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QUANTIFYING IMPACTS OF GROUND WATER WITHDRAWAL ON AVIAN COMMUNITIES IN DESERT RIPARIAN WOODLANDS OF THE SOUTHWESTERN U.S.

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Quantifying impacts of ground water withdrawal on avian communities in desert riparian woodlands of the southwestern U.S.

Final Report

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EXECUTIVE SUMMARY

Riparian woodlands in the desert southwest are an extremely important resource because they constitute <1% of the desert landscape, yet typically support >50% of the breeding birds. Riparian woodlands also provide shelter and critical food resources for dozens of species of migratory birds that alight in these woodlands during their spring and fall migrations across the desert southwest. Ground water withdrawal (and subsequent loss of surface water) to support urban developments, agriculture, mining, etc. in the desert southwest has the potential to degrade or eliminate riparian woodlands throughout the region, including riparian woodlands along the Upper San Pedro River adjacent to Fort Huachuca Military Reservation, Arizona. Military readiness could be jeopardized if limited military resources are diverted from the military's mission at Fort Huachuca Military Reservation (and at other military installations in the southwestern U.S.) to deal with the recovery of potentially dozens of declining populations of birds. The goal of this study was to quantify the value of riparian woodlands to the health and persistence of riparian bird communities in the desert southwest. Specifically, our objectives were to quantify the extent to which surface water and riparian vegetation health influence the abundance and diversity of riparian birds. From 2006-2008, we surveyed birds, sampled vegetation, and measured surface water at 28 replicate study sights located in riparian woodlands throughout southeastern Arizona, including several study sites situated along the Upper San Pedro River near Fort Huachuca Military Reservation. We used an information-theoretic approach to examine our data in both a spatial (i.e., using data collected at each of the 28 sites in at least one year of the study) and a temporal (i.e., using data collected at 8 sites sampled in both 2006 and 2008) analytical framework. We also sampled avian food resources (i.e., aerial and arboreal arthropods) and monitored nests of riparian bird species at a subset of these study sites.

We found that riparian areas contained 68% more species and 75% more individual birds compared to adjacent uplands, with this pattern holding true for both the breeding and non-breeding bird communities. We found that the presence and extent of surface water was positively associated with both total relative abundance and species richness of riparian birds. At the species level, we found that the majority of riparian birds analyzed were positively associated with surface water, including breeding birds like the Black Phoebe, Common Yellowthroat, Yellow Warbler, Song Sparrow, and Lesser Goldfinch, and long-distance, migrant birds like the Yellow-rumped Warbler and Wilson's Warbler (results were similar for both our spatial and temporal analyses). We found negative associations with surface water for several other riparian birds including White-winged Dove, Bell's Vireo, Yellow-breasted Chat, Abert's Towhee, and Summer Tanager. Results from our arboreal and aerial arthropod sampling indicated that arthropod biomass increased at sites with increased water. We observed that riparian trees with decreased water stress had more arboreal arthropod biomass compared to riparian trees with increased water stress and we found that aerial arthropod biomass of flies (*Diptera*) appeared to be positively associated with increased extent of surface water. These results suggest a possible causal connection between increased water and increased bird abundance and diversity in riparian woodlands within our study area. We detected few associations between our bird parameters and the health of riparian vegetation. However, it was clear from an examination of the vegetation data collected from our study sites that we did not have a representative sample of appropriate sites (i.e., sites with extensive dormant/dead vegetation) to adequately examine the issue of riparian vegetation health. We also observed decreased nesting attempts by Bell's

Vireos and Yellow Warblers at one study site (Rincon Creek) that appear to have resulted from extensive dormancy/die-back of riparian vegetation at the site. The exact cause of this tree dormancy/die-back remains undetermined, but almost 9 years of drought in the region may be a contributing factor.

We believe that riparian bird communities in Arizona are threatened in 2 ways by future water loss. First, should long-term drought conditions persist and/or ground water levels fall to the point where surface water flows are reduced or eliminated, populations of breeding (e.g., Black Phoebe, Common Yellowthroat, Yellow Warbler, Song Sparrow, and Lesser Goldfinch) and migrant (e.g., Yellow-rumped Warbler and Wilson's Warbler) species are likely to decline. Second, should long-term drought conditions persist and/or ground water levels fall to the point that riparian vegetation is negatively affected, populations of breeding species such as Bell's Vireos, Yellow Warblers, and others are likely to decline. Results from this study provide quantitative data that will allow resource managers on military lands (and elsewhere) to better predict how abundance and diversity of riparian birds will be affected by future reductions in ground and surface water levels on or near military installations in the desert southwest. This report summarizes results from a 3-year study funded, in part, by the DoD Legacy Resource Management Program.

INTRODUCTION

Low-elevation riparian woodlands (henceforth "riparian woodlands"; Fig. 1) in the desert southwest currently make up a small fraction of the desert landscape. For example, only 0.5% of the land area in Arizona is riparian woodland (Johnson et al. 1977). Despite the rarity of this vegetation community, riparian woodlands provide valuable wildlife habitat (Knopf and Samson 1994). Over 50% of breeding bird species in the southwestern U.S. are considered to be dependent upon riparian woodlands (Johnson et al. 1977). In addition, riparian woodlands provide critical stopover habitat for many species of long-distance, migratory birds. The high species richness of birds in riparian woodlands relative to surrounding vegetative communities is commonly attributed to the structural complexity of the vegetation (Anderson and Ohmart 1977, Bull and Skovlin 1982, Knopf and Samson 1994). However, the surface water itself may be equally or more important because riparian woodlands with surface water support higher densities of invertebrate prey (Jackson and Fisher 1986, Gray 1993). Little is known about the role that surface water itself plays in determining the relative value of riparian woodlands to birds in Arizona. If surface water directly enhances the value of riparian woodlands for birds, even relatively small reductions in the ground water table may have large repercussions on the availability of surface water and on the abundance and species composition of the avian community.

In addition to their support of birds, riparian woodlands appear to have a positive effect on the ecological integrity of surrounding desert areas because many species of desert birds regularly travel to riparian woodlands to obtain water and food (Pleasants 1979, Knopf and Samson 1994). Indeed, the positive effects of even a degraded riparian area in central Arizona extend up to 1 km into the adjacent uplands (Szaro and Jakle 1985). Riparian woodlands are threatened by many sources, including poor grazing practices and alteration for recreational use, but perhaps the greatest long-term issue is simply the removal of water. Recent droughts and increasing water needs of a growing human population in the desert southwest are leaving many areas more and more reliant on ground water. Ground water withdrawal can lead to lowering of local and regional water tables within entire watersheds (Judd et al. 1971), thus altering riparian plant communities that depend upon a shallow ground water table. Riparian plants appear well adapted to seasonal and annual variation in water availability (including periodic flooding), but cannot withstand alteration of flow or permanent reduction in the ground water table (Busch and Smith 1995). In addition, lowered ground water tables leads to direct loss of flowing water and pools in streams (Bedient and Huber 1992). Ground water withdrawal is currently a threat to many riparian woodlands throughout the desert southwest.

For example, the Upper San Pedro River, adjacent to Fort Huachuca Military Reservation and the City of Sierra Vista, Arizona, is the southwest's largest undammed river and supports one of the largest riparian woodlands in the desert southwest (Krueper 2003). Over 300 species of birds (including approximately 100 breeding and 250 migrant species) have been recorded in these riparian woodlands. Almost all of these species are protected under the Migratory Bird Treaty Act. Ground water withdrawal to support Fort Huachuca and the growing development associated with the City of Sierra Vista and Cochise County has the potential to degrade or even destroy the riparian woodlands along the Upper San Pedro River. Besides the Upper San Pedro

Figure 1. Riparian woodlands along A) Bonita Creek and B) Cienega Creek in southeastern Arizona. The tree species visible in the photographs are Fremont cottonwood, Goodding willow, and velvet ash.

River, rapidly expanding human populations near other important riparian areas in southern Arizona (e.g., Rincon Creek near Tucson, Santa Cruz River near Green Valley) have the potential to negatively impact riparian woodlands throughout the region. Other military bases in the southwestern U.S. have riparian woodlands (e.g., Fort Hood, TX) or are located adjacent to areas with riparian woodlands (e.g., White Sands Missile Range, NM) and may face similar problems in the foreseeable future. The loss or degradation of riparian woodlands throughout the desert southwest is a serious and growing threat to numerous species of birds that depend on these areas for breeding, wintering, and/or migratory habitat.

In-stream flows can be legally reduced via ground water pumping and surface water diversions and these actions may affect native wildlife. Regulations governing ground water pumping and surface water diversions do not automatically provide for protection of riparian plants despite their presumed importance to endemic wildlife. Quantifying the impacts of ground water withdrawal and surface water depletion on riparian wildlife is needed in order to justify protection of riparian woodlands (Stromberg et al. 1996). However, a clear link must be established between ground water, surface water, and the wildlife value of a riparian area in order to preserve in-stream flow rights. Establishing such a link is relatively easy for aquatic species such as fish, but is more difficult for non-aquatic species such as birds because we currently are not able to predict how reductions in surface water will affect the avian community. Recent biological inventories in southern Arizona have highlighted the value of riparian woodlands and have also created an awareness of how ground water withdrawal and surface water diversions may be potentially grave long-term concerns (Powell 2004). Human populations are growing rapidly in the desert southwest and new developments require new water sources.

Understanding connections between ground and surface water resources in the desert southwest requires a focused effort, and even rudimentary hydrological studies have yet to be conducted in most riparian areas. However, it is clear that the greatest areas of biological diversity are centered around major riparian woodlands where surface water is present at least part of the year. Indeed, the Arizona Partners in Flight (PIF) conservation plan has identified low-elevation riparian habitat as the top priority habitat in Arizona in need of conservation because it contains immense biological importance and is severely threatened within Arizona (Latta et al. 1999). Three species that inhabit low-elevation riparian woodland are considered Arizona PIF priority species: Southwestern Willow Flycatcher (*Empidonax traillii extremus*), Western Yellow-billed Cuckoo (*Coccyzus americanus occidentalis*), and Lucy's Warbler (*Vermivora luciae*). The Southwestern Willow Flycatcher and the Western Yellow-billed Cuckoo are considered wildlife of special concern in Arizona (Arizona Game and Fish Department 1996) and are federally listed as endangered and candidate species, respectively (Federal Register 1996). Both species are found breeding along the Upper San Pedro River and in other riparian areas in southern Arizona. Loss or degradation of riparian habitat is considered to be the single greatest threat to the persistence of populations of these 3 species in Arizona (Latta et al. 1999). An additional 8 species that inhabit low-elevation riparian woodland are considered Arizona PIF preliminary priority species: Brown-crested Flycatcher (*Myiarchus tyrannulus*), Northern Beardless-tyrannulet (*Camptostoma imberbe*), Bell's Vireo (*Vireo bellii*), Yellow Warbler (*Dendroica petechia*), Rufous-winged Sparrow (*Aimophila carpalis*), Abert's Towhee (*Pipilo aberti*), and Summer Tanager (*Piranga rubra*).

To address these growing concerns, we quantified the importance of riparian woodlands to the health of riparian bird communities from 2006-2008 within 28 replicate study sites located throughout southeastern Arizona. We conducted our study in replicate study sites that were characterized by similar riparian woodland vegetation but that varied in the amount and extent of surface water present as well as the "health" of the riparian vegetation present (as measured by the proportion of dormant or dead vegetation) Specifically, we measured avian abundance, species richness, and reproductive health within these riparian woodlands while at the same time quantifying the presence and extent of surface water, vegetation parameters, and abundance of arthropod food resources. Although bird species richness and abundance are often higher in riparian woodlands (compared to surrounding plant communities), we do not know whether these results are due to greater vegetation cover, food availability, or water availability. We examined this issue by attempting to identify the causal mechanisms that explain why riparian woodlands are so valuable for birds.

PROJECT OBJECTIVES

Efforts to protect the function and sustainability of riparian bird communities in the desert southwest require predictions about the potential effects of ground water withdrawal (and subsequent surface water depletion) on the natural resources in this important vegetation type. Therefore, the goal of this research project was to assess the value of riparian woodlands to the health and persistence of avian communities in the desert southwest. Specifically, we sought to quantify the extent to which surface water and the health of riparian vegetation (i.e., the percentage of vegetation that is dead or dormant) influence the abundance and diversity of riparian birds. Ultimately, our objective was to develop a set of models to allow resource managers on military (and other) lands to better predict the ultimate effects of future ground water withdrawal and surface water depletion on riparian bird communities along the Upper San Pedro River and elsewhere in the desert southwest. To facilitate the development of these models, we tested the following statistical hypotheses using data collected from 2006-2008.

1) Riparian areas have higher species richness and total relative abundance than the surrounding landscape

2) Amount of surface water in the 50 m surrounding a survey point is positively correlated with avian species richness and relative abundance

3) Proportion of riparian vegetation that is dead/dormant in the 50 m surrounding a survey point is negatively correlated with avian species richness and relative abundance

4) Increase in surface water (from 2006 to 2008) in the 50 m surrounding a survey point is positively correlated with an increase in avian relative abundance

5) Aerial arthropod biomass is greater in riparian areas with surface water compared to riparian areas lacking surface water

6) Arboreal arthropod biomass is greater on riparian tress with less water stress compared to riparian trees with more water stress

7) Clutch sizes, egg volumes, and nesting success are higher in riparian areas with surface water compared to riparian areas lacking surface water (for a focal species)

Maintaining the health of riparian woodlands (and their associated bird communities) is a top priority for the agencies that are mandated to protect and/or enhance natural resources in the desert southwest. Therefore, we sought to create partnerships among all of the federal agencies, state agencies, local agencies, non-governmental organizations, and private landowners that have a vested interest in protecting riparian woodlands in the desert southwest during the current study. Loss or degradation of riparian woodlands is an especially important issue for the Department of Defense (DoD) because ground water withdrawal has the potential to curtail installations' missions and reduce military readiness should ineffective action be taken to protect the health of vulnerable riparian woodlands on or near military bases in the desert southwest (e.g., Fort Huachuca, Fort Hood, and White Sands Missile Base). By being able to better predict the effects of ground water withdrawal on bird communities, the DoD and other agencies can work proactively to protect these areas before riparian woodlands become degraded and bird populations become threatened or endangered.

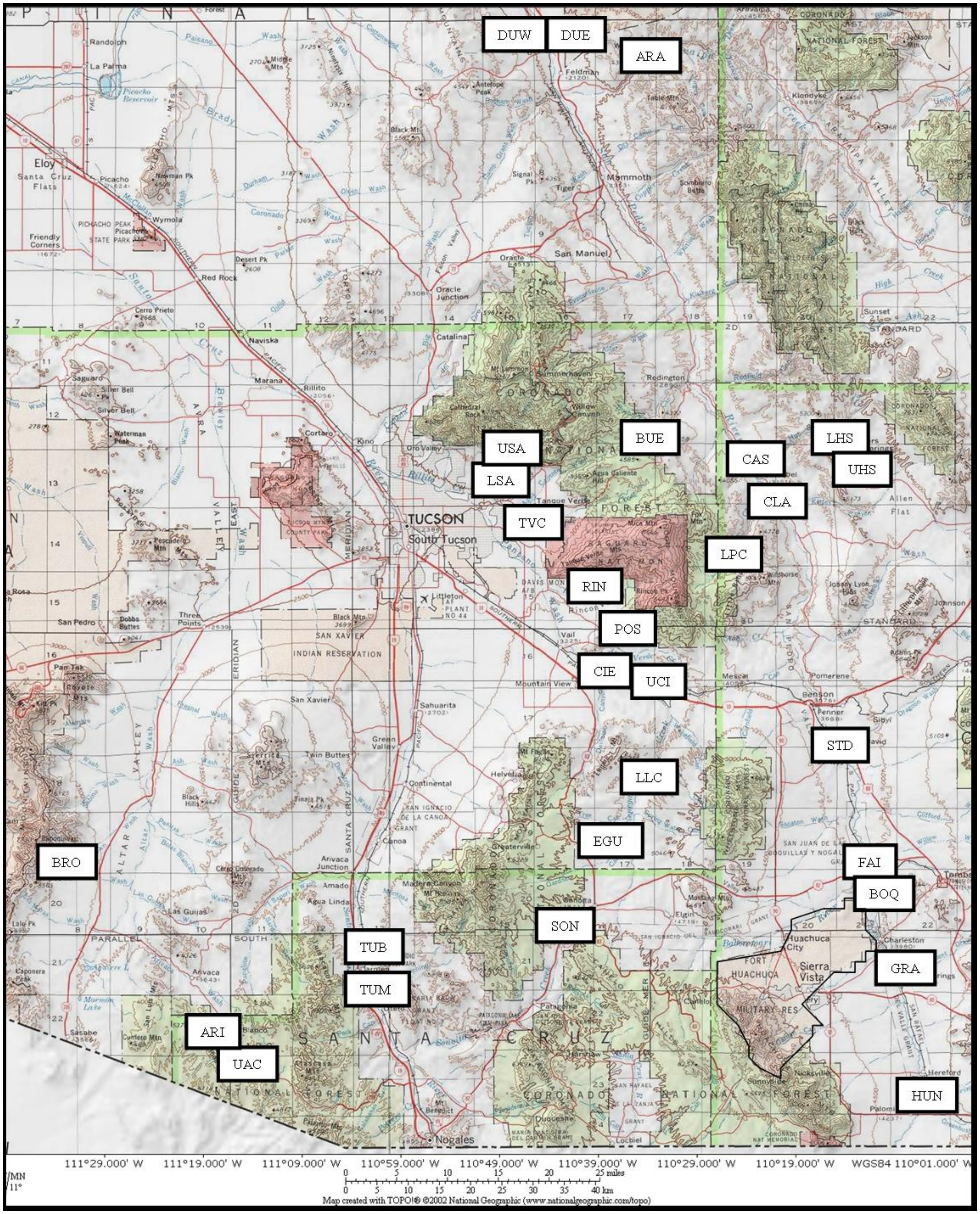
METHODS

Study Area--We conducted this research project in low-elevation (<1,400 m) riparian woodlands in an area of southeastern Arizona (Fig. 2) bounded by the Gila River to the North, the Altar Valley to the West, the U.S./Mexico border to the South, and the New Mexican border to the East. The study area straddled the division between the Sonoran Desert to the west and the Chihuahuan Desert to the East and was located between approximately 600-2800 m elevation. Climate in the region is arid/semi-arid with approximately 300 mm of precipitation falling per year in low-elevation areas. Annual precipitation is bimodal with a brief summer season of localized thunderstorms followed by a longer winter season of widespread frontal storms.

Cottonwood-willow and mixed-broadleaf riparian forests are the two major low-elevation riparian forest types in the region (Brown 1994). Both forest types are found along perennial and seasonally intermittent streams but cottonwood-willow forest is located primarily on alluvial soils on flood plains whereas mixed-broadleaf forest is located primarily along rubble-bottomed drainages in foothills or mountainous areas (Brown 1994). Dominant trees in cottonwood-willow forest include Fremont cottonwood (*Populus fremontii*) and Goodding willow (*Salix gooddingii*). Dominant trees in mixed-broadleaf forest include Arizona sycamore (*Plantanus wrightii*), velvet mesquite (*Prosopis velutina*), velvet ash (*Fraxinus velutina*), Arizona walnut (*Juglans major*), Fremont cottonwood, and various willows (*Salix* spp.). These riparian forest types are often flanked by mesquite or mesquite-hackberry (*Celtis* spp.) woodlands located in the transitional area between the riparian forest and the surrounding uplands.

Study Site Selection--We used a Geographic Information System (GIS; ArcInfo GIS software; Environmental Sciences Research Institute, Inc. 1999) to select potential sites within our study area that were broadly similar in terms of elevation, topography, and stream order. Using the

Figure 2. Study area in southeastern Arizona showing the location of 29 study sites and Fort Huachuca Military Reservation (bounded by black line; adjacent to the City of Sierra Vista and the San Pedro River). See Table 1 for description of study site codes and additional study site information. We cut the Aravaipa Creek study site (ARA) from the study after it suffered extensive flood damage during the summer of 2006.



GIS, we identified all potential sites within our study area that were located between 700-1,250 m elevation, that were not located in steep-sided canyons, and that contained streams classified as having stream orders of 4, 5, or 6 (Strahler 1952). We then created a list of these potential study sites ranking sites highly if they were accessible (e.g., not on private land) and near a USGS well and/or stream gauge. We also consulted with local biologists and hydrologists to ensure that we had not omitted any potential study sites from consideration.

We visited the top 25 potential study sites on our list to evaluate their suitability for the study. We sought extensive riparian vegetation at all study sites but wanted the presence and extent of surface water to vary between study sites as well as within study sites (for a subset of sites). Therefore, we sought to determine from the ground, from USGS stream flow records, and from discussions with local hydrologists and biologists whether each potential study site typically had perennially flowing surface water, seasonally or spatially intermittent surface water, or ephemeral surface water (i.e., flowing water present only after precipitation events). We deemed that 16 of the 25 potential study sites were suitable for inclusion in the study. To increase our sample size of sites, we identified 2 additional sites situated slightly higher than our initial elevational limit of 1,250 m and 11 additional sites located in riparian woodlands along 2 larger (stream order >6), perennially-flowing streams in southeastern Arizona because of the acknowledged importance of their riparian woodlands to riparian bird communities in the region (Skagen et al. 1999, Krueper 2003). Specifically, we chose 5 study sites along the Upper San Pedro River (3 of which were adjacent to Fort Huachuca Military Reservation), 4 study sites on the Lower San Pedro River, and 2 study sites along the Upper Santa Cruz River (Fig. 2). Of the 29 sites that we selected for the study, 9 had perennial flowing surface water, 14 had spatially or temporally intermittent surface water, and 6 had ephemeral surface water (Table 1).

Bird Survey Routes--At each of the study sites, we established a riparian point-count bird survey route (henceforth "riparian survey route") by using a hand-held Global Positioning System (GPS) receiver to locate survey points at 100-m intervals along a 900-1,500 m section of the stream channel (see Appendix A for UTM coordinates of each survey point). We chose a 100-m interval between survey points to capture small scale differences in surface water conditions (e.g., isolated standing pools of water) along the length of the stream channel. For larger, perennially-flowing streams, we placed survey points along one side of the stream channel only. For smaller streams, we alternated the placement of surveys points from one side of the stream channel to the other along the stream channel (determination of first survey point location decided by coin flip). We changed the location of a survey point to the opposite stream bank if the riparian vegetation narrowed appreciably on the chosen side (i.e., if >50% of the area within a 50-m radius of the survey point encompassed upland vegetation). We placed each survey point 10 m away from the edge of the high-water channel to ensure that we could hear singing/calling birds above the noise of flowing water (B. Powell, Pima County, personal communication).

We also established 2 "upland" point-count bird survey routes (henceforth "upland survey routes") on one side of the stream channel at a sub-set of 4 of our study sites (Buehman Canyon, Lower Las Cienegas, Posta Quemada, and Rincon Creek) in 2006. We flipped a coin to decide which side of the stream to place the 2 upland survey routes unless there were factors (e.g., steep slope, private property, presence of agriculture) that precluded the placement of the upland

Table 1. Twenty-nine study sites in southeastern Arizona used to examine the link between surface water depletion on the health and persistence of riparian bird communities from 2006-2008. Study sites organized by the type of surface water flow.

