SOUTHWESTERN WILLOW FLYCATCHER HABITAT SELECTION ALONG THE GILA AND LOWER SAN PEDRO RIVERS, ARIZONA: VEGETATION AND HYDROGEOMORPHIC CONSIDERATIONS

by

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ABSTRACT

The southwestern willow flycatcher (*Empidonax traillii extimus*, SWFL) is an endangered riparian obligate songbird whose habitat has been greatly altered by large-scale damming, flow diversion, and groundwater pumping that substantially changed hydrology, riparian vegetation, and nesting habitat quality. Conservation and restoration actions for the SWFL requires knowledge of habitat selection patterns and the environmental conditions and ecological processes that create and sustain suitable breeding habitat across space and time. I assessed differences in habitat characteristics between occupied and unoccupied patches within and between cottonwood-willow (C-W) and tamarisk (TAMA) dominated forest along a free-flowing (San Pedro) and a regulated river (Gila) in southeastern Arizona. I linked these patch-scale selection characteristics to local hydrogeomorphic conditions, and assessed the influence of basin-scale hydrological and geomorphic conditions on the composition and structure of riparian habitat that is available for SWFL nesting, on these two contrasting rivers.

SWFL selected similar habitat traits for both C-W and TAMA patches: high stem densities (500 – 1300 stems/ha) of young (5.5 - 15 cm dbh) trees (willow and tamarisk), dense foliage in the upper (7 – 9 m) canopy, high canopy cover ($\bar{x}$ = 88%), high abundance ($\bar{x}$ = 39%) of riparian forest within the 4.5-ha neighborhood surrounding the patch, and close proximity to water. Four of the five key patch-scale vegetation variables were associated with water availability and patch inundation rate. Foliage density at 7 – 9 m showed the strongest

pattern: density increased with higher water tables and low annual water table fluctuation in both C-W and TAMA dominated patches. Other key variables showed C-W or TAMA-specific relationships with hydrogeomorphic conditions. At the basin-scale the Gila River riparian plant community had low floristic and structural diversity, and an abundance of tamarisk forest, compared to the free-flowing San Pedro River, which had high patch floristic and structural diversity with co-dominant cottonwood-willow and tamarisk forest. On the San Pedro River, SWFL selection patterns suggested that willow forest was used more than expected, tamarisk less often than expected, and cottonwood in equal proportion based on availability.

These data can help better define SWFL habitat requirements when linked to selection patterns at other spatial scales. Hydrogeomorphic relationships highlight the importance of maintaining local and basin-scale hydrology within suitable ranges to support SWFL breeding habitat over short and long time frames. Land and water managers seeking to conserve and restore SWFL habitats can use these data to assess current habitat conditions and develop broad scale and local site management goals.

This thesis is dedicated to Rebecca for her unwavering support and love, to my parents for their encouragement in all my endeavors, and to my grandfather, Walter Michalak, for passing on his love of the outdoors.

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INTRODUCTION

Of the conservation efforts needed to conserve southwestern willow flycatcher (*Empidonax traillii extimus*, SWFL) populations, perhaps the most important is to protect and restore breeding-ground habitat (U.S. Fish and Wildlife Service 2002). Riparian forest used by the SWFL varies considerably across its breeding range, from oak woodland in California, to shrub willow patches along high elevation streams and meadows, to broad leaf deciduous forest along desert streams (Sogge and Marshall 2000). Managers need specific details regarding the floristic and structural characteristics that SWFL require to conserve and protect nesting habitat within these plant communities. They also need knowledge of the hydrological and fluvial processes that create and sustain these characteristics over time (Graf et al 2002, Kus and Sogge 2003).

In Arizona, the central portion of the SWFL breeding range, >95% of nests are located in low elevation broadleaf riparian deciduous forest (Paradzick and Woodward 2003). These forests have been greatly reduced and altered due to damming, water diversions, and groundwater pumping (Tellman et al. 1997). One of most conspicuous changes has been the decline in fremont cottonwood (*Populus fremontii*) and goodding willow (*Salix gooddingii*) forest (Stromberg 1993), with a contemporaneous increase in tamarisk (*Tamarix* spp.). This community shift has been attributed to changes in hydrologic conditions (Poff et al. 1997, Stromberg et al. 2004), and other environmental stressors, such as overgrazing by livestock (Belsky et al. 1999, Krueper et al. 2003). These changes have greatly reduced the bird’s distribution and abundance, and much work has been done to locate extant SWFL populations and characterize basic habitat requirements (Paradzick and Woodward 2003, Sogge et al. 2003).

One of the largest populations in Arizona occurs near the Gila/San Pedro River confluence. This population provides an opportunity to study how hydrology and fluvial geomorphology affect SWFL nesting habitat quality. The San Pedro River is free-flowing and has abundant cottonwood-willow forest, while flows in the Gila River are regulated by Coolidge Dam and tamarisk forest is the dominant species. By contrasting vegetation and hydrogeomorphic similarities and differences between cottonwood-willow and tamarisk patches, and between river reaches with different flow regimes, one can provide managers with information of use in restoring breeding habitat at local scales, as well as in assessing how water management influences SWFL habitat availability over space and time.

This thesis consists of three chapters, each of which was written in the format of a journal article. Collectively, the chapters provide a comprehensive picture of SWFL habitat selection and the underlying hydrologic conditions and processes that support breeding habitat. Chapter 1 identifies key floristic and structural vegetation characteristics important to SWFL selection within cottonwood-willow and tamarisk forest. I focused sampling efforts at the patch scale, to supplement existing SWFL habitat selection research at coarser (landscape) and finer (nest-site) scales, and to coincide with research examining SWFL reproductive rates. Chapter 2 examines the influence of local hydrogeomorphic conditions (i.e., surface and groundwater hydrology, fluvial surface location, and frequency of inundation) on the key floristic and structural variables. Finally, Chapter 3 explores how basin-scale hydrology influences SWFL habitat availability (forest composition and structure, and abundance over time) on the Gila and San Pedro Rivers.

LITERATURE CITED

Belsky, A.J., A. Matzke, and S. Uselman. 1999. Survey of livestock influences on stream and riparian ecosystems in the western United States. Journal of Soil and Water Conservation 54:419-431.

Graf, W.L., J. Stromberg, and B. Valentine. 2002. Rivers, dams, and willow flycatchers: summary of their science and policy connections. Geomorphology. 47:169–188.

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

Kus, B.E., and M.K. Sogge. 2003. Status and distribution – introduction. Studies in Avian Biology 26:3-4.

Paradzick, C.E., and A.A. Woodward. 2003. Distribution, abundance, and habitat characteristics of southwestern willow flycatchers (*Empidonax traillii extimus*) in Arizona, 1993 – 2000. Studies in Avian Biology 26:22–29.

Poff, N.L., J.D. Allan, M.B. Bain, J.R. Karr, K.L. Prestegaard, B.D. Richter, R.E. Sparks, and J.C. Stromberg. 1997. The natural flow regime – a paradigm for river conservation and restoration. Bioscience 47:769-784.

Sogge, M.K. and R.M. Marshall. 2000. A survey of current breeding habitats. Pages 43-56 *in* D. M. Finch, and S. H. Stoleson, editors. Status, ecology, and conservation of the southwestern willow flycatcher. Gen. Tech. Rep. RMRS-GTR-60. USDA Forest Service, Rocky Mountain Research Station, Ogden, Utah, USA.

_____, S.J. Sferra, T.D. McCarthey, S.O.Williams, and B.E. Kus. 2003. Distribution and characteristics of southwestern willow flycatcher breeding sites and territories: 1993 – 2001. Studies in Avian Biology 26:5-11.

Stromberg, J.C. 1993. Fremont cottonwood-Gooding willow riparian forests:a review of their ecology, threats, and recovery potential. Journal of the Arizona Academy of Science. 26:97-110.

_____, M. Briggs, C. Gourley, M. Scott, P. Shafroth, and L. Stevens. Human alterations of riparian ecosystems. 2004. Pages 99 -126. *in* M.B, Baker, P.F. Ffolliot, L.F. Debano, and D.G. Neary, editors. Riparian areas of the Southwestern United States: hydrology, ecology, and management. Lewis Publishers, Inc., Boca Raton, Florida, USA.

Tellman, B., R. Yarde, and M.G. Wallace. 1997. Arizona's changing rivers: how people have affected the rivers. Issue Paper #19, Water Resources Research Center, College of Agriculture, University of Arizona, Tucson Arizona, USA.

U.S. Fish and Wildlife Service. 2002. Southwestern willow flycatcher (*Empidonax traillii extimus*) - Final recovery plan. U.S. Fish and Wildlife Service, Albuquerque, New Mexico.

CHAPTER 1

SOUTHWESTERN WILLOW FLYCATCHER HABITAT SELECTION ALONG THE LOWER SAN PEDRO AND GILA RIVERS, ARIZONA

ABSTRACT

Conservation and restoration of suitable breeding habitat for the endangered southwestern willow flycatcher (SWFL; *Empidonax traillii extimus*) requires quantitative data describing important characteristics at multiple spatial scales. Data is lacking at the patch scale that could bridge landscape and nest-site scale studies. Similarly, data is lacking on the influence on SWFL habitat selection of tamarisk, a tree that has become abundant along many southwestern rivers. I assessed differences in habitat characteristics between occupied and unoccupied patches within and between cottonwood-willow and tamarisk dominated forest along the Gila and lower San Pedro rivers. I found that SWFL selected similar habitat traits for both cottonwood-willow and tamarisk patches: high stem densities (500 – 1300 stems/ha) of young (5.5 - 15 cm dbh) trees (willow and tamarisk), dense foliage in the upper (7 – 9 m) canopy, high canopy cover ($\bar{x}$ = 88%), high abundance ($\bar{x}$ = 39%) of riparian forest within the 4.5-ha neighborhood surrounding the patch, and close proximity to water. Using a multivariate logistic regression model, three variables were identified as significant predicators of SWFL occupancy: basal area of young trees, % forest in 4.5-ha neighborhood, and distance to water. Managers can couple these key patch characteristics with variables at coarser and finer spatial scales to better

conserve habitat. To accomplish recovery, conservation efforts should focus on ecological processes that create and sustain suitable breeding vegetation patches over the long-term.

INTRODUCTION

Avian habitat selection derives from innate or learned behavioral responses ultimately influenced by survival and fitness of individuals (Block and Brennan 1993). Breeding-ground habitat selection is often based on local physiognomic and floristic vegetation characteristics (MacArthur and MacArthur 1961, Hildén 1965, James 1971, Holmes and Robinson 1981, Rotenberry 1985, Knopf et al. 1990, Grzybowski et al. 1994), as well as habitat features across multiple scales (Gutzwiller and Anderson 1987, Wiens et al. 1987, Orians and Wittenberger 1991, Saab 1999). Defining breeding-habitat components and ecological processes that create and maintain such habitats provides information critical for making informed land and water management decisions that affect bird populations (Verner et al. 1986). Defining these associations is especially important for the conservation and recovery of endangered species that occur in high disturbance habitats, such as along arid-land rivers, where available habitat can fluctuate both spatially and temporally (Bravard et al. 1986, Martin 1992, Grzybowski et al. 1994).

SWFL is a riparian obligate songbird that was federally listed as endangered in 1995 (U.S. Fish and Wildlife Service 1995). The current breeding range includes six southwestern states: Arizona, California, Colorado, Nevada, New Mexico, and Utah (U.S. Fish and Wildlife Service 1995, Sogge et al. 2003). Habitat loss, alteration, and fragmentation within the breeding range are primary listed causes of SWFL population declines (U.S. Fish and Wildlife Service 1995). Other impacts listed as deleterious impacts include loss of wintering habitat, brown-headed cowbird (*Molothrus ater*) nest parasitism, and increase of invasive plants (specifically tamarisk, *Tamarix ramosissima*, in Arizona).

