) than detections at the annual level (500 m<sup>2</sup>). As a result, the remaining analyses were conducted at the annual level.

Table 3.6. Summary of the number of statistically significant ( $p < 0.01$ ) hot spots found in each sample period from 2009 to 2012.

<b>Year</b>	<b>Sample Period</b>	<b>Number of Hot Spots</b>
2009	1	1
2009	2	1
2009	3	3
2009	4	3
2010	1	2
2010	2	1
2010	3	2
2010	4	1
2011	1	1
2011	2	1
2011	3	1
2011	4	1
2012	1	2
2012	2	2
2012	3	3
2012	4	2

Statistically significant hot spots were found in all 6 years of cuckoo detection data ( $p < 0.01$ ). In 2007 and 2011, 13 hot spots occurred, while in 2010, 32 hot spots occurred. In 2008, 20 hot spots were detected, and in 2009, 21 hot spots were found. In 2012, 39 hot spots were detected (Figures 3.2 – 3.7). Similar to results within a year, across years there is considerable temporal variation in the location of hot spots (Figures 3.2 – 3.7).

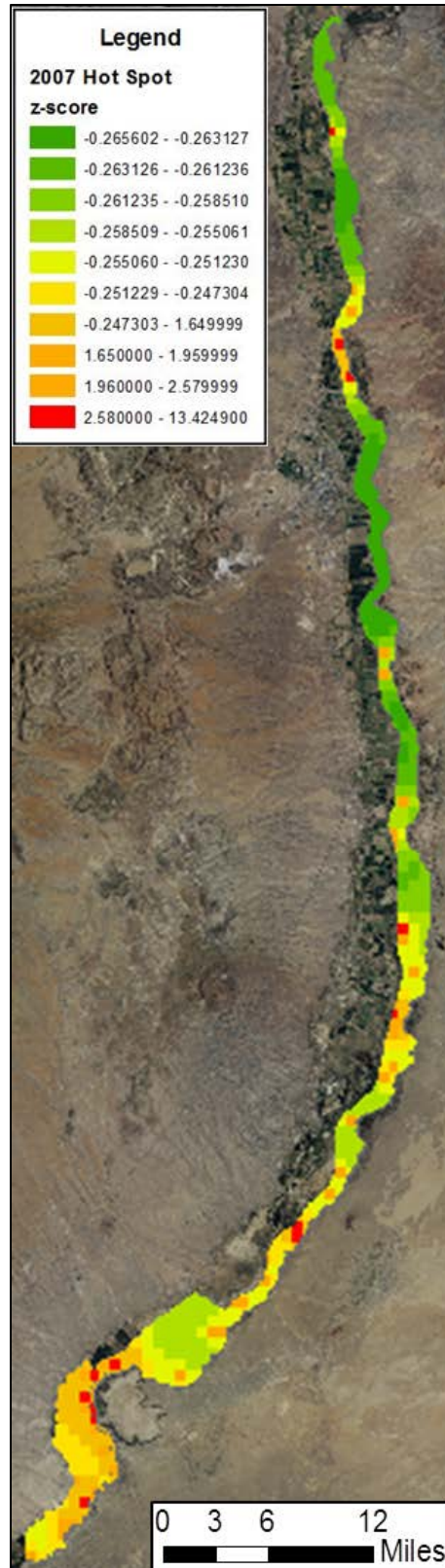


Figure 3.2. Hot spot analysis output of 2007 Western Yellow-billed Cuckoo detections. Red cells indicate a statistically significant ( $p < 0.01$ ) hot spot.

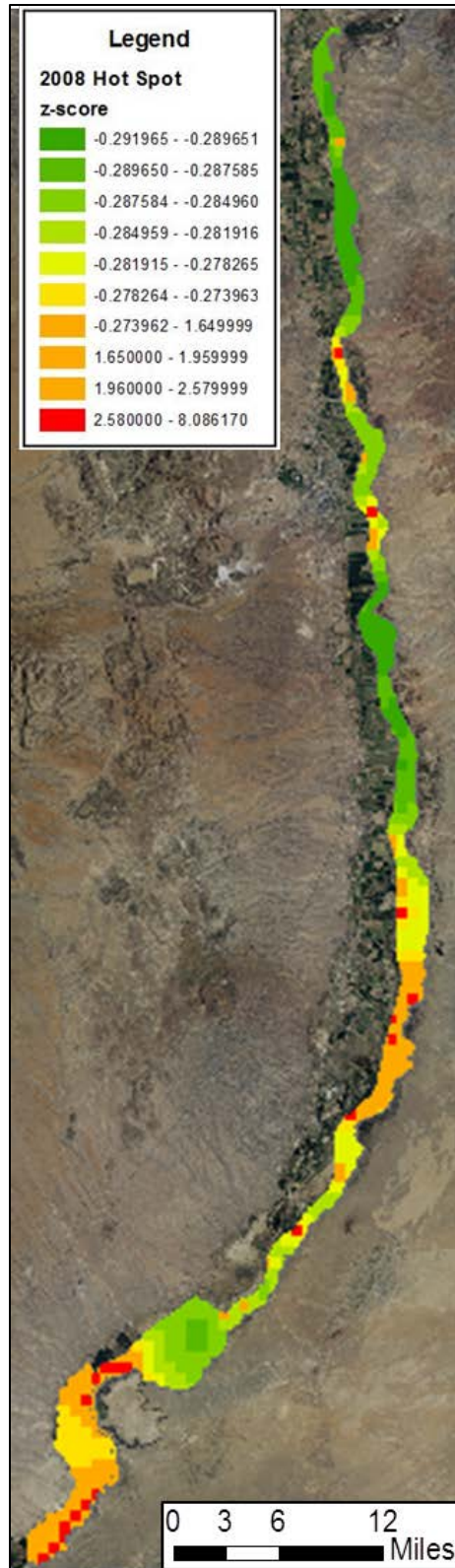


Figure 3.3. Hot spot analysis output of 2008 Western Yellow-billed Cuckoo detections. Red cells indicate a statistically significant ( $p < 0.01$ ) hot spot.

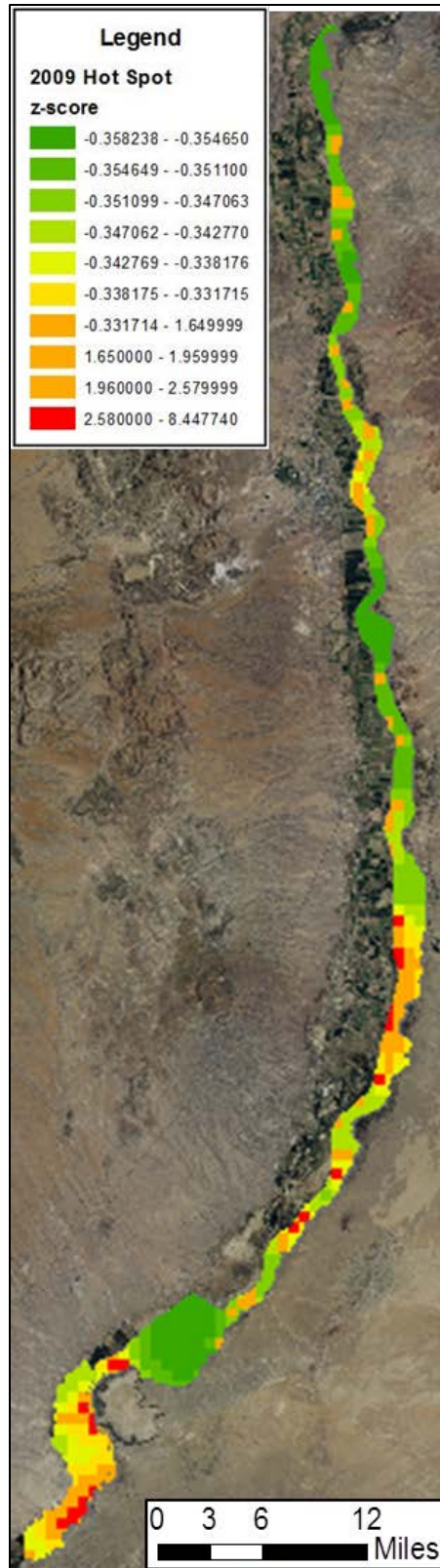


Figure 3.4. Hot spot analysis output of 2009 Western Yellow-billed Cuckoo detections. Red cells indicate a statistically significant ( $p < 0.01$ ) hot spot.

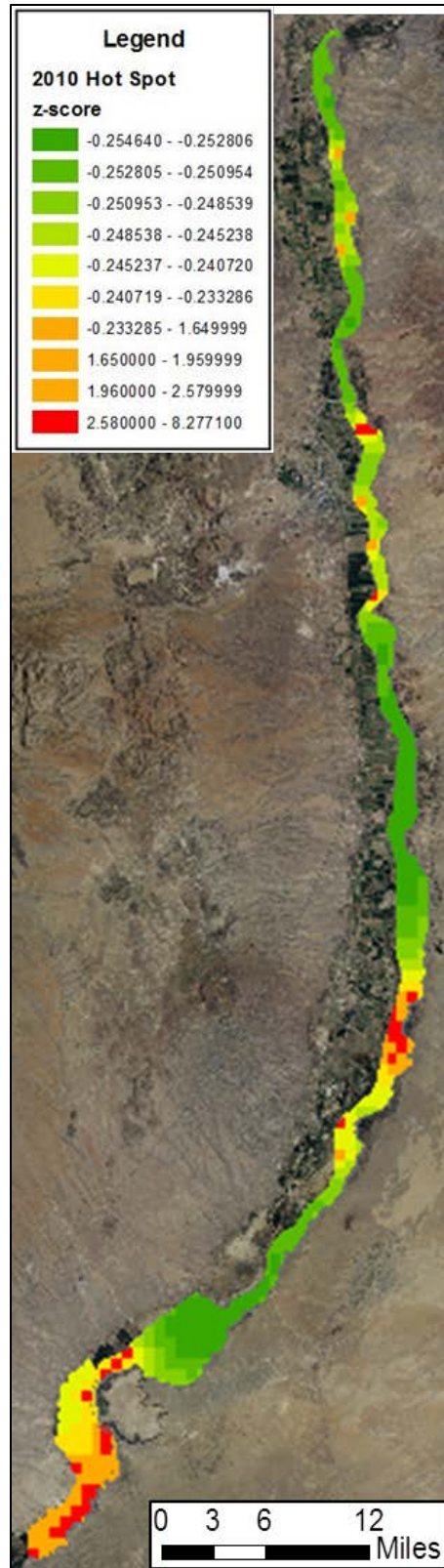


Figure 3.5. Hot spot analysis output of 2010 Western Yellow-billed Cuckoo detections. Red cells indicate a statistically significant ( $p < 0.01$ ) hot spot.



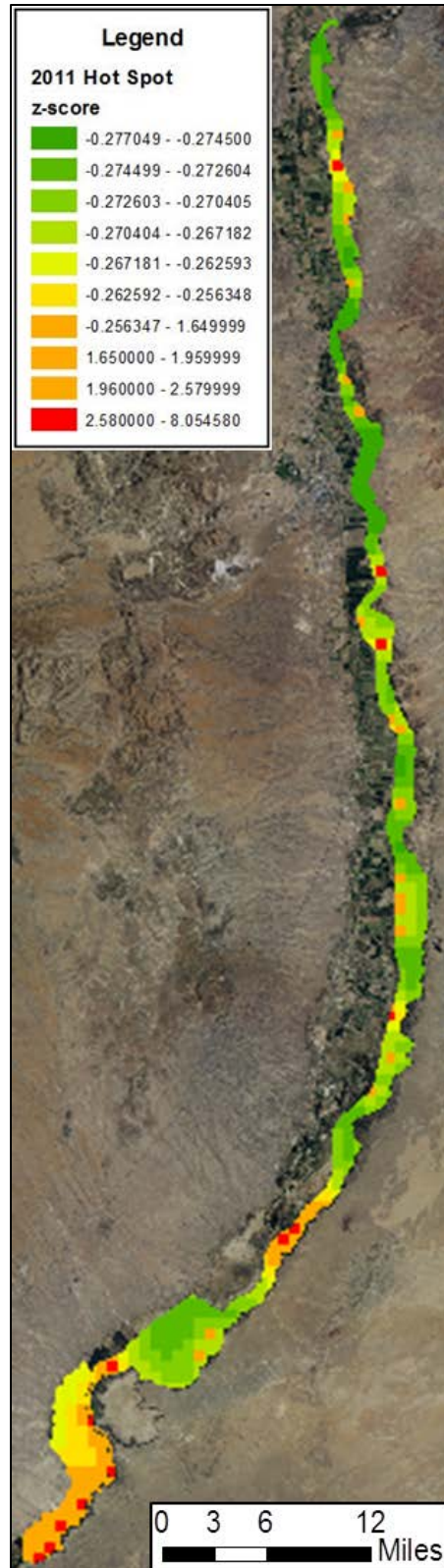


Figure 3.6. Hot spot analysis output of 2011 Western Yellow-billed Cuckoo detections. Red cells indicate a statistically significant ( $p < 0.01$ ) hot spot.