Name of Site	Site Code	Elevation (m)	Administering Agency	# Pts.	Surface Water	Year(s) Surveyed
Aravaipa Creek	ARA	750	The Nature Conservancy	15	Perennial	2006
Gray Hawk	GRA	1,210	U.S. Bureau of Land Management	12	Perennial	2006
Lower Hot Springs	LHS	1,200	The Nature Conservancy	15	Perennial	2006
Dudleyville West[1]	DUW	610	The Nature Conservancy	15	Perennial	2007
Sonoita Creek[1]	SON	1,215	The Nature Conservancy	15	Perennial	2007
Tubac[1]	TUB	990	Santa Cruz County	10	Perennial	2008
Lower Paige Creek	LPC	1,230	U.S. Forest Service	13	Perennial	2008
Boquillas[2]	BOQ	1,170	U.S. Bureau of Land Management	12	Perennial	2006-2007
Tumacacori[1]	TUM	1,005	National Park Service	10	Perennial	2006-2007
Brown Canyon	BRO	1,000	U.S. Fish and Wildlife Service	14	Intermittent	2006
Upper Sabino Creek	USA	850	U.S. Forest Service	11	Intermittent	2006
Buehman Canyon[3]	BUE	1,180	U.S. Forest Service	15	Intermittent	2006
Hunter Wash	HUN	1,230	U.S. Bureau of Land Management	12	Intermittent	2006
Cascabel	CAS	945	U.S. Bureau of Land Management	10	Intermittent	2007
St. David	STD	1,100	Private Land	12	Intermittent	2007
Tanque Verde Creek	TVC	795	Pima County	12	Intermittent	2008
Empire Gulch[1]	EGU	1,400	U.S. Bureau of Land Management	15	Intermittent	2008
Fairbank[2]	FAI	1,160	U.S. Bureau of Land Management	12	Intermittent	2006-2008
Rincon Creek[1,2,3]	RIN	965	National Park Service	10	Intermittent	2006-2008
Arivaca Creek	ARI	1,085	U.S. Fish and Wildlife Service	14	Intermittent	2006-2008
Cienega Creek[1,2,4]	CIE	1,020	Pima County Parks and Recreation Dept	15	Intermittent	2006-2008
Upper Hot Springs	UHS	1,230	The Nature Conservancy	15	Intermittent	2006-2008
Lower Sabino Creek	LSA	800	Private land	12	Intermittent	2006-2008
Dudleyville East[1]	DUE	620	The Nature Conservancy	11	Ephemeral	2007
Upper Cienega[1,2]	UCI	1,075	Pima County Parks and Recreation Dept	12	Ephemeral	2007
Lower Las Cienegas[1,3]	LLC	1,380	U.S. Bureau of Land Management	10	Ephemeral	2006-2008
Posta Quemada[1,2,3,4]	POS	1,060	Pima County Parks and Recreation Dept	9	Ephemeral	2006-2008
Clark Property	CLA	960	Private Property	8	Ephemeral	2008
Upper Arivaca Creek	UAC	1,075	U.S. Fish and Wildlife Service	7	Ephemeral	2008

[1] Study sites where we sampled aerial arthropods; [2] study sites where we monitored nests; [3] study sites where we surveyed both "riparian" and "upland" birds, [4] study sites where we sampled arboreal arthropods.

survey routes on one side of the stream. To determine the distance of the first upland survey route from the stream, we first used a GPS receiver to measure the maximum distance of riparian vegetation from the stream on the side where the upland survey routes were to be placed. We located the first upland survey route 200 m and the second upland survey route 500 m from the edge of the riparian vegetation at its widest point. We used a GPS receiver to locate survey points at 100-m intervals along each of the upland survey routes, both of which ran parallel to the stream channel. Each upland survey route had the same number of survey points as the riparian survey route (except for the 500 m upland survey route at the Lower Las Cienegas study site which had only 6 survey points due to constraints caused by topography; see Appendix A for UTMs coordinates).

Bird Surveys--Before the start of each field season, we trained and tested field personnel in the identification of southwestern birds (both by sight and sound) and the estimation of distances to objects during a formal 2-week training session. We conducted bird surveys from 1 April to 25 June. We selected this time period based on records of peak breeding activity for most common riparian and upland birds found in and near riparian areas in Arizona (Corman and Wise-Gervais 2005). However, some birds (e.g., Yellow-billed Cuckoo) were detected infrequently during our bird surveys because these species are more vocal (i.e., easier to detect) later in the summer (C. Kirkpatrick, personal observation). In addition to breeding birds, we also recorded detections of all long-distance migratory bird species (henceforth "migrant birds") during our surveys. We defined migrant birds as those species that did not breed in low-elevation (<2,000 m) areas of southern Arizona (Corman and Wise-Gervais 2005). We surveyed birds at some of our study sites during only 1 year (2006, 2007, or 2008) of the study for our "spatial" analysis, whereas at other study sites, we surveyed birds during 3 consecutive years (2006, 2007, and 2008) of the study for our "temporal" analysis (Table 1; see also "data analysis" section below). We surveyed birds along each riparian survey route approximately every 3 weeks (4 replicate bird surveys per route in 2007 and 2008; 5 replicate surveys per route in 2006) and alternated the direction in which we conducted surveys from one visit to the next. Because the probability of detecting birds is negatively correlated with time of day and wind speed, we conducted all bird surveys in the early morning (between sunrise and 2 hours after sunrise) on days without precipitation and with wind speeds <10 km/hr.

We recorded temperature (°C), wind speed (km/hr) using a hand-held anemometer, and % cloud cover at the start and end of each survey along each survey route. Eight observers surveyed birds in 2006, 5 observers surveyed birds in 2007, and 6 observers surveyed birds in 2008. To reduce observer bias, we rotated observers during subsequent replicate surveys at all study sites except at 4 study sites along the Upper San Pedro River in 2006 where, for logistical reasons, a single observer conducted all bird surveys. Three observers simultaneously surveyed the 1 riparian and 2 upland survey routes during the morning survey period to reduce temporal variance at the 4 study sites with upland and riparian bird survey routes. At each survey point, observers waited 1 minute and then began a count of all birds heard and/or seen during an 8-minute survey period. For each bird detected, observers recorded the species and distance (m) from the survey point to the point where the bird was first detected (measured with the aid of an infrared rangefinder). Birds that were detected flying over the survey point were recorded as "flyovers". In addition, observers recorded the 1-minute interval in which each bird was first detected during the 8-minute survey period and the type of detection for each bird (visual, auditory, or both).

Surface Water Sampling--Once every 3 weeks during the bird breeding season (following each replicate bird survey), we estimated the presence and extent of surface water within a 50-m radius surrounding each bird survey point along riparian bird survey routes at each study site using the following methods. We first walked the length of the survey route and mapped all flowing water and standing pools of water within approximately 100 m on either side of the survey route. For each standing pool of water, we used a GPS receiver to collect UTM coordinates for the start and end points of the pool and measured the maximum width and length of the pool using a carpenter's rule or metric tape. For each segment of flowing water, we estimated the length of the segment by collecting UTM coordinates for the start and end points of the segment and measuring the width of water along the stream segment at 50-m increments (or at the segment mid-point for segments <100 m in length). We modified these methods from surface water sampling protocols developed by the National Park Service (D. Swann, Saguaro National Park, personal communication).

We used a GIS to determine which pools of standing water and what proportion of flowing water segments were within 50 m of each survey point at each study site (Fig. 3). We then calculated the surface area of each pool of standing water using the formula for the surface area of an ellipse (surface area = *Pi* x [0.5 x max. length] x [0.5 x max. width]). We used this formula because an ellipse best approximated the average shape of standing pools of water within our study area. We calculated the surface area for each flowing segment of water within 50 m of each survey point by multiplying the length of the segment by the average of the 2 closest stream width measurements that we collected while in the field at 50 m increments along the segment. For our analyses, we calculated 2 surface water variables: 1) "total water" which was the total surface area of water present at each survey point during each replicate survey; and 2) "number of visits with water" which was the number of replicate surveys (0-4) where surface water was present at each survey point in each year.

Vegetation Sampling--After bird surveys were completed, we estimated 1) vegetation volume, 2) average height of large riparian trees, and 3) width of riparian vegetation within each of our 29 study sites. We sampled vegetation at some of our study sites during only 1 year (2006, 2007, or 2008) of the study for our "spatial" analysis, whereas at other study sites, we sampled vegetation during 2 years (2006 and 2008) of the study for our "temporal" analysis (Table 1; see also "data analysis" section below). We estimated vegetation volume within a 50-m radius plot surrounding each bird survey point using the point-line-intercept method (sensu Mills et al. 1991; Fig. 4). Standing at each survey point, we first took a random compass bearing and then used a meter tape to establish a 50-m transect along this bearing. We established 5 additional 50-m transects located at 60, 120, 180, 240, and 300° from the original compass bearing. We walked along each 50-m transect and sampled vegetation at 5 vegetation sampling points. The location of each of the 5 vegetation sampling point was selected systematically within 1 of 5 distance categories along each transect (0-22.5, 22.5-31.5, 31.5-38.5, 38.5-45, 45-50 m) so that we collected samples within uniform areas across the 50-m radius plot. We placed one end of a 5-m graduated pole on the ground at each vegetation sampling point and used a level to ensure that the pole was positioned vertically. Using the 5-m graduated pole as a reference point, we then estimated the number of vegetation "hits" within a vertical 0.25-m radius column centered on the pole and extending straight up and above the pole (Fig. 4). A "hit" occurred when vegetation (leaves, branches, stems, etc.) intersected the space within the vertical column. We recorded hits

Figure 3. Detail of GIS map showing a portion of the bird survey route at the Upper Hot Springs study site (red dots represent survey points #7-15 and gray stippling indicates the area <50 m from these survey points) at The Nature Conservancy's Muleshoe Ranch Preserve, Arizona. The light blue dot indicates a standing pool of water and the dark blue lines indicate segments of flowing water that were present on 3 May 2006.

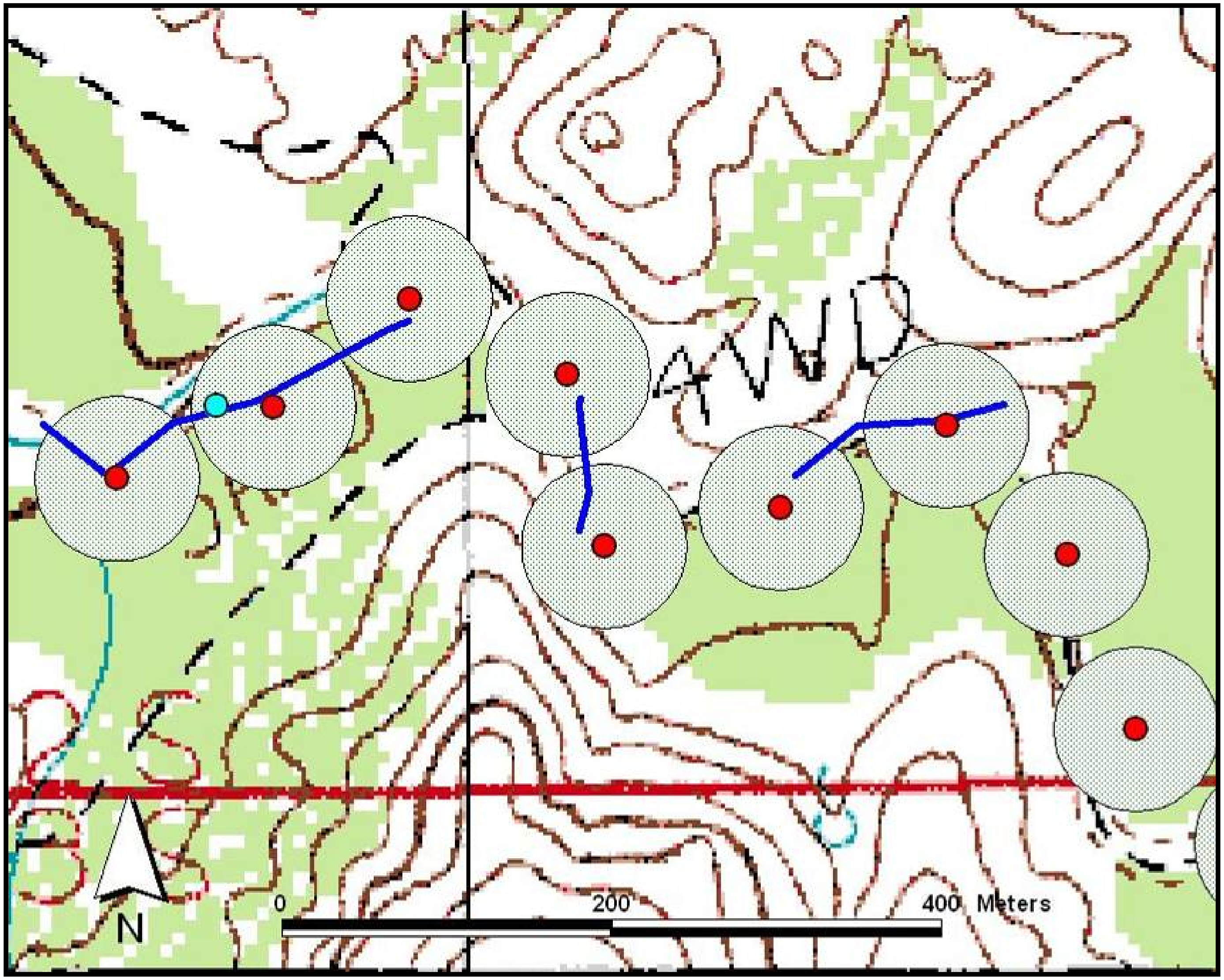


Figure 4. Photograph of observers using point-line-intercept method to estimate vegetation volume in riparian woodlands of southeastern Arizona in August 2006.

of vegetation separately for each plant species and noted whether the vegetation was alive or dormant/dead (we assumed that the proportion of dormant or dead vegetation, especially in the overstory, provided an index of the "health" of riparian woodlands). We placed herbaceous plant species in 2 general categories: 1) grass, or 2) forb.

We divided the vertical column into 3 general height classes (understory, mid-story, and overstory or canopy) and further divided these height classes into distinct sub-intervals. From 0-2.5 m height (the understory), we divided the vertical column into 25 10-cm sub-intervals. From 2.5-5 m height (the mid-story), we divided the vertical column into 25 10-cm sub-intervals. And finally, from 5-20 m height (the overstory), we divided the vertical column into 15 1-m sub-intervals. We recorded vegetation hits that were >20 m above ground but we did not include these data in subsequent analyses because only a tiny fraction of total vegetation hits (0.1% of 184,832) were >20 m in height. For each of the 3 height classes, we calculated the average relative volume of vegetation (henceforth "vegetation volume") within 50 m of each bird survey point using the following equation: h/xp; where h = total number of vegetation hits summed in each height class at each sampling point, x = the number of height intervals within each height class at each sampling point (n = 25, 25, and 15, respectively), and p = the total number of sampling points (n = 30) along the 6 transects at each bird survey point.

At each bird survey point, we also estimated the average height of large riparian trees using a modified version of the point-center-quarter method (Bookhout 1996). Using a meter tape, we measured the distance from the survey point to the center of the trunk of the nearest tree whose Diameter at Breast Height (DBH) was >40 cm. We did this separately for each of the 4 quadrants surrounding the survey point. We searched as far as 100-m from the survey point to locate a tree >40 cm DBH in each quadrant. Occasionally, no tree >40 cm was found in 1 (or more) of the 4 quadrants. If this happened, we located the next closest tree >40 cm in another quadrant and collected data from that tree. For each tree >40 cm DBH, we used a clinometer to estimate its height (m).

Finally, we mapped the width of riparian vegetation along the stream channel within each study site by using a GPS receiver to collect UTM coordinates while walking the edge of the cottonwood-willow or mixed-broadleaf forest out to 300 m on either side of the stream channel. We imported the UTM coordinates into a GIS and used the GIS to measure the approximate width of riparian vegetation (cottonwood-willow or mixed-broadleaf forest) perpendicular to the stream channel at each survey point. Some sites (e.g., Lower Sabino Creek) were bounded by private property or otherwise inaccessible and we were unable to map the extent of riparian woodlands from the ground. Thus, we viewed aerial photographs using Google Earth (Version 3.0.0762 software, Google, Inc. 2005) to estimate the width of riparian woodlands at each survey point at these study sites.

Nest Monitoring--From April to July 2006-2008, we located and monitored nests of all riparian and upland breeding bird species in an area approximately 150 m wide (centered on the stream channel) at a subset of "dry" and "wet" study sites. In 2006, we initially chose the Fairbank and Rincon Creek study sites to represent "dry" sites and the Cienega Creek and Boquillas study sites to represent "wet" sites. However, flowing water at the Fairbank study site persisted well into the bird breeding season (contrary to what we had expected) and we ultimately classified Fairbank to be a "wet" study site. In 2007, we selected the Posta Quemada and Upper Cienega study sites to represent "dry" sites and the Cienega Creek and Rincon Creek study sites to represent "wet" sites (note that Rincon Creek was a "dry" study site during nest monitoring in 2006). In 2008, we continued monitoring nests of riparian birds at the Cienega Creek and Rincon Creek study sites (both "wet sites that year). Although we collected data on nests of all species, we focused our efforts on collecting data on nests of Bell's Vireos (our focal species) because of the relative ease in finding and monitoring nests of this species in southwestern riparian woodlands (Powell 2004) and the conservation status of the species. We spent equal time and effort nest searching at each study site. We monitored nests every 2-3 days until the nest fate (failed or fledged) was determined. We recorded the number of eggs and/or nestlings on each nest visit and measured the length and width of eggs within each Bell's Vireo nest that we found during the incubation period.

Arthropod Sampling (Aerial)--Using sticky traps, we sampled aerial arthropods at each bird survey point at a subset of 5 of our study sites in early June 2006, a subset of 5 of our study sites in early June 2007, and at a subset of 2 of our study sites in early June 2008 (Table 1). Six of these 12 sites were "wet" (i.e., had substantial surface water) and 6 were "dry" (i.e., had no or only minimal surface water). We sampled Rincon Creek in both 2006 and 2007 because of the dramatic increase in surface water observed at this study site from one year to the next (see results). We sampled arthropods in early June because this is the peak of the breeding season for many riparian birds in the region (Corman and Wise-Gervais 2005). Each sticky trap consisted of a 20 x 28-cm transparency smeared with a layer of Tanglefoot (Tanglefoot, Inc., East Moline, Illinois). We attached each sticky trap to a 20 x 28 cm board and suspended these boards using string from a branch approximately 1 m above the ground at each survey point. We anchored the sticky traps to the ground to prevent them from blowing in the wind. We collected sticky traps after 4 days and brought them back to a lab at the University of Arizona.

Using a dissecting microscope, we identified all arthropods to taxonomic order and measured the length of each arthropod to the nearest mm. We used length-mass relationships derived for riparian arthropods (Sabo et al. 2000) to estimate dry biomass (mg) for the following arthropod orders: *Araneae* (spiders), *Coleoptera* (beetles), *Diptera* (flies), *Ephemeroptera* (mayflies), *Homoptera* (true bugs), *Hemiptera* (true bugs), *Hymenoptera* (bees, wasps, and ants), *Odonata* (dragonflies and damselflies), *Orthoptera* (grasshoppers and crickets), and *Trichoptera* (caddisflies). We used a length-mass relationship derived for terrestrial arthropods to estimate dry biomass (mg) for a composite group of the remaining orders (including unidentified arthropods; Rogers et al. 1976). We also calculated an average total dry biomass (for all orders combined) for each survey point.

Arthropod Sampling (Arboreal)--To determine indirectly how ground water levels may affect arboreal arthropod biomass, we collected data on the relationship between plant water stress and arboreal arthropod biomass at 1 "wet" site (Cienega Creek) and one "dry" site (Posta Quemada). We assumed that riparian trees that exhibited decreased water stress during the driest time of year (i.e., early summer) had access to increased ground water resources compared to trees that exhibited increased water stress during the driest time of year. At each study site, we selected 3 trees (2 velvet mesquites and 1 Goodding willows) at each bird survey point. We chose the closest mesquite and the closest willow to the stream channel <50 meters from each survey point. We also selected an additional mesquite in the adjacent upland. This tree was selected to be approximately 20 meters away from the edge of the floodplain shoulder. Whenever possible we selected medium-sized trees between 10-cm and 20-cm DBH.

We selected 4 branches (of approximate equal size and structure) for sampling on each of the 3 trees. We constructed bird exclosures for 2 of the branches on each tree using 1-cm square flexible plastic netting (Bird Block, Easy Gardener Inc., Waco Texas). We wrapped each exclosed branch with netting approximately 1.5 times to ensure that birds would not enter the exclosure and consume the arboreal arthropods within. We secured the netting to the branch and to itself using white plastic zip-ties (Commercial Electric, Atlanta, Georgia). We left an approximately 0.5-cm radius opening around the branch between the zip-tie and the branch to ensure that crawling arthropods would be able to enter or exit the exclosure. Exclosures were deployed between 2-4 June 2008. We placed zip-ties around each un-exclosed branch to control for any possible confounding effect of the zip-ties.

We sampled the arboreal arthropods on each exclosed and un-exclosed branch between 7-8 July 2008 by quickly placing a plastic trash bag over the branch, clipping the branch from the tree, and spraying the inside the bag (with the branch enclosed) with a general insecticide (Ortho Max; 0.0033% Esphenvalerate) to prevent escape of any motile arthropods. We evaluated all branch samples in the lab at the University of Arizona by: 1) sorting the leaf biomass, stem biomass, and arboreal arthropods; 2) identifying arthropods to Order and measuring the length (mm) of each arthropod; 3) drying the stem and leaf samples for 3 days in a drying oven; and 4) weighing the dry biomass of stems and leaves for each branch sample.

We measured the water stress of each tree between 11-12 June 2008 at Posta Quemada and between 17-19 June 2008 at Cienega Creek. This time period corresponded with end of the summer dry season and the period of time when riparian trees were likely experiencing their highest degree of water stress. No rain was recorded in the period of time between sampling at the 2 sites. Sampling for water stress takes time, so to prevent a bias between our dry and wet site, we sampled water stress in trees at our dry site (Posta Quemada) before sampling water stress in trees at our wet site (Cienega Creek). We measured stem water potential using a pressure chamber (Model 600) and we followed the operating procedure outlined by the pressure chamber manufacturer (PMS Instrument Company, Albany, Oregon). We took all measurements between 15 minutes before sunrise and 2 hours after sunrise which allowed us to sample trees before they were exposed to direct sunlight and before temperatures increased by >7° C. At a subset of trees, we measured multiple stems from the same tree and found that the variance in water stress was low for each tree (less than or equal to +/- 1 bar). Therefore, we proceeded to sample water stress from only a single branch collected from each tree due to the limited time available for sampling in the morning. We collected a second branch (and measured water stress) in a few instances where the observer had questions as to the accuracy of the initial sample measurement.

The Floods of 2006 and the Wildfires of 2008--Southeastern Arizona experienced one of the wettest monsoons on record during July and August 2006 (following an extremely dry winter/spring in 2005-2006). Heavy rains were prevalent across our study area and flash floods occurred at several of our study sites. The riparian woodlands at the Aravaipa Creek study site were hit especially hard by severe flash floods and many large cottonwood and willow trees were uprooted as a result (Arizona Daily Star 2006). Due to logistical constraints, we were forced to measure vegetation variables at Aravaipa Creek after the floodwaters had subsided. Consequently, we removed the Aravaipa study site from our analyses. In the spring of 2008, wildfires burned portions of our Tumacacori and Boquillas study sites. Given the dramatic impact of these wildfires on the vegetation (and presumably the riparian birds) at these 2 study sites, we did not collect data at either study site in 2008 and we removed both sites from our temporal analysis.

DATA ANALYSIS

Riparian vs. Upland Bird Surveys--We used one-way analysis of variance (ANOVA) to test the hypothesis that relative abundance (and species richness) of birds was greater in riparian areas compared to adjacent uplands (at both 200 m and 500 m from the edge of the riparian woodland) at 3 of our 4 study sites where we had both riparian and upland bird survey routes in 2006. We included data from all 5 replicate surveys conducted from March to June in our analysis to capture the peak breeding seasons of both upland birds (earlier in the year) and riparian birds (later in the year). We limited our data to include birds detected aurally and/or visually within 50 m of each survey point. We did not include detections of bird flyovers in our analyses, nor did we include data from our Buehman Canyon study site because we were unable to access upland survey routes at this study site for the second half of the 2006 field season. For the species richness analyses we used total species richness, species richness of breeding birds, and species richness of non-breeding birds (both migrant and over-wintering species combined).

