

BIRD USE OF COTTONWOOD-WILLOW PATCHES
IN THE LOWER COLORADO RIVER VALLEY

by
Suellen Lynn

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 SCIENCES
In the Graduate College
THE UNIVERSITY OF ARIZONA

1 9 9 6

STATEMENT BY AUTHOR

This thesis has been submitted in partial fulfilment of requirements for an advanced degree at The University of Arizona and is deposited in the University Library to be made available to borrowers under rules of the Library.

Brief quotations from this thesis are allowable without special permission, provided that accurate acknowledgment of source is made. Requests for permission for extended quotation from or reproduction of this manuscript in whole or in part may be granted by the head of the major department or the Dean of the Graduate College when in his or her judgment the proposed use of the material is in the interests of scholarship. In all other instances, however, permission must be obtained from the author.

SIGNED: _____

APPROVAL BY THESIS COMMITTEE

This thesis has been approved on the date shown below:

Michael L. Morrison
MICHAEL L. MORRISON, Thesis Director
Adjunct Professor of
Wildlife and Fisheries Sciences

23 Jan. 1996
Date

D. Philip Guertin
D. PHILIP GUERTIN
Assistant Professor of
Renewable Natural Resources

1/23/96
Date

R. William Mannan
R. WILLIAM MANNAN
Associate Professor of
Wildlife and Fisheries Sciences

1/24/96
Date

ACKNOWLEDGEMENTS

I thank the United States Fish and Wildlife Service, especially K. Milne and W. Martin, for funding and initiating this project, the personnel at Bill Williams River, Cibola, Havasu, and Imperial National Wildlife refuges, including Nancy Gilbertson, James Good, Timothy Green, Steven Hill, Elaine Johnson, Carmen Kennedy, Andrew Loranger, Angel Montoya, Barbara Raulston, Christy Smith, and Gregg Wolf, for logistical and moral support; Dawn Drumtra, Michael Dutenhoffer, Peter Hurley, Laurel Christoferson, and Nikole Brown for cheerful and competent help in the field; all my fellow graduate students, especially Maite Sureda, who sympathized and goaded me on, D.P. Guertin, R.W. Mannan, and M.L. Morrison for guidance, and especially John Martin, who is my inspiration.

TABLE OF CONTENTS

LIST OF FIGURES.....	6
LIST OF TABLES.....	7
ABSTRACT.....	8
INTRODUCTION.....	9
OBJECTIVES.....	20
STUDY SITE.....	21
Imperial National Wildlife Refuge.....	21
Cibola National Wildlife Refuge.....	26
Bill Williams River	
National Wildlife Refuge.....	29
Havasu National Wildlife Refuge.....	30
Overall.....	32
METHODS - OBJECTIVE #1.....	33
Cottonwood-Willow Patches.....	33
<u>Study Site Establishment</u>	33
<u>Survey Method</u>	34
<u>Vegetation Sampling</u>	36
<u>Statistical Analyses</u>	39
Micro-Scale.....	44
Meso-Scale.....	44
Macro-Scale.....	46
METHODS - OBJECTIVE #2.....	47
METHODS - OBJECTIVE #3.....	48
Bird Species of Interest.....	48
Survey Methods.....	48
Nest Vegetation Sampling.....	49
Statistical Analyses.....	50
RESULTS.....	54
Bird Abundance Analyses.....	54
<u>Micro Analyses</u>	54
<u>Meso Analyses</u>	59
<u>Macro Analyses</u>	62
<u>Individual Neotropical Migratory</u>	
<u>Species Over All Scales of Analysis</u>	69
Patch Size.....	69
Tree Density.....	69
Species Richness Analyses.....	71
<u>Micro Analyses</u>	71
<u>Meso Analyses</u>	71
<u>Macro Analyses</u>	75
Reproductive Analyses.....	75
DISCUSSION.....	80
Overall Conclusions.....	80
Intercorrelation Conclusions.....	80

TABLE OF CONTENTS - *Continued*

Neotropical Migrants and Cottonwood-	
Willow Obligates.....	81
Threshold Conclusions.....	83
Breeding Conclusions.....	84
Scale Conclusions.....	87
MANAGEMENT IMPLICATIONS.....	89
APPENDIX A - BIRD HABITAT USE	
DATA SHEET PROTOCOL.....	94
APPENDIX B - BIRD SURVEY VEGETATION SAMPLING	
PROTOCOL.....	97
APPENDIX C1 - NEST RECORD DATA SHEET 1 PROTOCOL.	101
APPENDIX C2 - NEST RECORD DATA SHEET 2 PROTOCOL.	103
APPENDIX D - VEGETATION SAMPLING IN 5-METER	
RADIUS CIRCLE AT NEST PROTOCOL.....	105
LITERATURE CITED.....	108

LIST OF FIGURES

FIGURE 1, Map of Study Sites.....	22
FIGURE 2, Bird Survey Point.....	35
FIGURE 3, Sector of Bird Survey Point.....	37
FIGURE 4, Sample Size Analysis: Correlation of Patch Size and Tree Density with Species Richness by Increasing Sample Size.....	43
FIGURE 5, Number of Bird Species with Significant Positive Relationships with Patch Size and Tree Density, Across All Scales ($P \leq 0.10$).....	70

LIST OF TABLES

TABLE 1, Common and Latin Names of the 42 Bird Species in the Lower Colorado River Valley Used in Analyses.....	17
TABLE 2, Study Plots, Location, Approximate Size of Cottonwood/Willow Patch, and General Vegetation Characteristics.....	23
TABLE 3, Mayfield Indices for Yellow-Breasted Chat and Bell's Vireo Across all Study Plots.	51
TABLE 4, Regression Statistics, Spearman's Rank Coefficient and Probability, for All Locally Breeding Birds in the Lower Colorado River Valley, Micro-Scale.....	55
TABLE 5, Intercorrelation Statistics: Spearman's r_s Between Independent Variables, Patch Size, Tree Density, and Maximum Distance to Nearest Cottonwood or Willow Tree, All Scales.....	58
TABLE 6, Regression Statistics, Spearman's Rank Coefficient and Probability, for All Locally Breeding Birds in the Lower Colorado River Valley, Meso-Scale.....	60
TABLE 7, Regression Statistics, Spearman's Rank Coefficient and Probability, for All Locally Breeding Birds in the Lower Colorado River Valley, Macro-Scale.....	63
TABLE 8, Bird Species Richness Regression Statistics: Pearson's r at all Analytical Scales.....	72
TABLE 9, Breeding Statistics for Bell's Vireo and Yellow-breasted Chat.....	76

ABSTRACT

Neotropical migratory birds and riparian forests have decreased in abundance over the past century. Decreases in bird populations have been linked to forest fragmentation. I performed bird surveys and monitored nesting success of Bell's Vireos (Vireo bellii) and Yellow-breasted Chats (Icteria virens) in a range of cottonwood/willow patch sizes and densities in the lower Colorado River valley to determine whether bird abundances, species richness, and reproductive success were related to cottonwood/willow patch size and/or tree density. Results suggest that neotropical migrants responded to patch size and tree density more than did resident birds. Results of breeding analyses suggest that small patches may be ecological sinks. Analyses excluding large patches indicated a threshold between 13 and 160 ha at which bird abundances stopped increasing with increasing patch size. This study demonstrated that neotropical migratory birds use small patches; however, large, dense patches are required for persistence of breeding populations.

INTRODUCTION

Numbers of neotropical migratory birds (Wilcove and Whitcomb 1983, Terborgh 1989, Robbins et al. 1989, Roth and Johnson 1993, Peterjohn and Sauer 1994) and the extent of riparian forests (Smith 1977, Ohmart et al. 1977, Howe and Knopf 1991, Mahoney and Rood 1991, Snyder and Miller 1992) are decreasing throughout the western United States. Riparian forests, with high structural and floristic diversity, are sources of food, water, shelter, and other necessary resources to breeding birds (MacArthur and MacArthur 1961, Carothers et al. 1974, Hubbard 1977, Mills et al. 1991). Because neotropical migratory birds tend to concentrate in riparian vegetation (Bottorff 1974, Carothers et al. 1974, Gates and Giffen 1991), a relationship may exist between the fragmentation and loss of riparian forest and the decline in abundance of neotropical migratory birds. Klebenow and Oakleaf (1984) documented a decline in neotropical migratory birds along the Truckee River in California concurrent with loss of riparian vegetation.

Along with the effect of general habitat loss, the size of the remaining fragments also has an effect on bird abundance and richness. Many studies have shown that bird density and species richness found in a forest fragment

are correlated with the area of that fragment (e.g., Martin 1981, Lynch and Whigham 1984, Askins et al. 1987), especially for neotropical migratory species (Holmes et al. 1992, Johns 1993, Robinson and Wilcove 1994).

A possible explanation for a decrease in bird density and species richness in small patches may be edge effect (Gates and Gysel 1978, Wilcove 1985, Holmes et al. 1992, O'Conner and Faaborg 1992). Smaller patches have proportionately more edge than larger patches (Ranney et al. 1981). Along with a decrease in abundance of forest interior birds and an increase in abundance of edge bird species, there may be an increase in predation and nest parasitism in these fragments (Gates and Gysel 1978, Wilcove 1985, Holmes et al. 1992, Robinson and Wilcove 1994). The smaller the fragment, the larger the impact of predation and nest parasitism on the birds present (Yahner and Scott 1988). Small patches may be ecological sinks (Pulliam 1988, Robinson 1992); birds may be present and breeding in similar numbers as in larger patches, but may have less breeding success. Therefore, the individuals that breed in the smaller patches may not contribute to the overall population and breeding effort is wasted.

Ecological sinks are less of a problem when a source area is nearby, in which breeding success is sufficient to

make up for natural mortality in the source area as well as supply excess individuals that can colonize other areas (i.e., the sinks; Askins and Philbrick 1987, Pulliam 1988, Robinson and Wilcove 1994). However, when there is only one source area and that area is fragile, one catastrophic event, such as a tree-killing fire or flood, could devastate the bird community.

A conservative estimate of edge effect in a forest fragment puts the width of the edge at two times the height of the tallest tree into the fragment (Franklin and Forman 1987). According to this criterion, the fragments of native riparian forest in the lower Colorado River valley, aside from the Bill Williams River valley, are comprised exclusively of edge, and therefore are subject to edge effect (Ranney et al. 1981).

The Colorado River is an example of the relationship between the disappearance of the native cottonwood-willow riparian vegetation and a concomitant loss in bird numbers. Historical records from the 1600's describe a cottonwood-willow forest corridor up to 4 kilometers wide running the length of the lower Colorado River, from the present location of Davis Dam to the Mexican border (322 km) (Bolton MS. in Ohmart et al 1977). Ohmart et al. (1977) described the loss of Fremont cottonwoods,

Goodding's willow, and mesquite (Prosopis spp.) from the lower Colorado River valley due to firewood harvest, agricultural practices, and flood control methods.

Rosenberg et al. (1991) conducted intensive monitoring of bird populations along the lower Colorado River from 1974 to 1986. They documented a decrease in the diversity and abundance of bird species in the cottonwood-willow riparian vegetation compared to Grinnell's findings in 1910 (Grinnell 1914). In addition, there was a significant decrease in abundance of several bird species while the study was underway (Rosenberg et al. 1991:34).

At the time of my study, there were no patches of mature native cottonwood-willow vegetation that covered more than 20 hectares along the lower Colorado River (Ohmart et al. 1988). The Bill Williams River valley supported the only large portion (about 160 ha) of native riparian forest left in the lower Colorado River valley. The Bill Williams riparian forest was mainly young cottonwood and willow trees gradually recovering from a prolonged release of flood waters in the early 1980's from the Alamo dam 30 kilometers upstream. The flood drowned a large portion of the mature cottonwoods in the Bill Williams riparian area (Hunter et al. 1987). Repeated

fires also reduced the Bill Williams native riparian forest to a fraction of its former extent (B. Raulston, United States Fish and Wildlife Service Biologist, Bill Williams River National Wildlife Refuge, pers. commun.).

A major factor in the decline of native riparian vegetation along the lower Colorado River was the introduction of salt cedar as an ornamental species and flood control measure in the early 1900's (Anderson et al. 1977). Initially, salt cedar was not a successful competitor with the native riparian vegetation. Grinnell (1914) did not mention or collect any salt cedar specimens during his journey down the lower Colorado River in 1910. Between 1910 and 1920, however, salt cedar gained a foothold along the lower Colorado River (Ohmart et al. 1977).

The increase in salt cedar abundance in the lower Colorado River valley was primarily due to alterations in the natural hydrologic cycle and the native vegetative community. Flood control decreased the deposition of sediments throughout the floodplain. These floods and sediments promoted seed dispersal and the natural regeneration of cottonwood and willow trees and aided in the decomposition of leaf litter. The accumulation of leaf litter has provided the fuel for cottonwood-killing

fires (Anderson et al. 1977). Channelization and agricultural irrigation have dropped the water table and raised the soil salinity on the floodplain, conditions which are fatal to cottonwoods. Salt cedar can tolerate high soil salinity, is highly flammable, and regenerates readily after fires (Howe and Knopf 1991). The native Fremont cottonwood cannot regenerate after intense fires, and flooding is necessary to cause cottonwood seed regeneration. Therefore, salt cedar has replaced cottonwood as the dominant riparian vegetation type in the lower Colorado River valley (Anderson et al. 1977).

Anderson et al. (1977) found that the most useful type of riparian vegetative community for birds was the native cottonwood-willow association. All structural types of cottonwood-willow were superior to any structural type of salt cedar, with respect to bird use. The most used salt cedar structural type--the nearly mature stands of salt cedar--ranked only sixth out of eight riparian vegetative communities for relative value to birds (Anderson et al. 1977).

As mature, gallery riparian forests no longer occur along the lower Colorado River, examining the remaining fragments of cottonwood-willow riparian vegetation can determine the importance of the native fragments to birds,

relative to the exotic species of riparian vegetation. As previously mentioned, the size of the cottonwood-willow forest fragment should be a major determinant of the number of birds found therein. However, the fragments that remained during my study also represented a great range in tree density and configuration. All of the remaining native cottonwood-willow forest fragments had a dense understory of, and were surrounded by, salt cedar. Salt cedar was not a primary attractor of birds in the lower Colorado River valley in the 1970's and 1980's (Anderson et al. 1977). However, the remaining stands of isolated and semi-isolated, single and small groups of cottonwood-willow trees, even with a dense salt cedar understory, probably attracted a small number of neotropical migratory birds, relative to pure salt cedar (Anderson et al. 1977).

