Department of Defense
Legacy Resource Management Program

PROJECT 06-290

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

CHRIS KIRKPATRICK, UNIV. OF AZ

January 2007

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

Final Report

Submitted to:

DoD Legacy Resource Management Program
1225 South Clark Street, Suite 1500
Arlington, VA 22202

Prepared By:

Chris Kirkpatrick
Courtney J. Conway
and
Dominic LaRoche

USGS Arizona Cooperative Fish & Wildlife Research Unit
104 Biological Sciences East
University of Arizona
Tucson, AZ 85721
Phone: 520-621-1959
Fax: 520-621-8801

(DoD Legacy Project #06-290)

15 January 2007

TABLE OF CONTENTS

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 Neotropical migratory birds that alight in these woodlands during their spring and fall migrations across the desert southwest. Groundwater withdrawal (and subsequent loss of surface water) to support urban developments 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 in 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 objective 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 both surface water and the health of riparian vegetation influence the abundance and diversity of riparian birds. Ultimately, our objective was to develop a set of models to allow resource managers on military lands to better predict the effects of future groundwater withdrawal/surface water depletion on riparian bird communities along the Upper San Pedro River and elsewhere in the desert southwest. From March to October 2006, we surveyed birds, sampled vegetation, and measured surface water at 17 study sights located in riparian woodlands throughout southeastern Arizona, including 4 study sites situated along the Upper San Pedro River near Fort Huachuca Military Reservation. We also sampled avian food resources (i.e., aerial arthropods) and monitored nests of riparian bird species at a subset of these study sites. We used multiple linear regression to examine the role of surface water and the health of riparian vegetation on bird parameters while controlling for potentially confounding variables such as vegetation structure and composition. We detected positive associations between the presence and extent of surface water and relative abundance for 4 species of birds: black phoebe, Wilson's warbler, common yellowthroat, and song sparrow. In addition, we found evidence of substantial declines in populations of riparian obligate bird species (including Bell's Vireo, Yellow Warbler, and Summer Tanager) following groundwater withdrawal and a subsequent tree die-off at one of our 17 study sites. We believe that riparian bird communities along the Upper San Pedro River (and elsewhere in the desert southwest) are threatened in 2 ways by future groundwater loss. First, should groundwater levels fall to the point where surface water flows are reduced or eliminated, populations of common bird species such as Black Phoebes, Wilson's Warblers, Common Yellowthroats, and Song Sparrows are likely to decline. Second, should groundwater levels fall to the point that riparian vegetation is strongly effected, populations of many other bird species, including riparian obligate birds like Bell's Vireo, Yellow Warbler, and Summer Tanager, are likely to decline. Continued drought conditions in the desert southwest are likely to compound the problems associated with groundwater withdrawal in the foreseeable future. Results from this study provide quantitative data and predictive models that will allow resource managers on military lands to better predict how abundance and diversity of riparian birds will be affected by future reductions in ground and surface water levels near military installations in the desert southwest.
.

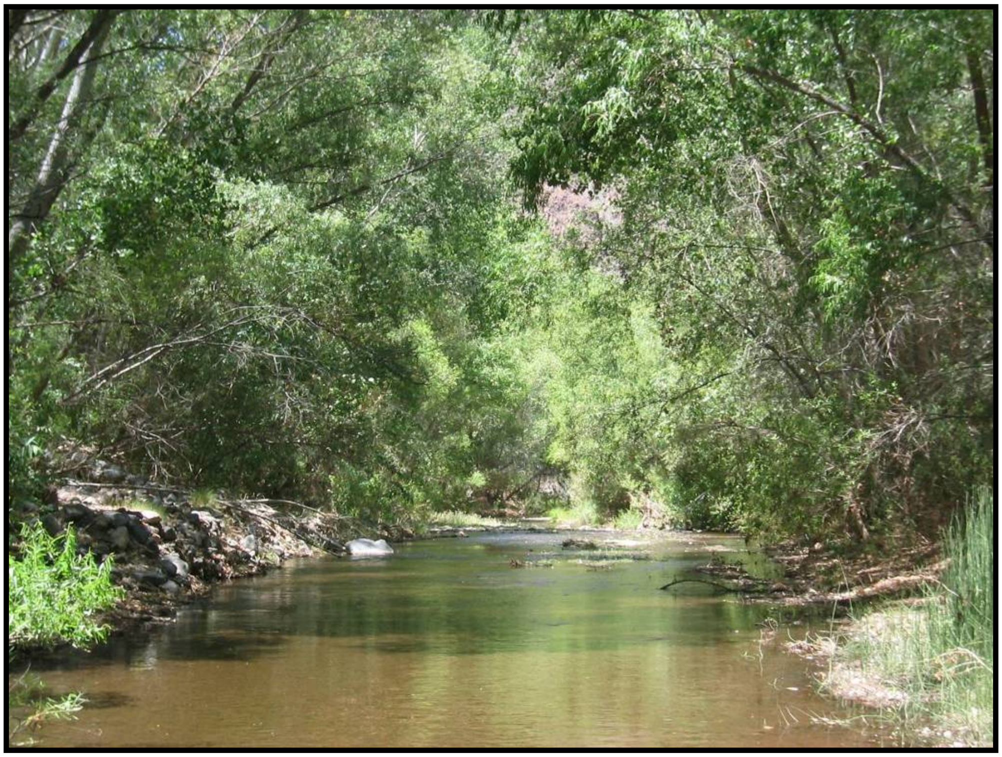
INTRODUCTION

Riparian woodlands in the desert southwest (Fig. 1) are an extremely important resource because they constitute less than 1% of the desert landscape yet typically support greater than 50% of the breeding birds (Johnson et al. 1977). Riparian woodlands also provide critical stopover habitat for hundreds of migratory bird species (Skagen et al. 1999). 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 areas with standing or flowing surface water support higher densities of invertebrate prey. Little is known about the role that surface water itself plays in determining the relative value of riparian woodlands to birds in the desert southwest. If surface water directly enhances the value of riparian woodlands for birds, even relatively small reductions in the groundwater table may have large repercussions on abundance and species composition of the avian community. Recent droughts and increasing water needs of a growing human population are leaving many areas in the region more and more reliant on groundwater.

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 southwestern U.S (Krueper 2003). Over 400 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. Groundwater 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 River, rapidly expanding human populations near other important riparian areas in the 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) or are located adjacent to areas with riparian woodlands (e.g., White Sands Missile Range) 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.

As part of a regional ecosystem initiative, Arizona Partners in Flight has identified low-elevation riparian woodland as a top priority habitat in need of conservation because it contains a tremendous diversity of birds and because it is severely threatened (Latta et al. 1999). Three bird species that inhabit low-elevation riparian habitat are considered Arizona Partners in Flight priority species of conservation concern: Southwestern Willow Flycatcher (*Empidonax traillii extremus*), Western Yellow-billed Cuckoo (*Coccyzus americanus occidentalis*), and Lucy's Warbler (*Vermivora luciae*). The Southwestern Willow Flycatcher is federally listed as endangered and the western Yellow-billed Cuckoo is a candidate for listing. Both species are found breeding along the Upper San Pedro River and in other riparian woodlands in southern Arizona. An additional eight species that inhabit low-elevation riparian woodlands are considered Arizona Partners in Flight preliminary species of conservation concern. These species include the Brown-crested Flycatcher (*Myiarchus tyrannulus*), Northern Beardless-

Figure 1. Photographs showing typical riparian vegetation along Aravaipa Creek (top photo) and the San Pedro River (near Gray Hawk Nature Center; bottom photo), two perennially flowing streams located in southeastern Arizona. The tree species visible in the photographs include Fremont cottonwood (*Populus fremontii*) and Goodding willow (*Salix gooddingii*).



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*; Latta et al. 1999).

Efforts to protect the function and sustainability of riparian bird communities in the desert southwest require predictions about the potential effects of groundwater 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 proportion of dead to live vegetation) influence the abundance and diversity of riparian birds. Ultimately, our objective was to develop a set of models to allow resource managers on military lands to better predict the ultimate effects of future groundwater withdrawal/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. The first 3 hypotheses sought to identify associations while the last 4 hypotheses sought to elucidate potential ecological processes (e.g., food availability, nest predation) underlying these associations.

1) Riparian areas have higher avian species richness and relative abundance (for each species) than surrounding uplands

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

3) Amount of dead or dormant riparian vegetation in the 50 m surrounding a survey point is negatively correlated with avian species richness and relative abundance (for each species)

4) Arthropod biomass is greater in riparian areas with substantial amounts of surface water compared to riparian areas lacking standing water

5) Clutch size is higher in riparian areas with substantial amounts of surface water compared to riparian areas lacking standing water (for a subset of focal species)

6) Nestling growth rates are higher in riparian areas with substantial amounts of surface water compared to riparian areas lacking standing water (for a focal species)

7) Probability of nest depredation is lower in riparian areas with substantial amounts of 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, and non-governmental organizations that have a vested interest in protecting riparian woodlands in the desert southwest during the current study (e.g., the U.S.

Bureau of Land Management, the U.S. Fish and Wildlife Service, the U.S. Forest Service, the National Park Service, the Arizona Game and Fish Department, Pima County Parks and Recreation Department, The Gray Hawk Nature Center and The Nature Conservancy). Loss or degradation of riparian woodlands is an especially important issue for the Department of Defense (DoD) in the desert southwest because groundwater 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 (e.g., Fort Huachuca, Fort Hood, and White Sands Missile Base). By being able to better predict the effects of groundwater 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. This research project addressed an emerging issue that will only become more important as an expanding human population places more demands on limited groundwater resources in the desert southwest.