Before running analyses, we examined distributions of variables to check assumptions of normality and homogeneity of variance. We applied square root + 0.1 transformations to help control for non-homogeneity of variance in variables where necessary. We report untransformed summary statistics in tables but used transformed data for analyses. We used estimates of the effect size from analyses to quantify the extent to which riparian areas increase avian abundance and species richness. To model these spatial trends, we first calculated the average distance of the riparian survey route from the 2 upland survey routes because these 2 upland survey routes were located 200 and 500 m from the edge of the riparian woodland, not the riparian survey route. The actual distance of the 200 and 500 m upland surveys routes from the riparian survey routes averaged 245 m (SE = 6.9 m) and 546 m (SE = 8.1 m), respectively, across the 3 study sites. We graphed our species richness and total relative abundance data and fit trend-lines to these data.

Influence of Surface Water on Riparian Birds (Spatial and Temporal Analyses)--We took 2 approaches to analyzing the influence of surface water on riparian birds. First, we conducted a spatial analysis using data collected from each of the 1,337 replicate surveys taken at the 337 survey points located within our 28 replicate study sites (we removed the Aravaipa Creek study site from the analysis because of extensive flooding in 2006; see above) for which we collected at least one year's worth of data in 2006, 2007, or 2008. Second, we conducted a temporal analysis using data collected from each of the 812 replicate surveys taken at the 203 survey points located within the 8 study sites for which we collected data in both 2006 and 2008 (we also collected data at Rincon Creek during 2007 and included these data in the temporal analysis). We limited our analyses to include birds detected aurally and/or visually within 50 m of each survey point and we excluded birds detected as flyovers. For our species-level response variables, we examined average relative abundances for the 10 most widely-distributed breeding species (present at ≥75% of our survey points), the 2 most widely-distributed migratory species (Wilson's Warbler [53% of survey points] and Yellow-rumped Warbler [41% of survey points]) and 3 species that have been associated anecdotally with the presence of surface water in Arizona (Black Phoebe, Common Yellow-throat, and Song Sparrow; Corman and Wise-Gervais 2005). We also examined 2 community-level response variables: 1) total relative abundance, and 2) species richness.

Before running analyses, we first screened all vegetation volume data and eliminated variables for which >80% of cases were equal to zero (note that data from the eliminated variables were retained in 3 total vegetation volume variables for the understory, mid-story, and overstory). We examined the distributions of each of the 44 remaining vegetation volume variables and applied transformations (e.g., arcsine, logit, rank) to control for outliers where necessary. We then used exploratory factor analysis to reduce the set of 44 vegetation volume variables to smaller sets of uncorrelated factors for use in subsequent analyses (Appendix B; Meyers et al. 2006). We retained factors with eigenvalues ≥1 and used a varimax rotation to facilitate interpretation of factor weights (Meyers et al. 2006). We identified 11 factors that retained 72% of the variability within our original vegetation volume data. The Kaiser-Meyer-Olkin measure of sampling adequacy was 0.79 which indicates that our data were suitable for factor analysis (Meyers et al. 2006). We described each factor based on the inclusion of variables that had factor weights ≥0.45, meaning that ≥20% of the variance in the original variable was accounted for in the factor. We combined these 11 factors with 8 other explanatory variables (year, elevation, latitude, canopy height, width of riparian vegetation, corridor or oasis site [Skagen et al. 1998], total water, and number of visits with water) into a single data set which we checked for multivariate outliers by calculating Mahalanobis distances (Morrison et al. 1998, Meyers et al. 2006). We found a single multivariate outlier which we removed from subsequent analyses.

We employed an information-theoretic approach (Burham and Anderson 2002, Anderson 2008) to determine support for alternative *a priori* models describing associations of surface water with our 2 community-level dependent variables: 1) total relative abundance, and 2) species richness. This multivariate analysis allowed us to examine the effect of surface water on our dependent variables while accounting for the effects of numerous other independent variables such as vegetation, elevation, etc. We developed a set of 32 *a priori* models to describe the relationship between the 18 explanatory variables and total bird abundance and species richness. The model set was composed of 9 models (including an intercept only model) which included various combinations of vegetation and other variables but which did not include any surface water variables. We then added surface water variables to each of these 9 models to generate an additional 10 models. The remaining models included various interactions between vegetation and surface water.

We used a Linear Mixed Model (package "lme4") in the R computing package to generate log likelihoods and parameter estimates for each model (Bates and Maechler 2009, R Development Core Team 2009). A Linear Mixed Model was the most appropriate statistical platform because it allowed us to account for the lack of independence among multiple surveys at survey points nested within study sites. We "centered" all independent variables that we used in interaction terms (Meyers et al. 2006). We designated site and survey point as random groups. We used a maximum likelihood estimator (MLE) to generate the log likelihood of each model and we used the unbiased restricted maximum likelihood (REML) to estimate parameters. We used the second order bias corrected Akaike Information Criteria (AICc) to rank and weight our models. We selected a confidence set of models by selecting the top ranked model and any subsequent model which had a weight >10% of the top ranked model. We used multi-model inference to develop predictive models by selecting all of the variables in the confidence set of models and averaging the parameter estimates from all possible combinations of these variables (see Appendix C; Barton 2009). We report standardized estimates of coefficients from our predictive models in the results section to allow for the comparison amongst variables in the confidence set of models.

We also developed model sets for each of 15 bird species. *A priori* models were derived from the relevant literature for each species as well as personal theory from the principal investigator (C. Conway). As with the community-level parameters, initial models were created without surface water variables and additional models were created by adding a surface water variable to an existing model. The result of this process was a model set for each species in which each model containing a surface water variable had an identical model without surface water. We evaluated the models using a generalized mixed model with a Poisson distribution and a log link function in program R (R Development Core Team 2009) and the package lme4 (Bates and Maechler 2009). We ranked models for each species using AICc and selected a confidence set of models using the same criteria as for the community level models. We used multi-model inference to develop predictive models following the same procedure as for the community-level models (see Appendix C; Barton 2009). However, due to computational limitations, we simply averaged the parameter estimates from the models in the confidence set for species with greater than 8 variables in the confidence set of models. We report standardized estimates of coefficients from our predictive models in the results section to allow for the comparison amongst variables in the confidence set of models.

For our temporal analysis, we used data collected from each of the 812 replicate surveys conducted at 203 survey points within the 8 study sites for which we collected bird, surface water, and vegetation data in both 2006 and 2008 (Table 1; we also collected bird, surface water, and vegetation data at the Rincon Creek study site in 2007). By repeating our measurements at the same survey points over multiple years, we were able to control for a wide range of variables that did not change from year to year such as elevation, latitude, width of riparian vegetation, canopy height, etc. We classified our vegetation volume variables into 3 height categories (0-2 m, 2.1-5 m, and 5.1-20 m) and 2 growth categories (live or dormant/dead) for a total of 6 vegetation volume variables. We created 3 models for each community-level parameter (total relative abundance and species richness) and for each of the 15 bird species examined in the spatial analysis. All 3 models contained the 6 vegetation variables. We added the variable “total water” to one model, the variable “number of visits with water” to the second model, and let the third model stand with vegetation variables only. This technique allowed us to evaluate whether surface water improved the model while controlling for potential effects of changes to the vegetation volume variables. We used the same generalized linear mixed effects model evaluation procedure as we used for the spatial analysis with the exception of an additional random factor to account for the repeated measure across years. We ranked models according to

AICc values as we did with the spatial analysis. We used model averaging across all possible combinations of the variables to generate predictive models for the community parameters.

Nest Monitoring--We found no Bell's Vireo nests at our only "dry" study site (Rincon Creek) in 2006. Therefore, we were able to compare data on Bell's vireo reproductive parameters (e.g., egg volume, nestling growth rate) between our one "dry" study site (Upper Cienega Creek) and our two "wet" study sites in 2007 only. We calculated egg volumes for Bell's Vireo eggs (and for the eggs of several other species for which we collected sufficient data in 2006) using the following equation from Hoyt (1979): (egg length x $(\text{egg width})^2$) x 0.51 and used independent samples *t*-tests to compare average egg volumes and clutch sizes for Bell's Vireos (and several other species for which we had sufficient data) between the "wet" and "dry" study sites.

Arthropod Sampling--We determined whether arthropod biomass collected on sticky traps at survey points improved model fit for our top community level bird models. We ran each of the models in our confidence set of models for the community parameters with and without arthropod biomass as a fixed variable. We ranked models as before using AICc. We also determined whether surface water was an important variable in predicting arthropod biomass by using the same set of models we developed for the community level bird analysis but substituting arthropod biomass as the dependent variable. We evaluated this new model set in the same way. Before running analyses, we eliminated arthropods that weighed >20 mg (mostly cicadas [*Cicadidae*]) because these individuals were outlying values. For our examination of arboreal arthropod biomass, we tested whether predation had a significant effect on our branch-clip samples by using a paired t-test to compare mean biomass of arthropods collected from exclosed and un-exclosed branches on the same tree. We used a linear mixed model to determine the relative effects of 1) study site ("wet" vs. "dry"), 2) location within the riparian woodland (flood plain vs. shoulder), 3) tree type (velvet mesquite vs. Goodding willow), and 4) water potential (i.e., water stress) on arboreal arthropod biomass. We also investigated the effect of tree location and study site on water stress of individual plants with a linear mixed model and controlling for tree type. Because differences in arboreal arthropod biomass among branch-clip samples could be due to differences in the amount of leaf biomass in each branch-clip sample, we controlled for differences in leaf biomass by dividing the arthropod biomass by the dry leaf biomass for each branch-clip sample. We used this corrected arthropod biomass for all analyses. We removed two outlying values from our dataset prior to analyses.

RESULTS

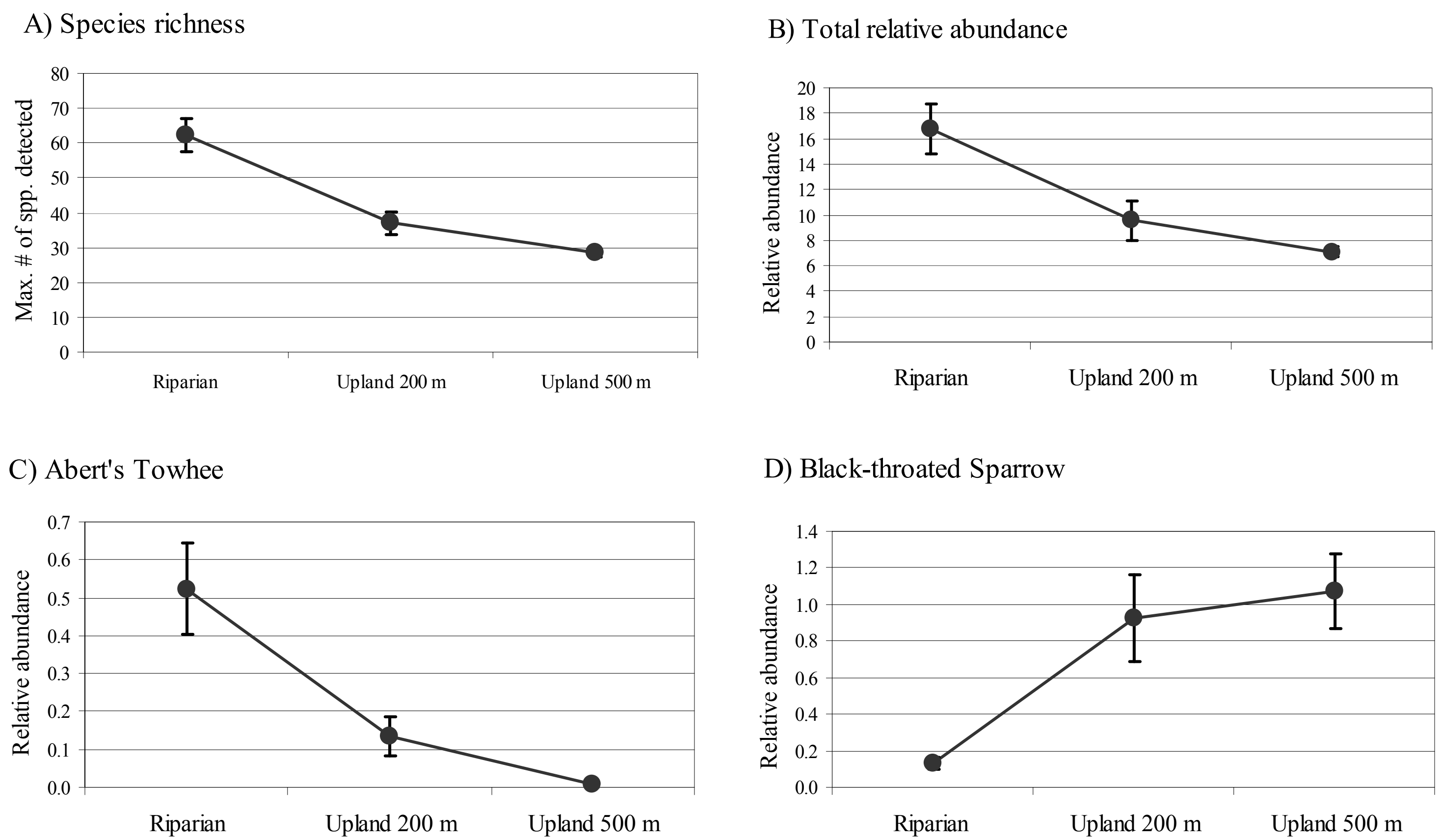
Riparian vs. Upland Bird Surveys--During 5 replicate surveys in 2006, we detected a total of 4,683 individuals of 90 species <50 m from survey points along our riparian and upland bird survey routes at the Lower Las Cienegas, Posta Quemada, and Rincon Creek study sites. Results from one-way ANOVAs revealed substantial differences in both species richness and total relative abundance of birds among riparian and upland survey routes (Table 2, Figs. 5a-b). At the community level, total relative abundance of birds along riparian survey routes was 75% greater compared to upland survey routes located 200 m away from the riparian edge and 136% greater compared to upland survey routes located 500 m away from the riparian edge. Similarly, species richness along riparian survey routes was 68% greater (44% for breeding species and

Table 2. Comparison of relative abundance and species richness of birds detected <50 m from survey points on bird survey routes located in riparian areas and in upland areas 200 and 500 m from riparian areas at 3 study sites in southeastern Arizona (March-June, 2006). Only significant (*P* < 0.15) results are shown in table.

		Riparian		Upland 200m		Upland 500m			
Species	Status[1]	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$F_{2,6}$	P
Gray Hawk[2]	B	0.07	0.0	0.01	0.01	0.00	0.00	3.0	0.122
Cooper's Hawk[2]	B	0.01	0.01	0.00	0.00	0.00	0.00	4.0	0.080
Turkey Vulture[2]	M	0.06	0.04	0.00	0.00	0.00	0.00	3.0	0.124
White-winged Dove	B	0.32	0.03	0.07	0.04	0.06	0.05	12.5	0.007
Anna's Hummingbird[2]	B	0.04	0.01	0.00	0.00	0.00	0.00	11.3	0.009
Gila Woodpecker	B	0.64	0.12	0.20	0.03	0.17	0.09	8.4	0.002
Cassin's Kingbird	B	0.37	0.06	0.09	0.08	0.01	0.01	10.9	0.010
Say's Phoebe[2]	B	0.03	0.01	0.00	0.00	0.01	0.01	3.3	0.107
Gray Flycatcher[2]	M	0.12	0.05	0.01	0.01	0.01	0.02	5.0	0.053
House Wren[2]	M	0.06	0.03	0.01	0.01	0.00	0.00	2.8	0.140
Bewick's Wren[2]	B	1.09	0.29	0.17	0.08	0.18	0.14	8.5	0.018
Ruby-crowned Kinglet[2]	M	0.39	0.12	0.01	0.01	0.00	0.00	19.4	0.002
Bushtit[2]	M	0.05	0.03	0.00	0.00	0.00	0.00	3.5	0.099
Hutton's Vireo[2]	M	0.04	0.01	0.00	0.00	0.00	0.00	14.4	0.005
Summer Tanager[2]	B	0.39	0.15	0.07	0.04	0.03	0.03	5.3	0.048
Back-throated Gray Warbler[2]	M	0.04	0.01	0.00	0.00	0.00	0.00	11.3	0.009
Townsend's Warbler	M	0.01	0.01	0.00	0.00	0.00	0.00	4.0	0.080
Yellow-rumped Warbler[2]	M	0.17	0.05	0.00	0.00	0.00	0.00	14.6	0.005
Yellow Warbler[2]	B	0.72	0.35	0.01	0.01	0.00	0.00	4.4	0.067
Lucy's Warbler	B	1.57	0.14	0.33	0.16	0.33	0.20	17.9	0.003
Orange-crowned Warbler[2]	M	0.02	0.01	0.00	0.00	0.00	0.00	3.1	0.120
Painted Redstart[2]	M	0.03	0.02	0.00	0.00	0.00	0.00	3.8	0.086
Lincoln's Sparrow[2]	W	0.09	0.02	0.00	0.00	0.00	0.00	35.2	0.000
White-crowned Sparrow[2]	W	0.27	0.18	0.03	0.02	0.00	0.00	3.0	0.127
Northern Cardinal[2]	B	0.22	0.09	0.06	0.04	0.03	0.02	3.5	0.098
Lesser Goldfinch[2]	B	0.87	0.40	0.15	0.06	0.05	0.02	3.6	0.094
Pyrrhuloxia[2]	B	0.06	0.00	0.01	0.02	0.00	0.00	13.2	0.006
Blue Grosbeak[2]	B	0.12	0.03	0.06	0.02	0.01	0.02	6.3	0.034
Brown-headed Cowbird[2]	B	0.26	0.12	0.04	0.02	0.09	0.01	3.2	0.113
Abert's Towhee[2]	B	0.52	0.12	0.13	0.05	0.01	0.01	16.9	0.003
Black-throated Sparrow[2]	B	0.13	0.04	0.93	0.24	1.07	0.21	11.9	0.008
Spp. richness (breeding)	-	45.00	2.52	31.33	3.84	24.67	1.20	14.3	0.005
Spp. richness (non-breed.)	-	17.33	2.40	5.67	2.67	3.67	1.67	10.4	0.011
Total relative abundance	-	16.75	1.95	9.56	1.57	7.10	0.39	11.7	0.008

[1] B = breeding species; M = migrant species; W = over-wintering species.
[2] Square root + 0.1 transformation used in analysis.

Figure 5. Spatial trends (mean ± SE) in A) species richness, B) total bird relative abundance, C) relative abundance of Abert's Towhee (a typical riparian breeding species), and D) relative abundance of Black-throated Sparrow (a typical upland breeding species) from riparian areas to upland areas located 200 and 500 m from riparian areas. Data were collected for birds detected <50 m from survey points during 5 replicate bird surveys from March to June 2006 at 3 study sites (Lower Las Cienegas, Posta Quemada, and Rincon Creek) in southeastern Arizona.



205% for non-breeding species) compared to upland survey routes located 200 m away and 120% greater (82% for breeding species and 371% for non-breeding species) compared to upland survey routes located 500 m away from the riparian edge. Spatial trends for total relative abundance and species richness were best modeled (R^2 = 0.983 for both) with the following logistic equations:

- Total Relative Abundance (within 50 m of survey point) = -1.4499(*ln* Distance) + 16.841.

- Species Richness (within 50 m of survey point) = -5.1053(*ln* Distance) + 62.641.

At the species level, results from our one-way ANOVAs revealed that 31 species showed significant ($P < 0.15$) differences in relative abundance among riparian and upland survey routes (Table 2). Ninety-seven percent of these species (including breeding, wintering and migrant species) exhibited trends in relative abundance that increased with proximity to riparian areas, as exemplified by the spatial trend for Abert's Towhee (Fig. 5c). Only the Black-throated Sparrow decreased in relative abundance with proximity to riparian areas (Fig. 5d). Because our sample size of study sites was small (n = 3), we may have lacked sufficient power to detect trends in relative abundance among riparian and upland survey routes for many of the remaining 68 species. Nevertheless, when we examined the direction of the non-significant trends in relative abundance for these 68 species, 52% displayed trends favoring riparian areas, 12% displayed trends favoring upland areas, and 31% displayed trends that had no clear direction.

Influence of Surface Water on Riparian Birds (Spatial Analysis)--At the community level, we detected positive associations between surface water and both total relative abundance and species richness during our spatial analysis (Tables 3 and 4). Total bird relative abundance was positively associated with both "number of visits with water" and "total water" (although the confidence interval slightly overlapped zero for both parameter estimates; Appendix C) and species richness was positively associated with "total water". Of the 15 riparian bird species for which we analyzed data, we detected positive associations with surface water for 6 birds, including 4 breeding species (Black Phoebe, Common Yellowthroat, Song Sparrow, and Lesser Goldfinch) and two migrant species (Yellow-rumped Warbler and Wilson's Warbler; Tables 3 and 4). Breeding species that were positively associated with water (i.e., Black Phoebe, Common Yellowthroat, Song Sparrow, and Lesser Goldfinch) were associated with "number of visits with water"; whereas, migrant species that were positively associated with water (i.e., Yellow-rumped Warbler and Wilson's warbler) were associated with "total water". We also detected negative associations with surface water for 2 breeding bird species (Bell's Vireo and Yellow-breasted Chat). Both of these species were negatively associated with "total water". We found no associations between bird parameters and the proportion of dormant/dead vegetation in the overstory of riparian woodlands (our index of riparian woodlands "health"). We report predictive models (with unstandardized coefficients) from our spatial analysis in Appendix C.

We detected breeding species throughout our annual survey period (early April to late June) but detected migrant species primarily during the first half of the annual survey period. For example, 99% of Yellow-rumped Warblers and 88% of Wilson's Warblers were detected < May 15). The extent of surface water (i.e., "total water") at our 28 study sites declined seasonally (Table 5) from an average of 3,464 m^2 at each study site in April to an average of 1,685 m^2 at

Table 3. Top-ranked models from our spatial analysis for community- and species-level bird parameters generated using multi-model inference on *a priori* model sets. Data collected from 28 study sites located in riparian woodlands throughout southeastern Arizona from 2006-2008.