My objective was to determine whether the fragments of cottonwood and/or willow forest remaining in the lower Colorado River valley are sufficient to sustain a healthy population of breeding birds. Wiens et al. (1987) and Steele (1992) found that often birds will exhibit a habitat association that can be differentiated between sites but is not a factor within a site. For example, Steele (1992) found that Black-throated Blue Warblers

(common and latin names of bird species in Table 1) showed an affinity for sites with more shrub cover, but within a site, individual birds did not select territories based on shrub cover. Therefore, I also examined the relationship of bird species richness and abundances with cottonwood-willow patch size and tree density at 3 scales (see methods).

Because bird density is often a misleading indicator of habitat quality (Van Horne 1983), I also examined nesting attempts to determine whether breeding attempts and success reflect the conclusions reached from measuring bird abundance and species richness in these cottonwood-willow patches. The results of my study will aid in making management decisions concerning the validity of maintaining small, isolated patches of cottonwood and willow trees, as well as the value of replanting cottonwood and willow trees; and determining the appropriate patch sizes and tree densities for revegetation efforts.

Table 1. Common and Latin Names of the all Bird Species in the Named in Text (AOU 1983).

Common Name	Latin Name
Gambel's Quail	<u>Callipepla gambelii</u>
Killdeer	<u>Charadrius vociferus</u>
*White-winged Dove	<u>Zenaida asiatica</u>
Mourning Dove	<u>Zenaida macroura</u>
*+Yellow-billed Cuckoo	<u>Coccyzus americanus</u>
Greater Roadrunner	<u>Geococcyx californianus</u>
Gila Woodpecker	<u>Melanerpes uropygialis</u>
Ladder-backed Woodpecker	<u>Picoides scalaris</u>
*+Vermilion Flycatcher	<u>Pyrocephalus rubinus</u>
*Ash-throated Flycatcher	<u>Myiarchus cinerascens</u>
*+Brown-crested Flycatcher	<u>Myiarchus tyrannulus</u>
*+Western Kingbird	<u>Tyrannus verticalis</u>
Verdin	<u>Auriparus flaviceps</u>
Cactus Wren	<u>Campylorhynchus</u> <u>brunneicapillus</u>
+Bewick's Wren	<u>Thryomanes bewickii</u>
Marsh Wren	<u>Cistothorus palustris</u>
Black-tailed Gnatcatcher	<u>Polioptila melanura</u>
Crissal Thrasher	<u>Toxostoma dorsale</u>

Table 1. Continued.

Common Name	Latin Name
Loggerhead Shrike	<u>Lanius ludovicianus</u>
European Starling	<u>Sturnus vulgaris</u>
*+Bell's Vireo	<u>Vireo bellii</u>
*Lucy's Warbler	<u>Vermivora luciae</u>
*+Yellow Warbler	<u>Dendroica petechia</u>
Black-throated Blue Warbler ^a	<u>Dendroica caerulescens</u>
Kirtland's Warbler ^a	<u>Dendroica kirtlandii</u>
*Common Yellowthroat	<u>Geothlypis trichas</u>
*+Yellow-breasted Chat	<u>Icteria virens</u>
*+Summer Tanager	<u>Piranga rubra</u>
*Blue Grosbeak	<u>Guiraca caerulea</u>
Abert's Towhee	<u>Pipilo aberti</u>
Song Sparrow	<u>Melospiza melodia</u>
Great-tailed Grackle	<u>Quiscalus mexicanus</u>
*Brown-headed Cowbird	<u>Molothrus ater</u>
*Northern Oriole	<u>Icterus galbula</u>
House Finch	<u>Carpodacus mexicanus</u>

+ Denotes cottonwood-willow riparian obligate.

* Denotes neotropical migrant.

Table 1. Continued.

^a Not detected on the study site.

OBJECTIVES

I examined remnant cottonwood-willow riparian forest in the lower Colorado River valley to determine the effectiveness of isolated cottonwood-willow patches in attracting and sustaining a population of birds over time. Specifically, my objectives were:

1. To determine if there is a correlation between abundance and richness of bird species and cottonwood-willow patch size, tree density, and proximity of birds to cottonwood-willow forest with a salt cedar understory.

2. To determine if there is a minimum patch size, and a minimum density of cottonwood-willow trees in a stand of dense salt cedar that will support a population of cottonwood-willow riparian obligate birds, and, if the minimum is <13 ha, what those minimums are.

3. To quantify breeding attempts and success of two representative cottonwood-willow riparian associated bird species, Yellow-breasted Chats and Bell's Vireos, in relation to the above listed objectives.

STUDY SITE

My study site was along the lower Colorado River, from the Davis Dam to the Mexican border (322 km; Figure 1). It consisted of four National Wildlife Refuges (NWR): Imperial NWR in Yuma and La Paz counties, Cibola NWR and Bill Williams River NWR in La Paz county, and Havasu NWR in Mohave county. Three of the four refuges (Bill Williams River NWR excepted) are managed for wintering waterfowl and therefore have large agricultural fields, surrounded by strips of salt cedar and mesquite.

My specific study plots were a set of mixed cottonwood-willow-salt cedar patches located on the 4 wildlife refuges (Table 2). Within the study plots, cottonwood-willow patches ranged from 0 ha (no cottonwood or willow trees) to 160 ha and cottonwood-willow tree density ranged from 0 to >100 trees/ha. Many of the fragments consisted of single isolated cottonwood or willow trees, or small numbers of cottonwood and willow trees grouped linearly. Also, there were clumps of 30 to 40 trees with outliers extending longitudinally along the river.

Imperial National Wildlife Refuge

The Imperial NWR riparian zone consisted of a strip of marsh lining the Colorado River and backwaters, giving

Figure 1. Map of Study Sites.

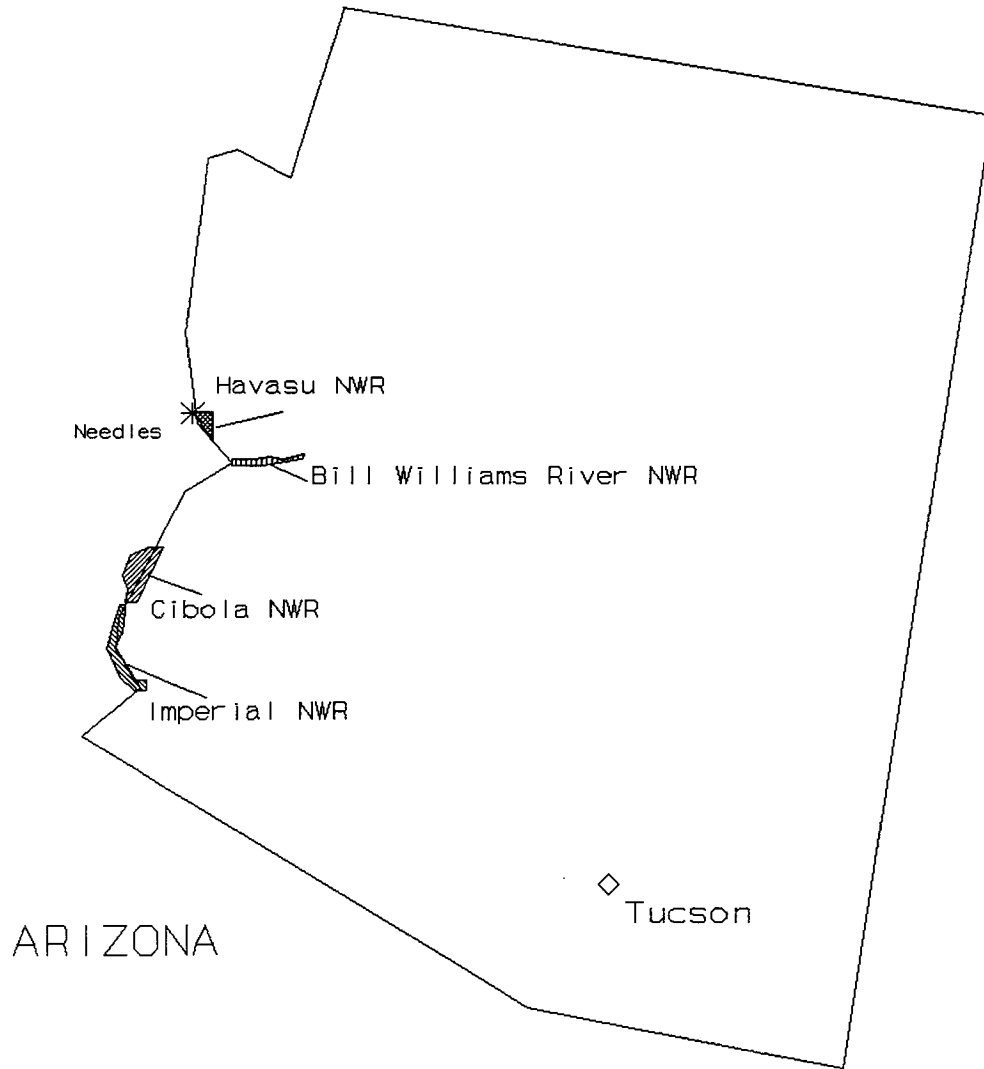


Table 2. Study Plots, Location, Approximate Size of Cottonwood/Willow Patch, and General Vegetation Characteristics.

Plot	Location	Appx. Size	Vegetation
C1	Cibola NWR	2.5 ha	Cottonwood-willow, Arrowweed and salt cedar
C2	Cibola NWR	0.1 ha	Cottonwood-willow, mesquite and salt cedar
C3	Cibola NWR	6.0 ha	Cottonwood-willow, revegetation patch
C5	Cibola NWR	12.0 ha	Cottonwood-willow, revegetation patch
C6	Cibola NWR	3.0 ha	Cottonwood-willow, quailbush understory
CX	Cibola NWR	0.3 ha	Willow, Arrowweed, salt cedar
SC	Cibola NWR	0.0 ha	Salt cedar
IB	Imperial NWR	0.7 ha	Cottonwood-willow, marsh and salt cedar
IS	Imperial NWR	0.8 ha	Cottonwood-willow, marsh and salt cedar

Table 2. Continued

Plot	Location	Approx. Size	Vegetation
BW	Bill Wms. NWR	160.0 ha	Cottonwood-willow, little salt cedar
B2	Bill Wms. NWR	160.0 ha	Cottonwood-willow, patchy salt cedar
B3	Bill Wms. NWR	13.0 ha	Cottonwood-willow, salt cedar
Y	Bill Wms. NWR	13.0 ha	Cottonwood-willow, salt cedar
Z	Bill Wms. NWR	0.01 ha	Patchy cottonwood- willow, patchy salt cedar
H1	Havasus NWR	0.7 ha	Cottonwood-willow, reveg. with salt cedar
H2	Havasus NWR	0.0 ha	Salt cedar and mesquite
H3	Havasus NWR	0.7 ha	Willow, salt cedar and arrowweed
H4	Havasus NWR	11.0 ha	Willow, marsh and salt cedar

Table 2. Continued

Plot	Location	Approx. Size	Vegetation
H5	Havasu NWR	0.3 ha	Willow, thick salt cedar

way to a strip of salt cedar which, in places, extended several hundred meters up the desert washes along the river, and edged the desert uplands where they approached the river. A few naturally occurring cottonwood and willow trees stood at the edges of four separate marsh areas. Several large desert washes emptied into the Colorado river within Imperial NWR. The washes were dominated by a mix of ironwood (Olneya tesota), palo verde (Cercidium spp.), honey mesquite (Prosopis glandulosa), catclaw acacia (Acacia greggii), quail bush (Atriplex lentiformis), and creosote bush (Larrea tridentata). Imperial NWR also contained an expanse of sparsely vegetated desert uplands, dominated by creosote bush.

Plots IS and IB consisted of two parallel strings of cottonwood and willow trees, each 300 m long and 300 m apart. Both patches were surrounded by marsh and marsh grasses, and were flooded. They were located at the southwest corner of the farm unit.

Cibola National Wildlife Refuge

Cibola NWR had a riparian zone similar to Imperial NWR, but lacked the desert uplands. It was located in a wider flood plain than Imperial NWR, and therefore had more extensive stands of salt cedar and salt cedar mixed with mesquite. Cibola NWR also contained four separate

revegetated patches of cottonwood and willow in various successional stages.

Plot C1 was 800 m long, and consisted of a string of cottonwoods and willows, beginning at the tie-back levee just north of Cibola Lake and extending northward. The plot was contained between two flood control levees, approximately 100 m apart. The south end of the plot consisted of a stand of several cottonwood and willow trees in close proximity to each other, trailing out to the north. The plot had a dense understory dominated by salt cedar with scattered mesquite, arrowweed (Pluchea sericia) and coyote willow (Salix exigua).

Plot C2 was 700 m long and ran along the 100 year levee road, 1.6 km south of the road leading from Farm Unit I to the levee road through the revegetated patch directly west of refuge headquarters. It sampled a small group of Goodding's willows with a dense understory of salt cedar and mesquite.

Plot C3 ran along the preexisting bird survey transect R (S. Lynn and A. Averill, unpubl. data), in a revegetated patch on the island unit. It was 900 m long and ran along scattered patches of cottonwood and willow, with an understory of sparse arrowweed, but surrounded by dense salt cedar and arrowweed.

Plot C5, located just north of Cibola NWR, on the west side of the Colorado River, ran along an 800 m long transect in a revegetated patch of mixed trees. The revegetation was 15 years old and consists of rows of cottonwoods and willows, interspersed with eucalyptus (Eucalyptus sp.), palo verde, mesquite, athel tamarix (Tamarix aphylla), and quail bush. The revegetation patch ran along the high levee road and was planted on a dredge spoil site created from channelizing the Colorado River through this area.

Plot C6 was also located in an old revegetated site. The plot was 500 m long and ran through a mixture of scattered willows and scattered salt cedar, often with a dense understory of quail bush. The plot was surrounded by monotypic salt cedar and abutted the high levee road directly west of the refuge headquarters.

Plot CX was located in a patch of a few naturally occurring willows surrounded by, and with an understory of, salt cedar and arrowweed. This plot was 200 m long, and was situated directly across the river from C1, between the high levee and low levee.

Plot SC ran along an 1.5 km long transect that followed a dirt road through a stand of dense salt cedar and mesquite, with no cottonwood or willow trees within

1000 m. It was located along the old river channel boat launch road, just west of the conjunction of the old river channel and the dry cut at Pretty Water.

Bill Williams River National Wildlife Refuge

Bill Williams River NWR consisted of the last extensive remnant of naturally occurring cottonwood-willow riparian vegetation, with a dense understory of salt cedar throughout most of the forest. In places, salt cedar was the dominant vegetation. Bill Williams River NWR was bordered by steep desert canyon walls, dominated by creosote bush and palo verde, and also contained a large marsh at the delta of the Bill Williams River into Lake Havasu.