STUDY AREA

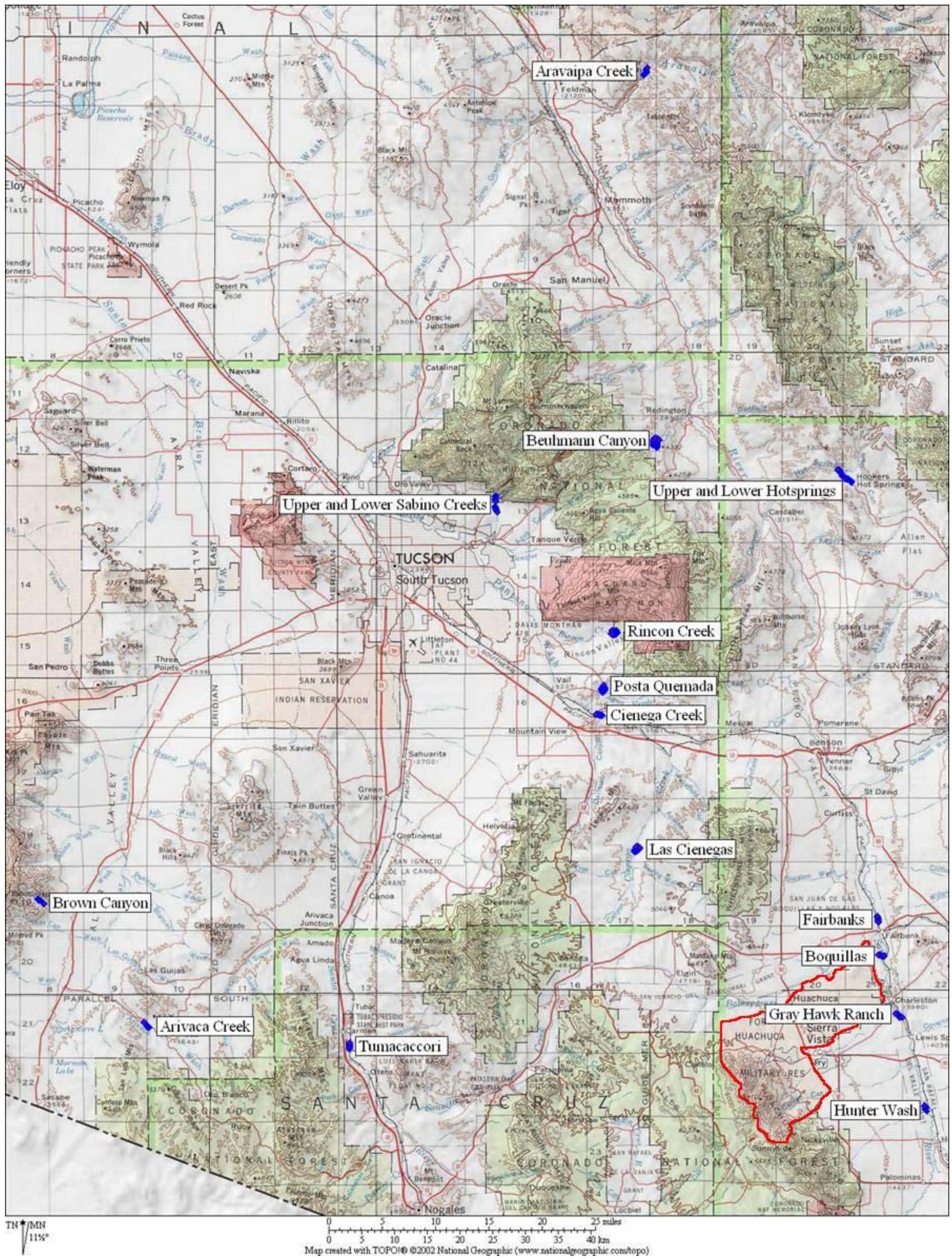
We conducted this research project in low-elevation riparian woodlands in an area of southeastern Arizona bounded by the Gila River to the North, the Altar Valley to the West, the Mexican border to the South, and the New Mexican border to the East (Fig. 2). The study area straddled the division between the Sonoran Desert to the west and the Chihuahuan Desert to the East and was located between approximately 700 and 1,250 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 (Fig. 1) 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 (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 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.

METHODS

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 GIS, we identified all potential sites within our study area that were located between 700 and 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

Figure 2. Study area in southeastern Arizona showing the locations of 17 study sites and the location of Fort Huachuca Military Reservation (bounded by red line) adjacent to the City of Sierra Vista and the San Pedro River. See Appendix 2 for detailed maps of each study site.



potential study sites ranking sites highly if they were accessible (e.g., not on private land) and were 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 20 potential study sites on our list during the winter/spring of 2006 to evaluate their suitability for the study. We 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 perennial flowing surface water, seasonally or spatially intermittent surface water, or ephemeral surface water (i.e., flowing water present only after precipitation events). Finally, we chose several additional study sites located in riparian woodlands along 2 larger, 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 4 study sites along the Upper San Pedro River adjacent to Fort Huachuca Military Reservation and 1 study site along the Santa Cruz River at Tumacacori National Historical Park (Fig . 2). All told, we selected 5 sites that had perennial flowing surface water, 9 sites that had intermittent surface water, and 3 sites that had ephemeral surface water (Table 1; Fig. 2; Appendix 1).

Bird Survey Routes--At each of the 17 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 (Appendix 2). For larger, perennially-flowing streams, we placed survey points along one side of 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 was too narrow on the original 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, University of Arizona, 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 the study sites (Buehman Canyon, Las Cienegas, Posta Quemada, and Rincon Creek). 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 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 maximum distance of riparian vegetation from the stream. 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 Las Cienegas study site which had

Table 1. Seventeen study sites used to examine the link between groundwater withdrawal and surface water depletion on the health and persistence of riparian bird communities in southeastern Arizona in 2006. Study sites are organized by the type of surface flow typical at each site.

Name of Site	Site Code	Administering Agency	# Pts.	Surface Water
Lower Hot Springs	LHS	The Nature Conservancy	15	Perennial
Aravaipa Creek	ARA	The Nature Conservancy	15	Perennial
Boquillas[1]	BOQ	U.S. Bureau of Land Management	12	Perennial
Gray Hawk[1]	GRA	U.S. Bureau of Land Management	12	Perennial
Tumacacori	TUM	National Park Service	10	Perennial
Fairbanks[1]	FAI	U.S. Bureau of Land Management	12	Intermittent
Rincon Creek	RIN	National Park Service	10	Intermittent
Arivaca Creek	ARI	U.S. Fish and Wildlife Service	14	Intermittent
Brown Canyon	BRO	U.S. Fish and Wildlife Service	14	Intermittent
Cienega Creek	CIE	Pima County Parks and Recreation Dept	15	Intermittent
Upper Hot Springs	UHS	The Nature Conservancy	15	Intermittent
Lower Sabino Creek	LSA	Private land	12	Intermittent
Upper Sabino Creek	USA	U.S. Forest Service	11	Intermittent
Buehman Canyon	BEU	U.S. Forest Service	15	Intermittent
Hunter Wash[1]	HUN	U.S. Bureau of Land Management	12	Intermittent
Las Cienegas	LLC	U.S. Bureau of Land Management	10	Ephemeral
Posta Quemada	POS	Pima County Parks and Recreation Dept	9	Ephemeral
Rincon Creek	RIN	National Park Service	10	Ephemeral

[1] Sites located along Upper San Pedro River adjacent to Fort Huachuca Military Reservation

only 6 survey points due to limited space). To facilitate the relocation of survey points, we marked each survey point with a small piece of flagging, recorded Universal Trans Mercator (UTM) coordinates at the point (Appendix 2), and took digital photographs of the point.

Bird Surveys--Before the start of the 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 15 March to 15 June. We selected this time period based on records of peak breeding activity for common riparian and upland birds found in and near riparian areas in Arizona (Corman and Wise-Gervais 2005). We surveyed birds along each survey route every 3 weeks (total of 4-5 replicate bird surveys per route per year) 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.

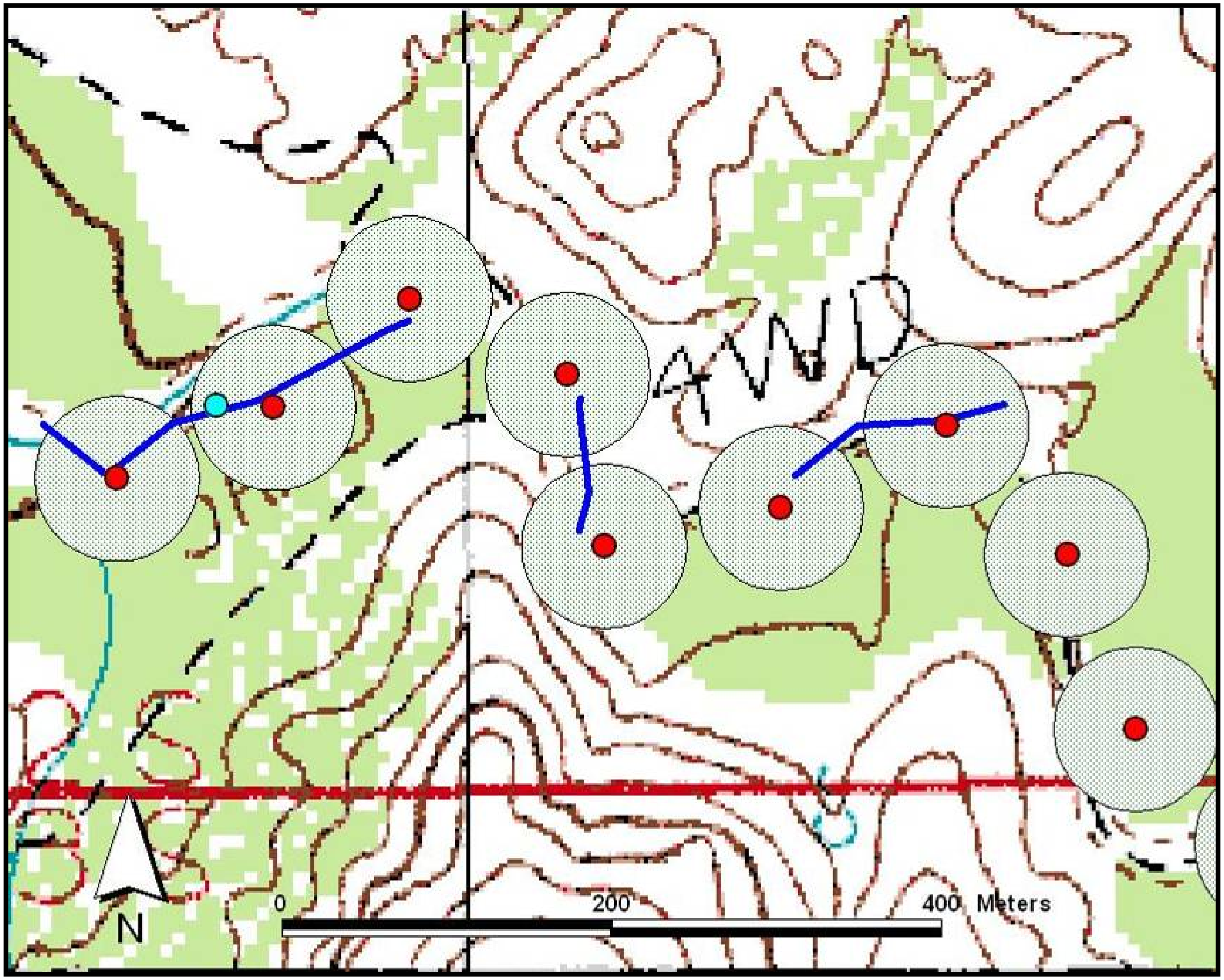
We recorded temperature (°C), wind speed (km/hr) using a hand-held anemometer, and % cloud cover at the start and end of each survey along each survey route. A total of 8 observers surveyed birds in 2006. To reduce observer bias, we rotated observers during subsequent replicate surveys at all study sites except at the 4 study sites along the San Pedro River where, for logistical reasons, a single observer conducted all bird surveys. To reduce temporal variance at the 3 sites were we had both upland and riparian bird survey routes, 3 observers simultaneously surveyed the 1 riparian and 2 upland survey routes during the morning survey period. At each survey point, observers waited 1 minute and then begin 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 bird (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 (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 area surrounding each bird survey point 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 for use at Rincon Creek (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 2 closest stream width measurements that we collected while in the field at 50 m increments along the segment. We then summed the total area of surface water (from both standing pools and flowing segments of water) across replicate surveys for each survey point and across survey points and replicate surveys for each study site.