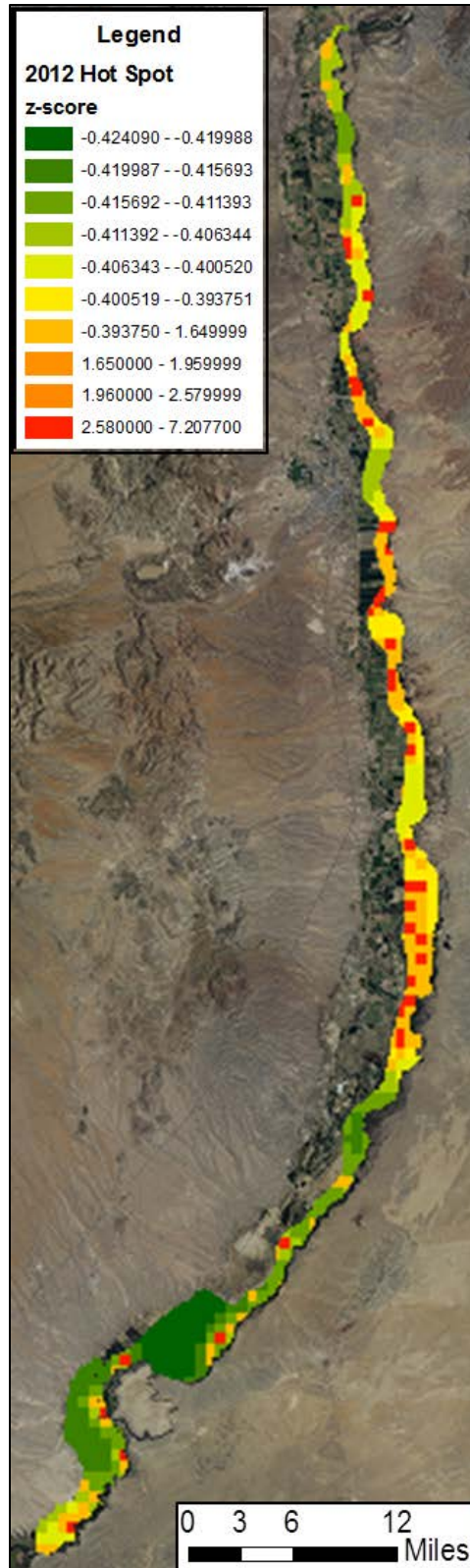


Figure 3.7. Hot spot analysis output of 2012 Western Yellow-billed Cuckoo detections. Red cells indicate a statistically significant ( $p < 0.01$ ) hot spot.

### 3.3.3 Analysis of Field Data

Vegetation data collection was completed for 12 500 m<sup>2</sup> hot spots and 13 500 m<sup>2</sup> cold spots at the annual level, rendering a total of 240 vegetation plots in hot spots and 383 vegetation plots in cold spots. As predicted, all hot spots at the annual level occurred near (< 400 m) surface water in stands of native overstory and dense understory. However, hydrology variables were problematic in analysis and could not be used; therefore, it is unclear if the probability of a hot spot occurring increased with occasional surface flooding. Mean area inundated at hot spots and cold spots under each of the flow regimes is provided in Table 3.7. Furthermore, hot spots had higher percent cover of Goodding's willow overstory and native overstory with dense native dominant understory than cold spots (Table 3.8). Additionally, cold spots had a higher percentage of woody stem density 4 (81% of sampled plots) than hot spots (74% of sampled plots). A breakdown of species composition of woody stem density class 4 is presented in Figure 3.8. Tamarisk comprises the majority of woody stem density 4 occurrences in both hot spots and cold spots (Figure 3.8).

Table 3.7. Mean (SD) area inundated at different flow regimes at hot spots and cold spots.

Variable	Hot Spot	Cold Spot
Area (m <sup>2</sup> ) inundated at 57 cms	24,984 (20,671)	22,327 (14,169)
Area (m <sup>2</sup> ) inundated at 101 cms	48,435 (45,015)	41,448 (64,270)
Area (m <sup>2</sup> ) inundated at 152 cms	68,191 (74,761)	65,339 (83,583)
Area (m <sup>2</sup> ) inundated at 213 cms	87,342 (94,745)	112,924 (103,301)



Table 3.8. Mean (SD) percent cover of vegetation communities in hot spots and cold spots. Vegetation communities included are community types deemed important in previous Western Yellow-billed Cuckoo habitat studies (Sechrist et al. 2009).

Variable	Hot Spot	Cold Spot
Cottonwood Overstory	36 (39)	35 (39)
Goodding's Willow Overstory	9 (20)	2 (11)
Native Overstory with Dense Native Dominant Understory	31 (32)	20 (28)
Native Overstory with Dense Exotic Dominant Understory	37 (38)	35 (38)

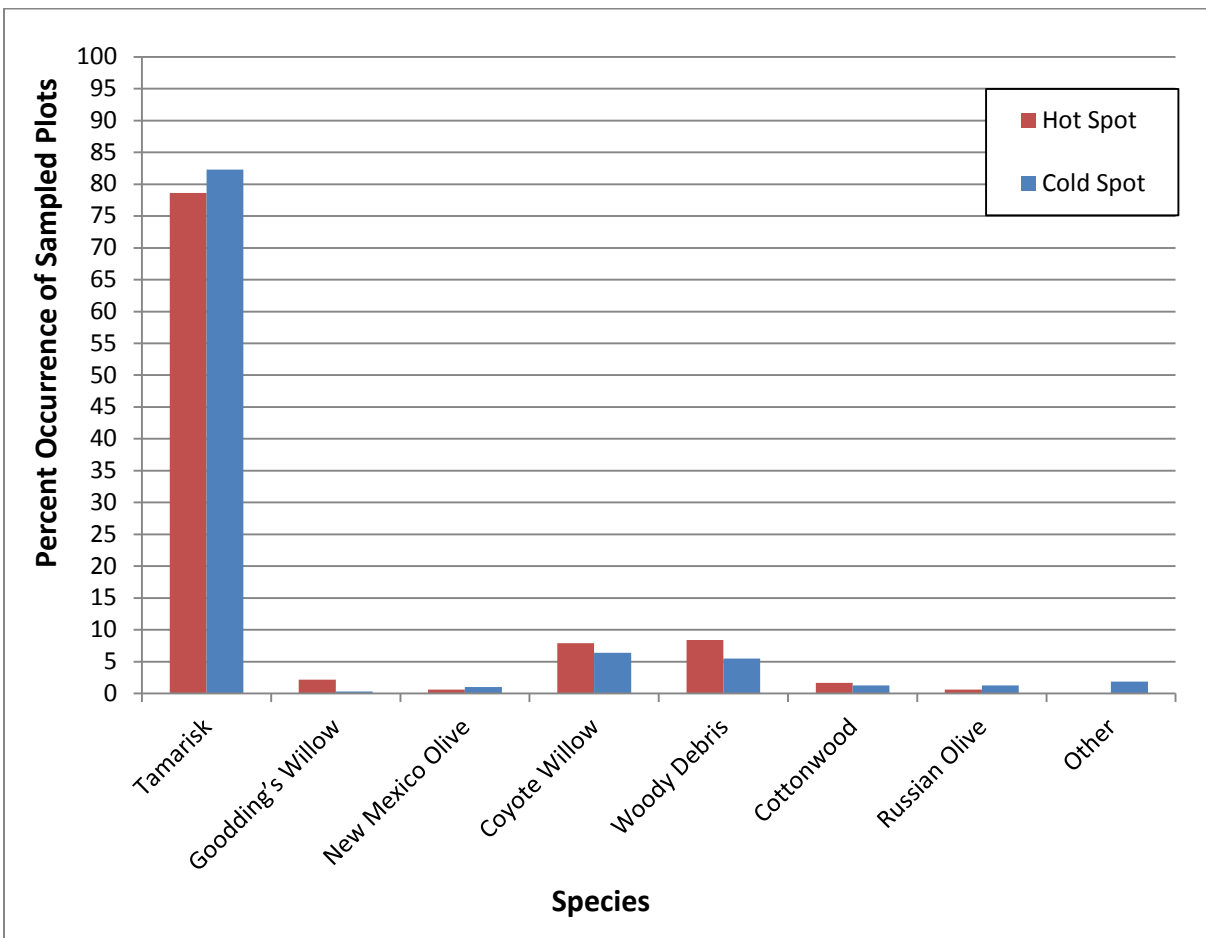


Figure 3.8. Percent occurrence of understory species in woody stem density class 4 in hot spots and cold spots.

Wet years decreased the probability of a hot spot occurring, while the occurrence of Goodding's willow, coyote willow, dense tamarisk, and woody debris as primary understory species at specific densities increased the probability of a hot spot occurring (Table 3.9 and 3.10). Furthermore, the occurrence of coyote willow and woody debris as a secondary understory component and the presence of New Mexico olive (*Forestiera neomexicana*) and woody debris as a tertiary understory component also increased the probability of a hot spot occurring (Table 3.9). Hot spots were more likely to occur in an area where Goodding's willow exceeded 40% cover in the understory, coyote willow exceeded 53% cover, tamarisk exceeded 97% cover, woody debris exceeded 47% cover, and New Mexico olive exceeded 6% cover (Table 3.10).

Table 3.9. P-values of significantly important variables from logistic regression.

Variable	$\beta$	p-value
Wet year	0.54	< 0.01
Goodding's willow - Primary Understory Species	-12.60	< 0.01
Coyote willow - Primary Understory Species	-14.11	< 0.01
Tamarisk - Primary Understory Species	-18.83	0.02
Woody debris – Primary Understory Species	-13.94	< 0.01
Coyote willow – Secondary Understory Species	-12.93	0.02
Woody debris – Secondary Understory Species	-10.71	< 0.01
New Mexico olive – Tertiary Understory Species	-2.29	0.02
Woody debris – Tertiary Understory Species	-9.72	0.05

Table 3.10. Thresholds of each important variable from logistic regression. Values greater than or equal to the values given increase the probability of a hot spot occurring.

Variable	Percent Cover
Goodding's willow understory	40
Coyote willow understory	53
Tamarisk understory	97
Woody debris in understory	47
New Mexico olive understory	6

### 3.4 DISCUSSION

The results of this study indicate that locations of Western Yellow-billed Cuckoos are clustered at the annual level, but there is considerable temporal variation in the location of hot spots among and within years. While the large spatial scale (2,500 m<sup>2</sup>) used at the sample period level reduced the strength of analyses, hot spot analysis at the annual level was effective in identifying the spatial location of clusters and provided insights into the habitat characteristics affecting the location of clusters. Our findings support the predictions that the spatial pattern of cuckoos is clustered at the annual level (Table 3.5) and that hot spots occurred near (< 400 m) the river channel in stands of native overstory and dense understory (Table 3.8). However, results are inconclusive for the prediction that more hot spots occurred in wet years than dry years.

The clustered spatial pattern of the cuckoo detection data at the annual level indicates that the cuckoos are strongly selecting for certain habitat conditions; however, the strength of clustering varies among years (Table 3.5). The cuckoos were less clustered in 2007 than other years; conversely, the cuckoos were most clustered in 2010 than other years. In spite of the range of z-scores amongst years (3.7 - 12.2), the range of variance amongst years was very small (0.000025 – 0.000028). This indicates that within and amongst each year, the data deviate very little from the mean. Currently, there is insufficient data to definitively state why the cuckoos clustered less strongly in 2007 and more strongly in 2010.

Furthermore, the hot spot analysis indicated temporal variation in the location of hot spots among years (Figures 3.2 – 3.7). From 2007 - 2011, most of the hot spots were found on the southern half of the study site, specifically on Bosque del Apache National

Wildlife Refuge and the northern boundary of Elephant Butte Reservoir (Figure 3.2 – 3.6). Both of these areas have more surface water than other sites on the San Acacia Reach. Due to the cuckoos' need to nest near water (Sechrist et al. 2009), it is not surprising that the majority of the hot spots would be located in these relatively mesic areas. While the hot spots are found in the same general areas from 2007 - 2011, there is variation in the location of the hot spots across years. As the plant communities do not radically change from year to year, it is unclear what is causing the cuckoos to cluster in different locations each year. Hughes (1999) states that the beginning of the breeding period for Yellow-billed Cuckoo is correlated with an abundant local food supply and Sechrist et al. (2009) reported that cuckoos need to nest near surface water. Thus, perhaps the cuckoos are clustering in different locations each year based on local food and surface water resources, but cuckoos also have large home ranges (5 to 282 ha) (Sechrist et al. 2009) and the different locations of hot spots from year to year may be different nesting sites within a home range.