Plot BW consisted of true cottonwood willow riparian forest, 1.5 km long, along the preexisting bird survey transect A, points 1-9 (S. Lynn and A. Averill, unpubl. data). This transect began at the conjunction of Bill Williams River NWR with Planet Ranch, on the north side of the river, and ran west along the river.

Plot B2 ran 400 m on the north side of the Bill Williams River from preexisting bird survey transect F, which extended upriver from where Mineral Wash intersected the Bill Williams River. It was vegetatively very similar to BW but with more horizontal patchiness and a denser

salt cedar understory.

Plot B3 was 300 m long and ran down the wash that began at the turnout 500 m west from the gate that marked the washout of Planet Ranch Road at the west end of the refuge. This patch ran along the preexisting bird survey transect C, points 1-3, and was characterized by a dense stand of cottonwoods and willows, with a patchy understory of salt cedar.

Plot Y ran 600 m along preexisting bird survey transect I, points 7-10. The plot ran along the channel of the Bill Williams River, with dense cottonwood and willow trees, and patchy salt cedar.

Plot Z ran 600 m along preexisting bird survey transect I, points 1-3. It was characterized by isolated small patches of cottonwood and/or willow interspersed with thick salt cedar. It ran along an old channel of the Bill Williams River.

Havasu National Wildlife Refuge

Havasu NWR was typified mostly by shallow water and the Topock Marsh. Salt cedar and screwbean mesquite (Prosopis pubescens) surrounded the marsh and lined several levee roads that crossed the marsh. Havasu NWR also had one revegetated cottonwood-willow patch with trees >10 m tall, and several sapling patches. Havasu NWR

was notable for its forest of athel tamarix, a relative of salt cedar that grows much taller than salt cedar and frequently has a closed canopy.

Plot H1 ran the length of the preexisting bird survey transect CR, 500 m along the new south dike road. It consisted of a linear patch of >10 m tall revegetated cottonwoods and willows surrounded by a very dense, 30 m wide strip of salt cedar and arrowweed. On the other side of the salt cedar and arrowweed was marsh.

Plot H2 was 700 m long and paralleled H1 on the south dike road, 800 m from transect H1. It consisted of a 60 m wide strip of salt cedar with scattered screwbean mesquite, bordered by extensive marsh.

Plot H3 was in a natural patch of decadent willows with little understory, surrounded by arrowweed and salt cedar, and located 100 m south of the west entrance to Havasu NWR. It was situated on the west side of the road and ran 200 m.

Plot H4 followed points 1-4 of preexisting bird survey transect GH, and was 600 m long. It began 15 m north of the intersection of the north dike road and the Glory Hole canal and ran west through a stand of decadent willows with conspicuous deadfall underneath, and surrounded by salt cedar on the north, and a marshy canal

to the south.

Plot H5 was located at the south end of the South Dike Road. It began 200 m north-west of the gate to Highway 95, and ran 200 m along the road through scattered willows with a dense understory of salt cedar and arrowweed. Ten m to the north of the road was Topock Marsh.

Overall

The entire study area was typical of a desert riparian system, with summer temperatures greater than 32C for an average of 177 days per year. Winter temperatures dropped below 0C for an average of 14 days per year. Average precipitation was 5-10 cm per year with an average relative humidity of 25% or less (Ohmart et al. 1988).

METHODS - OBJECTIVE #1

Cottonwood-Willow Patches

Study site establishment.--I established my study plots in 19 patches of cottonwood-willow forest, ranging in size from 0 ha (no cottonwood or willow present) to 160 ha. Within each study plot, I set reference transects. I generated a random number between 0 and 30 on a calculator, paced into each study plot area that many meters, and placed the first point of the transect. Thirty corresponded to 1/2 the width of each plot, the area in which I searched for nests. I established a transect along each study plot, running the length of the plot and 30 m or less from the edge of each stand of cottonwood-willow trees. Therefore, if a cottonwood-willow patch was <60 m wide, the plot also included surrounding vegetation. All plots included some salt cedar understory, and many included salt cedar surrounding the cottonwood and willow trees.

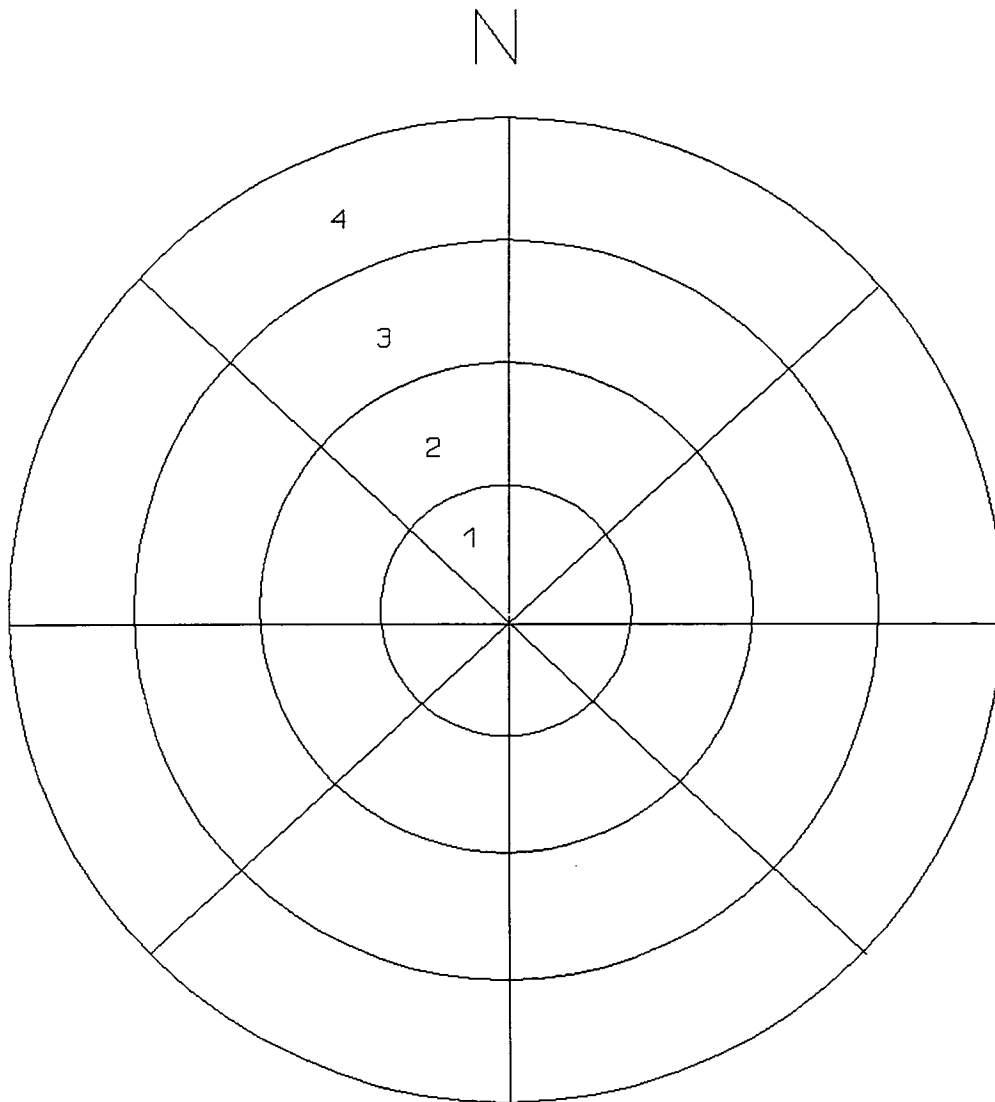
Points along the transect were established by pacing along the length of the plot and placing each point 100 meters apart. I flagged transects at 50 m intervals, and double flagged at each 100 m survey point. Ten study plots were established and surveyed only during 1994 and 9 more were established and surveyed only during 1995 (Table

2). I combined data from both years for analyses because I could only survey 9-10 plots each year, and increasing my sample size of patches was a priority. Plots for the first year spanned the range of patch size for the second year. I was also more interested in overall use of the patches by these birds than in annual trend data.

Survey Method.--Within each study plot, I stopped for 5 minutes at every 100 m interval point and counted birds seen and heard within 100 m. Birds were located by distance class (with reference to the 50 m and 100 m flags) for ease of estimation (1 = 0-25 m, 2 = >25-50 m, 3 = >50-75 m, 4 = >75-100 m), and by presence in one of 8 arcs of the circle, centered on the count point, (i.e, 1 = NNE, 2 = ENE, 3 = ESE, 4 = SSE, continuing clockwise) (Figure 2). In this manner, individual birds were located in small areas which are closely associated with the specific vegetation characteristics within the small area. Birds were identified and number of birds of the same species sharing this information was recorded (Appendix A).

Birds were surveyed 5 times each year (the time period between surveys in each plot approximately 10 days) beginning 20 May and ending by 10 July. Raphael (1987) found that simple total counts were as effective as

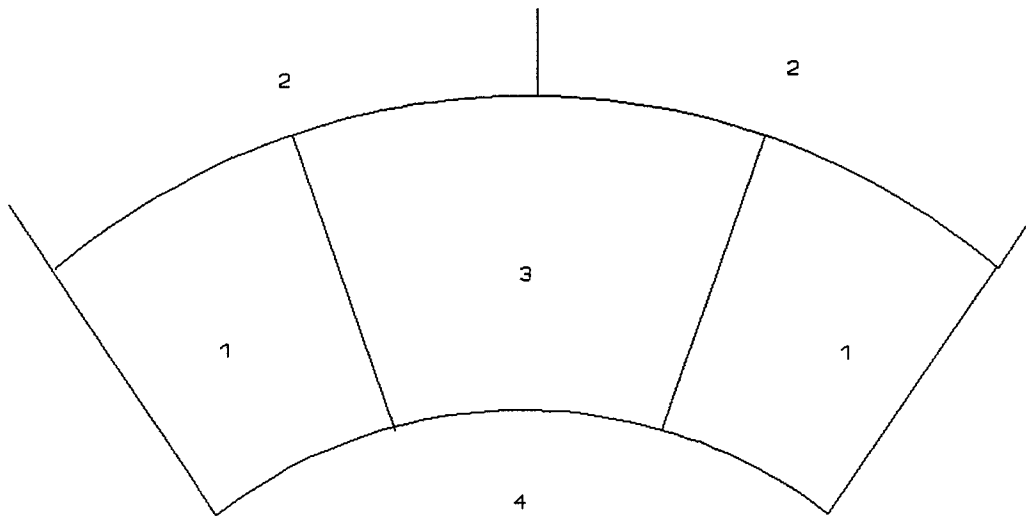
Figure 2. Bird Survey Point.



sophisticated adjusted density counts for calculating indices of abundance for birds within species across habitat types, so I summed detections over all 5 count periods as an index of bird abundance for each species.

Vegetation Sampling.--At each point established for my bird surveys, I measured the vegetation in the following manner. At each point, I established 8 transects radiating out 100 m from the point, 4 along the cardinal directions, and 4 equidistant between each cardinal transect (Figure 2). I delineated sector boxes, in the manner described for recording bird location for bird surveys (Figure 2), and counted the number of cottonwood and/or willow trees in each sector. There are 32 sectors per point, corresponding to 4 boxes between each of the 8 radial transects. I also recorded an index of dispersion of the trees in each sector (1 = clustered no more than 1/4 the width of the sector away from either of the radii, 2 = clustered no more than 1/2 the width of the sector away from either of the radii, 3 = clustered between 1/4 and 3/4 the width of the sector away from the either of the radii, 4 = spread evenly throughout the sector) (Figure 3) (Appendix B) to assist in determining proximity of a bird to the nearest cottonwood or willow tree.

Figure 3. Sector of Bird Survey Point, with Dispersion Indices.



I calculated the area of each sector using the formula for the area of a 45° arc, $(\pi \times \text{radius}^2/8)$, for each concentric circle (Figure 2) and subtracted the area of the next smaller radius arc. Then, I found the density of cottonwood-willow trees in each sector by dividing the number of trees counted by the sector area.

The relation of each bird to cottonwood-willow tree density and proximity to cottonwood-willow tree was determined by its sector location on the survey. The distance of a bird to a cottonwood-willow tree was determined by the maximum distance away from the tree that the bird could possibly be, and still be within the sector. For instance, in the outermost sector of the circle (distance = 4 on the survey), a bird could be no further away than 80 m from any cottonwood or willow tree within that sector, 60 m for the second-to-outermost sector (distance = 3), 40 m for the third-to-outermost sector (distance = 2), and 20 m for the innermost sector (distance = 1). By recording the dispersion of cottonwood or willow trees within a sector, I decreased these maximum distances. For instance, if there was a cottonwood tree directly in the middle of the sector, the maximum distance of bird to tree within that sector was halved. Similar calculations apply to birds in sectors with no trees, to

determine maximum distance possible to trees in other sectors. For each study patch, I paced the dimensions of the patch of cottonwood or willow trees to determine the size of the patch nearest the center of the area of interest. For patches exceeding 3 ha, I consulted recent aerial photos to determine the patch size (Appendix B).

Statistical Analyses.-- Bird species richness included all birds detected at each point except waterfowl. Indices of abundance were calculated for all bird species that breed in the lower Colorado River valley that I recorded on my surveys. Presentation of these analyses are as all breeders, as the subgroup of neotropical migrants that breed in the lower Colorado River valley, and for comparison, the subgroup of bird species that require cottonwood-willow riparian forest (Rosenberg et al. 1991).

In my study, the density of cottonwood and willow trees of each patch varied within each patch, so I chose to examine the relationship between abundance and richness of bird species at three different scales to determine if the pattern of abundance and richness of bird species followed a consistent pattern across scales (Fowler et al. 1992). The scales I used were micro, corresponding to the area of a sector (0.1 ha), meso, corresponding to the area

of a survey circle of 3.1 ha, and macro, corresponding to the area of a study plot size of 7.1 - 33.1 ha.

I used patch size as a variable across all statistical scales because it was the primary independent variable with which I was concerned. Also, as the scale of analysis decreased (macro to micro), I was able to identify birds with smaller patches (e.g., individual trees) that were obscured by larger scale measurements of patch size. For instance, at the meso-scale, 2 or more patches might have been present within the 100 m radius circle. I measured the patch closest to the center of the point to get size of the nearest associated cottonwood-willow patch at the meso-scale. At the micro-scale, a sector may have contained a different patch than the one measured for the meso-scale analysis.