SWFL historic distribution in Arizona has been reduced (Unitt 1987, Paradzick and Woodward 2003), influenced by significant alteration and loss of riparian habitat (Hunter et al. 1988, Governor's Riparian Habitat Task Force 1990). Arizona has over one-third of current known SWFL breeding territories (Sogge et al. 2003). Two locations, Roosevelt Lake and the Gila/San Pedro River confluence, contain >70% of SWFL territories in Arizona, and are the second and third largest populations rangewide (Paradzick and Woodward 2003). Quantifying suitable breeding habitat characteristics for these and other extant populations, and using this information as a target to restore riparian areas suitable for population expansion and long-term persistence, are among the most critical conservation needs required for recovery (Stoleson et al. 2000).

Breeding habitat characteristics vary greatly throughout the SWFL's range. Variation in woody plant assemblages, spatial distribution and size of patches, and water types used by SWFL (Sogge and Marshall 2000) confounds our ability to make anything but broad generalizations on how to best define, and thus conserve, habitats of extant populations and to identify restoration targets for degraded areas. However, most (>95%) breeding sites in Arizona are in low-elevation (<1200 m) riparian forest composed of dense stands of Fremont cottonwood (*Populus fremontii*), Goodding willow (*Salix gooddingii*), and tamarisk along rivers and reservoir deltas (Sogge and Marshall 2000, Paradzick and Woodward 2003).

Tamarisk, although listed as a cause of species decline, has become a dominant plant along many watercourses (Hunter et al. 1988, Graf 1982, Brock 1994, Everitt 1998), and >90% of SWFL nests located in Arizona from 1993 – 2000 were in tamarisk (Paradzick and Woodward 2003). There is a current initiative to reduce tamarisk abundance throughout the Western United States (http://www.tamariskcoalition.org/index.html) with a primary goal to restore native ecosystems to benefit native fauna, including the SWFL (DeLoach et al. 2000). However, little quantitative data exists describing the functional role tamarisk may now serve in altered riparian ecosystems where current hydrological conditions (i.e., lowered groundwater table, altered hydrograph) may not support native trees (Stromberg 1998b, Fleishman et al. 2003). The Arizona Game and Fish Department and U.S. Geological Survey have begun research to examine effects of tamarisk on SWFL reproductive rates and survivorship; also needed however, is an assessment of the similarities and differences of floristic and structural characteristics between tamarisk and cottonwood and willow habitats, and to determine if these differences influence SWFL habitat selection.

In Arizona, two published studies, both conducted at Gila/San Pedro River Confluence and Roosevelt Lake, have assessed SWFL habitat characteristics. Hatten and Paradzick (2003) identified SWFL breeding habitat-selection patterns coupling Geographic Information System (GIS) with remote sensing data over a range of scales (0.09 – 71 ha). Allison et al. (2003) characterized microhabitat-selection patterns, examining floristics and structural attributes within occupied patches. In both studies, authors recognized limitations of scale and methods used to characterize habitat use. The GIS study did not examine landscape or patch-scale vegetation floristics, but rather measured only vegetation density and specific structural attributes that were correlated to remote sensing variables, and authors recommended coupling results with on-the-ground field studies to better elucidate habitat choice. Allison et al. (2003) specifically examined female nest-site choice, and suggested that selection at coarser scales should be assessed as it is important for other SWFL life-cycle needs (see Sedgwick and Knopf 1992).

To complement these studies, research is needed at the patch scale to provide a more complete assessment of SWFL habitat requirements. Patch-level sampling would describe habitat used by the SWFL during much of the breeding period, and is inclusive of various breeding cycle needs (e.g., male singing perches, foraging sites, and nest sites; Anderson and Shugart 1974). Such data can be used on a patch-specific basis to manage vegetation and habitat components for SWFL, and when linked with stream processes give managers data needed to make decisions at watershed or ecosystem scales (Bravard et al. 1986, Richter and Richter 2000, Scott et al. 2003).

This study had two overall goals: 1) describe patch-scale SWFL habitat selection patterns for the population located near the Gila/San Pedro River confluence, and integrate these results with findings of the two previous studies; and 2) define the fluvial geomorphic and hydrologic conditions that create and sustain these habitat components. This chapter addresses the first goal. To describe selection patterns I set two main objectives: 1) to develop and test a model of habitat selection using patch-level presence-absence data and a suite of vegetation and environmental variables based on literature; and 2) to compare structural traits of tamarisk dominated occupied patches to occupied cottonwood-willow dominated patches to aid in the determination of tamarisk influence on SWFL persistence and recovery.

STUDY AREA

This study was conducted near the confluence of the Gila and San Pedro rivers in southeastern Arizona (Fig. 1-1). Elevation ranged from 536 – 680 m. Riparian vegetation for this region has been classified by Minckley and Brown (1994) as Sonoran riparian deciduous forest located within Sonoran Desertscrub formation. Dominant vegetation communities include tamarisk forest and woodland, Fremont cottonwood-Goodding willow forest, seepwillow (*Baccharis salicifolia*) shrubland, and mesquite (*Prosopis velutina*) forest. Tamarisk abundance varied within the study area from monotypic stands, to co-dominant with cottonwood and willow trees, to very low abundance or absent in some patches.

Gila River study sites were distributed over a 43-km reach from near Dripping Springs Wash confluence (13.5 km upstream of Winkelman) to 3 km downstream of the town of Kelvin. The northern end of the area is located 35 km downstream of Coolidge Dam. In most years, river flow is maintained during the breeding season (May – August) by scheduled releases for agriculture downstream of the study area. Some sites were upstream, and some downstream, of the confluence with the San Pedro River.

San Pedro River study sites were distributed over a 25-km reach from 5 miles upstream of the town of Mammoth downstream to the Gila River confluence. The San Pedro River enters the Gila River near the town of Winkelman. There are no significant surface water diversions, but groundwater withdrawals for agriculture, mining, and domestic use occur within the reach. River flow varies along the reach from intermittent to perennial; much of the study reach can be characterized as interrupted perennial, characterized by segments with surface flow punctuated by stretches of dry riverbed with shallow alluvial groundwater.

METHODS

Patch Selection

To determine habitat selection I compared habitat characteristics of occupied and unoccupied patches and built a logistic regression model using an equal number of occupied and unoccupied patches.

Occupied Patches.— Since 1997, Arizona Game and Fish Department (AGFD) has conducted presence-absence SWFL surveys (Sogge et al. 1997) throughout the study area (Smith et al. 2002, Paradzick and Woodward 2003, Smith et al. 2003). In 2001, AGFD located 17 occupied sites containing 131 SWFL territories (Smith et al. 2002). I delineated these sites into 25 patches; a patch was defined as a stand of trees with similar floristic and physiognomic characteristics, and with similar floodplain topography (i.e., on similar fluvial surface types). I selected 20 patches to build the model (10 on each drainage) that had high abundance of SWFL and had been occupied for the greatest number of years (this was to facilitate co-analysis by AGFD of vegetation effects on reproductive rates). This subset of patches supported 89% of the population in the study area in 2001. I used the remaining patches (5) for model validation and accuracy assessment.

Unoccupied Patches.— I selected 20 unoccupied patches (10 on each drainage). Because my goal was to more narrowly define habitat preferences at the patch scale, I restricted unoccupied patches to those that fell within the qualitative descriptions of habitat provided by Sogge et al. (1997). Each unoccupied patch had to have the following traits: >50% relative cover of at least 1 of the dominant pioneer riparian tree species (cottonwood, tamarisk, or willow), >50% canopy cover, and >5 m $\bar{x}$ tree height. I located potentially suitable unoccupied patches using 3 methods: 1) to take advantage of existing groundwater data that I used to examine water availability influence on vegetation characteristics in the second part of this study (Chapter 2), I selected 7 existing piezometers (shallow groundwater wells) on the San Pedro River and chose a random bearing and distance (<100 m) and searched for a suitable unoccupied patch near that point; 2) similarly, on the Gila River, I located 2 patches on land with landowner permission to install piezometers, and searched for a suitable unoccupied patch using the same method; and 3) for the remainder of patches (11), I created 25 random points using ArcView software (ESRI 2002), located these points on the ground with a Global Positioning System (GPS), and used the same search method above to chose a suitable unoccupied patch. All patches were surveyed by AGFD for SWFL in 2001-2002 following a standardized SWFL protocol (Sogge et al. 1997). One unoccupied patch was colonized during the study, and a replacement patch was located and measured in 2002.

Patch Measurements

In 2001, I attempted to sample 10% of the area within each patch using randomly placed 5 X 20 m quadrats. The area of occupied ($\bar{x}$ = 1.04 ha ± 0.80) and unoccupied ($\bar{x}$ = 1.28 ha ± 1.27) patches was similar. I sampled a mean of

9.3% (± 1.8) of the patch areas, which encompassed 7 – 15 quadrats per patch. Smaller percentages (< 10%) of area were sampled at large patches (>1.5 ha) that were homogeneous (i.e., those with large monotypic stands of cottonwood gallery forest).

Structure.— I measured canopy cover using a spherical densiometer, and total vegetation volume up to 9 m (maximum pole height) using the line intercept method (Mills et al. 1991), at the corners and center of each quadrat. I also calculated an index of foliage density within each of 3 height strata in relation to mean SWFL nest height within the study area: 0 – 4 m below; 4 - 7 m bracketed, and 7 - 9 m above, mean nest height (Smith et al. 2002). To standardize vegetation volume between height intervals, I divided total vegetation volume of each height interval by length of the interval (i.e., 4, 3, and 2 m, respectively). Maximum canopy height was recorded as the tallest tree within each quadrat. I calculated coefficient of variation of canopy cover and maximum canopy height, and foliage height diversity (following Mills et al. 1991), as measures of habitat heterogeneity within the patch.

Floristics.— Within each quadrat, I identified to species and counted all woody stems taller than breast height (1.5 m). I grouped stems (diameter at breast height, dbh) by species into 5 size categories for analysis: <1 cm, 1 – 5.5 cm, 5.5 – 15 cm, 15 – 25 cm, >25 cm. I calculated basal area ($cm^2/100m^2$) by multiplying number of stems by the basal area value for the midpoint of the size class. For stems >25 cm, I calculated basal area using measured dbh values.

Dominant tree and shrub species included Fremont cottonwood, Goodding willow, tamarisk, velvet mesquite (*Prosopis velutina*), and seepwillow. All snags, regardless of species, were grouped. Coyote willow (*S. exigua*) had low abundance and was grouped with *S. gooddingii*. Other species that were recorded in study patches but had low abundance included burrobrush (H*ymonoclea monogyra)*, desert broom (*Baccharis sarothoides*), velvet ash (*Fraxinus velutinus*), buttonbush (*Cephalanthus occidentalis*), common elderberry (*Sambucus canadensis mexicana*), Arizona walnut (*Juglans major*), Arizona sycamore (*Platanus wrightii*), and Texas mulberry (*Morus microphylla*). These species were included in patch-structure analysis (i.e., basal area, foliage density), but were not included in floristic analyses.

Groundcover and Water.— Percent groundcover by type (i.e., live herbaceous, dead herbaceous, dead/down woody, litter, water, bare) was estimated within each patch using randomly placed 1 x 1 m plots (Daubenmire 1959). Within each patch I sampled an equal number of plots as 5 x 20 sampling quadrats ($\bar{x}$ = 9 ± 4). Distance from patch to nearest water or saturated soil was measured during the last week of June in 2001, generally the driest part of the summer before July-August monsoon rains.