Top-ranked Models (*n* = total models in *a priori* model set)	*K*	AIC_c	ΔAIC_c	W_i
Community-level				
Total Relative Abundance (*n* = 31)				
Cottonwood Overstory & Other Live Overstory Veg., All Live Understory Veg., Number Visits with Water, Number Visits with Water x Cottonwood Overstory & Other Live Overstory Veg.	8	8768.15	0.00	0.28
Number Visits with Water, All Live Understory Veg., Number Visits with Water x All Live Understory Veg.	7	8769.10	0.94	0.18
Number Visits with Water, Cottonwood Overstory & Other Live Overstory Veg., Number Visits with Water x Cottonwood Overstory & Other Live Overstory Veg.	7	8770.74	2.59	0.08
Total Water, Cottonwood Overstory & Other Live Overstory Veg,, Total Water x Cottonwood Overstory & Other Live Overstory Veg,	7	8771.09	2.94	0.07
Total Water, All Live Understory Veg., Total Water x All Live Understory Veg.	7	8771.83	3.68	0.05
All Live Understory Veg.	5	8771.99	3.84	0.04
Total Water, Number Visits with Water, All Live Understory Veg.	7	8772.18	4.02	0.04
Total Water, Cottonwood Overstory & Other Live Overstory Veg,, All Live Understory Veg., Total Water x Cottonwood Overstory & Other Live Overstory Veg., Total Water x All Live Understory Veg.	9	8772.25	4.10	0.04
Total Water, Number Visits with Water, Cottonwood Overstory & Other Live Overstory Veg,, All Live Understory Veg., All Dead Understory Veg., All Dead Overstory Veg.	10	8772.41	4.26	0.03
Number Visits with Water	5	8772.64	4.48	0.03
Species Richness (*n* =31)				
Cottonwood Overstory & Other Live Overstory Veg., All Live Understory Veg., Number of Visits with Water, Number Visits with Water x Cottonwood Overstory & Other Live Overstory Veg., Number Visits with Water x All Live Understory Veg.	8	6774.23	0.00	0.81
Species-level				
White-winged Dove (*Zenaida asiatica*; *n* = 19)				
Mesquite and Graythorn, Netleaf Hackberry, Tamarisk, Cottonwood Overstory and Other Live Overstory Veg., All Live Understory Veg., All Dead Understory Veg., Brush & Absence of Desert Broom, Canopy Height	11	1401.17	0.00	0.26
Mesquite and Graythorn, Netleaf Hackberry, Tamarisk, Cottonwood Overstory and Other Live Overstory Veg., All Live Understory Veg., All Dead Understory Veg., Brush and Absence of Desert Broom, Canopy Height, Number Visits with Water	12	1401.88	0.71	0.19

Table 3. Continued.

Top-ranked Models (*n* = total models in *a priori* model set)	*K*	AIC_c	ΔAIC_c	W_i
Elevation, Mesquite and Graythorn, Cottonwood Overstory and Other Live Overstory Veg., Goodding Willow, Netleaf Hackberry, Tamarisk	9	1402.04	0.86	0.17
Intercept Only	3	1403.31	2.13	0.09
Mesquite and Graythorn, Netleaf Hackberry, Tamarisk, Cottonwood Overstory and Other Live Overstory Veg., All Live Understory Veg., All Dead Understory Veg., Brush and Absence of Desert Broom, Canopy Height, Total Water	12	1403.40	2.23	0.09
Elevation, Mesquite and Graythorn, Cottonwood Overstory and Other Live Overstory Veg., Goodding Willow, Netleaf Hackberry, Tamarisk, Total Water	10	1404.06	2.89	0.06
Mesquite and Graythorn	4	1405.00	3.83	0.04
Black Phoebe (*Sayornis nigricans*; *n* = 17)				
Canopy Height, Corridor or Oasis, Cottonwood Overstory and Other Live Overstory Veg., Tamarisk, All Live Understory Veg., All Dead Understory Veg., Number Visits with Water	10	284.10	0.00	0.82
Tamarisk, Corridor or Oasis, Number Visits with Water	6	288.42	4.32	0.09
Bewick's Wren (*Thryomanes bewickii*; *n* = 19)				
Mesquite and Graythorn, Cottonwood Overstory and Other Live Overstory Veg., Canopy Height, Tamarisk	7	1419.49	0.00	0.27
Intercept Only	3	1420.50	1.00	0.16
Mesquite and Graythorn, Cottonwood Overstory and Other Live Overstory Veg., Canopy Height, Tamarisk, Number Visits with Water	8	1421.36	1.86	0.11
Mesquite and Graythorn, Cottonwood Overstory and Other Live Overstory Veg., Canopy Height, Tamarisk, Total Water	8	1421.43	1.94	0.10
Goodding Willow	4	1421.81	2.32	0.08
Cottonwood Overstory and Other Live Overstory Veg.,	4	1422.49	2.99	0.06
Canopy Height, Corridor or Oasis, Mesquite and Graythorn, Cottonwood Overstory and Other Live Overstory Veg., Goodding Willow, Netleaf Hackberry, Tamarisk, All Live Understory Veg., All Dead Understory Veg., All Dead Overstory Veg., Brush and Absence of Desert Broom	14	1423.03	3.54	0.05
Goodding Willow, Total Water	5	1423.47	3.98	0.04
Goodding Willow, Number Visits with Water	5	1423.81	4.32	0.03

Table 3. Continued.

Top-ranked Models (n = total models in *a priori* model set)	K	AIC_c	ΔAIC_c	W_i
Bell's Vireo (*Vireo bellii*; n = 25)				
All Live Understory Veg., All Dead Understory Veg., Brush and Absence of Desert Broom, Width Riparian Veg., Mesquite and Graythorn, Tamarisk, Cottonwood Overstory and Other Live Overstory Veg., Elevation, Total Water	13	1059.02	0.00	0.45
Netleaf Hackberry, Mesquite and Graythorn, Total Water	6	1060.36	1.33	0.23
Elevation, Width Riparian Veg., Mesquite and Graythorn, Cottonwood Overstory and Other Live Overstory Veg., Goodding Willow, Netleaf Hackberry, Tamarisk, All Live Understory Veg., All Dead Understory Veg., Seep Willow, Brush and Absence of Desert Broom, Total Water	15	1061.16	2.13	0.15
Width Riparian Veg., Corridor or Oasis, Mesquite and Graythorn, Netleaf Hackberry, All Live Understory Veg., All Dead Understory Veg., Total Water	10	1062.63	3.61	0.07
Yellow-rumped Warbler (*Dendroica coronata*; n = 22)				
Canopy Height, All Live Understory Veg., All Dead Understory Veg., Total Water	7	1114.98	0.00	0.67
Elevation, Canopy Height, Width Riparian Veg., Mesquite and Graythorn, Goodding Willow, All Live Understory Veg., All Dead Understory Veg., Total Water	11	1117.84	2.87	0.16
Yellow Warbler (*Dendroica petechia*; n = 22)				
Canopy Height, Width Riparian Veg., Mesquite and Graythorn, Cottonwood Overstory and Other Live Overstory Veg., Goodding Willow, Tamarisk, Velvet Ash, All Live Understory Veg., All Dead Understory Veg., Seep Willow	13	1223.93	0.00	0.26
Canopy Height, Width Riparian Veg., Cottonwood Overstory and Other Live Overstory Veg.	6	1224.23	0.30	0.22
Canopy Height, Width Riparian Veg., Number Visits with Water	7	1224.46	0.53	0.20
Canopy Height, Width Riparian Veg., Mesquite and Graythorn, Cottonwood Overstory and Other Live Overstory Veg., Goodding Willow, Tamarisk, Velvet Ash, All Live Understory Veg., All Dead Understory Veg., Seep Willow, Number Visits with Water	14	1225.25	1.31	0.13
Canopy Height, Width Riparian Veg., Mesquite and Graythorn, Cottonwood Overstory and Other Live Overstory Veg., Goodding Willow, Tamarisk, Velvet Ash, All Live Understory Veg., All Dead Understory Veg., Seep Willow, Total Water	14	1225.84	1.91	0.10
Canopy Height, Width Riparian Veg., Cottonwood Overstory and Other Live Overstory Veg., Total Water	7	1226.06	2.13	0.09

Table 3. Continued.

Top-ranked Models (n = total models in *a priori* model set)	K	AIC_c	ΔAIC_c	W_i
Common Yellowthroat (*Geothlypis trichas*; n = 25)				
Corridor or Oasis, All Live Understory Veg., All Dead Understory Veg., Seep Willow, Number Visits with Water	8	795.69	0.00	0.89
Lucy's Warbler (*Vermivora luciae*; n = 13)				
Mesquite and Graythorn, Cottonwood Overstory and Other Live Overstory Veg., Goodding Willow, Total Water	7	1781.78	0.00	0.21
Mesquite and Graythorn, Elevation, Tamarisk, Netleaf Hackberry, Goodding Willow, Cottonwood Overstory and Other Live Overstory, Total Water	10	1782.06	0.27	0.18
Mesquite and Graythorn, Cottonwood Overstory and Other Live Overstory Veg., Goodding Willow, Number Visits with Water	7	1782.89	1.10	0.12
Mesquite and Graythorn, Cottonwood Overstory and Other Live Overstory Veg., Goodding Willow	6	1783.00	1.22	0.11
Mesquite and Graythorn, Elevation, Tamarisk, Netleaf Hackberry, Goodding Willow, Cottonwood Overstory and Other Live Overstory	9	1783.31	1.53	0.10
Mesquite and Graythorn, Elevation, Tamarisk, Netleaf Hackberry, Goodding Willow, Cottonwood Overstory and Other Live Overstory, Number Visits with Water	10	1783.49	1.70	0.09
Mesquite and Graythorn, Total Water	5	1784.35	2.57	0.06
Mesquite and Graythorn, Number Visits with Water	5	1784.68	2.89	0.05
Mesquite and Graythorn	4	1785.99	4.21	0.03
Wilson's Warbler (*Wilsonia pusilla*; n = 19)				
All Live Understory Veg., All Dead Understory Veg., Brush and Absence of Desert Broom, Cottonwood Overstory and Other Live Overstory Veg., Goodding Willow, Total Water	9	1350.86	0.00	0.44
Mesquite and Graythorn, Total Water	5	1352.48	1.62	0.19
Width Riparian Veg., Total Water	5	1352.57	1.71	0.18
Goodding Willow, Tamarisk, Total Water	6	1353.23	2.37	0.13
Canopy Height, Width Riparian Veg., Mesquite and Graythorn, Cottonwood Overstory and Other Live Overstory Veg., Goodding Willow, Tamarisk, All Live Understory Veg., All Dead Understory Veg., Brush and Absence of Desert Broom, Total Water	13	1355.02	4.16	0.05

Table 3. Continued.

Top-ranked Models (*n* = total models in *a priori* model set)	*K*	AIC_c	ΔAIC_c	W_i
Yellow-breasted Chat (*Icteria virens*; *n* = 31)				
Width Riparian Veg., All Live Understory Veg., All Dead Understory Veg., Total Water	7	1634.77	0.00	0.40
Canopy Height, Width Riparian Veg., Corridor or Oasis, Mesquite and Graythorn, Cottonwood Overstory and Other Live Overstory Veg., Goodding Willow, Net-leaf Hackberry, Tamarisk, Velvet Ash, All Live Understory Veg., All Dead Understory Veg., Seep Willow, Brush and Absence of Desert Broom, Total Water	17	1634.93	0.16	0.37
All Live Understory Veg., All Dead Understory Veg., Width Riparian Veg., Cottonwood Overstory and Other Live Overstory Veg., Total Water	8	1636.79	2.02	0.15
Song Sparrow (*Melospiza melodia*; *n* = 25)				
Seep Willow, Canopy Height, Number Visits with Water	6	816.63	0.00	0.55
Goodding Willow, Seep Willow, All Live Understory Veg., All Dead Understory Veg., Number Visits with Water	8	819.07	2.44	0.16
All Live Understory Veg., All Dead Understory Veg., Tamarisk, Number Visits with Water	7	820.09	3.46	0.10
House Finch (*Carpodacus mexicanus*; *n* = 16)				
Cottonwood Overstory and Other Live Overstory Veg., Goodding Willow, Tamarisk	6	1825.91	0.00	0.44
Cottonwood Overstory and Other Live Overstory Veg., Goodding Willow, Tamarisk, Total Water	7	1827.70	1.79	0.18
Cottonwood Overstory and Other Live Overstory Veg., Goodding Willow, Tamarisk, Number Visits with Water	7	1827.78	1.88	0.17
Goodding Willow, Cottonwood Overstory and Other Live Overstory Veg., Velvet Ash	6	1830.21	4.30	0.05
Intercept Only	3	1830.50	4.59	0.04
Lesser Goldfinch (*Carduelis psaltria*); *n* = 17)				
Number Visits with Water	4	2093.36	0.00	0.44
Elevation, Brush and Absence of desert Broom, Cottonwood Overstory and Other Live Overstory Veg., Goodding Willow, Netleaf Hackberry, Seep Willow, Width Riparian Veg., Total Water	13	2094.38	1.02	0.26
Cottonwood Overstory and Other Live Overstory Veg., Number Visits with Water	5	2095.21	1.85	0.17
Elevation, Width Riparian Veg., Mesquite and Graythorn, Cottonwood Overstory and Other Live Overstory Veg., Goodding Willow, Tamarisk, All Live Understory Veg., All Dead Understory Veg., Seep Willow, Brush and Absence of Desert Broom, Total Water	15	2097.75	4.40	0.05

Table 3. Continued.

Top-ranked Models (*n* = total models in *a priori* model set)	*K*	AIC_c	ΔAIC_c	W_i
Abert's Towhee (*Pipilo aberti*; *n* = 25)				
Width Riparian Veg., Seep Willow, All Live Understory Veg., All Dead Understory Veg., Total Water	8	1504.70	-1.19	0.26
Width Riparian Veg., Seep Willow, All Live Understory Veg., All Dead Understory Veg., Number Visits with Water	8	1505.89	0.00	0.14
Width Riparian Veg., Seep Willow, All Live Understory Veg., All Dead Understory Veg.	7	1505.97	0.09	0.14
All Live Understory Veg., All Dead Understory Veg., Number Visits with Water	6	1506.87	0.98	0.09
All Live Understory Veg., All Dead Understory Veg., Total Water	6	1507.49	1.60	0.06
Width Riparian Veg., Total Water	5	1507.63	1.74	0.06
All Live Understory Veg., All Dead Understory Veg.	5	1508.39	2.50	0.04
Width Riparian Veg.	4	1508.60	2.71	0.04
Width Riparian Veg., Number Visits with Water	5	1508.76	2.87	0.03
Summer Tanager (*Piranga rubra*; *n* = 19)				
Canopy Height, Cottonwood Overstory and Other Live Overstory Veg., Goodding Willow	6	1487.66	0.00	0.30
Canopy Height, Cottonwood Overstory and Other Live Overstory Veg., Goodding Willow, Total Water	7	1489.24	1.58	0.14
Canopy Height, Width Riparian Veg., Cottonwood Overstory and Other Live Overstory Veg.	6	1489.35	1.69	0.13
Canopy Height, Cottonwood Overstory and Other Live Overstory Veg., Goodding Willow, Number Visits with Water	7	1489.66	2.00	0.11
Canopy Height, Width Riparian Veg., Cottonwood Overstory and Other Live Overstory Veg., Velvet Ash	7	1490.00	2.34	0.09
Canopy Height, Width Riparian Veg., Cottonwood Overstory and Other Live Overstory Veg., Total Water	7	1490.75	3.09	0.06
Canopy Height, Width Riparian Veg., Cottonwood Overstory and Other Live Overstory Veg., Number Visits with Water	7	1491.35	3.69	0.05
Canopy Height, Width Riparian Veg., Cottonwood Overstory and Other Live Overstory Veg., Velvet Ash, Total Water	8	1491.45	3.80	0.05
Canopy Height, Width Riparian Veg., Cottonwood Overstory and Other Live Overstory Veg., Velvet Ash, Number Visits with Water	8	1491.92	4.26	0.04

[1] See Appendix B for description of vegetation factors.

Table 4. Averaged parameter estimates from our spatial analysis for community- and species-level bird parameters generated using multi-model inference from all possible combinations of all the variables in the confidence set of models (for species with greater than 8 variables in the confidence set of models, we simply averaged the parameter estimates from the models in the confidence set). We standardized estimates of coefficients to allow comparison amongst variables in the confidence set of models (see Appendix C for unstandardized parameter estimates in predictive models).

Variables	*B*	Unconditional SE	Relative Importance of Variables
Community-level			
Total Relative Abundance[1]			
Number Visits with Water	0.076	0.052	0.87
All Dead Understory Veg.	0.063	0.044	0.79
All Live Understory Veg.	0.028	0.047	0.74
Cottonwood Overstory and Other Live Overstory Veg.	-0.003	0.031	0.63
Water Total	0.046	0.049	0.63
Cottonwood Overstory and Other Live Overstory Veg. x Number Visits with Water	0.002	0.010	0.38
All Dead Overstory Veg.	0.021	0.033	0.28
All Live Understory Veg. x Number Visits with Water	-0.030	0.044	0.11
Species Richness[1]			
Number Visits with Water	0.119	0.045	1.00
All Live Understory Veg.	0.057	0.056	0.97
Cottonwood Overstory and Other Live Overstory Veg.	0.020	0.046	0.94
Cottonwood Overstory and Other Live Overstory Veg. x Number Visits with Water	-0.103	0.056	0.86
All Live Understory Veg. x Number Visits with Water	0.046	0.050	0.11
Species-level			
White-winged Dove[2]			
Mesquite and Graythorn	-0.019	0.056	0.90
Cottonwood Overstory and Other Live Overstory Veg.	-0.174	0.085	0.86
Netleaf Hackberry	-0.044	0.063	0.86
Tamarisk	-0.075	0.084	0.86
Canopy Height	-0.001	0.040	0.60
Brush and Absence of Desert Broom	0.056	0.065	0.60
All Live Understory Veg.	0.067	0.076	0.60
All Dead Understory Veg.	0.040	0.060	0.60
Elevation	0.002	0.044	0.26
Goodding Willow	-0.004	0.018	0.26
Number Visits with Water	0.021	0.042	0.20
Total Water	-0.002	0.014	0.18
Black Phoebe[1]			
Number Visits with Water	5.120	1.290	1.00
Tamarisk	-4.160	1.650	0.97
All Dead Understory Veg.	-2.100	1.050	0.91
Cottonwood Overstory and Other Live Overstory Veg.	-1.340	1.090	0.74
Corridor or Oasis	0.547	0.897	0.41
All Live Understory Veg.	-0.320	0.604	0.36
Canopy Height	0.217	0.454	0.33
Bewick's Wren[2]			
Cottonwood Overstory and Other Live Overstory Veg.	-0.016	0.029	0.65

Table 4. Continued.

Variables	*B*	Unconditional SE	Relative Importance of Variables
Canopy Height	0.061	0.059	0.58
Mesquite and Graythorn	0.032	0.038	0.58
Tamarisk	-0.020	0.036	0.58
Goodding Willow	-0.007	0.014	0.22
Total Water	0.002	0.008	0.15
Number Visits with Water	-0.002	0.009	0.15
Corridor or Oasis	-0.005	0.011	0.05
Brush and Absence of Desert Broom	0.000	0.002	0.05
Netleaf Hackberry	0.004	0.008	0.05
All Live Understory Veg.	0.000	0.002	0.05
All Dead Understory Veg.	0.002	0.005	0.05
All Dead Overstory Veg.	0.003	0.007	0.05
<u>Bell's Vireo[2]</u>			
Mesquite and Graythorn	0.125	0.043	1.00
Total Water	-0.206	0.071	1.00
All Live Understory Veg.	0.071	0.059	0.75
All Dead Understory Veg.	-0.001	0.037	0.75
Width Riparian Veg.	-0.036	0.058	0.75
Elevation	-0.379	0.292	0.66
Seep Willow	0.018	0.031	0.66
Brush and Absence of Desert Broom	-0.009	0.027	0.66
Cottonwood Overstory and Other Live Overstory Veg.	0.025	0.036	0.66
Tamarisk	0.027	0.053	0.66
Netleaf Hackberry	0.030	0.042	0.51
Goodding Willow	-0.002	0.008	0.17
Corridor or Oasis	0.018	0.039	0.08
<u>Yellow-rumped Warbler[1]</u>			
Total Water	0.869	0.119	1.00
All Dead Understory Veg.	0.286	0.175	0.84
Elevation	0.403	0.386	0.67
Canopy Height	0.176	0.175	0.65
All Live Understory Veg.	-0.160	0.169	0.62
Mesquite and Graythorn	-0.057	0.101	0.38
Width Riparian Veg.	-0.060	0.126	0.34
Goodding Willow	0.030	0.068	0.32
<u>Yellow Warbler[2]</u>			
Canopy Height	0.084	0.019	1.00
Cottonwood Overstory and Other Live Overstory Veg.	0.061	0.017	1.00
Width Riparian Veg.	0.081	0.029	1.00
Mesquite and Graythorn	-0.002	0.010	0.49
Seep Willow	-0.003	0.009	0.49
Gooding Willow	0.018	0.022	0.49
Tamarisk	-0.006	0.015	0.49
Velvet Ash	0.017	0.021	0.49
All Live Understory Veg.	-0.004	0.012	0.49
All Dead Understory Veg.	0.024	0.028	0.49
Number Visits with Water	0.009	0.017	0.33
Total Water	-0.001	0.005	0.19

Table 4. Continued.

Variables	*B*	Unconditional SE	Relative Importance of Variables
Common Yellowthroat[1]			
Corridor or Oasis	-1.430	0.354	1.00
Number Visits with Water	1.280	0.233	1.00
All Live Understory Veg.	0.388	0.157	0.95
All Dead Understory Veg.	0.092	0.143	0.43
Seep Willow	0.025	0.061	0.31
Lucy's Warbler[1]			
Mesquite and Graythorn	0.091	0.037	0.95
Cottonwood Overstory and Other Live Overstory Veg.	-0.062	0.035	0.86
Netleaf Hackberry	0.034	0.037	0.60
Elevation	0.075	0.086	0.59
Total Water	-0.039	0.045	0.59
Number Visits with Water	-0.021	0.035	0.42
Gooding Willow	0.003	0.011	0.29
Tamarisk	0.002	0.014	0.27
Wilson's Warbler[2]			
Total Water	0.441	0.079	1.00
Brush and Absence of Desert Broom	-0.058	0.076	0.49
Cottonwood Overstory and Other Live Overstory Veg.	0.027	0.052	0.49
Goodding Willow	-0.019	0.048	0.49
All Live Understory Veg.	-0.079	0.099	0.49
All Dead Understory Veg.	0.049	0.074	0.49
Mesquite and Graythorn	0.017	0.042	0.38
Width Riparian Veg.	-0.011	0.038	0.24
Canopy Height	0.019	0.036	0.19
Tamarisk	-0.003	0.010	0.05
Yellow-breasted Chat[2]			
Width Riparian Veg.	0.166	0.059	1.00
Total Water	-0.194	0.043	1.00
All Dead Understory Veg.	0.018	0.041	1.00
All Live Understory Veg.	0.115	0.038	1.00
Velvet Ash	0.014	0.025	0.40
Tamarisk	0.035	0.049	0.40
Netleaf Hackberry	0.012	0.026	0.40
Goodding Willow	0.022	0.032	0.40
Cottonwood Overstory and Other Live Overstory Veg.	0.009	0.025	0.56
Brush and Absence of Desert Broom	0.016	0.026	0.40
Seep Willow	0.002	0.013	0.40
Mesquite and Graythorn	0.006	0.018	0.40
Corridor and Oasis	-0.219	0.280	0.40
Canopy Height	-0.006	0.019	0.40
Song Sparrow[1]			
Number Visits with Water	1.150	0.145	1.00
Canopy Height	-0.116	0.081	0.80
All Live Understory Veg.	0.097	0.078	0.74
Seep Willow	0.069	0.065	0.68
All Dead Understory Veg.	0.046	0.067	0.46
Goodding Willow	0.029	0.051	0.38

Table 4. Continued.