Correlation and regression analyses rely on the assumption that the data are normally distributed with equal variances, the data are independent, and the relationship between variables is linear (Norusis 1990:248-249). Departure from the assumption of normality and equality of variance is frequent in populations of organisms in their natural environment (Cassie 1962), and occurred here as well. Normal probability plots and standardized residual scatter plots (Norusis 1990:257-261)

for the residuals of each species showed that the assumptions of normality and equality of variance were violated for all species abundance analyses, so I used Spearman's Rank Correlation as an alternate, nonparametric test (Zar 1984:318-320). Species richness data did not violate these assumptions, so regular Pearson's Correlation Coefficients were calculated for richness analyses to increase the power of the analysis.

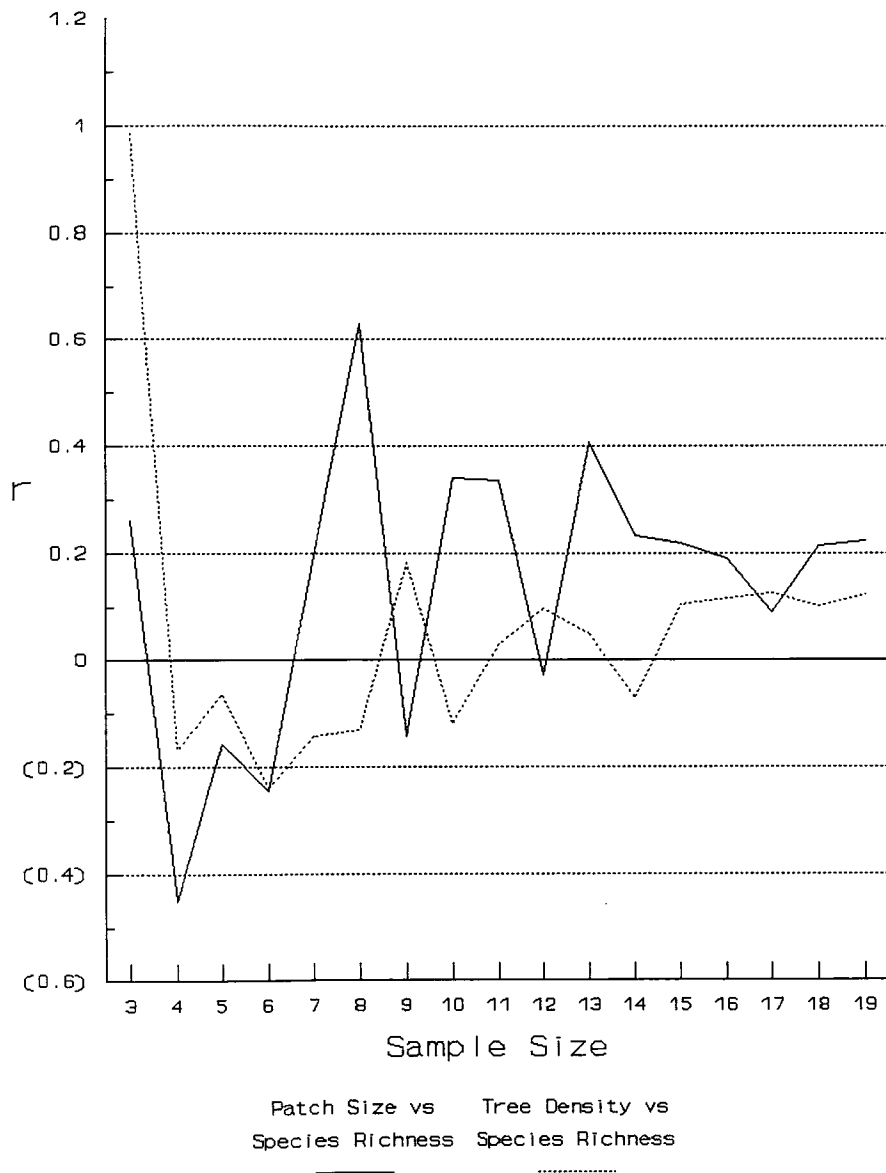
My indices of abundance for each species did not meet the assumptions for regression analysis; therefore, I could not perform normal multiple regression analyses to determine whether my independent variables were interacting. Instead, because my number of independent variables was small (2-3) and thus easily interpreted, I created a correlation matrix for the independent variables at each scale to determine how much intercorrelation there existed among these variables (Norusis 1990:184).

For species richness analyses, I also used forward stepwise multiple regression (Norusis 1990:278) to determine the overall contribution of all significant variables to the explanation of species richness.

Block et al. (1987) recommend a sample size of >50 plots when determining statistical significance of vegetation variables. In my study, at the micro scale, I

chose one sector for each point, thereby ensuring the independence of surveys in each sector analyzed, to give me a sample size of 134 sectors. This sample size exceeds the minimum requirement to perform simple linear and stepwise multiple regression. Also, with this sample size, the probability of correctly determining linearity (power of the analysis) with an $R^2 \geq 0.1$ and $P \leq 0.1$ is 98% (Zar 1984:312). At the meso scale, I had 62 points, which is also an adequate sample size for my analyses. The power of the analysis for a sample size of 62, given the same parameters as used for the micro-scale, is 81%. However, at the macro scale, I only had 19 patches, which does not meet the minimum requirement for sample size, according to Block et al. (1987). Sample size analysis (Morrison 1984) indicates that correlation coefficients of patch size and tree density begin to stabilize as the number of observations approaches 19 (Figure 4), but not conclusively. To achieve a power of 80% with this sample size, a confident prediction of R^2 must exceed 0.30. However, cottonwood and willow vegetation was limited on my study site so my study plots represent a good proportion of the accessible patches of cottonwood and willow available in the lower Colorado River valley. My results should reflect trends within the lower Colorado

Figure 4. Sample Size Analysis: Correlation of Patch Size and Tree Density with Species Richness by Increasing Sample Size.



River valley, but should be used with caution when extrapolating to other geographic areas.

The standard threshold for significance in scientific studies is $P \leq 0.05$; however, increasing the probability level at which a variable is deemed significant increases the power of the analysis (Zar 1984:43). Therefore, I chose to consider a variable significant if $P \leq 0.10$ to increase the likelihood that I would correctly classify a variable while retaining biological significance.

I performed correlation analyses for each bird species that was detected at ≥ 5 points of the survey points at each scale.

Micro Scale.--Within each sector, I correlated each bird species index of abundance and bird species richness against the maximum possible distance of the bird from a cottonwood or willow tree, the size of the nearest cottonwood-willow patch, and the density of cottonwood and willow trees in the nearest patch, each by Spearman's Rank Correlation (Zar 1984:318). I also created a correlation matrix (Norusis 1990:184) between maximum possible distance to nearest cottonwood or willow tree, patch size, and tree density to determine if any of these variables interacted at the micro-scale.

Meso Scale.--Because the points on each transect were

located so close together, I split my meso-scale surveys into two data sets: one with all odd numbered points and one with even numbered points. This technique assured that I was not double-counting the same individual bird at subsequent points and allowed me to duplicate analyses on each patch to confirm the significance of relevant variables. All analytical results reported herein for the meso-scale are from the odd point set. If the two data sets disagreed significantly on any factor, I did not consider the variable significant.

I combined all bird detections of each species at each point, recalculated tree density across the entire 100 m radius point, and recorded the size of the nearest associated cottonwood-willow patch at each point to do a meso scale analysis. I used Spearman's Rank correlation to quantify the relationship of patch size and tree density, with bird species richness and abundance (Zar 1984:318).

I created a correlation matrix (Norusis 1990:184) between patch size and tree density to determine if there were a significant interaction between these two variables at the meso-scale.

At the meso scale, I also divided bird species into groups of local breeders, passage migrants, neotropical

migrants, and cottonwood-willow riparian associated species. These groups were categorized to determine if there was any difference in the effect of patch size and tree density on each group, as compared to the primary group of interest: neotropical migrants. I used Pearson's correlation (Zar 1984:263) to analyze the species richness of each of these groups against patch size and tree density.

Macro Scale.--To detect overall relationships across patches, I also combined data to obtain the average tree density across the patch, the patch size, and the average index of abundance of each species and the average species richness at each point in a patch. For these analyses, I correlated the average index of abundance for each species in each patch, and the average species richness in each patch, with average tree density and patch size, using Spearman's Rank correlation (Zar 1984:318). To determine if there were any interaction between patch size and tree density at the macro-scale, I created a correlation matrix between these two variables (Norusis 1990:184).

METHODS - OBJECTIVE #2

I repeated the previous macro-scale analyses excluding plots B2 and BW, which contained patches that were 160 ha each, much larger than the largest of the remaining patches (13 ha). In this way, I could determine if these large patches were causing a significant correlation that would not occur in the smaller patches, indicating that there is a threshold patch size in-between 13 ha and 160 ha. I had no patches in the range between 13 and 160 ha because none exist in the lower Colorado River Valley.

METHODS - OBJECTIVE #3

Bird Species of Interest

I concentrated on two common bird species found at their greatest abundance in cottonwood-willow riparian forest in the lower Colorado River valley for the reproductive section of my study. These two species, the Yellow-breasted Chat and the Bell's Vireo, were abundant enough to obtain a sufficient sample size to make significant statistical conclusions. Both of these species are U. S. Fish and Wildlife Service designated species of concern, having exhibiting population declines over the past 20 years (Rosenberg et al. 1991).

Although I did not concentrate specifically on Yellow-breasted Chat and Bell's Vireo nests during the first year of my study, the systematic nest-search method that I used ensured that I found a high proportion of nests of these species relative to other species. Therefore, I included all nests of Yellow-breasted Chats and Bell's Vireos in my analyses of nesting attempts and success.

Survey Methods

I searched for nests of Bell's Vireos and Yellow-breasted Chats on my study plots, and monitored the success of these nests through fledging. My nest

searching protocol broadly followed Ralph et al. (1993). I searched each patch approximately every 5 - 7 days. Searches were conducted during the morning, and included incidental behavioral observations of any neotropical migratory bird species (Table 2) seen during the nest search. During each session I searched systematically throughout as much of the patch as time and temperature permitted, looking for any signs of nesting. I set a goal of finding at least one nest for every day of searching, as suggested by Ralph et al. (1993), but continued searching for the entire morning (Appendix C). Each nest found was flagged with compass direction and distance to nest written on the flag (Gates and Gysel 1978), and monitored at least every 5 - 7 days to determine status (e.g., nest building, incubating, feeding nestlings). I documented breeding success in this way for all nests found in 1994 and 1995.

Nest Vegetation Sampling

For each nest found that was known to be active, I recorded the following information: observer initials, date, refuge on which the nest was located, transect on which the nest was located, bird species corresponding to the nest, nest number, plant species in which the nest was located, paced or tape-measured distance to nearest

cottonwood or willow tree within 100 m of nest, estimated number of cottonwood and/or willow trees within 30 m of the nearest cottonwood or willow tree to the nest, estimated number of cottonwood/willow trees beyond 30 m but within 60 m of the nearest cottonwood or willow tree to the nest, and size of the patch nearest to the nest (Appendix D).

Statistical Analyses

I calculated the number of nests found on each plot that were known to be active, divided this by the total number of person-hours spent searching the plot, and divided this by the total area of the plot to determine an index of nest attempts on each study plot.

For each study plot, I also calculated an index of success for each species using the modified Mayfield method (Mayfield 1961, 1975). I ranked the success of each nest: 0 = did not finish building nests or lay eggs, 1 = at least one egg of that species successfully laid in the nest, and 2 = at least one nestling of that species successfully hatched (Table 3). When the fate of a nest was unknown during any of the above stages, I included it as if it made it half way through the stage (i.e., add 1/2 to the total number of successful nests in that stage for each unknown). I then averaged this rank for each species

Table 3. Mayfield Indices for Yellow-Breasted Chat and Bell's Vireo Across all Study Plots.

Plot	YBCH	BEVI
B2	2.00	1.00
B3	1.75	0.92
BW	1.14	1.25
C1	1.22	---- ^a
C2	0.75	1.00
C3	----	----
C5	----	----
C6	----	----
CX	----	----
H1	1.50	2.00
H2	0.88	----
H3	----	----
H4	1.33	0.86
H5	2.00	----
IB	----	----
IS	2.00	----
SC	----	----
Y	1.33	----

Table 3. Continued.

Plot	YBCH	BEVI
Z	0.75	-----

^a No active nests found in this patch.

across the entire patch. I excluded a rank for successfully fledged nests because neither Bell's Vireos nor Yellow-breasted Chats remained near the nest after fledging. Therefore, few fledglings were actually observed near a possible source nest, although fledglings of both species were observed throughout the study period.

I used an index of abundance for the number of nests of Bell's Vireos and Yellow-breasted Chats found per person-hour searched per hectare of each patch. The person-hours of search time was not related to patch size, so I used both person-hours searched and size of patch in weighing the index of nest abundance.

Inspection of the normal probability and standardized residual plots for nest data showed that nest data did not violate the assumptions of normal distribution and equal variances. Therefore, I ran simple linear regression (Zar 1984:263) and stepwise multiple regression analysis (Norusis 1990:244) to determine the relationship between patch size and tree density with the index of nest abundance and average nest success rank within a patch.

RESULTS

Bird Abundance Analyses

Micro Analyses.--I used 16 bird species that breed in the lower Colorado River valley in correlation analyses. Ten of the 16 species are neotropical migratory passerines, and 3 of the 16 species are obligate cottonwood-willow riparian associated species.

The abundance of 13% of all bird species increased significantly with increasing patch size and none decreased significantly with increasing patch size (Table 4). The indices of abundance of 20% of neotropical migrant species increased significantly with increasing patch size; the index of abundance of 33% of cottonwood/willow riparian obligates increased significantly with increasing patch size. No neotropical migrant or cottonwood/willow riparian obligate species decreased significantly with increasing patch size.

For all species, the index of abundance of 31% increased significantly with increasing tree density, while none decreased significantly with increasing tree density (Table 4). The index of abundance of 50% of the neotropical migrant species increased significantly with increasing tree density none decreased significantly with increasing tree density; the index of abundance for 66% of

Table 4. Regression Statistics, Spearman's Rank Coefficient and Probability, for All Locally Breeding Birds in the Lower Colorado River Valley, Micro-Scale.

Species	Patch Size		Tree Density		Max Distance ^a	
	r_s	P^b	r_s	P	r_s	P
*White-winged Dove	0.086	0.32	0.147	0.09	0.007	0.94
Mourning Dove	0.012	0.89	-0.063	0.47	0.194	0.03
Ladder-backed Woodpecker	-0.097	0.27	0.030	0.73	-0.178	0.04
*Ash-throated Flycatcher	0.047	0.59	0.057	0.51	-0.143	0.10
**Western Kingbird	0.123	0.16	0.161	0.06	-0.001	0.99
Verdin	-0.074	0.40	-0.027	0.76	0.116	0.18
*Lucy's Warbler	-0.108	0.21	-0.084	0.33	-0.038	0.66
*Common Yellowthroat	-0.016	0.86	-0.057	0.51	0.011	0.90
**Yellow-breasted Chat	-0.035	0.69	0.125	0.15	-0.042	0.62
**Summer Tanager	0.202	0.02	0.181	0.04	-0.103	0.24
*Blue Grosbeak	-0.063	0.47	-0.051	0.56	-0.038	0.66
Abert's Towhee	0.068	0.43	-0.009	0.92	-0.034	0.70

Table 4. Continued.

