PATTERNS OF HABITAT USE BY BIRDS AND LIZARDS IN URBAN RIVER CORRIDORS OF TUCSON, ARIZONA

by

Teresa Moore Frederick

A Thesis Submitted to the Faculty of the

SCHOOL OF RENEWABLE NATURAL RESOURCES

In Partial Fulfillment of the Requirements
For the Degree of

MASTER OF SCIENCE
WITH A MAJOR IN WILDLIFE AND FISHERIES SCIENCE

In the Graduate College

THE UNIVERSITY OF ARIZONA

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SIGNED: Teresa Moore Frederick

APPROVAL BY THESIS COMMITTEE

This thesis has been approved on the date shown below:

William W. Shaw, Thesis Director, Professor of Wildlife and Fisheries Science — Date: 24 May 96

Robert W. Mannan, Professor of Wildlife and Fisheries Science — Date: 6 June 1996

William J. Matter, Associate Professor of Wildlife and Fisheries Science — Date: 5-24-96

ACKNOWLEDGEMENTS

Without the support and encouragement of my major professor, Bill Shaw, this project would not have been possible. He allowed me to learn from plenty of my own mistakes, and was always available when I needed advice and reassurance. I also am especially grateful to Bill Mannan and Randy Gimblett for providing valuable assistance in the design of this project and to Bill Matter in providing helpful comments on the thesis drafts. I would like to thank my advisory team: Glenn Frederick, Sherry Ruther and Scott Richardson of the Arizona Game and Fish Department and Laurel Parker of Pima County Flood Control and Transportation District. They contributed many valuable suggestions, ideas, and encouragement for this project. Cecil Schwalbe and Michael Morrison also assisted in developing sampling protocols. I would also like to thank Joy Mehulka and Susan Beebe of Pima County Illustration Department who cheerfully provided me with maps and photos. I am grateful to the many landowners who gave me permission to conduct surveys on their property. Robert Ramirez was very helpful in adjusting his maintenance schedule on the Santa Cruz River Park just to help my study. I would also like to thank the many field technicians who made this study possible, especially Jean Paul Charpentier. Special thanks go to Cindy Lovely and John Stair for volunteering their valuable time to help with vegetation sampling. Joan Scott of Arizona Game and Fish Department was very helpful with plant identification, as was the staff of the University of Arizona herbarium. Charise Hedlund helped with greeting river park recreationists during bird surveys. Jean Paul Charpentier was instrumental in providing the GIS data. Keireth Snyder and Howard Frederick rescued me from many computer problems. Pat Jones provided advise on statistical analysis. Most of all, I would like to thank Glenn Frederick. He gave me valuable suggestions, helped with vegetation sampling in the hottest days of the year, endured early morning bird surveys, and most of all, he gave me encouragement and cheerful support. Funding for this project was made available through the Arizona Game and Fish Department's Heritage Grant-In-Aid Program.

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ABSTRACT

I surveyed songbirds and lizards adjacent to dry rivers throughout metropolitan Tucson and related species richness to recreational use and habitat using stepwise multiple regression. Habitat characteristics included vegetation structure and floristics in river-edge areas, adjacent land uses, and land uses of the surrounding landscape.

Bank stabilization had a negative effect on species richness of all bird groups. Total vegetation cover, mesquite (*Prosopis velutina*) density, and natural open space had a positive effect on species richness of most bird groups. Tall vegetation was important for species richness of lizards.

River corridors could function as conservation corridors for five bird species and two lizard species. However, habitat for many other species was not continuous across the metropolitan area.

Recommendations include protecting mesquite bosques without bank stabilization, protecting wide areas of upland vegetation near large protected areas, and increasing structural diversity and use of native plants in river parkways.

INTRODUCTION

Loss of Sonoran desert vegetation to urbanization is an increasing threat to some wildlife populations in Arizona. Arizona is one of the most rapidly urbanizing states in the nation, and Tucson, in particular, has grown 23% in the last decade (U.S. Census Bureau 1991). As this growth continues, natural open space is converted to residential and commercial developments. These developments support fewer bird species (Emlen 1974, Tweit and Tweit 1986, Stenberg 1988, Germaine 1995). Bird species often lost with urban development are generally insectivorous, ground-nesting, cavity-nesting, or territorial (Emlen 1974, Beissinger and Osborne 1982). Information on the effects of urbanization on lizards is scarce, but in Tucson, many lizard species decline in abundance at high housing densities (Germaine 1995).

Fragmentation of remaining open spaces may accelerate wildlife population declines. Fragmentation of forests has frequently been related to the loss of avian species, especially those associated with forest interiors (Whitcomb et al. 1981, Ambuel and Temple 1983, Lynch and Whigham 1984, Wilcove 1985, Freemark and Merriam 1986, Askins et al. 1987, Blake and Karr 1987, Robbins et al. 1989). Fragmentation also has been associated with a reduced diversity of birds in riparian areas (Gutzwiller and Anderson 1987) and in chaparral surrounded by urban developments (Soule et al. 1988). The causes of these patterns remain unclear, but several suggestions have been proposed. First, isolation of small habitat patches could result in localized extinctions (MacClintock et al. 1977, Lynch and Whigham 1984, van Dorp and Opdam 1987). Although isolation seems unlikely for such a mobile group as birds, some species are reluctant to cross habitat gaps (Wegner and Merriam 1979, Soule et al. 1988, Haas 1995). Second, changes in plant species composition or microclimate conditions could make small habitat patches unsuitable. Third, increased edge to area ratios could increase nest predation in small habitat patches (Gates and Gysel 1978, Yahner and Scott 1988, Franzreb 1989, Faaborg et al. 1992, see review in Paton 1994). Fourth, increased amounts of edge could increase nest parasitism (Brittingham and Temple 1983, see review in Paton 1994). Fifth, misplaced individuals from adjacent newly disturbed areas may alter population dynamics causing a temporary increase in abundance of some species, followed by a more substantial decrease possibly as a result of behavioral dysfunction causing lowered pairing success (Hagan et al. 1996).

Suggestions to alleviate the problems of fragmentation usually incorporate habitat reserves connected with corridors (Noss and Harris 1986, Adams and Dove 1989, Merriam 1991). A potential network of habitat reserves and corridors based on riparian areas could be developed in Tucson (Shaw and Supplee 1987). This potential is due, in part, to Tucson's unusually large number of undeveloped blocks of land that have native vegetation (natural open spaces) within the metropolitan area (Stenberg 1988). The network could include small washes which provide high quality habitat for many species (Shaw et al. 1986). These washes could be connected to natural open spaces and to each other by the major river corridors of the city.

The river corridors, which include all areas adjacent to the major river beds regardless of their condition or function, are an important component of this potential natural open space network. This study focuses on the river corridors because unlike most of the smaller washes, much of the area is publicly owned and therefore subject to public management. Additionally, they could serve functions that cannot be met in the developed urban matrix. These functions include: 1) habitat for riparian birds and neotropical migratory landbirds, 2) connections between reserves of natural open space, and 3) areas for wildlife viewing.

Providing habitat for riparian species and neotropical migratory landbirds are important functions for the river corridors. Natural riparian areas are valuable to many wildlife species, particularly in the desert Southwest. Nationally, riparian vegetation supports more bird species than all other vegetation types combined, even though it occurs on only 1% of the landscape (Knopf et al. 1988). Riparian areas are particularly important to birds that migrate to the neotropics (Carothers and Johnson 1975, Ohmart and Anderson 1982, Rice et al. 1983, Krueper 1993). Neotropical migratory landbird populations are declining nationally (Robbins et al. 1989), and are the focus of much management concern (Finch and Stangel 1993). Riparian areas are also extremely valuable for amphibians and reptiles (Jones 1988). However, riparian areas have suffered serious declines in the Southwestern United States (Krueper 1993) and in Tucson (Shaw 1986) so conservation of the remaining areas with riparian vegetation is critical.

Another important function for the river corridors is their role as conservation corridors. Conservation corridors are defined here as linear areas which connect natural open space patches and contain habitat for species sensitive to urbanization. Conservation corridors serve as areas for animal movement between habitat patches which enables: genetic interchange, population movement in response to disasters, and recolonization of areas that have lost species (Beier and Loe 1992). These functions could be achieved by a few long movements by wide-ranging species, or by long-term occupation of the corridors by corridor dwellers.

A third function for the river corridors is to provide wildlife viewing opportunities. Although numerous wildlife viewing areas are already available in Tucson, the river corridors are convenient and heavily used by recreationists. This heavy use makes them ideal areas to recruit new participants into wildlife viewing and appreciation.

The first step in determining if the river corridors fulfill these functions is to determine which species occupy them. Only areas with riparian species, neotropical migrants, species sensitive to urbanization, or high species diversity can fulfill the functions of riparian habitat, neotropical migratory bird habitat, conservation corridors, or wildlife viewing, respectively. The second step is to determine the habitat associations of the species that occupy the river corridors. Knowledge of these characteristics will also enable managers to rank areas for acquisition and restoration. Such priorities are important for the upcoming river park master plan and for regional planning efforts.

My objectives were to:

1. Describe the vegetation and land covers found at several areas adjacent to the major rivers of Tucson.

2. Inventory populations of passerine birds and diurnal lizards in several areas adjacent to the major rivers of Tucson.

3. Identify occurrence patterns of passerine birds and diurnal lizards in relationship to habitat at three spatial scales including river-edge vegetation structure, adjacent land use patterns, and landscape scale fragmentation patterns.

4. Develop guidelines for long term monitoring of selected vertebrate species.

5. Provide recommendations for river park design and maintenance to enhance values for selected wildlife species.

STUDY AREA

This study was conducted in the Tucson metropolitan area. Human population of the area is approximately 603,823 (U.S. Census Bureau 1991). Elevation of the river corridors ranges from 683 m to 841 m. Topography of the area is gentle.

At one time perennial water and riparian vegetation were found along parts of the major rivers of Tucson. Riparian plant species such as cottonwoods (*Populus fremontii*) can be seen in historical photos along the Santa Cruz River (Betancourt 1990). Marshy areas were found along the Santa Cruz in the nineteenth century (Hastings 1959). Just south of Tucson, Velvet mesquite (*Prosopis velutina*) grew tall and formed bosques, or groves of large trees. Vertebrate species in these areas included riparian associated bird species such as the yellow-billed cuckoo (*Coccyzus americanus*) (Arnold 1940). However, a combination of groundwater depletion, overgrazing, urbanization, channelization and water diversions combined with climatic events resulted in severe downcutting of the banks, and eliminated overground flow except during periods of flooding (Betancourt and Turner 1988). As a result, there has been an almost complete loss of the riparian-associated flora and fauna in the Tucson basin.

The river corridors today are characterized by dry river beds. Some areas still have mesquite bosques, and fewer have deciduous riparian tree species. Upland vegetation near the rivers includes the Paloverde-mixed Cacti ("Arizona upland")

Series and small areas of the Saltbush Series of the Sonoran Desert Scrub Biome (Brown et al. 1979, Turner and Brown 1982). Riparian vegetation includes the Mesquite Series and Cottonwood-willow series of the Sonoran Riparian and Oasis Forests Biome, the Saltcedar Disclimax Series of the Sonoran Deciduous Swamp and Riparian Scrub Biome, and the Mixed Scrub Series of the Sonoran Interior Strand Biome (Brown et al. 1979).

Three types of land uses characterize the areas immediately adjacent to the river banks (river-edge areas). These include natural open space, graded land, and river parks. Natural open space is characterized by upland vegetation or less frequently by riparian vegetation that has not been graded. Graded land is characterized by exotic forbs and grasses soon after disturbance, and later by desert broom (*Baccharis sarothroides*), burrobush (*Hymenoclea monogyra*), or burroweed (*Aplopappus tenuisecta*). River park areas are city or county-owned parks characterized by bike trails, exercise courses, rest rooms, picnic areas and a landscaped mix of drought-tolerant and native plant species. Some areas of the river parks are planted with turf and exotic plant species. These parkways are generally about 15 m wide, but some areas are up to 30 m wide. All river banks by the river parks and some banks in other areas are stabilized with soil cement or rip-rap. Road bridges are abundant. Land uses adjacent to the river corridors range from commercial to residential to natural open space.