Vegetation Sampling--From July to October 2006, we estimated 1) vegetation volume, 2) average height of large riparian trees, and 3) width of riparian vegetation within each of our 17 study sites. 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). 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 uniformly across the 50-m radius plot. We placed one end of a 5-m graduated pole on the ground at each

Figure 3. Detail of map showing a portion of the bird survey route at the Upper Hot Springs study site (red dots represent survey points #7-15 and green stippling indicates area within 50 m of 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.



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 column 0.25-m in radius 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" of vegetation separately for each plant species and noted whether the vegetation was alive or dead/dormant (we used the proportion of live to dead/dormant vegetation to estimate riparian vegetation "health"). We placed herbaceous plant species into 1 of 2 general categories (grasses or forbs).

We divided the vertical column into 3 general height classes (understory, mid-story, and 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 canopy), we divided the vertical column into 15 1-m sub-intervals. Although we recorded vegetation hits >20 m, we did not include these data in subsequent analyses because only a tiny fraction of vegetation "hits" (0.1% of 86,568 total "hits") were >20 m in height. For each of the 3 height classes, we calculated the % 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. We estimated vegetation volume for each study site by averaging total vegetation volume estimates across all bird survey points at each study site.

At each bird survey point, we estimated the 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 >40 cm Diameter at Breast Height (DBH) in each of 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 estimated its height with the aid of a clinometer.

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 riparian woodlands. We mapped the edges of both cottonwood-willow/mixed-broadleaf forest and mesquite/mesquite-hackberry woodlands 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/mixed-broadleaf forest and cottonwood-willow/mixed-broadleaf forest plus mesquite/mesquite-hackberry woodlands) at each survey point. Some sites (e.g., Lower Sabino Creek) were bounded by private property and we were unable to map the extent of mesquite/mesquite-hackberry 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 these study sites.

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

Nest Monitoring--From April to July 2006, 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 4 of our 17 study sites. Although we collected data on nests of all species, we focused our efforts on collecting data on nests of Bell's Vireos (Fig. 5) because of the relative ease in finding and monitoring nests of this species in southwestern riparian woodlands (Ehrlich et al. 1988, Powell 2000). We initially choose the Fairbanks 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 Fairbanks study site persisted well into the bird breeding season (contrary to what we had expected) and we ultimately classified Fairbanks to be a "wet" study site. We spent equal time and effort nest searching at the Fairbanks vs. the Boquillas study sites and at the Rincon Creek vs. the Cienega Creek study sites. We monitored nests every 2-3 days until the fate (failed or fledged) was determined. We recorded the number of eggs and/or nestlings on each nest visit. For Bell's vireos, we marked each nestling with an indelible maker and weighed each nestling during subsequent nest visits.

Arthropod sampling--Using sticky traps, we sampled arthropods in early June 2006 at each survey point at a subset of 6 of our 17 study sites. Based on the presence of surface water at the 6 study sites in early June, we classified Las Cienegas, Posta Quemada, and Rincon Creek as "dry" study sites and Aravaipa Creek, Cienega Creek, and Tumacacori as "wet" study sites. 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.). We attached each sticky trap to a 20 x 28 cm board and suspended these boards above the ground at each survey point. We attempted to place sticky traps as high in the forest canopy as possible, but 4 m was as about as high as we could place traps using a string thrown over low-hanging branches. We anchored the sticky traps to the ground using string 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 calculated average total dry biomass and average dry biomass per order across survey points at the 6 study sites at which we trapped arthropods.

The Floods of 2006--Southeastern Arizona experienced one of the wettest monsoons on record during July and August 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. Several of our other study sites experienced flash floods that removed or altered understory (<2.5 m) vegetation primarily. Due to logistical constraints, we were forced

Figure 5. An adult Bell's Vireo, a locally common breeder in riparian woodlands of southeastern Arizona.

to measure vegetation variables at our study sites after the floodwaters had subsided. Consequently, all of our vegetation data from Aravaipa Creek and much of the understory vegetation data that we collected at other study sites were compromised to some extent. Where possible, we took measures during the analysis of the data to control for these potential biases.

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. 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 flyover 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-way of the 2006 field season. For species richness analyses we used total species richness, species richness of breeding birds, and species richness of non-breeding birds.

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 upland 200 and upland 500 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 the data.

Influence of Surface Water and Vegetation Health on Riparian Birds--We took two approaches to examining whether the presence of surface water and the health of riparian vegetation influenced the relative abundance and species richness of birds within our study area. We analyzed our data at 1) the level of the study site (n = 16; we excluded the Aravaipa study site - see below) and 2) the level of the survey point (n = 213) using stepwise multiple linear regression. For all analyses, we included data from 4 of the 5 possible replicate surveys conducted from April to June to capture the peak breeding season for riparian birds and because some of our study sites were surveyed only 4 times. We limited our analyses to include birds detected aurally and/or visually within 50 m of each survey point and we excluded data of bird flyover detections. We also limited our analyses to the 39 species (33 breeding and 6 migrants) for which we detected a total of ≥50 individuals during replicate surveys in 2006. For species richness analyses, we used total species richness and species richness for a subset of 28 “riparian-obligate” species found within our study area (Hunter et al. 1987, USGS Northern Prairie Research Center 2006).

At the level of the study site, we used stepwise multiple linear regression to model relative abundance (total and by species) and species richness of birds in relation to the following explanatory variables: average surface area of water (m^2); average volume of live vegetation in the understory, mid-story, and canopy; average proportion of live to dead/dormant vegetation in the understory, mid-story, and canopy; average volume of live vegetation for the 3 most common plant species in the understory, mid-story, and canopy; and average canopy height (m) of large (>40 cm DBH) riparian trees. We included 2 additional explanatory variables in our regression models: the average width of cottonwood-willow/mixed-broadleaf riparian vegetation; and the average width of all riparian vegetation (cottonwood-willow/mixed-broadleaf forest plus mesquite/mesquite-hackberry woodlands) estimated to a distance of 300 m on either side of each survey point. Before running analyses, we examined distributions of both our response and explanatory variables to check assumptions of normality and applied transformations (square root + 0.1 or *ln* + 1) where necessary. We report untransformed summary statistics in tables but use transformed data for analyses. Our sample size of study sites was small ($n = 17$) and thus our power to detect associations was relatively limited for these analyses.

At the level of the survey point, we used stepwise multiple linear regression to model total relative abundance and species richness data in relation to the following explanatory variables: 1) average surface area of water (m^2); 2) average volume of live vegetation in the understory, mid-story, and canopy; 3) average volume of dead or dormant in the understory, mid-story, and canopy; 4) average volume of live vegetation for the 3 most common plant species in the understory, mid-story, and canopy; and 5) average canopy height of large (>40 cm DBH) riparian trees. We included 2 additional explanatory variables in our regression models: 1) the average width of cottonwood-willow/mixed-broadleaf riparian vegetation; and 2) the average width of all riparian vegetation (cottonwood-willow/mixed-broadleaf forest plus mesquite/mesquite-hackberry woodlands) estimated to a distance of 300 m on either side of each survey point. Because we lacked sufficient numbers of detections at each survey point for most bird species, we did not model relative abundance data for species at the point level using multiple linear regression. However, to confirm results from our site-level analyses, we ran point-level analyses on any species for which we found significant associations with surface water or riparian vegetation “health” during site-level analyses.

For all analyses, we used a stepwise procedure to fit candidate models by entering variables at each step (using $P \leq 0.10$ for variable inclusion and $P \leq 0.15$ for retention) based on likelihood-ratio tests. Because we sampled vegetation after the 2006 floods (but collected bird data before the 2006 floods), we reran our analyses using a subset of data that did not include vegetation variables for the understory (<2.5 m) because this was the height class of vegetation most affected by the floodwaters. We then compared these resulting models with those generated using the full data set. We also excluded data from the Aravaipa Creek study site from all analyses because of the extensive flood damage to the riparian woodland at this study site (e.g., many large cottonwood and willow trees were removed from the site during the floods).

Nest Monitoring--We used independent samples *t*-tests to compare average cultch sizes between our 3 "wet" and our 1 "dry" study sites for species of breeding birds in which we were able to determine clutch size in >4 nests in both "wet" and "dry" study sites. For our focal bird species (Bell's Vireo), we used exposure days to estimate the probability of nest depredation (Mayfield 1961, 1975) across all sites and at "dry" and "wet" sites.

Arthropod sampling-- We used a one-way ANOVA to test the hypothesis that arthropod biomass was greater at the 3 "wet" sites compared to the 3 "dry" sites. We applied square root + 0.1 or *ln* + 1 transformations to help control for non-homogeneity of variance in 2 of the response variables. We report untransformed summary statistics in tables but used transformed data for analyses. Before running analyses, we eliminated 12 arthropods that weighed between 20 and 329 mg (mostly cicadas [*Cicadidae*]) because these individuals were outliers within the data set.

RESULTS

Riparian vs. Upland Bird Surveys--During 5 replicate surveys, we detected a total of 4,683 individuals of 90 species (67 breeding and 30 non-breeding) <50 m from survey points along our riparian and upland bird survey routes at the 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. 6a and 6b). 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 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 trend 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. 6c). Only the Black-throated Sparrow decreased in relative abundance with proximity to riparian areas (Fig. 6d). 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.