In 2012, the majority of the locations of highly significant hot spots shifted upstream, moving away from the northern boundary of Elephant Butte Reservoir and on to the northern half of Bosque del Apache National Wildlife Refuge and stretching up to river mile 109, near San Acacia Dam (Figure 3.7). It is unclear why the hot spots occurred further upstream in 2012, but it could be related to the low flows (Figures 3.9 – 3.14) and reservoir levels in 2012 (Figure 3.15). During late May-mid June, the time period when cuckoos arrive on the MRG and begin nesting, we observed the lowest river flows of the entire study period in 2012 (Table 3.1 and Figures 3.9 – 3.14). Furthermore, reservoir levels were also at their lowest level of the entire study period in 2012 (Figure

3.15). Therefore, it is possible that limited surface water just upstream of Elephant Butte Reservoir in 2012 caused the upstream shift of hot spots. It is also possible that the upstream shifts in hot spots may be related to the degrading habitat north of Elephant Butte Reservoir, where most of the hot spots occurred from 2007 – 2011. Recent headcutting north of the reservoir has created an incised channel and led to significant drops in groundwater level (Holste et al. 2011; Holste 2013), causing much of the understory to die off as the plants' roots can no longer reach the groundwater (Caplan et al. 2013). While our data show that the native overstory of cottonwood and Goodding's willow continues to persist in the area, the understory is quickly dying-off, leaving large amounts of standing woody debris. Continued cuckoo surveys and subsequent habitat assessment at cuckoo hot spots and cold spots could determine if the 2012 shift upstream was a single year occurrence, or a long-term shift due to habitat degradation north of Elephant Butte Reservoir.

Although temporal variation in the location of hotspots was observed, our data were inconclusive as to the effects of wet years versus dry years on the development of hotspots. Our statistical analyses suggested that wet years decreased the probability of a hot spot occurring; however, the raw numbers of hot spots reported in the results do not agree with this finding. In 2008 and 2009 (wet years), 20 and 21 hot spots occurred, respectively, while in 2011 and 2012 (dry years), 13 and 39 hot spots occurred, respectively. Therefore, the effect of wet years versus dry years on the number of hot spots is inconclusive.

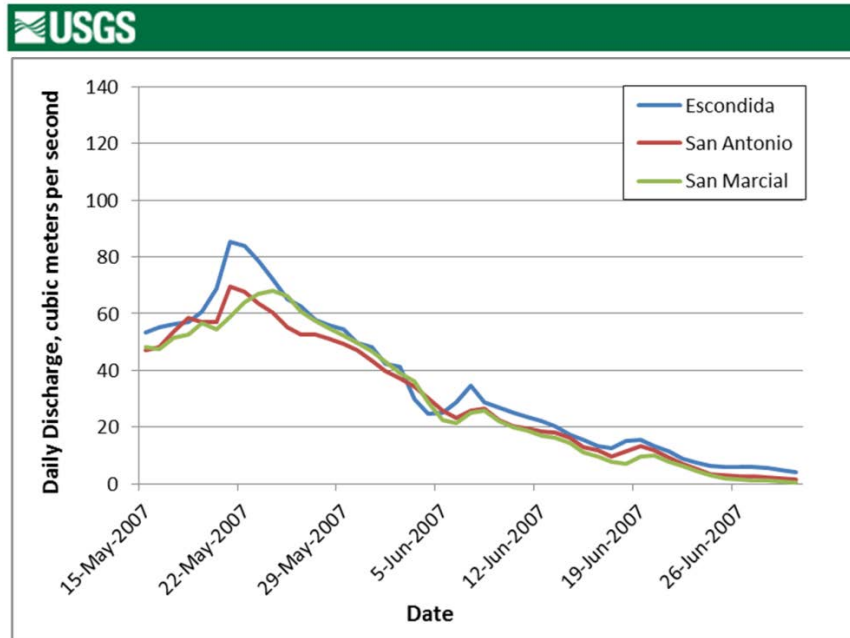


Figure 3.9. Hydrograph of river flows at three different gauges along the San Acacia Reach in 2007. Daily discharge rates are given from May 15 to June 30 as these are approximate dates when cuckoos arrive on the MRG and begin nesting. The river gauge at Escondida is located at River Mile 104; the river gauge at San Antonio is at River Mile 87. The river gauge at San Marcial is south of River Mile 69.

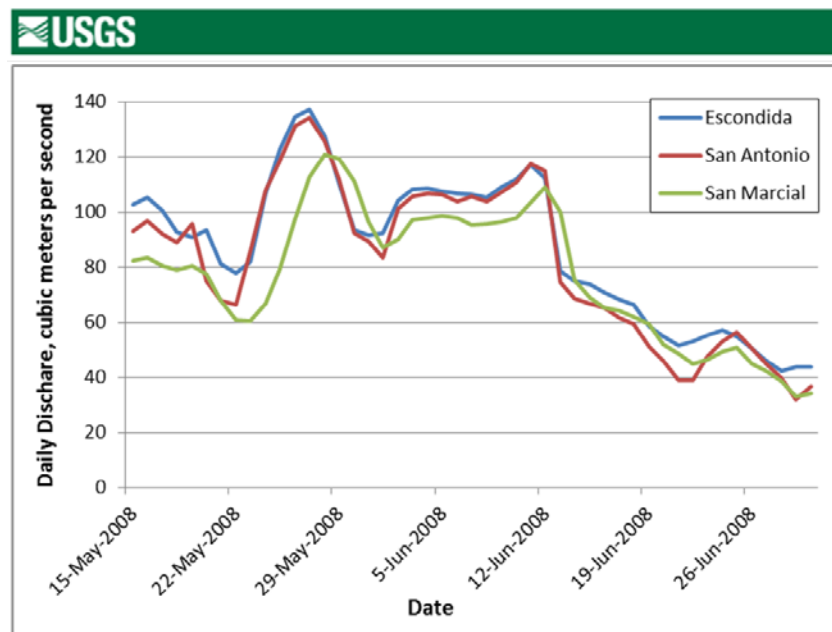


Figure 3.10. Hydrograph of river flows at three different gauges along the San Acacia Reach in 2008. Daily discharge rates are given from May 15 to June 30 as these are approximate dates when cuckoos arrive on the MRG and begin nesting. The river gauge at Escondida is located at River Mile 104; the river gauge at San Antonio is at River Mile 87. The river gauge at San Marcial is south of River Mile 69.

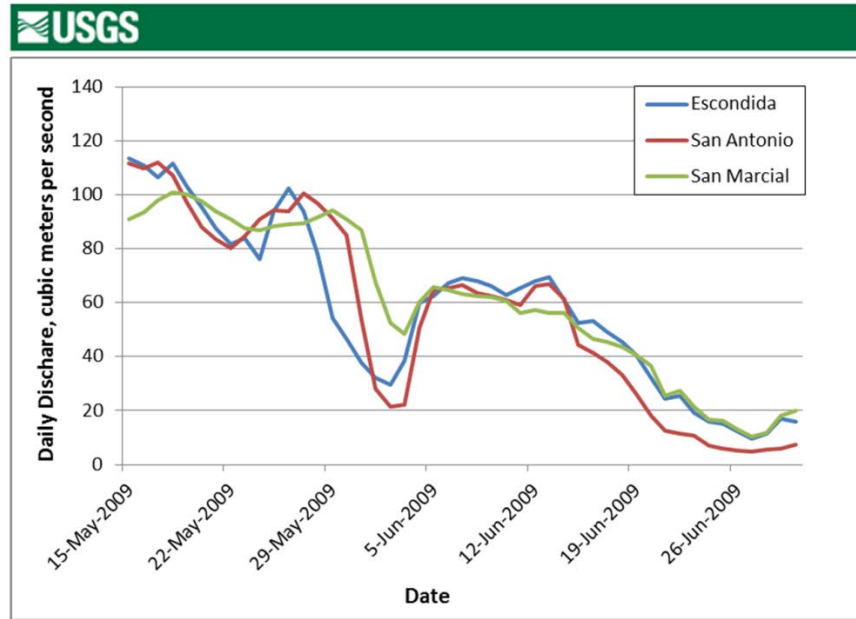


Figure 3.11. Hydrograph of river flows at three different gauges along the San Acacia Reach in 2009. Daily discharge rates are given from May 15 to June 30 as these are approximate dates when cuckoos arrive on the MRG and begin nesting. The river gauge at Escondida is located at River Mile 104; the river gauge at San Antonio is at River Mile 87. The river gauge at San Marcial is south of River Mile 69.

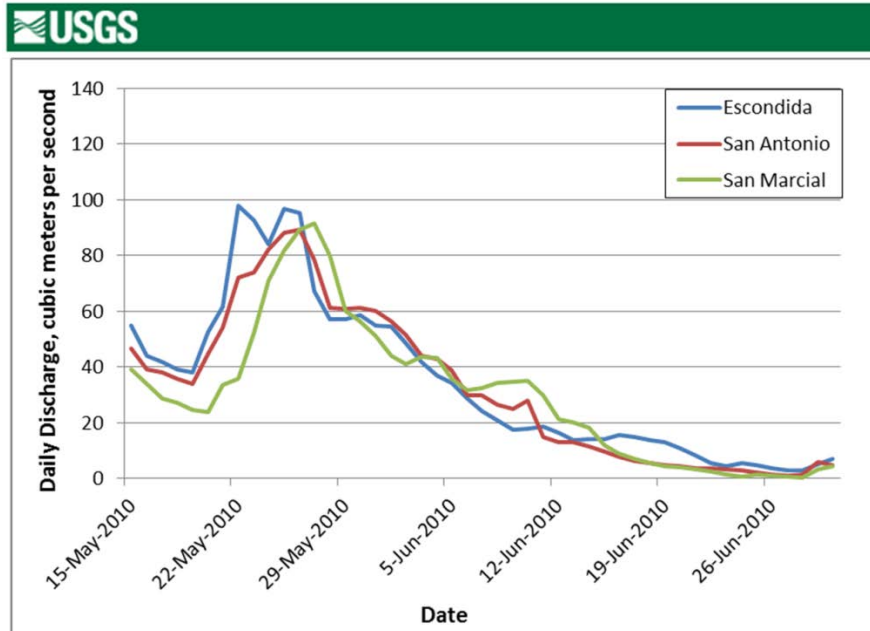


Figure 3.12. Hydrograph of river flows at three different gauges along the San Acacia Reach in 2010. Daily discharge rates are given from May 15 to June 30 as these are approximate dates when cuckoos arrive on the MRG and begin nesting. The river gauge at Escondida is located at River Mile 104; the river gauge at San Antonio is at River Mile 87. The river gauge at San Marcial is south of River Mile 69.

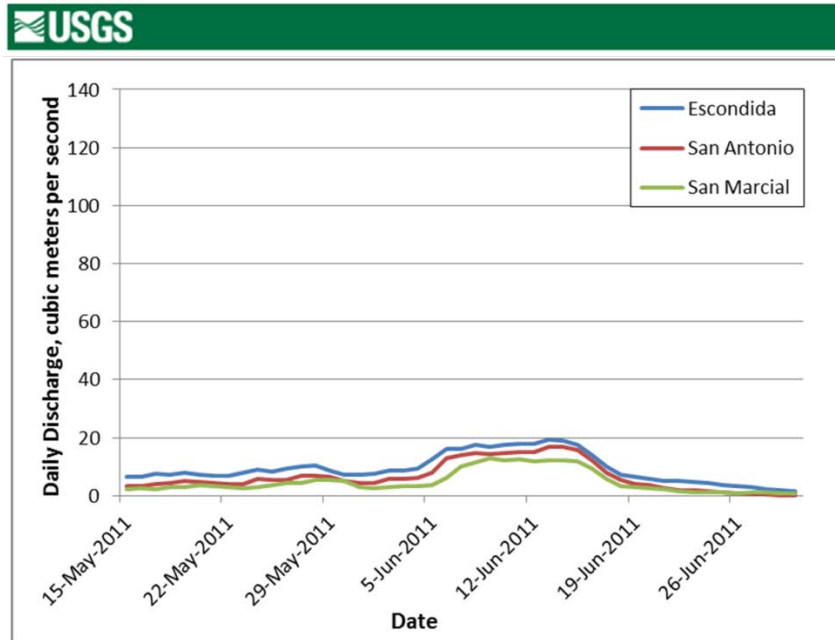


Figure 3.13. Hydrograph of river flows at three different gauges along the San Acacia Reach in 2011. Daily discharge rates are given from May 15 to June 30 as these are approximate dates when cuckoos arrive on the MRG and begin nesting. The river gauge at Escondida is located at River Mile 104; the river gauge at San Antonio is at River Mile 87. The river gauge at San Marcial is south of River Mile 69.

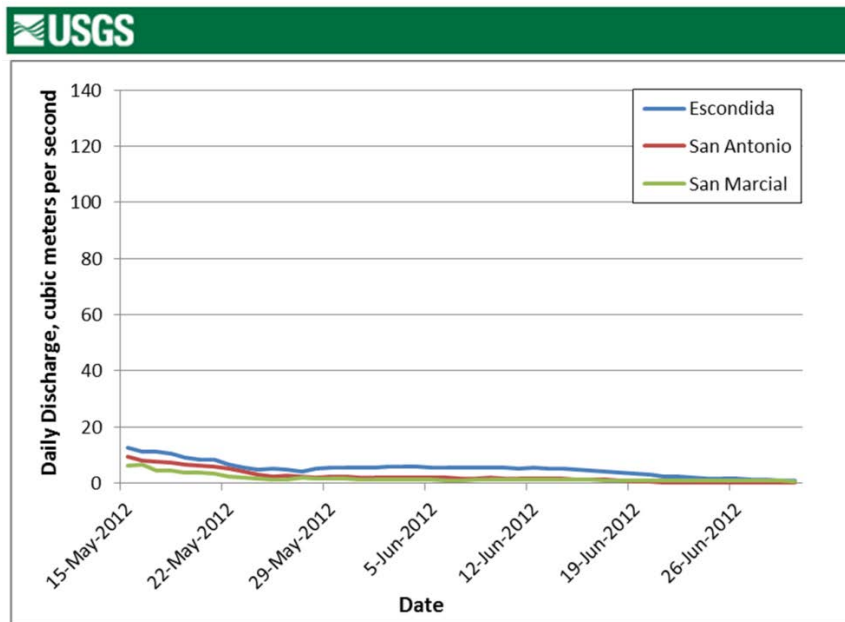


Figure 3.14. Hydrograph of river flows at three different gauges along the San Acacia Reach in 2012. Daily discharge rates are given from May 15 to June 30 as these are approximate dates when cuckoos arrive on the MRG and begin nesting. The river gauge at Escondida is located at River Mile 104; the river gauge at San Antonio is at River Mile 87. The river gauge at San Marcial is south of River Mile 69.



