Final Report:
Riparian Forests of Sonora, Mexico

Prepared by:

Michael L. Scott and Elizabeth W. Reynolds
USGS, Fort Collins Science Center,
Fort Collins, CO

I. INTRODUCTION

A. Overview

In this final report, we summarize work accomplished as part of the riparian forest component of the Western North American Migratory Landbird Project, funded by the U.S. Fish and Wildlife Service. This component of the project involves developing an ecological understanding of riparian forests in Sonora, Mexico at two spatial scales relevant to migratory landbirds; A) a landscape scale (hundreds of kilometers) and B) a river reach scale (hundreds of meters).

Riparian habitats in western North America cover less than 0.1% of the landscape (Knopf et al. 1988), yet they support a disproportionately large number of bird species and greater densities of birds than any other forested habitats in the continental US (Johnson et al. 1977, Mosconi and Hutto 1982). However, in northwestern Mexico, the relationship between bird use and riparian forest structure, composition and functional status has not been well established. Moreover, economic development and concomitant increases in human populations along the US-Mexico border in the last decade have intensified demands on scarce resources like water (Revah 2000), and pose tangable threats to the ecological integrity of riparian forests in the form of stream dewatering (damming and diversion, ground water pumping), grazing, and floodplain conversion to agriculture. Such activities result in profound changes in, or loss of, riparian ecosystems and riparian-dependent species. Riparian forests in Mexico are infrequently visited by biologists and poorly monitored for their ecological significance and functional integrity (Nabhan and Holdsworth 1999). Conservation of migratory bird species depends upon a clear understanding of their specific habitat requirements and the physical and biotic processes that create and maintain those habitats (Askins 2000). Because most riparian forest land in Mexico is privately or communally owned, effective conservation and restoration efforts must also demonstrate their biological and economic value and enlist the support of communities and land owners through outreach and education.

B. Objectives

Study objectives for the riparian component of this proposal are: (1) to provide state-wide estimates of riverine bottomland area, extent of riparian forest and the amount of bottomland converted to agriculture; (2) to characterize a range of riparian forest habitat throughout Sonora; and (3) to provide a list of vegetation metrics that could be used to assist managers in the identification and ranking of high priority riparian forest sites for conservation and restoration efforts throughout Sonora.

C. Background

The state of Sonora is the second largest state in Mexico, representing an area of 185, 430 km^2. It is topographically and biologically, diverse encompassing five major vegetation types: Oak-Pine woodlands and forest at higher elevations of mountain ranges in the eastern part of the state; Tropical deciduous forest in the southeast, at middle elevations; Chihuahuan desertscrub and grasslands in the northeast at lower elevations; Thornscrub, from the southwest coastal plain to

central Sonora; and Sonoran desertscrub across the broad arid valleys and plains of western and northwestern part of the state (Felger et al. 2001).

Three major extra-regional rivers, the Río Colorado, Río Yaqui and Río Mayo, flow through Sonora and empty into the Gulf of California. Smaller rivers like the Río Sonora, Río Matape, Río Santa Cruz and Río Moctezuma arise within the state and flow into the Gulf or are tributary to larger rivers within or outside of the state. Both larger and smaller rivers intersect a variety of vegetation types and provide connections between them. Riparian corridors in Sonora typically include species unique to riparian areas as well as some upland species from adjacent hillslopes or higher elevations (Martin et al. 1998). Because of the presence of surface water or shallow groundwater, favorable microclimates, high patch disturbance rates and linear connectivity, riparian vegetation, as in other regions, is more structurally and compositionally diverse than vegetation of the surrounding uplands.

All three extra-regional rivers once supported extensive, low elevation cottonwood and willow forests. However, these rivers have been dammed and flows diverted and the cottonwood-willow forests that remain are largely relict (Martin et al. 1998). Smaller rivers like the Río Sonora, Río Altar and Río Sahuaripa also have been dammed and along most unconfined river valleys, riparian forests have been extensively cleared for agriculture. Basic, state-wide information on the composition, current range of conditions and trends in riparian forest resources for Sonora are generally lacking.

II. METHODS

A. Study Sites

We selected 15 reaches along 11 rivers throughout Sonora, where we sampled riparian vegetation (Appendix A, Figure 1). Avian data collected as part of this project, indicated that riparian sites containing Cottonwood species (*Populus* spp.) and Willow-Bald Cypress (*Salix* spp. – *Taxodium distichum* var. *mexicanum*) were especially important in terms of bird abundance and diversity. Thus, sites were selected in part, based on the presence of Cottonwood, Willow and Bald Cypress. At each of these sites, except for the Río San Pedro, birds had been sampled by point count, each January and February from 2004 through 2006 (see avian section of this report).

At the Río Mayo and Río Sahuaripa sites, which were located below in-channel dams, the flow was perennial. Annual stream flow at the remaining sites is intermittent or spatially interrupted and seasonally variable. Throughout Sonora, stream flow is influenced by two general periods of precipitation: wide-spread winter-spring rains of long-duration resulting from frontal storm systems off the Pacific; and a summer monsoon-like rainy season, featuring localized but intense, short-duration precipitation events from convective thunderstorms.

B. Satellite Imagery

Archival, black and white satellite imagery (georeferenced with 0.6-1 meter resolution) was obtained for the following five northern cottonwood/willow riparian sites in 2004 (see site

locations in Figure 1):

- Río Altar near Seric and Tubutama
- Río Santa Cruz
- Río Cocospera
- Río San Pedro

In early March 2006, new Ikonos high-resolution satellite images (orthorectified black & white at ~ 1 m resolution and multispectral imagery delivered as four files of one band each (near infrared, red, green, blue) at ~ 4 m resolution) were acquired for the following sites in central and southern Sonora: In early March 2006, new Ikonos satellite images (georeferenced black & white at ~ 1 m resolution and color at ~ 4 m resolution) were acquired for the following sites in central and southern Sonora:

- Río Matape near San Jose de Pimas
- Río Mayo near Presa Mocuzari
- Río Sahuaripa near Bamori and Cajon de Onapa
- Río Sonora near Baviacora and Aconchi
- Río Moctezuma near Jecori and Terapa
- Río San Miguel near Cucurpe

Both images were used to create "pan-sharpened" color images with a resolution of ~ 1 m. Pan-sharpening is a process that combines the one-meter spatial resolution of the panchromatic image with the spectral resolution of the multi-spectral bands to create a 1-meter product. An archival color satellite images from Digital Globe (~ 4 m resolution) also was obtained for the site at:

- Río Cuchujaqui

C. Field Methods

At each site, we used a large paper copy of the image of the study area, on which the locations of previous bird point-counts were overlain, along with a 50 m radius circle centered on the points. These images were printed at a scale of approximately 1:9000, and in conjunction with a hand-held GPS unit were used to precisely re-locate each bird point-count location. We selected an average of 6-7 points per site to identify and map all woody vegetation, by species and cover, contained within a 50 m radius (circular plot) at each sampled point-count location (see Appendix A, Figures 5c-17c). At sites with multiple bird survey points, we chose a subset of points that spanned the study reach and were centered on the channel. Some points appeared to be shifted outside of the riparian zone up to 200 m, possibly the result of a datum error. We avoided sampling these points. Where points were shifted away from the channel by less than 50 m, we repositioned the point as close to the center of the channel as possible, mapped the point at the new location and took a new GPS reading. On the ground, we identified uniform patches of vegetation within each plot and delineated these on the field-copy image using a colored pencil. Each unique polygon within a plot was given a number code on the field sheet. At the same time, this code was entered on a field data sheet, along with the percent cover of each woody plant species or physical feature (e.g., *water*, *agricultural field* or *road*) contained within the mapped polygon.

For important riparian tree species, we identified cover by size/height classes. For Cottonwood and Willow species, Tamarix (*Tamarix ramossissima*) and Bald-cypress, we recognized the following size/height classes: seedlings (< 1 m in height); sapling (> 1 m in height and ≤ 5 cm

diameter at breast height (dbh)); pole (>5 cm – 15 cm dbh); small tree (>15 cm dbh – 50 cm dbh) and large tree (> 50 cm dbh). For Mesquite species (*Prosopis* spp.) and Baccharus species (*Baccharis* spp.), we recognized two height classes; < 5 m and ≥ 5 m and < 2 m and ≥ 2 m, respectively. Unknown plant species were collected, numbered and pressed in the field and returned to the University of Sonora for subsequent identification.