Variables	B	Unconditional SE	Relative Importance of Variables
Tamarisk	-0.002	0.018	0.27
House Finch[1]			
Cottonwood Overstory and Other Live Overstory Veg.	-0.120	0.053	0.93
Tamarisk	-0.118	0.090	0.76
Velvet Ash	0.006	0.018	0.29
Total Water	-0.005	0.017	0.29
Goodding Willow	0.005	0.018	0.28
Number Visits with Water	-0.007	0.024	0.28
Lesser Goldfinch[2]			
Number of Visits with Water	0.074	0.062	0.66
Cottonwood Overstory and Other Live Overstory Veg.	-0.004	0.018	0.53
Elevation	-0.069	0.102	0.34
Seep Willow	0.002	0.011	0.34
Brush and Absence of Desert Broom	-0.009	0.017	0.34
Goodding Willow	0.005	0.013	0.34
Netleaf Hackberry	-0.003	0.013	0.34
All Live Understory Veg.	-0.005	0.016	0.34
All Dead Understory Veg.	-0.018	0.029	0.34
Total Water	0.042	0.058	0.34
Width Riparian Veg.	0.007	0.022	0.34
Mesquite and Graythorn	0.000	0.002	0.05
Tamarisk	-0.002	0.005	0.05
Abert's Towhee[1]			
All Live Understory Veg.	0.146	0.061	0.94
Width Riparian Veg.	0.165	0.099	0.85
Water Total	-0.101	0.076	0.78
Number Visits with Water	0.100	0.100	0.65
All Dead Understory Veg.	0.029	0.047	0.42
Seep Willow	0.002	0.015	0.27
Summer Tanager[1]			
Cottonwood Overstory and Other Live Overstory Veg.	0.203	0.055	1.00
Canopy Height	0.096	0.073	0.76
Goodding Willow	0.045	0.055	0.55
Velvet Ash	-0.027	0.044	0.41
Width Riparian Veg.	0.031	0.056	0.38
Total Water	0.016	0.034	0.32
Number of Visits with Water	0.001	0.021	0.27

[1] Parameter estimates generated from all possible combinations of variables in the confidence set of models.
[2] Parameter estimates generated by averaging the parameter estimates for species with greater than 8 variables in the confidence set of models.

Table 5. Decrease in surface water during the bird breeding season at 28 study sites in southeastern Arizona where we measured surface water during 4 replicate surveys from April to June (2006-2008) for our spatial analysis.

Study Site	% Survey Points with >0 m^2 Surface Water				Total Surface Water (m^2)[1]				
	April	Early May	Late May	June	April	Early May	Late May	June	% Decrease (April to June)
Arivaca Creek[2]	29	29	7	7	408	84	1	0	100
Buehman Canyon[2]	27	13	7	0	247	39	1	0	100
Boquillas[2]	100	100	100	50	6,174	5,524	3,674	716	88
Brown Canyon[2]	7	7	7	7	30	37	12	13	57
Cienega Creek[2]	73	67	67	67	3,676	3,393	3,395	1,158	68
Fairbank[2]	100	100	83	17	6,160	4,738	1,388	6	100
Gray Hawk[2]	100	100	100	100	9,334	9,421	9,574	8,970	4
Hunter Wash[2]	100	100	50	25	10,277	9,440	988	94	99
Lower Hot Springs[2]	67	47	40	20	1,900	1,600	979	1,099	42
Lower Las Cienegas[2]	0	0	0	10	0	0	0	1	
Lower Sabino Creek[2]	92	33	8	8	1,117	197	31	2	100
Posta Quemada[2]	0	0	0	0	0	0	0	0	
Rincon Creek[2]	0	0	0	0	0	0	0	0	
Tumacacori[2]	100	100	100	100	6,179	8,573	6,257	5,802	6
Upper Hot Springs[2]	67	53	13	20	1,275	979	214	83	94
Upper Sabino Creek[2]	100	45	18	9	1,906	350	53	9	100
Cascabel[3]	60	50	20	0	1,717	1,293	1	0	100
Dudleyville East[3]	0	0	0	0	0	0	0	0	
Dudleyville West[3]	100	100	100	100	7,741	6,529	5,527	2,433	69
Sonoita Creek[3]	100	100	100	100	8,155	9,214	9,530	10,087	-24
St. David[3]	100	100	100	83	6,004	3,707	2,914	1,739	71
Upper Cienega Creek[3]	0	0	0	0	0	0	0	0	
Clark Property[4]	13	0	0	0	2	0	0	0	100
Empire Gulch[4]	27	27	27	27	2,033	1,089	956	1,016	50
Lower Paige Creek[4]	100	100	100	54	3,703	2,940	2,213	714	81
Tubac[4]	100	100	n/a[5]	100	12,106	1,1287	n/a[5]	12,495	-3
Tanque Verde Creek[4]	100	100	92	17	4,212	3,783	2,208	38	99
Upper Arivaca Creek[4]	14	0	0	0	107	0	0	0	100
Weighted Average	62	55	43	35	3,464	3,076	1,924	1,685	58

[1] Surface water totaled across survey points at each study site for each the 4 replicate surveys; [2] Surveyed in 2006; [3] Surveyed in 2007; [4] Surveyed in 2008; [5] Missing data.

each study site in June. In addition, the presence of surface water (i.e., “number of visits with water”) at our 28 study sites declined seasonally from an average of 62% of survey points at each study site that had >0 m^2 surface water in April to 35% of survey points at each study site that had >0 m^2 surface water in June (Table 5).

Influence of Surface Water on Riparian Birds (Temporal Analysis)--For the temporal analysis of our bird data (2006 vs. 2008), we found no associations with surface water for our community-level parameters (i.e., confidence interval around parameter estimates for water variables included zero; Table 6; Appendix D). However, we detected positive associations with surface water for 7 bird species, including 5 breeding (Black Phoebe, Common Yellowthroat, Yellow Warbler, Song Sparrow, and Lesser Goldfinch) and two migrant (Yellow-rumped Warbler and Wilson’s Warbler; Table 6; Appendix D) species. Black Phoebe, Yellow-rumped Warbler, and Wilson’s Warbler were positively associated with “total water”; whereas, Common Yellowthroat, Yellow Warbler, Song Sparrow, and Lesser Goldfinch were positively associated with “number of visits with water”. We also detected negative associations with surface water for 4 breeding species (White-winged Dove, Yellow-breasted Chat, Abert’s Towhee, and Summer Tanager). All of these species (except Summer Tanager) were negatively associated with “total water”. We report predictive models (with unstandardized coefficients) from our temporal analysis in Appendix D.

The extent of surface water (i.e., “total water”) at each study site increased from an average of 987 m^2 in 2006 to 2,618 m^2 in 2008 and the presence of surface water (i.e., “number of visits with water”) increased from an average of 52% of survey points at each study site that had >0 m^2 surface water in 2006 to an average of 82% of survey points at each study site that had >0 m^2 surface water in 2008 (as measured at the 8 sites where we collected surface water measurements in all 3 years of the study; Table 7).

Nest Monitoring--From April-July 2006-2008, we located a total of 951 nests of 53 species at 6 study sites (Boquillas, Fairbank, Cienega Creek, Posta Quemada, Upper Cienega Creek, and Rincon Creek; Table 8). We found a total of 63 nests of 18 species at the Boquillas study site, 65 nests of 19 species at the Fairbank study site, 389 nests of 38 species at the Cienega Creek study site (including 2 Yellow-billed Cuckoo nests), 101 nests of 30 species at the Upper Cienega Creek study site (including 1 Yellow-billed Cuckoo nest), 108 nests of 28 species at the Posta Quemada study site, and 225 nests of 33 species at Rincon Creek study site. Using our 2006 nest-monitoring data, we determined average clutch sizes for 18 species of riparian and upland birds for which we were able to observe nest contents for ≥1 nest (Table 9). We had sufficient data (>3 nests in both “wet” and “dry” study sites) to compare clutch sizes for 2 of these species. We were unable to detect differences in average clutch size for Black- chinned Hummingbirds ($t = 1.8$, $P = 1.000$) or White-winged Doves ($t = 1.9$, $P = 0.228$) between our “wet” and “dry” study sites. Although we found many nests of Bell’s Vireo (our focal species; Fig. 7), we were unable to compare Bell’s Vireo clutch sizes between “wet” and “dry” study sites in 2006 because of the virtual absence of nesting attempts by this species at our only “dry” study site (Rincon Creek).

For example, we found a total of 42 nests of Bell’s Vireos of which 98% were located at our 3 “wet” study sites (60% at Cienega Creek, 19% at Fairbank, and 19% at Boquillas) and only 1 nest was located at our “dry” study site at Rincon Creek. Because of the lack of Bell’s Vireo

Table 6. Top-ranked models from our temporal analysis for community- and species-level bird parameters generated using multi-model inference of *apriori* model sets.

Top-ranked Models	K	AIC_c	ΔAIC_c	W_i
Community-level				
Total Relative Abundance				
All Vegetation Variables[1], Total Water	12	5412.18	0.00	1.00
Species Richness				
All Vegetation Variables[1], Total Water	12	4312.93	0.00	1.00
Species-level				
White-winged Dove				
All Vegetation Variables[1], Total Water	11	878.62	0.00	0.99
Black Phoebe				
All Vegetation Variables[1], Total Water	11	164.90	0.00	0.94
Bewick's Wren				
All Vegetation Variables[1]	10	912.29	0.00	0.72
All Vegetation Variables[1], Number Visits with Water	11	914.14	1.85	0.28
Bell's Vireo				
All Vegetation Variables[1], Total Water	11	710.69	0.00	0.71
All Vegetation Variables[1], Number Visits with Water	11	713.72	3.03	0.16
All Vegetation Variables[1]	10	714.11	3.42	0.13
Yellow-rumped Warbler				
All Vegetation Variables[1], Total Water	11	603.79	0.00	1.00
Yellow Warbler				
All Vegetation Variables[1], Number Visits with Water	11	747.66	0.00	0.79
Common Yellowthroat				
All Vegetation Variables[1], Number Visits with Water	11	257.89	0.00	0.99
Lucy's Warbler				
All Vegetation Variables[1]	10	1106.49	0.00	0.51
All Vegetation Variables[1], Number Visits with Water	11	1106.59	0.10	0.49

Table 6. Continued.

Top-ranked Models	K	AIC_c	ΔAIC_c	W_i
Wilson's Warbler				
All Vegetation Variables[1], Total Water	11	698.35	0.00	1.00
Yellow-breasted Chat				
All Vegetation Variables[1], Total Water	11	783.90	0.00	1.00
Song Sparrow				
All Vegetation Variables[1], Number Visits with Water	11	284.46	0.00	1.00
House Finch				
All Vegetation Variables[1]	10	1247.32	0.00	0.71
All Vegetation Variables[1], Number Visits with Water	11	1249.08	1.76	0.29
Lesser Goldfinch				
All Vegetation Variables[1], Number Visits with Water	11	1342.52	0.00	0.67
All Vegetation Variables[1]	10	1343.96	1.43	0.33
Abert's Towhee				
All Vegetation Variables[1], Total Water	11	873.53	0.00	0.95
Summer Tanager				
All Vegetation Variables[1], Total Water	11	829.00	0.00	0.97

[1] All Vegetation Variables = 6 vegetation variables combined: 1) live vegetation volume 0-2 m; 2) dormant/dead vegetation volume 0-2 m; 3) live vegetation volume 2.1-5 m; 4) dormant/dead vegetation volume 2.1-5 m; 5) live vegetation volume 5.1-20 m; and 6) dormant/dead vegetation volume 5.1-20 m.

Table 7. Increase in surface water across years (from 2006-2008) at 8 study sites in southeastern Arizona where we measured surface water during 4 replicate surveys from April to June (2006-2008) for our temporal analysis.

Study Site	% Survey Points with >0 m^2 Surface Water[1]			Total Surface Water (m^2)[2]			
	2006	2007	2008	2006	2007	2008	Increase (2006 to 2008)
Arivaca Creek	29	50	100	123	434	3,708	3,584
Cienega Creek	73	73	73	2,905	3,150	4,338	1,432
Fairbank	100	100	100	3,073	4,384	5,447	2,374
Lower Las Cienegas	10	100	100	0	404	577	577
Lower Sabino Creek	92	100	100	337	1,046	1,950	1,614
Posta Quemada	0	11	11	0	6	1	1
Rincon Creek	0	100	100	0	2,157	2,406	2,406
Upper Hot Springs	73	67	67	638	902	1,224	586
Weighted Average	52	75	82	987	1,626	2,618	1,630

[1] For any of the 4 replicate surveys conducted in each year.

[2] Surface water averaged across the 4 replicate surveys conducted at each survey point in each year, then totaled across survey points at each study site.

Table 8. Summary nest characteristics for 951 nests of 53 species found at 6 study sites (Boquillas, Fairbank, Cienega Creek, Posta Quemada, Rincon Creek, and Upper Cienega Creek) located in riparian woodlands of southeastern Arizona, April-July 2006-2008.

		Nest Height (m)		Species of plant comprising nesting substrate[*]									
Bird Species	*n*	$\overline{x}$	S.E.	1st	%	2nd	%	3rd	%	4th	%	5th	%
Abert's Towhee	33	2.07	0.97	PROVEL	18	TAMARI	18	ZIZOBT	18	SALGOO	15	OTHER	30
Anna's Hummingbird	13	3.63	2.44	CELRET	38	FRAPEN	31	POPFRE	15	SALGOO	15		
Ash-throated Flycatcher	11	9.14	5.05	POPFRE	36	SALGOO	27	FRAPEN	18	PROVEL	18		
Broad-billed Hummingbird	10	1.87	1.09	CELRET	60	SALGOO	20	ZIZOBT	10	FRAPEN	10		
Brown-crested Flycatcher	18	8.44	3.40	CARGIG	56	POPFRE	17	SALGOO	17	PLAWRI	6		
Black-chinned Hummingbird	67	3.04	4.30	CELRET	25	FRAPEN	34	SALGOO	12	POPFRE	15	OTHER	12
Bell's Vireo	174	1.77	0.99	CELRET	18	ZIZOBT	16	PROVEL	12	FRAPEN	11	OTHER	25
Bewick's Wren	21	5.58	3.26	SALGOO	4	POPFRE	19	FRAPEN	14	PROVEL	10	OTHER	15
Blue Grosbeak	8	2.31	1.19	CELRET	25	TAMARI	25	FRAPEN	13	PROVEL	13	OTHER	26
Black Phoebe	4	17.50	13.23	OTHER	75								
Black-tailed Gnatcatcher	2	2.10	0.14	CELRET	50	FRAPEN	50						
Black-throated Sparrow	25	1.00	0.65	PROVEL	24	SALGOO	16	CELRET	12	ZIZOBT	12	OTHER	36
Bullock's Oriole	2	16.00	5.66	POPFRE	100								
Bushtit	1	4.00	-	POPFRE	100								
Cactus Wren	2	6.50	2.12	CARGIG	50	CELRET	50						
Cassin's Kingbird	14	17.79	6.40	POPFRE	57	PLAWRI	21	SALGOO	14				
Canyon Towhee	5	1.54	1.05	PROVEL	40	ACAGRE	20	FRAPEN	20	ZIZOBT	20		
Canyon Wren	1	2.50	-	OTHER	100								
Curve-billed Thrasher	1	1.00	-	OPUNTIA	100								
Common Ground-Dove	4	3.50	1.08	PROVEL	50	TAMARI	25	FRAPEN	25				
Cooper's Hawk	5	15.40	12.38	POPFRE	60	SALGOO	40						
Costa's Hummingbird	1	1.00	-	UNID	100								
Common Raven	1	20.00	-	POPFRE	100								
Common Yellowthroat	1	0.30	-	BACSAL	100								
Gilded Flicker	5	6.00	3.74	CARGIG	100								
Gila Woodpecker	13	7.54	2.70	CARGIG	62	POPFRE	23	PROVEL	8	SALGOO	8		
Gambel's Quail	2	0.00	0.00	CELRET	50	GRASS	50						
Gilded Flicker	5	6.00	3.74	CARGIG	100								
Gila Woodpecker	13	7.54	2.70	CARGIG	62	POPFRE	23	PROVEL	8	SALGOO	8		

Table 8. Continued.

		Nest Height (m)		Species of plant comprising nesting substrate*									
Bird Species	*n*	$\bar{x}$	S.E.	1st	%	2nd	%	3rd	%	4th	%	5th	%
Inca Dove	1	1.50	-	SALGOO	100								
Ladder-backed Woodpecker	9	7.50	3.78	PROVEL	44	POPFRE	22	SALGOO	22	FRAPEN	11		
Lesser Goldfinch	22	5.09	2.42	POPFRE	50	SALGOO	18	FRAPEN	14	PROVEL	9	OTHER	10
Lucy's Warbler	62	3.98	3.97	PROVEL	31	FRAPEN	19	POPFRE	15	CELRET	13	OTHER	14
Mourning Dove	33	2.52	1.23	PROVEL	39	FRAPEN	15	SALGOO	12	CELRET	6	OTHER	15
N.-beardless Tyrannulet	3	7.90	3.64	FRAPEN	67	OTHER	33						
Northern Cardinal	35	2.95	2.57	CELRET	23	PROVEL	20	SALGOO	17	TAMARI	9	OTHER	26
N. Rough-winged Swallow	4	13.00	18.87	OTHER	100								
Phainopepla	9	11.00	5.73	FRAPEN	44	SALGOO	22	PROVEL	11	TAMARI	11		
Purple Martin	8	8.69	2.99	CARGIG	100								
Rufous-crowned Sparrow	1	1.50	-	ZIZOBT	100								
Red-tailed Hawk	2	22.50	10.61	POPFRE	100								
Rufous-winged Sparrow	13	1.67	0.73	PROVEL	31	TAMARI	15	ZIZOBT	15	OTHER	15		
Song Sparrow	7	0.74	0.50	BACSAL	86								
Summer Tanager	20	8.53	4.42	POPFRE	40	FRAPEN	25	PROVEL	15	SALGOO	10	CELRET	10
Vermillion Flycatcher	35	9.94	6.10	POPFRE	37	FRAPEN	23	PROVEL	17	SALGOO	17	OTHER	3
Verdin	84	3.33	2.18	PROVEL	24	ZIZOBT	23	CELRET	17	POPFRE	6	OTHER	28
Western Kingbird	3	16.00	6.93	FRAPEN	100								
White-winged Dove	42	3.77	2.25	PROVEL	33	SALGOO	24	FRAPEN	19	CELRET	17	OTHER	4
Yellow-breasted Chat	63	1.50	0.66	BACSAL	37	ZIZOBT	13	FRAPEN	11	CELRET	10	OTHER	31
Yellow-billed Cuckoo	3	5.50	3.91	POPFRE	67	SALGOO	33						
Yellow Warbler	16	10.96	5.28	POPFRE	75	PROVEL	13	FRAPEN	6	SALGOO	6		
Zone-tailed Hawk	1	40.00	-	POPFRE	100								

* ACAGRE = Catclaw Acacia (*Acacia greggii)*; BACSAL = Seep Willow (*Baccharis salicifolia)*; CARGIG = Saguaro Cactus (*Carnegiea gigantea*); CELRET = (*Celtis reticulate*); FRAPEN = Velvet Ash (*Fraxinus pennsylvanica*); OPUNTIA = Cholla cacti spp. (*Opuntia* spp.); PLAWRI = Arizona Sycamore (*Platanus wrightii)*; POPFRE = Fremont Cottonwood (*Populus fremontii*); PROVEL = Velvet Mesquite (*Prosopis velutina*); SALGOO = Goodding Willow (*Salix gooddingii*); SAMMEX = Mexican Elderberry *(Sambucas mexicana)*; TAMARI = Tamarisk spp. (*Tamarix* spp.); ZIZOBT = Gray Thorn (*Ziziphus obtusifolia*).

Table 9. Average clutch sizes of 18 species of riparian birds for which we were able to determine nest contents at ≥1 nest at 4 study sites (Boquillas, Cienega Creek, Fairbank, and Rincon Creek) located in riparian woodlands of southeastern Arizona, April-July 2006.

		Clutch size			
Species	*n*	$\bar{x}$	SE	Min	Max
Abert's Towhee	6	3.2	0.17	3	4
Broad-billed Hummingbird	4	1.8	0.25	1	2
Black-chinned Hummingbird	16	2.0	0.09	1	3
Bell's Vireo	25	3.0	0.09	2	4
Black-throated Sparrow	1	3.0	-	-	-
Canyon Towhee	1	2.0	-	-	-
Common Yellowthroat	1	3.0	-	-	-
House Finch	3	3.3	0.33	3	4
Lesser Goldfinch	1	3.0	-	-	-
Lucy's Warbler	2	3.5	0.50	3	4
Mourning Dove	6	1.8	0.17	1	2
Northern Cardinal	4	2.8	0.25	2	3
Rufous-winged Sparrow	1	4.0	-	-	-
Song Sparrow	2	3.5	0.50	3	4
Vermillion Flycatcher	3	2.7	0.33	2	3
Verdin	3	3.3	0.33	3	4
White-winged Dove	15	2.0	0.10	1	3
Yellow-breasted Chat	24	3.3	0.11	2	4

Figure 7. A pair of Bell's Vireos (*Vireo bellii*) feeding young at a nest at the Cienega Creek study site in southeastern Arizona (photo credit: B. Taubert).

nesting attempts at Rincon Creek, we were also unable to compare nest depredation rates between "wet" and "dry" study sites during the 2006 breeding season. Nevertheless, we did collect data on Bell's Vireo breeding biology and reproductive success across our study area in 2006. We determined the earliest and latest initiation dates for Bell's Vireo nests as 27 April and 30 July, respectively. Forty of the 42 Bell's Vireo nests survived until at least the start of laying. Brown-headed Cowbirds parasitized 45% of these 40 nests, laying an average of 1.2 (SE = 1.00; range 1-2) eggs per Bell's Vireo nest. Daily nest survival was 0.890 (95% CI = 0.845-0.936) for the laying and incubation periods and 0.766 (95% CI = 0.645-0.887) for the nestling period. Overall daily nest survival (laying through nestling periods) was 0.865 (95% CI = 0.820-0.909) and overall nesting success was only 2%. Of the 33 nests that failed, 42% failed due to Brown-headed Cowbird nest parasitism, 42% failed due to nest predators, 12% failed for unknown reasons, and 6% failed due to abandonment by adults. Successful Bell's Vireo nests produced an average of 1.6 (SE = 0.26; range 1-3) fledglings per nest.

Using our 2007 nest-monitoring data, we found a total of 100 Bell's Vireo nests at 3 of our 4 study sites (Rincon Creek had no breeding Bell's Vireos in 2007). We were unable to detect a difference in Bell's Vireo clutch size between our 2 "wet" sites ($\bar{x}$ = 3.47 eggs, n = 15) versus our 1 "dry" site ($\bar{x}$ = 3.35 eggs, n = 20; t = 1.7, P = 0.579) in 2007. We were also unable to detect a difference in Bell's Vireo egg volume between our 2 "wet" sites ($\bar{x}$ = 1,420 mm^3 eggs, n = 19) versus our 1 "dry" site ($\bar{x}$ = 1,404 mm^3, n = 28; t = 1.7, P = 0.753) in 2007.

We found that nesting attempts by Bell's Vireos increased at the Rincon Creek study site from the beginning to the end of the study. In 2006, we found a single Bell's Vireo nest that was abandoned while the nest was under construction. In 2007, we found no Bell's Vireo nests. In 2008, we found 4 Bell's Vireo nests, 2 of which fledged young, and 2 of which were depredated. These 4 nesting attempts represent breeding efforts by at least 3 pairs of Bell's Vireos at Rincon Creek. We also found that Yellow Warblers bred for the first time at Rincon Creek in 2008.

Arthropod Sampling (Aerial)--Using sticky traps, we captured arthropods representing 18 Orders at our 12 study sites (6 that were "wet" and 6 that were "dry"). In our analysis, we found that the addition of the predictor variable total arthropod biomass did not improve model fit for any of the bird community-level models. The community level bird models were generally no better than the null model at predicting arthropod biomass for all arthropod orders evaluated with the exception of *Diptera*. The 11 best models predicting *Diptera* biomass on traps included both "total water" and "number of visits with water" as predictors (Table 10). *Diptera* were positively associated with "total water" but negatively associated with "number of visits with water" (although the confidence interval slightly overlapped zero for "number of visits with water"; Tables 11 a-b).

When we compared arthropods captured at our Rincon Creek study site in 2006 (a "dry" year) and 2007 (a "wet" year), we found that total dry biomass of arthropods increased 171% at Rincon Creek from one year to the next. In addition, dry biomass increased for *Coleoptera* (369%), *Diptera* (268%), and *Hemiptera* (4,300%) from 2006 to 2007. Only dry biomass of Thysanoptera decreased (63%) from 2006 to 2007. We captured individuals of 2 arthropod

Table 10. Top-ranked models for predicting biomass of *Diptera* selected from our *a priori* community-level bird model set. Aerial arthropod data collected from 12 study sites located in riparian woodlands throughout southeastern Arizona from 2006-2008.