4.5-ha Neighborhood Sampling.— I sampled vegetation within a larger neighborhood area containing and surrounding each patch (Fig. 1-2). Based on habitat-selection results of Hatten and Paradzick (2003), this neighborhood area was set at 4.5-ha. A 150 x 300 m rectangular plot was centered on a random point within each patch with long axis positioned parallel to the stream channel. Plots were divided into 3 equal sections; within each section I randomly placed a 150-m transect positioned perpendicular to the stream channel. Along each 150-m transect, I visually delineated major vegetation patch types based on growth form, dominant plant species, and dominant size class of trees. I recorded width of each patch type and I measured dbh of 2 trees representing the most common age class. Patches were grouped into 6 main categories based on dominant community type (Grossman et al. 1998): 1) grass-forb land; 2) shrubland (>25% canopy cover of <5 m tall trees or multistemmed shrubs); 3) woodland (25 - 60% canopy cover of >5 m tall trees); 4) forest (>60% cover of >5 m tall trees); 5) water/stream channel; and 6) open (<25% vegetative cover). Forest and woodland patches were further categorized into 4 size classes using dbh measurements: <5.5 cm; 5.5 - 15 cm; 15 – 25 cm; >25 cm. I calculated the Shannon-Wiener diversity index (H') to describe community heterogeneity (Zar 1999). There were 58 different patches types, which I collapsed into 15 categories for analysis.

Analysis

To determine the floristic groupings of occupied and unoccupied patches a cluster analysis (Ward linkage method; Johnson and Wichern 2002) was run using total basal area of the 5 dominant tree and shrub species (cottonwood, willow, tamarisk, mesquite, and seepwillow). Cluster analysis supported field observations, in that there were two main floristic patch types: cottonwood-willow

(C-W) dominated (58.1% ± 15.1 C-W relative basal area) and tamarisk (TAMA) dominated (51.3% ± 14.0 TAMA relative basal area).

To contrast mean values of attributes between unoccupied and occupied patches a two-tailed Mann-Whitney U-test was used, within each floristic type. The nonparametric Mann-Whitney U-test was used rather than parametric t-tests because sample size was small and most variables had non-normal distributions. Contrasts were also made between occupied cottonwood-willow and occupied tamarisk, to compare structural traits between floristic types. Unless otherwise noted values reported are mean ± 1 SD.

Logistic Regression Model.— To determine variables important to SWFL habitat selection, I constructed a multiple logistic regression model, using both patch-scale and neighborhood-scale variables. Logistic regression was used because the response variable was binary (i.e., occupied or unoccupied patch), and these models are useful in making predictions based on one or more predictor variables (Neter et al. 1996). Because data were observational, I expected multicollinearity (i.e., predictor variables are correlated and can confound interpretation of model results), thus strictly using numerous univariate tests or single logistic regressions to filter variables prior to multiple logistic regression was not appropriate (Neter et al. 1985). Similarly, because sample size was small, a large number of covariates could produce spurious results. Rather, I used a Spearman rank correlation analysis (r_s), a nonparametric test, to examine the relationship among vegetation variables to identify redundant structural measurements. For example, I assessed if stem density within the various stem-class sizes were correlated to foliage volume within specific height intervals. If the correlation was significant ($p < 0.05$), I used the specific stem count variable in the model to also represent the variability of foliage density within the related height interval. I used this information in combination with selection patterns identified in the Mann-Whitney U-tests (but not significant p values), to select a subset of variables that would not be redundant. I also grouped floristic patch types for the multivariate analysis and focused on structural rather than floristic attributes because structural traits appeared generally similar between occupied C-W and TAMA patch types.

I used Best Subsets procedure (SAS 8.2) for model selection because it provided a method to evaluate the large number of potential models (i.e., all combinations of the predictor variables). I did not *a priori* select models because I was interested in evaluating the various covariate combinations of all candidate models. To screen candidate models and select the final model, I first used the Score Value (a statistical measure of the significance of the covariates within each subset) to rank the top 3 models in each variable subset (Hosmer and Lemshow 2000); this process resulted in 21 models for further evaluation. However, because the Score Value will increase as the number of covariates increase, the global model (all covariates) will always appear to be the best model. To adjust for model richness (i.e., the number of covariates), I calculated an approximate Mallow C_q value for the 21 models (Hosmer and Lemshow

2000). Mallows Cq is based on the Score Values with adjustment for the number of covariates for the global model and each candidate model. I selected the top 6 models where the difference between q (number of covariates) and Cq approached 1, which maximizes statistical significance, while minimizing number of covariates (Hosmer and Lemeshow 2000). From this set, I selected the most biologically and parsimonious model. Final model output (i.e., covariate coefficients, SE, odds ratios) was calculated using SPSS 11.5. Odds ratio for each independent variable describes the relative amount by which the odds of the outcome (i.e., patch being occupied) increase (> 1.0) or decrease (< 1.0) when the value of the variable is increased by 1.0 units. To ease interpretation of the odds ratio some variables were transformed prior to analysis. For example, instead of describing how the odds of a patch being occupied changed with a 1 cm / 100 m^2 increase in willow basal area, I was more interested in the change with each 20 cm / 100 m^2 increase in basal area.

Model Validation.— I sampled the remaining occupied patches (5) in the study area and 6 additional unoccupied patches located using random points generated in ArcView as described above. I used the final model coefficients to predict if each patch was occupied or unoccupied using a 50% model cut point. Model accuracy was evaluated following Story and Congalton (1986).

RESULTS

Differences between Occupied and Unoccupied Patches

Patch Structure.— Within both C-W and TAMA patch types, occupied patches had greater basal area and total foliage volume than unoccupied patches (Table 1-1). Higher basal area in occupied patches was largely due to greater abundance of 5.5 - 15 cm diameter stems, for C-W and TAMA patches. TAMA occupied patches also had more smaller stems (<5.5 cm) and fewer large trees (>25 cm) than unoccupied patches. There was a trend for greater foliage density within all height intervals in occupied patches compared to unoccupied patches. The differences between occupied and unoccupied patches within floristic patch types were most pronounced in the 4 - 7, and 7 – 9 intervals. However, occupied C-W patch foliage density at the 4 –7 m interval was comparable to unoccupied TAMA patches. The same pattern was evident for total vegetation volume (Table 1-1). Foliage height diversity did not differ between unoccupied and occupied patches.

Canopy cover was greater and less variable in occupied patches than unoccupied patches across floristic patch types. Average canopy cover was 88% (± 7) and minimum canopy cover was 71% in both occupied C-W and TAMA patches. While maximum canopy height did not differ between occupied and unoccupied patches, there was less variation in height in occupied patches, with several unoccupied patches supporting very tall trees.

Patch Floristics.— Abundance of 2 of the 3 pioneer riparian tree species within the 5.5 – 15 cm DBH size class differed between occupied and unoccupied patches. Willow and tamarisk were the dominant species within C-W and TAMA occupied habitat patches, respectively (Fig. 1-3). There was little difference in abundance of 5.5 – 15 cm cottonwood stems between unoccupied and occupied C-W patches. However, there was greater abundance of tamarisk within occupied than unoccupied C-W habitat (Fig. 1-3) within 1 – 5.5 and 5.5 – 15 cm size classes. Similarly, there was a slightly greater abundance of willow within occupied than unoccupied TAMA habitat (Fig. 1-3).

Groundcover and Water.—There were similar patterns for most groundcover type percentages between occupied C-W and TAMA habitat, and between occupied and unoccupied patches within florisitic patch types. Litter was the dominant cover type in both floristic patch types. Occupied C-W had less dead herbaceous cover than all other patch types. Occupied TAMA patches had greater litter and less bare ground than unoccupied TAMA patches.

Seventeen occupied patches, but only 7 unoccupied patches, were adjacent to water/saturated soil (i.e., less than one meter away). The furthest distance from an occupied patch to water was 198 m. This patch was C-W dominated and located on the Gila River along an old (pre-1993 flood) river channel. The two remaining occupied patches were TAMA dominated and located 47 and 162 m from water.

4.5-ha Neighborhood.— The 4.5-ha neighborhood surrounding both C-W and TAMA occupied patches contained more forest patch area ($\bar{x}$ = 39.7% ± 15.0) than unoccupied patches (Table 1-1, Fig. 1-4). TAMA occupied patches were surrounded by more woodland and less shrubland and open habitat than unoccupied patches, whereas C-W occupied patches had less grass-forb patches than unoccupied patches.

Variation between Cottonwood-Willow and Tamarisk Occupied Patches

While stem density among size classes and total basal area were similar, total foliage volume was greater in TAMA compared to C-W occupied habitat (Table 1-1). TAMA occupied patches had greater foliage volume in lower height intervals than C-W occupied patches. However, foliage density above mean nest height (7 - 9 m) and canopy cover were similar among occupied patch types. While foliage height diversity was higher in C-W occupied habitat than other patch types, the difference was small, and probably is not biologically significant. Slightly greater foliage height diversity is likely due to greater abundance of large trees and higher maximum canopy in C-W occupied patches compared to TAMA occupied patches.

The vegetation community within the 4.5-ha neighborhood surrounding C-W occupied patches had the highest floristic and structural diversity compared to all other patch types (Table 1-1). Specifically, the forest community surrounding C-W occupied habitat contained a greater diversity of willow, cottonwood, and tamarisk forest patches and size classes compared to TAMA habitat (Fig. 1-4).

The area surrounding TAMA occupied patches, in contrast, was primarily dominated by tamarisk forest and woodland, and was less diverse than that surrounding unoccupied TAMA patches.

Multiple Logistic Regression Model

Based on relationships between variables (Table 1-2) and considering univariate analyses (Table 1-1), the following 8 variables were entered into the logistic regression model: basal area (cm^2/20) within each of 5 size classes; proportion of forest within 4.5-ha neighborhood (% Forest/10); distance to water (binary variable: x ≤1 m, x >1 m); and proportion of bare ground (% open groundcover/10).

Following model reduction, there were 6 models that were further evaluated (Table 1-3). Basal area of 5.5 - 15 cm stems, distance to water, and percent forest within 4.5-ha neighborhood were present in all but 1 of the top 6 models. I chose the 3-variable model containing these variables as the final model (Table 1-4).

The 3-variable model explained 77% of the variability in patch occupancy and produced good fit with data used in model development (Hosmer and Lemeshow Test: $p = 0.78$). I found no significant interaction between covariates, so I interpreted the odds ratio for each variable. For each 20-cm^2 increase in basal area of 5.5 – 15 cm stems, odds of patch occupancy more than doubled. Similarly, with each 10% increase of forest cover within the 4.5-ha neighborhood, the odds of patch occupancy doubled. Presence of water had the highest odds ratio. Patches that were adjacent to water were 6 times more likely to be occupied than unoccupied. However, the wide confidence interval, bracketing 1 (i.e., no change in the odds ratio), suggests that while most occupied patches were adjacent to water, unoccupied patches were also near water; thus highlighting the importance of a multivariate approach for predicting occupancy. While not included in the final model, greater abundance of smaller stems (<1, 1 – 5.5 cm), and lower abundance of larger trees (>25 cm) were included in 2 of the 6 models, and greater groundcover (i.e., less bare ground) was included in three of the models. These covariates explained variation in the data when included with the top three predictor variables.

*Model Validation – Accuracy Assessment.***—** Measurements for 5 occupied (3 C-W, 2 TAMA) and 6 unoccupied (2 C-W, 4 TAMA) patches were entered into the final logistic regression model. Overall accuracy of the final model was 55%. Sixty percent of the occupied sites were correctly classified, whereas 50% of unoccupied sites were correctly classified. There was little difference in model accuracy between C-W and TAMA patches, with 60% and 50% of patches correctly classified, respectively.

DISCUSSION

Patch Selection

Nesting SWFL along the Gila and lower San Pedro rivers selected dense patches dominated by young tamarisk and willow trees located near moist soils or standing water, and within a larger complex of riparian forest. Stands of young trees (5.5 –15 cm) had dense canopy cover and high foliage density, which supports the qualitative descriptions of SWFL habitat requirements (Sogge and Marshall 2000), and is similar to results of other studies of SWFL habitat use in Arizona (Brown 1988, Allison et al. 2003, Hatten and Paradzick 2003).