D. Geospatial Materials and Methods

1. Field Data

Interpreted field sheets were returned to the lab and all polygons within the sampled plots were digitized and entered into a GIS database. This information was joined to the data on species cover by polygon entered from the field sheets. Species cover was then area-weighted by polygon and summarized by sample plot for each point. Site-based summaries were done in SYSTAT and graphs prepared in SIGMAPLOT.

III. RESULTS AND DISCUSSION

A. Site-based Assessments

1. Overall Riparian Plant Species Diversity, Frequency and Abundance

A total of 79 woody riparian species were identified across all 15 sites. Across all sites, the most dominant tree species, in terms of cover, were Willow speices, Freemont cottowood, Mesquite species and Acacia species. The most dominant shrubs were tall and short Seepwillow and Burrobush (Table 1). The most frequently occurring species, based on number of occurrences across plots,

Table 1. The top ten most dominant species across all sites sampled. Dominance here is calculated as the total mean area-weighted cover by species (m^2/ha) across all sample plots (n = 84). For a complete list of species ranked by dominance, see Appendix B, Table 1.

Species	Common name	Dominance
Baccharis salicifolia (>2m)	Seepwillow	63311
Salix spp. (tree)	Willow spp.	48136
Populus fremontii (small tree)	Fremont Cottonwood	38531
Populus fremontii (pole)	Fremont Cottonwood	27489
Prosopis spp. (large)	Mesquite spp.	21696
Baccharis salicifolia (<2m)	Seepwillow	21310
Salix spp. (pole)	Willow spp.	19995
Hymenoclea monogyra	Burrobush	18775
Populus fremontii (large tree)	Fremont Cottonwood	17682
Acacia farensiana or A. constricta	Acacia spp.	9900

were primarily shrubs and small trees, including short and tall Seepwillow, small Mesquite and Acacia trees, and Desert Hackberry. Willow pole and tree-sized stems were the most frequently encountered trees, along with large and small Mesquite stems (Table 2). The importance of

Seepwillow (*Baccharis salicifolia*) is interesting in that in that in our experience, in the US and Sonora, this species is typically associated with surface water or shallow alluvial groundwater.

Table 2. The top ten most frequently encountered species across all sites sampled. Frequency is calculated as the total number of occurrence of a species across all sample plots (n = 84). For a complete list of species ranked by frequency, see Appendix B, Table 2.

Species	Common name	Frequency
Baccharis salicifolia (<2m)	Seepwillow	79
Baccharis salicifolia (>2m)	Seepwillow	77
Prosopis spp. (small)	Mesquite spp.	75
Salix spp (tree)	Willow species	59
Acacia farensiana or A. constricta	Sweet acacia or White-thorn Acacia	58
Hymenoclea monogyra	Burrobush	59
Salix spp. (pole)	Willow species	53
Celtis pallida	Desert hackberry	49
Prosopis spp. (large)	Mesquite spp.	49
Nicotiana glabra	Tree tobacco / Cornetón	48

Burrowbrush and Desert hackberry also were common, along with Tree tobacco, which appeared as a widespread weed in riparian areas across the state. Finally, notable in its rarity across all sites, is *Tamarisk ramossissima*, which occurred as a few small individuals at three sites; the Rio Cuchujaqui near Alamos, the Rio Matape at San Jose de Pimas and the Rio Sonora near Baviacora.

The Río Mayo had the most species (n = 31), whereas the Río Altar at Tubutama had the fewest species (n = 8). The Río Mayo, together with the Río Cuchujaqui, had by far the greatest number of unique species (n = 12 each; Table 3). Of all the species that occurred at a single site (n = 34), over 70% occurred at the Río Mayo or the Río Cuchujaqui. Additionally, four species (*Pisonia capatata*, *Ficus* sp., *Agonandra racemosa* and *Cryptostegia grandiflora*) occurred at both the Río Cuchajaqui and Río Mayo, but nowhere else. Many of the species unique or common to both of these sites are of tropical origin, with affinities to the Tropical deciduous forest (Brown 1982, Felger et al. 2001). Most of the species found at the Río Mayo reflect the downstream effects of the dam at Mocuzari. Whereas the Río Mayo once supported extensive gallery forests of Mexican cottonwood (*Populus mexicana* subsp. *dimorpha*) and Willow (*Salix gooddingii*), existing stands are considered relict due to the lack of flow variability and related geomorphic change (Martin et al. 1998). Indeed, no Cottonwoods, Willows or Seepwillow species occurred in any of the Río Mayo plots, and former fluvial surfaces (e.g., channel bars and flood plain) were dominated by species characteristic of drier riparian settings or upland sites in thornscrub or tropical deciduous forest, such as Manila tamarind (*Pithecellobium dulce*), Mexican palo verde (*Parkinsonia aculeate*), Palo joso (*Albizia sinaloensis*) and Garabato (*Pisonia capitata*). A number of cacti also were found growing on these fluvial terraces. *Cryptostegia grandiflora*, a non-native species introduced from India, had relatively high cover at the Rio Mayo, growing as a climbing vine on trees along the edge of the channel.

In contrast to the Río Mayo, the Río Cuchujaqui had riparian vegetation in a range of size/height classes including Mexican cottonwood, Willow species, Seepwillow, and Button-bush

(*Cephalanthus salicifolius*). This also was the only site that included Bald cypress (*Taxodium distichum* var. *mexicanum*), a riparian vegetation type that has been shown to be especially important to birds (this report).

Table 3. Total number of species found at each site and the number of species unique to that site.

SITE Name (number)	Number of Species	No. Unique Species
Rio Mayo at Presa Mocuzari (6)	31	12
Rio Cuchujaqui at Alamos (4)	27	12
Rio San Miguel at Cucupre (11)	22	4
Rio Moctezuma at Terapa (8)	21	1
Rio Moctezuma at Jecori (7)	21	2
Rio Sahuaripa at Bamori (9)	20	1
Rio Sonora at Baviacora (14)	18	1
Rio Matape at San Jose de Pimas (5)	17	1
Rio Cocospera at Rancho Aribabi (3)	16	0
Rio Sahuaripa at Cajon de Onapa (10)	14	0
Rio Santa Cruz at San Lazaro (12)	13	0
Rio Sonora at Aconchi (13)	13	0
Rio Altar at Tubutama (2)	8	0

2. Willow-Bald Cypress Riparian Ecosystems: Río Cuchujaqui

Given the importance of riparian ecosystems like the Río Cuchujaqui to avian communities, it seems important, from a habitat conservation perspective, to highlight the characteristics of these ecosystems in Sonora. Bald cypress occurs along rivers and steams in the foothills zone of southeastern and east-central Sonora. Physical settings include arroyos and canyons with permanent water (or sometimes seasonally-dry), which also may be subject to high-intensity floods. In addition to the Río Cuhujaqui, known stands of Bald cypress occur along the lower Arroyo Guajaráy, Arroyo Guirocoba, Arroyo Tábelo, Arroyo Techobampo, and near Cedros on the Arroyo Cedro (Martin et al. 1998). The northernmost location reported in Sonora is near San Javier on a tributary of the Río Yaqui (Felger et al. 2001).

The study reach on the Río Cuchujaqui (Appendix A, Figure 8c) occupies a relatively steep, narrow canyon (cañone) bounded on both sides by bedrock throughout most of its length. There was interrupted surface flow at the time of sampling (29 March, 2006) but with extensive standing water in pools throughout the reach. Flood debris and flood-trained stems indicated that this reach experiences occasional high-energy floods.