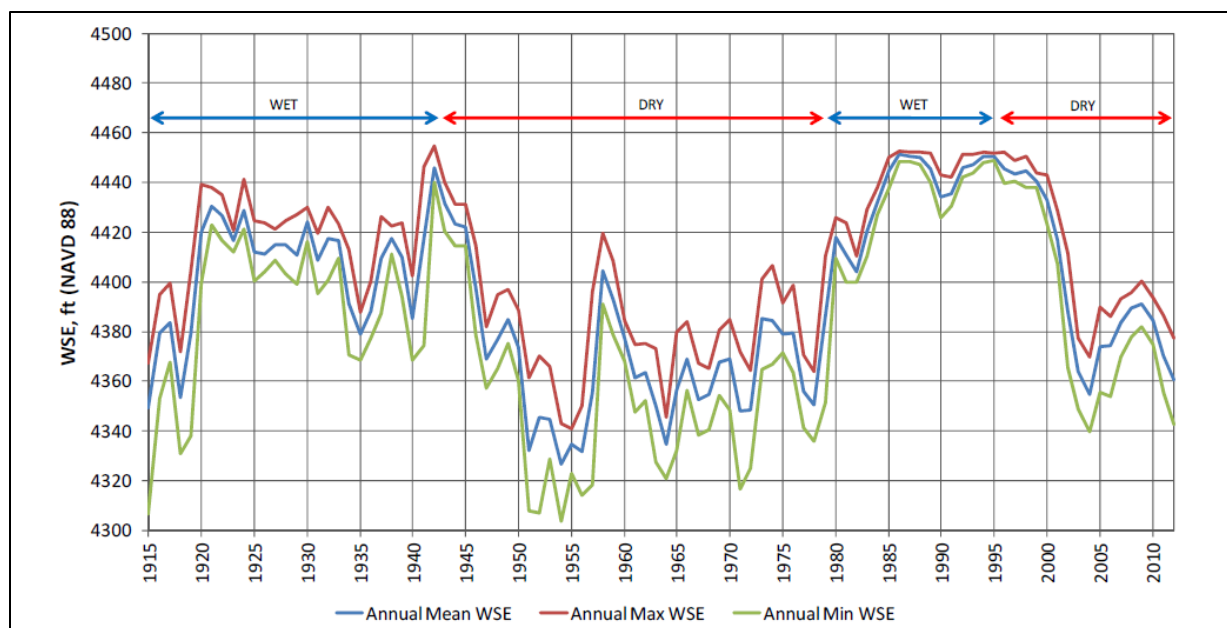


Figure 3.15. Elephant Butte Reservoir pool elevation time series (1915–2012) (Holste 2013). WSE is water surface elevation.

My prediction that hot spots would be near ( $< 400$  m) surface water was supported, but overall the hydrology variables were problematic in analysis and could not be used. I can only compare the mean area ( $\text{m}^2$ ) inundated at hot spots versus cold spots at various flows; therefore, it is unclear if the probability of a hot spot occurring increased with occasional surface flooding (Table 3.7). However, these results may also be affected by the coarseness of the hydrologic variables. I did not have annual hydrologic data for each cell, thus I could only estimate hydrologic conditions based on the most current data derived from the 2006 Rio Grande channel planform mapping data (Makar and AuBuchon 2012) and the FLO2D modeling output from the Upper Rio Grande Water Operations Model (Tetra Tech 2002). Because the headcutting north of Elephant Butte Reservoir noticeably began in 2004 (Holste et al. 2011; Holste 2013), it is possible that our hydrology data did not adequately describe the hydrologic conditions of each hot spot.

Sechrist et al. (2009) found that native canopy with either exotic, native, or mixed understory is important to Western Yellow-billed Cuckoo breeding habitat. My results refine this statement as I found that the occurrence of 5 statistically significant understory components of Western Yellow-billed Cuckoo habitat, including 3 native species (Goodding's willow, coyote willow, and New Mexico olive) and 1 exotic (tamarisk) (Table 3.9), increased the probability of a hot spot occurring. Additionally, woody debris is an important component of hot spots. As cuckoos prefer dense understories, woody debris provides the understory structure needed to attract cuckoos. North of Elephant Butte Reservoir, where most of the hot spots occurred, woody debris is abundant as recent headcutting on the channel has led to widespread die off of the understory (Holste et al. 2011; Holste 2013; personal observation).

From a canopy perspective, previous studies show that cottonwood and Goodding's willow are important to Western Yellow-billed Cuckoos as they nest in trees, as well as use them for foraging sites (Hughes 1999; Halterman et al. 2009; Sechrist et al. 2009). However, the analysis for this study did not indicate that these two native overstory species were a statistically significant part of cuckoo habitat. I believe these results suggest that a multivariate relationship with native overstory and other variables, such as the understory species listed above or surface water, are important to cuckoo breeding habitat. In other words, simply the presence of native overstory is not sufficient habitat for breeding cuckoos, but the combination of native overstory and other factors, such as understory species or surface water, are important to breeding cuckoos.

Based on the results of this study and others (Sechrist et al. 2009), it appears that cuckoos are generalists in terms of understory vegetation species composition as long as

the understory is dense (Table 3.10); however, cuckoos need native overstory species. These findings have important implications for habitat restoration and maintenance of long-term habitat for the Western Yellow-billed Cuckoo. While Table 3.10 indicates that maintenance of woody debris and dense tamarisk in the understory would increase suitable cuckoo habitat, these two understory components would not provide long-term suitable habitat. Currently, many of the hot spots are comprised of native overstory with dense, dominantly exotic species understory (Table 3.8). As the native overstory naturally senesces and dies, the presence of a dense tamarisk understory will prevent regeneration of cottonwood and Goodding's willow. Therefore, dense understories of tamarisk provide suitable habitat now and in the near future, but these habitat conditions are not sustainable for long-term cuckoo use. Similarly, many hot spots comprised of native overstory with woody debris in the understory (25% of sampled plots) are not sustainable for long-term cuckoo use either. These communities were found in the incised reach north of Elephant Butte Reservoir where the woody debris is a result of vegetative die-off due to groundwater declines. Because of the incised channel, overbank floods rarely occur in the area. Thus, native overstory species will not regenerate and these sites will not be suitable for long-term cuckoo use.

It is important to note that this study only addressed spatial distribution of cuckoos, not productivity of cuckoos. Therefore, it is unknown whether or not productivity is related to the number and spatial distribution of hot spots. Assuming hotspot conditions are representative of areas of high productivity, restoration and maintenance of habitat will be necessary to develop and/or sustain long-term suitable habitat for Western Yellow-billed Cuckoos as communities of native overstory with

woody debris or those dominated by exotic species understory are ephemeral suitable cuckoo habitat. Goodding's willow and cottonwood need bare mineral substrate and overbank flows to germinate and establish (Stromberg 1993), thus periodic overbank flows will be necessary to regenerate native overstory. Furthermore, at sites where dense tamarisk is present, the tamarisk must be removed prior to overbank floods to allow native species establishment (Cleverly and Dello Russo 2007). For instance, cold spots that were inundated at 213 cms and have a shallow depth to groundwater may be ideal restoration sites as these areas have the necessary hydrologic conditions to support native species. In conclusion, management of riparian forests that promotes overbank floods and the regeneration and survival of cottonwood and Goodding's willow overstory, with a mixed understory of Goodding's willow, coyote willow, and New Mexico olive would provide long-term suitable habitat for Western Yellow-billed Cuckoos.

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## **CHAPTER 4**

### **ASSESSMENT OF STRUCTURAL VARIABILITY IN THE HINK AND OHMART CLASSIFICATION SYSTEM**

#### **4.1 INTRODUCTION**

Vegetation classification provides a valuable and helpful tool for research, land management, and biological conservation (Hernandez-Stefanoni et al. 2006; Jennings et al. 2009; De Cáceres and Wiser 2012). Classification schemes enable land managers to catalog existing vegetation communities on the landscape, as well as develop and implement conservation plans and decisions by determining areas in need of habitat management (Hernandez-Stefanoni et al. 2006). Classification systems can be based on one or several criteria, such as vegetation structure, species composition, climatic conditions, physiognomy, or soil conditions (UNESCO 1973; Walter 1973; Pfister & Arno 1980; Adams 1999; Dengler et al. 2008; Jennings et al. 2009; De Cáceres and Wiser 2012). Furthermore, various sampling and analytical methods, including an array of measurement protocols, different sizes of sampling units, various clustering algorithms, and data transformations, are valid and effectively applied (Mucina 1997; De Cáceres and Wiser 2012). Additionally, new methods of vegetation classification are still being recommended, only further adding to the multitude of existing methods described above (De Cáceres et al. 2010; Schmidtlein et al. 2010; Tichý et al. 2011). To date, there is not one universally accepted method for classifying vegetation communities (De Cáceres and Wiser 2012). However, the selection of a universal vegetation classification system should be based on practical applications that concisely provide researchers and managers with a holistic, thorough description of vegetative communities (Mucina 1997; Ewald 2003; De Cáceres and Wiser 2012).

Within the existing vegetation classification methods, two fundamentally different approaches prevail (Jennings et al. 2009). One type of classification system uses structural



characteristics, utilizing data that describes the growth form of dominant plants of the community; while the other type of classification system uses floristic characteristics, utilizing data that describes composition and abundances of taxa (Jennings et al. 2009). Both structural and species composition data are important when describing critical habitat needs of wildlife species (MacArthur and MacArthur 1961; Lovejoy 1974; Tomoff 1974; Power 1975; Willson 1974; James and Wamer 1982; Rotenberry 1985; Martin et al. 2012; Kalies and Rosenstock 2013; Teuscher et al. 2013). Not only does each wildlife species require certain species of vegetation, it also requires a particular vegetative structure in order to meet its life history needs (MacArthur and MacArthur 1961; Rotenberry 1985). Habitat management plans that only focus on structure or species composition may be inadequate management strategies (Rotenberry 1985). Therefore, if wildlife habitat management is a goal, it is important that vegetation classification systems capture both structural and floristic characteristics (Jennings et al. 2009).

Vegetative structure (density and height) and species composition is particularly important when managing songbird communities as different guilds of songbirds require certain vegetative height, density, and species composition (MacArthur and MacArthur 1961; Willson 1974; Rotenberry and Wiens 1980; Schemske and Brokaw 1981; Rotenberry 1985; Faccio 2003; Zurita and Zuleta 2009). For instance, open forest canopies allow sunlight to reach the forest floor, promoting the growth of herbaceous plants and increasing arthropod abundance, thus ultimately increasing food resources for understory insectivorous songbirds (Faccio 2003; Zurita and Zuleta 2009). Conversely, canopy foragers need closed-canopy woodlands in order to survive (Faccio 2003). Furthermore, Rotenberry and Wiens (1980) found that there were significant correlations between songbird abundances and forb and woody plant density. Species such as American Robin (*Turdus migratorius*) and Mountain Bluebird (*Sialia currucoides*) were

highly correlated with forb and woody plant density, while McCown's Longspur (*Rhynchophanes mccownii*) was highly correlated with woody plant density (Rotenberry and Wiens 1980). As Rotenberry (1985) suggests, it is difficult to elucidate which aspect of vegetation, structure or species composition, is more important to particular songbird species; therefore, it is best to record information on both floristic and structural characteristics to ensure comprehensive habitat management of songbirds (MacArthur and MacArthur 1961; Willson 1974; Schemske and Brokaw 1981; Rotenberry 1985; Faccio 2003; Zurita and Zuleta 2009; Jennings et al. 2009).

Thorough vegetation classification is central to management of endangered species as land cover data defines and delineates habitat (Straatsma et al. 2013; Blank and Blaustein 2014). Currently along the Middle Rio Grande (MRG) of New Mexico, breeding riparian-obligate songbirds, such as the Western Yellow-billed Cuckoo (*Coccyzus americanus occidentalis*) and the endangered Southwestern Willow Flycatcher (*Empidonax traillii extimus*), are rapidly declining as native riparian forests are replaced by exotic tamarisk (*Tamarix* spp) stands due to hydrologic alterations (Yong and Finch 1997; Levine and Stromberg 2001; Pruett et al. 2001; Wiggins 2005; Schmidt-Petersen 2007). The impacts of hydrologic alterations are projected to increase as a result of growing urban, commercial and agricultural demands on water, placing greater pressure on a limited resource and further depleting an already water-stressed system (Jackson et al. 2001; Robert 2007). There is an increasing awareness that river conservation and restoration is needed along the MRG and that such efforts depend on restoring historic hydrologic regimes and native riparian vegetation as much as possible (Towne 2007; Brand et al. 2011).