Species	<u>Patch Size</u>		<u>Tree Density</u>		<u>Max Distance</u>	
	\bar{x}_s	\bar{P}	\bar{x}_s	\bar{P}	\bar{x}_s	\bar{P}
Song Sparrow	0.073	0.40	0.000	1.00	-0.021	0.81
Great-tailed Grackle	-0.068	0.44	-0.025	0.78	-0.063	0.47
*Brown-headed Cowbird	0.012	0.89	0.242	0.01	-0.060	0.49
*Northern Oriole	0.144	0.10	0.163	0.06	-0.026	0.77

* Denotes neotropical migratory species.

+ Denotes cottonwood-willow riparian obligate species.

^a Maximum distance to nearest cottonwood or willow tree.

^b Two-tailed.

cottonwood/willow riparian obligates increased significantly with increasing tree density. No neotropical migrant or cottonwood/willow riparian obligate species decreased significantly with increasing tree density.

The index of abundance of 6% of all bird species increased significantly with increasing maximum distance to the nearest cottonwood or willow tree, and 13% decreased significantly with increasing maximum distance to the nearest cottonwood or willow tree (Table 4). No neotropical migrant species or cottonwood/willow riparian obligate species significantly increased or decreased with increasing maximum distance to the nearest cottonwood or willow tree.

Correlation between all indices of abundance with patch size, tree density, and maximum distance to nearest cottonwood or willow tree did not exceed 0.10, and were therefore not biologically meaningful according to my criterion.

Patch size increased with increasing tree density, with 34% ($R^2 = 0.34$) of the variability of patch size accounted for by the variability in the tree density (Table 5; Zar 1984:308). Patch size and tree density increased with increasing maximum distance to the nearest

Table 5. Intercorrelation Statistics: Spearman's r_s Between Independent Variables, Patch Size, Tree Density, and Maximum Distance to Nearest Cottonwood or Willow Tree, All Scales.

Scale	<u>Patch Size vs Density</u>		<u>Patch Size vs Max. Dist</u>		<u>Density vs Max Dist</u>	
	r_s	P	r_s	P	r_s	P
Micro	0.58	0.00	0.27	0.00	-0.25	0.00
Meso	0.88	0.00	NA	----	NA	----
Macro	0.82	0.00	NA	----	NA	----

cottonwood or willow tree, but neither correlation exceeded 10%.

Meso Analyses.--I used 31 species in the meso-scale analyses; 15 were Neotropical migrant species and 9 were cottonwood-willow riparian obligate species. Thirty-five percent of all bird species had indices of abundance that increased with increasing patch size, and 16% had decreasing indices of abundance with increasing patch size (Table 6). The index of abundance of 40% of neotropical migrant species increased with increasing patch size and the index of abundance of 78% of cottonwood/willow riparian obligate species increased with patch size. No neotropical migrant or cottonwood/willow riparian obligate species decreased with increasing patch size. All correlations of neotropical migrants and cottonwood/willow riparian obligates with patch size exceeded r^2 of 0.10, and therefore were considered biologically meaningful at the meso-scale.

The indices of abundance of 32% of all bird species had positive relationships with tree density, and 19% had negative relationships with tree density (Table 6). Forty percent of neotropical migratory bird species had an increasing index of abundance with increasing tree density, and one species (Lucy's warbler) had a negative

Table 6. Regression Statistics, Spearman's Rank Coefficient and Probability, for All Locally Breeding Birds in the Lower Colorado River Valley, Meso-Scale.

Species	<u>Patch Size</u>		<u>Tree Density</u>	
	<u>r_s</u>	<u>P^a</u>	<u>r_s</u>	<u>P</u>
Gambel's Quail	0.087	0.50	0.032	0.80
*White-winged Dove	-0.028	0.82	0.005	0.98
Mourning Dove	0.248	0.06	0.306	0.02
*+Yellow-billed Cuckoo	0.373	0.00	0.327	0.02
Greater Roadrunner	0.031	0.82	0.054	0.68
Gila Woodpecker	0.384	0.00	0.441	0.00
Ladder-backed Woodpecker	-0.025	0.84	-0.020	0.88
*+Vermilion Flycatcher	0.522	0.00	0.450	0.00
*Ash-throated Flycatcher	-0.044	0.74	-0.113	0.38
*+Brown-crested Flycatcher	0.495	0.00	0.516	0.00
*+Western Kingbird	0.168	0.20	0.096	0.46
Verdin	-0.429	0.00	-0.450	0.00
Cactus Wren	0.061	0.64	0.100	0.44
+Bewick's Wren	0.622	0.00	0.651	0.00
Marsh Wren	-0.370	0.00	-0.372	0.00
Black-tailed Gnatcatcher	-0.382	0.00	-0.446	0.00
Crissal Thrasher	-0.329	0.00	-0.378	0.00
Loggerhead Shrike	0.118	0.36	0.104	0.42

Table 6. Continued.

Species	<u>Patch Size</u>		<u>Tree Density</u>	
	<u>r_s</u>	<u>P</u>	<u>r_s</u>	<u>P</u>
*+Bell's Vireo	0.482	0.00	0.468	0.00
*Lucy's Warbler	-0.159	0.22	-0.277	0.04
*+Yellow Warbler	0.189	0.14	0.179	0.16
*Common Yellowthroat	0.029	0.82	0.096	0.46
*+Yellow-breasted Chat	0.371	0.00	0.395	0.00
*+Summer Tanager	0.575	0.00	0.526	0.00
*Blue Grosbeak	0.163	0.20	0.106	0.42
Abert's Towhee	0.245	0.06	0.113	0.38
Song Sparrow	0.084	0.52	0.100	0.44
Great-tailed Grackle	-0.348	0.00	-0.349	0.00
*Brown-headed Cowbird	-0.053	0.68	-0.073	0.58
*Northern Oriole	0.121	0.36	-0.010	0.94
House Finch	0.209	0.10	0.276	0.04

* Denotes neotropical migratory species.

+ Denotes cottonwood-willow riparian obligate species.

^a Two-tailed.

relationship with tree density. The index of abundance of 66% of cottonwood/willow riparian obligate species increased with increasing tree density and none decreased with increasing tree density. All of the correlations between neotropical migrants and cottonwood/willow riparian obligates with tree density exceeded 10% except for Lucy's Warblers.

Patch size increased with increasing tree density at the meso-scale, with 77% of the variability of patch size accounted for by the variability in tree density (Table 5; Zar 1984:308).

Macro Analyses.--I used 32 species for the macro-scale analyses, 14 of which were neotropical migrants and 8 of which were cottonwood/willow riparian obligates. The indices of abundance of 22% of all species increased with increasing patch size and 3% (1 species, Great-tailed grackle) decreased with increasing patch size (Table 7). The index of abundance of 36% of neotropical migrant species increased with increasing patch size, and 75% of cottonwood/willow riparian obligate species had increasing indices of abundance with increasing patch size. No neotropical migrant or cottonwood/willow riparian obligate species decreased with increasing patch size. The index of abundance of only one species, Bewick's Wren,

Table 7. Regression Statistics, Spearman's Rank Coefficient and Probability, for All Locally Breeding Birds in the Lower Colorado River Valley, Macro-Scale.

Species	<u>Patch Size</u>		<u>Trun. Patch Size^a</u>		<u>Density</u>		<u>Trun. Density^b</u>	
	r_s	P^c	r_s	P	r_s	P	r_s	P
Gambel's Quail	0.107	0.66	0.024	0.92	-0.052	0.84	-0.086	0.74
Killdeer	0.277	0.26	0.264	0.30	0.165	0.50	0.092	0.72
*White-winged Dove	0.026	0.92	0.271	0.30	0.063	0.80	0.253	0.32
Mourning Dove	0.228	0.34	0.232	0.38	0.263	0.28	0.297	0.24
*+Yellow-billed Cuckoo	0.480	0.04	0.354	0.16	0.293	0.22	0.139	0.60
Greater Roadrunner	0.054	0.82	-0.092	0.72	0.216	0.38	0.126	0.64
Gila Woodpecker	0.455	0.06	0.375	0.14	0.588	0.00	0.554	0.02
Ladder-backed Woodpecker	0.057	0.82	0.011	0.96	0.101	0.68	0.100	0.70
*Ash-throated Flycatcher	-0.055	0.82	-0.187	0.48	-0.087	0.72	-0.140	0.60
*+Brown-crested Flycatcher	0.513	0.02	0.539	0.02	0.541	0.02	0.593	0.02
*+Western Kingbird	-0.024	0.92	0.042	0.88	-0.259	0.28	-0.183	0.48
Verdin	-0.367	0.12	-0.203	0.44	-0.272	0.26	-0.147	0.58

Table 7. Continued.

Species	<u>Patch Size</u>		<u>Trun. Patch Size</u>		<u>Density</u>		<u>Trun. Density</u>	
	\bar{K}_s	\bar{P}	\bar{K}_s	\bar{P}	\bar{K}_s	\bar{P}	\bar{K}_s	\bar{P}
Cactus Wren	0.030	0.90	0.177	0.50	-0.102	0.68	-0.023	0.94
+Bewick's Wren	0.552	0.02	0.468	0.06	0.723	0.00	0.679	0.00
Marsh Wren	-0.373	0.12	-0.320	0.22	-0.428	0.06	-0.385	0.12
Black-tailed Gnatcatcher	-0.306	0.20	-0.281	0.28	-0.354	0.14	-0.342	0.18
Crissal Thrasher	-0.146	0.56	-0.146	0.38	-0.333	0.16	-0.323	0.20
Loggerhead Shrike	0.101	0.68	0.270	0.30	0.321	0.18	0.453	0.06
European Starling	0.207	0.40	0.188	0.48	0.284	0.24	0.221	0.40
*+Bell's Vireo	0.387	0.10	0.219	0.40	0.476	0.04	0.400	0.12
*Lucy's Warbler	-0.067	0.78	-0.342	0.18	-0.105	0.68	-0.267	0.30
*+Yellow Warbler	0.202	0.40	0.272	0.30	0.213	0.38	0.203	0.44
*Common Yellowthroat	-0.148	0.54	-0.253	0.32	-0.113	0.64	-0.221	0.40
*+Yellow-breasted Chat	0.388	0.10	0.208	0.42	0.321	0.18	0.211	0.42

Table 7. Continued.

Species	<u>Patch Size</u>		<u>Trun. Patch Size</u>		<u>Density</u>		<u>Trun. Density</u>	
	r_s	P	r_s	P	r_s	P	r_s	P
*+Summer Tanager	0.460	0.04	0.239	0.36	0.438	0.06	0.308	0.24
*Blue Grosbeak	0.147	0.54	-0.049	0.86	0.061	0.80	-0.038	0.88
Abert's Towhee	0.323	0.18	0.167	0.52	0.234	0.34	0.167	0.52
Song Sparrow	-0.071	0.78	-0.194	0.46	-0.073	0.76	-0.114	0.66
Great-tailed Grackle	-0.510	0.02	-0.451	0.08	-0.502	0.02	-0.468	0.06
*Brown-headed Cowbird	-0.115	0.64	0.215	0.40	-0.091	0.72	0.018	0.94
*Northern Oriole	0.358	0.14	0.434	0.08	0.070	0.78	0.137	0.60
House Finch	0.059	0.82	-0.126	0.64	0.126	0.60	0.025	0.92

* Denotes neotropical migratory species.

+ Denotes cottonwood-willow riparian obligate species.

^a Patch size regression without the 2 large patches.

Table 7. Continued.

^b Density regression without the 2 large patches.

^c Two-tailed.

correlated with patch size with $R^2 \geq 0.30$, and was therefore considered biologically significant.

The indices of abundance of 16% of all bird species increased with increasing tree density, 6% decreased with increasing tree density (Table 7). The indices of abundance of 21% of all neotropical migrant species increased with increasing tree density, and 38% of cottonwood-willow riparian obligate species also increased with increasing tree density. No neotropical migrant or cottonwood/willow riparian obligate decreased with increasing tree density. The indices of abundance of only 2 species, Gila Woodpecker and Bewick's Wren, correlated with tree density with $R^2 \geq 0.30$, and were therefore considered biologically significant.

When the 2 plots with the large cottonwood-willow patches were removed from analysis, the index of abundance of one species showed a change to a positive relationship with patch size (Northern Oriole, a neotropical migrant; Table 7). One neotropical migrant species and 2 cottonwood-willow riparian obligate species retained positive relationship with patch size. The indices of abundance of 29% of neotropical migrant species were no longer related to patch size when the 2 plots with the large patches were removed, as were the indices of

abundance for 50% of cottonwood/willow riparian obligates. No species correlated with patch size with $R^2 \geq 0.30$ when the 2 plots with the large patches were removed.

When the plots with the 2 large patches were removed from the tree density correlation analysis, only one species, Loggerhead Shrike, became correlated with increasing tree density in the remaining plots with small patches (Table 7). For 14% of neotropical migratory species, and 25% of cottonwood/willow riparian obligate species, the removal of the 2 plots with the large patches resulted in the loss of relationship with tree density ($P \leq 0.10$ to $P > 0.10$; Table 7). One species of neotropical migrant and 2 species of cottonwood/willow riparian obligates did not change their relationship with tree density when I removed the 2 plots with the large patches from analysis. The indices of abundance of only 2 species, Gila Woodpecker and Bewick's Wren, correlated with tree density among the remaining plots with small patches with $r^2 \geq 0.30$, and were therefore considered biologically meaningful.