No doubt the high species diversity found at the Río Cuchujaqui contributes to its importance as habitat for birds, and this diversity results in large part from the fact that the study site lies within the tropical deciduous forest and many of the species found at this site are near the northern terminus of their range. The presence of species derived from uplands as well as those characteristic of arroyo and canyon bottoms (Brown 1982) also contribute to vertical structural diversity, a key habitat feature for birds (Brinson et al. 1981). Along drainages like the Cuchujaqui, the riparian zone combines woody riparian species that are typical dominants along

streams the arid western U.S. (Cottonwood, Willow and Seepwillow) as well as species characteristic of humid, bottomland forest of the southeastern U.S. (Bald cypress and Button-bush). At the Cucujaqui, Bald-cypress is the dominant riparian tree, with nearly twice the total cover of Willow (2036 m^2 versus 1404 m^2). Mexican cottonwood is a relatively minor component of the forest at this site, with a total cover of 281 m^2. Whereas large Bald-cypress trees dominate overall cover for this species, seedlings, saplings and pole-sized stems are also well represented (Figure 2), suggesting that the population is healthy and actively recruiting new stems. Although representing a smaller total aerial coverage, Willow and Mexican cottonwood at the study site also show a range of stem size/height classes (Figure 3), suggesting the occurrence of flow-related geomorphic processes that are typically required for active recruitment and longer-term maintenance of these early successional riparian species (Scott et al. 2003). Finally, there was

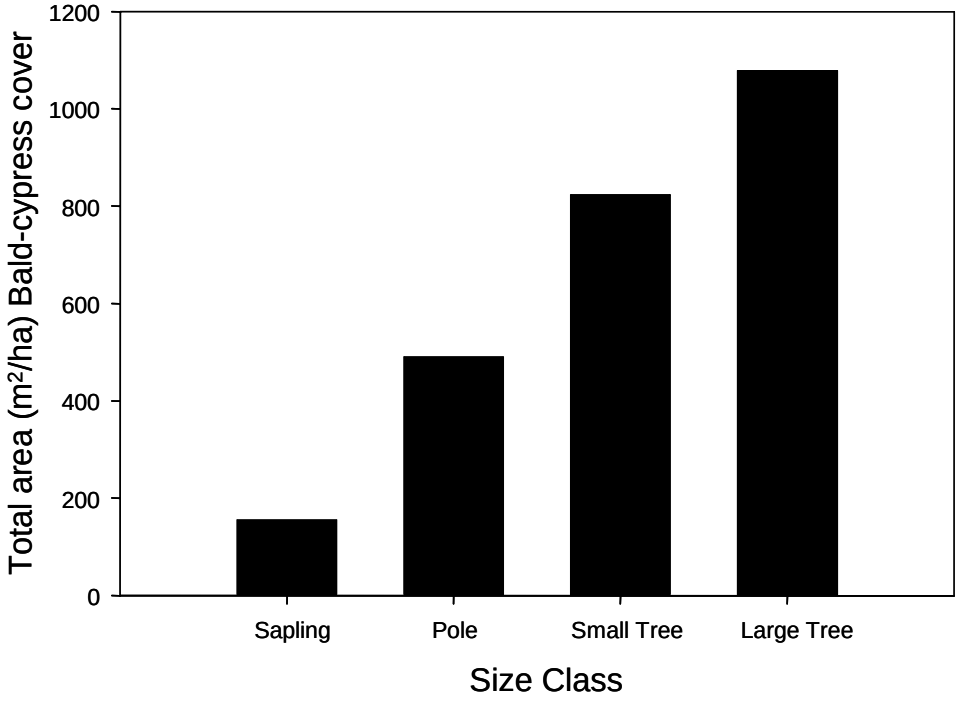

Figure 2. Total cover, by size/height class, for riparian Bald-cypress stems at the Río Cuchujaqui near Alamos, Sonora. See text for size/height class definitions.

relatively high cover of both tall and short Seepwillow as well as Button-bush at the Cuchujaqui study site (Figure 4).

In conclusion, riparian sites dominated by Willow and Bald-cypress have been shown in this study to be especially important avian habitat in Sonora. This importance likely relates to the high plant species and structural diversity at these sites, as well as their location in southern Sonora, which the northern terminus for a number of tropical plant and animal species (Brown 1982). Given the importance of this spatially limited riparian forest type in Sonora, important

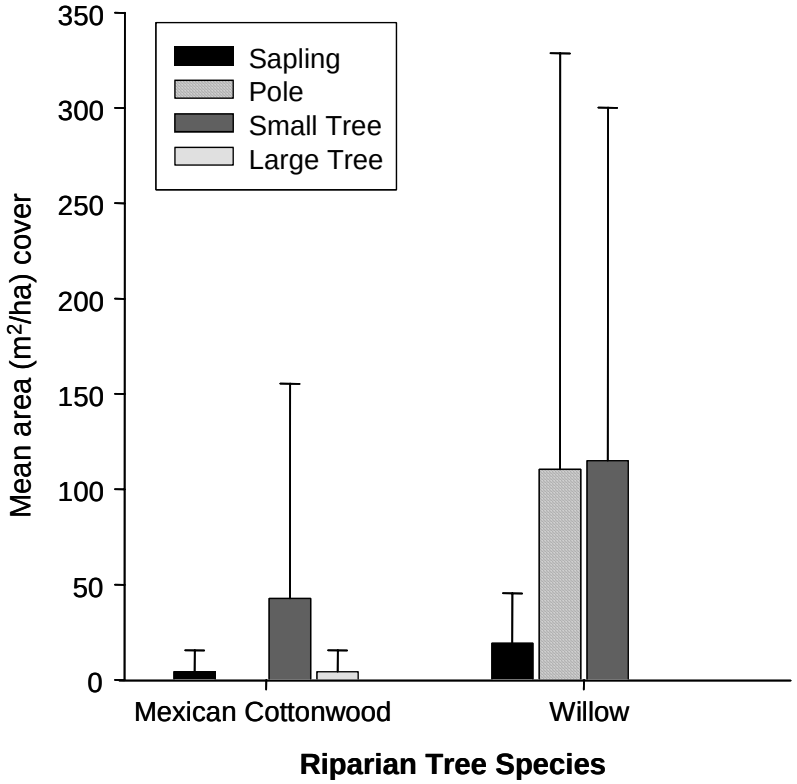

Figure 3. Mean cover (m^2/ha) ± s.d., by size/height class, for Mexican cottonwood and Willow species at the Río Cuchujaqui near Alamos, Sonora. See text for size/height class definitions.

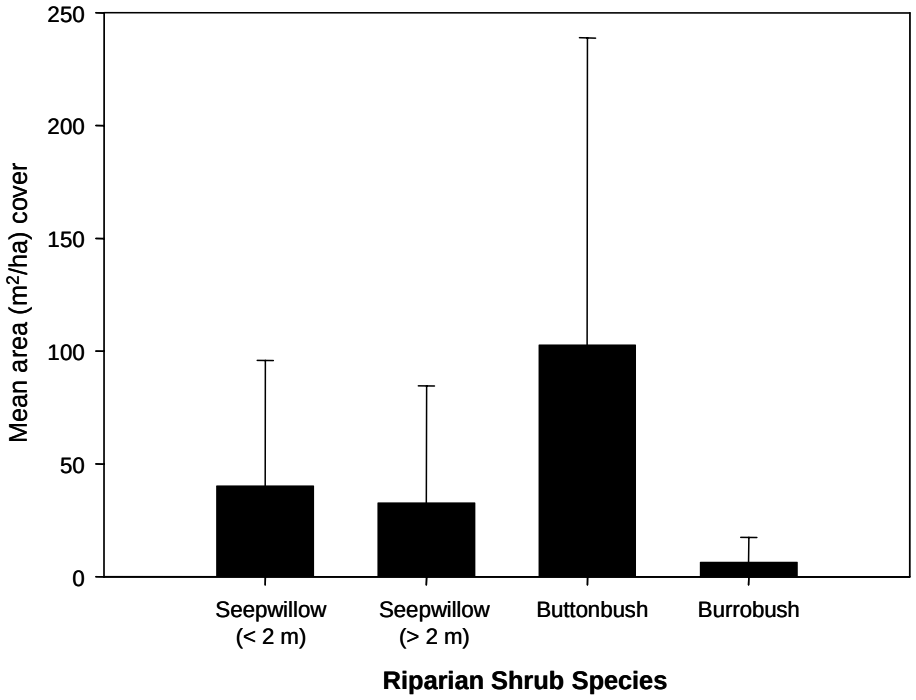

Figure 4. Mean cover (m^2/ha) ± s.d., for three shrub species at the Río Cuchujaqui near Alamos, Sonora. See text for size/height class definitions.

future conservation goals should include an inventory of known sites as well as an effort to locate additional new sites, in order to identify sites with high conservation value.