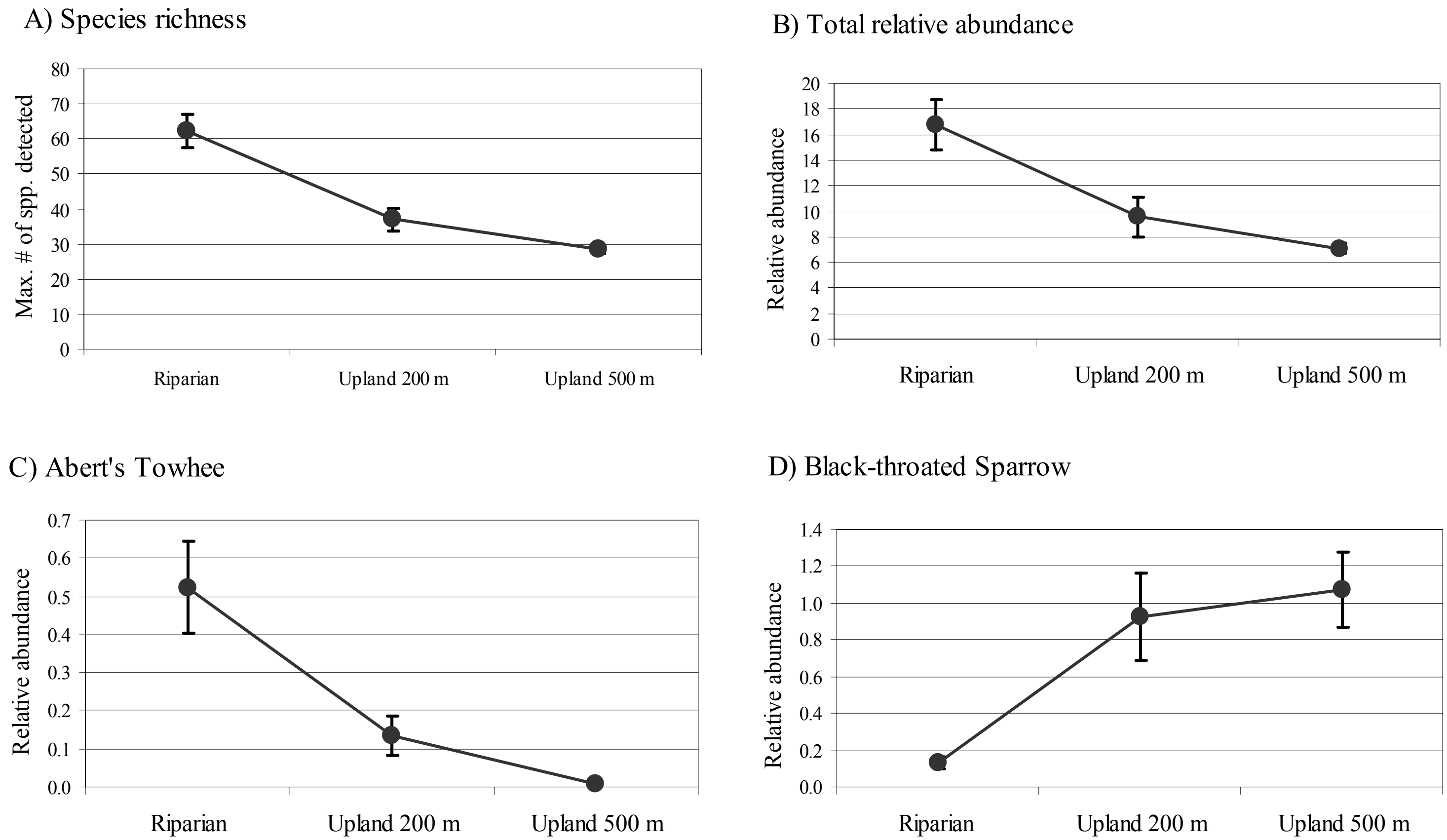
Table 2. Comparison of mean relative abundance and species richness of birds detected <50 m from survey points on bird survey routes located in riparian areas and in upland areas 200 and 500 m from riparian areas at 3 study in southeastern Arizona (March-June, 2006). Only significant results ($P < 0.15$)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

		Riparian		Upland 200m		Upland 500m			
Species	Status[1]	$\overline{x}$	SE	$\overline{x}$	SE	$\overline{x}$	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 = wintering species.

[2] Square root + 0.1 transformation used in analysis.

Figures 6a-d. Spatial trends (mean ± SE) in A) species richness, B) total bird relative abundance, C) relative abundance of Abert's Towhee (a typical riparian-obligate 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 (Las Cienegas, Posta Quemada, and Rincon) in southeastern Arizona.



Surface Water--Estimated surface area (m^2) of flowing and standing pools of water declined 56% from April to June across our 17 study sites, from an average of 3,633 m^2 to an average of 1,617 m^2 (Figs. 7a and 7b; Table 3). The apparent increase in surface water at the Tumacacori study site from April to early May was likely due to measurement error; several pools of water were located adjacent to the stream in early May that were apparently overlooked during surface water sampling in April.

Influence of Surface Water and Vegetation Health on Riparian Birds--During 4 replicate bird surveys at each of our 17 study sites, we detected a total of 16,056 individuals of 123 species (68 breeding and 55 non-breeding) <50 m from survey points along our riparian bird survey routes. The species that we detected most frequently were Yellow Warbler (*n* = 1,618), Lucy's Warbler (*n* = 1,042), Bewick's Wren (*n* = 951), Bell's Vireo (*n* = 904), Lesser Goldfinch (*n* = 824), House Finch (*n* = 787), Yellow-breasted Chat (*n* = 739), Abert's Towhee (*n* = 488), Verdin (*n* = 478), Wilson's Warbler (*n* = 447), White-winged Dove (*n* = 427), Summer Tanager (*n* = 414), Gila Woodpecker (*n* = 404), Northern Cardinal (*n* = 319), Brown-crested Flycatcher (*n* = 290), Yellow-rumped Warbler (*n* = 286), Song Sparrow (*n* = 285), Vermillion Flycatcher (*n* = 282), Cassin's Kingbird (*n* = 258), Brown-headed Cowbird (*n* = 242), Ruby-crowned Kinglet (*n* = 208), Common Yellowthroat (*n* = 193), Mourning Dove (*n* = 186), Ash-throated Flycatcher (*n* =168), and Ladder-backed Woodpecker (*n* = 160). Of the 3 bird species that are considered Arizona Partners in Flight priority species of conservation concern (Latta et al. 1999), we detected numerous Lucy's Warblers (see above) but no Southwestern Willow Flycatchers and only 2 Western Yellow-billed Cuckoos during bird surveys in 2006.

Results from our stepwise multiple linear regression analyses revealed the following associations. At the species level, we detected associations between the presence and extent of surface water and relative abundance for 4 species of birds: Black Phoebe, Wilson's warbler, Common Yellowthroat, and Song Sparrow (Table 4). All 4 species exhibited positive associations with presence and extent of surface water. Adjusted R^2 values for models were 0.37 for Black Phoebe, 0.78 for Wilson's warbler, 0.80 for Common Yellowthroat, and 0.76 for Song Sparrow, suggesting that variables in the models explained the majority of the variance in the data for most of these species. The adjusted R^2 value for Black Phoebe was relatively low: partial correlation coefficients of excluded variables indicate that the volume of live velvet mesquite vegetation in the canopy (positive association) and the volume of Goodding willow in the mid-story (negative association) would have been the next 2 variables to be included in the model. We found that relative abundance for all 4 species was consistently associated with presence and extent of surface whether we analyzed our data at the site or at the point level, whether we included or excluded understory vegetation from analyses, or whether we included or excluded the Rincon Creek study site (an outlier in our data set; see below) from analyses. The predictive equations for the 4 models are:

- Black Phoebe relative abundance (within 50 m of survey point) = 0.001(extent of surface water [m^2] within 50 m of survey point) – 0.002.

Table 3. Estimated surface area (m^2) of flowing and standing pools of water present during 4 replicate surveys from April to June 2006 within 50 m of all survey points (range = 9-15 survey points per site; see table 1) at 17 study sites in southeastern Arizona. Study sites are arranged in order of decreasing average surface water.

	Date of survey				
Study Site	April	Early May	Late May	June	Average
Aravaipa Creek	12,239	11,321	9,747	9,455	10,691
Gray Hawk	9,334	9,421	9,574	8,970	9,325
Tumacacori	6,477	9,132	6,532	5,914	7,014
Hunter Wash	10,277	9,440	988	94	5,200
Boquillas	6,174	5,524	3,674	716	4,022
Fairbanks	6,160	4,738	1,388	6	3,073
Cienega Creek	3,676	3,393	3,395	1,128	2,898
Lower Hot Springs	2,390	2,162	1,087	1,099	1,685
Upper Hot Springs	1,305	1,107	332	83	707
Upper Sabino Creek	1,930	350	53	9	586
Lower Sabino Creek	1,117	197	16	2	333
Arivaca Creek	408	84	1	0	123
Buehman Canyon	247	22	0	0	67
Brown Canyon	30	37	12	13	23
Las Cienegas	0	0	0	1	0
Posta Quemada	0	0	0	0	0
Rincon Creek	0	0	0	0	0
Average	3,633	3,349	2,165	1,617	

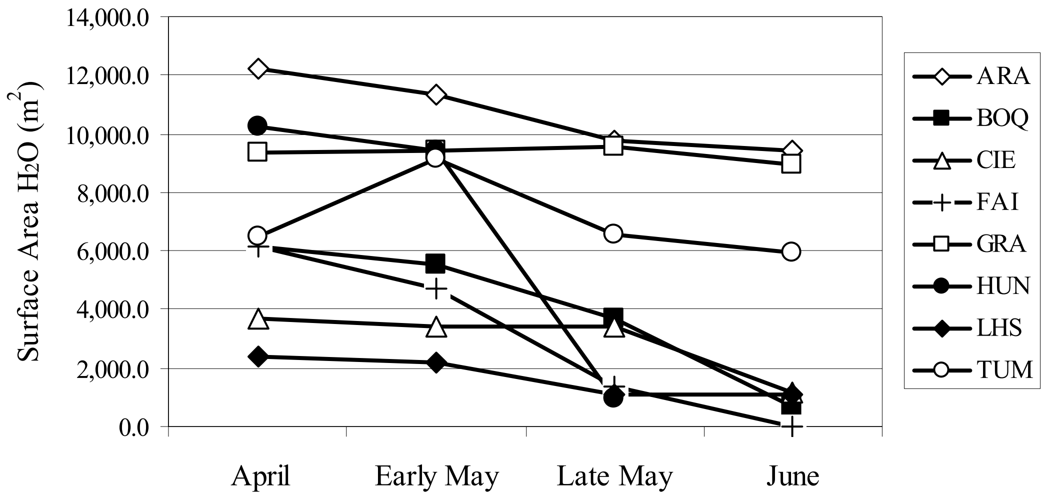
- Common Yellowthroat relative abundance (within 50 m from survey point) = 0.003(extent of surface water [m^2] within 50 m from survey point) + 0.169 (volume of grass in understory within 50 m of survey point) – 0.42.

- Wilson's Warbler relative abundance (within 50 m of survey point) = 0.003(extent of surface water [m^2] within 50 m of survey point) + 0.252(volume of live velvet mesquite in understory within 50 m of survey point) + 0.113.

- Song Sparrow relative abundance (within 50 m of survey point) = 0.005(extent of surface water [m^2] within 50 m of survey point) + 0.029(volume of dead vegetation in understory within 50 m of survey point) – 0.682(volume of live velvet mesquite in canopy within 50 m of survey point) – 0.267.

Figures 7a-b. Trends in surface area (m^2) of flowing and standing pools of water present from April to June 2006 at A) 8 of 17 study sites with extensive surface water (i.e., ≥2,000 m^2) during the bird breeding season and B) 6 of 17 study sites with less-extensive surface water (<2,000 m^2) during the bird breeding season in riparian woodlands of southeastern Arizona. Three study sites (Las Cienegas, Posta Quemada, and Rincon Creek) had no or virtually no surface water present during this time period. See Table 1 for description of site codes.

A)



B)

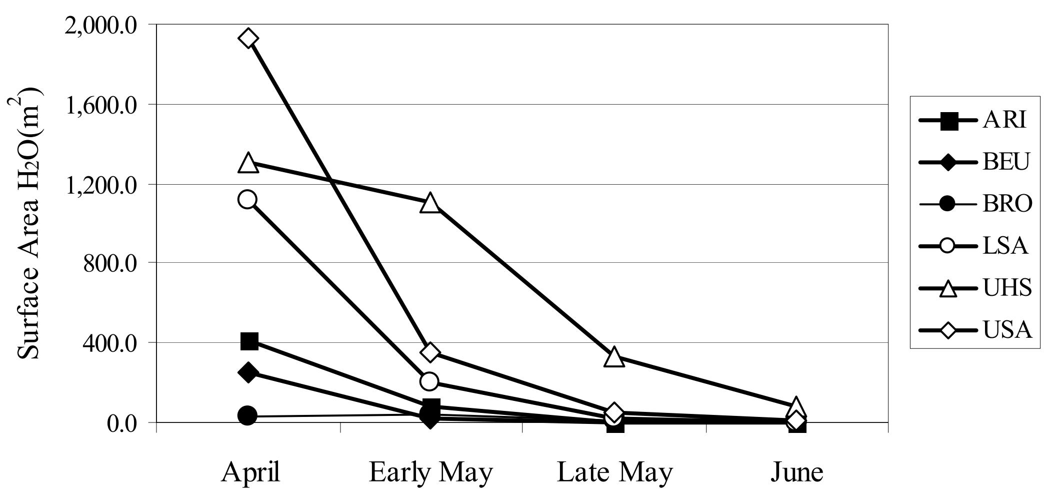


Table 4. Final models for 7 species of riparian birds generated from stepwise multiple linear regression using data collected from 15 study sites (Aravaipa and Rincon Creek study sites were excluded; see methods) located in riparian woodlands of southeastern Arizona (April-October 2006).