High stem densities of young tamarisk and willow provide the needed within-patch structure during the breeding season. Dense vegetation can benefit offspring production through nest concealment from predators (Martin and Roper 1988), and may also provide a cooler microclimate that could be especially important in the desert southwest (Walsberg 1981). Similarly, the presence of water could not only influence microclimate through evaporative cooling, but might also increase insect abundance (Drost et al. 2003), and the vigor and growth of riparian trees used during the breeding season (Stromberg et al. 1996, Scott et al. 1999, Shafroth et al. 2000; Horton et al. 2001a, b).

Patterns of habitat selection on the Gila and lower San Pedro rivers were similar in part to those of a large population of nesting SWFL at Cliff-Gila Valley, New Mexico. Nest sites at Cliff-Gila Valley had greater canopy cover and denser foliage between 3 -10 m, more trees and higher abundance of box elder (*Acer negudo*) stems, and less cottonwood than non-nesting plots (Stoleson and Finch 2003). However, size class of preferred trees varied significantly between the Cliff-Gila Valley and the Gila and San Pedro rivers. At Cliff-Gila Valley, SWFL nested primarily in large ($\bar{x}$ = 22.4 ± 16.7 cm dbh) box elder, but along the Gila and lower San Pedro birds used young trees and selected against larger trees

(>25 cm dbh). In contrast, as Stoleson and Finch (2003) noted, that while nests placed in box elder were located higher in trees than nests in other substrates, the relative position of the nest within the tree was similar to other SWFL breeding habitats (i.e., within the densest foliage), and canopy cover and subcanopy vegetation density remained high among occupied sites. Thus, the SWFL may show plasticity in selection of patch floristics, provided that structural requirements are met.

Cottonwood was used as a nesting substrate (Smith et al. 2002) in the San Pedro-Gila study area and was often co-dominant with willow in native tree dominated patches, but lack of direct selection of cottonwood by SWFL at the patch-scale area needs to be further explored. One potential cause for the lack of association with occupied habitat could be due to interspecific differences in thinning rates between the riparian pioneer species. In general, a linear relationship exists such that as forest stands age, average plant mass increases and plant density declines. However, as Weller (1987) notes, the rate of thinning is species specific. Field observations suggest that tamarisk may have the slowest thinning rate of the three species, retaining high stem densities in older stands. More subtle, yet ecologically significant, differences may exist between willow and cottonwood thinning patterns, which should be explored as a mechanism influencing SWFL patch selection. Also, cottonwood has broad leaves compared to the narrow leaves of willow or tamarisk, which might influence predator cover or nest shading. Insect abundance and diversity differences between floristic patch types could also influence SWFL use, although recent research suggests that the SWFL can utilize a diverse array of prey taxa (Durst 2004) and that cottonwood has similar insect abundance as tamarisk habitat (Mund-Meyerson 1998). However, cottonwood often germinates and grows on floodplain surfaces slightly farther from water (on the order of a few meters) than same-aged Goodding willow (Stromberg 1993), which might subtly influence within-patch micro-climate or insect abundance.

Patterns of SWFL selection were similar to other willow flycatcher subspecies. While most other subspecies use predominantly riparian-shrub habitat, habitat for all has dense canopy cover and is associated with water (Altman et al. 2003, King and King 2003, Kulba and McGillivray 2003, Bombay et al. 2003). *E.t. brewsterri* in the Willamette Basin Oregon used both riparian shrub-dominated habitats, and early-seral conifer forest (4 - 15 years of age) that established after natural disturbances or timber harvest (Altman et al. 2003). Stand age of conifer forest was similar to the forest age-class *E.t. extimus* uses at the Gila and lower San Pedro rivers sites (3 – 21 yrs) based on age-tree diameter regression analysis along the San Pedro River (Stromberg 1998a).

Tamarisk as Breeding Habitat

While the USFWS (1995) lists tamarisk as a causal factor in the decline of the subspecies, I found that SWFL nested in patches composed of young tamarisk. Use of both young tamarisk and willow trees suggests that patch structure (i.e., stem, foliage, and canopy density), as well as floristics, could be a primary determinant in patch selection by the SWFL, as with other avian species (MacArthur et al. 1966, Anderson and Shugart 1974, Rotenberry and Wiens 1980).

Avian survival and reproductive rates are linked to habitat choice (Martin 1992) and habitat selection does not necessarily reflect reproductive viability if the habitat is a sink for the species (Van Horne 1983, Powell and Steidl 2000). Some researchers (e.g., DeLoach et al. 2000) have hypothesized that tamarisk has negative effects on SWFL fitness; however, little empirical data has been presented to substantiate this assertion. The Arizona Game and Fish Department and U.S. Geological Survey have been conducting a long-term SWFL study since 1995 examining SWFL reproductive rates, nest success, juvenile and adult survivorship, and breeding-season physiological conditions at Gila and lower San Pedro rivers and Roosevelt Lake. Preliminary analysis suggests that there is no difference between cottonwood-willow and tamarisk dominated habitats, and the population is stable or expanding at both areas (M. Sogge and A. Tudor pers comm.). SWFL diet analyses (Drost et al. 2003), and insect abundance and diversity studies in cottonwood-willow and tamarisk habitats at Roosevelt Lake, suggest that while tamarisk stands have different insect composition, prey taxa biomass remains high and sufficient for the SWFL (Sogge pers comm.). Additionally, Owen and Sogge (2002) found no evidence of poorer nutritional condition or negative physiological affects to SWFL that nest in tamarisk habitats. These data highlight the need to collect quantitative data through empirical studies to make informed SWFL management and conservation decisions (also see Fleishman et al. 2003).

Model Accuracy

Overall accuracy rate (55%) was on the lower end of other SWFL habitat models (range 56 – 95%) (Hatten and Paradzick 2003, Dockens et al. 2004). In those studies, unoccupied habitat was randomly selected from within the floodplain, whereas, in my study unoccupied patches were constrained *a priori* to have higher potential as nesting habitat. Thus, parameter variation between occupied and some unoccupied patches used for validation might have been small, resulting in classification errors. Also, those studies used retrospective sampling of remote sensing data with little field vegetation data collection to assess habitat. Unoccupied sites were easily generated and evaluated, and occupied sites were nest locations, thus sample size to test the models was much higher than my study. Due to time and logistical constraints, and limited number of occupied patches in the study area, sampling of additional validation patches was not possible. To better evaluate model accuracy, researchers could collect and test additional patch-scale measurements at unoccupied patches and newly occupied patches within the study area and in similar habitat types (i.e., C-W, TAMA) outside of the study area (e.g., Roosevelt Lake, Gila River upstream of Winkelman near Safford, Arizona).

Other factors that may have caused low accuracy could be due to patches that were misclassified as occupied but have not been colonized yet because of the low number of SWFL or were unsuitable due to other factors not measured. For patches that were occupied but classified as unoccupied, errors may have been due to lack of model robustness to capture slight variation in habitat parameters. For example, one occupied patch for model validation that was misclassified as unoccupied had low number of birds in 2001 and was unoccupied in years before (1997 – 2000) and after my study (2002 –2004). Finally, the model used only patch-level and 4.5-ha sampling scales; accuracy could be improved by using habitat parameters at both coarser and finer spatial scales, changes to quantity and quality over time, and by considering SWFL behavioral traits related to habitat selection. If additional patch data was collected to better evaluate the model as described above, researchers could also incorporate these considerations to construct and test a more robust SWFL habitat selection model.

Building a Better Model: Spatial, Temporal, and Behavior Considerations

Habitat selection by organisms occurs along multiple spatial and temporal scales (Wiens 1989, Orians and Wittenberger 1991, Wiens 2002). Patch-level analysis, coupled with within-patch willow SWFL nest-site selection studies (Allison et al. 2003) and landscape-scale analysis (Hatten and Paradzick 2003), supports a multiscaled approach to species-habitat analyses and management (Gutzwiller and Anderson 1987, Kotliar and Wiens 1990, Wiens et al. 1993, Saab 1999). A synthesis of habitat-selection results of the three studies completed along the Gila and lower San Pedro rivers is shown in Table 1-5. As Hatten and

Paradzick (2003) found, when multiple scales where included in the GIS model, model fit improved.

Habitat relationships may be scale dependent - what is significant at one scale might not be observed on another scale (MacNally 1990). Thus, better-informed management decisions can be made when a more complete picture of selection is provided (Wiens 2002). For example, at coarse and fine scales, edge or canopy breaks were positively related to SWFL selection, however at mid-scales (i.e., patch-level), this characteristic was selected against (see Canopy Cover CV – Table 1-1). Patchiness of the surrounding floodplain may be important for refuge, dispersal, and foraging for juvenile or adult SWFL (Lehmkuhl 1984, Lande 1987); dense, even canopy at the patch-scale could provide more shade, thus more favorable microclimate conditions (Walsberg 1981), or concealment from nest predators (Martin and Roper 1988); while nests, placed closer to small canopy openings within the relatively dense homogenous patch, could provide foraging sites or male song perch display areas (Flett and Sanders 1987, Allison et al. 2003).

When assessing habitat associations, managers should also consider patch and landscape history, which can influence current breeding bird distribution (Block and Brennan 1993). SWFL settlement patterns and nesting behavior could be altered by the high rates of natural disturbances along southwestern rivers (e.g., floods). Similarly, floodplains are often used and manipulated extensively by humans (e.g., cattle grazing, agricultural land clearing, pesticide or herbicide application, and irrigation runoff), which may have altered past habitat conditions, but which are not presently evident.

These legacy effects, together with behavioral traits, such as the high rate (60%) of site fidelity (Luff et al. 2000), confound our ability to clearly assess habitat associations. The willow flycatcher (*E. traillii*) has been described as a semi-colonial nester, having the tendency for individuals to settle near one another (McCabe 1991, U.S. Fish and Wildlife Service 2002). This behavior has been documented to influence endangered black-capped vireo (*Vireo atricapilla*) distribution and habitat use across the landscape (Ward and Schlossberg 2004). Field observations of SWFL colonization patterns along the lower San Pedro River suggest that these factors might influence habitat selection. Together, these data provide the foundation for development of a more comprehensive model of SWFL breeding habitat, which could also be used to evaluate the influence of habitat components on fitness across multiple spatial and temporal scales (see Bombay et al. 2003).

Riparian Ecosystem Considerations

Wiens (1977) suggests that habitat-use patterns should be studied over long time scales to capture bird response to environmental changes - a consideration crucial to species that occupy ephemeral habitats that have high temporal variability in habitat conditions and bird distributions (e.g., floodplain forests). In 1993, a large (100 yr) flood removed a significant portion of the near channel vegetation along the lower San Pedro River and Gila River (T.

McCarthey pers comm., Huckleberry 1994, Huckleberry 1996, Wood 1997). Another smaller, yet significant flood occurred in 1995 (USGS Gage 09473999: http://waterdata.usgs.gov/az/nwis/nwis). Researchers conducting SWFL surveys in the breeding seasons following these events located nesting birds mostly in tamarisk-dominated patches on elevated terraces above the scoured floodplain (Sferra et al. 1997). However, three to five years following these events SWFL colonized regenerating C-W habitat that had established lower in the San Pedro River floodplain (Paradzick and Woodward 2003). In 2003, Smith et al. (2004) documented SWFL emigrating from these areas that were ca. 8 - 10 yrs old to younger habitats upstream. In 2002, a similar pattern occurred at Cliff-Gila Valley, New Mexico; SWFL were recorded moving from older stands of box elder to younger willow patches near the active channel (Brodhead et al. 2002). More research is needed to determine the ultimate causes for preference of younger stands of forest, such as increased reproduction due to high foodbase, or lower nest predation in novel habitats.