3. Relatively Disturbed and Undisturbed Riparian Site Comparisons: Ríos Sonora, Moctezuma & Sahuaripa

Although relatively disturbed and undisturbed riparian sites did not have overall significant differences in avian diversity or abundance (this report), it has been shown in this study that relatively undisturbed sites are related to lower physiological stress in birds in some years. Thus, we attempt here to quantify important structural and compositional differences between relative disturbed and undisturbed sites.

Three site pairs on the Rios Sonora, Moctezuma and Sahuaripa were selected in this regard (see bird community section of this report), based primarily upon the relative amount of agricultural conversion of riparian forest. Clearly, the amount of river bottomland area converted to agricultural use along the broad valley reaches of these three rivers is high relative to the area of riparian forest (Appendix A, Table 1). Along the Rio Sonora, both disturbed and undisturbed reaches occupy similar valley settings and, the percentage of bottomland in agriculture is > 60%. However, because the active channel and zone of riparian forest is comparatively wide, when agricultural cover is viewed at the scale of the 50 m radius vegetation plots, which were centered within the riparian corridor (Appendix A, Figures xc and yc), the amount of plot area classified as agriculture appears relatively low at both sites (Figure 5). In contrast, the Rio Moctezuma and

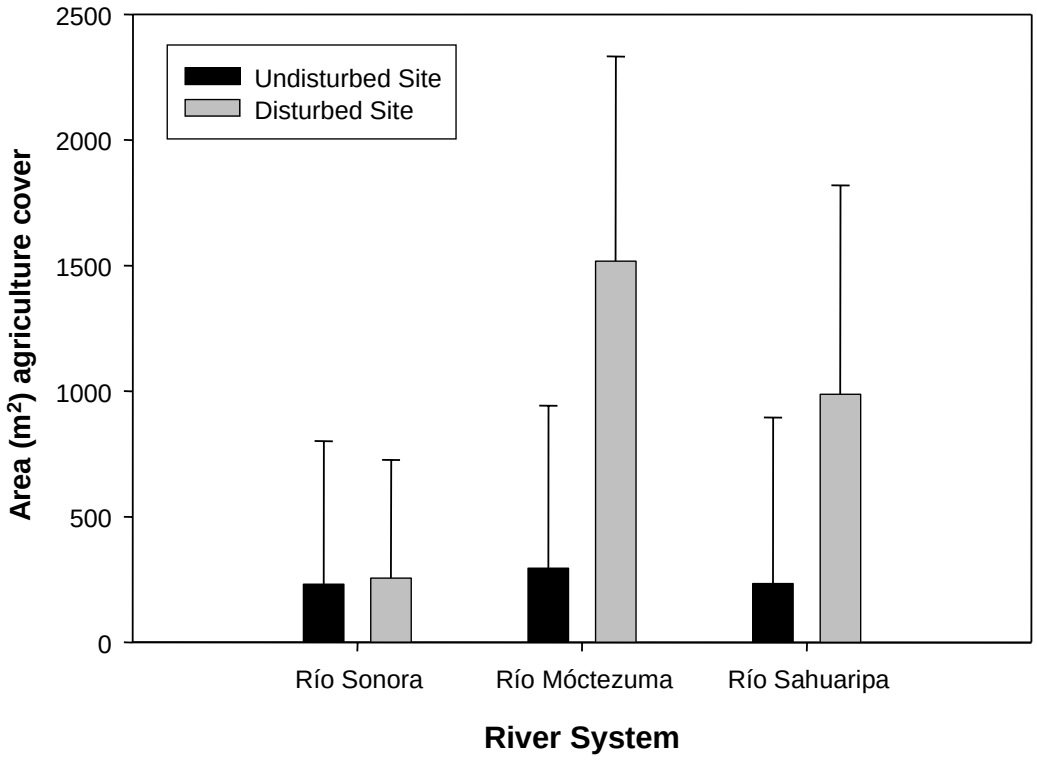

Figure 5. Mean cover (m^2/ha) ± s.d., of agricultural land-use within vegetation plots located within the riparian zone of three rivers with paired *disturbed* and *undisturbed* reach types.

Rio Sahuaripa, are both smaller rivers than the Sonora; and, their bottomlands, active channels, and riparian forest zones are correspondingly narrower. Thus, vegetation plots typically included fluvial surfaces that at the disturbed sites (Rio Moctezuma at Jecori and Rio Sahuaripa at Bamori) were often cleared for agriculture, leaving narrow strips of riparian forest between the field and the channel (Appendix A, Figures xxc and yyc) and giving these sites relatively high values for agricultural cover (Figure 5). Disturbed sites (near Terapa on the Rio Moctezuma and at Cajon de Onapa on the Rio Sahuaripa) both occurred in comparatively narrow valley settings, which limited agricultural development compared with the undisturbed sites (Appendix A, Figures xxxc and yyyc; Figure 5).

From a conservation perspective, it appears that agricultural conversion of riparian forest is especially pronounced along perennial and intermittent reaches of mid-sized rivers within relatively broad, unconfined valley settings. In such settings, agricultural clearing encroaches tightly on the active channel of the river, resulting in narrow, discontinuous bands of riparian trees between the channel and the field and leaving little room for recruitment of new stems. In some cases, a single rank of cottonwood or willow stems, are planted between the channel and the field edge. This, in essence, substitutes for the natural recruitment process and maintains vertical structural diversity on a limited scale. Examples of this kind of agricultural development within the riparian zone include the Rio Moctzuema near Jecori, the Rio Sahuaripa near Bamori and the Rio San Miguel near Cucurpe. In contrast, wider, more continuous tracts of riparian forest exist on the Rio Sonora near Baviacora, between the active channel and agricultural fields (Appendix A, Figure xc). This may relate to the fact that the Rio Sonora here is a bigger river and a large buffer of forest is left by the farmers to protect fields from floods. However, if these larger forest buffers provide superior habitat for wintering migratory birds, this suggests that wider forest buffers along some of the smaller rivers in the state could be encouraged as a way of protecting fields from floods while providing improved bird habitat. However, since such a change would take some land out of production and represents a departure from long-standing agricultural practices, the advantages of this change would have to be clearly demonstrated to landowners or supported with incentives.

We also examined vegetation structural and compositional difference between disturbed and undisturbed site pairs by looking at size class diversity of the dominant riparian shrubs and trees, as well as overall species composition, including the cover of native versus non-native species.

There were no clear differences in overall species diversity patterns between disturbed and undisturbed sites. At the Rio Moctezuma, both sites had relatively high species diversity (n = 21; Table 3). On the Rio Sahuaripa, the disturbed site at Bamori had six more species (n = 20) than the undisturbed site near Cajon de Onapa (n = 14). Both sites in the Rio Sahuaripa are downstream of a dam at Cajon de Onapa, which was completed in the early 1980s. Following completion of the dam, base flows downstream of the dam have been more consistent and locals report that the riparian forest at Bamori, dominated by Willow species, did not exist prior to the dam. Thus, the relatively low species diversity, especially at the Cajon de Onapa site, may be due in part to the recent development of this riparian forest. Species diversity at both Rio Sonora sites was relatively low (Table 3), likely the result of intensive agricultural activity and frequent fluvial disturbance, as suggested by stands of young cottonwoods and willows. Non-native species, interestingly, were not important at any of the sites sampled, and overall, had very low

frequency and abundance (cover) values (Appendix B, Table 1). At the disturbed and undisturbed site pairs, the non-native tree Chinaberry (*Melia azedarach*) appeared at all disturbed sites but with relatively low cover (Figure 6). Tamarix (*Tamarisk ramossissima*), which was present at the two southern-most sites (Rio Cuchujaqui and Rio Mayo), was found only at one other site; the undisturbed site on the Rio Sonora. Here, a sapling-sized individual was growing under the canopy of a young stand of cottonwoods in one of the sample plots. Tree tobacco (*Nicotiana glabra*), native to South America, was the most widespread non-native species and occurred at all but three sites (Rio Cucujaqui, Rio Mayo and Rio Sahuaripa near Cajon de Onapa). The mean cover for this species was consistently higher in disturbed versus non-disturbed sites (Figure 6), suggesting that it may be a good general disturbance indicator. Taken together, it appears that the non-native species, Chinaberry and Tree tobacco are generally more abundant at disturbed riparian sites, although there frequency and cover are very low compared to the native riparian species. Tamarisk, which is the focus of expensive eradication efforts along many rivers in the U.S., is at present, very rare in the systems we examined in this study.