Variables selected in final models	*b*	SE	Beta	*t*	*P*
Black Phoebe					
Constant	-0.002	0.023	-	-0.1	0.947
Surface water[1]	0.001	0.000	0.609	2.8	0.016
Bell's Vireo					
Constant	5.940	0.722	-	8.2	<0.001
Width riparian area 2 (m)[2,3]	-0.427	0.148	-0.325	-2.9	0.016
Volume of forbs in understory (0-2.5 m)	-0.505	0.133	-0.337	-3.8	0.003
Volume of grass in understory (0-2.5 m)	-0.401	0.084	-0.504	-4.8	0.001
Volume of live POPFRE[4] in mid-story (0-2.5 m)	-0.550	0.136	-0.389	-4.0	0.002
Yellow Warbler					
Constant	-6.463	1.588	-	-4.1	0.002
Canopy height (m)	0.211	0.061	0.577	3.4	0.005
Width riparian area 2 (m)[2,3]	0.884	0.365	0.408	2.4	0.032
Lucy's Warbler					
Constant	0.890	0.115	-	7.7	<0.001
Volume of dead veg. in understory (0-2.5)	0.008	0.003	0.522	2.2	0.046
Wilson's Warbler					
Constant	0.113	0.119	-	1.0	0.360
Surface water[1]	0.003	0.001	0.893	6.5	<0.001
Volume of live PROVEL[4] veg. in understory (0-2.5 m)	0.252	0.056	0.620	4.5	0.001
Common Yellowthroat					
Constant	-0.420	0.133	-	-3.2	0.008
Volume of Grass in understory (0-2.5 m)	0.169	0.053	0.463	3.2	0.008
Surface water[1]	0.003	0.001	0.601	4.1	0.001
Song Sparrow					
Constant	-0.267	0.289	-	-0.9	0.374
Surface water[1]	0.005	0.002	0.588	3.2	0.008
Volume of dead veg. in understory (0-2.5)	0.029	0.008	0.724	3.4	0.006
Volume of live PROVEL[1,4] veg. in canopy (5-20 m)	-0.682	0.292	-0.577	-2.3	0.039
Summer Tanager					
Constant	-0.114	0.093	-	-1.2	0.244
Volume of live veg. in canopy (5-20 m)	0.051	0.009	0.720	5.6	<0.001
Volume of dead veg. in understory (0-2.5)	0.007	0.002	0.424	3.3	0.007

[1] Square-root + 0.1 transformation applied to variable.
[2] Average width (m) of riparian area (cottonwood-willow/mixed-broadleaf forest plus mesquite/mesquite-hackberry woodlands) at study site.
[3] *Ln* + 1 transformation applied to variable.
[4] POPFRE = Fremont cottonwood (*Populus fremontii*); PROVEL = velvet mesquite (*Prosopis velutina*).

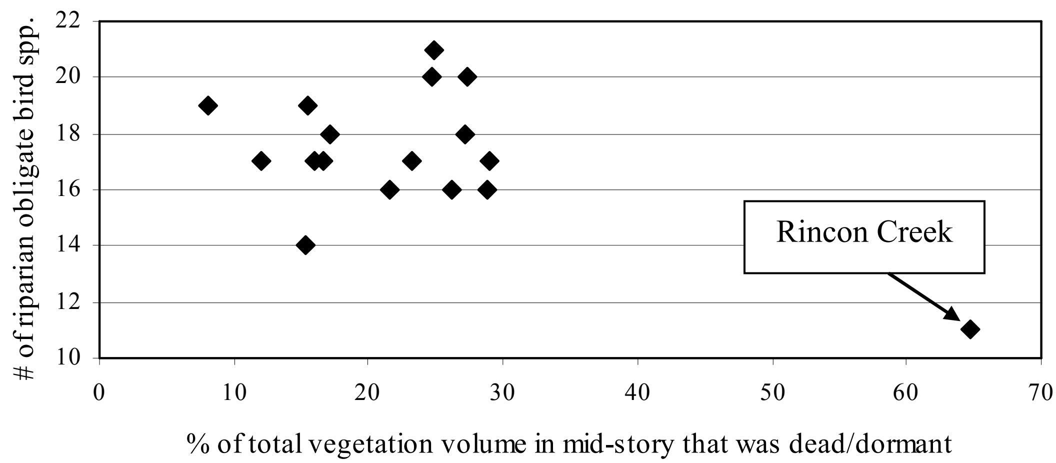
Although we did not detect associations between relative abundance and surface water for Bell's vireo, Lucy's Warbler, Yellow Warbler, and Summer Tanager, we report models for these 4 riparian obligate species (Table 4) because they are considered to be either priority species of conservation concern (Lucy's warbler) or species of potential conservation concern in Arizona (Latta et al. 1999). Adjusted R^2 values for models were 0.27 for Lucy's Warbler, 0.89 for Bell's Vireo, 0.75 for Yellow Warbler, and 0.77 for Summer Tanager, indicating that variables in the models explained the majority of the variance in the data for most of these species. The adjusted R^2 value for Lucy's Warbler was relatively low: partial correlation coefficients of excluded variables suggest that volume of live velvet mesquite vegetation in the mid-story and in the understory (both positive associations) would have been the next 2 variables included in the model for Lucy's Warbler. Except for a few positive associations with dead vegetation in the understory for birds like Lucy's Warbler, Song Sparrow, and Summer Tanager (Table 4), we were unable to detect associations between bird relative abundance and dead vegetation in the mid-story or canopy for any of the bird species in our analyses.

At the community level, we initially ran analyses using data from 16 of our 17 study sites (the Aravaipa Creek study site was excluded from all analyses due to flood damage; see methods). We detected associations between 2 of our community-level response variables (total species richness and species richness of riparian obligate species) and surface water (positive associations) and dead vegetation in the mid-story (negative associations). However, these associations disappeared from models when we excluded the Rincon Creek study site from our analyses. The Rincon Creek study site was unlike any of the other 16 sites within our study area because recent groundwater pumping in the area combined with long-term drought conditions have led to an extensive die-off of riparian tress along the creek in the last several years (Figs. 8a-b; Don Swann, Saguaro National Park, personal communication). Given the disparity between Rincon Creek and the other study sites, we considered Rincon Creek to be an outlier within the data set and excluded it from subsequent analyses. During these subsequent analyses, we were unable to detect associations between our community-level response variables and surface water or the health of riparian vegetation whether we examined our data at the site or at the point level or whether we included or excluded understory vegetation from analyses. We report models for our community level measures in Table 5. Adjusted R^2 values for these models were 0.21 for total species richness, 0.38 for species richness of riparian obligate species, and 0.79 for total relative abundance.

Arthropod Sampling--Using sticky traps, we captured a total of 42,630 arthropods representing 18 arthropod orders at our 6 study sites (Table 6). Total dry biomass of these arthropods was 4,202 mg. In terms of frequency of capture, 92% of the arthropods were Thysanoptera, 4% were Diptera, 2% were Homoptera or Hemiptera, 1% was Hymenoptera, and 1% was from other orders. In terms of biomass, 35% of the arthropod biomass was attributable to Hymenoptera, 32% to Homoptera or Hemiptera, 16% to Diptera, 10% to Coleoptera, and the remaining 7% to other orders. Despite their numerical dominance on the sticky traps, Thysanoptera comprised only 1% of the total arthropod biomass due to their small size (generally <1 mm). We were unable to detect a difference in total arthropod biomass between our "wet" and "dry" study sites (Table 6). However, we did detect differences in arthropod biomass between "wet" and "dry"

Figures 8a-b. Relationship between species richness of riparian obligate birds and A) the % of total vegetation in the mid-story (2.5-5 m) that was either dead or dormant, and B) the % of total vegetation in the canopy (5-20 m) that was either dead or dormant using data collected from 17 study sites in riparian woodlands of southeastern Arizona (April to October 2006). The location of the Rincon Creek study site, an outlier in our data set, is indicated in both plots.

A)



B)

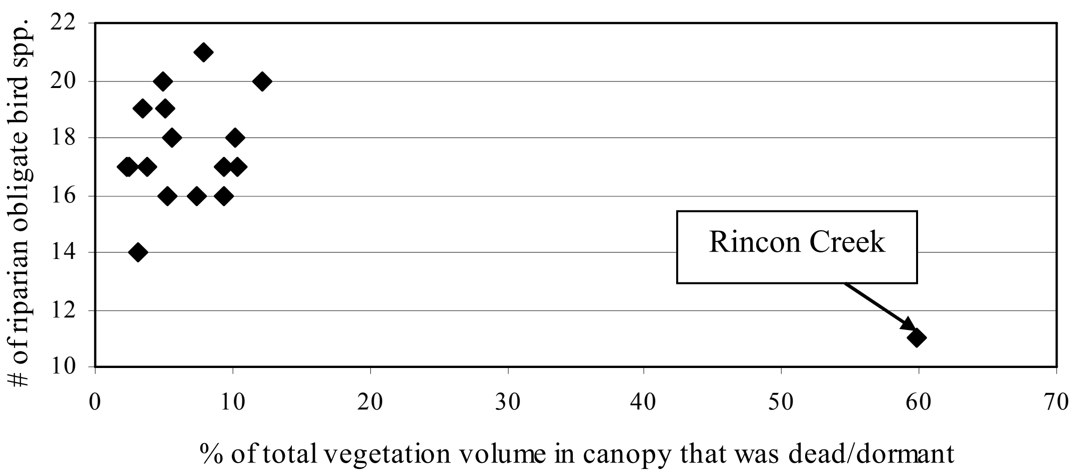


Table 5. Final models for community-level bird parameters (species richness and total relative abundance) generated from stepwise multiple linear regression using data collected from 15 study sites (Aravaipa and Rincon Creek study sites were excluded; see methods) located in riparian woodlands of southeastern Arizona in 2006.