River courses included in this study included the Santa Cruz, Rillito, Canada del Oro, Pantano, and Tanque Verde. The outer limits of the study area were defined by the points at which the predominant housing density adjacent to both sides of the river dropped below one house per acre. Additionally, I sampled only areas that: 1) had no perennial water or sewage effluent 2) areas adjacent to the river bed were river parks, graded land, or natural open space wider than 15 m, and 3) had no alteration in the previous year by bank stabilization, grading, or landscaping.

METHODS

Sampling Design

I stratified river corridors by the land use of the river-edge area (the area immediately adjacent to the river bank). Strata included natural open space, graded land, or river park. The first two strata were consistent with the classification scheme proposed by Shaw et al. (1993) because it is likely to be used by land managers in the Tucson basin. Natural open space areas sometimes contained exotic plant species, trash dumping, and dirt roads but none showed evidence of grading of the overall area. Graded land areas showed evidence of mechanical grading (see Shaw et al. 1993 for definitions). A 15-m wide minimum was set because this is the legal width for many river parks and a minimum width was needed to enable lizard and vegetation sampling. I chose 26 random points along the rivers in areas that met these criteria. I also randomly chose an additional three points within the river park system to increase sample sizes in this strata. Lizard transects and transects of bird sample points began at these random points.

Lizard transects proceeded either upstream or downstream (the choice made randomly) for 300 m. The center line of transects ran parallel to the bank and 7.5 m inland from the bank so that a 15-m wide strip would fit within the narrowest river-edge areas. If the land use type or bank stabilization type changed within this 300-m section, I discarded the transect and began a new transect 300 m from the random point. If the land use or bank stabilization changed within the new transect, I discarded the transect. Twenty-seven lizard transects were sampled.

Bird survey transects also proceeded either upstream or downstream (the choice made randomly). One to five survey points were marked at 300-m intervals along each transect (n = 118 points). Each point was located 7.5 m inland from the river bank so that it was centered within the narrowest river-edge areas. If a bank was not present the point was located 7.5 m inland from where the vegetation structure became taller or species composition changed, indicating that flooding occurs only infrequently. Points were discarded if landowner permission was not granted, if they were within 300 m of another point on another transect, or if background noise made it difficult to hear birds. If more than one consecutive point was discarded, the transect was terminated at the last valid point.

Vertebrate surveys

Lizards

I sampled relative abundance of lizards three times between 20 May and 9 September 1994 and five times between 18 April and 7 September in 1995. On each transect I walked slowly (0.4 - 0.8 km/hour) and visually scanned all surfaces that a lizard could occupy. I recorded the species, sex, and location of each lizard observed. At the start and end of each transect I recorded cloud cover, an index of wind speed (estimated with the Beaufort scale), and shaded ambient temperature at the ground level, 0.05 m above ground level, and 1.5 m above ground level. Transects were run between three and five hours after dawn on days when wind was less than Beaufort scale 3, cloud cover was less than 50%, shaded ambient temperature ranged between 25 °C and 40 °C, and there was no precipitation. Two transects were run each day with the order reversed at each repetition to decrease bias caused by increasing temperatures later in the morning.

Birds

I censused birds five times each breeding season (9 March to 16 August 1994 and 15 March to 19 August 1995) using a modification of the variable circular plot technique (Reynolds et al. 1980). For each bird within 100 m of the sample point, I recorded the species, sex, distance, and location within the river-edge area, adjacent land, or river bed. Additionally, temperature, cloud cover, and wind speed at each point were recorded. I surveyed birds within the first three hours after dawn on days with no precipitation and wind less than Beaufort Scale four (13-18) mph. The order that points were sampled within a morning was systematically rotated to minimize bias due to decreasing detectability after dawn (Shields 1977, Grue et al. 1981).

Recreational Use

I measured human recreational use of study sites by counting each walker, jogger, bicyclist, skater, or horseback rider detected during the bird point counts. Each dog observed outside of a fenced yard was also recorded.

Vegetation and Land Use

To quantify river attributes of river corridors I used three spatial scales (Figure 1 and 2). At the micro scale, I examined vegetation structure and floristics immediately adjacent to the river bank. At the meso scale, I examined land uses in a 100-m wide area surrounding lizard transects and bird points. The macro scale examined land uses in a 1-km radius area surrounding lizard transects and a subset of bird points.

At the micro scale I measured vegetation cover, volume, and density at each bird sample point and at four points spaced 100 m apart along lizard transects. I centered a 15-m long transect on the point, and oriented the transect in a random direction. I then centered a second 15-m transect on the point, and oriented the transect perpendicular to the first transect. I measured ground cover and vegetation cover at 16 points along each line. Ground cover was classified at each point along the transects. Vegetation cover was measured in three height layers: 0 - 0.2 m, 0.21 to 2.0 m, and > 2.00 m. Within these height categories, I estimated the percent cover of each species, the total cover of native species, and the total cover of all species by counting the number of points where vegetation touched the line.

Vegetation volume was measured at each point using a modification of the methods used by Mills (1991). A 5.5-m rod was divided into decimeter sections. A cylinder of 1-dm radius was imagined around this rod. The number of decimeter sections of the cylinder which contained vegetation was tallied for each meter for each

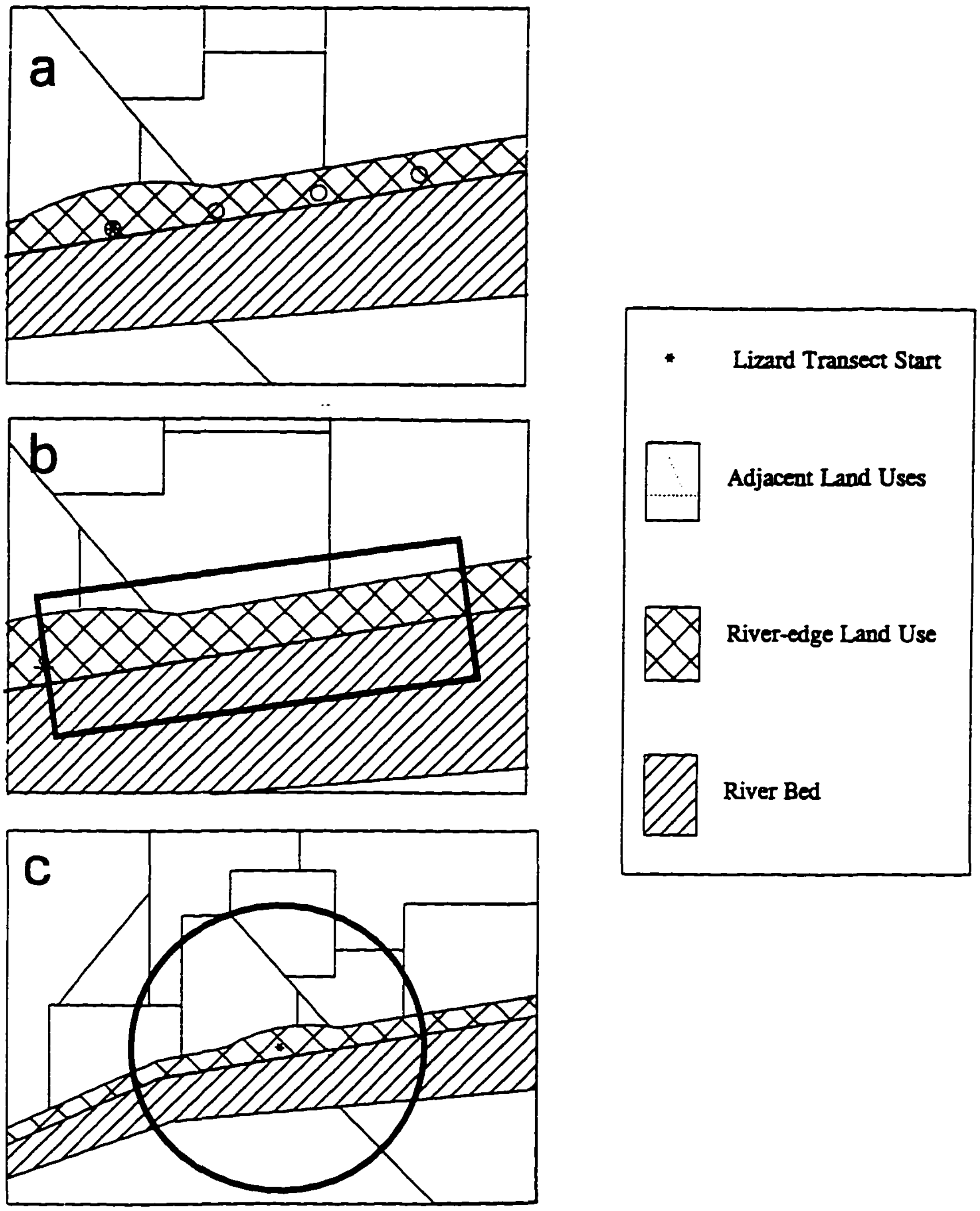

FIGURE 1. Habitat sampling scheme for lizards: a) micro scale, showing four 7.5-m radius plots spaced at 100-m intervals along lizard transect; b) meso scale, showing 100 m x 300 m rectangle centered lengthwise on the lizard transect; c) macro scale, showing 1 km-radius plot centered on the start of the lizard transect.

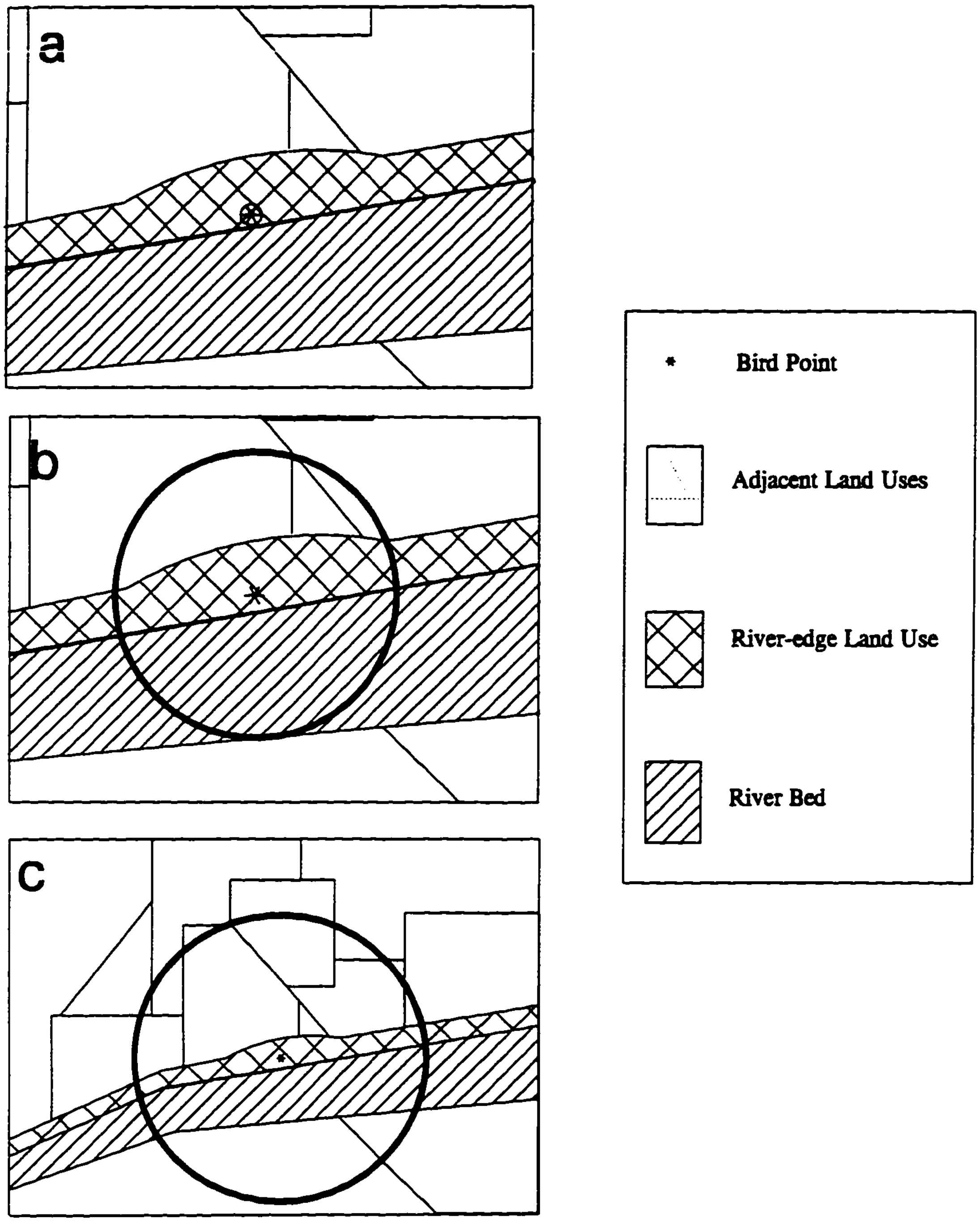

FIGURE 2. Habitat sampling scheme for birds: a) micro scale, showing 7.5-m radius plot centered on bird point; b) meso scale, showing 100-m radius plot centered on bird point; c) macro scale, showing 1-km radius plot centered on bird point.

plant species. By holding the pole over our heads vegetation up to 8 m tall could be measured. I measured volume in this manner at 2-m intervals along each 15-m long transect.