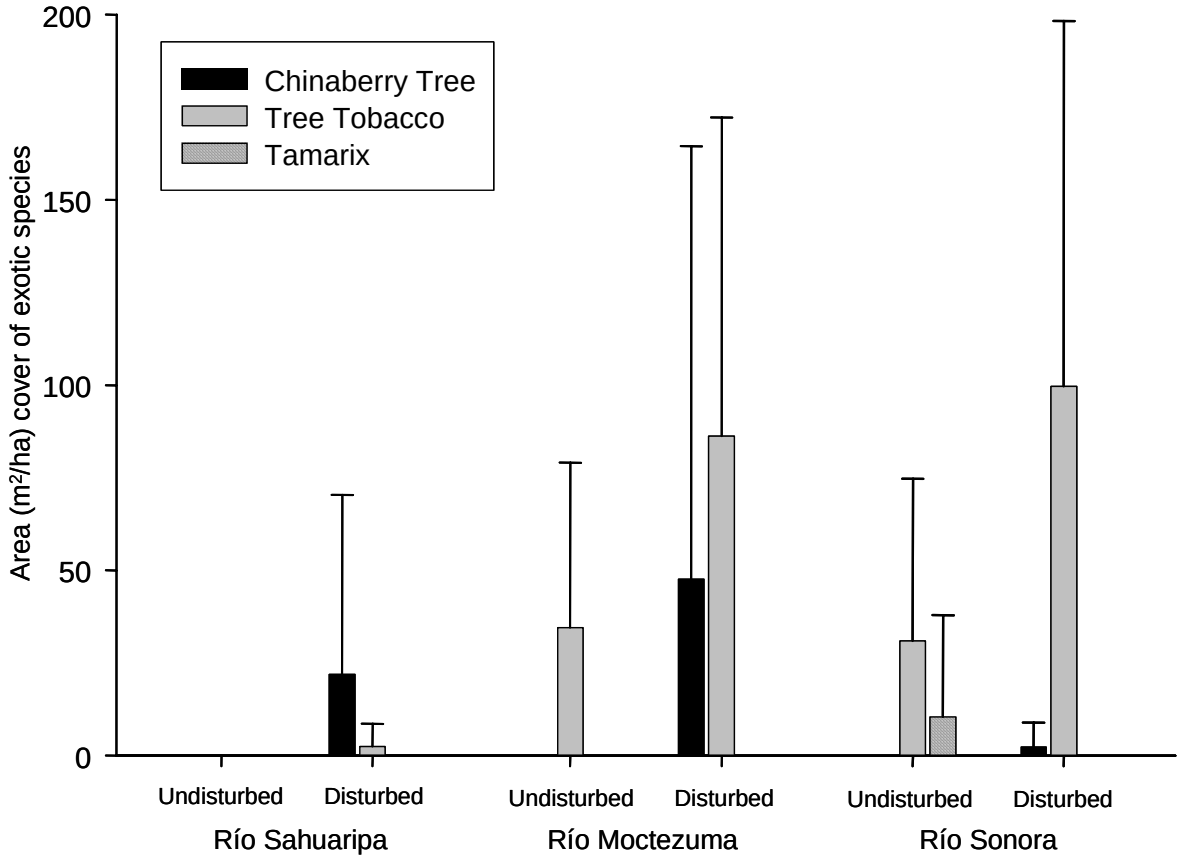

Figure 6. Mean cover (m^2/ha) ± s.d., for three non-native species found at relatively disturbed and undisturbed riparian sites along three rivers in Sonora, Mexico. Disturbed sites on the Sahuaripa, Moctezuma and Sonora rivers were near Bamori, Jecori, and Aconchi, respectively. Undisturbed sites were near Cajon de Onapa, Terapa and Baviacora, respectively.

Vertical structural diversity, presented here as mean area for different size- and height-classes of important riparian trees and shrubs, appears to be greater for cottonwood and willow stems at undisturbed sites when compared with disturbed sites (Figures 7-9).

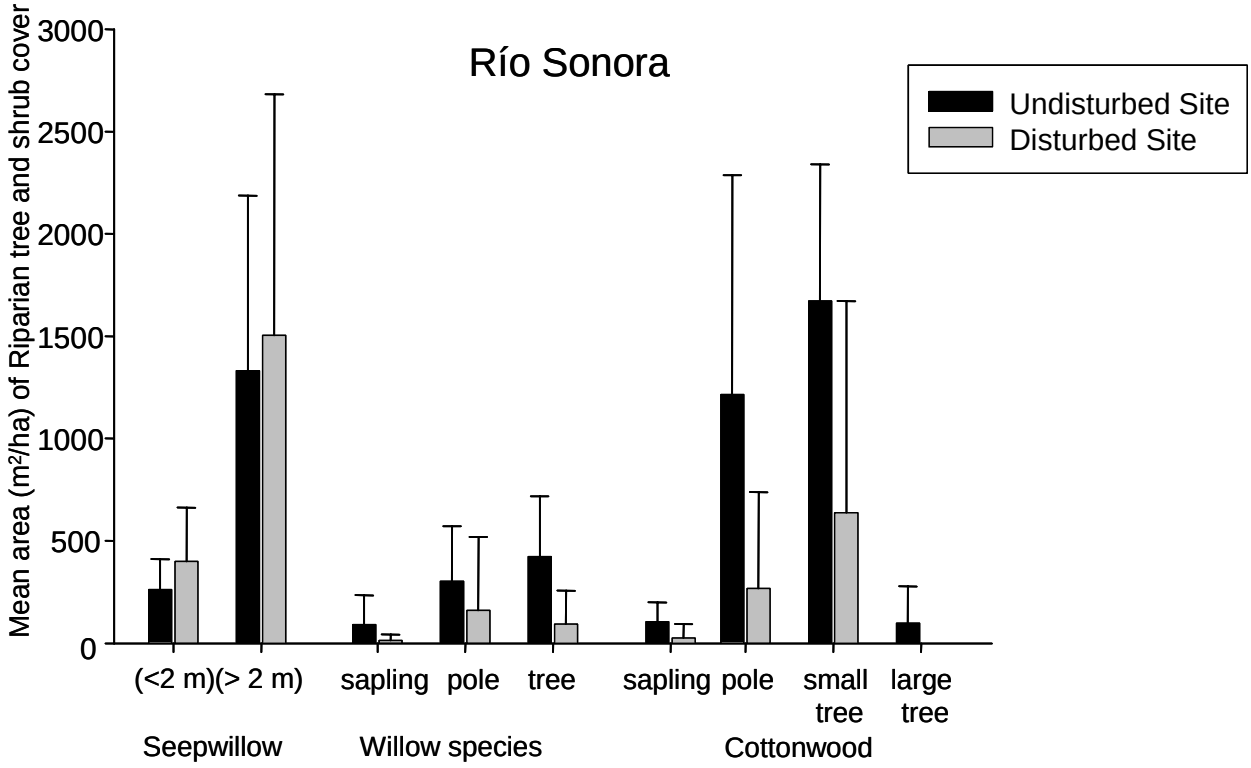

Figure 7. Mean cover (m^2/ha) ± s.d., of different stem height/size classes for Seepwillow (*Baccharis salicifolia*), Willow species (*Salix* spp.) and Cottonwood (*Populus fremontii*) along the Rio Sonora at disturbed riparian sites (near Aconchi) and relatively undisturbed sites (near Baviacora).