SWFL along the Gila and lower San Pedro rivers had a narrow habitat preference, selecting for dense stands of young (5.5 – 15 cm) willow or tamarisk forest. Stromberg (1998a) suggests that the 5-cm tree diameter interval represents an approximate age range of 2-3 years for cottonwood and willow, and 7 years for tamarisk on the San Pedro River. Thus, life span of suitability for cottonwood-willow and tamarisk could be <9 yr and <21 yr, respectively, which parallel SWFL movement data described above. Interestingly, due to the structure of tamarisk, forests remain suitable for SWFL longer than cottonwood-willow dominated habitats. This process also highlights the importance of periodic disturbance in the riparian ecosystem to produce new cohorts of trees suitable for SWFL nesting over the long-term (see Paradzick and Hatten 2004). Researchers should consider the response of SWFL to disturbance events and vegetation succession when evaluating habitat preferences and developing conservation activities.

Within the floodplain, cottonwood-willow forests generally have low tree diversity, but high age class and structural diversity (Stromberg 1993). Young willow stands are generally found near the active channel, close to shallow groundwater, and are frequently flooded (Stromberg 1993, Lite 2003, Bagstad *in review*). Tamarisk often dominates in slightly more xeric conditions, where the groundwater is deeper (Stromberg 1993, Stromberg et al. 1996, Lite and Stromberg *in press*, Bagstad *in review*), or where grazing impacts are high (Hughes 1993, Stromberg et al. 1997, Stromberg 1998a). Density of young cottonwood, willow, and tamarisk increase in abundance in the downstream direction along the length of the San Pedro River, and are most dense and have greatest patch width along lower portions near the confluence with the Gila River due to frequent flooding events (Lite 2003). These environmental conditions support suitable breeding habitat for the SWFL.

MANAGEMENT IMPLICATIONS

Locating and Restoring Suitable Habitat

Dockens et al. (2004) used the Hatten and Paradzick (2003) GIS model to map possible SWFL breeding habitat across Arizona below 1500 m elevation. They suggest that the map can be used as a starting point for managers to locate potential breeding habitat, but on-the-ground habitat evaluations are needed to further define breeding suitability. By measuring stem density by species and size class, distance to water, and the amount of forest surrounding the patch, land managers could better determine site potential for SWFL breeding suitability, and could determine if restoration measures are needed to improve habitat quality. SWFL restoration or mitigation activities need clearly defined objectives during the planning stages, and measurable outcomes (Kondolf and Micheli 1995). These data gathered at patch/site scale, together with information from other SWFL studies, provide needed quantitative estimates of habitat components to establish suitable breeding conditions within cottonwood-willow-tamarisk forest communities, and to judge the effectiveness of restoration projects.

Watershed Management

Historically, arid land stream floodplains had high spatial and temporal heterogeneity (Auble et al. 1994, Minckley and Brown 1994, Poff et al. 1997). River damming and subsequent flow alteration (Graf 1982, Fenner et al. 1985, Busch and Smith 1995, Merritt and Cooper 2000, Graf et al. 2002), groundwater declines (Stromberg et al. 1996, Horton and Clark 2001), and livestock grazing (Belsky et al. 1999) have influenced the distribution, abundance, and composition of southwestern riparian forest communities affecting populations of riparian obligate birds and other fauna (Hunter et al. 1988, Ellis 1995, Fleishman et al. 2003). Managing for long-term persistence of SWFL populations will require coupling SWFL habitat requirements, across temporal and spatial scales, with the physical, chemical, and hydrological processes that create and sustain riparian forests. Opportunities exist for managing water resources and land-uses (see Lamb and Lord 1992) to meet expanding needs of the growing human population in the southwest, while maintaining and enhancing riparian communities including those used by breeding SWFL (Poff et al. 1997, Richter and Richter 2000, Ward et al. 2001, Graf et al. 2002, Krueper et al. 2003, Rood et al. 2003).

Table 1-1. Habitat characteristics measured at willow flycatcher occupied and unoccupied patches on the Gila and lower San Pedro rivers in 2001. Unless noted values are mean ± 1 SD.

		Floristic patch type			
		Cottonwood-willow		Tamarisk	
Variable (units)	Variable subcategories	Occupied n = 7	Unoccupied n = 5	Occupied n = 13	Unoccupied n = 15
Basal area ($cm^2/100m^2$)	Size classes (dbh):				
	0 - 1 cm	56 ± 45	47 ± 29	38 ± 39	41 ± 46
	1 – 5.5 cm	146 ± 85	140 ± 121	151 ± 31**	103 ± 68
	5.5 – 15 cm	160 ± 73*	74 ± 32	144 ± 42**	68 ± 34
	15 – 25 cm	31 ± 15	29 ± 20	31 ± 16	22 ± 19
	> 25 cm	30 ± 40	26 ± 26	14 ± 12**	24 ± 27
	Total area	399 ± 159	290 ± 138	378 ± 64**	254 ± 102
Index of foliage density	Height intervals:				
	0 – 4 m	0.19 ± 0.06[aa]	0.15 ± 0.07	0.28 ± 0.05	0.25 ± 0.07
	4 – 7 m	0.23 ± 0.08	0.16 ± 0.09	0.29 ± 0.09*	0.22 ± 0.13
	7 – 9 m	0.24 ± 0.09	0.18 ± 0.07	0.24 ± 0.08**	0.12 ± 0.11
Total vegetation volume (m^3/m^2)		1.95 ± 0.64[a]	1.45 ± 0.59	2.48 ± 0.46**	1.92 ± 0.72
Foliage height diversity		2.16 ± 0.02[aa]	2.14 ± 0.13	2.12 ± 0.04	2.03 ± 0.17
Canopy cover (%)	Mean	86 ± 8*	74 ± 7	89 ± 7*	67 ± 15
	CV	7.8 ± 4.8**	20.3 ± 7.4	7.13 ± 4.46**	23.0 ± 14.3
Maximum canopy height (m)	Mean	16 ± 3[a]	14 ± 3	13 ± 4	11 ± 4
	CV	16 ± 6.9**	25.5 ± 4.8	17.8 ± 8.9*	30.0 ± 21.7
Ground cover (%)	Cover types:				
	Live herbaceous	2 ± 3	2 ± 2	3 ± 4	1 ± 3
	Dead herbaceous	0 ± 1**, [aa]	5 ± 3	3 ± 4	6 ± 14
	Woody	19 ± 14	18 ± 9	18 ± 11	19 ± 11
	Litter	59 ± 19	54 ± 14	57 ± 14**	40 ± 17
	Bare	18 ± 8[aa]	21 ± 16	19 ± 12**	33 ± 17

Table 1-1 (continued). Habitat characteristics measured at willow flycatcher occupied and unoccupied patches on the Gila and lower San Pedro rivers in 2001. Unless noted values are mean ± 1 SD.

		Floristic patch type			
		Cottonwood-willow		Tamarisk	
Variable (units)	Variable subcategories	Occupied n = 7	Unoccupied n = 5	Occupied n = 13	Unoccupied n = 15
4.5 ha neighborhood (% of 4.5 ha)	Patch types:				
	Forest	46.4 ± 15.9**	18.8 ± 17.4	36.1 ± 14.4**	16.4 ± 15.6
	Woodland	18.2 ± 15.4	19.4 ± 15.2	22.5 ± 13.0**	13.9 ± 12.8
	Shrubland	17.5 ± 9.3	14.4 ± 12.0	18.5 ± 10.4**	32.7 ± 16.1
	Grass-forb land	1.0 ± 2.0**	19.1 ± 12.6	3.7 ± 4.9	4.2 ± 5.5
	Open	8.0 ± 9.0	26.5 ± 23.8	13.3 ± 16.9*	23.0 ± 17.1
4.5 ha neighborhood diversity index (H’)		2.45	2.03	2.25	2.30
Distance to water or saturated soil (m)	Mean	28 ± 75	37 ± 53	16 ± 46	423 ± 1249
	Median	0	15	0	11

* significant difference ($p < 0.1$) between unoccupied and occupied patches within floristic patch types

** significant difference ($p < 0.05$) between unoccupied and occupied patches within floristic patch types

[a] significant difference ($p < 0.1$) between Cottonwood-Willow and Tamarisk occupied habitat

[aa] significant difference ($p < 0.05$) between Cottonwood-Willow and Tamarisk occupied habitat

Table 1-2. Correlation (r_s) between basal area size classes and vertical foliage density, canopy cover, and maximum canopy height within willow flycatcher unoccupied and occupied patches on the Gila and lower San Pedro rivers in 2001 (n=40).

Basal area size classes (dbh)	Index of foliage density height intervals (m) 0 - 4	4 - 7	7 - 9	Total vegetation volume (0 – 9 m)	% Canopy Cover	Maximum canopy height
0 – 1 cm	0.05	-0.49**	-0.31*	-0.34**	-0.31*	-0.20
1 – 5.5 cm	0.39*	0.05	0.01	0.21	0.16	-0.38*
5.5 – 15 cm	0.40*	0.56**	0.56**	0.63**	0.61**	-0.05
15 – 25 cm	-0.05	0.33*	0.32*	0.23	0.44**	0.45**
>25 cm	-0.20	0.15	0.17	0.05	0.17	0.57**

* significant at p < 0.05
** significant at p< 0.01

Table 1-3. Six best models identified using the score test approximation to Mallow's Cq, (S_8 = 27.1520) explaining willow flycatcher habitat patch selection on the Gila and lower San Pedro rivers in 2001 (X indicates variable included in model).

	Covariates									
	Basal area ($cm^2/100m^2$) stem size class									
Model	<1	1 – 5.5	5.5 - 15	15 - 25	>25	Distance to water	% forest within 4.5-ha neighborhood	% open groundcover	Sq	Cq
2-1			X			X			22.882	1.27
3-1*			X			X	X		24.868	1.28
4-1			X		X	X	X		25.311	2.84
4-2	X		X			X	X		25.283	2.87
4-3		X	X			X	X		25.243	2.91
5-1		X	X			X	X	X	26.167	3.99
5-2	X		X			X	X	X	26.082	4.07
5-3			X		X	X	X	X	25.913	4.24

* Final model selected (see Table 1-4)

Table 1-4. Final variables included in the logistic regression model explaining willow flycatcher habitat patch selection on the Gila and lower San Pedro rivers in 2001.

Variable	Coeff	SE	Wald	P	Odds Ratio	Odds ratio 95% CI Lower	Upper
Basal Area 5.5 – 15 cm[a]	0.863	0.354	5.939	0.015	2.37	1.18	4.75
Water[b]	1.911	1.195	2.558	0.110	6.76	0.65	70.27
% Forest in 4.5-ha neighborhood[c]	0.691	0.356	3.780	0.052	2.00	0.99	4.01
Constant	-7.634	2.437	9.812	0.002			

[a] Odds ratio calculated in 20-cm increments: $(cm^2/100m^2)/20$
[b] Modeled as a binary variable 1 = water <1 m from patch, 0 = water >1 m from patch
[c] Odds ratio calculated in 10% increments

Table 1-5. Summary of habitat characteristics associated with willow flycatcher site selection at multiple scales, Gila and lower San Pedro rivers.