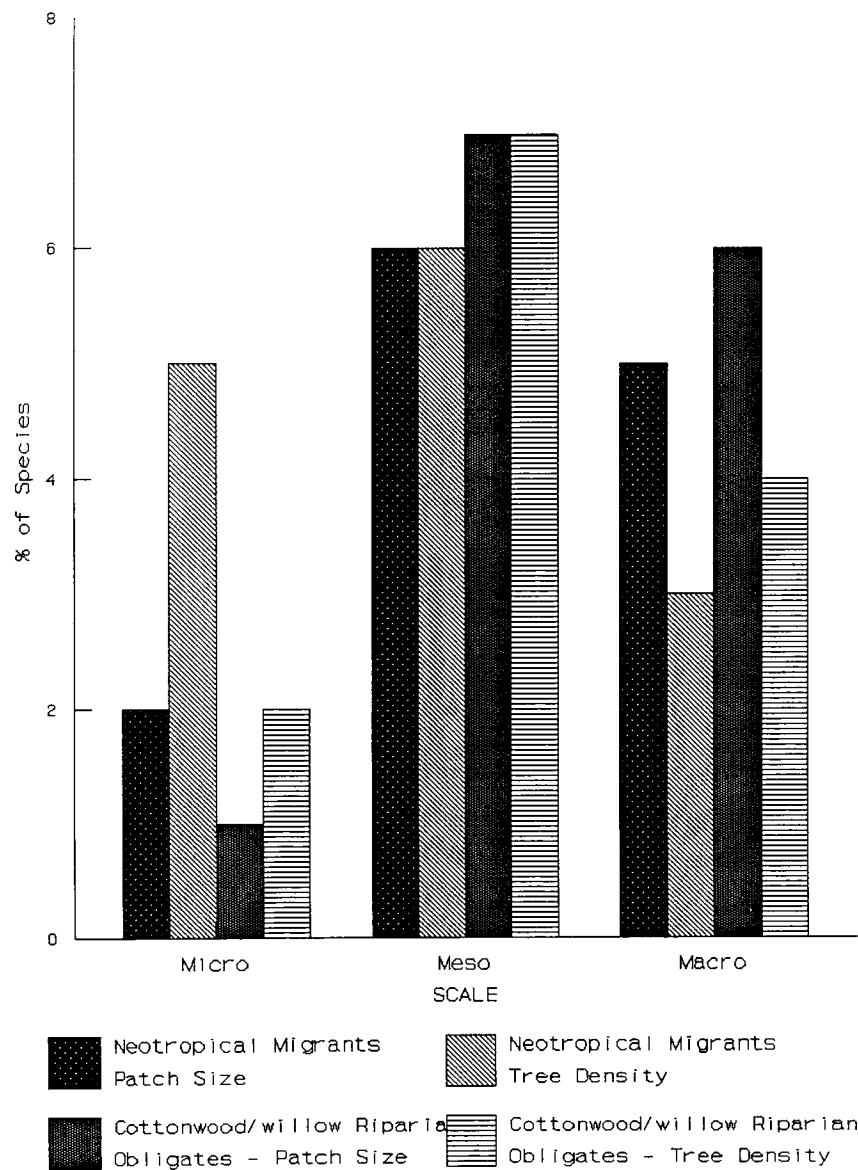
Patch size increased with increasing tree density at the macro-scale, with 67% of the variability of patch size accounted for by the variability in tree density (Table 5; Zar 1984:308).

Individual Neotropical Migratory Species Over All Scales of Analysis.--

Patch size.--Numbers of Summer Tanager consistently increased with increasing patch size at all analytical scales (Figure 5, Tables 4, 6, 7). Numbers of Northern Orioles increased with increasing patch size at the micro-scale and at the macro-scale, when the 2 large patches were removed. No other neotropical migrant species had increasing numbers with increasing patch size at the micro-scale. Numbers of Yellow-billed Cuckoos, Vermilion Flycatchers, Brown-crested Flycatchers, Bell's Vireos, and Yellow-breasted Chats also increased with increasing patch size at the meso-scale and numbers of Yellow-billed Cuckoos, Brown-crested Flycatchers, Bell's Vireos, and Yellow-breasted Chats also increased with increasing patch size at the macro-scale.

Tree Density.--The index of abundance of Summer Tanagers consistently increased with increasing tree density across all analytical scales (Figure 5, Tables 4, 6, 7). At the micro-scale, numbers of White-winged Doves, Western Kingbirds, Yellow Warblers, Brown-headed Cowbirds, and Northern Orioles increased with increasing tree density. At the meso-scale, numbers of Yellow-billed Cuckoos, Vermilion Flycatchers, Brown-crested Flycatchers,

Figure 5. Number of Bird Species with Significant Positive Relationships with Patch Size and Tree Density, Across All Scales ($P \leq 0.10$).



Bell's Vireos, and Yellow-breasted Chats increased with increasing tree density. Numbers of Lucy's Warblers decreased with increasing tree density at the meso-scale. The index of abundance of Brown-crested Flycatchers and Bell's Vireos also increased with increasing tree density at the macro-scale.

Species Richness Analyses

Micro Analyses.--Species richness increased with increasing patch size and tree density at the micro-scale, but did not increase with increasing maximum distance to the nearest cottonwood or willow tree (Table 8). With multiple regression, tree density explained the most about species richness at the micro-scale (predicted species richness = $1.63 + 29.84(\text{tree density})$; Adjusted $R^2 = 0.03$); however, this correlation did not exceed 10% and was therefore not considered biologically meaningful. No other variables contributed a significant amount the richness of bird species at this scale.

Meso Analyses.--Species richness at the meso-scale increased with increasing patch size and increasing tree density, separately (Table 8). Tree density contributed the most to the explanation of variability in species richness at the meso-scale (predicted species richness = $15.60 + 0.02(\text{tree density})$; Adjusted $R^2 = 0.21$).

Table 8. Bird Species Richness Regression Statistics: Pearson's r at all Analytical Scales.

Scale	<u>Patch Size</u>		<u>Tree Density</u>		<u>Max. Dist</u>		<u>Multiple</u>	
	r	P	r	P	r	P	Adj R^{2a}	P
Micro	0.16	0.06	0.20	0.02	-0.08	0.38	0.03	0.02 ^b
Meso								
All Species ^c	0.45	0.00	0.47	0.00	-- ^d	--	0.21	0.00 ^b
Breeding ^e	0.43	0.00	0.42	0.00	--	--	0.17	0.00 ^f
Pass. Migr. ^g	0.07	0.61	0.14	0.27	--	--	NS ^h	
Neotrop. ⁱ	0.54	0.00	0.38	0.00	--	--	0.28	0.00 ^f
Cot.-Will. ^j	0.60	0.00	0.59	0.00	--	--	0.38	0.00 ^{bf}
Macro								
All Plots	0.52	0.02	0.41	0.08	--	--	0.22	0.02 ^f
W/O Large ^k	0.07	0.80	0.32	0.22	--	--	NS	

Table 8. Continued.

- a Adjusted R^2 for multiple regression.
- b Significant Variable is Tree Density.
- c All species included in analysis.
- d Variable not applied at this scale.
- e Local breeding species.
- f Significant Variable is Patch Size.
- g Passage migrant species.
- h Not significant correlation ($\underline{P} > 0.10$).
- i Neotropical migrant species.
- j Cottonwood/willow riparian obligate species.
- k Analysis without 2 plots with large patches (B2 and BW).

Richness of bird species that breed locally (in the lower Colorado River valley) was positively related to both patch size and tree density separately (Table 8), but only patch size explained the variability in species richness of local breeders in a multiple regression (predicted species richness of local breeders = $15.47 + 0.02(\text{patch size})$; Adjusted $R^2 = 0.17$). Richness of passage migrants through the lower Colorado River valley was not significantly related to patch size or tree density, either separately or in the multiple regression. Richness of neotropical migratory birds had a positive relationship with both patch size and tree density separately, but patch size was the only variable that significantly accounted for the variability in species richness of neotropical migrants in multiple regression (predicted species richness of neotropical migrants = $7.40 + 0.02(\text{patch size})$; Adjusted $R^2 = 0.28$). Richness of bird species that were cottonwood-willow riparian obligates was positively related to patch size and tree density separately, and significantly related to both patch size and tree density together in multiple regression (predicted species richness of cottonwood/willow riparian obligates = $1.78 + 0.014(\text{patch size}) + 0.009(\text{tree density})$; Adjusted $R^2 = 0.38$). All significant

relationships between species richness and patch size and tree density exceeded 10% correlation and were therefore considered biologically meaningful.

Macro Analyses.--Over all patches (19 total), bird species richness increased with increasing patch size but not with tree density (Table 8). With multiple regression analysis, only patch size contributed significantly to the variability in species richness (predicted species richness = $16.38 + 0.02(\text{patch size})$; Adjusted $R^2 = 0.22$). When the 2 plots with the large patches (BW and B2, both 160 ha) were removed from the analysis of bird species richness with patch size, bird species richness was no longer significantly related to patch size or tree density, either separately or with multiple regression.

Reproductive Analyses

I found Bell's Vireo nests in 6 of the 19 patches that I sampled (patch size range: 0.10 - 160 ha; Table 3). Mayfield indices for Bell's Vireo nests across all patches increased with increasing patch size and increasing tree density (Table 9). Only patch size significantly contributed to the variation in Mayfield indices for Bell's Vireos in the multiple regression (predicted Mayfield index = $0.26 + 0.005(\text{patch size})$; Adjusted $R^2 = 0.15$). When the 2 plots with the large patches (B2 and

Table 9. Breeding Statistics for Bell's Vireo and Yellow-breasted Chat.

Analytical Group	With or Without 2 Large Patches	<u>Patch Size</u>		<u>Tree Density</u>		<u>Multiple</u>	
		<u>x̄</u>	<u>P</u>	<u>x̄</u>	<u>P</u>	<u>AdjR^{2a}</u>	<u>P</u>
Bell's Vireo							
Mayfield Indices	With	0.45	0.05	0.44	0.03	0.15	0.05 ^b
	Without	0.11	0.34	0.27	0.15	NS ^c	
Yellow-breasted Chat							
Mayfield Indices	With	0.33	0.09	0.23	0.18	NS	
	Without	0.16	0.27	0.26	0.15	NS	
Index of Nest Abundance							
	With	0.39	0.11	0.34	0.15	NS	
	Without	0.47	0.05	0.72	0.00	0.49	0.00 ^d

^a Adjusted R² for multiple regression.

^b Significant variable is tree density.

Table 9. Continued.

c Not significant correlation ($P > 0.10$).

d Significant variable is patch size.

BW, both 160 ha) were removed from analysis, Mayfield indices for Bell's Vireo nests were no longer significantly related to patch size or tree density, either separately or together in multiple regression.

I found Yellow-breasted Chat nests in 12 of my 19 study patches (patch size range: 0 - 160 ha; Table 3). Mayfield indices for chat nests across all patches increased with increasing patch size but not significantly with increasing tree density. Neither variable explained the variability in Mayfield indices for chat nests in multiple regression. Upon removal of the 2 plots with the large patches from analysis, Mayfield indices for chat nests were no longer significantly related to patch size or tree density, either separately or together in multiple regression.

The index of nest abundance did not have a significant relationship with patch size or with tree density, either separately or together (in multiple regression). However, when I removed the 2 plots with the large patches from analysis, the index of nest abundance increased with both increasing patch size and increasing tree density. With multiple regression, only tree density significantly contributed to the variability in the index of nest abundance (predicted Mayfield index = $0.007 +$

0.002 (tree density); Adjusted $\underline{R}^2 = 0.49$).

DISCUSSION

Overall Conclusions

My analyses show that patch size and tree density affected the index of abundance for many species and the overall species richness in the lower Colorado River valley. Most species, especially neotropical migrants, showed an increase in index of abundance with increasing patch size and tree density.

Analyses of indices of nest abundance and nest success, however, indicated that even though the birds were in the smaller patches, and did not place significantly fewer nests in the smaller patches, they were not able to breed as successfully as in the larger patches. In this respect, smaller patches seem to be ecological sinks (Pulliam 1988).

Patterns of bird associations for neotropical migrants seemed to be consistent across scales, with the same core species exhibiting positive relationships with patch size and tree density.

Intercorrelation Conclusions

Patch size and tree density showed similar effects in many of my analyses, and the correlation matrices at each scale showed that they are intercorrelated to a certain extent. The most intercorrelation was at the meso-scale,

but even at this scale, at least 23% of the variation in patch size was not due to variability in tree density. Each parameter has value separate from the other in explaining variations in bird populations.

The correlation between patch size and tree density also shows that the smaller patches were not homogeneous extensions of the larger patches. The smaller patches, with more dispersed trees, differed statistically from the larger patches and therefore had a different effect on bird populations.

Neotropical Migrants and Cottonwood-Willow Obligates

The percent of neotropical migratory birds and cottonwood-willow riparian associated species related to patch size and tree density was consistently higher than the percent of all species correlated with patch size and tree density. Neotropical migrants have been found to be closely associated with riparian vegetation (Bottorff 1974, Carothers et al. 1974, Gates and Giffen 1991), and my study indicates that neotropical migrants also more strongly require larger patch sizes and more densely packed cottonwood and willow trees than the average lower Colorado River valley breeding species.

Rosenberg et al. (1991:56) found that the most stressful time of year for birds was the winter, and that

during summer, resources are abundant in all vegetation types. Therefore, year-round residents may have been able to acquire food resources in a broad range of vegetation types during the summer (Rosenberg et al. 1991:57). As Gates and Giffen (1991) found, neotropical migrants might have been selecting for the greater structural diversity in cottonwood-willow vegetation as compared to other, less complex vegetation types in the lower Colorado River valley.

Only one neotropical migratory species, and no cottonwood/willow riparian obligates, demonstrated a negative relationship with either patch size or tree density: Lucy's Warbler. Grinnell (1914) also found this species to be less closely associated with cottonwood/willow riparian forest than mesquite.

At all scales, bird species richness in the 19 patches in my study indicated that larger patches of cottonwood and willow supported a greater diversity of bird species, especially of neotropical migratory birds, and predictably of cottonwood-willow associated species. Not only were neotropical migratory birds dependent on riparian vegetation, as demonstrated elsewhere (Bottorff 1974, Carothers et al. 1974, Gates and Giffen 1991, Mills et al. 1991), but, as Johns (1993) found, they were

dependent on large patches of cottonwood-willow riparian vegetation.

Richness of passage migrants was not correlated with patch size or tree density, indicating that those species that used the lower Colorado River valley as a migratory stop-over site did not select cottonwood-willow vegetation over all other vegetation types. Insects are abundant in salt cedar, as well as in cottonwood-willow vegetation (Rosenberg et al. 1982) and perhaps this prey abundance was enough to support the passage migrants. MacArthur and MacArthur (1961), Carothers et al. (1974), and Mills et al. (1991) reported that many bird species required structural diversity in vegetation, such as that found in riparian forests. Apparently, passage migrants didn't require the structural diversity of cottonwood-willow vegetation for stop-over resources.

Threshold Conclusions

Bird abundance analyses at the macro-scale were relevant in pointing out the probable threshold patch size for birds in general and neotropical migrants and cottonwood-willow riparian associates in particular. With the removal of the 2 plots with the largest patches (160 ha), the majority of species lost the significant positive relationship with patch size that they had shown with the

inclusion of the 2 large patches. Overall richness analyses at the macro-scale also indicated that there was a threshold patch size somewhere between the large (160 ha) patches and the remainder of the patches (13 ha and smaller), above which increasing patch size seemed to have a positive relationship with bird species richness.