Variables selected in final models	*b*	SE	Beta	*t*	*P*
Species richness (total)					
Constant	13.542	1.344	-	10.1	<0.001
Volume of live PROVEL[1] in understory (0-2.5 m)	2.190	0.844	0.545	2.6	0.023
Species richness (riparian obligate species)					
Constant	13.542	1.344	-	10.1	<0.001
Volume of live PROVEL[1,2] in canopy (5-20 m)	2.190	0.844	0.545	2.6	0.023
Volume of grass in understory (0-2.5 m)	0.839	0.411	0.429	2.0	0.064
Total relative abundance					
Constant	-11.245	5.113	-	-2.2	0.050
Width riparian area 2 (m)[3,4]	5.557	0.819	0.877	6.8	<0.001
Volume of live PROVEL[1,2] in mid-story (2.5-5 m)	2.144	0.598	0.470	3.6	0.004
Volume of live veg. in understory (0-2.5 m)	-0.139	0.053	-0.330	-2.6	0.023

[1] PROVEL = velvet mesquite (*Prosopis velutina*).
[2] Square-root + 0.1 transformation applied to variable.
[3] Average width (m) of riparian area (cottonwood-willow/mixed-broadleaf forest plus mesquite/mesquite-hackberry woodlands) at study site.
[4] *Ln* + 1 transformation applied to variable.

sites for 2 orders: dry biomass of Diptera and Mecoptera (scorpionflies) was greater (10.53 mg and 0.45 mg, respectively) at "wet" sites compared to "dry" sites. In addition, we found tentative evidence ($P < 0.15$) suggesting that Trichoptera biomass was greater at "wet" sites compared to "dry" sites, although this apparent difference was small (0.28 mg). Because our sample size of study sites was small ($n = 6$), we may have lacked sufficient power to detect trends in biomass between "wet" and "dry" sites for other arthropod orders.

Nest Monitoring--From April-July 2006, we located a total of 360 nests of 42 species at 4 study sites (Boquillas, Cienega Creek, Fairbanks, and Rincon Creek). We found 64 nests of 18 species at the Boquillas study site, 66 nests of 19 species at the Fairbanks study site, 148 nests of 32 species (including 1 yellow-billed cuckoo nest) at the Cienega Creek study site, and 86 nests of 25 species at Rincon Creek study site. We found that riparian birds used a diversity of nesting substrates and located nests from ground level (e.g., song sparrow) to 35 m above the ground (e.g., black phoebe) (Table 7). We determined average clutch sizes for 18 species of riparian and upland birds for which we were able to see nest contents of ≥1 nest (Table 8). 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 other common riparian breeding species (e.g., Bell's Vireo and Yellow-breasted Chat), we were unable to compare clutch sizes between "wet" and

Table 6. Dry biomass (mg; mean ± SE) of arthropods within 18 orders captured using sticky traps placed at approximately 4-m height at survey points located within 3 "wet" study sites and 3 "dry" study sites in riparian woodlands of southeastern Arizona during a 4-day sampling period in early June 2006.

	"Wet" study sites (with surface water)						"Dry" study sites (no surface water)								
	Aravaipa		Cienega Creek		Tumacacori		Las Cienegas		Posta Quemada		Rincon Creek				
Order	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	Mean Diff.[1]	$F_{1,4}$	P
Acari	0.02	0.01	0.05	0.03	0.01	0.01	0.00	0.00	0.01	0.01	0.01	0.01	0.02	1.7	0.265
Araneae	1.70	0.83	0.76	0.25	1.63	0.61	0.27	0.13	1.99	1.63	0.01	0.01	0.61	0.8	0.429
Colembola	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.02	0.00	0.00	0.00	0.00	-0.01	1.0	0.374
Coleoptera	4.13	1.33	8.87	1.65	10.80	1.71	11.02	3.82	2.73	0.67	3.17	1.18	2.29	0.5	0.531
Diptera[2]	10.80	1.82	11.63	4.27	24.20	4.61	7.00	2.33	4.08	1.13	3.96	1.35	10.53	11.9	0.026
Emphemeroptera[3]	0.08	0.05	0.01	0.01	0.00	0.00	0.30	0.20	0.00	0.00	0.01	0.01	-0.07	0.4	0.549
Hemiptera	0.40	0.25	2.16	0.54	4.60	2.02	5.04	1.83	1.20	0.69	0.25	0.16	0.22	0.0	0.912
Homoptera	1.56	0.50	7.29	2.46	5.55	1.27	5.02	1.83	4.11	1.11	0.81	0.35	1.49	0.5	0.523
Hymenoptera	10.53	2.19	29.73	3.72	27.98	5.46	26.57	5.34	23.30	5.88	6.31	2.11	4.03	0.2	0.670
Isoptera	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.1	0.795
Lepidoptera	0.40	0.24	0.10	0.10	0.00	0.00	2.63	1.53	0.01	0.01	0.91	0.64	-1.02	1.7	0.261
Mecoptera	0.30	0.10	0.66	0.24	0.64	0.15	0.16	0.06	0.00	0.00	0.09	0.04	0.45	13.0	0.023
Neuroptera	0.00	0.00	0.01	0.01	0.00	0.00	7.12	3.26	0.00	0.00	0.21	0.21	-2.44	1.1	0.356
Odonata	0.00	0.00	0.00	0.00	0.54	0.54	0.00	0.00	0.00	0.00	0.00	0.00	0.18	1.0	0.374
Orthoptera	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.32	0.32	0.00	0.00	-0.11	1.0	0.374
Pseudoscorpiones	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.02	0.00	0.00	-0.01	1.0	0.374
Thysanoptera	2.95	0.36	27.92	6.28	20.27	3.43	32.92	10.38	12.60	4.11	8.25	1.97	-0.87	0.0	0.938
Trichoptera	0.16	0.10	0.28	0.28	0.59	0.59	0.19	0.11	0.00	0.00	0.00	0.00	0.28	3.9	0.121
Unidentified	0.03	0.02	0.78	0.50	0.34	0.33	0.00	0.00	0.05	0.03	0.00	0.00	0.37	2.8	0.172
Total	33.06	3.90	90.26	12.65	97.14	13.55	98.26	16.70	50.14	8.28	23.99	5.11	16.02	0.3	0.621

[1] Difference in mean dry biomass (mg) between "wet" sites and "dry" sites.
[2] *Ln* transformation used in analysis.
[3] Square-root + 0.1 transformation used in analysis.

Table 7. Summary nest characteristics for 360 nests of 42 species found at 4 study sites (Boquillas, Cienega Creek, Fairbanks, and Rincon Creek) located in riparian woodlands of southeastern Arizona, April-July 2006.

		Nest height (m)				Nesting substrate[1]				Species of plant comprising nesting substrate[2]							
Species	*n*	$\bar{x}$	SE	Min	Max	1st	%	2nd	%	1st	%	2nd	%	3rd	%	4th	%
Abert's Towhee	10	1.9	0.4	0.6	5.0	BR	100	-	-	PROVEL	30	POPFRE	20	SALGOO	20	OTHER	30
Anna's Hummingbird	10	4.4	0.7	2.0	10.0	BR	100	-	-	CELRET	30	FRAPEN	30	POPFRE	20	SALGOO	20
Ash-throated Flycatcher	4	7.4	2.4	2.0	13.0	CA	100	-	-	POPFRE	50	FRAPEN	25	PROVEL	25	-	-
Broad-billed Hummingbird	4	1.7	0.5	1.0	3.0	BR	100	-	-	CELRET	75	FRAPEN	25	-	-	-	-
Brown-crested Flycatcher	9	7.1	0.8	3.0	11.0	CA	100	-	-	CARGIG	44	PLAWRI	22	POPFRE	22	SALGOO	22
Black-chinned Hummingbird	26	2.6	0.3	1.0	9.0	BR	100	-	-	POPFRE	31	SALGOO	19	CELRET	19	OTHER	31
Bell's Vireo	42	1.5	0.1	0.5	4.0	BR	100	-	-	SALGOO	26	CELRET	17	FRAPEN	14	PROVEL	9
Bewick’s Wren	10	5.4	0.8	3.0	10.0	CA	100	-	-	SALGOO	40	POPFRE	30	FRAPEN	20	PROVEL	10
Blue Grosbeak	1	2.0	0.0	-	-	BR	100	-	-	TAMARI	100	-	-	-	-	-	-
Black Phoebe	1	35.0	0.0	-	-	BD	100	-	-	N/A	-	-	-	-	-	-	-
Black-tailed Gnatcatcher	2	2.1	0.1	2.0	2.2	BR	50	BF	50	FRAPEN	50	CELRET	50	-	-	-	-
Black-throated Sparrow	5	0.8	0.1	0.5	1.0	BR	100	-	-	SALGOO	40	FRAPEN	20	PROVEL	20	OPUNTIA1	20
Bullock's Oriole	1	12.0	0.0	-	-	BR	100	-	-	POPFRE	100	-	-	-	-	-	-
Bushtit	1	4.0	0.0	-	-	BR	100	-	-	POFRE	100	-	-	-	-	-	-
Cactus Wren	1	8.0	0.0	-	-	CA	100	-	-	CARGIG	100	-	-	-	-	-	-
Cassin's Kingbird	4	12.3	2.3	7.0	18.0	BR	100	-	-	POFRE	100	-	-	-	-	-	-
Canyon Towhee	1	1.5	0.0	-	-	BR	100	-	-	FRAPEN	100	-	-	-	-	-	-
Copper's Hawk	1	7.0	0.0	-	-	BR	100	-	-	SALGOO	100	-	-	-	-	-	-
Common Yellowthroat	1	0.3	0.0	-	-	BR	100	-	-	BACSAL	100	-	-	-	-	-	-
Gilded Flicker	2	4.0	1.0	3.0	5.0	CA	100	-	-	CARGIG	100	-	-	-	-	-	-
Gila Woodpecker	7	8.0	1.2	4.0	14.0	CA	100	-	-	POPFRE	43	CARGIG	43	SALGOO	14	-	-
Gray Hawk	1	15.0	0.0	-	-	BR	100	-	-	POPFRE	100	-	-	-	-	-	-
House Finch	20	5.6	1.0	0.5	18.0	BR	95	BF	5	SALGOO	40	OPUNTIA2	20	POPFRE	15	OTHER	25
Ladder-backed Woodpecker	3	4.7	2.4	-	-	CA	100	-	-	PROVEL	67	SALGOO	33				
Lesser Goldfinch	12	4.8	0.6	1.9	10.0	BR	100	-	-	POPFRE	58	SALGOO	17	FRAPEN	8	BACSAL	8
Lucy' Warbler	19	4.0	0.9	1.0	17.0	CA	73	BF	27	PROVEL	32	POPFRE	21	CELRET	16	FRAPEN	16
Mourning Dove	6	1.8	0.7	0.0	4.0	BR	67	GR	33	PROVEL	100	-	-	-	-	-	-
Northern-beardless Tyrannulet	1	10.0	0.0	-	-	BR	100	-	-	FRAPEN	100	-	-	-	-	-	-
Northern Cardinal	6	1.8	0.2	1.0	2.5	BR	100	-	-	SALGOO	50	FRAPEN	17	TAMARI	17	CELRET	17
North. rough-winged Swallow	2	0.0	0.0	-	-	GR	100	-	-	N/A	-	-	-	-	-	-	-
Phainopepla	4	6.4	0.7	4.5	8.0	BR	100	-	-	SALGOO	50	TAMARI	25	PROVEL	25	-	-
Purple Martin	3	7.0	0.0	-	-	BR	100	-	-	CARGIG	100	-	-	-	-	-	-

Table 7 Cont.