I recorded density by counting the number of individuals of each plant species taller than 2 m within the 15-m diameter plot. Plants were classified to life form (tree, shrub, cactus, or snag) and by species.

Each plot was classified as natural open space, graded land, or river park. Where applicable, the vegetation community of plots was classified according to Brown et al. (1979). The presence or absence of bank stabilization (either rip-rap or soil cement) was also recorded. The width of the land use type of the river-edge area was measured using a tape if it was less than 100 m wide, or measured on 1:4800 scale aerial photographs is it was greater than 100 m wide.

For the meso scale analysis land use variables were measured from 1:4800 scale, 1990 aerial photographs. I centered a mylar template representing a 100 m by 300 m rectangle and divided into 10 sections lengthwise on lizard transects. I centered a mylar template representing a 100-m radius circular plot and divided into eight sections on bird points. The percent cover of each land use was then estimated to the nearest five percent. I classified land use according to the seven major categories proposed by Shaw et al. (1993) with three exceptions (Appendix A). First, I added a category for river parks. Second, instead of using the major category called water, I used the subcategories major river, wash/riparian area, and pond. Third, I subdivided the residential major category into high density (> 1 house/acre) and low density ($\leq$ 1 house/acre) subcategories. The total amount of vegetation cover was estimated to the nearest 25%. Natural open space and low density housing areas were classified according to Brown et al. (1979) and the percent cover of each was estimated.

At the macro scale of analysis, I measured landscape level data using Arcinfo on an existing land use database (Shaw et al. 1993). The 29 random points were drawn onto 1:12000 orthophotos and then digitized. A 1-km radius circle was made around each point and the percent cover of each of the seven major categories (Appendix A) calculated. Because final modifications had not been made to the database, I also updated polygon classifications and shapes based on 1995 aerial photos and field knowledge of the land covers present. Additionally, the Santa Cruz River banks were digitized from 1:12,000 orthophotos and overlaid onto the land use coverages because the banks were not shown on the interim coverage. In addition to land covers, the distance from each sample point to the nearest natural open space larger than 10 ha was also determined using ArcInfo.

Analysis

Because lizards are more difficult to detect than birds and because counts are not likely to be inflated by a highly mobile group moving into the site, I assumed lizard numbers were always underestimated. Therefore I used the maximum number of any species seen at each transect in each year as an index of abundance. In addition to species abundances, I calculated the species richness of each site in each year.

Bird sample points were treated individually in all analyses. Sample sizes were too small for many bird species to determine bird density with variable circular plots. However, distance data for the most abundant species were used to objectively determine a fixed radius plot size. Bird data points were stratified by four levels of vegetation and structural density which could have influenced bird detectability. Detection distances for each species with more than 40 observations in each stratum were analyzed using the program DISTANCE (Laake et al. 1993). Effective detection distances (EDR) were computed for each species in each strata (Buckland et al. 1993). The smallest of these distances was chosen as a fixed radius plot size. The rationale behind this approach was that detectability would be similar close to the observer, although more birds could be detected at long distances in more open plots. A plot radius chosen to adequately sample the more dense plots would also adequately sample the more open plots.

The long sampling period from March through August was necessary to sample during detectability peaks in most species. I defined these peaks as the 3 highest counts of each species at each point. The mean of these three highest counts was used as an index of abundance for each species.

I also used the number of species (species richness) of several management groups of native breeding birds. These management groups were chosen because they may indicate the success of several possible functions for the river park system (see

Appendix B for the species in each management group). Total species richness included all native, breeding birds that are not shorebirds, waterfowl, raptors, swallows, or swifts. This group may indicate the quality of an area for wildlife viewing. Riparian-associated birds (defined by Tucson Audubon Society 1995) may indicate the success of vegetation management to mitigate losses of riparian-obligate vegetation due to flood control efforts. Neotropical migrants (as listed by Gauthreaux 1992, Tucson Audubon Society 1995) may indicate successful management for a group that is nationally declining. Finally, a group of species identified as sensitive to urbanization in the Tucson area (Emlen 1974, Tweit and Tweit 1986, Stenberg 1988, Germaine 1995) may indicate the ability of the river corridors to function as conservation corridors.

The mean number of recreationists at each point over both years was used in analysis. Recreational uses were lumped into the categories foot (walkers and joggers), wheels (bicyclists and skaters), and dog (leashed or unleashed). Horseback riders occurred on plots too infrequently for analysis.

I used the densities of the five most frequent plant species in multiple regression models. Similarly, I used the cover and volume of the three plant species with the highest total cover and volume. Several deciduous riparian-associated tree species (Mexican elderberry (*Sambucus mexicana*), fremont cottonwood (*Populus fremontii*), netleaf hackberry (*Celtis reticulata*), Arizona walnut (*Juglans major*), and velvet ash (*Fraxinus velutina*) were lumped together into three variables representing their cover in the three height categories. Infrequent ground covers were lumped for analysis (Appendix C shows variables used). The mean of vegetation values for the four plots was used for lizard transects.

All species richness, recreation, and habitat variables were entered into stepwise multiple regression. I analyzed each species richness variable separately for each year of the study. Bank stabilization was given dummy coding of 0 or 1. Land use was given dummy coding and tested by entering the two dummy variables together in the final step. I checked for violations of the assumptions of multiple regression by looking at residuals as recommended by Norusis (1990). First, I plotted predicted values against residuals to detect homogeneity of variance. Second, I plotted residuals against independent variables in the equation with all other variables held constant (partial regression plot) to search for nonlinear relationships. Third, I looked for normality in residuals by plotting histograms and normal probability plots. Fourth, I deleted outliers (cases where the absolute values of standardized residuals exceeded 3). I built equations for bird values upon a random subset of 80% of the data. I then fit the remaining 20% to the final equation and examined residuals examined with histograms and partial plots as I did for the original equation. I also compared histograms of the residuals from the original equation to those in the new data set. If the residuals in the new data set were mostly positive or negative then the equation under or overestimated, respectively, the dependent variables in the new data (Norusis 1990).

Once analyses at the micro and meso scales were completed, I began macro scale analysis. Macro scale variables were only available for the 29 random start points. I therefore used only a subset of the bird species richness data (for those 29 points) and the lizard species richness data from the 27 transects as dependent variables. Predictor variables included the macro-scale variables plus micro and meso scale variables that were significant in the first equations. I examined residuals for violations of assumptions as I did for earlier analyses. I did not cross-validate these models because sample sizes were too small.

RESULTS

Lizards

I detected 10 species of lizards (Table 1). The most frequently encountered species were western whiptails, tree lizards, unidentified whiptail lizards, and zebra-tailed lizards (scientific names in Table 1). I only observed Sonoran spotted whiptails and Gila spotted whiptails on natural open space transects, and side-blotched lizards on natural open space and graded land. Regal horned lizards and Clark's spiny lizards were observed on all land use types except graded land. Several species which occur in the Tucson area but were never seen included Gila monsters (*Heloderma suspectum*), Collared lizards (*Crotaphytus collaris*), Lesser earless lizards (*Holbrookia maculata*), Long-nosed leopard lizards (*Gambelia wislizennii*), Long-tailed brush lizards (*Urosaurus graciousus*), and Giant spotted whiptails (*Cnemidophorus burti*).

Species richness at plots ranged from 0 to 8 (Table 2), and species richness values were highest on natural open space and river park transects. A mesquite bosque on Tanque Verde Creek and the Rillito River Park east of First Avenue had the greatest number of lizard species.

Temperatures during surveys ranged from 19 °C to 48 °C at ground level, 18 °C to 42 °C at 0.05 m and 19 °C to 40 °C at 1.5 m.

Residuals from multiple regression models based on individual species abundances violated the assumptions of homogeneity of variance and normality.

TABLE 1. Percentage of 15 m x 300 m transects (n=27) with detections of lizard species in the study area and by land use adjacent to major rivers of Tucson, Arizona; 1994 and 1995.

		% transects with detections			
			Land use		
Common name	Scientific name	Study Area	Natural	River Parks	Graded
Western whiptail	*Cnemidophorus tigris*	92.0	83.3	100.0	0.0
Tree lizard	*Urosaurus ornatus*	80.0	75.0	85.7	50.0
Unidentified whiptail	*Cnemidophorus sp.*	68.0	58.3	85.7	16.7
Zebra-tailed lizard	*Callisaurus draconoides*	52.0	58.3	42.9	0.0
Side-blotched lizard	*Uta stansburiana*	40.0	50.0	0.0	0.0
Desert spiny lizard	*Sceloporus magister*	40.0	25.0	42.9	50.0
Unidentified spiny lizard	*Sceloporus sp.*	24.0	33.3	14.3	66.7
Clark's spiny lizard	*Sceloporus clarkii*	16.0	16.7	28.6	16.7
Regal horned lizard	*Phrynosoma solare*	12.0	8.3	28.6	83.3
Gila spotted whiptail	*Cnemidophorus flagellicaudus*	12.0	25.0	0.0	50.0
Greater earless lizard	*Cophosaurus texanus*	8.0	0.0	14.3	0.0
Sonoran spotted whiptail	*Cnemidophorus sonorae*	4.0	8.3	0.0	33.3

TABLE 2. Mean species richness of lizards by land use adjacent to major rivers of Tucson, AZ; 1994-1995.

Year	Mean species richness (S.D.) by land use					
	Natural		Graded		River Parks	
1994	4.08	(0.40)	3.17	(0.87)	4.28	(0.52)
1995	4.75	(0.59)	2.50	(1.06)	3.86	(0.83)

Therefore models were built using species richness only. The height of the tallest tree or shrub in the plot and the cover of desert broom in the 0.21 to 2.00-m height layer predicted lizard species richness in several equations (Table 3). When the macro-scale variables were added to the set of significant variables, the only macro-scale variable to enter a model was the cover of high density housing which was positively associated with lizard species richness in only one model (Table 3). However, all equations had low adjusted R-squared values (Table 3), indicating that much of the variance in lizard species diversity was unexplained.

Birds

I observed 99 species of birds (Table 4). The most frequently encountered species in all land use types were mourning dove, cactus wren, and house finch (scientific names in Table 4). I observed 50 species in the river park plots. I detected seventeen species exclusively in natural open space (Table 5), two species exclusively in graded land, and nine species exclusively in river parks. However, none of the species exclusive to graded land or river parks included native breeding bird species adequately sampled by point counts.

Several species associated with natural riparian areas of southeast Arizona were not detected, including gray hawk (*Buteo nitidus*), Mississippi kite (*Ictinia mississippiensis*), common black hawk (*Buteogallus anthracinus*), yellow-billed cuckoo (*Coccyzus americanus*), green kingfisher (*Chloroceryle americana*), willow

TABLE 3. Multiple regression equations predicting species richness of lizards from vegetation, land use, and recreational use characteristics of 15 m x 300 m transects (micro scale, variables in lower case), 100 m x 300 m rectangles (meso scale, variables in upper case), and 1-km radius circles (macro scale, variables in bold upper case) centered on 15 m x 300 m lizard transects (n=27) adjacent to major rivers of Tucson, AZ; 1994 and 1995.