Top-ranked Models	K	AIC_c	ΔAIC_c	W_i
Total Water, Number Visits with Water	5	1016.88	0.00	0.22
All Live Understory Veg., Total Water, Number Visits with Water	6	1017.34	0.46	0.18
Cottonwood Overstory & Other Live Overstory Veg,, Total Water, Number Visits with Water	6	1018.44	1.56	0.10
All Dead Understory Veg,, All Dead Overstory Veg., Total Water, Number Visits with Water	7	1018.50	1.62	0.10
Total Water, Cottonwood Overstory & Other Live Overstory Veg,, Total Water x Cottonwood Overstory & Other Live Overstory Veg,	6	1018.97	2.09	0.08
Cottonwood Overstory & Other Live Overstory Veg,, All Live Understory Veg., Total Water, Number Visits with Water	7	1019.16	2.28	0.07
Total Water	4	1019.39	2.51	0.06
All Live Understory Veg., Total Water, Total Water x All Live Understory Veg.	6	1020.20	3.32	0.04
Total Water, Number Visits with Water, Cottonwood Overstory & Other Live Overstory Veg,, All Live Understory Veg., All Dead Understory Veg., All Dead Overstory Veg.	9	1021.23	4.35	0.03
All Dead Understory Veg., All Dead Overstory Veg., Total Water, All Dead Understory Veg. x Total Water, All Dead Overstory Veg. x Total Water	8	1021.36	4.49	0.02
All Live Understory Veg.	4	1021.48	4.60	0.02

Table 11a. Standardized parameter estimates for biomass of *Diptera* selected from our *a priori* community-level bird model set. We standardized estimates of coefficients to allow comparison amongst variables in the confidence set of models.

Variables	*B*	Unconditional SE	Relative Importance of Variables
Total Water	0.633	0.276	0.98
Number Visits with Water	-0.344	0.273	0.75
All Live Understory Veg.	0.054	0.087	0.36
Cottonwood Overstory and Other Live Overstory Veg.	-0.026	0.052	0.30
All Dead Understory Veg.	-0.002	0.017	0.16
All Dead Overstory Veg.	0.022	0.042	0.16
Total Water, Cottonwood Overstory and Other Live Overstory Veg.	-0.019	0.036	0.08
Total Water x All Live Understory Veg.	0.004	0.010	0.05
Total Water x All Dead Understory Veg.	0.000	0.003	0.03
Total Water x All Dead Overstory Veg.	0.004	0.008	0.03

Table 11b. Predictive model showing unstandardized parameter estimates for biomass of *Diptera* selected from our *a priori* community-level bird model set.

Variables	*B*	Unconditional SE	Lower 95% CL	Upper 95% CL
Intercept	22.9000	5.1600	12.7000	33.0000
Cottonwood Overstory and Other Live Overstory Veg.	-0.5070	1.0000	-2.4700	1.4600
All Live Understory Veg.	0.8740	1.4000	-1.8700	3.6200
All Dead Understory Veg.	-0.0263	0.2930	-0.6010	0.5490
All Dead Overstory Veg.	0.3980	0.7480	-1.0700	1.8600
Total Water	0.9750	0.4260	0.1400	1.8100
Number Visits with Water	-3.3200	2.6400	-8.5000	1.8500
Total Water, Cottonwood Overstory and Other Live Overstory Veg.	-0.0275	0.0534	-0.1320	0.0772
Total Water x All Live Understory Veg.	0.0061	0.0142	-0.0218	0.0339
Total Water x All Dead Understory Veg.	0.0000	0.0038	-0.0076	0.0075
Total Water x All Dead Overstory Veg.	0.0056	0.0118	-0.0174	0.0286

Orders (*Ephemeroptera* and *Trichoptera*) in which all species have an aquatic life stage at Rincon Creek in 2007, but we did not capture individuals from these 2 Orders in 2006.

Arthropod Sampling (Arboreal)--We collected arboreal arthropods representing 14 Orders on branches clipped from trees at our "wet" (Cienega Creek) and at our "dry" (Posta Quemada) sites. Branches with predator exclosures had 496% more arthropod biomass than exposed branches (t = 3.5, P = 0.001). We found branches at Cienega Creek had 124% more arthropods than branches at Posta Quemada while controlling for tree type, sample type, and proximity to the floodplain as random variables (t = 2.7, P = 0.004). However, this trend diminished when we included fixed variables for water stress, tree type, proximity to the floodplain, and sample type in the model (t = 1.1, P = 0.142). Exposed mesquite branches collected from trees located away from the stream channel (i.e., in the upland) had 31% greater arthropod biomass (t = 1.4, P = 0.083). However, this trend disappeared when we considered only branches with predator exclosures (t = 0.3, P = 0.380), indicating that the difference was likely due to increased predation pressure on arthropods in riparian woodlands along the stream channel. We found that arthropod biomass on velvet mesquite branches was greater than on Goodding willow branches (t = -1.8, P = 0.040). But again this trend diminished when we considered only excluded branches (t= 1.2, P = 0.126) suggesting that Goodding willow experienced higher arthropod predation pressure. Water stress of trees was predicted by study site and proximity to the floodplain. Trees at Cienega Creek had lower water stress (130% lower for riparian willows and 72% lower for riparian mesquites) than those at Posta Quemada (t = 9.9, P < 0.001), and mesquites located in the floodplain had 40% lower stress than those in the upland (t = 4.5, P < 0.001). Finally, we found that the increased water stress in trees was negatively associated with arboreal arthropod abundance (t = -1.6, P = 0.056; Figs. 8a-b).

Summary Results for Statistical Hypotheses Tested: A "Yes" next to an alternative statistical hypothesis indicates that we found evidence to support the hypothesis during the current study. A "No" next to an alternative statistical hypothesis indicates that we were unable to reject the null hypothesis during the current study.

1) Riparian areas have higher species richness and total relative abundance than the surrounding landscape - **Yes**

2) Amount of surface water in the 50 m surrounding a survey point is positively correlated with avian species richness and relative abundance - **Yes**

3) Proportion of riparian vegetation that is dead/dormant in the 50 m surrounding a survey point is negatively correlated with avian species richness and relative abundance - **No**

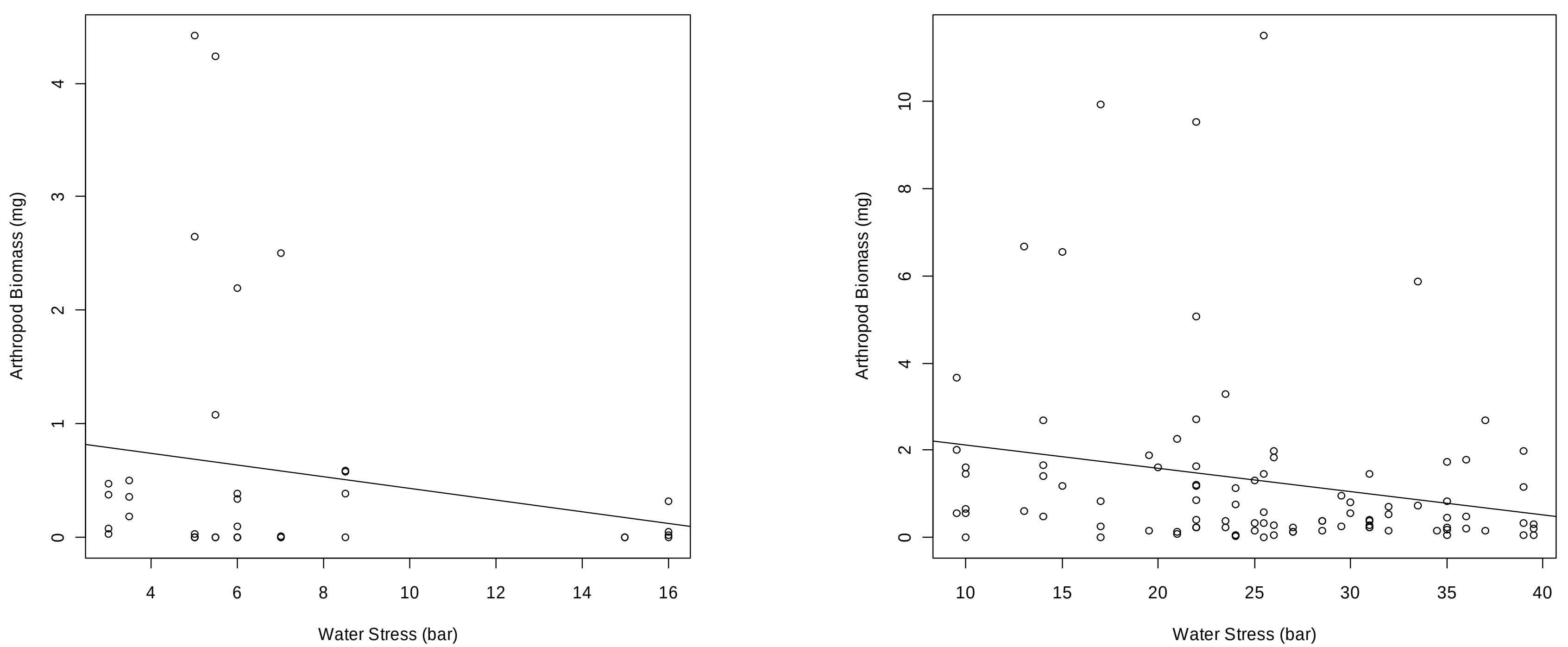
4) Increase in surface water (from 2006-2008) in the 50 m surrounding a survey point is positively correlated with an increase in avian relative abundance - **Yes (for selected species)**

5) Aerial arthropod biomass is greater in riparian areas with surface water compared to riparian areas lacking surface water - **Yes (tentative**)

Figures 8a-b. Graphs illustrating the linear bivariate relationship between arthropod biomass (mg) and plant water stress (bar) in two riparian tree species, A) velvet mesquite and B) Goodding willow, at the Cienega Creek and Posta Quemada study sites, southeastern Arizona (2008). In the results, we present findings for the overall effect of water stress on arthropod abundance from our multivariate analysis (including the effects of study site, location of tree within the riparian woodland, and tree species).

A) Velvet mesquite

B) Goodding willow



6) Arboreal arthropod biomass is greater on riparian tress with less water stress compared to riparian trees with more water stress - **Yes**

7) Clutch sizes, egg volumes, and nesting success are higher in riparian areas with surface water compared to riparian areas lacking surface water (for a focal species) - **No**

DISCUSSION

Our results confirm findings from numerous other studies showing that riparian woodlands in the desert southwest support substantially higher avian species richness and relative abundance than adjacent uplands (Johnson et al. 1977, Engel-Wilson and Ohmart 1978, Ohmart and Anderson 1982, Powell 2004). We found that riparian areas (at a subset of our study sites) contained 68% more species and 75% more individual birds compared to adjacent uplands, with this pattern holding true for both the breeding and migrant bird communities. Moreover, our results indicate that the presence of riparian areas positively influences avian species richness and relative abundance in upland areas adjacent to riparian woodlands. This effect is not linear and decreases rapidly with distance from the riparian area. These results underscore the importance of riparian woodlands to avian species abundance and diversity in the desert southwest and highlight the continued need to protect riparian woodlands because of the disproportionate number of birds (both breeders and migrants) that depend on this critical resource.

The high species richness and abundance of birds in riparian woodlands relative to surrounding uplands is commonly attributed to the structural complexity of the riparian vegetation (Anderson and Ohmart 1977, Bull and Skovlin 1982, Knopf and Samson 1994). We sought to identify whether the presence and extent of surface water in riparian woodlands had an additional effect on these bird parameters after controlling for vegetation structure, vegetation composition, and numerous other potentially confounding variables. At the community level, results from our spatial analysis showed that both total relative abundance and species richness of riparian birds was positively associated with presence and extent of surface water in our study area. This finding corroborates results from 2 previous studies that found positive associations between surface water and total bird abundance and species richness of riparian birds in the desert southwest (Hinojosa-Huerta 2006, Brand et al. 2008). However, these 2 studies were limited in their scope because they estimated only community-level parameters for breeding birds within a spatial analytical framework. We estimated both community- and species-level parameters for both breeding and migrant birds in both a spatial and a temporal analytical framework. To the best of our knowledge, ours is the first study to examine the influence of surface water on avian abundance and diversity in such a comprehensive manner.

At the species level, results from our spatial analysis revealed that several breeding birds were positively associated with increased presence of surface water during the breeding season (i.e., increased “number of visits with water”), including Black Phoebe, Common Yellowthroat, Song Sparrow, and Lesser Goldfinch. We found that the presence of surface water decreased across our study area during the bird breeding season with an average of 62% of survey points with at least some surface water present in April but only 35% of survey points with at least some surface water present in June. This seasonal decrease in presence of surface water may have resulted in some early-season breeders departing survey points that subsequently dried up or some late-season breeders not selecting survey points that were initially wet but dried up as the breeding season progressed. Whatever the mechanism, we detected fewer individuals of these 4 species at survey points that experienced seasonal declines in the presence of surface water. These trends are unlikely to have resulted from potentially confounding factors such as a seasonal decline in detection probability (e.g., perhaps due to a seasonal decrease in singing) or the presence of both long-distance migrants and local breeders of the same species early in the season but the presence of only local breeders later in the season, because our experimental design and statistical analysis controlled for these 2 potential biases.

Indeed, previous studies provide anecdotal evidence indicating that Black Phoebes, Common Yellowthroats, Song Sparrows, and Lesser Goldfinches are all positively associated with surface water to some degree in the desert southwest. For example, Song Sparrows typically inhabit areas of dense undergrowth near perennial waterways, ponds, and marshes in arid areas such as southern Arizona (Arcese et al. 2002, Corman and Wise-Gervais 2005) and Common Yellowthroats typically breed in wet areas with dense undergrowth in Arizona (Guzy and Ritchison 1999, Corman and Wise-Gervais 2005). Black Phoebes are described as being "invariably associated with water" (Wolf 1997; p. 1) and "seldom encountered away from water sources" (Corman and Wise-Gervais 2005; p. 312) and Lesser Goldfinches have been observed drinking from water catchments (Lynn et al. 2006). We found that presence of surface water during the breeding season was the strongest predictor of Black Phoebe, Common Yellowthroat, Song Sparrow, and Lesser Goldfinch abundance within our study area. Our results not only confirm anecdotal observations indicating an affinity of these 4 breeding bird species to surface water, but also provide the first quantitative measure of the relationship between surface water and relative abundance for these species in the desert southwest (see predictive models in Appendix C).

In addition to these breeding species, we found that 2 migrant birds (Yellow-rumped Warbler and Wilson's Warbler) were positively associated with increased extent of surface water (i.e., increased "total water") at survey points. We detected the majority (>87%) of migrant Yellow-rumped Warblers and Wilson's Warblers during the first half of our annual survey period (i.e., < May 15th) and this pattern may explain, in part, why these 2 species were positively associated with increased extent and not increased presence of surface water at survey points during the bird breeding season. In other words, Yellow-rumped Warblers and Wilson's Warblers were largely absent from our study area during the second half of our annual survey period (mid-May to the end of June) and thus could not have been influenced directly by the disappearance of surface water at surveys points later in the season. Although Yellow-rumped Warblers and Wilson's Warblers occasionally drink from wildlife water developments (e.g., cattle tanks) in the Sonoran Desert, experimental research has shown that the surface water per se rarely attracts migrants at these water developments (Lynn et al. 2006). Indeed, the density and composition of adjacent riparian vegetation is thought to provide the primary settlement cues for migrants during stopover in the desert southwest (Lynn et al. 2006). Our research indicates that migrant Yellow-rumped Warblers and Wilson's Warblers are positively associated with gross structural vegetation cues (e.g., increased canopy height for Yellow-rumped warblers and increased overstory vegetation volume for Wilson's Warblers) that may facilitate initial selection of riparian woodlands as stopover habitat. Once they settle into riparian woodlands, we speculate that Yellow-rumped Warblers and Wilson's Warblers make smaller-scale movements along riparian corridors to locate sites with higher-quality stopover habitat (e.g., areas with increased surface water).

In contrast, results from our spatial analysis showed negative associations with increased extent of surface water for 2 common riparian breeding bird species, the Bell's Vireo and Yellow-breasted Chat. Yellow-breasted Chats typically inhabit cottonwood/willow riparian woodlands with a dense understory of mesquite, tamarisk, and other shrubs in Arizona (Corman and Wise-Gervais 2005). Bell's Vireos inhabit riparian woodlands along perennial and intermittent streams with a dense understory of mesquite and shrubs, but they also inhabit drier thickets and mesquite bosques in Arizona (Corman and Wise-Gervais 2005). Indeed, we found that Bell's Vireos and Yellow-breasted Chats were both positively associated with dense understory growth. Although vegetation factors are the most important habitat characteristics for these 2 species, we cannot explain the negative associations with surface water observed for these 2 birds, other than to say that drier sites containing the requisite riparian vegetation appear to be preferred by Bell's Vireos and Yellow-breasted Chats. Alternatively, variation in either surface water and/or understory vegetation volume in the years prior to our study (<2006) may have influenced our results. For example, if Bell's Vireos and Yellow-breasted Chats exhibit high site-fidelity within our study area, they may respond more slowly to changing habitat conditions, including changes in surface water and understory vegetation volume from one year to the next. Indeed, our nest monitoring data from the Rincon Creek study site indicate that Bell's Vireos experienced a lag time in their response to increasing surface water and vegetation at the site between 2006 and 2008. We found that Bell's vireos did not nest at Rincon Creek in 2007, despite a considerable increase in surface water and understory vegetation volume from 2006 to 2007 (only in 2008 did Bell's vireos resume nesting at Rincon Creek; see below).

We also examined our data using a temporal analysis. Taking this second analytical approach was especially useful given that the desert southwest experienced an extremely dry winter/spring in 2005-2006 followed by years with normal or above-average precipitation in 2007 and 2008. This increased precipitation more than doubled (from 987 to 2,618 m^2) the average extent of surface water present at each study site between 2006 and 2008 and increased the presence of surface water from 52% of survey points in 2006 to 82% of survey points in 2008 (as measured at the 8 study sites where we collected data at both the start and end of our study). With this increase in surface water from 2006-2008, we detected positive associations with surface water for several species of birds in our temporal analysis, and most of these results corroborated findings from our spatial analysis. For example, Common Yellowthroat, Song Sparrow, and Lesser Goldfinch were all associated with increased presence of surface water and Black Phoebe, Yellow-rumped Warbler and Wilson's Warbler were all associated with increased extent of surface water. In addition, we detected a positive association for Yellow Warbler with increased presence of surface water in our temporal analysis (unlike our spatial analysis). We also detected negative associations with surface water for 4 breeding species (White-winged Dove, Yellow-breasted Chat, Abert's Towhee, and Summer Tanager). All of these species (except Summer Tanager) were negatively associated with the extent of surface water at survey points.

In addition to looking for associations between our various bird parameters and surface water conditions, we also sought to identify potential ecological processes (e.g., variation in food resources) underlying these associations. We were unable to detect a difference in average clutch size, egg volume, or nesting success (all breeding parameters that could be influenced by the availability of food resources) between our "wet" and "dry" sites for Bell's vireo, our focal nest-monitoring species. However, results from our arboreal and aerial arthropod sampling showed that arthropod biomass increased at study sites with increased water. For example, we observed that riparian trees with decreased water stress had more arboreal arthropod biomass than riparian trees with increased water stress, suggesting a potential link between the availability of ground water resources and the availability of arboreal arthropod food resources for birds. In addition, we found that aerial arthropod biomass of flies (*Diptera*) was positively associated with increased extent of surface water (paradoxically, we found a negative association between the presence of surface water and *Diptera* biomass as well). Finally, we found that aerial arthropod biomass increased substantially between 2006 to 2007 at the Rincon Creek study site and that several arthropod orders that have aquatic life stages (e.g., *Ephemeroptera*, *Tricoptera*) that were absent from Rincon Creek in 2006 were present at this study site in 2007. The appearance of these arthropod orders at Rincon Creek during wet conditions in 2007 (but not during dry conditions in 2006) suggests that some arthropods can respond quickly to spatial variation in surface water conditions from one year to the next. Previous studies have also found that riparian woodlands with surface water support higher densities of invertebrate prey (Jackson and Fisher 1986, Gray 1993).

Many bird species forage primarily on arthropods gleaned from the foliage of trees (Ehrlich et al. 1988). Foliage-gleaning birds likely benefit by foraging on riparian trees (especially Goodding Willow in our study area) that exhibit less water stress because these trees support a greater biomass of arboreal arthropods (as we found in the current study). In addition, riparian bird species that prey upon aerial arthropods likely benefit from foraging in riparian woodlands that have greater surface water because of the increased aerial arthropod biomass found in these areas (as we showed tentatively for *Diptera* in the current study; Jackson and Fisher 1986, Gray 1993). For example, some birds that we found positively associated with surface water (e.g., Black Phoebe) prey extensively upon aerial arthropods. Other riparian bird species (e.g., Yellow Warblers) are known to prey heavily upon *Chironomid* midge flies that require surface water for aquatic life stages (Busby and Sealy 1978, Yard et al. 2004). We found that Yellow Warblers were positively associated with surface water in our temporal analyses suggesting that this species might be capable of tracking and responding to changing water conditions (and increasing *Diptera* and/or arboreal arthropod biomass) from one year to the next.

Because native riparian trees are highly sensitive to changes in groundwater levels in the desert southwest (Brown 1994, Ohmart 1994, Webb and Leake 2005), rapid lowering of ground water levels can kill riparian trees within a short period of time (Webb and Leake 2005). To examine this potential threat, we sought to determine how the health of riparian vegetation (as measured by the proportion of dormant/dead vegetation) influenced avian species richness and relative abundance within our study area. We detected few associations between our bird parameters and the health of riparian vegetation. However, it was clear from an examination of the vegetation data collected from our 28 study sites that we did not have a representative sample of sites to adequately examine the issue of riparian vegetation health. Only at our Rincon Creek study site did we observe extensive tree dormancy (or die-back). Powell (2004) noted that some

Figures 9a-b. The Rincon Creek study site (Saguaro National Park) in July-August 2006 showing: A) large dormant (or dead) Fremont cottonwood and Arizona sycamore trees lining the stream channel (see center of the photograph); and B) dormant (or dead) velvet ash and velvet mesquite trees near the stream channel. Southeastern Arizona experienced an extremely dry winter/spring in 2005-2006 followed by one of the wettest monsoons on record during July-August 2006 (note flowing water in Photo B). Photo B courtesy of the National Park Service.