Because of overall high variance and relatively small sample sizes, a robust statistical examination of structural differences of the dominant native riparian trees and shrubs was not possible. However, we preformed a preliminary statistical analysis to compare total cottonwood cover between disturbed and undisturbed sites at the Rio Sonora and Rio Moctezuma (Figures 7 and 8). We did not include data from the Rio Sahuaripa, since cottonwood cover there was so low (Figure 9). For this analysis, using data from both rivers, we totaled cover across all cottonwood size-classes in seven sample plots at each disturbed and undisturbed location. We then used a paired two sample t-test to compare the means of the seven disturbed and undisturbed plots. These preliminary results indicate that cottonwood cover across all size classes in plots at undisturbed sites ($\mu = 4419$, $n = 7$) was significantly greater ($t = -4.15$; $p = 0.01$) than cover at disturbed sites ($\mu = 1572$, $n = 7$). This result supports the patterns seen in the graphs, that, at least with regard to the dominant native riparian trees and shrubs, relatively undisturbed riparian sites have more vertical structural diversity than relatively disturbed sites. This supports the idea than undisturbed sites represent better habitat for birds and is consistent with the findings from this study that in certain years, birds found in these locations may be under less physiological stress than birds at disturbed riparian forest sites.

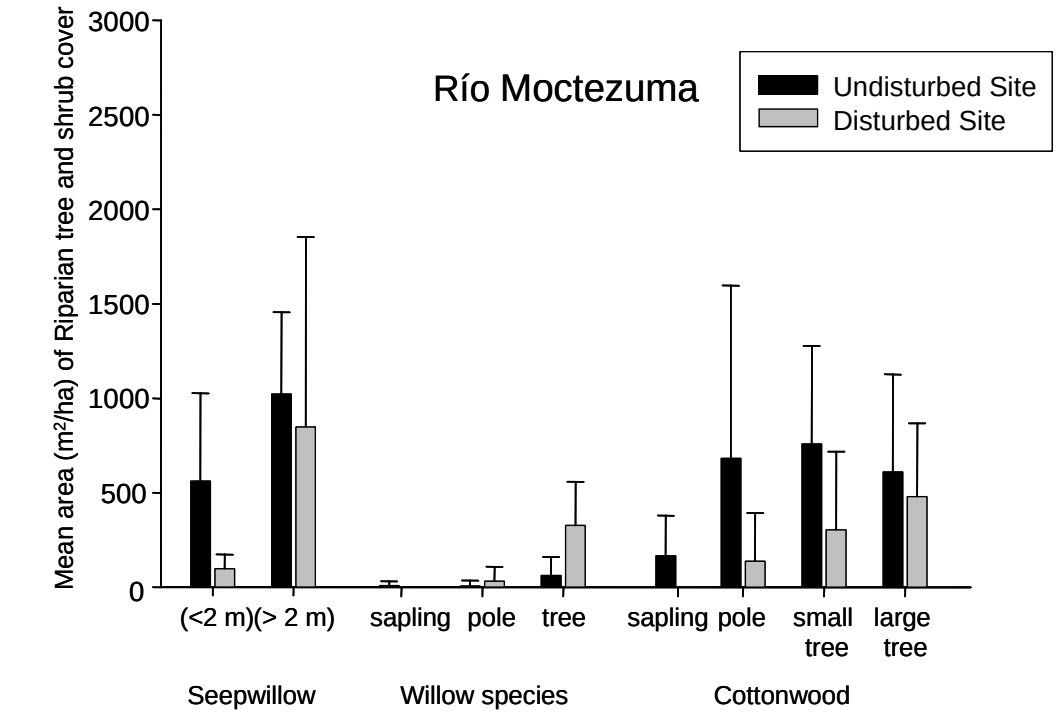

Figure 8. Mean cover (m^2/ha) ± s.d., of different stem height/size classes for Seepwillow (*Baccharis salicifolia*), Willow species (*Salix* spp.) and Cottonwood (*Populus fremontii*) along the Rio Moctezuma at disturbed riparian sites (near Jecori) and relatively undisturbed sites (near Terapa).

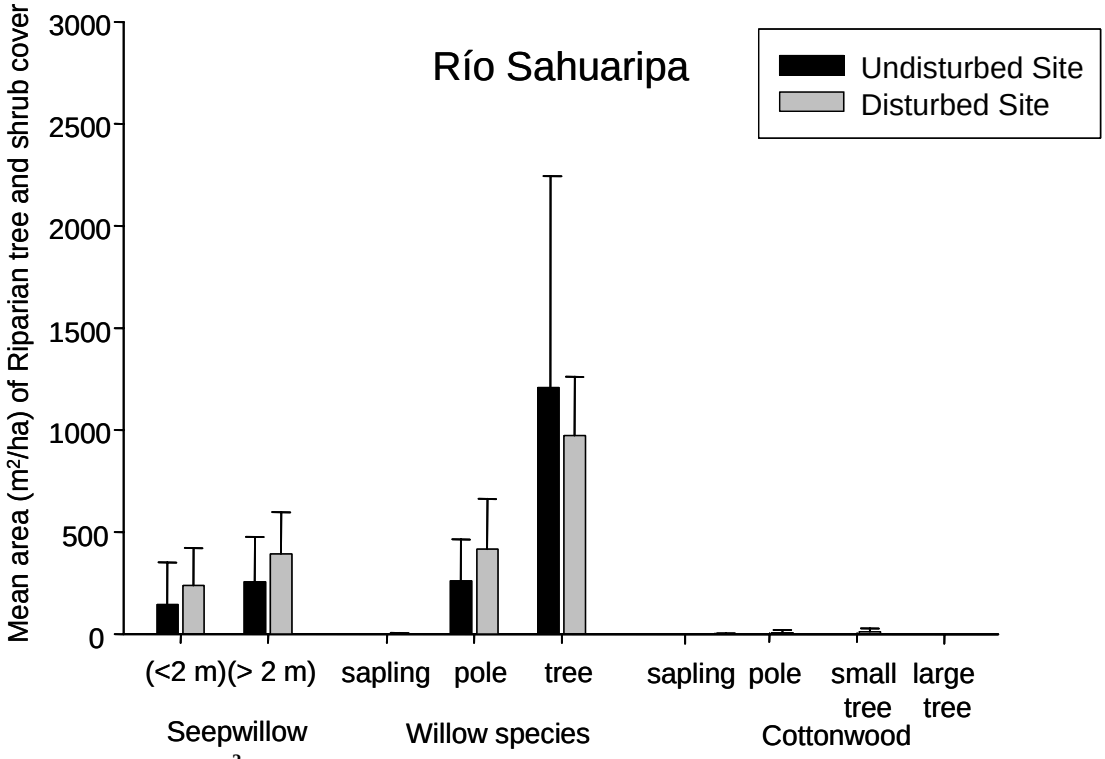

Figure 9. Mean cover (m^2/ha) ± s.d., of different stem height/size classes for Seepwillow (*Baccharis salicifolia*), Willow species (*Salix* spp.) and Cottonwood (*Populus fremontii*) along the Rio Sahuaripa at disturbed riparian sites (near Bamori) and relatively undisturbed sites (near Cajon de Onapa).

IV. SUMMARY

A. Conservation Implications and Recommendations

- Willow-Baldcypress riparian ecosystems are biologically diverse and have been shown in this study to be important habitat for birds. Mapping and inventorying biological diversity in these ecosystems throughout southern Sonora, should be a high-priority conservation goal.

- Relatively undisturbed riparian sites are correlated with lower physiological stress in birds in some years. Undisturbed riparian forest sites are characterized by having more continuous forest cover, greater size diversity of riparian trees and therefore, greater structural height diversity than disturbed riparian sites. These differences appear to be especially pronounced along smaller rivers in Sonora, where in wide, alluvial valleys agriculture typically encroaches tightly on the active channel. This results in narrow, often discontinuous bands of riparian vegetation between the channel and agricultural fields, leaving little or no space available for natural establishment.

- Planting of cottonwood and willow stems along field edges may substitute to some extent for a lack of natural recruitment of riparian trees in such settings and suggests a way by which wider, more contiguous riparian forest buffers could be restored between active river channels and agricultural fields. However, whereas such buffers would be likely to improve the overall quality of habitat for birds, establishing such buffers would necessarily take some agricultural land out of production and represents a departure from long-standing agricultural practices. The advantages of such a change would have to be clearly demonstrated to landowners or perhaps supported with incentives.