Scales used	Year	Equation[a]	Adjusted R^2 [b]
Micro and meso	1994	no variables entered	
Micro and meso	1995	0.568basa2 + 0.448maxht + 1.47	0.462
Micro, meso, and macro	1994	0.019**WRESIDHI** + 0.231maxht + 2.261	0.386
Micro, meso, and macro	1995	0.579basa2 + 0.434maxht + 1.542	0.457

[a] basa2 = Cover of desert broom from 0.21-2.0 m, maxht = height of tallest tree or shrub in plot, WRESIDHI = % of 1-km radius circle with >1 house/acre.
b All F tests are significant at $p < 0.001$.

TABLE 4. Percentage of 100-m radius plots (n=118) with detections of bird species in the entire study area and by land use adjacent to major rivers of Tucson, Arizona; 1994 and 1995.

		% points with detections			
			Land use		
Common name	*Scientific name*	Study Area	Natural	River Parks	Graded
Cactus Wren	*Campylorhynchus brunneicapillus*	99.2	100.0	100.0	97.9
Mourning Dove	*Zenaida macroura*	99.2	97.8	100.0	100.0
House Finch	*Carpodacus mexicanus*	97.5	93.5	100.0	100.0
Gambel's Quail	*Callipepla gambelii*	95.8	97.8	84.0	100.0
Verdin	*Auriparus flaviceps*	92.4	100.0	88.0	87.2
Northern Mockingbird	*Mimus polyglottos*	86.4	78.3	96.0	89.4
Anna's Hummingbird	*Calypte anna*	84.7	82.6	88.0	85.1
Gila Woodpecker	*Melanerpes uropygialis*	82.2	93.5	80.0	72.3
Curve-billed Thrasher	*Toxostoma curvirostre*	80.5	93.5	64.0	76.6
Great-tailed Grackle	*Quiscalus mexicanus*	78.0	60.9	92.0	87.2
House Sparrow	*Passer domesticus**	67.8	52.2	92.0	70.2
White-winged Dove	*Zenaida asiatica*	66.1	82.6	56.0	55.3
Northern Flicker	*Colaptes auratus*	63.6	82.6	24.0	66.0
Killdeer	*Charadrius vociferus*	59.3	39.1	72.0	72.3

TABLE 4. Continued.

		% points with detections			
			Land use		
Common name	*Scientific name*	Study Area	Natural	River Parks	Graded
Greater Roadrunner	*Geococcyx californianus*	56.8	76.1	36.0	48.9
European Starling	*Sturnus vulgaris**	50.8	50.0	56.0	48.9
Northern Cardinal	*Cardinalis cardinalis*	50.0	71.7	28.0	40.4
Ash-throated Flycatcher	*Myiarchus cinerascens*	47.5	84.8	28.0	21.3
White-crowned Sparrow	*Zonotrichia leucophrys*	45.8	58.7	48.0	31.9
Abert's Towhee	*Pipilo aberti*	39.8	69.6	12.0	25.5
Black-tailed Gnatcatcher	*Polioptila melanura*	39.0	71.7	12.0	21.3
Brown-headed Cowbird	*Molothrus ater*	37.3	65.2	16.0	21.3
Lucy's Warbler	*Vermivora luciae*	36.4	65.2	12.0	21.3
Western Kingbird	*Tyrannus verticalis*	33.1	39.1	32.0	27.7
Ladder-backed Woodpecker	*Picoides scalaris*	31.4	54.3	20.0	14.9
Yellow-rumped Warbler	*Dendroica coronata*	30.5	47.8	12.0	23.4
Brewer's Sparrow	*Spizella breweri*	30.5	34.8	16.0	34.0
Phainopepla	*Phainopepla nitens*	30.5	60.9	4.0	14.9
Say's Phoebe	*Sayornis saya*	29.7	32.6	28.0	27.7

TABLE 4. Continued.

Common name	Scientific name	% points with detections			
			Land use		
		Study Area	Natural	River Parks	Graded
Pyrrhuloxia	*Cardinalis sinuatus*	29.7	52.2	16.0	14.9
Loggerhead Shrike	*Lanius ludovicianus*	28.8	15.2	28.0	42.6
Inca Dove	*Columbina inca*	28.0	15.2	60.0	23.4
Northern Rough-winged Swallow	*Stelgidopteryx serripennis*	28.0	34.8	4.0	34.0
Cassin's Kingbird	*Tyrannus vociferans*	24.6	32.6	16.0	21.3
Bell's Vireo	*Vireo bellii*	21.2	39.1	4.0	12.8
Raven sp.	*Corvus sp*	19.5	28.3	0.0	21.3
Lesser Goldfinch	*Carduelis psaltria*	19.5	39.1	8.0	6.4
Red-tailed Hawk	*Buteo jamaicensis*	17.8	17.4	4.0	25.5
Bewick's Wren	*Thryomanes bewickii*	14.4	30.4	0.0	6.4
Rock Dove	*Columba livia**	13.6	2.2	32.0	14.9
Black-chinned Hummingbird	*Archilochus alexandri*	12.7	19.6	12.0	6.4
Brewer's Blackbird	*Euphagus cyanocephalus*	11.9	8.7	8.0	17.0
Lark Bunting	*Calamospiza melanocorys*	11.9	2.2	16.0	19.1
Brown Towhee	*Pipilo fuscus*	11.9	21.7	0.0	8.5

TABLE 4. Continued.

Common name	*Scientific name*	% points with detections			
			Land use		
		Study Area	Natural	River Parks	Graded
Wilson's Warbler	*Wilsonia pusilla*	11.0	23.9	4.0	2.1
Yellow Warbler	*Dendroica petechia*	10.2	19.6	0.0	6.4
Lark Sparrow	*Chondestes grammacus*	9.3	8.7	16.0	6.4
Red-winged Blackbird	*Agelaius phoeniceus*	8.5	10.9	0.0	10.6
Black-throated Sparrow	*Amphispiza bilineata*	8.5	21.7	0.0	0.0
Northern Oriole	*Icterus galbula*	7.6	10.9	0.0	8.5
Brown-crested Flycatcher	*Myiarchus tyrannulus*	7.6	19.6	0.0	0.0
Rufous-winged Sparrow	*Aimophila carpalis*	6.8	17.4	0.0	0.0
American Kestrel	*Falco sparverius*	5.9	0.0	4.0	12.8
Barn Swallow	*Hirundo rustica*	5.9	2.2	12.0	6.4
Northern Beardless-Tyrannulet	*Camptostoma imberbe*	5.9	13.0	0.0	2.1
Horned Lark	*Eremophila alpestris*	5.1	4.3	0.0	8.5
Vermillion Flycatcher	*Pyrocephalus rubinus*	5.1	6.5	4.0	4.3
Summer Tanager	*Piranga rubra*	4.2	10.9	0.0	0.0
Peregrine Falcon	*Falco peregrinus*	4.2	2.2	0.0	8.5

TABLE 4. Continued.

Common name	*Scientific name*	% points with detections			
			Land use		
		Study Area	Natural	River Parks	Graded
Cedar Waxwing	*Bombycilla cedrorum*	4.2	8.7	0.0	2.1
Western Meadowlark	*Sturnella neglecta*	4.2	2.2	0.0	8.5
Chipping Sparrow	*Spizella passerina*	4.2	8.7	0.0	2.1
Cooper's Hawk	*Accipiter cooperii*	3.4	6.5	0.0	2.1
Black Phoebe	*Sayornis nigricans*	3.4	4.3	0.0	4.3
Violet-green Swallow	*Tachycineta thalassina*	3.4	6.5	0.0	2.1
Turkey Vulture	*Cathartes aura*	2.5	4.3	0.0	2.1
Great Blue Heron	*Ardea herodias*	2.5	2.2	0.0	4.3
Rufous-crowned Sparrow	*Aimophila ruficeps*	2.5	4.3	0.0	2.1
Yellow-breasted Chat	*Icteria virens*	2.5	4.3	4.0	0.0
Broad-tailed Hummingbird	*Selasphorus platycercus*	2.5	6.5	0.0	0.0
Blue Grosbeak	*Guiraca caerulea*	2.5	4.3	0.0	2.1
Ruby-crowned Kinglet	*Regulus calendula*	1.7	2.2	4.0	0.0
Tropical Kingbird	*Tyrannus melancholicus*	1.7	2.2	0.0	2.1
Harris' Hawk	*Parabuteo unicinctus*	1.7	2.2	0.0	2.1

TABLE 4. Continued.

Common name	*Scientific name*	% points with detections			
		Study Area	Land use		
			Natural	River Parks	Graded
White-throated Swift	*Aeronautes saxatalis*	1.7	2.2	0.0	2.1
Mallard	*Anas platyrhynchos*	1.7	2.2	0.0	2.1
Scott's Oriole	*Icterus parisorum*	1.7	2.2	0.0	2.1
Solitary Vireo	*Vireo solitarius*	1.7	4.3	0.0	0.0
Prairie Falcon	*Falco mexicanus*	1.7	0.0	0.0	4.3
Great Horned Owl	*Bubo virginianus*	1.7	4.3	0.0	0.0
Sharp-shinned Hawk	*Accipiter striatus*	0.8	0.0	0.0	2.1
Costa's Hummingbird	*Calypte costae*	0.8	0.0	0.0	2.1
Bronzed Cowbird	*Molothrus aeneus*	0.8	2.2	0.0	0.0
Northern Harrier	*Circus cyaneus*	0.8	0.0	0.0	2.1
Common Ground-Dove	*Columbina passerina*	0.8	0.0	0.0	2.1
Virginia's Warbler	*Vermivora virginiae*	0.8	0.0	4.0	0.0
White-breasted Nuthatch	*Sitta carolinensis*	0.8	2.2	0.0	0.0
Belted Kingfisher	*Ceryle alcyon*	0.8	0.0	0.0	2.1
Black-chinned Sparrow	*Spizella atrogularis*	0.8	2.2	0.0	0.0

TABLE 4. Continued.

Common name	*Scientific name*	% points with detections			
			Land use		
		Study Area	Natural	River Parks	Graded
Ringed Turtle-Dove	*Streptopelia risoria**	0.8	2.2	0.0	0.0
Western Tanager	*Piranga ludoviciana*	0.8	2.2	0.0	0.0
Western Flycatcher	*Empidonax difficilis*	0.8	2.2	0.0	0.0
Cliff Swallow	*Hirundo pyrrhonota*	0.8	0.0	4.0	0.0
Black-headed Grosbeak	*Pheucticus melanocephalus*	0.8	0.0	0.0	2.1
Western Wood-Pewee	*Contopus sordidulus*	0.8	2.2	0.0	0.0
Ferruginous Hawk	*Buteo regalis*	0.8	2.2	0.0	0.0
Barred Owl	*Strix varia*	0.8	2.2	0.0	0.0
Yellow-headed Blackbird	*Xanthocephalus xanthocephalus*	0.8	0.0	0.0	2.1
Hermit Thrush	*Catharus guttatus*	0.8	2.2	0.0	0.0

TABLE 5. Bird species detected in only one land use adjacent to major rivers of Tucson, AZ; 1994 and 1995.

Land use		
Natural	Graded	River Parks
Barn owl	Sharp-shinned hawk	Cliff swallow
Ferruginous hawk	Northern harrier	Virginia's warbler
Hermit thrush	Cooper's hawk	
Bronzed cowbird	Prairie falcon	
Cordilleran flycatcher	Common ground dove	
Western tanager	Belted kingfisher	
Black-chinned sparrow	Black-headed grosbeak	
Ring-necked dove	Yellow-headed blackbird	
Summer tanager		
Black-throated sparrow		
Rufous-winged sparrow		
Brown-crested flycatcher		
Western wood pewee		
White-breasted nuthatch		
Broad-tailed hummingbird		
Solitary vireo		
Great horned owl		

flycatcher (*Empidonax traillii*), common yellowthroat (*Geothlypis trichas*), and marsh wren (*Cistothorus palustris*) as well as most waterfowl and shorebirds.

Species richness of native breeding birds at each plot ranged from 4 to 26 (Table 6). In both 1994 and 1995 the five points with the highest species richness were on the eastern Tanque Verde Wash and on northern Canada del Oro Wash. In both 1994 and 1995 the five points with the highest species richness of riparian species and neotropical migrants were along the eastern Tanque Verde Wash. In contrast to the other groups, four of the five points with the highest species richness of birds sensitive to urbanization were along northern Canada del Oro Wash and one along eastern Pantano Wash.