		Nest height (m)				Nest substrate[1]				Species of plant comprising substrate[2]							
Species	*n*	$\overline{x}$	SE	Min	Max	1st	%	2nd	%	1st	%	2nd	%	3rd	%	4th	%
Rufous-winged Sparrow	1	1.5	0.0	-	-	BR	100	-	-	TAMARI	100	-	-	-	-	-	-
Song Sparrow	7	0.7	0.2	0.0	1.3	BR	86	GR	14	BACSAL	100	-	-	-	-	-	-
Summer Tanager	4	9.8	1.3	6.0	12.0	BR	100	-	-	FRAPEN	50	POPFRE	25	CELRET	25	-	-
Vermillion Flycatcher	20	8.0	1.1	1.5	18.0	BR	100	-	-	POPFRE	40	PROVEL	25	SALGOO	20	FRAPEN	15
Verdin	37	3.3	0.3	1.0	12.0	BR	100	-	-	PROVEL	35	ZIZPHUS	22	FRAPEN	11	CELRET	11
Western Kingbird	2	14.0	6.0	8.0	20.0	BR	100	-	-	FRAPEN	100	-	-	-		-	-
White-winged Dove	24	3.6	0.5	2.0	12.0	BR	100	-	-	PROVEL	33	CELRET	25	SALGOO	21	OTHER	21
Yellow-breasted Chat	39	1.4	0.1	0.4	3.5	BR	100	-	-	BACSAL	59	TAMARI	7	OTHER	34		
Yellow-billed Cuckoo	1	3.5	0.0	-	-	BR	100	-	-	POPFRE	100	-	-	-	-	-	-
Yellow Warbler	5	10.1	1.9	4.4	16.0	BR	100	-	-	POPFRE	60	PROVEL	20	SALGOO	20	-	-

[1] BD = bridge; BF = bark flake; BR = branch; CA = cavity; and GR = ground.

[2] BACSAL = seep willow (*Baccharis salicifolia*); CARGIG = saguaro cactus (Carnegiea gigantea); CELRET = (*Celtis reticulate*); FRAPEN = velvet ash (*Fraxinus pennsylvanica*); OPUNTIA1 = prickly pair cacti spp. (*Opuntia* spp.); OPUNTIA2 = cholla cacti spp. (*Opuntia* spp.); POPFRE = Fremont cottonwood (*Populus fremontii*); PROVEL = velvet ash (*Prosopis velutina*); SALGOO = Goodding willow (*Salix gooddingii*); TAMARI = tamarisk spp. (*Tamaricaceae* spp.); ZIZOBT = graythorn (*Ziziphus obtusifolia*).

Table 8. Average clutch sizes of 18 species of riparian birds for which we were able to determine nest contents of ≥1 nest at 4 study sites (Boquillas, Cienega Creek, Fairbanks, and Rincon Creek) located in riparian woodlands of southeastern Arizona, April-July 2006.

Species	*n*	Clutch size $\bar{x}$	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

"dry" study sites because of the almost complete absence of nesting attempts by these species at our "dry" study site at Rincon Creek.

For example, we found a total of 42 nests of Bell's Vireos (our focal nest-monitoring species) of which 98% were located at our 3 "wet" study sites (60% at Cienega Creek, 19% at Fairbanks, and 19% at Boquillas) and 2% were located at our "dry" study site at Rincon Creek. Because of the lack of Bell's Vireo nesting attempts at Rincon Creek, we were also unable to compare nest predation rates or nestling growth 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 within our study area. 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 the laying period. 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 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.

DISCUSSION

Our results confirm findings from numerous other studies showing that riparian woodlands in the desert southwest have substantially higher avian species richness and relative abundance than adjacent uplands (Johnson et al. 1977, Engel-Wilson and Ohmart 1978, Ohmart and Anderson 1982). 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 non-breeding 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 for many species of birds in the desert southwest and highlight the continued need to protect riparian woodlands because of the disproportionate number of birds 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 areas had an additional effect on bird parameters after controlling for this important association. At the community level, we were unable to detect associations between surface water and either avian species richness or total relative abundance. Instead, these bird parameters tended to be positively associated with the volume of velvet mesquite in the understory, mid-story, or canopy. Velvet mesquite is a species that supports high densities of arthropods (a primary food resource for birds) due to its numerous flowers and rich pollen and nectar resources (Neff et al 1978, Simpson et al. 1977). At the species level, we were also unable to detect associations between surface water and relative abundance for the majority of bird species that we analyzed. However, we did detect positive associations between surface water and relative abundance for Black Phoebe, Wilson's Warbler, Common Yellowthroat, and Song Sparrow.

The Black Phoebe (Fig. 9) is a year-round resident in southern Arizona and is 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). Black Phoebes feed primarily on aerial insects, often within a few meters of standing or flowing surface water, and require mud to construct nests (Wolf 1997). Although Black Phoebes are a locally common breeder in riparian woodlands of Arizona (Corman and Wise-Gervais 2005), destruction of riparian woodlands and diversion of water from drainages represent major threats to this species (Wolf 1997). Our results for black phoebe not only confirm this species affinity for surface water, but also provide the first quantitative measure of the strength of this association in riparian woodlands of the desert southwest. For example, using our predictive model for Black Phoebe (see results), we estimate that bird survey points in riparian woodlands with substantial surface water (e.g., 1,000 m^2 within 50 m of a survey point) will have an average relative abundance of 0.998 black phoebes, whereas bird survey points in riparian woodlands with less surface water (e.g., 225 m^2 within 50 m of a survey point) will have an average relative abundance of 0.223 Black Phoebes.

Figure 9. A Black Phoebe perched on a cottonwood branch at the Cienega Creek study site.

We also found that Song Sparrows, Wilson's Warblers, and Common Yellowthroats were positively associated with presence and extent of surface water. Song Sparrows 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). Although the Song Sparrow is a locally common resident in Arizona, disturbance to Song Sparrow habitat presents a threat to this species in the desert southwest (Arcese et al. 2002). The Wilson's Warbler is a Neotropical migrant that does not breed in Arizona but utilizes riparian woodlands during its spring and fall migrations across the state. During migration, Wilson's Warblers primarily inhabit dense understory vegetation within riparian woodlands (Ammon and Gibert 1999). Common Yellowthroats are found breeding in wet areas with dense undergrowth (Guzy and Ritchison 1999, Corman and Wise-Gervais 2005) and are locally common in wetlands and riparian areas in Arizona (Corman and Wise-Gervais 2005). Populations of both Common Yellowthroats and Wilson's Warblers are threatened by degradation of riparian woodlands in the western U.S. (Ammon and Gibert 1999, Guzy and Ritchison, 1999).

As stated above, previous research indicates that Song Sparrows, Wilson's Warblers, and Common Yellowthroats all share a strong affinity for dense understory vegetation near water in riparian woodlands (Ammon and Gibert 1999, Arcese et al. 2002, Guzy and Ritchison 1999, Corman and Wise-Gervais 2005). During the current study, we were able to detect some positive associations between understory vegetation and relative abundance for these 3 species (e.g., positive association between volume of grass in understory and relative abundance of Common Yellowthroats). However, our inability to detect additional associations with understory vegetation likely resulted from the removal of understory vegetation from some our study sites by the 2006 floods (i.e., before we had a chance to sample vegetation). Consequently, we cannot rule out the possibility that song sparrows, Wilson's warblers, and common yellowthroats were associated primarily with dense understory vegetation and secondarily with presence and extent of surface water within our study area. Nevertheless, given that dense understory vegetation and surface water are commonly associated with one another in riparian woodlands of Arizona (Corman and Wise-Gervais 2005), loss of surface water that leads to the loss of adjacent understory vegetation would likely have a negative affect on populations of these 3 bird species in the region.

In addition to looking for associations with surface water, we also sought to identify potential ecological processes (e.g., food resources, nest predation) underlying these associations. We lacked sufficient data to be able to compare nest predation rates between "wet" and "dry" sites for Bell's vireo, our focal nest monitoring species. However, results from our aerial arthropod sampling indicate that aerial arthropod biomass was greater in "wet" versus "dry" sites for several arthropod orders. For example, we found that areas with increased surface water had on average 10.5 mg of additional fly (*Diptera*) dry biomass per trap. Birds that prey heavily upon flies, such as Wilson's Warblers (Ammon and Gibert 1999), may benefit from foraging in riparian woodlands that have greater surface water because of the increased fly biomass in these areas. We need to conduct additional arthropod sampling to confirm or refute this association and to control for the effects of vegetation structure and composition on aerial arthropod biomass (which we did not do during this study). In addition, a diet analysis of migratory and breeding birds would provide a direct measure of the type and frequency of arthropods utilized as food resource in riparian woodlands of the desert southwest.

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 groundwater 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 live to dead vegetation) influenced avian species richness and relative abundance within our study area. We were unable to detect associations between any of our bird parameters and the health of riparian vegetation in either the mid-story or the canopy of riparian woodlands. However, it was clear from an examination of our 17 study sites (and especially Rincon Creek; Figs. 8a-b), that we did not have a representative sample of sites to adequately examine this issue. Powell (2004) noted that some of the riparian trees along Rincon Creek appeared to be dead or dormant in 2004. We observed a similar phenomenon in 2006, although to a much greater extent (Fig. 10). The exact cause of this tree die-off remains undetermined, but the combination of almost 8 years of drought in the region and current levels of groundwater pumping in the area are likely contributing to the recent decline in the health of this riparian woodland (D. Swann, Saguaro National Park, Personal Communication). Further research is needed to examine this issue, especially at sites like Rincon Creek where ≥ 60% of vegetation volume in the canopy and in the mid-story was dead or dormant.

Figure 10. The Rincon Creek study site in July 2006. Note the large dead/dormant Fremont cottonwood and Arizona sycamores trees lining the stream channel in the center of the photograph.