Rosenberg et al. (1991) examined a range of cottonwood and willow patches during the 1970's and 1980's and determined that the critical plot size of cottonwood/willow revegetation for birds in the lower Colorado River valley was 20 ha. Because of low recruitment rate of young cottonwood and willow trees, and the encroachment of salt cedar, larger patches of cottonwood and willow that occurred in the lower Colorado River valley in the past had shrunk substantially by the time of my study. There were no cottonwood-willow patches in the lower Colorado River Valley between 13 and 160 ha during my study; therefore, I was unable to determine the critical threshold patch size in these analyses.

Breeding Conclusions -- Ecological Sink

Breeding success for both Bell's Vireos and Yellow-breasted Chats increased with patch size, following the trend for bird abundance and species richness outlined above. Once again, when the 160 ha patches were removed,

the correlation was no longer significant, indicating that there was a threshold patch size between 13 ha and 160 ha above which patch size had a positive influence on breeding success. Breeding success for Bell's Vireos increased with increasing tree density while Yellow-breasted Chat breeding success did not.

The number of nests of both species found in each patch was not significantly correlated with patch size or tree density over all patches. This makes sense given the preference for nest sites of both species. Bell's Vireos tend to place their nests near the edge of open thickets, or under an isolated tree, protected by dense foliage and branches (Barlow 1962). These conditions were present in both large and small patches of cottonwood and willow trees. Bell's Vireos do not typically require the high song perches that Yellow-breasted Chats require (Barlow 1962, Petrides 1938, Bent 1953, Thomson and Nolan 1973).

Yellow-breasted Chats require high song-perches, from which they can easily see and be seen (Petrides 1938, Bent 1953, Thomson and Nolan 1973), but also require dense shrub nearby in which to place a nest (Thomson and Nolan 1973). Cottonwoods and willows were the tallest trees in this riparian community, their crowns extending above the surrounding brushy vegetation. When cottonwoods and

willows were sparse, the tall trees that were present became useful to yellow-breasted chats as high song-perches. Yellow-breasted Chats also used snags as song-perches when live tall trees were not present.

As stated previously, because nesting success was lower in smaller patches, the smaller patches may have acted as ecological sinks. These small patches might not have been able to sustain a healthy breeding population of birds because of various possible environmental pressures: edge effect, cowbird nest parasitism, nest predation, and inter/intra specific competition (Gates and Gysel 1978, Wilcove 1985, Small and Hunter 1988, Yahner and Scott 1988, O'Connor and Faaborg 1992, Robinson and Wilcove 1994).

Besides edge effect, heat may have been a detrimental factor contributing to low bird abundance in areas devoid of, or with only small patches of, cottonwood or willow trees. In drainages other than the lower Colorado River, Hunter et al. (1985) showed that salt cedar supported populations of passerines. They postulated that temperature tolerance accounted for the disparity in numbers of bird species using salt cedar across different drainages. Salt cedar in the lower Colorado River valley could not provide a sufficient buffer against the higher

daily temperatures than in the other drainages. Anderson et al. (1977) added that the majority of birds that use salt cedar are found in taller, almost successional mature stands of salt cedar, which are dominated by the greatest development in foliage volume between 6 and 10 meters above the ground. Such a canopy provides more shade and consequently a cooler environment than the dominant structural types of salt cedar in which the greatest foliage density is 0 to 2 meters high.

Scale Conclusions

The percentage of birds correlated with patch size and tree density varied as the scale of analysis grew larger. However, the species that were significantly correlated with patch size and tree density were often the same. Therefore, as Fowler et al. (1992) found, analyses at different scales supported each other and validated overall patterns.

On the other hand, the largest number of species showed powerful ($\geq 80\%$) positive relationships with patch size and tree density at the meso-scale, indicating that these birds seem to be choosing large patch size and higher tree density at the meso-scale. Territories of both Bell's Vireos and Yellow-breasted Chats average about 1 ha (Nolan 1960, Dennis 1958), which corresponds most

closely with the meso-scale samples. Therefore, the micro-scale analyses may be inappropriate for these species because the sample area size (0.1 ha) may have been too small to be ecologically meaningful to individual birds (Addicott et al. 1987, Wiens 1989). With a larger sample of patches, the macro-scale might have shown more significance to any particular species as a whole (Wiens 1989).

MANAGEMENT IMPLICATIONS

Currently, agency personnel are replacing the exotic salt cedar with cottonwood-willow trees in revegetation efforts along the lower Colorado River. Revegetation is a quick, short-term way of increasing vegetative structure, and thus abundance and diversity of birds in the lower Colorado River valley (Rosenberg et al. 1991). Rosenberg et al. (1991) documented the changes in bird use of an artificially revegetated site along the lower Colorado River, and found a significant increase in bird species richness and abundance with increasing vegetation maturity. Pairs of birds were found to be nesting successfully within 3 years of planting on revegetated sites (Rosenberg et al. 1991:62).

Such revegetation efforts are mitigation measures, because of the complete denaturalization of the hydrologic dynamics of the river. There is little evidence of natural regeneration occurring along the lower Colorado River, except in the Bill Williams River valley which is still subject to the periodic flooding that promotes the natural regeneration of cottonwood and willow trees (Anderson et al. 1977).

If the management goal is to increase bird numbers, revegetated areas should be increased in tree density and

plot size, beyond the 1 - 12 ha plots currently being planted in the lower Colorado River valley, to provide suitable, long-term habitat for birds in the lower Colorado River valley. Configuration of the revegetated cottonwood/willow patches should be circular or in blocks of similar dimensions, rather than in long strips. This would increase the tree density in the core of the revegetated plot, as well as decrease the edge-to-area ratio. Initial size of revegetated patches should also be expanded to allow for tree mortality and shrinking of the plot. The largest mature revegetated site in the lower Colorado River valley during my study, outside of the Bill Williams River Valley, was <13 ha. This patch was originally 30 ha when planted, but encroachment by salt cedar, poor water availability, and high soil salinity contributed to cottonwood and willow tree mortality and the decrease in area of the revegetated patch and the revegetated tree density over time.

For the revegetated patches to remain suitable habitat for birds, they should also be planted in areas where they can access water, and where soil salinity is low enough to reduce tree mortality. Yearly flooding of revegetated patches simulating the natural hydrologic cycle, with enough water to flush surface salinity and

accumulated leaf litter and disperse cottonwood and willow trees, would increase the vigor of these patches, as was demonstrated in the Kissimmee River valley in Florida (Toth 1993).

Management goals to increase bird numbers cannot rely on revegetation alone. Riparian forests, by nature, are linear and therefore present a high edge-to-area ratio. Many sources describe the problems confronted by edge-dwelling species, especially cowbird nest parasitism, and nest predation (Gates and Gysel 1978, Wilcove 1985, O'Connor and Faaborg 1992, Robinson and Wilcove 1994). Averill (unpubl. data) documented a high rate of nest failure in the lower Colorado River valley, during the same years as my study, due to cowbird nest parasitism and nest predation. Data from cowbird control programs suggest that rates of brood parasitism have been reduced by cowbird trapping and egg removal elsewhere (e.g., Kirtland's Warblers in Ohio [Kelly and DeCapita 1982], least Bell's Vireos in Southern California [RECON 1989 in Franzreb 1990]). However, pilot cowbird control programs in the lower Colorado River valley have been limited and have so far met with no success (B. Raulston, pers. commun.). Nest predation has not been formally studied in the lower Colorado River valley.

The small patches in my study were not adequate for most breeding neotropical migrants, but they did provide resources and attract birds that did not occur in tracts of pure salt cedar or other non-cottonwood or willow vegetation in the lower Colorado River valley. Year-round resident birds also were found in greater numbers in the small patches of cottonwood-willow vegetation than in areas that lacked these patches. The small patches of cottonwood and willow serve as song perches as well as canopy cover for a limited area, protecting birds, and other wildlife, from the weather and aerial predators. Therefore, to maintain the population of birds that currently exist in the lower Colorado River valley, these small patches should be protected.

Anderson et al. (1977) found that salt cedar, when allowed mature and attain structural complexity approaching that of cottonwood-willow forest, supported more birds than younger stands of pure salt cedar. Salt cedar is not easily eradicated and will therefore probably be a permanent component of the vegetation in the lower Colorado River valley. Therefore, if the management goal is to promote the growth of bird populations in the valley, efforts should be made to both promote and protect cottonwood and willow vegetation and to allow salt cedar

to reach maturity (i.e., by preventing frequent burning of salt cedar groves, and allowing floods that scour the flood-plain).

APPENDIX A - BIRD HABITAT USE DATA SHEET PROTOCOL

DATE = YR MO DY

OBS = Observer's initials

REF = Refuge's first initial (I = Imperial, C = Cibola, B
= Bill Williams, H = Havasu)

TRAN = Transect ID code

PT = Point number along transect

SP. = Four letter code for bird species observed

LOC = Vegetation type location in which bird is observed
(see Appendix D)

SEX = Sex of individual bird observed (M, F, U)

AGE = Age of individual bird observed (A = adult, I =
immature, J = juvenile, U = unknown)

DET = Method of detection of bird (V = visually, S = by
song, C = by call, B = both by sound and sight)

ACT = Activity of bird (F = foraging, A = areal, H =
hawking, P = perched, N = nesting, C = food carry, L
= courtship or copulation, W = swimming)

PLT = Two letter plant code, initials of latin name of
plant species in which bird was observed

SECT = Section of circle divided into eight equal parts
and centered at survey point, beginning at NNE, in
which bird was observed.

DIST = Distance from point center to bird (1 = < 25m, 2 =

26-50m, 3 = 51-75m, 4 = 76-100m)

RPT = Number of birds with identical characteristics as
listed above

APPENDIX B - BIRD SURVEY VEGETATION SAMPLING PROTOCOL

OBS = Observer.

DATE = Date (YR MO DY).

REFUGE = Refuge.

TRANS = Transect ID code.

POINT # = Bird survey point number.

DIR = Direction of vegetation transect (N=north,
NE=northeast, E=east, SE=southeast, etc.).

Hgt = Height of plant intersecting vertical line (1 = 0-
0.6m, 2 = 0.61-4.5m, 3 = 4.51-7.0m, 4 = 7.0-12m, 5 =
>12m).

SP = Four letter species code for plant species
intersecting vertical line.

Fol. or Bran. = Type of vegetation structure intersecting
vertical line (F=foliage, B=branch).

Alive or Dead = Vigor of vegetation intersecting vertical
line (A=alive, D=dead).

CAN = Canopy cover (+ = yes, - = no), tree contributing
canopy cover must have diameter at breast height >8
cm.

GRD = Ground cover (+ = yes, - = no).

TP GD = Type of ground cover (GR = bare ground, DT =
dead twig or stick, LL = leaf litter, HE =
herbaceous, WA = water).

4m, 8m, ... = Meter mark at which line intercept is performed.

DIMENSIONS OF PATCH = Obtained from Aerial Photos.

ARC = Radial arc (wedge-shaped) of relative use survey point: 1=NNE, 2=ENE...

1 (0-25m) = First sector out from the center of the point.

2 (25-50m) = Second sector out from the center of the point.

3 (50-75m) = Third sector out from the center of the point.

4 (75-100m) = Fourth sector out from the center of the point.

In each of these boxes, record number of cottonwood and/or willow trees within the defined sector, and the dispersion index in parentheses.

Dispersion index :

1 = clustered no more than $1/4$ the width of the sector away from either of the radii;

2 = clustered no more than $1/2$ the width of the sector away from either of the radii;

3 = clustered between $1/4$ and $3/4$ the width of the sector away from the either of the radii;

4 = spread evenly throughout the sector.

APPENDIX B CONTINUED

BIRD SURVEY VEGETATION SAMPLING DATA SHEET

OBS	DATE	REFUGE	TRANS	POINT #		
DIR	Hgt/SP/Fol. or Bran./Alive or Dead	CAN	GRD	TP	GD	
8m						
16m						
24m						
32m						
40m						
48m						
56m						
64m						
72m						
80m						
88m						
94m						
100m						

APPENDIX B - Continued

OBS ____ DATE _____ REFUGE ____ TRANS ____ POINT ____
 DIMENSIONS OF PATCH

In each cell, record # PF/SG and (dispersion index in parentheses)

ARC	1 (0-25m)	2 (25-50m)	3 (50-75m)	4 (75-100m)
1 NNE				
2 ENE				
3 ESE				
4 SSE				
5 SSW				
6 WSW				
7 WNW				
8 NNW				

Dispersion index :

- 1 = clustered no more than 1/4 the width of the sector away from either of the radii;
- 2 = clustered no more than 1/2 the width of the sector away from either of the radii;
- 3 = clustered between 1/4 and 3/4 the width of the sector away from the either of the radii;
- 4 = spread evenly throughout the sector.

APPENDIX C1 - NEST RECORD DATA SHEET 1 PROTOCOL

Obs = Initials of observer who found nest.

Refuge = I:Imperial, C:Cibola, B:Bill Williams, H:Havasu.

Transect = Transect ID code.

Date = Date of nest search (YR / MO / DY).

Time begin = Time nest search began.

Time end = Time nest search ended. Breaks in search time also recorded here.

Species = Bird species corresponding to nest found, or fledglings observed.

Nest number = Observer's first initial and the number corresponding to that person's nest search total (e.g., suellen's 35th nest of the season would be S35).

Status = Nest building, Egg laying, Incubating, Nestlings present, Fledglings Present, Abandoned.

Contents = # eggs or nestlings present, separated into host and cowbird.

Time found = Time the nest was found, must be within the nest search time recorded above.

Nest location description = Detailed instructions on how to find the nest again.

Activity of Adults = What are any present adults doing?

APPENDIX C1 CONTINUED

Obs _____ Refuge _____ Transect _____

Date ___/___/___

Time begin _____ Time end _____

Species _____ Nest number _____ Status _____ Contents _____ Time
found _____Nest location description _____
_____Activity of Adults _____
_____Species _____ Nest number _____ Status _____ Contents _____ Time
found _____Nest location description _____
_____Activity of Adults _____
_____Species _____ Nest number _____ Status _____ Contents _____ Time
found _____Nest location description _____
_____Activity of Adults _____

APPENDIX C2 - NEST RECORD DATA SHEET 2 PROTOCOL

Refuge = I:Imperial, C:Cibola, B:Bill Williams, H:Havasu.

Transect = Transect ID code.

Spp. = Bird Species corresponding to nest.

Nest # = Nest number, observer's initial plus nest number.

Nest Site Description = Detailed instructions for finding the nest again.