Residuals from multiple regression models based on individual species abundances violated the assumptions of normality and homogeneity of variance. Therefore models were built using species richness only. Species richness of all bird groups was negatively associated with bank protection in both years (Tables 7 and 8). Total vegetation cover on the 100-m radius plot was positively associated with species richness of all bird groups in at least one year (Tables 7 and 8). Mesquite density was positively associated with species richness of riparian and neotropical migrant groups in both years, and with species richness of all native breeders in 1995. In contrast, human recreational use was not associated with species richness of any management group.

Regression models had similar variables in 1994 and 1995 for all management

TABLE 6. Mean species richness of bird groups by land use adjacent to major rivers of Tucson, AZ; 1994-1995.

		Mean species richness (S.D.) by land use							
Bird Group	Year	Natural		Graded		River Park		Total	
All native breeders	1994	17.9	(3.6)	13.0	(3.0)	11.3	(2.6)	14.5	(4.2)
	1995	16.7	(3.7)	10.8	(4.1)	10.3	(2.1)	13.0	(4.7)
Urbanization sensitive	1994	8.4	(1.9)	5.6	(1.8)	4.6	(1.4)	6.5	(2.3)
	1995	7.4	(1.7)	4.7	(2.1)	4.2	(1.5)	5.7	(2.3)
Riparian	1994	3.3	(2.8)	1.1	(1.6)	0.4	(0.5)	1.8	(2.4)
	1995	3.7	(2.9)	1.1	(1.9)	0.6	(1.0)	2.0	(2.6)
Neotropical migrants	1994	3.3	(2.0)	1.5	(1.4)	1.2	(1.1)	2.1	(1.9)
	1995	3.3	(2.4)	1.2	(1.6)	1.0	(1.0)	2.0	(2.0)

TABLE 7. Equations predicting species richness of native, breeding birds from vegetation, land use, recreational use, and habitat fragmentation characteristics of 7.5-m radius (micro scale, variables in lower case) and 100-m radius (meso scale, variables in upper case) plots centered on 118 sample points adjacent to major rivers of Tucson, AZ; 1994 and 1995.

Year	Equation[a]	Adjusted R^2 [b]
1994	0.053NATURAL + 0.265nathgt1 - 2.854bank + 0.148RESIDLOW - 0.080brgr - 0.072RECREAT5 - 0.030GRADED + 14.448	0.708
1995	-3.332bank + 1.251VCOVER + 0.255nathgt1 + 0.462prosvel - 0.041dummy2 + 2.604dummy1 + 8.498	0.685

[a] NATURAL = % area natural open space, nathgt1 = % cover native vegetation 0-0.2 m, bank = presence of bank stabilization, RESIDLOW = % area of residential housing of ≤ 1 house/acre, brgr = % cover bare ground, RECREAT5 = % area river park, GRADED = % area graded land, VCOVER = % cover vegetation, dummy2 = graded land, dummy1 = natural open space.

[b] All F tests are significant at $p < 0.001$

TABLE 8. Equations predicting species richness of management groups of birds from vegetation, land use, recreational use, and habitat fragmentation characteristics of 7.5-m radius (micro scale, variables in lower case) and 100-m radius (meso scale, variables in upper case) plots centered on 118 sample points adjacent to major rivers of Tucson, AZ; 1994 and 1995.

Management group[a]	Year	Equation[b]	Adjusted R^2 [c]
Urbanization -sensitive	1994	0.053NATURAL - 1.478bank +6.096	0.660
	1995	0.025NATURAL - 1.979bank + 0.833VCOVER + 0.247raised + 3.817	0.661
Riparian	1994[d]	0.724VCOVER + 0.077heightl - 0.899bank + 0.262prosvelu - 0.882	0.567
	1995[d]	0.765VCOVER + 0.473prosvelu - 1.185bank +0.129nathgtl - 0.021RESIDHI - 0.335	0.620
Neotropical migrants	1994[d]	0.418VCOVER + 0.170nathgtl - 1.170bank + 0.324prosvelu + 0.611	0.485
	1995[d]	0.567VCOVER + 0.156nathgtl - 1.474bank + 0.220prosvelu - 0.229raised - 0.047brgr + 0.920	0.513

[a] Species in each group are given in Appendix B

[b] NATURAL= % area natural open space, bank= presence of bank stabilization, VCOVER= % cover vegetation, raised= % ground cover of rocks, trash, logs, heightl = % vegetation cover from 0-0.2 m, prosvelu= density of *Prosopis velutina*, nathgtl = % cover native vegetation 0-0.2 m, RESIDHI= % area residential of > 1 house/acre, BRGR = % cover bare ground.

[c] All F tests are significant at $p < 0.001$

[d] This equation violated homogeneity of variance assumption

groups (Tables 7 and 8), indicating these models are likely to be useful in future years despite year to year variation in vegetation and vertebrate abundance.

Total species richness and urbanization-sensitive species richness models did not appear to violate assumptions of homogeneity of variance, normality, or linearity in either year. Analysis of residuals indicated models for neotropical migrants and riparian species slightly violated the homogeneity of variance assumption. This violation probably results from a high frequency of zeros for these variables. Despite this violation, the models may still reflect true patterns because the chances of generating similar models for 1994 and 1995 based on spurious correlations is highly unlikely.

Multiple R values for cross-validation models were similar to those for the original equations with the exceptions of the 1995 neotropical migrant model and the 1995 riparian model (Appendix D). Cross-validation models for total native species richness and urbanization-sensitive species did not overestimate or underestimate predicted values (histograms of standardized residuals were balanced around 0). Cross-validation models indicated the species richness values predicted by the neotropical migrant equation were too high in 1995 (residuals were mostly negative) and too low in 1994 (residuals were mostly positive). I suggest avoiding using the riparian and neotropical migrant models for predictive purposes, but suggest the variables which occurred consistently must have repeatedly entered models due to real underlying patterns and not due to spurious correlations.

I found several patterns when variables from the macro-scale were added to the significant variables from the previous equations. The amount of vegetation cover on the meso-scale plots and the presence of bank stabilization were significant (Tables 9 and 10). The amount of commercial land in the macro-scale plots was negatively associated with total species richness in both years and neotropical migrants in 1994 (Tables 9 and 10). Conversely, the amount of natural open space in the macro-scale plots was positively associated with the species richness of urban-sensitive birds. The similarity of the 1994 and 1995 models indicate that they will be useful in future years and imply that spurious correlations were not likely.

TABLE 9. Equations predicting species richness of native, breeding birds from vegetation, land use, recreational use, and habitat fragmentation characteristics of 7.5-m radius (micro scale, variables in lower case), 100-m radius (meso scale, variables in upper case), and 1-km radius (macro scale, variables in bold upper case) plots centered on 29 sample points adjacent to major rivers of Tucson, AZ; 1994 and 1995.

Year	Equation[b]	Adjusted R^2 [b]
1994	1.951VCOVER - 2.917bank - 0.013**WCOMMER** + 11.831	0.674
1995	3.519VCOVER - 0.011**WCOMMER** + 4.423	0.740

[a] VCOVER= % vegetation cover, bank= presence of bank stabilization, WCOMMER = % area commercial development.
[b] All F tests are significant at $p < 0.001$

TABLE 10. Equations predicting species richness of management groups of birds from vegetation, land use, recreational use, and habitat fragmentation characteristics of 7.5-m radius (micro scale, variables in lower case), 100-m radius (meso scale, variables in upper case), and 1-km radius (macro scale, variables in bold upper case) plots centered on 29 sample points adjacent to major rivers of Tucson, AZ; 1994 and 1995.

Management group[a]	Year	Equation[b]	Adjusted R^2 [c]
Urbanization -sensitive	1994	-2.444bank + 0.009**WNATURAL** + 6.771	0.694
	1995	0.063NATURAL + 0.006**WNATURAL** + 3.757	0.746
Riparian	1994	1.825VCOVER - 1.211bank -2.593	0.709
	1995	2.283VCOVER - 4.174	0.682
Neotropical migrants	1994	1.205VCOVER - 0.006**WCOMMER** - 0.214	0.532
	1995	1.839VCOVER - 3.003	0.534

[a] Species in each group are given in Appendix B

[b] bank= presence of bank stabilization, **WNATURAL**= % area natural open space, NATURAL= % area natural open space, VCOVER= % cover vegetation, **WCOMMER**= % area commercial development.

[c] All F tests are significant at $p < 0.001$

DISCUSSION

Lizard distribution and habitat

Only three variables were significant in lizard habitat models and two of the three, cover of desert broom and cover of high residential housing, were inconsistent and probably unreliable as predictors. The third variable, height of the tallest tree on the plot, indicates that areas with tall trees will have more lizard species. The presence of arboreal species such as tree lizards and spiny lizards undoubtedly accounts for this increased species richness in areas with tall trees. However, species richness was not consistent from year to year. Additionally, species richness does not indicate replacement of species that might occur between sites.

Individual species distributions revealed patterns not evident by the species richness models. Western whiptails were found on nearly every transect, including all river park transects. In contrast, Gila spotted whiptails and Sonoran spotted whiptails were never detected on river park plots or graded land. This suggests Sonoran Spotted and Gila Spotted whiptails are more sensitive to urbanization than western whiptails.

Side-blotched lizards, one of the most abundant lizards in natural desert uplands (Pianka 1975, Jakle and Gatz 1985, Warren and Schwalbe 1985, Pianka 1986, Szaro and Belfit 1986), were detected infrequently and were never observed on river park plots. The low number of observations of this species could be due to sampling methodology. Sampling times were chosen to reflect the temperature requirements of the majority of lizard species, which are active at slightly higher air temperatures than side-blotched lizards (Pianka 1986). However, I do not think sampling methodology explains the complete absence of side-blotched lizards in some areas. Each lizard transect was visited repeatedly in cooler times for bird and vegetation sampling, yet few incidental observations of this species were made, and none were made in the areas where side-blotched lizards were absent from formal transects.

Why were western whiptails more widespread in the river parks than side-blotched lizards? Both species are extremely common in desert environments over a large geographic range (Pianka 1986), are associated more with upland vegetation than riparian vegetation (Jakle and Gatz 1985, Szaro and Belfit 1986), and are ground foraging insectivores. However, foraging strategy differs between the two species. Side-blotched lizards are sit-and-wait predators and western whiptails are widely-foraging predators (Parker and Pianka 1975). Western whiptails move steadily around low shrubs and leaf litter searching for prey (Pianka 1986). This species has been associated with low shrubs, leaf litter, and open canopies (Jones and Glinski 1985). Side-blotched lizards, on the other hand, often sit upon small rocks or at the base of shrubs while ambushing prey (Parker and Pianka 1975), and are associated with rock substrates (Jones and Glinski 1985, Warren and Schwalbe 1985). Perhaps a lack of rock substrates or suitable prey are limiting side-blotched lizards on the river parks and graded lands. Another possibility is greater predation on the river park and graded land transects, but I was unable to measure predation. Side-blotched lizards were also infrequently observed throughout the Tucson metropolitan area (Germaine 1995), and seem to be one of the first species to disappear as areas become more urbanized (C. Schwalbe, University of Arizona, personal communication).

Zebra-tailed lizards are also sit-and-wait predators, but were common on the river parks. Zebra-tailed lizards wait for their prey on sand (Jones and Glinski 1985, Pianka and Parker 1972), and spend most of their active time in open sun (Pianka and Parker 1972, 1986). Not surprisingly, they have been associated with open canopies and sand substrates (Jones and Glinski 1985). Open spaces between plants are common on the river parks and probably accommodate the foraging needs of zebra-tailed lizards better than those of side-blotched lizards. Also, river beds tend to be wider in the river park and disturbed areas, providing more sandy substrates for zebra-tailed lizard foraging. The widespread presence of this species in the river corridors is encouraging because it is another species negatively associated with urbanization (Germaine 1995).

Arboreal lizard species (tree lizards, desert spiny lizards, and Clark's spiny lizards) were most abundant on mesquite woodland plots and rare in disturbed plots. Tree lizards are associated with large mesquite trees with dense, overlapping canopies (Vitt et al. 1981). This species also seems to thrive where other vertical substrates allow a diversity of microclimates for temperature regulation. In cities, these vertical substrates can be walls, buildings, rocks, or exotic trees. Tree lizards were the only native lizards positively associated with measures of urbanization in a Tucson study (Germaine 1995). This species does so well in urban areas that densities of tree lizards on the University of Arizona campus nearly doubled that of a mesquite woodland (Holme 1988). Longevity and survivorship were also greater in the urban site. Holme (1988) hypothesized that the warmer temperatures in the urban site allow longer activity periods which increases survivorship and productivity. In my study, mesquite bosques and river parks provided the vertical structure important for tree lizards.