Perhaps more informative than our comparison of data collected at Rincon Creeks with those collected at our other 16 study sites is a comparison of data collected at Rincon Creek with those collected by Powell (2004) only two years previously (i.e., at the start of the tree die-off along Rincon Creek). Powell (2004) detected considerably more Yellow Warblers and Bell's Vireos at Rincon Creek during bird surveys than we did during our surveys in 2006. For instance, Powell (2004) found that Yellow Warbler was the 10th most abundant species at Rincon Creek in 2004, whereas, we detected only a single, non-singing yellow warbler during all of our replicate surveys in 2006. Moreover, Powell (2004) found evidence of breeding for Yellow Warblers, Bell's Vireos, and Summer Tanagers at Rincon Creek in 2004; whereas, we found no Yellow Warbler nests, only 1 Bell's Vireo nest, and only 2 Summer Tanager nests, despite spending considerably more person-hours in the field nest searching than was spent in 2004 (B. Powell, University of Arizona, personal communication). The change in breeding activity was particularly pronounced for Bell's Vireo. Powell (unpublished data) found 9 Bell's Vireo nests along Rincon Creek prior to 2004, but we found only 1 nest that failed even before it had been fully constructed. Similar declines in Bell's Vireos populations have been observed along the Colorado River following habitat destruction during the 1970s and 1980s (Ohmart 1994). The 2 Summer Tanager nests that we found at Rincon creek were located in clumps of mistletoe (Fig.11; unlike Summer Tanager nests found at our 3 other nest-monitoring study sites), perhaps because mistletoe represented the best available cover for these birds within the dying riparian

Figure 11. Nest of a summer tanager at the Rincon Creek study site in July 2006. Note how the nest is located in the best available cover, a small clump of mistletoe in a dying velvet ash tree. The nest is indicated by the white arrow in the photograph.

canopy along Rincon Creek. Riparian obligate species such as Bell's Vireo, Yellow Warbler, and Summer Tanager appear to be in decline in riparian woodlands along Rincon Creek. Compared to Powell's (2004) data, Lucy's Warbler, Rufous-winged Sparrow, and riparian/upland species such as Gambel's Quail, Mourning Dove, and Gila Woodpecker were the only species that did not appear to be experiencing declines at Rincon Creek. Lucy's Warblers breed in mesic riparian woodlands (e.g., cottonwood-willow woodland) in southeastern Arizona but they're also a common breeder in more xeric riparian woodlands and mesquite-grasslands throughout the region (Johnson et al. 1997, Kirkpatrick et al. 2002). This species may do better with drier climatic conditions compared to riparian obligate species such as Bell's Vireo, Yellow Warbler, and Summer Tanager that nest primarily in live foliage of riparian trees (Powell 2004). For example, Lucy's Warblers typically nest in cavities and behind dead bark flakes (Johnson et al. 1997) and we found numerous Lucy's Warbler nests in cavities and bark flakes of the dead or dying trees along Rincon Creek.

MANAGEMENT IMPLICATIONS

Groundwater use in Arizona 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 face an uncertain future, perhaps none more so than the riparian woodland along the Upper San Pedro River. Groundwater use at Fort Huachuca Military Reservation and the City of Sierra Vista has not substantially reduced groundwater levels in the alluvial aquifer; however, future groundwater developments in the area pose a major threat to nearby riparian woodlands along the Upper San Pedro River (Stromberg et al. 1996, Pool and Coes 1999). We believe that riparian bird communities along the Upper San Pedro River (and elsewhere in the desert southwest) are threatened in 2 ways by future groundwater loss. First, should groundwater levels fall to the point where surface water flows are reduced or eliminated (i.e., a "Stage 2" effect of groundwater pumping; Webb and Leake 2005), populations of bird species such as Black Phoebes, Wilson's Warblers, Common Yellowthroats, and Song Sparrows are likely to decline. Second, should groundwater levels fall to the point that riparian vegetation is strongly effected (i.e., a "Stage 3" effect of groundwater pumping; Webb and Leake 2005), populations of many other bird species, including riparian obligate birds like Bell's Vireo, Yellow Warbler, and Summer Tanager, are likely to decline. Continued drought conditions in the desert southwest are likely to compound problems associated with groundwater 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 groundwater 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, groundwater withdrawal, 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 to better predict how abundance and diversity riparian birds will be affected by future reductions in ground and surface water levels on or near military installations in the desert southwest.

ACKNOWLEDGMENTS

This project was funded by the DoD Legacy Resource Management Program, the Arizona Game and Fish Department, the National Park Service, the U.S. Geological Survey, and the University of Arizona. M. Ali, J. Barr, G. Bieber, Z. Holderby, K. Frye, D. LaRoche, P. Rainbolt, E. Rose, N. Stephens, and S. Toas conducted fieldwork. J. Kirkpatrick, G. Bodner, and S. Steckler assisted with fieldwork. We thank B. Powell for insight into his 2004 research along Rincon Creek. We received information and/or logistical support from the following people: D. Swann, N. Kline (Saguaro National Park), K. Baldwin, D. Carter, J. Fonseca, M. Maierhauser, S. Schorr (Pima County Parks and Recreation Department), A. Rasor (Tumacacori National Historical Park), S. Gall, M. Hunnicut, K. Senter (Buenos Aires National Wildlife Refuge), K. Simms, J. Simms, B. Childress, M. Fredlake, M. Lambert, H. Blasisus, P. O'Neill (Bureau of Land Management), M. Haberstitch, R. Marshall, B. Rogers, S. Crask (The Nature Conservancy), J.

Sutton, J. Taiz (Coronado National Forest), D. Kooi (Hidden Valley Homeowner's Association), K. Ulhman, M. Reed (University of Arizona), and S. Stone (Fort Huachuca Military Reservation). We thank the Bureau of Land Management, the Buenos Aires National Wildlife Refuge, and The Nature Conservancy for providing field housing.

LITERATURE CITED

Anderson, B. W., and R. D. Ohmart. 1977. Vegetation structure and bird use in the lower Colorado River Valley. Pages 23-34 in R.R. Johnson and D. A. Jones, eds. Importance, preservation and management of riparian habitat: a symposium. General Technical Report RM-166. U.S. Forest Service, Fort Collins, CO.

Arcese, P., M., K. Sogge, A. B. Marr, and M. A. Patten. 2002. Song Sparrow. Volume 704 *in* A. Poole and F. Gill, editors. The birds of North America. The Academy of Natural Sciences. Washington, D.C.

Ammon, E. M., and W. M. Gilbert. 1999. Wilson's Warbler. Volume 778 *in* A. Poole and F. Gill, editors. The birds of North America. The Academy of Natural Sciences. Washington, D.C.

Bookhout T. A. 1996. Research and management techniques for wildlife and habitats. 5th edition. The Wildlife Society. Bethesda, MD.

Bull, E. L., and J. M. Skovlin. 1982. Relations between avifauna and streamside vegetation. Transactions of the N. A. Wildlife and Natural Resources Conference 47:496-506.

Busch, D. E., and S. D. Smith. 1995. Mechanisms associated with decline of woody species in riparian ecosystems in the southwestern U.S. Ecological Monographs 65:347-370.

Brown, D. E. 1994. Biotic Communities Southwestern United States and Northwestern Mexico. University of Utah Press, Salt Lake City, Utah.

Corman, T. E., and C. Wise-Gervais. 2005. Arizona breeding bird atlas. University of New Mexico Press, Albuquerque, NM.

Engel-Wilson R. W, and R. D. Ohmart. 1978. Assessment of vegetation and terrestrial vertebrates along the Rio Grande between Fort Quitman, Texas and Haciendita, Texas. Tempe (AZ): Arizona State University. Prepared for the U.S. Section, International Boundary and Water Commission, El Paso, TX.

Guzy, M. J., and G. Ritchison. 1999. Common Yellowthroat. Volume 448 *in* A. Poole and F. Gill, editors. The birds of North America. The Academy of Natural Sciences. Washington, D.C.

Hunter, H. C., R. D. Ohmart, B. W. Anderson. 1987. Status of breeding riparian-obligate birds in southwestern riverine systems. Western Birds 18:10-18.

Johnson, R. R., L. T. Haight, and J. M. Simpson. 1977. Endangered species vs. endangered habitats: A concept. Pages 68-79 in R. R. Johnson and D. A. Jones, eds. Importance, preservation, and management of riparian habitat: A symposium. General Technical Report RM-166. U.S. Forest Service, Fort Collins, CO.

Johnson, R. R., H. K. Yard, and B. T. Brown. 1997. Lucy's Warbler. The Birds of North America, No. 318. American Ornithologist Union. Academy of Natural Sciences, PA..

Judd, J. B., J. M. Laughlin, H. R. Guenther, and R. Hendergrade. 1971. The lethal decline of mesquite on the Casa Grande National Monument. Great Basin Naturalist 31:153-159.

Mills, G. S., J. B. Dunning, Jr., and J. M. Bates. The relationship between breeding bird density and vegetation volume. Wilson Bulletin 103: 486-479.

Kirkpatrick, C., S. DeStefano, R. W. Mannan, and J. Lloyd. 2002. Trends in abundance of grassland birds following a spring prescribed burn in southern Arizona. The Southwestern Naturalist 47:282-292.

Knopf, F. L., and F. B. Samson. 1994. Scale perspectives on avian diversity in western riparian ecosystems. Conservation Biology 8:669-676.

Krueper. D, J. Bart, and T. D. Rich. 2003. Response of vegetation and breeding birds to the removal of cattle on the San Pedro River, Arizona. Conservation Biology 17:607-615.

Latta, M .J, C. J. Beardmore, and T. E. Corman. 1999. Arizona Partners in Flight Bird Conservation Plan. Version 1.0.

Naiman, R. J., H. Decamps, and M. Pollock. 1993. The role of riparian corridors in maintaining regional biodiversity. Ecological Applications 3:209-212.

Neff, J. L. and B. B. Simpson. 1977. Flowers – flower visitor system. Pages 204-224 *in* G. H. Orians and O. T. Solbrig, editors. Convergent evolution in warm deserts. Dowden, Hutchinson, and Ross, Stroudsburg, PA.

Ohmart, R., and B. Anderson. 1982. North American desert riparian ecosystems. Pages 433-479 i*n* Reference Handbook on the Deserts of North America. Greenwood Press, CT.

Pool, D. R., and A. L. Coes. 1999. Hydrologeologic investigations of the Sierra Vista subwatershed of the Upper San Pedro Basin, Cochise County, southeast, AZ. Water-Resources Investigations Report 99-4197.

Powell, B. F. 2004. Assessment of the bird community along the Middle Reach of Rincon Creek, Saguaro National Park. Final report to Saguaro Nation Park, Tucson, Arizona.

Rogers, L. E., W. T. Hinds, and R. L. Buschbom. 1976. A general weight vs. length relationship for insects. Annals of the Entomological Society of America. 69: 387-389.

Sabo, J. L., J. L. Barstow, and M.E. Power. 2002. Length-mass relationships for adult aquatic and terrestrial invertebrates in a California watershed, Journal of the North American Benthological Society 21:336-343.

Skagen, S. K., C. P. Melcher, W. H. Howe, M. H. Olson, D. E., Shindler, and B. R. Herwig. 1998. Comparative use of riparian corridors and oases by migratory birds in southeast Arizona. Conservation Biology 12: 896-909.

Simpson, B. B., J. L. Neff, and A. R. Moldenke. 1977. *Prosopis* flowers as a resource. Pages 84-107 *in* B. B. Simpson, editor. Mesquite. Dowden, Hutchinson, and Ross, Stroudsburg, PA.

Strahler, A. N. (1952). Dynamic basis of geomorphology. Geological Society of America Bulletin, 63, 923 - 938.

Stromberg, J. C., R. Tiller, and B. Richter. 1996. Effects of groundwater decline on riparian vegetation of semiarid regions: The San Pedro, AZ. Ecological Applications 6:113-131.

USGS. 2006. Birds as indicators of riparian vegetation condition in the western U.S. - riparian obligate species. http://www.npwrc.usgs.gov/resource/birds/ripveg/obligate.htm. Accessed 31 December 2006.

Webb, R.H., and S. A. Leake. 2005. Ground-water surface-water interactions and long-term change in riverine riparian vegetation in the southwestern United States. Journal of Hydrology320:302-323.

Wolf, B. O., 1997. Black Phoebe. Volume 268 *in* A. Poole and F. Gill, editors. The birds of North America. The Academy of Natural Sciences. Washington, D.C.