Variable	Description of variable	Relationship with habitat selection
Landscape Scale (≥4.5 ha)		
Vegetation community composition and structure[a,b]	Geographic information systems (GIS) model used to estimate vegetation density[a]; patch types (species composition and structural traits) measured in 4.5- ha neighborhood[b]	Occupied sites contained greater amounts ($\bar{x}$ = 40%) of dense cottonwood, willow, and tamarisk forest in the 4.5-ha neighborhood than unoccupied sites
Floodplain width	GIS model used to estimate amount of flat terrain (floodplain) surrounding site.	Occupied sites were located in wider floodplains, > flat terrain in 41-ha neighborhood than unoccupied sites
Forest edge[a]	GIS model used to estimate standard deviation of densest vegetation class in 4.5 ha neighborhood	Occupied sites had greater variation in the densest vegetation within the 4.5 ha neighborhood compared to unoccupied sites (i.e., > edge and canopy breaks than unoccupied sites)
Patch Scale		
Patch floristics and structure[b]	Stem density of willow and tamarisk trees within patch	Occupied patches had greater abundance of tamarisk and willow stems 5.5 –15 cm dbh (range: 500 – 1300 stems/ha) than unoccupied patches
Canopy Cover	Average cover throughout patch	Occupied patches had >70% cover
Water[b]	Distance from patch to water	Most occupied patches were adjacent to water

Table 1-5 (continued). Summary of habitat characteristics associated with southwestern willow flycatcher site selection at multiple scales, Gila and lower San Pedro rivers, Arizona.

Variable	Description of variable	Relationship with habitat selection
Within patch scale		
Water[c]	Distance from nest to water	Nests were placed closer ($\bar{x}$ = 67 m) to water than unoccupied plots
Canopy openings[c]	Distance from nest to canopy opening	Nests were placed closer to canopy breaks ($\bar{x}$ = 9 m) than unoccupied plots
Foliage density at the nest[a, c]	GIS model used to estimate foliage density within 0.09 ha (30 x 30 m) surrounding nest; percent canopy cover, vertical foliage density at 2, 5 and 7.6 m above ground	Nests were placed within the densest vegetation within the floodplain, and foliage density was greater below, at, and above mean nest height than unoccupied plots
Species composition and size class[c]	Stem density of tree species measured within 11.3 m radius of nest, grouped into 3 size classes: < 2.5 cm, 2.5 – 8 cm, > 8 cm.	Nest plots contained greater density of 2.5 – 8 and > 8 cm tamarisk and willow trees than unoccupied plots.

[a] Hatten and Paradzick (2003) – GIS model using 30-m resolution multispectral satellite imagery, digital elevation models, GIS, and logistic regression.
[b] This study
[c] Allison et al. (2003) – measure habitat characteristics in 11.3-m radius plots around nests and random unoccupied plots with the same patch.

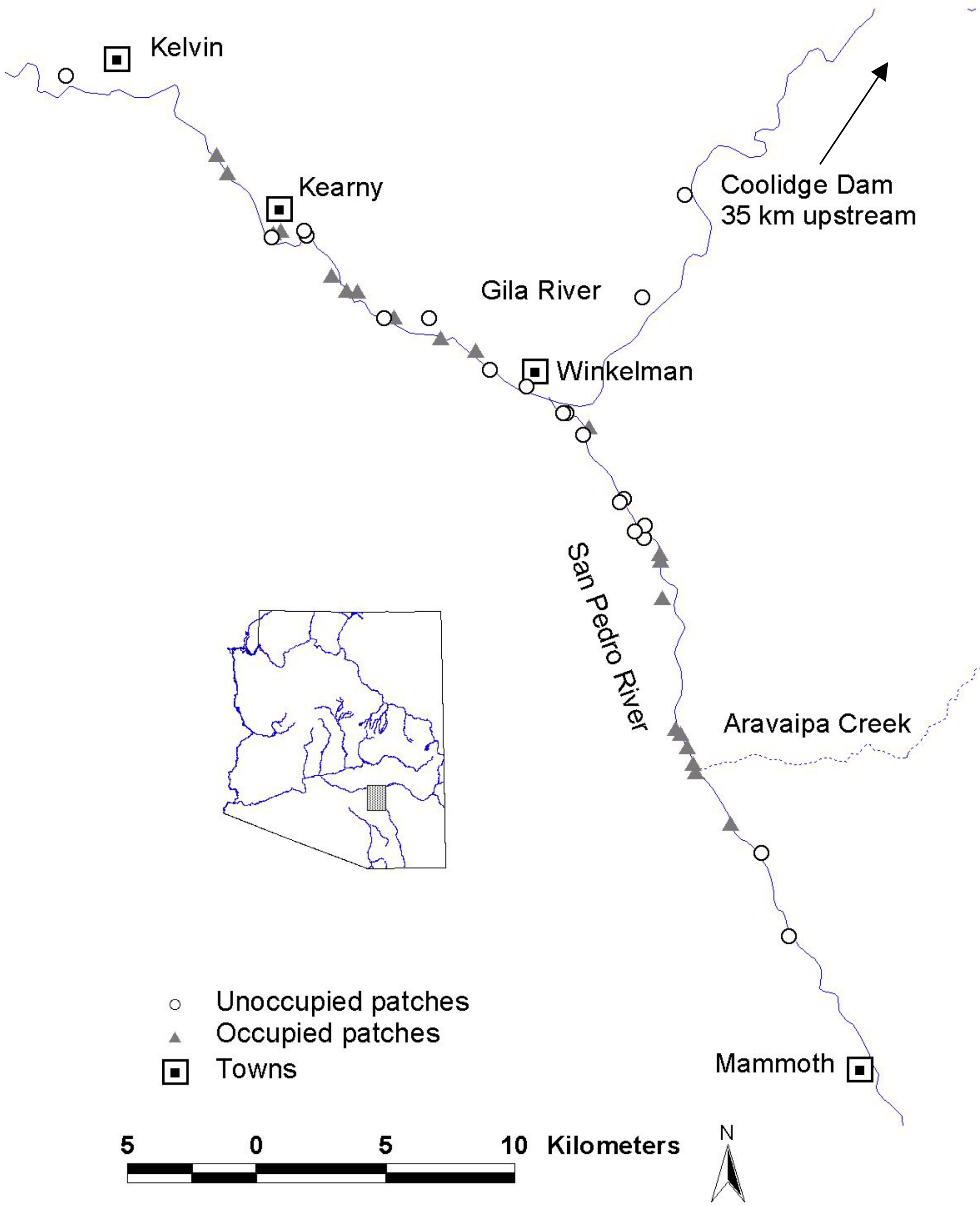


Fig. 1-1. Map of Gila River and lower San Pedro River confluence in southeastern Arizona showing study sites.

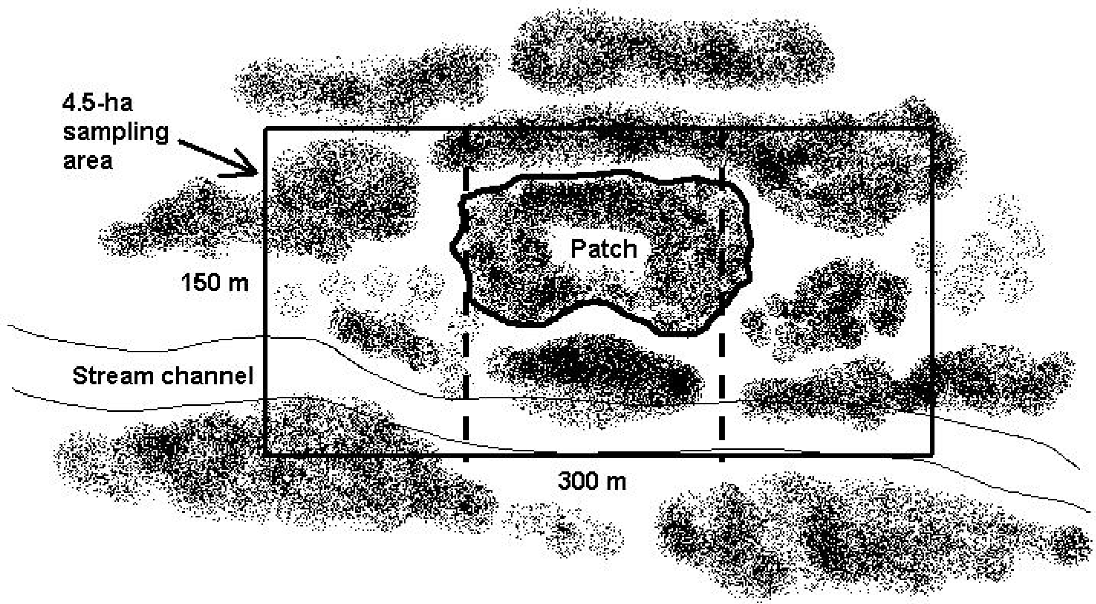


Fig. 1-2. Diagram of 4.5-ha area sampled. Rectangular plot (300 x 150 m) centered on a random point within unoccupied or occupied patches. Plot was further subdivided into 3 equal sections (dashed lines). Within each section, abundance (length) of vegetation patches types was measured along one 150-m transect placed perpendicular to stream.

Fig. 1-3 (following page). Box plots of tamarisk, willow, and cottonwood basal areas grouped by size class within cottonwood-willow (C-W) and tamarisk (TAMA) dominated unoccupied and willow flycatcher occupied patches, along the Gila and lower San Pedro rivers in 2001. Box bottom indicates 25^{th} percentile, solid line within box is median, top of box indicates 75^{th} percentile; whiskers above and below box indicate the 90^{th} and 10^{th} percentiles.