Spiny lizards were also found primarily in mesquite bosques and landscaped river parks. Desert spiny lizards also use vertical substrates, but utilize a larger range of tree sizes and spend more time on the ground than tree lizards (Vitt et al. 1981). Clark's spiny lizards were only found in two locations, on the eastern Tanque Verde wash and the Rillito River Park. Both locations are relatively mesic and have large shrubs and trees.

Bird Distribution and Habitat

Bank stabilization was negatively associated with species richness of every bird group. Although bank stabilization itself probably has little influence on birds, it is negatively correlated with many other habitat variables, including nearly all measures of native vegetation cover and volume (Appendix E). Individually, these other variables do not uniquely predict the number of bird species in each management group. However, the combination of habitat features found in bank stabilized areas are associated with reduced bird diversity. I cannot say from my data if bank stabilization causes the land use and vegetation changes which prevent occupation by some bird species, or if those land use characteristics lead to bank protection. I can say that current conditions on bank stabilized areas do not encourage a rich diversity of birds, and the river park system does not currently restore these areas sufficiently to overcome the negative effects of bank stabilization. However, because most bank stabilization has occurred in the past 10 years, it is possible that habitat suitability of these areas will improve for some species when the vegetation matures.

The canopy cover of the 100-m radius plots was also important to most bird groups, but canopy cover of the 15-m plot was not. In fact, few variables measured on the 15 m plot were important predictors of species richness. These narrow corridors may be similar to hedgerows, which add cover, foraging, and nesting sites for edge-adapted species. Although characteristics of hedgerows are important predictors of bird species present, characteristics of the surrounding countryside are also important (Arnold 1983). Therefore, landscaping vegetation on a typical 15-m wide river corridor alone will probably not increase bird species diversity substantially. Instead, managers must also try to manage vegetation on a wider area. Preferably, Pima County or the City of Tucson could acquire river corridors that are at least 100 m wide and manage for abundant canopy cover of native trees. If only 15-m wide areas are available for acquisition, they will be most valuable for most bird groups if located next to natural open spaces with extensive cover of native trees.

Human recreational use was not correlated with any species richness variable. However, this does not mean birds and lizards are unaffected by human recreation. Human recreation measures were all correlated with bank protection, which was a better predictor of species richness patterns. Therefore, although bank stabilization and concrete paths associated with high human-use areas may have more of an impact on wildlife use than the humans themselves, habitat changes and human use are commonly found together.

Vegetation volume, a measure currently used to delineate some riparian habitats in Tucson (Pima County Transportation and Flood Control District 1994), was also not correlated with any species richness value. Managing solely for vegetation volume without consideration for other habitat conditions will probably not greatly benefit birds or lizards in the river corridors. However, this variable was measured on the micro-scale plots and vegetation volume could be a better predictor of wildlife richness if managed on a larger area.

Neotropical migrants and riparian species displayed strikingly similar patterns in predictive models. Both groups would be best managed by providing areas of high canopy cover, high mesquite density, no bank stabilization, and high native vegetation cover in the first 2 dm above ground.

In contrast, birds sensitive to urbanization were most diverse in different places than where neotropical migrants or riparian species were most diverse. Richness of this group was associated with sites that contain large amounts of natural open space in the immediate vicinity and in the surrounding landscape, as well as a lack of bank stabilization. These species are mostly associated with upland vegetation such as paloverde-saguaro and creosote communities. Many of these birds were never seen in the mesquite woodlands important to neotropical migrants and riparian birds.

Functions of the River Corridor System

I have identified several functions for the river corridor system which could benefit wildlife populations in the Tucson area. The functions I suggest for the river corridors include providing habitat for neotropical migratory land birds and riparian birds, wildlife viewing areas, and conservation corridors. Our models relating the richness of management groups to habitat variables can help managers achieve those functions.

Habitat for Riparian and Neotropical Migratory Birds

Providing habitat for riparian species will also benefit neotropical migratory birds. However, the absence of perennial water obviously limits the capability of the river corridors to provide riparian habitat. In fact, I never observed many riparian species, including some found historically in the study area. The few areas which have riparian vegetation, such as mesquite bosques and cottonwood patches, are important to maintain because riparian vegetation has declined drastically in the southwestern United States (Krueper 1993). The importance of variables on the 100-m radius plots to riparian and neotropical migratory birds suggests that vegetation corridors narrower than this may have less effect on species richness than adjacent land uses. To manage for these birds, areas at least 100 m wide should be acquired. Even areas 100 m wide may be influenced by adjacent land uses. Studies of natural riparian areas in southeast Arizona suggest that adjacent land uses are important in describing bird species composition (Strong and Bock 1990). Similarly, adjacent land uses are important in predicting bird species densities and species richness in urban strip corridors in Florida (Smith and Schaefer 1992). In my study area, the amount of commercial land uses in the surrounding landscape is negatively associated with the number of neotropical migratory bird species. Therefore, habitat reserves for neotropical migratory birds and riparian birds should be located away from commercially developed areas.

Wildlife viewing

Wildlife viewing is a function that can be provided in landscaped river parks. Although bird species diversity is low in river parks, lizard viewing opportunities are also available. The accessibility of the river parks and high visitor use make them good sites to recruit new participants into wildlife observation. Interpretive displays for beginning wildlife viewers may increase participation. Increasing bird species diversity in the river parks would make them more interesting to wildlife watchers. I cannot predict the effectiveness of vegetation management to increase bird species diversity in the river parks because the existing bank protection system is negatively associated with all bird groups. However, many vegetation variables are negatively associated with the presence of bank stabilization (Appendix E), and increasing those variables may help in mitigating for its negative effects. Most of these variables can be increased by planting native trees and shrubs and allowing them to grow unpruned in the lower and middle height layers. Further support for this recommendation comes from studies which suggest decreased vegetation cover in low and middle height layers may be responsible for reduced bird species richness in urban areas (Hooper et al. 1975, Beissinger and Osborne 1982).

Conservation corridors

Many authors have recommended using conservation corridors, particularly based on riparian habitat, to connect fragmented wildlife populations (Merriam 1981, Noss and Harris 1986, Adams and Dove 1989). In Tucson, lizards and the urbanization-sensitive birds are the most likely groups to benefit from such corridors. However, these species are not associated with riparian-obligate vegetation. Therefore, the value of using corridors of riparian-obligate vegetation for the purpose of connecting patches of Sonoran desert is questionable. Instead, areas of upland vegetation, which include the smaller washes and some of the drier sections of our study area, would be more valuable for this purpose.

Because the river parks have upland vegetation, they may be useful for connecting patches of Sonoran desert. Evidence supporting this possibility includes the distribution of one bird and two lizard species, Verdin, Zebra-tailed lizard, and Western whiptail, which have been negatively associated with urbanization (Germaine 1995) but were commonly found in the river parks. Several other species, Gambel's quail, Cactus wren, Curve-billed thrasher, and Gila woodpecker, were also common in the river parks but studies have not consistently found these species to be sensitive to urbanization (Emlen 1974, Tweit and Tweit 1986, Stenberg 1988, Germaine 1995).

A disadvantage of using the river parks for conservation corridors is that they are extremely narrow (generally 15 m wide) and are likely to be dominated by vertebrates from adjacent areas. The importance of variables on meso-scale plots suggests that bird species present in the river parks are heavily influenced by adjacent land uses. If these adjacent land uses are commercial or high density housing, competition with exotic species and urban adapted species such as house sparrows, starlings, inca doves, northern mockingbirds and great-tailed grackles could limit other bird populations. It is also likely that increased numbers of domestic cats from high density residential areas will prey upon both birds and lizards. Additionally, none of the species considered most sensitive to urbanization, such as black-throated sparrows, black-tailed gnatcatchers, or side-blotched lizards occurred in the river parks. I do not believe the river parks could function as conservation corridors for these species. Undeveloped areas with upland vegetation would be more suitable as conservation corridors for these species.

Because species richness of the urbanization sensitive bird group was negatively associated with bank stabilization and positively associated with the amount of natural open space in the landscape, it is unlikely many of these species will occur in river corridors within the center of Tucson. This lack of continuity prevents the river corridors from connecting populations of these species that occur in the major protected areas around Tucson. However, smaller open space patches around the suburban edge may be connected by river corridors that are natural open space. Identification of these patches and river corridor sections should be a priority for urban planners.

The role of corridors in conservation remains unclear and their value has been debated (Simberloff and Cox 1987, Noss 1987, Mann and Plummer 1995). This debate is complicated by the lack of data on wildlife use of conservation corridors. My study shows that some wildlife species do use conservation corridors within Tucson. Several species which are sensitive to urbanization occur within the river corridors and could use these areas at least for travel. If all of their life history needs are met, they may also be able to live there as corridor dwellers. However, other species did not occur within the river corridors and these species may require different conservation strategies than those which rely on using corridors to connect habitat patches.

The need for conservation corridors will remain unknown until we know more about the dispersal capabilities of species whose habitats are being fragmented. In the meantime, I suggest it would be wise to retain natural open space corridors, in case they are important for maintaining wildlife populations in fragmented landscapes. Many of the major rivers and washes proposed for such corridors support high species diversity and should be protected as valuable wildlife habitat even if they do not function to connect subpopulations of all species sensitive to habitat fragmentation in the Tucson area.

MANAGEMENT RECOMMENDATIONS

1. Manage for native species diversity by emphasizing the habitat needs of species that are not found elsewhere in the urban matrix.

The river corridor areas of Tucson will be most valuable for conservation if they function to increase overall native species diversity in the Tucson metropolitan area. They could increase this diversity most if they provide habitat for species that are not found elsewhere in the urban matrix. These species include neotropical migratory landbirds, riparian birds, birds sensitive to urbanization, and many lizards.

Maintaining habitat for neotropical migratory birds should be a priority in management plans because they are experiencing population declines nationally (Robbins et al. 1993). This group is considered sensitive to habitat fragmentation caused by agriculture and urbanization. Maintaining habitat for riparian species also should be a priority because the river corridors are about the only areas in Tucson that could provide habitat for this group. Bird species sensitive to urbanization and lizards also need special management emphasis as Tucson expands and habitat for these groups is lost. The river corridors may function as conservation corridors for these groups. It is important to consider lizards as well as the urbanization-sensitive birds because lizards are not very mobile, forage on insects, and require low shrub cover, all characteristics that may make them sensitive to urbanization and habitat fragmentation.

A. Recognize the different management needs of each species group and manage for each.

Different species and groups of species have different habitat requirements. These requirements may not always be compatible. As a result, separate conservation strategies for each group are necessary. For example, neotropical migratory birds and riparian birds had similar habitat associations in this study, but birds sensitive to urbanization and lizards were associated with different habitat features. Lizards were not assigned to riparian or urbanization-sensitive groups due to our lack of knowledge on their habitat requirements. Once those associations are determined, lizard groups may also need separate conservation strategies. Nocturnal rodents, bats, amphibians, snakes, invertebrates, and plants may all have different habitat needs than those presented in this study. Specific recommendations for the management groups addressed in this study include:

B. Manage connected areas of tall vegetation for lizards.

The best management strategy for lizards is still difficult to define. Areas with tall trees and shrubs have the highest lizard species diversity in my study area. In general, the tallest trees are in the riparian zones with mesquite bosques and cottonwood patches, However, in other parts of Arizona, lizard species diversity is greater in desert upland than riparian zones of willow-tamarisk (Szaro and Belfit 1986) or mesquite bosque (Jakle and Gatz 1985). Additionally, many areas along the river courses of Tucson characterized by upland vegetation also have high lizard diversity and these areas could be managed for lizards as well.

Connected habitat is probably important for lizards. Even short barriers, such as road crossings, could inhibit lizard movement. Currently river park crossings under roads consist solely of a bike path. Yet lizards can also be hit on bike paths (personal observation). I suspect that movement of some lizard species through the river corridors is restricted by the road under crossings.