Hink and Ohmart (1984; hereafter HO) conducted a biological survey of riparian habitats along the MRG to identify the primary community types of riparian habitat and to categorize the vegetation and terrestrial vertebrate assemblages of each community type. In this survey, HO (1984) recorded forest canopy and understory species composition and created six structure types to describe riparian vegetation structure in the Rio Grande Valley. These six structure types are delineated by presence/absence of an overstory and understory, approximate height of overstory and understory, approximate age of overstory, and vague descriptions of understory density for each class (Hink and Ohmart 1984; Table 4.1). HO (1984) classification is widely used throughout the Middle Rio Grande and is a useful tool for rapid and broad scale classification of habitats.

The six broad structure types of HO potentially allow for high structural variability (specifically high variability in stem density) within a given classification (Figure 4.1). High variability in stem density within a class could be a noteworthy shortcoming when managing habitat for songbirds (MacArthur and MacArthur 1961; Willson 1974; Rotenberry and Wiens 1980; Schemske and Brokaw 1981; Rotenberry 1985; Faccio 2003; Zurita and Zuleta 2009). Therefore, in songbird studies, it is important to assess vegetative communities in a manner that captures variability in habitat structure (density and height) and species composition (MacArthur and MacArthur 1961; Willson 1974; Rotenberry and Wiens 1980; Schemske and Brokaw 1981; Rotenberry 1985; Faccio 2003; Zurita and Zuleta 2009). While Ahlers et al. (2010a) used a Modified Hink and Ohmart classification system to better describe suitable habitat for the Southwestern Willow Flycatcher by including a “dense” qualifier to note when aerial vegetative cover was greater than 50 percent, no further quantitative data were provided. However, visual obstruction and stem density measurements quantitatively describe the structure of vegetation,

rather than the HO structure classes that qualitatively describe presence/absence of overstory and understory. Visual obstruction provides information on the patchiness of the vegetative stand as well as the degree of cover provided for shrub-nesting songbirds (Toledo et al. 2008; Thiele et al. 2013). Stem density measurements provide numerical descriptions of the woody stem densities of each stand (Rotenberry and Wiens 1980), rather than the vague density descriptions used in HO structure classes (Table 4.1).

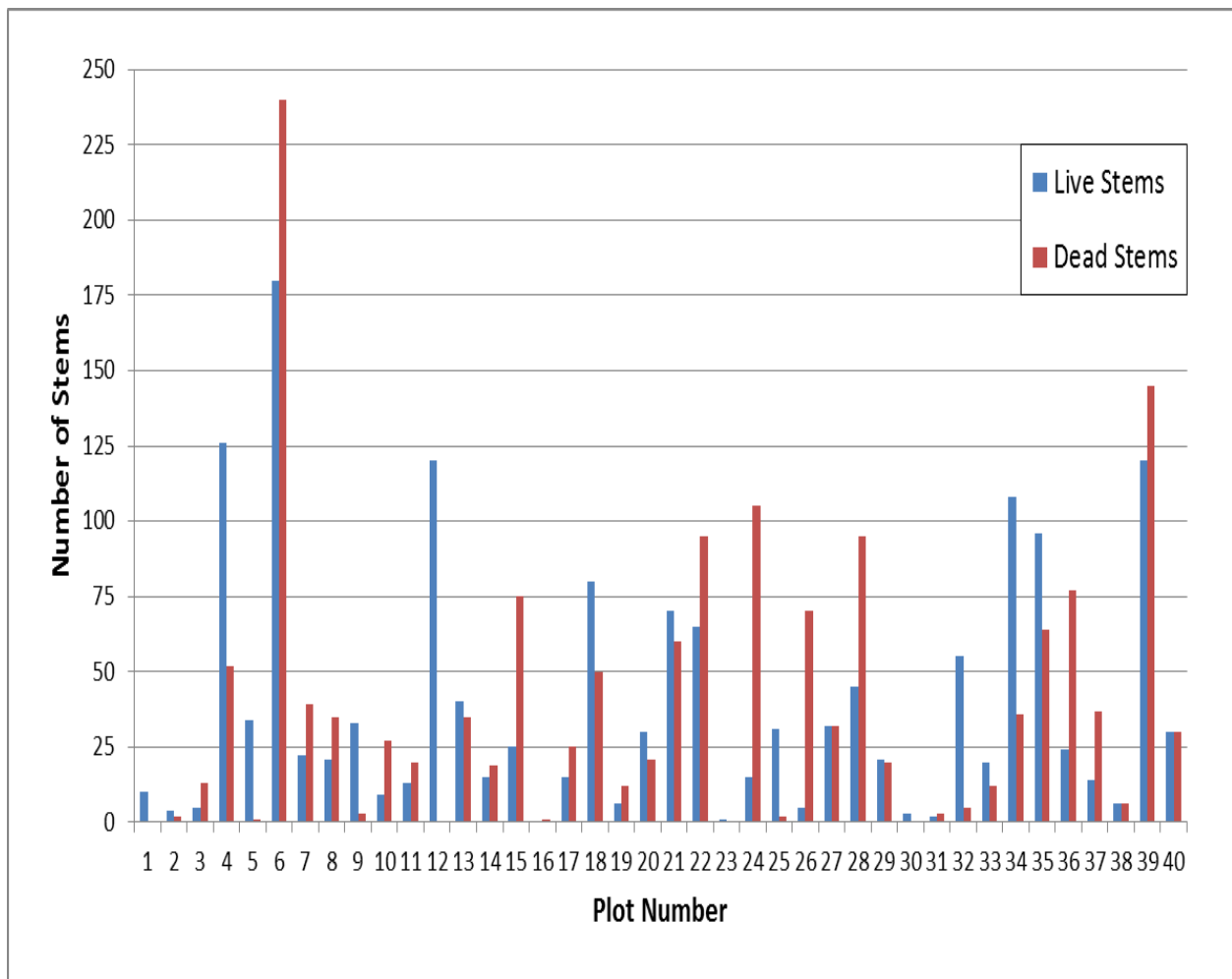


Figure 4.1. Stem density in plots classified as Tamarisk 5 using Hink and Ohmart (1984) classification scheme.

Table 4.1. Hink and Ohmart (1984) vegetation structure classes.

Structure Class	Description
1	Vegetation in all foliage layers, with trees reaching 50 to 60 ft. Mature to mixed age class stands. 25% or greater of understory is vegetated.
2	Mature stands of trees up to 50 to 60 ft tall, with most of the foliage in the canopy layer > 30 ft. Sparse, patchy understory and little herbaceous growth.
3	Intermediate age stand with a thick understory. Dense vegetation up through about 30 ft, but little above 30 ft. 25% or greater of understory is vegetated.
4	Relatively open stands of intermediate-age stands. Most of the foliage was between 20 and 40 ft. Shrubs widely spaced and herbaceous growth is sparse.
5	Dense vegetation at about 10 or 15 ft high, often including a thick layer of grass and annuals. Some taller trees scattered throughout.
6	Low and relatively sparse herbaceous and/or shrubby vegetation, with most foliage below 5 ft.

In this study, I quantify the variability within HO structure classes. Specific objectives are: 1) quantify the variability found within HO structure classes for selected plant communities, and 2) propose modifications to the current classification system for use in songbird habitat studies. If the HO structure classes describe vegetation structure well, I predict that the clusters produced from a cluster analysis would closely align with the HO structure classes. Additionally, if the HO classification scheme captures vegetation species composition and structure well, I predict that the probabilities of misclassifications in a canonical discriminant function analysis will be low.

#### 4.1.1 Study Area

The study was conducted in the San Acacia Reach of the Middle Rio Grande (MRG) of New Mexico within the active floodplain of the Rio Grande from the San Acacia Diversion (river mile 116) to the full pool boundary of Elephant Butte Reservoir (river mile 62). The San

Acacia Reach is unique because, although altered by valley infrastructure, there are two uncontrolled tributaries that input sediment and water during summer monsoon storm events. In addition, the spring hydrograph maintains the historic timing although magnitude and duration of flows have been altered. These processes result in a dynamic river (in certain subreaches) that supports one of the largest continuous stretches of native riparian habitat, specifically cottonwood (*Populus deltoides*), Goodding's willow (*Salix gooddingii*), and coyote willow (*Salix exigua*), and associated wildlife (Ahlers et al. 2010b). The reach is significant due to population status and occurrence of the federally endangered Rio Grande Silvery Minnow (*Hybognathus amarus*) and Southwestern Willow Flycatcher, and candidate species, the Western Yellow-billed Cuckoo and the New Mexico Meadow Jumping Mouse (*Zapus hudsonius luteus*) (U.S. Fish and Wildlife Service 2003; Ahlers et al. 2010a; Ahlers et al. 2010b; U.S. Fish and Wildlife Service 2013). Land management in the reach includes two National Wildlife Refuges (Sevilleta National Wildlife Refuge and Bosque del Apache National Wildlife Refuge), U.S. Bureau of Reclamation river maintenance, and numerous private lands with opportunities for habitat protection and improvement partnerships.

## **4.2 METHODS**

### **4.2.1 Vegetation Sampling**

Forty four transects of variable length based on floodplain width were placed perpendicular to the river at stratified random locations. Sites were stratified by vegetation type so that all dominant vegetation types found along the San Acacia Reach (Moore and Ahlers 2008) occurred along selected transects (Table 4.2). Two vegetation data sets were collected. The first data set (hereafter referred to as the categorical data set) was collected to assess the vegetative communities along all forty four transects; the second data set (hereafter referred to as

the quantitative data set) was collected to quantify the woody species composition and structure (height and density) of selected HO classifications that had high structural variability (Table 4.3).

Table 4.2. Dominant vegetation types along the San Acacia Reach; based on 2002 vegetation data from Bureau of Reclamation (Moore and Ahlers 2008).

<b>Vegetation Type</b>	<b>Area (ha)</b>
Dense Tamarisk	1,591.5
Intermediate Aged Cottonwood with a Dense Tamarisk Understory	439.6
Mature Aged Cottonwood with a Dense Tamarisk Understory	194.7
Intermediate Aged Cottonwood with an Open Understory	119.3
Mature Aged Cottonwood with an Open Understory	0.09
Dense Early Succession Cottonwood	0.08
Intermediate Aged Goodding's Willow with a Dense Tamarisk Understory	0.07
Dense Coyote Willow	0.07

Table 4.3. Hink and Ohmart (1984) community types sampled with quantitative data collection. Canopy and understory layers are separated by a slash (/). Species within the same layer are separated by a hyphen (-). The number indicates the Hink and Ohmart (1984) structure class (Table 4.1).

<b>Community Type</b>	<b>Number of Plots Sampled</b>
Salt Cedar 5	40
Cottonwood Overstory / Dense Salt Cedar 3	39
Coyote Willow 5	9
Cottonwood 5	9
Cottonwood 4	5
Russian Olive – Coyote Willow 5	2
Salt Cedar – Coyote Willow 5	2

The categorical data set was collected at all forty four transects to assess the vegetative communities of the San Acacia Reach. Forest canopy and understory species composition and

stand structure were categorically assessed along each transect at 50 meter intervals using HO classification (Table 4.1 and Figure 4.2). This layout was designed to assess vegetation communities within avian point count plots (Chapter 2). Therefore, plots were placed every 50 m along the transect (east to west), every 20 m north and south of the transect at the edge of the point count plots (0 m, 200 m, 250 m, and 450 m from river), and 50 m and 100 m north and south of the transect near the point count plots center (50 m, 100 m, 150 m, 300 m, 350 m, and 400 m from river) (Figure 4.2). At each data point, observers estimated the percent cover of the four most dominant overstory ( $> 4.5$  m) species and the four most dominant understory (0.6 m to 4.5 m) species within a 10 meter radius circle of the data point (Hink and Ohmart 1984). Percent cover was estimated in increments of five. Stand structure was classified using HO structure classes (Table 4.1) (Hink and Ohmart 1984). While my methods were based on the HO classification system, I further refined the broad structural HO classes by adding 2 variables that are important to songbird habitat (Rotenberry and Wiens 1980; Rotenberry 1985; Faccio 2003; Toledo et al. 2008; Thiele et al. 2013) but were not included in the HO classification scheme: density and visual obstruction. The number of woody stems and *Kochia*  $> 1.37$  m tall was recorded in four classes: 0 – 500, 500 – 1,000, 1,000 – 3,500, and  $> 3,500$  stems per plot. Visual obstruction was measured using a modified method of Robel et al. (1970). We positioned a piece of letter-sized paper 1.68 m above the ground and estimated the percent of the paper that was obstructed by vegetation when viewed from 5 m away. Visual obstruction measurements were taken in each cardinal direction.