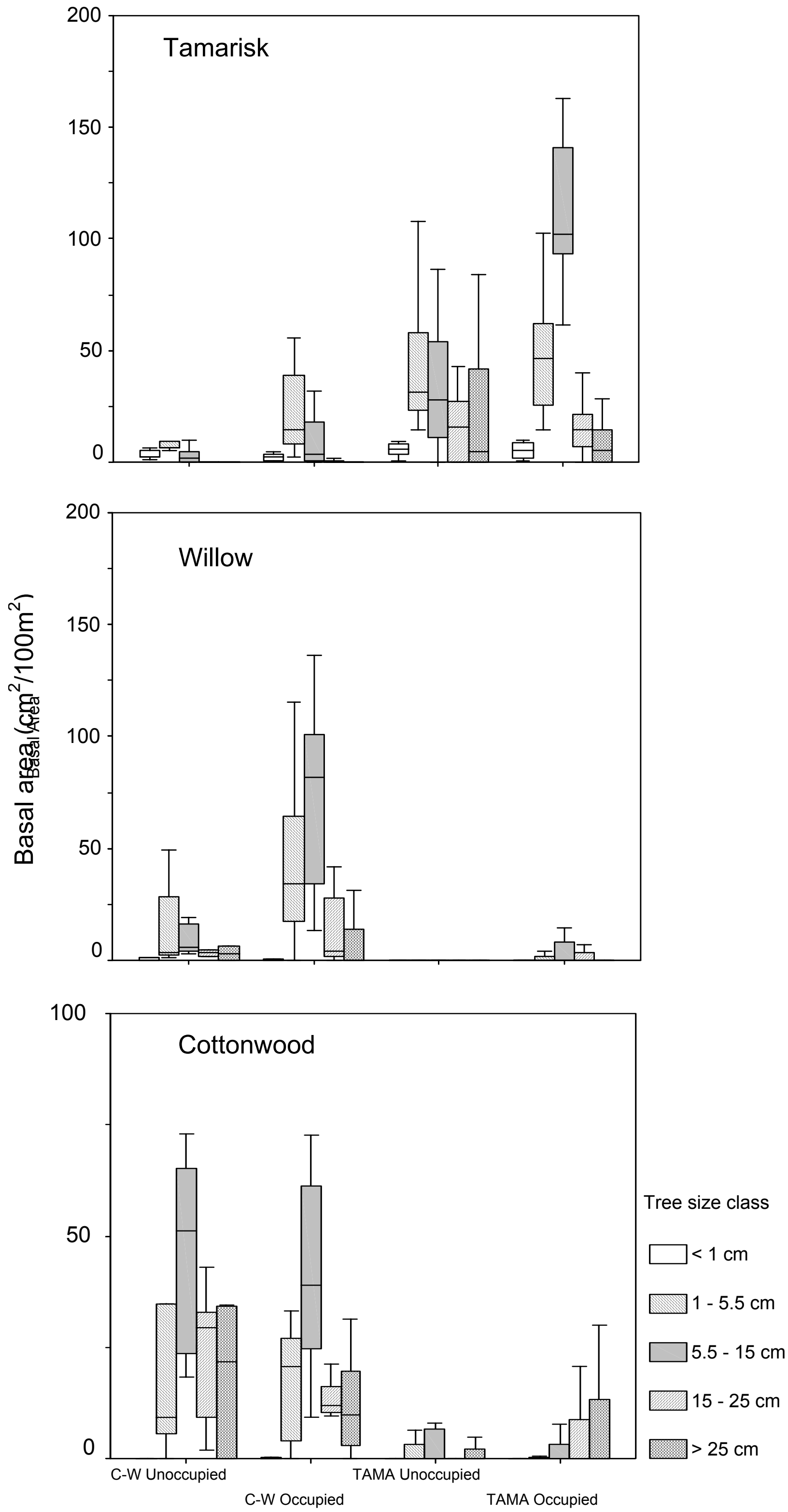
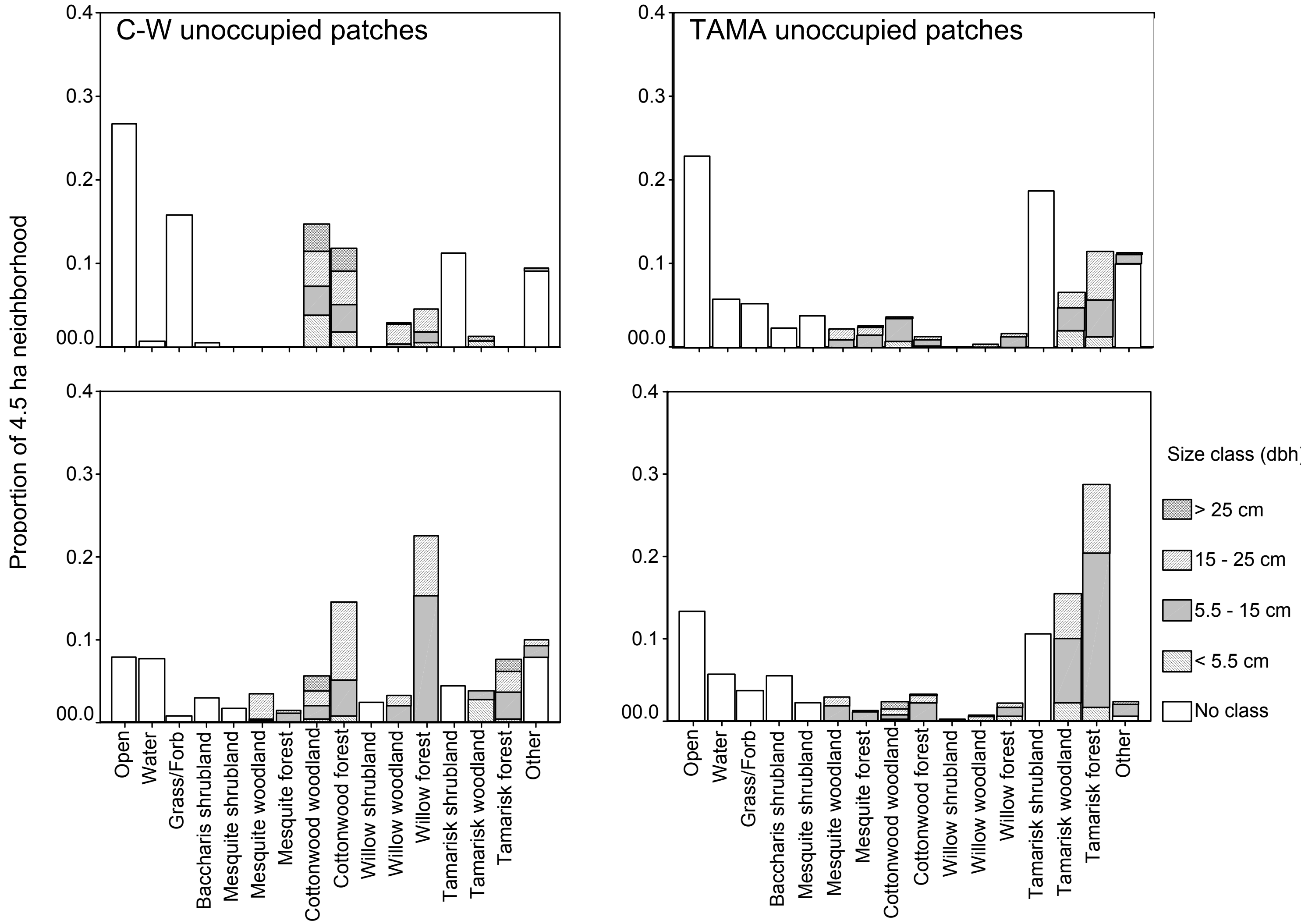

Tamarisk
Willow
Cottonwood
Basal area (cm2/100m2)
Basal Area
200
150
100
50
0
C-W Unoccupied
C-W Occupied
TAMA Unoccupied
TAMA Occupied
Tree size class
< 1 cm
1 - 5.5 cm
5.5 - 15 cm
15 - 25 cm
> 25 cm

Fig. 1-4 (following page). Community composition in 4.5-ha neighborhood surrounding unoccupied and occupied willow flycatcher patches within cottonwood-willow (C-W) and tamarisk (TAMA) dominated habitat along the Gila and lower San Pedro rivers in 2001.


C-W unoccupied patches
TAMA unoccupied patches
Proportion of 4.5 ha neighborhood
0.4
0.3
0.2
0.1
00.0
Open
Water
Grass/Forb
Baccharis shrubland
Mesquite shrubland
Mesquite woodland
Mesquite forest
Cottonwood woodland
Cottonwood forest
Willow shrubland
Willow woodland
Willow forest
Tamarisk shrubland
Tamarisk woodland
Tamarisk forest
Other
Size class (dbh)
> 25 cm
15 - 25 cm
5.5 - 15 cm
< 5.5 cm
No class

LITERATURE CITED

Allison, L.J., C.E. Paradzick, J.W. Rourke, and T.D. McCarthey. 2003. A characterization of nesting and non-nesting plots for southwestern willow flycatchers in central Arizona. Studies in Avian Biology 26: 81-89.

Altman, B., M. Boulay, S. Dowlan, D. Crannell, K. Russell, K. Beal, and J. Dillon. 2003. Willow flycatcher nesting ecology and habitat relationships in the Willamette Basin, Oregon. Studies in Avian Biology 26:73-80.

Anderson, S.H., and H.H Shugart. 1974. Habitat selection of breeding birds on an east Tennessee deciduous forest. Ecology 55:828-837.

Auble, G.T., J.M. Friedman, and M.L. Scott. 1994. Relating riparian vegetation to past and future streamflows. Ecological Applications 4:544-554.

Bagstad, K.J., S.J. Lite, and J.C. Stromberg. *In review*. Vegetation, soils, and hydro-geomorphology of riparian patch types of a dryland river. Submitted to Western North American Naturalist

Belsky, A.J., A. Matzke, and S. Uselman. 1999. Survey of livestock influences on stream and riparian ecosystems in the western United States. Journal of Soil and Water Conservation 54:419-431.

Block, W.M., and L.A. Brennan. 1993. The habitat concept in ornithology - theory and applications. Current Ornithology 11:35-91

Bombay, H.L., M.L. Morrison, and L.S. Hall. 2003. Scale perspectives in habitat selection and animal performance for willow flycatchers (*Empidonax traillii*) in central Sierra Nevada, California. Studies in Avian Biology 26:60-72.

Bravard, J-P., C. Amoros, and G. Pautou. 1986. Impact of civil engineering works on the successions of communities in a fluvial system. Okios 47:92-111.

Brock, J.H. 1994. Tamarix spp. (salt cedar) an invasive exotic woody plant in arid and semiarid habitats of Western USA. Pages 27-44 *in* L.C. DeWall, editor. Ecology and management of invasive riverside plants. John Wiley, New York, New York, USA.

Brodhead, K.M., D.M. Finch, and S.H. Stoleson. 2002. Southwestern willow flycatcher in the Cliff-Gila Valley - Results of nest monitoring and climatic influence on breeding – Summary report for the 2002 field season. U.S.

Forest Service, Rocky Mountain Research Station Report. Ogden Utah, USA.

Brown, B.T. 1988. Breeding ecology of a willow flycatcher population in Grand Canyon, Arizona. Western Birds 19:25-33.

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

Daubenmire, R. 1959. A canopy-coverage method of vegetational analysis. Northwest Science 33:43-64.

DeLoach, C.J., R.I. Carruthers, J.E. Lovich, T.L. Dudley, and S.D. Smith. 2000. Ecological interactions in the biological control of saltcedar (*Tamarix* spp.) in the United States: toward a new understanding. Pages 819-873 *in* N. R. Spencer, editor. Proceedings of the X International Symposium on Biological Control of Weeds. 4 - 14 July, 1999, Montana State University, Bozeman, Montana, USA.

Dockens, P.E.T., C.E. Paradzick, and J.R. Hatten. 2004. Application of a southwestern willow flycatcher GIS-based habitat model: an estimate of breeding habitat in Arizona, 2001. Pages 28-59 *in* P.E.T. Dockens and C.E. Paradzick, editors. Mapping and monitoring southwestern willow flycatcher habitat in Arizona: a remote sensing approach. Nongame and Endangered Wildlife Program Technical Report 223. Arizona Game and Fish Department. Phoenix, Arizona, USA

Drost, C.A., E.H. Paxton, M.K. Sogge, and M.J. Whitfield. 2003. Food habitats of the southwestern willow flycatcher during the nesting season. Studies in Avian Biology 26:96-103.

Durst, S.L. 2004. Southwestern willow flycatcher potential prey base and diet in native and exotic habitats. MS Thesis, Northern Arizona University, Flagstaff, Arizona, USA.

Ellis, L.M. 1995. Bird use of saltcedar and cottonwood vegetation in the Middle Rio Grande Valley, New Mexico, U.S.A. Journal of Arid Environments 30:339-349.

ESRI. 2002. ArcView 8. Environmental Systems Research Institute, Inc. Redlands, California, USA.

Everitt, B.L. 1998. Chronology of the spread of tamarisk in the central Rio Grande. Wetlands 18:658-668.

Fenner, P., W.W. Brady, and D.R. Patton. 1985. Effects of regulated flow on regeneration of Fremont cottonwood. Journal of Range Management 38:135-138.

Fleishman, E., N. McDonal, R. Mac Nally, D.D. Murphy, J. Walters, and T. Floyd. 2003. Effects of floristics, physiognomy, and non-native vegetation on riparian bird communities in a Mohave Desert Wash. Journal of Animal Ecology. 72:484-490.

Flett, M.A., and S.D. Sanders. 1987. Ecology of a Sierra Nevada population of willow flycatchers. Western Birds 18:37-42.

Governor's Riparian Habitat Task Force. 1990. Final report and recommendations to fulfill Executive Order 89-16 Streams and Riparian Resources. Governor's Office. Phoenix, Arizona, USA.

Graf, W.L. 1982. Tamarisk and river-channel management. Environmental management 6:283-296.

_____, J. Stromberg, and B. Valentine. 2002. Rivers, dams, and willow flycatchers: summary of their science and policy connections. Geomorphology. 47:169–88.

Grossman, D.H., D. Faber-Langendoen, A.S. Weakly, M. Anderson, P. Bourgeon, R. Crawford, K. Goodin, S. Landaal, K. Metzler, K.D. Patterson, M. Pyne, M. Reid, and S.L. Sneddon. 1998. International classification of ecological communities: terrestrial vegetation of the United States. Volume I. The National Vegetation Classification System: development, status, and applications. Nature Conservancy, Arlington, Virginia, USA.