I recommend designating areas for lizard habitat management emphasis on the equestrian side of the river parks. Not only will lizards be safer from traffic on this side, but equestrians and walkers may appreciate the wider parkways and more open vegetation more than would the fast-moving bicyclists and in-line skaters.

C. **Manage for riparian birds and neotropical migrants in areas with no bank stabilization, high canopy cover, and high mesquite density. Place these management areas away from commercial development. Focus efforts on maintaining existing mesquite bosques and cottonwood patches rather than trying to restore degraded sites to these conditions.**

Habitat for riparian and neotropical migratory birds is similar. Protecting areas with high canopy cover, high mesquite density, and no bank stabilization will best benefit these species. These conditions are best represented by mesquite bosques and cottonwood patches in my study area. Purchases or conservation easements of mesquite bosques and cottonwood patches wider than 100 m would not only provide habitat for riparian and neotropical migratory birds but would also alleviate the need for bank stabilization projects which appear so detrimental to these management groups. Even wider areas may be necessary to alleviate the problems associated with habitat edges. Commercial land uses are negatively associated with neotropical migrants and edges with this land use type should be avoided. It is also important to maintain high water tables to maintain the riparian vegetation associated with these management groups.

Specific areas that I studied that are suitable for riparian birds and neotropical migrants included the Tanque Verde Creek and to a lesser extent, parts of Canada del Oro and the Rillito River near Christopher City. Additional areas can also be identified with models or by identifying mesquite bosques and cottonwood patches on aerial photographs. Because attempts to restore mesquite bosques are expensive and largely unsuccessful (Stromberg 1993), retaining these areas in their current state would be far more cost-efficient and effective than restoring currently degraded lands elsewhere.

D.Manage for urbanization-sensitive birds in wide areas of natural open space with upland vegetation. Focus management areas for this group near large areas of protected upland vegetation.

Areas of natural open space with no bank stabilization and upland vegetation of Paloverde-mixed cactus, creosote, or drier mesquite woodland are best for this group. The specific locations with the highest diversity of this group include Canada del Oro Wash from Overton road north to Catalina State Park, and sections of natural open space along Pantano Wash near Harrison road. However, the models should be used to identify other areas within the Tucson basin that may be suitable for urbanization-sensitive birds, especially if they connect natural open space patches. The amount of natural open space in the surrounding landscape is important to this group and I recommend placing management areas near large areas of protected natural open space.

3. Identify areas suitable for each species, management group, and community of concern.

I have identified several areas with high species richness that should be targeted for protection. Even more importantly, because a random sample of the study areas was used, the predictive equations can be used to identify areas for protection, even if they were not sampled in this study. Many of the variables which predicted management group richness were taken from the GIS database (WHIPS) proposed by Shaw et al. (1993) that will be available to planners and useful for identifying areas with the characteristics for each management group. For example, to manage for the urbanization-sensitive bird group, all areas with natural open space wider than 100 m and with no bank stabilization can be easily identified. Areas meeting this criteria that are not protected can be targeted for acquisition and ranked based on the amount of open space in the surrounding landscape. Once areas are identified with GIS, field visits can help determine which areas also represent ideal micro-scale conditions. The top ranking areas can be acquired or maintained for the birds sensitive to urbanization.

Similarly, gaps in habitat for target groups can be identified and targeted for restoration. The trade-off between the benefits of acquiring new lands versus the benefits of restoring land that is already owned but degraded vary with the management group. For example, neotropical migrants and riparian birds both require tall canopies and fairly pristine vegetation which would be difficult, expensive, and slow to achieve with restoration. Some of the lizard species, on the other hand, require only low shrubs and have small territories. Restoration may work well for these species.

4. Increase vegetation structural diversity and use of native plants in existing river parks.

Revegetated river parkways do not compensate for the negative effects of bank stabilization. However, many species do utilize the river park system, including some species sensitive to urbanization. The river parks also provide opportunities for wildlife viewing. In graded areas which are already bank stabilized, any restoration of native vegetation will benefit most species. Increasing the density of mesquites and increasing the understory of native vegetation in the river parks and graded areas will improve conditions for many species. Providing vegetation that provides continuous cover in each height layer will benefit many urban species more than isolated plantings (Beissinger and Osborne 1982).

5. Plan for effects caused by adjacent land uses. Manage wide areas where possible.

Many of the most powerful predictors of species richness were from 100-m radius plots, and the 1 km-radius plots, not from the smaller 15-m radius plots which are the typical width of river parks. This indicates managers will need to consider a wider area when planning wildlife habitat protection and restoration. For many types of animals, species present in the 15-m wide legal width of managed river corridors will be influenced as much by adjacent land uses as by the river park itself. As a result, it is important for managers to consider the effects of adjacent land uses when planning river corridor management. Adjacent areas that are natural open space or have high cover of native trees will be most beneficial to the management groups I examined. Because managers cannot control adjacent land uses, the ideal management option is to make the width of the river corridors themselves at least 100 m wide.

In addition to planning for the effects of adjacent land uses, managers must also consider the general landscape context of the river corridors. The extent of commercial land uses in the landscape has a negative effect on species diversity of some management groups. Conversely, natural open space has a positive effect. These effects must be considered when making management plans. For example, placing 100-m wide corridors for species that are sensitive to urbanization in the center of a commercial landscape will probably not be as beneficial as placing the corridors in a landscape of mixed low density housing and natural open space.

6. Monitor species of conservation concern

Managers should monitor smaller areas in more detail than was done in this initial study. In addition to species richness, species composition and abundances of a few individual species should be monitored. However, so little is still known about lizard use of urban areas I suggest monitoring all species of this taxon, using the same methods I used in this study plus some pitfall trapping grids. I suggest monitoring a few bird species that are riparian obligates, neotropical migrants, or sensitive to urbanization using the same point count methodology as discussed in this study. Because abundance alone may be a poor indicator of the habitat suitability of a site (Van Horne 1983, Pulliam 1988), I also strongly recommend monitoring nest success and survivorship of species in these management groups.

Important monitoring locations would be those areas which have high species richness for each group now, but are surrounded by changing land uses, such as areas along Canada del Oro and the Tanque Verde Creek. I also recommend monitoring areas which have been revegetated as they continue to mature.

7.Conduct further research on needs of individual species

Black-tailed gnatcatchers and black-throated sparrows were not found in the river parks. These two species have been identified as sensitive to urbanization (Emlen 1974, Stenberg 1988, Germaine 1995), and may need special management to ensure their persistence as development of the Tucson metropolitan area continues. Similarly, the needs of side-blotched lizards raise a lot of questions. Although not a species of concern now, this species is not found in the river park system and will not be protected if that system is relied upon as conservation corridors.

In summary, the river corridors of Tucson will be most beneficial to wildlife conservation if they provide habitat for species not found elsewhere in the urban matrix. Those species include many lizards, riparian birds, neotropical migratory birds, and birds sensitive to urbanization. Lizards require areas of tall vegetation, riparian and neotropical migratory landbirds require dense canopies associated with mesquite bosques, and birds sensitive to urbanization require natural open space of mostly upland vegetation. Restoration efforts should focus on increasing use of native plants and increasing vegetation structural diversity. Planners also need to consider effects of adjacent land uses and general landscape context when planning management of river corridors.

APPENDIX A

Land Cover Categories

Categories used in 100 meter radius plots and 100 meter by 300 meter transects in the river corridor areas of Tucson, AZ, 1994-1995. Classification is from Shaw et al. (1993).

1.0 RESIDENTIAL

1.1 Planned Community/Cluster Residential

A residential area/subdivision that is arranged or planned around a focal point, such as a golf course or natural open space. The focal point is an integral part of the residential development.

1.11 Golf Course Community

The land cover category of a planned community with residential units (single family homes, town houses, duplexes, and apartment complexes) designed and integrated with a golf course.

1.12 Tanque Verde River Community

The land cover category of homes (main house, garage, adjacent buildings, stables, barns, guest house) and the surrounding property. This area has been developed within the flood plain of the Tanque Verde River. The vegetation in and around the residential area is strongly influenced by the river. This category includes the Tanque Verde River.

1.2 > 10 acres\house

The land cover category of homes with > 10 acres per house included buildings (main house, garage, adjacent buildings, stables, guest house) and the surrounding property.

1.3 4-10 acres\house

The land cover category of homes with 4-10 acres and included buildings (main house, garage, adjacent buildings, stables, guest house) and the surrounding property.

1.4 1-3 acres\house

The land cover category of homes with 1-3 acres and included buildings (main house, garage, adjacent buildings, stables, guest house) and the surrounding property.

1.5 >1-3 RAC (residences/acre)

The land cover category of 1-3 residences/acre and included buildings (main house, garage, guest house) and the surrounding property.

1.6 >3-6 RAC (residences/acre)

The land cover category of 4-6 residences/acre and included buildings (main house, garage, guest house) and the surrounding property.

1.7 Multiple unit housing (Apartments)

Apartment and condominium complexes consisted of residential buildings, recreational areas (pool, shuffle board court, patio), parking facilities, and offices.

1.8 Town houses/Duplexes

The land cover category of town houses and duplexes included the residential buildings, their surrounding property, and community recreational services (park, swimming pool, rental office).

1.9 Mobile Home Parks

Mobile home parks consisted of permanent units (mobile homes in a permanent setting), temporary units (typically recreational vehicles parked on a short term basis), and a recreational center (club house, pool, parking facilities).

2.0 COMMERCIAL/INDUSTRIAL/SCHOOL

2.1 Commercial/Industrial

Commercial and industrial property consisted of buildings and parking facilities. On an aerial photograph this land cover category was distinct because of its usually large parking area and minimal vegetative cover.

2.2 School

Private and public schools consisted of buildings, playgrounds, and parking facilities.

2.3 Regional Mall

A regional mall was defined as a retail shopping center ≥50 acres that served the community. A regional mall included the buildings housing the shopping center as well as the surrounding parking facilities and access roads.

2.4 Major Transportation Routes

Major transportation routes included roadways ≥ 4 lanes (or the equivalent) and railway yards. Roadways in this category contained medians with plant materials and/or shoulder easements with plant materials. Roadways < 4 lanes were incorporated into the surrounding prominent land cover category. The railway yards contained a central rail switching area and included buildings, rail, parking facilities, and graded vacant land.

2.5 Community Services (Firehouse/ambulance)

Community services included public paramedic (ambulance) and firehouse property. This land cover category included buildings, separate garages, parking areas, and surrounding property.

3.0 RECREATION

3.1 Zoological Park

Zoological parks contained parking facilities, administrative offices, as well as the area housing the animal exhibits.

3.2 Urban Golf Courses and Associated Recreation Areas

Characteristics of urban and suburban/rural golf courses and associated recreation areas (tennis, swimming pool, recreation center) differ. An urban golf course typically encompasses less overall area and offers less amenities (swimming pool, restaurants, tennis) than a suburban/rural (country club) golf course. Urban and suburban/rural golf courses were separate land cover categories.

An urban golf course and associated recreation areas contained the golf course, driving range, club house, parking facilities, and recreation areas (tennis courts, swimming pool).

3.3 Suburban/Rural Golf Course (Country Club)

This land cover category included the golf course(s), clubhouse, driving range, restaurants, tennis area, swimming pool(s), parking area, entrance roadway, and landscaped property.

3.4 Park and Playground

The characteristics of parks and playgrounds varied by size of the community they served and was reflected in the park's area. There are 3 classifications of parks and playgrounds in Pima County and they reflect the use of the park as well as the park's area.

3.41 Neighborhood Park (≤ 10 acres)

A park or playground designed for neighborhood use ≤10 acres. A neighborhood park usually contained lawn, picnic areas, playgrounds, bathrooms, and parking facilities.

3.42 District Park (11-49 acres)

A park designed for district use was 11-49 acres. A district park usually contained lawn, picnic areas, playgrounds, bathrooms, ball fields (baseball, soccer, and or basketball), and parking facilities. A district park may contain a public swimming pool.

3.43 Regional Park (≥ 50 acres)

A park designed to accommodate people on a regional scale was ≥ 50 acres. A regional park contained a variety of recreational amenities, including picnic areas, baseball field (professional), swimming pool, garden, recreational fields (dog training, basketball, football), lawns, administration offices, and parking facilities.