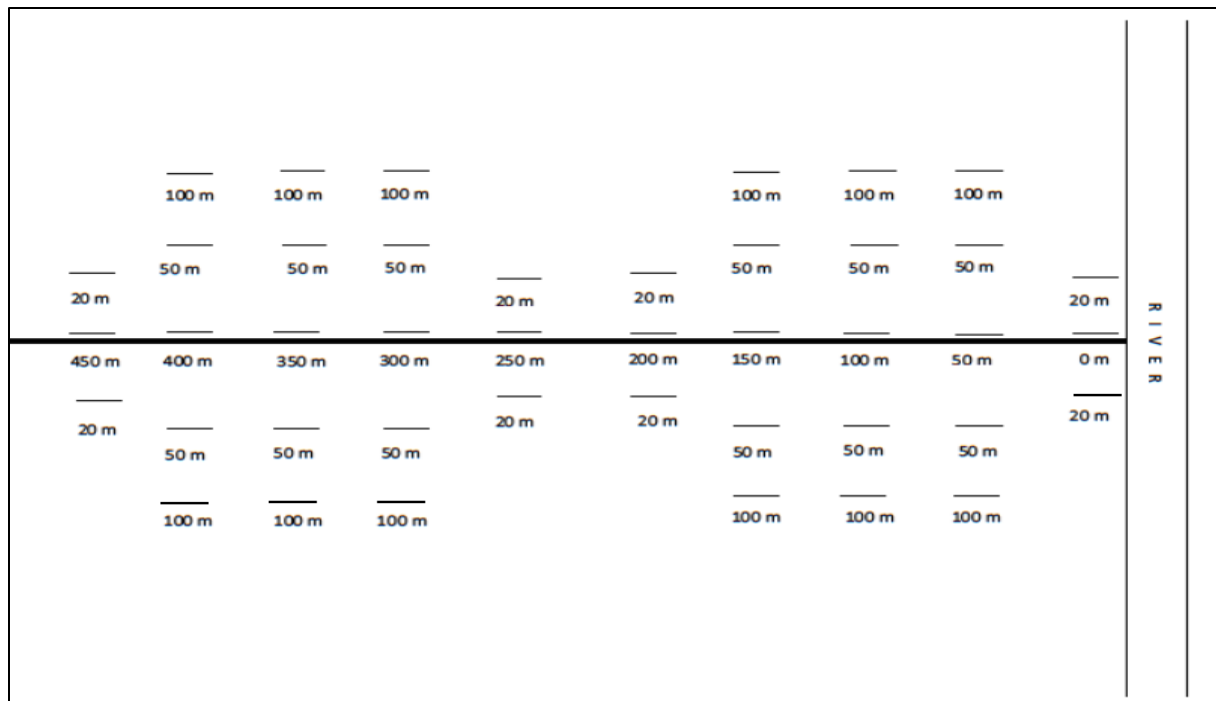


Figure 4.2. Plot layout along a belt transect. Transects were oriented perpendicular to the river and vegetation composition and stand structure were qualitatively assessed at each plot.

Using the categorical vegetation survey data, a transect was chosen that had at least 3 occurrences of the HO classification of interest (Table 4.3). Then, three plots of the categorical vegetation survey were randomly chosen. Five by ten meter plots were set up at the center of the categorical vegetation survey plot; the 10 m axis ran parallel to the river (Stromberg et al. 1996). Herbaceous cover was estimated in a 1 m<sup>2</sup> quadrat. Percent cover of the understory and overstory was assessed with a densitometer. Understory height was measured using a Robel pole (Robel et al. 1970). Tree and woody stem density was determined by counting trees and stems in the plot. Diameter was measured at 1.37 m for each woody stem, and used to calculate basal area for each plot.

#### 4.2.2 Statistical Analyses

The categorical data set was analyzed with a K-means cluster analysis to determine the amount of variability within the HO classifications (PROC FASTCLUS in SAS 9.3). Nine variables were analyzed: visual obstruction of the understory, HO structure classes 1, 3, 5, and 6 (Table 4.1), and all 4 woody stem density classes. HO structure classes 2 and 4 were not used in analysis as they occurred too rarely ( $< 1\%$ ) in the data set. The median of the four visual obstruction measurements was used as the visual obstruction measurement of the plot. Because these variables were measured on different scales, each variable was given a constant of 1 and was Z-transformed. I evaluated a range of a priori cluster numbers (2 – 10 clusters) with cluster analysis. Cubic clustering criterion, pseudo-F, and  $R^2$  were used to determine the most number of clusters with best fit.

To determine how well the HO classifications described the vegetation composition and structure, canonical discriminant function analysis with hold-one-out cross validation was used on the quantitative vegetation composition and structure data set (PROC CANDISC and PROC DISCRIM in SAS 9.3). Using quantitative variables and the HO class, canonical discriminant function analysis created a classification criterion, based on a linear combination of all quantitative variables, to classify each observation into a HO structure class. Probabilities proportional to the sample size of each HO classification were used for cross validation, meaning that the expected distribution of classifications was the same as the observed distribution of classifications, as opposed to an expectation of equal distribution of classes. Hold-one-out cross validation tested the ability of the classification criterion to correctly classify observations into a HO class by obtaining a linear combination of all quantitative variables, but randomly holding out one observation and then testing whether that observation was correctly classified into the

observed HO class (Khatree and Naik 2000). This process was repeated until all observations had been held out and tested (Khatree and Naik 2000). Canonical discriminant function analysis then assessed the performance of the HO classification system by estimating probabilities of misclassifications, or error rates (Khatree and Naik 2000).

### **4.3 RESULTS**

Categorical vegetation data collection was completed for all 44 transects, rendering a total of 1,801 vegetation plots. The three most prevalent communities in our data set were monotypic stands of dense tamarisk (756 of 1,801 sampled plots), dense stands of coyote willow (168 of 1,801 sampled plots), and intermediate aged cottonwood overstory with a dense, tamarisk-dominant understory (107 of 1,801 sampled plots). Because dense tamarisk and intermediate aged cottonwood overstory with a dense, tamarisk-dominant understory had the highest structural variability, these community types were prioritized for quantitative data collection. In total, 40 plots were completed in monotypic stands of dense tamarisk and 39 plots were completed in stands of intermediate aged cottonwood overstory and tamarisk understory. Additionally, 27 plots representing 5 different communities were also sampled (Table 4.3). Communities with the highest mean stem densities contained coyote willow and young cottonwood (Table 4.4). Dense stands of monotypic tamarisk have moderate stem density (1 - 420), while communities with an overstory have low stem density (0 – 209; 0 - 319) as the overstory competes for sunlight and prevents highly dense understories from developing (Table 4.4).

Six clusters provided the best fit for the categorical dataset (Psuedo  $F = 497.73$ ;  $R^2 = 0.29$ ; cubic clustering criterion = 159.65). HO structure class 1 was well aligned with Cluster 5 (Table 4.5). However, HO structure classes 3, 5, and 6 did not align well with the clusters

because these HO structure classes occur in several clusters (Table 4.5). Density and visual obstruction were frequently co-observed as high visual obstruction values were in the same clusters as high density classes and low visual obstruction values were in the same clusters as low density classes (Table 4.5).

Table 4.4. Mean, standard error, and range of stem densities per 50 m<sup>2</sup> of each community type sampled for quantitative data collection. Canopy and understory layers are separated by a slash (/). Species within the same layer are separated by a hyphen (-). The number indicates the Hink and Ohmart (1984) structure class (Table 4.1).

<b>Vegetation Community</b>	<b>Mean</b>	<b>Standard Error</b>	<b>Range</b>
Salt Cedar 5	77.88	12.84	1- 420
Cottonwood / Salt Cedar 3	68.13	12.78	0 – 319
Cottonwood 5	766.78	206.11	56 – 1,985
Coyote Willow 5	1,343.89	173.91	585 – 2,230
Cottonwood 4	48.40	40.54	0 – 209
Russian Olive – Coyote Willow 5	1,017.50	202.50	815 – 1,220
Salt Cedar – Coyote Willow 5	1,275.00	165.00	1,110 – 1,440

Table 4.5. Number of plots cross-referenced by variable and cluster number. Percentages of each structure and density class are in parentheses. Obstruction values are the mean values of each cluster.

<b>Cluster</b>	<b>HO Structure 1</b>	<b>HO Structure 3</b>	<b>HO Structure 5</b>	<b>HO Structure 6</b>	<b>Obstruction</b>	<b>Density 1</b>	<b>Density 2</b>	<b>Density 3</b>	<b>Density 4</b>
1	0 (0)	80 (26)	386 (33)	2 (1)	0.19	0 (0)	0 (0)	244 (78.7)	222 (19)
2	0 (0)	2 (1)	0 (0)	131 (85)	0.01	129 (79)	0 (0)	8 (3)	0 (0)
3	0 (0)	217 (72)	669 (58)	0 (0)	0.64	0 (0)	0 (0)	1 (0.3)	885 (75)
4	9 (6)	0 (0)	0 (0)	0 (0)	0.07	0 (0)	9 (8)	0 (0)	0 (0)
5	135 (94)	0 (0)	32 (3)	0 (0)	0.29	35 (21)	0 (0)	57 (18)	74 (6)
6	0 (0)	4 (1)	72 (6)	21 (14)	0.05	0 (0)	97 (92)	0 (0)	0 (0)

HO structure class 3 occurred predominately in two clusters because of the varying density and visual obstruction within this HO class (Table 4.5). Cluster 1 grouped HO structure class 3 with density class 3 and visual obstruction of 0.19, while Cluster 3 grouped HO structure class 3 with density class 4 and visual obstruction of 0.64. HO structure class 5 occurred primarily in Clusters 1 and 3, but also occurred occasionally in Cluster 5 and 6 (Table 4.5). Varying density within HO structure class 5 explains why this class is grouped in 4 different clusters. Cluster 1 grouped HO structure class 5 with density class 3 and visual obstruction of 0.19, while Cluster 3 grouped HO structure class 5 with density class 4 and visual obstruction of 0.64. Furthermore, Cluster 5 grouped a small percentage of HO structure class 5 with density classes 1, 3, and 4 and visual obstruction of 0.29, while Cluster 6 grouped a small percentage of HO structure class 5 with density class 2 and visual obstruction of 0.05. HO structure class 6 occurred predominately in Cluster 2, but also occurred in Cluster 6 (Table 4.5). Varying density within HO structure class 6 explains why this class is grouped in 2 different clusters. Cluster 2 grouped HO structure 6 with density class 1 and visual obstruction of 0.01, and Cluster 6 grouped HO structure class 6 with density class 2 and visual obstruction of 0.05. These findings indicate that the HO structure classes 3, 5, and 6 do not describe vegetative structure well.

The canonical discriminant function analysis found 6 statistically significant axes (Axis 1 - 5,  $p < 0.01$ ; Axis 6,  $p < 0.02$ ). However, these axes were poor predictors of Hink and Ohmart (1984) classes. With exception of community type Salt Cedar 5 and Salt Cedar - Coyote Willow 5, other classes have a large number of misclassifications, meaning that most observations were misclassified from their a priori classifications (Table 4.6). Only 67% of plots with community type “Cottonwood overstory and Salt Cedar understory 3” were classified

correctly. However, 100 % of community type “Salt Cedar – Coyote Willow 5” was classified correctly and 95 % of community type “Salt Cedar 5” was correctly classified (Table 4.6).

Table 4.6. Confusion matrix from canonical discriminant function analysis. Vegetation community types are denoted using Hink and Ohmart notation. C/SC3: intermediate aged cottonwood overstory with dense tamarisk understory; C4: intermediate aged cottonwood with a sparse understory; C5: dense early succession cottonwood; CW5: dense coyote willow; RO-CW5: dense early succession Russian olive dominant - coyote willow second dominant; SC-CW5: dense tamarisk dominant - coyote willow second dominant; SC5: dense tamarisk.