- Relatively undisturbed riparian sites generally support fewer non-native species than disturbed sites however the overall cover of non-native species in the riparian forests sampled in this study was very low. The non-native woody shrub, Tamarix, which is widespread and dominant in riparian zones along many rivers in the southwestern U.S. was extremely rare and occurred in small numbers at only 3 of 14 sites sampled. Tree tobacco (*Nicotiana glabra*), native to South America, was the most widespread non-native species and occurred at all but three sites. It was more abundant at disturbed sites and may represent a good general indicator of anthropogenic disturbance levels.

- Undisturbed riparian sites appear to have significantly greater stem size- and height-class diversity, which is generally recognized as being an important habitat feature for birds. Greater structural diversity could be restored along rivers with intensive agricultural development by establishing wider forest buffers between fields and the river channel. Wider riparian buffers would allow for the establishment of more structurally diverse and contiguous riparian forest cover by natural recruitment process, restoration efforts or both.

V. ACKNOWLEDGEMENTS

We thank the U.S. Fish and Wildlife's Neotropical Migratory Bird Program and the Sonoran Joint Venture Program (SJV) for providing the funding for this work. Thanks also to SJV for providing logistical support while in Mexico. Many thanks to Eduardo Gómez Limón for companionship in the field and for sharing his deep knowledge of the Sonoran landscape, ecology and culture. Tammy Fancher provided critical GIS support and Jill Majerus assisted with data entry. Juan Caicedo and Patrick Shafroth were key contributors to study design and implementation and Jesús Sanchez, at La Universidad de Sonora, assisted with the positive identification of several confusing plant species.

VI. LITERATURE CITED

Askins, R. A. 2000. Restoring North America's birds. Yale University Press, New Haven, Connecticut.

Brown, D.E. (ed.) 1982. Biotic communities of the American Southwest—United States and Mexico. Desert Plants 4:3-341.

Felger, R.S., M.B. Johnson and M.F. Wilson. 2001. The trees of Sonora, Mexico. Oxford University Press, New York, New York.

Johnson, R. R., L. T. Haight, and J. M. Simpson. 1977. Endangered species vs. endangered habitats: a concept. Pages 68-79 *in* Importance, preservation and management of riparian habitat: a symposium (R. R. Johnson and D. A. Jones, Jr., Eds.). USDA For. Serv. Gen. Tech. Rep. RM-43.

Knopf, F. L., R. R. Johnson, T. Rich, F. B. Samson, and R. C. Szaro. 1988. Conservation of riparian ecosystems in the United States. *Wilson Bulletin* 100:272-284.

Martin, P.S., D. Yetman, M. Fishbein, P. Jenkins, T. R. Van Devender and R. K. Wilson. 1998. Gentry's Rio Mayo Plants: the tropical deciduous forest and environs of northwest Mexico. The University of Arizona Press. Tucson, Arizona.

Mosconi, S. L., and R. L. Hutto. 1982. The effect of grazing on the land birds of a western Montana riparian habitat. Pages 221-233 *in* Proceedings of the wildlife-livestock relationships symposium (L. Nelson and J. M. Peek, Eds.). Forest, Wildlife and Range Experiment Station, Univ. Idaho, Moscow, ID.

Nabhan, G.P., and A.R. Holdsworth. 1999. State of the Desert Biome Uniqueness, Biodiversity, Threats and the Adequacy of Protection in the Sonoran Bioregion. The Wildlands Project, 2nd ed., Arizona-Sonora Desert Museum. Tucson, AZ.

Revah, L.O. 2000. Land use and the conservation of natural resources in the Tijuana river basin. Pages 210-232 *in* L.A. Hirzog, (ed.). Shared space: Rethinking the U.S.-Mexico border environment. La Jolla, CA. Center for U.S.-Mexican Studies, University of California, San Diego, CA.

Scott, M.L., S.K. Skagen, and M.F. Merligiano. 2003. Relating breeding bird diversity to geomorphic change and grazing in riparian forests. *Conservation Biology* **17**:284-296.

Appendix B

Table 1. Ranking of riparian species by dominance (total cover m^2/ha) across all sites.

Scientific name	**Common name**	**Cover (m2/ha)**
Baccharis salicifolia (>2 m)	Seepwillow / Batamote	63311
Salix spp (tree)	Willow species / Sauce	48136
Populus fremontii (small tree)	Fremont Cottonwood / Alamo	38531
Populus fremontii (pole)	Fremont Cottonwood / Alamo	27489
Prosopis spp (large)	Mesquite species / Mesquite	21696
Baccharis salicifolia (<2 m)	Seepwillow / Batamote	21310
Salix spp (pole)	Willow species / Sauce	19995
Hymenoclea monogyra	Burrobush / Jécota	18775
Populus fremontii (large tree)	Fremont Cottonwood / Alamo	17682
Acacia spp; farensiana or constricta	Sweet acacia or White-thorn / Vinorama	9900
Prosopis spp (small)	Mesquite species / Mesquite	9715
Parkinsonia aculeata	Mexican palo verde / Huacaporo	8428
Havardia mexicana	/ Palo chino	6696
Celtis pallida	Desert hackberry / Cumbro	5824
Populus fremontii (sapling)	Fremont Cottonwood / Alamo	4775
Pithecellobium dulce	Manila tamarind/ Guamúchil	3477
Nicotiana glabra	Tree tobacco / Cornetón	3267
Vallesia glabra	/ Sitavaro	3122
Acacia cochliacantha	Boat-thorn acacia / Chírahui	2014
Salix spp (sapling)	Willow species / Sauce	1975
Pisonia capitata	/ Garabato	1946
Cryptostegia grandiflora	/ Bejuco	1854
Sambucus nigra	Elderberry /	1800
Buddleja sessiliflora	/ Tepozana	1332
Cephalanthus salicifolius	Button-bush / Mimbro	1311
Trixis californica?		1220
Juglans major	Walnut / Nogal	1171
Taxodium distichum var. mexicanum (large tree)	Bald cypress / Sabino	1078
Baccharis sarathroides (<2 m)	Broom baccharis / Hierba del pasmo	873
Taxodium distichum var. mexicanum (small tree)	Bald cypress / Sabino	823
Fraxinus velutina	Velvet Ash / Fresno	716
Guazuma ulmifolia	Pricklenut / Guásima	677
Tamarisk ramossissima (pole)	Tamarix / Tamarisco	597
		553
Baccharis sarathroides (>2 m)	Broom baccharis / Hierba del pasmo	510
Melia azedarach	Chinaberry Tree / Piocha	505
Lycium spp		495
Taxodium distichum var. mexicanum (pole)	Bald cypress / Sabino	490
Chrysothamnus spp	Rabbitbrush /	470
Salix exigua	Sandbar Willow /	406
Havardia spp, H. mexicana or H. sonorae	/ Palo chino or Palo jócono	401
Platanus wrightii	Arizona sycamore /	395
Baccharis spp (<2 m)		338
Baccharis spp (>2 m)		325
Phaulothamnus spinescens	Snake-eyes / Báaco	317
Arundo donax	Giant reed / Carrizo	300
Albizia sinaloensis	/ Palo joso	299
Populus mexicana s ubsp. *dimorpha* (small tree)	Mexican Cottonwood / Alamo	298

Appendix B

Table 1. Ctd.