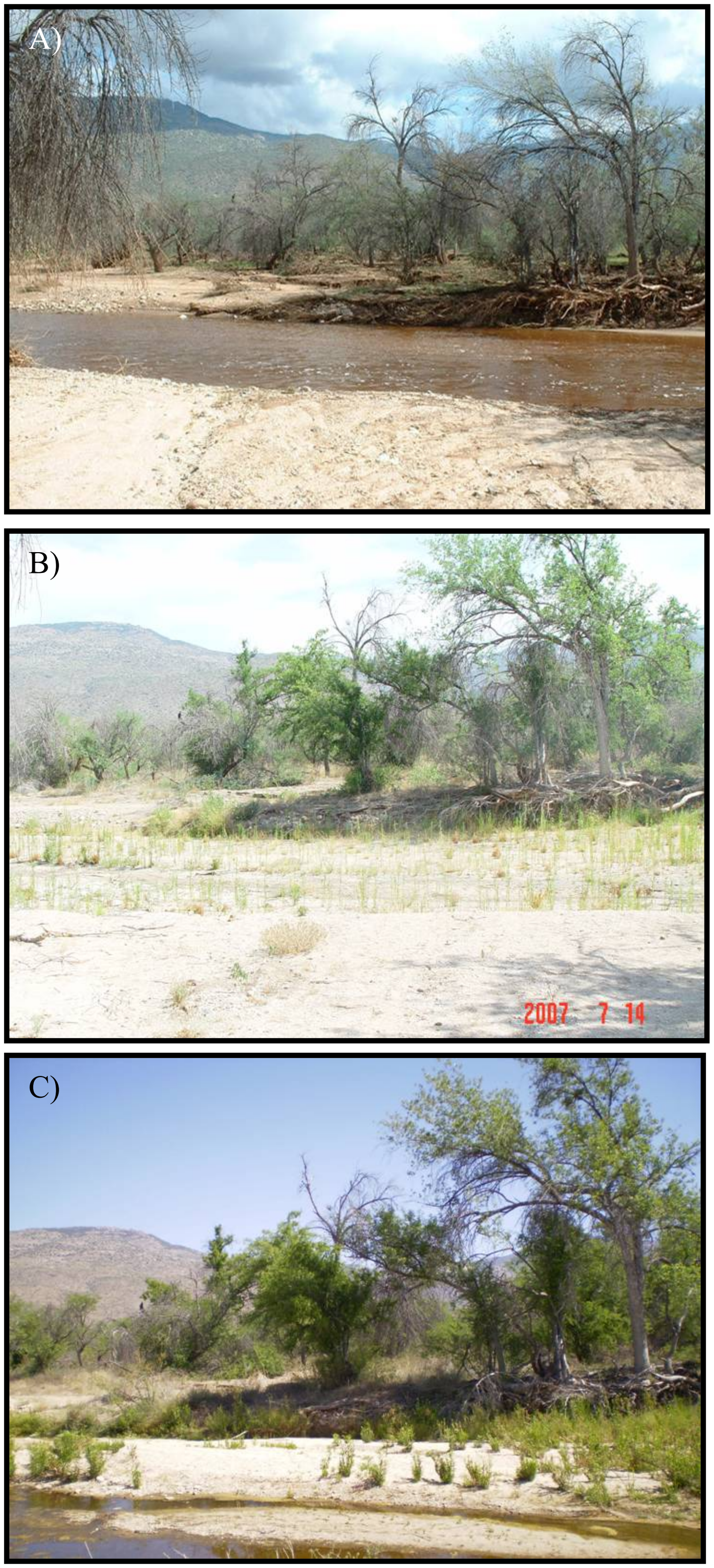
riparian trees along Rincon Creek appeared to be dormant or dying in 2004. We observed a similar phenomenon in 2006, although to a much greater extent (Figs. 9a-b). The exact cause of this tree dormancy/die-back remains undetermined, but almost 9 years of drought in the region may be a contributing factor. Nevertheless, in our analysis examining water stress in riparian trees at a subset of our study sites, we detected lower water stress in riparian trees at a site with surface water (Cienega Creek) compared to a nearby site with similar vegetation but without surface water (Posta Quemada). In addition, we found that velvet mesquite trees located in the floodplain had 40% lower water stress than those in the adjacent uplands at both study sites, suggesting that proximity to water (both surface and ground) can have a measurable effect on the health of riparian trees that isn't evident in terms of the presence of dormant or dying vegetation.

Perhaps more informative than our comparison of data collected at Rincon Creek with those collected at our other study sites is a comparison of nest-monitoring data that we collected from 2006-2008 at Rincon Creek with those collected by Powell (2004) only two years previously (i.e., at the start of the tree dormancy/die-back along Rincon Creek). Powell (2004) found evidence of breeding for Yellow Warblers and Bell's Vireos at Rincon Creek in 2004 and he located 9 Bell's Vireo nests along Rincon Creek prior to 2004 (B. Powell, Pima County, unpublished data). In contrast, we found no Yellow Warbler nests and only 1 partially constructed Bell's Vireo nest during intensive nest searching at Rincon Creek in 2006 when conditions were drier and vegetation volume was reduced. Only in 2008, when the riparian vegetation had recovered to some extent after a year of wet conditions (Figs. 10a-c; C. Kirkpatrick, personal observation), did Bell's Vireos and Yellow Warblers return to breed at Rincon Creek. Similar declines in Bell's Vireos populations have been observed along the Colorado River following habitat destruction during the 1970s and 1980s (Ohmart 1994). Further research is needed to examine this issue, especially at sites like Rincon Creek where the majority of the vegetation volume is dormant or dying.

MANAGEMENT IMPLICATIONS

Results from our study provide some of the first evidence that the presence and extent of surface water can influence the relative abundance and diversity of breeding and migrant birds within riparian woodlands of the desert southwest. Previous research has shown that ground water pumping from and unconfined aquifer can have a negative effect on the presence and extent of surface water in nearby riparian systems (Bedient and Huber 1992). In Arizona, ground water pumping has increased rapidly during the 20th century (Webb and Leake 2005) and will continue to increase as human populations grow in the desert southwest. In light of this threat, many riparian woodlands in the region face an uncertain future, perhaps none more so than the riparian woodland along the Upper San Pedro River. Ground water pumping at Fort Huachuca Military Reservation and the City of Sierra Vista has not substantially reduced ground water levels in the alluvial aquifer yet; however, future ground water developments in the area pose a major threat to nearby riparian woodlands along the Upper San Pedro River (Stromberg et al. 1996, Stromberg et al. 2009, Pool and Coes 1999). We believe that riparian bird communities in the desert southwest are threatened in 2 ways by future water loss. First, should ground water levels fall to the point where surface water flows are reduced or eliminated (i.e., a "Stage 2" effect; Webb and Leake 2005), populations of breeding and migrant bird species such as the Black

Figures 10a-c. Photo series taken at Rincon Creek, Saguaro National Park (at junction of Rincon Creek and Big Wash) showing the re-growth of riparian vegetation over the 3 years of the study: A) early August 2006; B) 14 July 2007; and C) 2 May 2008. Note the virtual absence of foliage on riparian trees in 2006 (Photo A). Photographs courtesy of the National Park Service.



Phoebe, Common Yellowthroat, Yellow Warbler, Yellow-rumped Warbler, Wilson's Warbler, Song Sparrow, and Lesser Goldfinch are likely to decline. Second, should ground water levels fall to the point that riparian vegetation is negatively affected (i.e., a "Stage 3" effect; Webb and Leake 2005), populations of breeding bird species such as Bell's Vireos and Yellow Warblers are likely to decline. Continued long-term drought conditions in the desert southwest are likely to compound problems associated with ground water withdrawal in the foreseeable future (Webb and Leake 2005).

Developing a sustainable water management plan is critical for Fort Huachuca and other military installations located in the southwestern U.S. If no effort is made to preserve the health of riparian woodlands in the desert southwest (including riparian woodlands on or near military installations), the potential loss of breeding, wintering, and/or migratory habitat could be substantial for many bird species, especially if ground water loss is great enough to degrade or eliminate riparian vegetation. Most riparian woodlands in the desert southwest have already been altered by human development, cattle grazing, ground water withdrawal, and/or surface water diversions (Ohmart 1994, Webb and Leake 2005). Thus, we need to protect the health of the remaining riparian woodland in the region given the sheer number of bird species that are dependent upon this threatened resource. Military readiness could be jeopardized if limited military resources are diverted from the military's mission at Fort Huachuca Military Reservation (and at other military installations in the southwestern U.S.) to deal with the recovery of potentially dozens of declining populations of birds. Results from this study provide quantitative data that will allow resource managers on military lands (and elsewhere) to better predict how abundance and diversity of riparian birds will be affected by future reductions in ground and surface water levels on or near military installations in the desert southwest. The conservation of flowing surface water in riparian woodlands in the desert southwest is both of regional and national concern given that we found that breeding and long-distance migrant species were positively associated with surface water in these woodlands.

Finally, we suggest that additional management attention be focused on several riparian bird species that have been ranked low on the list of species of conservation concern in the desert southwest (e.g., Black Phoebe, Song Sparrow, and Lesser Goldfinch; Latta et al. 1999). In particular, the Black Phoebe (Fig. 11) is considered to be locally common in riparian woodlands throughout Arizona (Phillips et al. 1964, Corman and Wide-Gervais 2005), and consequently, the species has been afforded no special conservation status (Latta et al. 1999). However, we found Black Phoebes to be relatively uncommon in our study area (at study sites with Black Phoebes, we detected <1-2 pairs at most; C. Kirkpatrick, personal observation). In addition, the Black Phoebe was one of the few riparian bird species that we detected almost exclusively at survey points with surface water during the breeding season. Indeed, of the 41 survey points where ≥1 Black Phoebe was detected, 95% of these survey points had at least some surface water present. Furthermore, we found that Black Phoebes were negatively associated with tamarisk, an invasive species that is overrunning many riparian areas by displacing native vegetation. And yet, the Black Phoebe is not considered a riparian obligate bird in the desert southwest (USGS 2006), despite its strong affinity for surface water and native riparian vegetation. We propose that the Black Phoebe be re-classified as a riparian obligate species in the desert southwest and suggest that monitoring of this species be undertaken to track the species' abundance We believe that the

Figure 11. A Black Phoebe (*Sayornis nigricans*) perched on a branch of a Fremont cottonwood at the Cienega Creek study site (photo credit: A. Nelson).

Black Phoebe may ultimately prove to be a valuable indicator species of the health of native riparian woodlands in the region.

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Appendix A. UTM coordinates (NAD 83) for bird survey points along riparian (R) and upland (U2, U5) survey routes at 29 riparian study sites in southeastern AZ.

	ARAVAIPA CREEK		ARIVACA CREEK		BUEHMAN CANYON (R)		BOQUILLAS (R)		BROWN CANYON (R)		CASCABEL (R)	
	North	East	North	East	North	East	North	East	North	East	North	East
1	539957	3639456	465096	3495295	542193	3583040	577247	3506387	448077	3514786	557275	3574018
2	539984	3639520	464994	3495280	542232	3583132	577190	3506302	448176	3514764	557273	3574122
3	540045	3639600	464920	3495349	542301	3583208	577094	3506268	448254	3514702	557324	3574201
4	540128	3639677	464853	3495424	542280	3583307	576995	3506284	448335	3514643	557407	3574254
5	540197	3639667	464756	3495451	542289	3583406	576898	3506299	448431	3514614	557506	3574229
6	540278	3639674	464731	3495549	542329	3583501	576812	3506351	448530	3514603	557545	3574334
7	540372	3639721	464675	3495634	542312	3583601	576772	3506443	448627	3514576	557567	3574429
8	540415	3639834	464626	3495725	542329	3583706	576712	3506522	448651	3514481	557494	3574498
9	540390	3639935	464558	3495797	542268	3583786	576612	3506537	448704	3514396	557479	3574599
10	540386	3640043	464483	3495869	542296	3583882	576511	3506529	448784	3514315	557407	3574675
11	540373	3640150	464404	3495932	542275	3583980	576414	3506489	448883	3514310		
12	540386	3640282	464328	3495999	542325	3584066	576314	3506472	448986	3514139		
13	540420	3640359	464262	3496077	542391	3584141			449050	3514062		
14	540451	3640466	464241	3496175	542487	3584172			449147	3514086		
15	540509	3640574			542499	3584273						

	CIENEGA CREEK (R)		CLARK PROPERTY (R)		DUDLEYVILLE E. (R)		DUDLEYVILLE W. (R)		EMPIRE GULCH (R)		FAIRBANKS (R)	
Point	North	East	North	East	North	East	North	East	North	East	North	East
1	534052	3542378	561921	3569520	525039	3641941	524562	3642833	533111	3516885	576316	3511522
2	534018	3542479	561825	3569485	525032	3642041	524545	3642932	533211	3516885	576289	3511617
3	534081	3542566	561725	3569486	525027	3642140	524543	3643032	533310	3516866	576251	3511710
4	534027	3542650	561641	3569540	525004	3642237	524536	3643131	533409	3516862	576228	3511807
5	533937	3542626	561550	3569587	525004	3642340	524507	3643228	533511	3516866	576209	3511903
6	533855	3542568	561454	3569559	525055	3642425	524499	3643328	533605	3516901	576253	3511994
7	533752	3542524	561358	3569529	525032	3642527	524469	3643421	533703	3516893	576272	3512092
8	533659	3542523	561262	3569499	525017	3642626	524395	3643488	533799	3516923	576239	3512186
9	533612	3542615			525042	3642725	524295	3643473	533890	3516964	576166	3512255
10	533574	3542699			525047	3642823	524195	3643474	533984	3516929	576077	3512208
11	533467	3542683			525005	3642917	524098	3643504	534081	3516959	576078	3512309
12	533358	3542716					524030	3643583	534184	3516981	576122	3512398
13	533255	3542701					524000	3643678	534281	3516998		
14	533144	3542714					524020	3643779	534381	3517015		

Appendix A. Continued.

Point	GRAY HAWK (R)		HUNTER WASH (R)		L. HOT SPRINGS (R)		LAS CIENEGAS (U2)		LAS CIENEGAS (U5)		LAS CIENEGAS (R)	
15	533051	3542666					524094	3643853	534467	3516963		
Point	North	East	North	East	North	East	North	East	North	East	North	East
1	579765	3497085	583923	3482951	570330	3578846	539339	3521912	539683	3522100	539047	3521909
2	579665	3497095	583837	3483003	570323	3578958	539326	3522011	539731	3522191	539057	3522010
3	579577	3497137	583756	3483063	570267	3579054	539330	3522112	539753	3522286	539067	3522112
4	579535	3497228	583702	3483147	570250	3579160	539373	3522203	539814	3522370	539127	3522193
5	579513	3497326	583729	3483242	570254	3579267	539418	3522292	539828	3522478	539163	3522291
6	579509	3497424	583789	3483323	570180	3579342	539457	3522384	539843	3522583	539202	3522384
7	579462	3497512	583773	3483421	570073	3579359	539495	3522474			539231	3522483
8	579371	3497555	583709	3483498	570024	3579459	539543	3522560			539300	3522557
9	579271	3497537	583660	3483585	570024	3579569	539563	3522657			539328	3522650
10	579195	3497603	583590	3483659	569993	3579668	539568	3522757			539264	3522727
11	579098	3497633	583535	3483745	569948	3579764						
12	579017	3497691	583528	3483844	569889	3579846						
13					569779	3579861						
14					569671	3579837						
15					569584	3579898						

	L. PAIGE CREEK (R)		L. SABINO CREEK (R)		POSTA QUEMADA (R)		POSTA QUEMADA (U2)		POSTA QUEMADA (U5)		RINCON CREEK	
Point	North	East	North	East	North	East	North	East	North	East	North	East
1	552184	3558431	517759	3574112	534144	3546046	534052	3546138	533929	3546481	536331	3555056
2	552117	3558356	517756	3574011	534245	3546034	534123	3546208	533976	3546569	536228	3555053
3	552040	3558291	517771	3573912	534306	3546114	534165	3546301	534026	3546655	536126	3555045
4	552023	3558192	517866	3573873	534355	3546203	534222	3546384	534087	3546732	536035	3555008
5	551935	3558142	517871	3573773	534395	3546295	534261	3546477	534143	3546813	535936	3554997
6	551884	3558058	517883	3573674	534439	3546388	534312	3546564	534184	3546905	535834	3555002
7	551791	3558020	517859	3573577	534492	3546468	534372	3546643	534241	3546986	535728	3555015
8	551769	3557923	517925	3573501	534552	3546549	534432	3546725	534262	3547084	535629	3555011
9	551749	3557825	517944	3573401	534610	3546631	534491	3546806	534294	3547181	535524	3555019
10	551713	3557731	518007	3573324							535431	3555055
11	551646	3557657	518050	3573234								
12	551628	3557559	518133	3573166								
13	551614	3557462										

Appendix A. Continued.

Point	RINCON CREEK (U5) North	East		RINCON CREEK (R) North	East		SONOITA CREEK (R) North	East		ST. DAVID (R) North	East		TUBAC (R) North	East		TUMACACORI (R) North	East
1	536311	3555354		536258	3554850		522243	3488715		574031	3526299		495537	3495443		495692	3492010
2	536210	3555347		536156	3554799		522267	3488623		573962	3526367		495451	3495399		495717	3492107
3	536099	3555342		536066	3554760		522212	3488542		573901	3526450		495400	3495313		495732	3492201
4	536007	3555305		535961	3554775		522150	3488468		573884	3526548		495351	3495226		495726	3492298
5	535907	3555296		535866	3554708		522105	3488380		573868	3526647		495347	3495125		495700	3492399
6	535807	3555300		535766	3554735		522046	3488281		573856	3526750		495354	3495021		495708	3492503
7	535707	3555314		535664	3554720		522006	3488184		573827	3526852		495347	3494922		495711	3492602
8	535608	3555310		535569	3554759		521956	3488101		573802	3526942		495380	3494828		495714	3492705
9	535508	3555324		535473	3554785		521908	3488012		573749	3527026		495437	3494747		495702	3492810
10	535412	3555354		535386	3554842		521808	3487995		573677	3527109		495507	3494676		495681	3492914
11							521710	3488007		573581	3527143						
12							521616	3487964		573482	3527168						
13							521516	3487955									
14							521415	3487975									
15							521297	3487942									

Point	TANQUE VERDE CREEK (R) North	East		U. ARIVACA CREEK (R) North	East		U. CIENEGA CREEK (R) North	East		U. HOT SPRINGS (R) North	East		U. SABINO CREEK (R) North	East
1	526074	3567097		465287	3495232		539938	3540061		571747	3577937		517800	3575733
2	525984	3567136		465387	3495226		539997	3540152		571698	3578030		517798	3575633
3	525889	3567167		465421	3495321		539957	3540244		571699	3578146		517867	3575562
4	525788	3567182		465518	3495343		539901	3540334		571583	3578209		517837	3575466
5	525686	3567164		465591	3495275		539801	3540336		571539	3578317		517807	3575369
6	525599	3567117		465644	3495194		539699	3540316		571418	3578279		517760	3575280
7	525493	3567120		465719	3495122		539612	3540258		571333	3578350		517727	3575186
8	525392	3567119					539511	3540267		571291	3578455		517767	3575096
9	525296	3567133					539417	3540238		571218	3578533		517815	3575008
10	525201	3567142					539310	3540251		571117	3578484		517822	3574909
11	525104	3567172					539226	3540317		571011	3578460		517818	3574809
12	525002	3567186					539202	3540419		570989	3578565			
13										570892	3578611			
14										570810	3578545			
15										570715	3578502			

Appendix B. Result of exploratory factor analysis to reduce the set of 44 vegetation volume variables to a smaller set of 11 uncorrelated factors. We retained factors with eigenvalues ≥1 and used a varimax rotation to facilitate interpretation of factor weights (Meyers et al. 2006).

Factor #	Factor Description[1]	# Original Variables[1]	Initial Eigen Value	% Variance Explained[2]
1	Mesquite and graythorn	7	7.6	10.3
2	Cottonwood overstory and other live overstory vegetation	7	6.1	9.5
3	Goodding willow (esp. live vegetation)	6	4.2	9.5
4	Netleaf hackberry (esp. live vegetation)	4	2.8	8.2
5	Tamarisk (live and dead vegetation)	5	2.4	7.9
6	Velvet ash (live vegetation)	3	2.2	5.8
7	All live understory vegetation (esp. grass and forbs)	3	1.7	5.1
8	All dead understory vegetation (esp. grass and forbs)	3	1.4	4.9
9	All dead overstory vegetation (esp. Fremont cottonwood and velvet mesquite)	3	1.2	4.0
10	Seep willow (live and dead vegetation)	2	1.1	3.6
11	Brush and absence of desert broom (live)	2	1.0	3.4
Total				72.2

[1] We described each factor based on the inclusion of the variables that had factor weights ≥0.45, meaning that ≥20% of the variance in the original variable was accounted for in the factor.

[2] Percentage variance explained by rotation sums of squares loadings.

Appendix C. Predictive models from our spatial analysis for community- and species-level bird parameters generated using multi-model inference to select all of the variables in the confidence set of models and average the parameter estimates from all possible combinations of these variables (for species with greater than 8 variables in the confidence set of models, we simply averaged the parameter estimates from the models in the confidence set).

Variables	*B*	Unconditional SE	Lower 95% CL	Upper 95% CL
Community-level				
Total Relative Abundance[1]				
Intercept	17.1000	0.8210	15.5000	18.7000
Cottonwood Overstory and Other Live Overstory Veg.	-0.0256	0.2250	-0.4670	0.4160
All Live Understory Veg.	0.2100	0.3460	-0.4680	0.8880
All Dead Understory Veg.	0.4620	0.3260	-0.1760	1.1000
All Dead Overstory	0.0175	0.0771	-0.1340	0.1690
Water Total	0.0011	0.0011	-0.0011	0.0033
Number Visits with Water	0.3360	0.2280	-0.1110	0.7820
Cottonwood Overstory and Other Live Overstory Veg. x Number Visits with Water	-0.0897	0.1310	-0.3460	0.1660
All Live Understory Veg. x Number Visits with Water	0.0705	0.1140	-0.1530	0.2940
Species Richness[1]				
Intercept	10.8000	0.3330	10.2000	11.5000
Cottonwood Overstory and Other Live Overstory Veg.	0.0667	0.1560	-0.2390	0.3720
All Live Understory Veg.	0.1960	0.1940	-0.1830	0.5750
Number Visits with Water	0.2420	0.0911	0.0629	0.4200
Cottonwood Overstory and Other Live Overstory Veg. x Number Visits with Water	-0.1420	0.0777	-0.2940	0.0107
All Live Understory Veg. x Number Visits with Water	0.0729	0.0791	-0.0821	0.2280
Species-level				
White-winged Dove[2]				
Intercept	-0.9160	0.3050	-1.5100	-0.3180
Canopy Height	-0.0002	0.0076	-0.0151	0.0146
Elevation	0.0000	0.0002	-0.0004	0.0004
Mesquite and Graythorn	-0.0170	0.0490	-0.1130	0.0790
Brush and Absence of Desert Willow	0.0489	0.0566	-0.0620	0.1600
Cottonwood Overstory and Other Live Overstory Veg.	-0.1530	0.0746	-0.2990	-0.0065
Goodding Willow	-0.0032	0.0159	-0.0344	0.0281
Netleaf Hackberry	-0.0382	0.0550	-0.1460	0.0697
Tamarisk	-0.0658	0.0729	-0.2090	0.0771
All Live Understory Veg.	0.0594	0.0669	-0.0716	0.1900
All Dead Understory Veg.	0.0350	0.0527	-0.0683	0.1380
Total Water	0.0000	0.0000	-0.0001	0.0001
Number Visits with Water	0.0112	0.0220	-0.0319	0.0543
Black Phoebe[1]				
Intercept	-6.0600	0.9190	-7.8700	-4.2600
Canopy Height	0.0097	0.0203	-0.0301	0.0495
Corridor or Oasis	0.2370	0.3880	-0.5240	0.9970

Appendix C. Continued.