4.0 WATERCOURSES AND PONDS

The watercourse and pond land cover category included major rivers, washes, and ponds. Each contained different features in land cover, and therefore different potential habitat for wildlife species.

4.1 Major River

Examples of rivers include within Pima County include the Santa Cruz, Tanque Verde, Canada del Oro, Pantano, and the Rillito. Rivers in an urban environment display various forms of human impact, such as bank stabilization for flood control. Bank stabilization was defined as a river or wash bank that had been secured from overflow or flooding by contoured soil or cement. Examples of rivers included the Santa Cruz, Pantano, Tanque Verde, Rillito, and Canada del Oro. Rivers included three degrees of bank stabilization: none, partial (one side of river), and predominant (both sides). Each was treated as a separate subcategory.

4.2 Wash/Riparian Area

Similar to urban rivers, washes and riparian areas in an urban environment display various forms of human impact, such as bank stabilization for flood control. Bank stabilization was defined as a wash or river bank that had been secured from overflow or flooding by contoured soil or cement. Washes included four degrees of human impact: no stabilization, partial stabilization (one side of wash), predominant stabilization (both sides), and soil grading.

4.3 Pond

The land cover category of pond included the body of water (pond) $\geq$ 0.25 acre and the surrounding land that was directly influenced by the pond. The degree of influence (or zone) by the pond on adjacent land was determined by the type of plant species present, such as cottonwood (Populus fremontii), Arizona ash (Fraxinus velutina), Goodding's willow (Salix gooddingii), and Arizona sycamore (Platanus wrightii).

5.0 NATURAL OPEN SPACE

The natural open space land cover category included land that had maintained its natural integrity and did not show evidence of recent human impact (presence of land grading or buildings). Watercourses and ponds with natural vegetation were classified separately.

6.0 GRADED VACANT LAND

The graded vacant land cover category included land that showed evidence of recent human impacts (land grading, roadway, vacant buildings). Successional processes were underway on many of the land parcels in this category. Graded vacant land contained predominately first stage successional plant species, such as desert broom (Baccharis sarothroides), burro weed (Haplopappus tenuisectus), and exotic lovegrass species (Eragrostis spp.).

7.0 AGRICULTURAL LAND

7.1 Animals

This land cover category included commercial businesses comprised of horse, sheep, and/or cattle operations. The category included buildings (house, stables, barn, garage, equipment storage), horse riding areas, pastures, and natural open spaces used for grazing.

7.2 Crops

This land cover category included commercial property in the business of raising plant crops for sale. The category included buildings (house, barn, storage areas, garage, equipment storage) agricultural crop fields, irrigation fields, access roads, and natural open space (land with native plants and no human disturbance--typically found between agricultural fields). This land cover category contained subcategories of currently used agricultural crop lands and abandoned agricultural crop lands.

APPENDIX B
Bird Species in Management Groups

Riparian species
Northen cardinal
Aberts' towhee
Lucy's warbler
Phainopepla
Bell's vireo
Lesser goldfinch
Bewick's wren
Black-chinned hummingbird
Red-winged blackbird
Northern oriole
Northern beardless tyrannulett
Yellow warbler
Vermillion flycatcher
Summer tanager
Black phoebe
Blue grosbeak
Yellow-breasted chat
Tropical kingbird
Common ground dove
Western wood pewee

Neotropical migrants
White-winged dove
Ash-throated flycatcher
Lucy's warbler
Western kingbird
Cassin's kingbird
Bell's vireo
Black-chinned hummingbird
Yellow warbler
Brown-crested flycatcher
Northern oriole
Northern beardless tyrannulet
Summer tanager
Blue grosbeak
Yellow-breasted chat
Tropical kingbird
Scott's oriole
Common ground dove
Western wood pewee
Costa's hummingbird

Species sensitive to urbanization
Black-tailed gnatcatcher
Black-throated sparrow
Verdin
Northern flicker
Pyrrholoxia
Gambel's quail
Gila woodpecker
Ash-throated flycatcher
Curve-billed thrasher
Cactus wren
Greater roadrunner
Loggerhead shrike
Canyon towhee
Rufous-winged sparrow
Ladder-backed woodpecker

APPENDIX C
Variable Descriptions

Variable	Description	Units	Mean	SD
Variables from 7.5m radius plots				
HEIGHT1	Vegetation cover from 0-0.2 meters	% cover	25.69	19.25
HEIGHT2	Vegetation cover from 0.21 to 2.0m	% cover	26.16	19.50
HEIGHT3	Vegetation cover >2m	% cover	15.28	23.41
NATHGT1	Native vegetation cover 0-0.2m	% cover	9.09	10.97
NATHGT2	Native vegetation cover 0.21 to 2.0m	% cover	20.19	18.50
NATHGT3	Native vegetation cover greater than 2.0	% cover	12.84	22.97
BRGR	Bare ground cover	% cover	25.84	22.28
GRAV	gravel cover	% cover	20.59	23.31
LITT	litter cover	% cover	40.94	22.81
IMPERV	Impervious substrate cover	% cover	4.84	9.88
LIVE	Live vegetation cover	% cover	4.03	6.56
RAISED	Raised cover (log + trash + rock)	% cover	1.75	4.47
PRVEH2	Velvet mesquite cover in 0.21-2.0m layer	% cover	4.59	8.91
PRVEH3	Velvet mesquite cover over 2.0 m	% cover	7.50	17.34
BASAH3	Desert broom cover over 2.0m	% cover	0.44	2.13
EXGRH1	Exotic grass cover 0-0.2m	% cover	11.84	16.06

Appendix C. Continued.

Variable	Description	Units	Mean	SD
EXGRH2	Exotic grass cover 0.21-2.0m	% cover	2.88	6.38
RIPTREE1	Riparian tree cover 0-0.2m	% cover	0.09	0.88
RIPTREE2	Riparian tree cover 0.21-2.0m	% cover	0.56	2.88
RIPTREE3	Riparian tree cover greater than 2.0m	% cover	1.63	10.03
BANK	Bank stabilization (y/n)	Y/N	0.51	0.50
DUMMY1	Dummy representing Natural open space	0/1	0.38	0.49
DUMMY2	Dummy representing disturbed open space	0/1	0.40	0.49
TVV	Total vegetation volume	No. hits out of 128 possible	77.85	67.71
HGTDIV	Number of vertical meters with vegetation	No.	3.24	2.09
NVV	Native vegetation volume	No. hits out of 128 possible	56.63	61.19
TREE	Density of trees	No. in plot	1.15	1.99
SHRUB	Density of shrubs	No. in plot	2.70	4.19
BACCSARO	Density of desert broom	No. in plot	0.69	1.92
PROSVELU	Density of velvet mesquite	No. in plot	0.97	2.59
HEIGHT	Height of tallest tree or shrub	Meters	3.68	3.15

Variables from 100m radius plots

Appendix C. Continued.

Variable	Description	Units	Mean	SD
RESIDLOW	Residential ≤1 to 1 house per acre	% cover	1.82	6.43
RESIDHI	Residential >1 house per acre	% cover	7.25	14.20
COMMER	Commercial	% cover	2.71	8.18
RECREAT	Recreation	% cover	1.19	5.46
RECREAT5	River Parkways	% cover	4.45	9.76
WATER1	Major river	% cover	40.38	10.98
WATER2	Wash	% cover	1.02	3.04
WATER3	Pond	% cover	0.34	2.90
NATURAL	Natural open space	% cover	22.03	25.53
GRADED	Graded vacant land	% cover	17.12	19.22
AGRIC	Agriculture	% cover	2.16	7.50
VCOVER2	Total canopy cover	1-4	2.68	0.78
Recreation variables				
DOG	Number of dogs counted	No.	0.10	0.20
FOOT	Number of walkers/joggers counted	No.	0.52	1.05
WHEELS	Number of bicycles/skaters counted	No.	0.19	0.57

APPENDIX D
Cross-validation Results

	Multiple R		X of Standard Residuals		S.D. of Standard Residuals	
Equation	original	validation	original	validation	original	validation
94 Neotropical migrants	0.7125	0.7118	0.0594	0.5418	1.015	0.9722
95 Neotropical migrants	0.7381	0.2874	0.000	-0.0026	0.9665	1.030
94 Riparian	0.7655	0.6022	0.0749	0.5282	1.160	2.274
95 Riparian	0.8006	0.5043	0.1295	-0.1277	1.255	2.505
94 Urbanization sensitive	0.8171	0.9490	0.0192	-0.0583	0.9743	0.8538
95 Urbanization sensitive	0.8223	0.7455	0.0000	-0.3881	0.9778	1.119
94 Total species richness	0.8552	0.9508	0.0703	0.0857	1.0258	1.1572
95 Total species richness	0.8399	0.9120	0.0182	0.1282	0.9673	1.4855

APPENDIX E
Variables Correlated with Bank Stabilization

Variables Positively Correlated With Bank	Variables Negatively Correlated With Bank
Gravel	Height1
Imperv	Height2
Dummy2	Height3
Residhi	Nathgt2
Commer	Nathgt3
Recreat5	Brgr
Water1	Litt
Dog	Dummy1
Foot	Prveh2
Wheels	Prveh3
	Exgrh1
	Exgrh2
	TVV
	Hgtdiv
	NVV
	Shrub
	Prosvelu
	Height
	Residlow
	Natural
	Vcover

APPENDIX F
Plant Species Occurring on River Corridors

Acacia constricta
Acacia farnesiana
Acacia greggii
Acacia redolens
Acalypha neomexicana
Allionia
Amaranthus fimbriatus
Amaranthus palmeri
Ambrosia confertiflora
Ambrosia deltoidea
Amsinckia intermedia
Aplopappus tenuisecta
Aristida
Aristida adscensionis
Aristida purpurea
Atriplex
Atriplex canescens
Atriplex elegans
Atriplex lentiformis
Atriplex polycarpa
Avena fatua
Baccharis salicifolia
Baccharis sarothroides
Baileya multiradiata
Boerhavia
Boerhavia erecta
Bouteloua aristidoides
Bouteloua gracilis
Bromus carinatus
Bromus rubens
Buddleia marrubifolia
Caesalpinia pulcherrima
Calliandra eriophylla
Carnegiea gigantea
Celtis pallida
Celtis reticulata
Centaurea melitensis

Cercidium floridum
Cercidium microphyllum
Chenopodium berlandieri
Chilopsis linearis
Circidium microphyllum
Clematis drummondii
Cucurbita digitata
Cynodon dactylon
Cyperus aristatus
Cyperus esculentus
Dalea greggii
Dasylirion wheeleri
Datura wrightii
Dodonaea viscosa
Echinochloa colonum
Encelia farinosa
Ephedra
Eragrostis echinochloidea
Eragrostis echinocloidea
Eragrostis lehmanniana
Ericalaric
Erioneuron pulchellum
Erioplanos
Eucalyptus
Euphorbia
Euphorbia hyssopifolia
Euphorbia micromera
Fraxinus velutina
Grama
Heterotheca subaxillaris
Hordeum murinum
Hymenoclea monogyra
Hymenoclea salsola
Hymenothrix wislizeni
Juglans major
Kallstroemia californica
Koeberlinia spinosa
Larrea tridentata
Lepidium medium
Leptochloa viscida

Leucophyllum laevigatum
Lycium
Lycium andersonii
Machaeranthera
Machaerantheraeranthera
Machaerantherarantherа
Melilotis
Mistletoe
Muhlenbergia porteri
Mulberry
Mustard
Nerium oleander
Oenothera caespitosa
Olneya tesota
Opuntia engelmannii
Panicum antidotale
Panicum hirticoula
Parkinsonia aculeata
Pennisetum ciliare
Pennisetum setaceum
Penstemon parryi
Populus fremontii
Prosopis chilensis
Prosopis glandulosa
Prosopis hybrid
Prosopis velutina
Ratibida columnaris
Rose
Salsola kali
Salvia clevelandii
Sambucus mexicana
Sarcostema cynachoides
Schismus arabicus
Schismus barbatus
Senecio longilobus
Solanum eleganifolium
Sphaeralcea ambigua
Sporobolus cryptandrus
Tamarix ramossisima
Tidestromia lanuginosa

Trianthema portulacastrum
Tridens pulchellus
Vauquelinia californica
Verbena officinalis
Verbesina encelioides
Ziziphus obtusifolia

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