Scientific name	Common name	Cover m2/ha
Condalia globosa var. globosa	Bitter condalia / Mesquitillo	276
Ricinus communis	Castor-bean / Higuerilla	265
Ziziphus obtusifolia	Gray-thorn / Ciruela de monte	248
Acacia gregii	Catclaw acacia / Uña de gato	232
Salix spp (seedling)	Willow species / Sauce	195
Ficus spp		172
Morus spp	Mulberry /	162
Taxodium distichum var. mexicanum (sapling)	Bald cypress / Sabino	156
Tamarisk aphylla	Athel / Pino salado	153
Aster spinosis	Spiny aster /	131
Senna atomarra	/ Palo zorillo	123
Prosopis glandulosa	Honey mesquite / Mesquite	106
Tamarisk ramossissima (sapling)	Tamarix / Tamarisco	103
Ziziphus spp, Z. amole or Z. obtusifolia	/ Saituna or Gray-thorn / Ciruela de	100
Acacia farensiana	Sweet acacia / Vinorama	93
Celtis igunea	/ Granjeno	84
Vitex mollis	/ Uvalama	74
Morus microphylla	Texas mulberry / Salsa mora	70
Randia echinocarpa	/ Papache	65
Celtis reticulata	Netleaf hackberry / Cumbro	57
Agonandra racemosa	/ Palo verde	54
Parkinsonia spp	Palo verde /	46
Taxodium distichum var. *mexicanum* (seedling)	Bald cypress / Sabino	45
Indigofera suffruticosa	Indigo / Añil	41
Populus fremontii (seedling)	Fremont Cottonwood / Alamo	38
Populus mexicana s ubsp. *dimorpha* (sapling)	Mexican Cottonwood / Alamo	30
Populus mexicana subsp. *dimorpha* (large tree)	Mexican Cottonwood / Alamo	30
Psidium guajava	/ Guayabo	30
Bursura spp		29
Coursetia glandulosa	/ Samo prieto	26
Heliocarpus spp; H. attenuatus or H. palmeri	/ Samo blanco or Samo prieto	26
Malus pumila	Apple / Manzana	25
Parkinsonia praecox	/ Palo brea	25
Cassia spp		20
Ziziphus amole	/ Saituna	20
Dodonaea viscosa	/ Jarilla	18
Stegnosperma halimifolium	/ Amole	14
Condalia globosa var. pubescens	Bitter condalia / Mesquitillo	13
Tamarisk ramossissima (seedling)	Tamarix / Tamarisco	9
Salix spp (resprout)	Willow species / Sauce	7
Bebia juncea		7
Karwinskia humboldtiana	Buckthorn / Cacachila	6
Typha spp	Cattail species /	3
Parkinsonia florida	Blue palo verde / Palo verde	3
Populus fremontii (resprout)	Fremont Cottonwood / Alamo	2

Appendix B

Table 2. Ranking of riparian species by frequency (total cover m^2/ha) across all sites.

Scientific name	Common name	Frequency
Baccharis salicifolia	Seepwillow / Batamote	79
Baccharis salicifolia	Seepwillow / Batamote	77
Prosopis spp (small)	Mesquite species / Mesquite	75
Salix spp (resprout)	Willow species / Sauce	62
Acacia spp; farensiana or constricta	Sweet acacia or White-thorn / Vinorama	59
Hymenoclea monogyra	Burrobush / Jécota	59
Salix spp (tree)	Willow species / Sauce	53
Celtis pallida	Desert hackberry / Cumbro	49
Prosopis spp (large)	Mesquite species / Mesquite	49
Nicotiana glabra	Tree tobacco / Cornetón	48
Parkinsonia aculeata	Mexican palo verde / Huacaporo	46
Populus fremontii (small tree)	Fremont Cottonwood / Alamo	43
Populus fremontii (pole)	Fremont Cottonwood / Alamo	41
Populus fremontii (large tree)	Fremont Cottonwood / Alamo	29
Salix spp (pole)	Willow species / Sauce	29
Buddleja sessiliflora	/ Tepozana	28
Populus fremontii (sapling)	Fremont Cottonwood / Alamo	27
Sambucus nigra or mexicana	Elderberry /	19
Acacia cochliacantha	Boat-thorn acacia / Chírahui	16
Havardia mexicana	/ Palo chino	16
Lycium spp		15
Juglans major	Walnut / Nogal	13
Salix spp (seedling)	Willow species / Sauce	12
Acacia gregii	Catclaw acacia / Uña de gato	11
Baccharis sarathroides	Broom baccharis / Hierba del pasmo	10
Cephalanthus salicifolius	Button-bush / Mimbro	10
Pithecellobium dulce	Manila tamarind/ Guamúchil	10
Chrysothamnus spp	Rabbitbrush /	9
Fraxinus velutina	Velvet Ash / Fresno	9
Cryptostegia grandiflora	/ Bejuco	8
Vallesia glabra	/ Sitavaro	8
Phaulothamnus spinescens	Snake-eyes / Báaco	7
Ricinus communis	Castor-bean / Higuerilla	7
Baccharis spp		6
Pisonia capitata	/ Garabato	6
Acacia farensiana	Sweet acacia / Vinorama	5
Condalia globosa var. globosa	Bitter condalia / Mesquitillo	5
Melia azedarach	Chinaberry Tree / Piocha	5
Platanus wrightii (or racemosa)	Arizona sycamore /	5
Ziziphus obtusifolia	Gray-thorn / Ciruela de monte	5
Ziziphus spp, Z. amole or Z. obtusifolia	/ Saituna or Gray-thorn / Ciruela de monte	5
Arundo donax	Giant reed / Carrizo	4
Bursura spp		4
Ficus spp		4
Havardia spp, H. mexicana or H. sonorae	/ Palo chino or Palo jócono	4
Morus spp	Mulberry /	4
Populus fremontii (seedling)	Fremont Cottonwood / Alamo	4
Taxodium distichum var. mexicanum (pole)	Bald cypress / Sabino	4
Baccharis sarathroides	Broom baccharis / Hierba del pasmo	3

Appendix B

Table 2. Ctd.

Scientific name	Common name	Frequency
Celtis reticulata	Netleaf hackberry / Cumbro	3
Guazuma ulmifolia	Pricklenut / Guásima	3
Randia echinocarpa	/ Papache	3
Salix exigua	Sandbar Willow /	3
Taxodium distichum var. mexicanum (small tree)	Bald cypress / Sabino	3
Trixis californica?		3
Vitex mollis	/ Uvalama	3
Albizia sinaloensis	/ Palo joso	2
Baccharis spp		2
Celtis igunea	/ Granjeno	2
Indigofera suffruticosa	Indigo / Añil	2
Parkinsonia spp	Palo verde /	2
Prosopis glandulosa	Honey mesquite / Mesquite	2
Senna atomarra	/ Palo zorillo	2
Tamarisk ramossissima (sapling)	Tamarix / Tamarisco	2
Taxodium distichum var. mexicanum (large tree)	Bald cypress / Sabino	2
Taxodium distichum var. mexicanum (sapling)	Bald cypress / Sabino	2
Taxodium distichum var. *mexicanum* (seedling)	Bald cypress / Sabino	2
Agonandra racemosa	/ Palo verde	1
Aster spinosis	Spiny aster /	1
Bebia juncea		1
Cassia spp		1
Condalia globosa var. pubescens	Bitter condalia / Mesquitillo	1
Coursetia glandulosa	/ Samo prieto	1
Dodonaea viscosa	/ Jarilla	1
Heliocarpus spp; H. attenuatus or H. palmeri	/ Samo blanco or Samo prieto	1
Karwinskia humboldtiana	Buckthorn / Cacachila	1
Morus microphylla	Texas mulberry / Salsa mora	1
Parkinsonia florida	Blue palo verde / Palo verde	1
Parkinsonia praecox	/ Palo brea	1
Populus fremontii (resprout)	Fremont Cottonwood / Alamo	1
Populus mexicana subsp. *dimorpha* (large tree)	Mexican Cottonwood / Alamo	1
Populus mexicana s ubsp. *dimorpha* (sapling)	Mexican Cottonwood / Alamo	1
Populus mexicana s ubsp. *dimorpha* (small tree)	Mexican Cottonwood / Alamo	1
Psidium guajava	/ Guayabo	1
Salix spp (sapling)	Willow species / Sauce	1
Stegnosperma halimifolium	/ Amole	1
Tamarisk aphylla	Athel / Pino salado	1
Tamarisk ramossissima (pole)	Tamarix / Tamarisco	1
Tamarisk ramossissima (seedling)	Tamarix / Tamarisco	1
Typha spp	Cattail species /	1
Malus pumila	Apple / Manzana	1
Punica granatum	Pomegranate	1
Ziziphus amole	/ Saituna	1