Nest Checks =

Date = Date found and subsequent check dates for that nest (YR / MO / DY).

Adults = Are adults present, and what are they doing?

OBS = Observer who found / checked nest.

Contents = Contents of nest (eggs, nestlings, host, cowbird...).

Comments = Any relevant comments (cowbirds present, egg shells under nest, nest destroyed, etc...).

APPENDIX D - VEGETATION SAMPLING IN

5-METER RADIUS CIRCLE AT NEST - PROTOCOL

Obs. : Observers initials.

Date : yr/mo/da.

Refuge : I = Imperial, C = Cibola, B = Bill Williams, H =
Havasu.

Tran. : Transect label.

Spp.: Bird species of nest.

Nest #: Nest identification number.

Nest-plant species: Two letter code for plant in which
nest is located.

Dist. to nearest SG/PF (< 100 meters away): Distance to
nearest cottonwood or willow from nest.

of SG/PF within 30 meters of above tree: Number of
cottonwoods and willows within 30 meters of the
nearest cottonwood or willow tree to the nest. (1 =
0-10 trees, 2 = 11-20 trees, 3 = 21-30 trees, 4 = 31-
70 trees, 5 = 1-100 trees, 6 = >100 trees).

beyond 30 m: How many cottonwood or willow trees are there
between 30 and 60 meters away from the nearest
cottonwood or willow tree to the nest (a = 0-10
trees, b = 11-50 trees, c = >50 trees).

DIR = direction of transect (N, S, E, W).

SPP. = Plant species two letter code, latin name.

HGT = Height class in which plant hits vertical line

(1 = 0-0.6 m, 2 = 0.61-4.5 m, 3 = 4.51-7 m, 4 = 7.01-12 m, 5 = >12 m).

DEAD OR ALIVE = D = dead, A = alive.

FOL OR BRAN = F = foliage, B = branch.

CAN = Canopy cover (+/-).

GRD = Ground cover (+/-).

TP GRD = Type of ground cover (ll = leaf litter, he = herbaceous, wa = water, gr = bare ground, dt = dead wood)

1M, 2M, ..., 11M = Meter marks at which above data are taken.

APPENDIX D CONTINUED

VEGETATION SAMPLING IN 5-METER RADIUS CIRCLE AT NEST

Obs ___ Date __/__/__ Refuge __ Tran. ___

Spp. _____ Nest # _____ Nest-plant species _____

Dist. to nearest SG/PF (< 100 meters away): _____

of SG/PF within 30 meters of above tree _____

beyond 30m _____

DIR___ SP/HGT/DEAD OR ALIVE/FOL OR BRAN CAN GRD TP GRD

1M. _____

2M. _____

3M. _____

4M. _____

5M. _____

DIR___

1M. _____

2M. _____

3M. _____

4M. _____

5M. _____

LITERATURE CITED

- Addicott, J. F., J. M. Aho, M. F. Antolin, D. K. Padilla, J. S. Richardson, and D. A. Soluk. 1987. Ecological neighborhoods: scaling environmental patterns. *Oikos* 49:340-346.
- AOU (American Ornithologists Union). 1983. Check-list of North American birds. The Lord Baltimore Press, Inc., Baltimore, MD. 691 p.
- Anderson, B. W., A. E. Higgins, R. D. Ohmart. 1977. Avian use of saltcedar communities in the lower Colorado River valley. p. 128-136 In: Johnson, R.R. and D.A. Jones, tech. coords., Importance, Preservation and Management of Riparian Habitat: A Symposium. USDA Forest Service General Technical Report RM-43, Rocky Mountain Forest and Range Experiment Station, Fort Collins, CO, 217 p.
- Askins, R. A. and M. J. Philbrick. 1987. Effect of changes in regional forest abundance on the decline and recovery of a forest bird community. *Wilson Bull.* 99:7-21.
- , -----, and D. S. Sugeno. 1987. Relationship between the regional abundance of forest and the composition of forest bird communities. *Biol. Conserv.* 39: 129-52.
- Barlow, J. C. 1962. Natural history of the Bell Vireo. *Univ. Kansas. Publ. Mus. Nat. Hist.* 12:241-296.
- Bent, A. C. 1953. Life histories of North American wood warblers. Part 2. *U. S. Nation. Mus. Bull.* 203:367-734.
- Block, W. M., K. A. With, and M. L. Morrison. 1987. On measuring bird habitat: influence of observer variability and sample size. *Condor* 89:241-251.
- Bottorff, R. L. 1974. Cottonwood habitat for birds in Colorado. *Amer. Birds* 28:975-79.

- Carothers, S. W., R. R. Johnson, and S. W. Aitchison. 1974. Population structure and social organization of Southwestern riparian birds. *Amer. Zool.* 14:97-108.
- Cassie, R. M. 1962. Frequency distribution models in the ecology of plankton and other organisms. *J. Anim. Ecol.* 31:65-92.
- Dennis, J. V. 1958. Some aspects of the breeding ecology of the Yellow-breasted Chat (*Icteria virens*). *Bird Banding* 29:169-183.
- Fowler, A. J., P. J. Doherty, and D. M. Williams. 1992. Multi-scale analysis of recruitment of a coral reef fish on the Great Barrier Reef. *Marine Ecol. Prog. Ser.* 82:131-141.
- Franklin, J. F. and R. T. T. Forman. 1987. Creating landscape patterns by forest cutting: ecological consequences and principles. *Landscape Ecology* 1:5-18.
- Franzreb, K. E. 1990. An analysis of options for reintroducing a migratory native passerine the endangered least Bell's Vireo (*Vireo bellii* *pusillus*) in the Central Valley California, USA. *Biol. Conserv.* 53:105-124.
- Gates, J. E. and N. R. Giffen. 1991. Neotropical migrant birds and edge effects at a forest-stream ecotone. *Wilson Bull.* 103:204-217.
- and L. W. Gysel. 1978. Avian nest dispersion and fledging success in field-forest ecotones. *Ecology* 59:871-83.
- Grinnell, J. 1914. An account of the mammals and birds of the lower Colorado River valley, with special reference to the distributional problems presented. University of California Publications. *Zoology* 12:51-294.

- Holmes, R. T., T. W. Sherry, P. P. Marra, and K. E. Petit. 1992. Multiple brooding and productivity of a neotropical migrant, the Black-throated Blue Warbler (Dendroica caerulescens), in an unfragmented temperate forest. *Auk* 109:321-333.
- Howe, W. H. and F. L. Knopf. 1991. On the imminent decline of Rio Grande cottonwoods in central New Mexico (U.S.A.). *Southwest. Nat.* 36:218-224.
- Hubbard, J. P. 1977. Importance of riparian ecosystems : biotic considerations. p. 14-18 In: Johnson, R.R. and D.A. Jones, tech. coords. USDA Forest Service General Technical Report RM-43, Rocky Mountain Forest and Range Experiment Station, Fort Collins, CO, 217 p.
- Hunter, W. C., B. W. Anderson, and R. D. Ohmart. 1985. Summer avian community composition of Tamarix habitats in three southwestern desert riparian systems. p. 128-134 In: R. R. Johnson, C. D. Ziebell, D. R. Patton, P. F. Ffolliott, and R. H. Hamro, tech. coords. Riparian Ecosystems and their Management : Reconciling Conflicting Uses. U.S. Forest Service General Technical Report RM-120.
- , -----, and ----- . 1987. Avian community structure changes in a mature floodplain forest after extensive flooding. *J. Wildl. Manage.* 51:495-502.
- Johns, B. W. 1993. The influence of grove size on bird species richness in aspen parklands. *Wilson Bull.* 105:256-264.
- Kelly, S. T. and M. E. DeCapita. 1982. Cowbird control and its effect on Kirtland's Warbler reproductive success. *Wilson Bull.* 94:363-365.
- Klebenow, D. A. and R. J. Oakleaf. 1984. Historical avifaunal changes in the riparian zones of the Truckee River, Nevada. Pages 203-210 In: R. E. Warner and K. N. Hendrix, eds. California Riparian Systems. University of California Press, Berkeley.
- Lynch, J. F. and D. F. Whigham. 1984. Effects of forest fragmentation on breeding bird communities in Maryland, USA. *Biol. Conserv.* 28:287-324.

- MacArthur, R. H. and J. W. MacArthur. 1961. On bird species diversity. *Ecology* 42:594-598.
- Martin, T. E. 1981. Limitation in small habitat islands: chance or competition? *Auk* 98:715-34.
- Mayfield, H. F. 1961. Nesting success calculated from exposure. *Wilson Bull.* 73:255-261.
- . 1975. Suggestions for calculating nest success. *Wilson Bull.* 87:456-466.
- Mills, G. S., J. B. Dunning Jr., and J. M. Bates. 1991. The relationship between breeding bird density and vegetation volume. *Wilson Bull.* 103:468-479.
- Mahoney, J. M. and S. B. Rood. 1991. A device for studying the influence of declining water table on poplar growth and survival. *Tree Physiol.* 8:305-314.
- Morrison, M. L. 1984. Influence of sample size and sampling design on analysis of avian foraging behavior. *Condor* 86:146-150.
- Nolan, V., Jr. 1960. Breeding behavior of the Bell Vireo in Southern Indiana. *Condor* 62:223-244.
- Norusis, M. J. 1990. SPSS base system user's guide. SPSS Inc., Chicago, IL. 520 p.
- O'Connor, R. J. and J. Faaborg. 1992. The relative abundance of the Brown-headed Cowbird (Molothrus ater) in relation to exterior and interior edges in forests in Missouri. *Trans. Missouri Acad. Sci.* 26:1-9.
- Ohmart, R. D., B. W. Anderson, and W. C. Hunter. 1988. The ecology of the lower Colorado River from Davis Dam to the Mexico-United States international boundary: a community profile. U.S. Fish and Wildlife Service Biological Report 85(7.19), 296 p.

- , W. O. Deason, and C. Burke. 1977. A riparian case history: the Colorado River. p. 35-47 In: Johnson, R.R. and D.A. Jones, tech. coords. USDA Forest Service General Technical Report RM-43, Rocky Mountain Forest and Range Experiment Station, Fort Collins, CO, 217 p.
- Peterjohn, B. G. and J. R. Sauer. 1994. Population trends of woodland birds from the North American Breeding Bird Survey. *Wildl. Soc. Bull.* 22:155-164.
- Petrides, G. A. 1938. A life history study of the Yellow-breasted Chat. *Wilson Bull.* 50:184-189.
- Pulliam, H. R. 1988. Sources, sinks, and population regulation. *Am. Nat.* 132:652-661.
- Ralph, C. J., G. R. Geupel, P. Pyle, T. E. Martin, and D. F. DeSante. 1993. Field methods for monitoring landbirds. Pacific Southwest Research Station, Albany, CA. 41 p.
- Ranney, J. W., M. C. Bruner, and J. B. Levenson. 1981. The importance of edge in the structure and dynamics of forest islands. Pages 67-95 in: R. L. Burgess and D. M. Sharpe, eds. *Forest island dynamics in man-dominated landscapes*. Springer-Verlag, New York, N. Y.
- Raphael, M. G. 1987. Estimating relative abundance of forest birds: simple versus adjusted counts. *Wilson Bull.* 99:125-131.
- RECON (Regional Environmental Consultants). 1989. Draft comprehensive species management plan for the least Bell's vireo (Vireo bellii pusillus). San Diego Association of Governments, San Diego, CA.
- Robbins, C. S., J. R. Sauer, R. S. Greenberg, and S. Droege. 1989. Population declines in North American birds that migrate to the neotropics. *Proc. Natl. Acad. Sci.* 86:7658-7662.

- Robinson, S. K. 1992. Population dynamics of breeding neotropical migrants in a fragmented Illinois landscape. Pages 408-418 in: Hagan, J. M. III and D. W. Johnston. Ecology and conservation of neotropical migrant landbirds. Smithsonian Inst. Press, Washington and London.
- and D. S. Wilcove. 1994. Forest fragmentation in the temperate zone and its effect on migratory songbirds. Bird Conserv. International. 4:233-249.
- Rosenberg, K. V., R. D. Ohmart, and B. W. Anderson. 1982. Community organization of riparian breeding birds: response to an annual resource peak. Auk 99:260-274.
- , -----, W. C. Hunter, and B. W. Anderson. 1991. Birds of the Lower Colorado River Valley. The University of Arizona Press, Arizona Board of Regents. 416 p.
- Roth, R. R. and R. K. Johnson. 1993. Long-term dynamics of a Wood Thrush population breeding in a forest fragment. Auk 110:37-48.
- Small, M. F. and M. L. Hunter. 1988. Forest fragmentation and avian nest predation in forested landscapes. Oecologia 76:62-64.
- Smith, F. 1977. A short review of the status of riparian forests in California. Pages 1-2 in: A. Sands, ed. Riparian forests in California: their ecology and conservation. Publ. Inst. Ecol., Davis, CA, No. 15.
- Snyder, W. D. and G. C. Miller. 1992. Changes in riparian vegetation along the Colorado River and Rio Grande, Colorado. Great Basin Nat. 52:357-363.
- Steele, B. B. 1992. Habitat selection by breeding Black-throated Blue Warblers at two spatial scales. Ornis Scandinavica 23:33-42.
- Terborgh, J. W. 1989. Where Have All the Birds Gone?: Essays on the Biology and Conservation of Birds that Migrate to the American Tropics. Princeton, NJ: Princeton University Press.

- Thomson, C. F. and V. Nolan Jr. 1973. Population biology of the Yellow-breasted Chat (Icteria virens L.) in Southern Indiana. *Ecol. Monogr.* 43:145-171.
- Toth, L. A. 1993. The ecological basis of the Kissimmee River restoration plan. *Florida Scientist* 56:25-51.
- Van Horne, B. 1983. Density as a misleading indicator of habitat quality. *J. Wildl. Manage.* 47:893-901.
- Wiens, J. A., J. T. Rotenberry, and B. Van Horne. 1987. Habitat occupancy patterns of North American shrubsteppe birds: the effects of spatial scale. *Oikos* 48:132-147.
- . 1989. Spatial scaling in ecology. *Functional Ecology* 3:385-397.
- Wilcove, D. 1985. Nest predation in forest tracts and the decline of migratory songbirds. *Ecology* 66:1211-1214.
- Wilcove, D. S. and R. F. Whitcomb. 1983. Gone with the trees. *Natural History* 92: 82-91.
- Yahner, R. and D. P. Scott. 1988. Effects of forest fragments on depredation of artificial nests. *J. Wildl. Manage.* 52:158-161.
- Zar, J. H. 1984. *Biostatistical analysis*, 2nd edition. Prentice-Hall Inc., Englewood Cliffs, N. J. 718 p.