Variables	*B*	Unconditional SE	Lower 95% CL	Upper 95% CL
Cottonwood Overstory and Other Live Overstory Veg.	-0.2800	0.2270	-0.7240	0.1640
Tamarisk	-0.8620	0.3420	-1.5300	-0.1910
All Live Understory Veg.	-0.0674	0.1270	-0.3160	0.1820
All Dead Understory Veg.	-0.4350	0.2170	-0.8600	-0.0095
Number Visits with Water	0.6370	0.1600	0.3230	0.9500
<u>Bewick's Wren</u>[2]				
Intercept	0.0158	0.0998	-0.1800	0.2110
Canopy Height	0.0136	0.0131	-0.0121	0.0392
Corridor or Oasis	-0.0114	0.0244	-0.0592	0.0363
Mesquite and Graythorn	0.0326	0.0393	-0.0445	0.1100
Brush and Absence of Desert Broom	0.0005	0.0024	-0.0041	0.0051
Cottonwood Overstory and Other Live Overstory Veg.	-0.0160	0.0301	-0.0751	0.0430
Goodding Willow	-0.0069	0.0148	-0.0359	0.0221
Netleaf Hackberry	0.0040	0.0081	-0.0119	0.0199
Tamarisk	-0.0203	0.0373	-0.0934	0.0529
All Live Understory Veg.	0.0001	0.0023	-0.0043	0.0046
All Dead Understory Veg.	0.0021	0.0048	-0.0074	0.0116
All Dead Overstory Veg.	0.0037	0.0074	-0.0108	0.0181
Total Water	0.0000	0.0000	0.0000	0.0001
Number Visits with Water	-0.0012	0.0054	-0.0117	0.0093
<u>Bell's Vireo</u>[2]				
Intercept	1.6300	1.6800	-1.6700	4.9300
Corridor or Oasis	0.0382	0.0834	-0.1250	0.2020
Elevation	-0.0020	0.0015	-0.0049	0.0010
Mesquite and Graythorn	0.1280	0.0444	0.0408	0.2150
Seep Willow	0.0189	0.0326	-0.0449	0.0828
Brush and Absence of Desert Broom	-0.0089	0.0278	-0.0634	0.0455
Cottonwood Overstory and Other Live Overstory Veg.	0.0252	0.0373	-0.0478	0.0983
Goodding Willow	-0.0018	0.0082	-0.0179	0.0144
Netleaf Hackberry	0.0305	0.0427	-0.0531	0.1140
Tamarisk	0.0276	0.0542	-0.0787	0.1340
All Live Understory Veg.	0.0740	0.0616	-0.0467	0.1950
All Dead Understory Veg.	-0.0009	0.0380	-0.0753	0.0736
Total Water	-0.0007	0.0002	-0.0011	-0.0002
Width Riparian Veg.	-0.0963	0.1580	-0.4070	0.2140
<u>Yellow-rumped Warbler</u>[1]				
Intercept	-4.5300	1.6100	-7.6900	-1.3600
Canopy Height	0.0293	0.0292	-0.0280	0.0866
Elevation	0.0016	0.0015	-0.0014	0.0045
Mesquite and Graythorn	-0.0445	0.0779	-0.1970	0.1080
Goodding Willow	0.0232	0.0528	-0.0803	0.1270
All Live Understory Veg.	-0.1250	0.1330	-0.3850	0.1350
All Dead Understory Veg.	0.2210	0.1350	-0.0443	0.4860
Total Water	0.0021	0.0003	0.0016	0.0027
Width Riparian Veg.	-0.1240	0.2580	-0.6300	0.3820

Appendix C. Continued.

Variables	*B*	Unconditional SE	Lower 95% CL	Upper 95% CL
Yellow Warbler[2]				
Intercept	0.2600	0.1900	-0.1120	0.6330
Canopy Height	0.0298	0.0068	0.0165	0.0431
Mesquite and Graythorn	-0.0029	0.0161	-0.0345	0.0287
Seep Willow	-0.0047	0.0155	-0.0350	0.0256
Cottonwood Overstory and Other Live Overstory Veg.	0.1010	0.0287	0.0443	0.1570
Goodding Willow	0.0301	0.0359	-0.0403	0.1000
Tamarisk	-0.0100	0.0251	-0.0593	0.0393
Velvet Ash	0.0281	0.0347	-0.0399	0.0961
All Live Understory Veg.	-0.0060	0.0203	-0.0458	0.0338
All Dead Understory Veg.	0.0393	0.0461	-0.0511	0.1300
Total Water	0.0000	0.0000	-0.0001	0.0000
Number Visits with Water	0.0092	0.0164	-0.0229	0.0413
Width Riparian Veg.	0.3540	0.1280	0.1030	0.6060
Common Yellowthroat[1]				
Intercept	-0.5310	0.7520	-2.0100	0.9440
Corridor or Oasis	-1.7900	0.4420	-2.6500	-0.9220
Seep Willow	0.0154	0.0370	-0.0570	0.0879
All Live Understory Veg.	0.2360	0.0956	0.0483	0.4230
All Dead Understory Veg.	0.0550	0.0853	-0.1120	0.2220
Number Visits with Water	0.4580	0.0835	0.2950	0.6220
Lucy's Warbler[1]				
Intercept	-0.5490	0.5770	-1.6800	0.5820
Elevation	0.0005	0.0005	-0.0006	0.0015
Mesquite and Graythorn	0.1140	0.0461	0.0232	0.2040
Cottonwood Overstory and Other Live Overstory Veg.	-0.0771	0.0442	-0.1640	0.0095
Goodding Willow	0.0038	0.0141	-0.0239	0.0314
Netleaf Hackberry	0.0420	0.0466	-0.0494	0.1330
Tamarisk	0.0019	0.0168	-0.0310	0.0349
Total Water	-0.0002	0.0002	-0.0005	0.0002
Number Visits with Water	-0.0160	0.0262	-0.0673	0.0352
Wilson's Warbler[2]				
Intercept	-2.1300	0.2700	-2.6500	-1.6000
Canopy Height	0.0038	0.0073	-0.0105	0.0181
Mesquite and Graythorn	0.0155	0.0392	-0.0614	0.0923
Brush and Absence of Desert Broom	-0.0545	0.0705	-0.1930	0.0837
Cottonwood Overstory and Other Live Overstory Veg.	0.0252	0.0483	-0.0695	0.1200
Goodding Willow	-0.0179	0.0447	-0.1050	0.0696
Tamarisk	-0.0031	0.0094	-0.0215	0.0154
All Live Understory Veg.	-0.0745	0.0935	-0.2580	0.1090
All Dead Understory Veg.	0.0456	0.0690	-0.0897	0.1810
Total Water	0.0013	0.0002	0.0008	0.0018
Width Riparian Veg.	-0.0261	0.0931	-0.2090	0.1560
Yellow-breasted Chat[2]				
Intercept	0.4190	1.2300	-1.9900	2.8200
Canopy Height	-0.0017	0.0051	-0.0117	0.0083

Appendix C. Continued.

Variables	*B*	Unconditional SE	Lower 95% CL	Upper 95% CL
Corridor or Oasis	-0.5770	0.7400	-2.0300	0.8740
Mesquite and Graythorn	0.0078	0.0226	-0.0366	0.0521
Seep Willow	0.0032	0.0172	-0.0305	0.0368
Brush and Absence of Desert Broom	0.0206	0.0331	-0.0442	0.0854
Cottonwood Overstory and Other Live Overstory Veg.	0.0117	0.0313	-0.0498	0.0731
Goodding Willow	0.0274	0.0402	-0.0513	0.1060
Netleaf Hackberry	0.0157	0.0336	-0.0501	0.0815
Tamarisk	0.0439	0.0620	-0.0776	0.1650
Velvet Ash	0.0174	0.0319	-0.0452	0.0799
All Live Understory Veg.	0.1480	0.0488	0.0527	0.2440
All Dead Understory Veg.	0.0227	0.0517	-0.0786	0.1240
Total Water	-0.0008	0.0002	-0.0011	-0.0004
Width Riparian Veg.	0.5600	0.1970	0.1740	0.9460
Song Sparrow[1]				
Intercept	-3.5200	0.4600	-4.4300	-2.6200
Canopy Height	-0.0237	0.0166	-0.0563	0.0088
Seep Willow	0.0670	0.0631	-0.0566	0.1910
Goodding Willow	-0.0021	0.0169	-0.0353	0.0310
Tamarisk	0.0271	0.0486	-0.0682	0.1220
All Live Understory Veg.	0.0933	0.0750	-0.0536	0.2400
All Dead Understory Veg.	0.0437	0.0640	-0.0817	0.1690
Number Visits with Water	0.6520	0.0824	0.4910	0.8140
House Finch[1]				
Intercept	-0.7260	0.1580	-1.0400	-0.4160
Cottonwood Overstory and Other Live Overstory Veg.	-0.1570	0.0695	-0.2940	-0.0211
Goodding Willow	0.0062	0.0229	-0.0386	0.0510
Tamarisk	-0.1540	0.1170	-0.3820	0.0747
Velvet Ash	0.0078	0.0233	-0.0380	0.0535
Total Water	0.0000	0.0001	-0.0002	0.0001
Number Visits with Water	-0.0052	0.0187	-0.0418	0.0314
Lesser Goldfinch[2]				
Intercept	0.0716	0.8340	-1.5600	1.7100
Elevation	-0.0005	0.0008	-0.0020	0.0010
Mesquite and Graythorn	0.0007	0.0031	-0.0054	0.0068
Seep Willow	0.0026	0.0167	-0.0302	0.0354
Brush and Absence of Desert Broom	-0.0128	0.0251	-0.0620	0.0365
Cottonwood Overstory and Other Live Overstory Veg.	-0.0064	0.0271	-0.0595	0.0467
Goodding Willow	0.0071	0.0195	-0.0312	0.0454
Netleaf Hackberry	-0.0039	0.0189	-0.0410	0.0332
Tamarisk	-0.0033	0.0081	-0.0192	0.0126
All Live Understory Veg.	-0.0079	0.0240	-0.0549	0.0391
All Dead Understory Veg.	-0.0268	0.0428	-0.1110	0.0570
Total Water	0.0002	0.0003	-0.0003	0.0007
Number Visits with Water	0.0653	0.0551	-0.0426	0.1730
Width Riparian Veg.	0.0276	0.0856	-0.1400	0.1950

Appendix C. Continued.

Variables	*B*	Unconditional SE	Lower 95% CL	Upper 95% CL
Abert's Towhee[1]				
Intercept	-0.6500	0.1970	-1.0400	-0.2650
Seep Willow	0.0023	0.0151	-0.0273	0.0318
All Live Understory Veg.	0.1450	0.0607	0.0262	0.2640
All Dead Understory Veg.	0.0280	0.0454	-0.0611	0.1170
Total Water	-0.0003	0.0002	-0.0008	0.0001
Number Visits with Water	0.0587	0.0588	-0.0565	0.1740
Width Riparian Veg.	0.4280	0.2570	-0.0761	0.9320
Summer Tanager[1]				
Intercept	-0.6980	0.1120	-0.9170	-0.4780
Canopy Height	0.0181	0.0139	-0.0091	0.0453
Cottonwood Overstory and Other Live Overstory Veg.	0.1790	0.0484	0.0837	0.2740
Goodding Willow	0.0394	0.0487	-0.0562	0.1350
Velvet Ash	-0.0237	0.0385	-0.0993	0.0518
Total Water	0.0000	0.0001	-0.0001	0.0002
Number Visits with Water	0.0003	0.0110	-0.0213	0.0220
Width Riparian Veg.	0.0725	0.1290	-0.1810	0.3260

[1] Parameter estimates generated from all possible combinations of variables in the confidence set of models.
[2] Parameter estimates generated by averaging the parameter estimates for species with greater than 8 variables in the confidence set of models.

Appendix D. Parameter estimates from our temporal analysis for community- and species-level bird parameters for the top model in the model set.

Variables	*B*	Unconditional SE	Lower 95% CL	Upper 95% CL
Community-level				
Total Relative Abundance				
Intercept	15.4000	1.3800	12.7000	18.1000
Total Water	0.0005	0.0013	-0.0020	0.0031
Veg. Volume 0-2 m (Dead)	0.0067	0.0077	-0.0083	0.0218
Veg. Volume 0-2 m (Live)	0.0012	0.0023	-0.0033	0.0057
Veg. Volume 2-5 m (Dead)	-0.0071	0.0106	-0.0278	0.0137
Veg. Volume 2-5 m (Live)	0.0013	0.0029	-0.0044	0.0070
Veg. Volume 5-20 m (Dead)	-0.0029	0.0169	-0.0360	0.0301
Veg. Volume 5-20 m (Live)	-0.0066	0.0106	-0.0274	0.0142
Species Richness				
Intercept	9.7400	0.6460	8.4800	11.0000
Total Water	-0.0001	0.0007	-0.0014	0.0011
Veg. Volume 0-2 m (Dead)	0.0027	0.0035	-0.0042	0.0097
Veg. Volume 0-2 m (Live)	0.0016	0.0020	-0.0023	0.0055
Veg. Volume 2-5 m (Dead)	-0.0016	0.0034	-0.0082	0.0051
Veg. Volume 2-5 m (Live)	0.0012	0.0021	-0.0029	0.0053
Veg. Volume 5-20 m (Dead)	0.0005	0.0075	-0.0142	0.0151
Species-level				
White-winged Dove				
Intercept	-0.8859	0.3142	-1.5143	-0.2575
Total Water	-0.0010	0.0003	-0.0016	-0.0004
Veg. Volume 0-2 m (Live)	0.0005	0.0008	-0.0011	0.0021
Veg. Volume 0-2 m (Dead)	-0.0007	0.0017	-0.0042	0.0027
Veg. Volume 2-5 m (Live)	0.0002	0.0014	-0.0027	0.0030
Veg. Volume 2-5 m (Dead)	0.0053	0.0030	-0.0006	0.0112
Veg. Volume 5-20 m (Live)	-0.0052	0.0037	-0.0126	0.0023
Veg. Volume 5-20 m (Dead)	-0.0029	0.0125	-0.0278	0.0220
Black Phoebe				
Intercept	-2.7218	0.7398	-4.2014	-1.2421
Total Water	0.0025	0.0006	0.0013	0.0037
Veg. Volume 0-2 m (Live)	-0.0012	0.0034	-0.0080	0.0055
Veg. Volume 0-2 m (Dead)	-0.0137	0.0068	-0.0273	0.0000
Veg. Volume 2-5 m (Live)	-0.0012	0.0059	-0.0130	0.0105
Veg. Volume 2-5 m (Dead)	-0.0058	0.0121	-0.0300	0.0185
Veg. Volume 5-20 m (Live)	-0.0038	0.0130	-0.0297	0.0222
Veg. Volume 5-20 m (Dead)	0.0480	0.0417	-0.0353	0.1313
Bewick's Wren				
Intercept	-0.4411	0.2012	-0.8435	-0.0386
Veg. Volume 0-2 m (Live)	0.0006	0.0006	-0.0006	0.0019
Veg. Volume 0-2 m (Dead)	0.0026	0.0011	0.0005	0.0047
Veg. Volume 2-5 m (Live)	-0.0007	0.0009	-0.0024	0.0011

Appendix D. Continued.

Variables	*B*	Unconditional SE	Lower 95% CL	Upper 95% CL
Veg. Volume 2-5 m (Dead)	-0.0012	0.0019	-0.0050	0.0026
Veg. Volume 5-20 m (Live)	-0.0004	0.0021	-0.0047	0.0039
Veg. Volume 5-20 m (Dead)	0.0127	0.0079	-0.0032	0.0286
<u>Bell's Vireo</u>				
Intercept	-0.4995	0.3078	-1.1150	0.1160
Veg. Volume 0-2 m (Live)	0.0002	0.0007	-0.0011	0.0015
Veg. Volume 0-2 m (Dead)	0.0004	0.0012	-0.0020	0.0027
Veg. Volume 2-5 m (Live)	0.0013	0.0009	-0.0005	0.0031
Veg. Volume 2-5 m (Dead)	-0.0001	0.0021	-0.0043	0.0040
Veg. Volume 5-20 m (Live)	-0.0025	0.0021	-0.0067	0.0018
Veg. Volume 5-20 m (Dead)	0.0006	0.0091	-0.0177	0.0188
<u>Yellow-rumped Warbler</u>				
Intercept	-2.8470	0.5697	-3.9864	-1.7076
Total	0.0024	0.0004	0.0016	0.0032
Veg. Volume 0-2 m (Live)	-0.0016	0.0021	-0.0057	0.0025
Veg. Volume 0-2 m (Dead)	0.0038	0.0033	-0.0028	0.0103
Veg. Volume 2-5 m (Live)	0.0000	0.0029	-0.0059	0.0058
Veg. Volume 2-5 m (Dead)	-0.0134	0.0061	-0.0255	-0.0012
Veg. Volume 5-20 m (Live)	0.0096	0.0062	-0.0028	0.0220
Veg. Volume 5-20 m (Dead)	-0.0047	0.0279	-0.0605	0.0511
<u>Yellow Warbler</u>				
Intercept	-0.2145	0.3161	-0.8466	0.4177
Number Visits with Water	0.0663	0.0258	0.0148	0.1178
Veg. Volume 0-2 m (Live)	-0.0014	0.0006	-0.0025	-0.0003
Veg. Volume 0-2 m (Dead)	0.0017	0.0009	-0.0002	0.0036
Veg. Volume 2-5 m (Live)	0.0008	0.0008	-0.0007	0.0023
Veg. Volume 2-5 m (Dead)	-0.0019	0.0016	-0.0052	0.0013
Veg. Volume 5-20 m (Live)	0.0093	0.0017	0.0059	0.0127
Veg. Volume 5-20 m (Dead)	-0.0112	0.0086	-0.0284	0.0060
<u>Common Yellowthroat</u>				
Intercept	-5.9950	1.1923	-8.3796	-3.6104
Number Visits with Water	0.6663	0.2002	0.2659	1.0666
Veg. Volume 0-2 m (Live)	0.0017	0.0028	-0.0038	0.0072
Veg. Volume 0-2 m (Dead)	0.0054	0.0047	-0.0040	0.0148
Veg. Volume 2-5 m (Live)	-0.0052	0.0040	-0.0132	0.0029
Veg. Volume 2-5 m (Dead)	0.0092	0.0075	-0.0059	0.0242
Veg. Volume 5-20 m (Live)	-0.0188	0.0104	-0.0397	0.0021
Veg. Volume 5-20 m (Dead)	-0.0084	0.0621	-0.1325	0.1157
<u>Lucy's Warbler</u>				
Intercept	0.1214	0.1734	-0.2253	0.4681
Veg. Volume 0-2 m (Live)	-0.0007	0.0006	-0.0018	0.0005
Veg. Volume 0-2 m (Dead)	0.0014	0.0010	-0.0007	0.0034
Veg. Volume 2-5 m (Live)	0.0012	0.0008	-0.0005	0.0029
Veg. Volume 2-5 m (Dead)	0.0023	0.0018	-0.0013	0.0060
Veg. Volume 5-20 m (Live)	-0.0042	0.0020	-0.0083	-0.0001
Veg. Volume 5-20 m (Dead)	-0.0018	0.0070	-0.0158	0.0122

Appendix D. Continued.

Variables	*B*	Unconditional SE	Lower 95% CL	Upper 95% CL
Wilson's Warbler				
Intercept	-2.3612	0.4336	-3.2284	-1.4940
Total Water	0.0013	0.0003	0.0007	0.0019
Veg. Volume 0-2 m (Live)	-0.0006	0.0015	-0.0035	0.0023
Veg. Volume 0-2 m (Dead)	0.0038	0.0021	-0.0005	0.0080
Veg. Volume 2-5 m (Live)	-0.0009	0.0021	-0.0051	0.0033
Veg. Volume 2-5 m (Dead)	0.0012	0.0036	-0.0060	0.0084
Veg. Volume 5-20 m (Live)	0.0013	0.0041	-0.0070	0.0096
Veg. Volume 5-20 m (Dead)	-0.0114	0.0217	-0.0547	0.0320
Yellow-breasted Chat				
Intercept	-1.8892	0.8973	-3.6839	-0.0946
Total Water	-0.0031	0.0004	-0.0038	-0.0023
Veg. Volume 0-2 m (Live)	0.0009	0.0010	-0.0010	0.0028
Veg. Volume 0-2 m (Dead)	-0.0011	0.0016	-0.0043	0.0020
Veg. Volume 2-5 m (Live)	0.0025	0.0012	0.0000	0.0049
Veg. Volume 2-5 m (Dead)	0.0026	0.0026	-0.0025	0.0077
Veg. Volume 5-20 m (Live)	0.0004	0.0031	-0.0058	0.0065
Veg. Volume 5-20 m (Dead)	-0.0162	0.0154	-0.0470	0.0145
Song Sparrow				
Intercept	-6.1806	0.9350	-8.0506	-4.3105
Number Visits with Water	0.7023	0.1637	0.3749	1.0297
Veg. Volume 0-2 m (Live)	0.0006	0.0017	-0.0028	0.0040
Veg. Volume 0-2 m (Dead)	0.0057	0.0031	-0.0006	0.0119
Veg. Volume 2-5 m (Live)	-0.0015	0.0031	-0.0076	0.0046
Veg. Volume 2-5 m (Dead)	-0.0007	0.0062	-0.0131	0.0117
Veg. Volume 5-20 m (Live)	0.0018	0.0083	-0.0148	0.0185
Veg. Volume 5-20 m (Dead)	0.0371	0.0314	-0.0257	0.0999
House Finch				
Intercept	0.1074	0.2925	-0.4777	0.6924
Veg. Volume 0-2 m (Live)	-0.0010	0.0010	-0.0030	0.0010
Veg. Volume 0-2 m (Dead)	-0.0009	0.0018	-0.0045	0.0028
Veg. Volume 2-5 m (Live)	-0.0004	0.0015	-0.0033	0.0025
Veg. Volume 2-5 m (Dead)	0.0002	0.0032	-0.0061	0.0066
Veg. Volume 5-20 m (Live)	-0.0085	0.0039	-0.0163	-0.0008
Veg. Volume 5-20 m (Dead)	-0.0145	0.0131	-0.0407	0.0117
Lesser Goldfinch				
Intercept	0.2594	0.3345	-0.4096	0.9284
Number Visits with Water	0.0512	0.0273	-0.0035	0.1059
Veg. Volume 0-2 m (Live)	-0.0010	0.0004	-0.0019	-0.0001
Veg. Volume 0-2 m (Dead)	-0.0015	0.0011	-0.0038	0.0007
Veg. Volume 2-5 m (Live)	-0.0006	0.0009	-0.0023	0.0012
Veg. Volume 2-5 m (Dead)	-0.0003	0.0019	-0.0042	0.0036
Veg. Volume 5-20 m (Live)	-0.0028	0.0025	-0.0077	0.0022
Veg. Volume 5-20 m (Dead)	-0.0060	0.0073	-0.0206	0.0085
Abert's Towhee				
Intercept	-1.0587	0.3374	-1.7335	-0.3839
Total Water	-0.0009	0.0003	-0.0015	-0.0003
Veg. Volume 0-2 m (Live)	0.0002	0.0009	-0.0015	0.0019

Appendix D. Continued.

Variables	*B*	Unconditional SE	Lower 95% CL	Upper 95% CL
Veg. Volume 0-2 m (Dead)	-0.0004	0.0017	-0.0038	0.0031
Veg. Volume 2-5 m (Live)	0.0017	0.0014	-0.0010	0.0045
Veg. Volume 2-5 m (Dead)	-0.0024	0.0029	-0.0083	0.0035
Veg. Volume 5-20 m (Live)	0.0014	0.0034	-0.0053	0.0082
Veg. Volume 5-20 m (Dead)	0.0172	0.0112	-0.0052	0.0397
Summer Tanager				
Intercept	-1.5393	0.3266	-2.1925	-0.8862
Total Water	-0.0009	0.0003	-0.0016	-0.0002
Veg. Volume 0-2 m (Live)	-0.0003	0.0009	-0.0022	0.0015
Veg. Volume 0-2 m (Dead)	0.0028	0.0015	-0.0002	0.0059
Veg. Volume 2-5 m (Live)	-0.0003	0.0014	-0.0031	0.0026
Veg. Volume 2-5 m (Dead)	0.0050	0.0031	-0.0013	0.0112
Veg. Volume 5-20 m (Live)	0.0038	0.0033	-0.0028	0.0104
Veg. Volume 5-20 m (Dead)	0.0048	0.0144	-0.0239	0.0336