<b>Vegetation Community</b>		<b>C/SC 3</b>	<b>C 4</b>	<b>C 5</b>	<b>CW 5</b>	<b>RO - CW 5</b>	<b>SC – CW 5</b>	<b>SC 5</b>	<b>Total</b>
<b>C/SC 3</b>	Number of Plots	26	3	1	1	3	2	3	39
	Percentage of Plots	66.7%	7.7%	2.6%	2.6%	7.7%	5.1%	7.7%	100%
<b>C 4</b>	Number of Plots	4	0	1	0	0	0	0	5
	Percentage of Plots	80.0%	0.0%	20.0%	0.0%	0.0%	0.0%	0.0%	100%
<b>C 5</b>	Number of Plots	0	2	6	1	0	0	0	9
	Percentage of Plots	0.0%	22.2%	66.7%	11.1%	0.0%	0.0%	0.0%	100%
<b>CW5</b>	Number of Plots	0	0	3	4	1	1	0	9
	Percentage of Plots	0.0%	0.0%	33.3%	44.4%	11.1%	11.1%	0.0%	100%
<b>RO – CW 5</b>	Number of Plots	0	0	0	0	1	1	0	2
	Percentage of Plots	0.0%	0.0%	0.0%	0.0%	50.0%	50.0%	0.0%	100%
<b>SC – CW 5</b>	Number of Plots	0	0	0	0	0	2	0	2
	Percentage of Plots	0.0%	0.0%	0.0%	0.0%	0.0%	100%	0.0%	100%
<b>SC 5</b>	Number of Plots	1	0	0	1	0	0	38	40
	Percentage of Plots	2.5%	0.0%	0.0%	2.5%	0.0%	0.0%	95.0%	100%
<b>Total</b>	Number of Plots	31	5	11	7	5	6	41	106
	Percentage of Plots	29.3%	4.7%	10.4%	6.6%	4.7%	5.7%	38.7%	100%

## 4.4 DISCUSSION

The results of this study indicate that there is substantial variability in vegetative structure in the Hink and Ohmart (1984) classes (Figure 4.1). The K-means clusters did not align well with HO structure classes 3, 5, and 6, indicating that there was high variability in stem density and visual obstruction in these HO classes. The quantitative data set did not well elucidate the classes as there was a high number of misclassifications in the canonical discriminant function analysis (Table 4.6), suggesting that the HO structural classifications are coarse. Numerous studies indicate that vegetative structure, such as stem density and visual obstruction, is important for songbirds (MacArthur and MacArthur 1961; Willson 1974; Rotenberry and Wiens 1980; Schemske and Brokaw 1981; Rotenberry 1985; Faccio 2003; Zurita and Zuleta 2009). The high variability in stem density and visual obstruction within the HO classes could lead to erroneous decisions regarding habitat needs of avian species, including endangered species in the region.

Vegetation classification systems should be based on practical considerations and management objectives (Mucina 1997; Ewald 2003; De Cáceres and Wiser 2012). The Hink and Ohmart (1984) classification method may be well suited for broad scale analyses. For example, the broad scale classification that is currently used (Ahlers et al. 2010a) categorizes the five different vegetation communities in Figure 4.3 as one vegetation community (also see Figure 4.4 and 4.5). However, for the purpose of identifying important habitats for songbird species, particularly endangered species, HO classification scheme is ineffective because there is high variability in stem density and visual obstruction within HO structure classes (Table 4.5) that occludes the development of clear management prescriptions.

The HO classes have high structural variability and large numbers of misclassifications when considering them in the context of data required to quantify bird habitat (Table 4.5 and 4.6), indicating that the classification system is too coarse if the objective of the study is to quantify songbird habitat. For instance, a management recommendation to manage for HO community type Coyote Willow 5 is too vague because it gives no quantitative guidelines on structural characteristics such as stem density and visual obstruction, thus allowing for a wide range of structures to be implemented in management (Table 4.5), leading to potentially erroneous habitat manipulations (Table 4.6). Within the HO community type Coyote Willow 5, stem densities ranged from 585 – 2,230 in a 5 x 10 m plot (Table 4.4). Large variability was also observed in stem densities in HO community types Cottonwood 5 and Salt Cedar 5 (Table 4.4). Therefore, when habitat management is implemented, managers need quantitative data, such as percent cover, visual obstruction, and stem density, rather than qualitative data, to guide habitat manipulations. When a songbird species of interest, such as the endangered Southwestern Willow Flycatcher, needs high stem density in its habitat (Ahlers et al. 2010a), managers need to have a quantitative definition of high stem density, rather than just a HO structure class.

Analyses indicated that including density classes and visual obstruction in conjunction with the current Hink and Ohmart (1984) classification methodology would improve this classification method (Table 4.5). However, analyses showed that visual obstruction and density classes captured the same information; therefore only the addition of woody stem density classes to the HO methodology is necessary. Vegetation surveys conducted using the woody stem density classes in conjunction with the HO classification methods will provide more robust data, better inform management prescriptions, and improve understanding of avian habitat needs along the MRG.



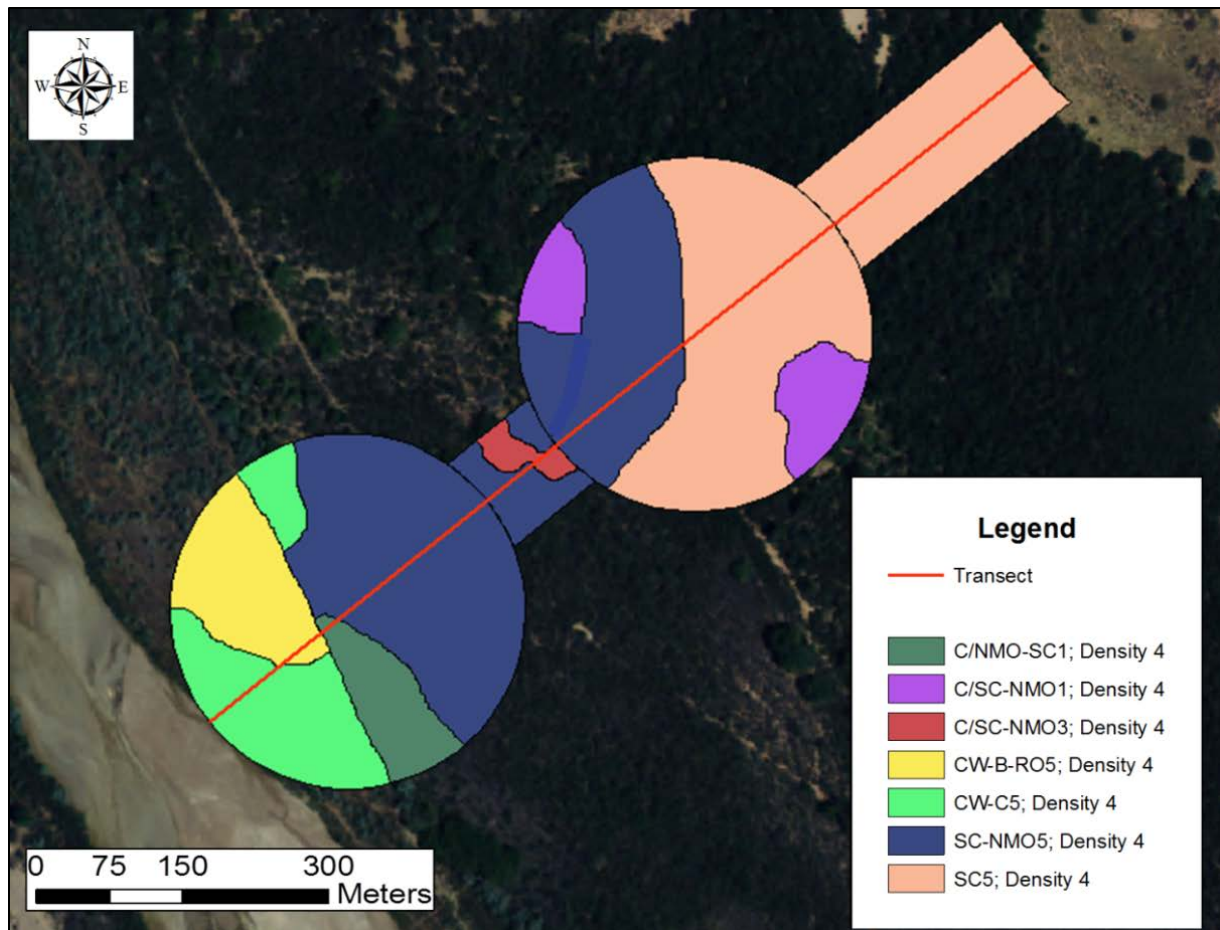


Figure 4.3. Vegetation types along a 600 m transect as classified using the categorical vegetation survey methods used in this study. In previous vegetation surveys, these plots have been classified as one Hink and Ohmart (1984) vegetation community. Vegetation community types are denoted using Hink and Ohmart notation. C/NMO-SC1: mature aged cottonwood overstory with dense New Mexico olive dominant - tamarisk second dominant understory; C/SC-NMO1: mature aged cottonwood overstory with dense tamarisk dominant – New Mexico olive second dominant understory; C/SC-NMO3: intermediate aged cottonwood overstory with dense tamarisk dominant – New Mexico olive second dominant understory; CW-B-RO5: dense coyote willow dominant – *Baccharis* second dominant– Russian olive third dominant; CW-C5: dense early succession coyote willow dominant – cottonwood second dominant; SC-NMO5: dense tamarisk dominant – New Mexico olive second dominant; SC5: dense tamarisk.

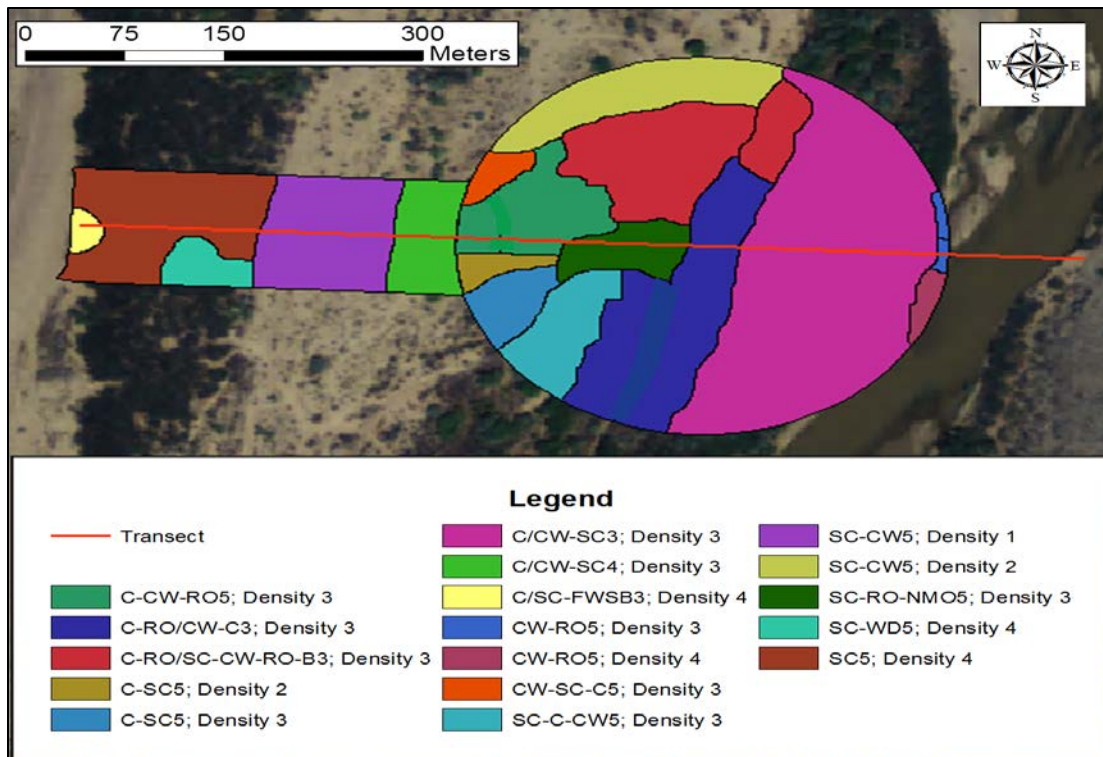


Figure 4.4. Vegetation types along a 350 m transect as classified using the categorical vegetation survey methods used in this study. In previous vegetation surveys, this transect was classified as three different Hink and Ohmart (1984) vegetation communities. Vegetation community types are denoted using Hink and Ohmart notation. C-CW-RO5: dense early succession cottonwood dominant - coyote willow second dominant – Russian olive third dominant; C-RO/CW-C3: intermediate aged cottonwood dominant – Russian olive second dominant overstory with dense coyote willow dominant – cottonwood second dominant understory; C-RO/SC-CW-RO-B3: intermediate aged cottonwood dominant – Russian olive second dominant overstory with dense tamarisk dominant – coyote willow second dominant – Russian olive third dominant - *Baccharis* forth dominant understory; C-SC5: dense early succession cottonwood dominant – tamarisk second dominant; C/CW-SC3: intermediate aged cottonwood overstory with dense coyote willow dominant – tamarisk second dominant understory; C/CW-SC4: intermediate aged cottonwood overstory with sparse coyote willow dominant – tamarisk second dominant understory; C/SC-FWSB3: intermediate aged cottonwood overstory with dense tamarisk dominant – four-wing saltbush second dominant understory; CW-RO5: dense coyote willow dominant - early succession Russian olive second dominant; CW-SC-C5: dense coyote willow dominant – tamarisk second dominant – early succession cottonwood third dominant; SC-C-CW5: dense early succession tamarisk dominant – cottonwood second dominant – coyote willow third dominant; SC-CW5: dense tamarisk dominant – coyote willow second dominant; SC-RO-NMO5: dense tamarisk dominant – early succession Russian olive second dominant – New Mexico olive third dominant; SC-WD5: dense tamarisk dominant – woody debris second dominant; SC5: dense tamarisk.

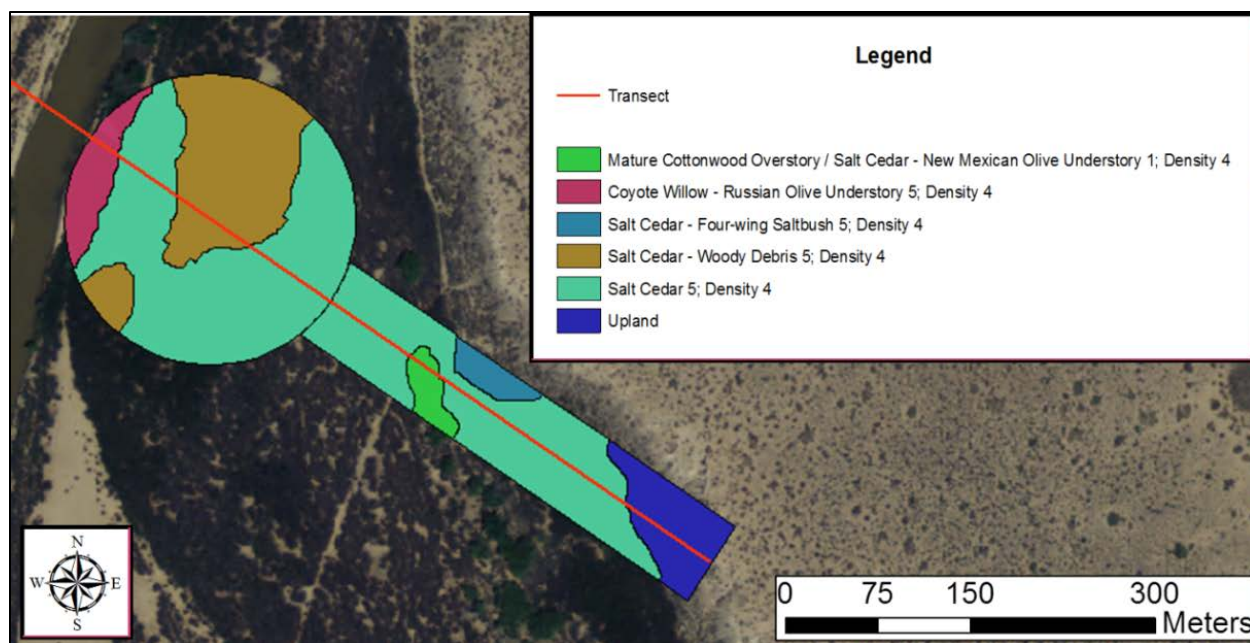


Figure 4.5. Vegetation types along a 450 m transect as classified using the categorical vegetation survey methods used in this study. In previous vegetation surveys, this transect was classified as two different Hink and Ohmart (1984) vegetation communities. Vegetation structure types are denoted using Hink and Ohmart structure classes (Table 4.1).

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## **CHAPTER 5 CONCLUSIONS**

### **5.1 CONCLUSIONS**

The San Acacia Reach of the Middle Rio Grande is highly modified, resulting in vegetative shifts from native cottonwood/willow forests to exotic tamarisk stands. This is reflected as invasive tamarisk was the dominant species in all 3 subreaches. Even along Subreach 2, where surface flooding is most active, exotic understory was the most dominant plant cover. The unanticipated low cover of native vegetation along Subreach 2 could be related to increased depths to groundwater and/or the presence of exotic understory that is preventing native species establishment. For instance, 31% of inundated plots at 152 cms (a 5 year flood) along Subreach 2 supported dense tamarisk (Hink and Ohmart class: Salt Cedar 5). If tamarisk was not present at these sites, native vegetation could be established during these high flow events. While Subreach 2 has the highest restoration potential as overbank flooding is most active along this subreach, dense tamarisk must be removed first to allow native species establishment. Because surface flooding is limited along incised Subreaches 1 and 3, restoration efforts must include bank modification (e.g., lowering bank height, removal of root armoring) as well as tamarisk removal prior to surface flooding to promote native vegetation recruitment.

This research has increased understanding of songbird responses to vegetation and the limitations of hydrology and geomorphology in a semi-arid system. By delineating the geomorphic and hydrologic differences among subreaches of the San Acacia Reach, I was able to compare vegetative and songbird communities in different hydrogeomorphic settings. Results suggest that maintaining or increasing overbank flows would enhance avian relative abundance, particularly in Bell's Vireos, Black-chinned Hummingbirds, Summer Tanagers, Western Yellow-



billed Cuckoos, Lucy's Warblers, and other canopy-nesting species, as overbank flows promote establishment and survival of native overstory and understory (Stromberg et al. 1996; Johnson 2000; Levine and Stromberg 2001, Brand et al. 2008; Caplan et al. 2013). Even along incised subreaches, I found legacy cottonwood and Goodding's willow trees that provide suitable habitat for canopy-nesting birds now and in the near future. However, incised channels do not well support regeneration of cottonwood and Goodding's willow as overbank flows occur less frequently along incised reaches (Stromberg et al. 1996; Katz et al. 2005; Stromberg et al. 2007). Therefore, incised subreaches with legacy trees provide suitable habitat for canopy-nesting birds now and in the near future, but these habitat conditions are not sustainable long-term. The legacy native overstory will eventually die off, and if increased surface flooding is not restored along incised subreaches to regenerate native tree species, a decline of canopy-nesting birds and species of concern, such as the Western Yellow-billed Cuckoo and Lucy's Warbler, should be expected.

Based on findings of previous studies, surface flooding alone may be insufficient to support native vegetation as depth to groundwater has a strong influence on regeneration of cottonwood and Goodding's willow and can strongly affect tree growth, stress, and survival (Stromberg et al. 1996; Horton et al. 2001; Brand et al. 2010; Brand et al. 2011). As increased depths to groundwater is a pressing issue along the Middle Rio Grande (Bowman 2007), future research should assess and integrate groundwater processes to enhance our understanding of water, vegetation, and avian community linkages.

Particular focus was placed on the habitat needs of the Western Yellow-billed Cuckoo as it is a candidate for listing under the Endangered Species Act and is listed as

endangered, threatened, or sensitive by the states of Utah, New Mexico, Arizona, Colorado, and California (Sechrist et al. 2009). Based on the results of this study and others (Sechrist et al. 2009), it appears that cuckoos are generalists in terms of understory vegetation species composition as long as the understory is dense; however, cuckoos need native overstory species. These findings have important implications for habitat restoration and maintenance of long-term habitat for the Western Yellow-billed Cuckoo.

Communities of native overstory with woody debris or those dominated by exotic species in the understory are ephemeral suitable cuckoo habitat, and restoration and maintenance of habitat will be necessary to develop and/or sustain long-term suitable habitat for Western Yellow-billed Cuckoos. Goodding's willow and cottonwood need bare mineral substrate and overbank flows to germinate and establish (Stromberg 1993), thus periodic overbank flows will be necessary to regenerate native overstory. Furthermore, at sites where dense tamarisk is present, the tamarisk must be removed prior to overbank floods to allow native species establishment (Cleverly and Dello Russo 2007). For instance, cold spots that were inundated at 213 cms and have a shallow depth to groundwater may be ideal restoration sites as these areas have the necessary hydrologic conditions to support native species. In conclusion, management of riparian forests that promotes overbank floods and the regeneration and survival of cottonwood and Goodding's willow overstory, with a mixed understory of Goodding's willow, coyote willow, and New Mexico olive would provide long-term suitable habitat for Western Yellow-billed Cuckoos.

In this study, I also quantified the amount of variability that occurs within the six Hink and Ohmart (1984) vegetation structure classes, a vegetation classification scheme that is widely

used throughout the Middle Rio Grande. These six structure types are delineated by presence/absence of an overstory and understory, approximate height of overstory and understory, approximate age of overstory, and vague descriptions of understory density for each class (Hink and Ohmart 1984). However, the six broad structure types of Hink and Ohmart potentially allow for high structural variability (specifically high variability in stem density) within a given classification. High variability in stem density within a class could be a noteworthy shortcoming when managing habitat for songbirds; therefore, in songbird studies, it is important to assess vegetative communities in a manner that captures variability in habitat structure (density and height) and species composition (MacArthur and MacArthur 1961; Willson 1974; Rotenberry and Wiens 1980; Schemske and Brokaw 1981; Rotenberry 1985; Faccio 2003; Zurita and Zuleta 2009). My analyses indicated that vegetation surveys conducted using woody stem density classes (class 1: 0 – 500; class 2: 500 – 1,000; class 3: 1,000 – 3,500; and class 4: > 3,500 stems) in conjunction with the Hink and Ohmart (1984) classification methods will provide more robust data, better inform management prescriptions, and improve understanding of avian habitat needs along the Middle Rio Grande.

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# APPENDIX A

## LIST OF ALL LAND BIRD SPECIES DETECTED THROUGHOUT THIS STUDY

Ring-necked Pheasant	<i>Phasianus colchicus</i>
Gambel's Quail	<i>Callipepla gambelii</i>
Killdeer	<i>Charadrius vociferus</i>
White-winged Dove	<i>Zenaida asiatica</i>
Mourning Dove	<i>Zenaida macroura</i>
Eurasian Collared Dove	<i>Streptopelia decaocto</i>
Western Yellow-billed Cuckoo	<i>Coccyzus americanus occidentalis</i>
Greater Roadrunner	<i>Geococcyx californianus</i>
Black-chinned Hummingbird	<i>Archilochus alexandri</i>
Northern Flicker	<i>Colaptes auratus</i>
Downy Woodpecker	<i>Picoides pubescens</i>
Hairy Woodpecker	<i>Picoides villosus</i>
Ladder-backed Woodpecker	<i>Picoides scalaris</i>
Western Wood-Pewee	<i>Contopus sordidulus</i>
Southwestern Willow Flycatcher	<i>Empidonax traillii extimus</i>
Cordilleran Flycatcher	<i>Empidonax occidentalis</i>
Black Phoebe	<i>Sayornis nigricans</i>
Say's Phoebe	<i>Sayornis saya</i>
Vermillion Flycatcher	<i>Pyrocephalus rubinus</i>
Ash-throated Flycatcher	<i>Myiarchus cinerascens</i>
Western Kingbird	<i>Tyrannus verticalis</i>
Loggerhead Shrike	<i>Lanius ludovicianus</i>
Bell's Vireo	<i>Vireo bellii</i>
Plumbeous Vireo	<i>Vireo plumbeus</i>
Warbling Vireo	<i>Vireo gilvus</i>
Common Raven	<i>Corvus corax</i>
Chihuahuan Raven	<i>Corvus cryptoleucus</i>

Tree Swallow	<i>Tachycineta bicolor</i>
Northern Rough-winged Swallow	<i>Stelgidopteryx serripennis</i>
Barn Swallow	<i>Hirundo rustica</i>
Cliff Swallow	<i>Petrochelidon pyrrhonota</i>
Verdin	<i>Auriparus flaviceps</i>
Bushtit	<i>Psaltiriparus minimus</i>
White-breasted Nuthatch	<i>Sitta carolinensis</i>
Bewick's Wren	<i>Thryomanes bewickii</i>
Canyon Wren	<i>Catherpes mexicanus</i>
Black-tailed Gnatcatcher	<i>Polioptila melanura</i>
American Robin	<i>Turdus migratorius</i>
Northern Mockingbird	<i>Mimus polyglottos</i>
Gray Catbird	<i>Dumetella carolinensis</i>
Curve-billed Thrasher	<i>Toxostoma curvirostre</i>
Crissal Thrasher	<i>Toxostoma crissale</i>
Phainopepla	<i>Phainopepla nitens</i>
Lucy's Warbler	<i>Vermivora luciae</i>
Yellow Warbler	<i>Dendroica petechia</i>
Yellow-rumped Warbler	<i>Dendroica coronata</i>
American Redstart	<i>Setophaga ruticilla</i>
MacGillivray's Warbler	<i>Oporornis tolmiei</i>
Common Yellowthroat	<i>Geothlypis trichas</i>
Wilson's Warbler	<i>Wilsonia pusilla</i>
Hooded Warbler	<i>Wilsonia citrina</i>
Yellow-breasted Chat	<i>Icteria virens</i>
Western Tanager	<i>Piranga ludoviciana</i>
Summer Tanager	<i>Piranga rubra</i>
Indigo Bunting	<i>Passerina cyanea</i>
Blue Grosbeak	<i>Guiraca caerulea</i>
Black-headed Grosbeak	<i>Pheucticus melanocephalus</i>
Spotted Towhee	<i>Pipilo maculatus</i>

Cassin's Sparrow	<i>Aimophila cassinii</i>
Black-throated Sparrow	<i>Amphispiza bilineata</i>
Lark Sparrow	<i>Chondestes grammacus</i>
Bullock's Oriole	<i>Icterus bullockii</i>
Western Meadowlark	<i>Sturnella neglecta</i>
Red-winged Blackbird	<i>Agelaius phoeniceus</i>
Great-tailed Grackle	<i>Quiscalus mexicanus</i>
Brown-headed Cowbird	<i>Molothrus ater</i>
House Finch	<i>Carpodacus mexicanus</i>
Lesser Goldfinch	<i>Carduelis psaltria</i>
American Goldfinch	<i>Carduelis tristis</i>



## **VITA**

Sarah Hamilton was born and raised in north Alabama. She graduated with a Bachelor of Science in Wildlife Science from Auburn University in 2009. Prior to enrolling in the graduate program at Louisiana State University in 2011, she spent several years traveling and working in the wildlife biology field for Auburn University, Student Conservation Association, and Jatun Sacha Foundation. She is a candidate for a Master's of Science degree.