Grzybowski, J.A., D.J. Tazik, and G.D. Schnell. 1994. Regional analysis of black-capped vireo breeding habitats. Condor 96:512-544.

Gutzwiller, K.J. and S.J. Anderson 1987. Multiscale associations between cavity-nesting birds and features of Wyoming streamside woodlands. Condor 89:534-548.

Hatten, J.R., and C.E. Paradzick. 2003. A multiscaled model of southwestern willow flycatcher breeding habitat. Journal of Wildlife Management 67:774-788.

Hildén, O. 1965. Habitat selection in birds. Annales Zoologici Fennici 2:53-75.

Holmes, R.T., and S.K. Robinson. 1981. Tree species preferences of foraging insectivorous birds in a northern hardwoods forest. Oecologia 48:31-35.

Horton, J.L., and J.L. Clark. 2001. Water table declines alters growth and survival of *Salix gooddingii* and *Tamarix chinensis* seedlings. Forest Ecology and Management 140:239-247.

_____, T.E. Kolb, and S.C. Hart. 2001a. Physiological response to groundwater depth varies among species and with river flow regulation. Ecological Application 11:1046-1059.

______, ______, and S.C. Hart. 2001b. Responses of riparian trees to interannual variation in ground water depth in a semi-arid river basin. Plant, Cell and Environment 24:293-304.

Hosmer, D.W., and S. Lemeshow. 2000. Applied logistic regression. John Wiley and Sons, Inc, New York, New York, USA.

Huckleberry, G. 1994. Contrasting channel response to floods on the middle Gila River, Arizona. Geology 22:1083-1086.

______. 1996. Historical channel changes on the San Pedro River, southeastern Arizona. Arizona Geological Survey, Tucson, Arizona, USA. Open File Report 96-15.

Hughes, L.E. 1993. The devils own – tamarisk. Rangelands. 15:151-155.

Hunter, W.C., R.D. Ohmart, and B.W. Anderson. 1988. Use of exotic saltcedar (*Tamarisk chinensis*) by birds in arid riparian systems. Condor 90:113-123.

James, F.C. 1971. Ordinations of habitat relationships among breeding birds. Wilson Bulletin. 83:215-236.

Johnson, R.A., and D.W. Wichern. 2002. Applied multivariate statistical analysis. Prentice-Hall, Inc. Upper Saddle River, New Jersey, USA.

King, A.M., and J.R. King. 2003. Willow flycatchers in Warner Valley, Plumas County, California. Studies in Avian Biology 26:56-59.

Knopf, F.L., J.A. Sedgwick, and D.B. Inkley. 1990. Regional correspondence among shrubsteppe bird habitats. Condor 92:45-53.

Kotliar, N.B., and J.A. Wiens. 1990. Multiple scales of patchiness and patch structure: a hierarchical framework for the study of heterogeneity. Oikos 59: 253-260.

Kondolf, G.M., and E.R. Micheli. 1995. Evaluating stream restoration projects. Environmental Management 19:1-15.

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

Kulba, B., and W.B. McGillivray. 2003. Distribution and habitat characteristics of the willow flycatcher (Empidonax traillii) in Alberta. Studies in Avian Biology 26:36-40.

Lamb, B.L., and E. Lord. 1992. Legal mechanisms for protecting riparian resource values. Water Resources Research. 28:965-977.

Lande, R. 1987. Extinction thresholds in demographic models of terrestrial populations. American Naturalist 130:624-635.

Lehmkuhl, J.F. 1984. Determining size and dispersion of minimum viable populations for land management planning and species conservation. Environmental Management 8: 167-176.

Lite, S. 2003. San Pedro River riparian vegetation across water availability and flood disturbance gradients. PH.D Dissertation, Arizona State University, Tempe, Arizona.

Lite, S.J., and J.C. Stromberg. *In press*. Surface and ground-water thresholds for maintaining *Populus-Salix* forests, San Pedro River, Arizona. Biological Conservation.

Luff, J.A., E.H. Paxton, K.E. Kenwood, and M.K. Sogge. 2000. Survivorship and movements of southwestern willow flycatchers in Arizona – 2000. U.S. Geological Survey report to the U.S. Bureau of Reclamation, Phoenix, Arizona, USA.

MacArthur, R.H. and J.W. MacArthur. 1961. On bird species diversity. Ecology 42:594-598.

MacArthur, R.H., H. Recher, and M.L. Cody. 1966. On the relationship between habitat selection and species diversity. American Naturalist 100: 319-332.

MacNally, R.C. 1990. An analysis of density responses of forest and woodland birds to composite physiognomic variables. Australian Journal of Ecology 15:267-275.

Martin, T.E. 1992. Breeding productivity considerations; what are the appropriate habitat features for management? Pages 455-473 *in* J.M. Hagan III and D.W. Johnston, editors. Ecology and conservation of neotropical migrant landbirds, Smithsonian Institution Press, Washington D.C., USA.

______,. and J.J. Roper. 1988. Nest predation and nest-site selection of a western population of hermit thrush. Condor 90:51-57.

McCabe, R.A. 1991. The little green bird: ecology of the willow flycatcher. Palmer Publications, Inc., Amherst, Wisconsin, USA.

Merritt, W.L., and D.J. Cooper. 2000. Riparian vegetation and channel change in response to river regulation: a comparative study of regulated and unregulated streams in the Green River Basin, U.S.A. Regulated Rivers Research and Management 16:543-564.

Mills, G.S., J.B. Dunning, and J.M. Bates. 1991. The relationship between breeding bird density and vegetation volume. Wilson Bulletin 103:468-479.

Minckley, W.L., and D.E. Brown. 1994. Wetlands. Pages 223-301 *in* D.E. Brown, editor. Biotic communities of southwestern United States and northwestern New Mexico. University of Utah Press, Salt Lake City, Utah, USA.

Mund-Meyerson, M.J. 1998. Arthropod abundance and composition on native and exotic trees in the Middle Rio Grande riparian forest as related to avain foraging. MS Thesis, University of New Mexico, Albuquerque, New Mexico, USA.

Neter, J., M.H. Kutner, C.J. Nachtsheim, W. Wasserman. 1996. Applied linear statistical models. McGraw-Hill, Boston Massachusetts, USA.

_____, W. Wasserman, and M.H. Kutner. 1985. Applied linear statistical models. Irwin, Homewood, Illinois, USA.

Orians, G.H., and J.F. Wittenberger. 1991. Spatial and temporal scales in habitat selection. American Midland Naturalist 137:S29-S49.

Owen, J.C., and M.K. Sogge. 2002. Physiological condition of southwestern willow flycatchers in native and saltcedar habitats. U.S. Geological Survey report to the Arizona Department of Transportation, Phoenix, Arizona, USA.

Paradzick, C.E., and A.A. Woodward. 2003. Distribution, abundance, and habitat characteristics of southwestern willow flycatchers (*Empidonax traillii extimus*) in Arizona, 1993 – 2000. Studies in Avian Biology 26:22–29.

_____, and J.R. Hatten. 2004. Southwestern willow flycatcher habitat change detection analysis: Roosevelt Lake, Arizona, 1985-2001. Pages 60-82 *in* P.E.T. Dockens and C.E. Paradzick, editors. Mapping and monitoring southwestern willow flycatcher habitat in Arizona: a remote sensing approach. Nongame and Endangered Wildlife Program Technical Report 223. Arizona Game and Fish Department, Phoenix, Arizona, USA.

Poff, N.L., J.D. Allan, M.B. Bain, J.R. Karr, K.L. Prestegaard, B.D. Richter, R.E. Sparks, and J.C. Stromberg. 1997. The natural flow regime – a paradigm for river conservation and restoration. Bioscience 47:769-784.

Powell, B.F., and R.J. Steidl. 2000. Nesting habitat and reproductive success of southwestern riparian birds. Condor 102:823-831.

Richter, B.D., and H.E. Richter. 2000. Prescribing flood regimes to sustain riparian ecosystems along meandering rivers. Conservation Biology 14:1467-1478.

Rood, S.B., C.R. Gourley, E. M. Ammon, L.G. Heki, J. R. Klotz, M.L. Morrison, D. Mosley, G.G. Scoppettone, S. Swanson, and P.L. Wagner. 2003. Flows for floodplain forest: successful riparian restoration. BioScience 53:647-656.

Rotenberry, J.T. 1985. The role of habitat in avian community composition: physiognomy or florisitics? Oecologia 67:213-217.

Rotenberry, J., and J.A. Wiens. 1980. Habitat structure, patchiness, and avian communities in North American steppe vegetation: a multivariate approach. Ecology: 61:1228-1250.

Saab, V. 1999. Importance of spatial scale to habitat use by breeding birds in riparian forests: a hierarchical analysis. Ecological Applications 9:135-151.

Scott, M.L., P.B. Shafroth, and G.T. Auble. 1999. Reponses of riparian cottonwoods to alluvial water table declines. Environmental Management 23:347-358.

_____, S.K. Skagen, and M.F. Merigliano. 2003. Relating geomorphic change and grazing to avian communities. Conservation Biology 17:284-296.

Sedgwick, J.A., and F.L. Knopf. 1992. Describing willow flycatcher habitats: scale perspectives and gender differences. Condor 94:720-733.

Sferra, S.J., T.E. Corman, C.E. Paradzick, J.W. Rourke, J.A. Spencer, and M.W. Sumner. 1997. Arizona partners in flight southwestern willow flycatcher survey: 1993-1996 summary report. Nongame and Endangered Wildlife Program Technical Report 113. Arizona Game and Fish Department, Phoenix, Arizona, USA.

Shafroth, P.B., J.C. Stromberg, and D.T. Patten. 2000. Woody riparian vegetation response to different alluvial water table regimes. Western North American Naturalist. 60:66-76.

Smith, A.B., P.E.T. Dockens, A.A. Tudor, H.C. English, and B.L. Allen. 2004. Southwestern willow flycatcher 2003 survey and monitoring report. Nongame and Endangered Wildlife Program Technical Report 233. Arizona Game and Fish Department, Phoenix, Arizona, USA.

_____, A.A. Woodward, P.E.T. Dockens, J.S. Martin, and T.D. McCarthey. 2003. Southwestern willow flycatcher 2002 survey and monitoring report. Nongame and Endangered Wildlife Program Technical Report 210. Arizona Game and Fish Department, Phoenix, Arizona, USA

_____, C.E. Paradzick, A.A. Woodward, P.E.T. Dockens, and T.D. McCarthey. 2002. Southwestern willow flycatcher 2001 survey and monitoring report. Nongame and Endangered Wildlife Program Technical Report 191. Arizona Game and Fish Department, Phoenix, Arizona, USA.

Sogge, M.K. and R.M. Marshall. 2000. A survey of current breeding habitats. Pages 43-56 *in* D. M. Finch, and S. H. Stoleson, editors. Status, ecology, and conservation of the southwestern willow flycatcher. Gen. Tech. Rep. RMRS-GTR-60. USDA Forest Service, Rocky Mountain Research Station, Ogden, Utah, USA.

_____, R.M. Marshall, S.J. Sferra, and T.J. Tibbitts. 1997. A southwestern willow flycatcher natural history summary and survey protocol. National Park Service Cooperative Studies Unit. USGS Colorado Plateau Research Station NRTR-97/12, Northern Arizona University, Flagstaff, Arizona, USA.

_____, S.J. Sferra, T.D. McCarthey, S.O.Williams, and B.E. Kus. 2003. Distribution and characteristics of southwestern willow flycatcher breeding sites and territories: 1993 – 2001. Studies in Avian Biology 26:5-11.

Stoleson, S.H. and D.M. Finch. 2003. Microhabitat use by breeding southwestern willow flycatchers on the Gila River, New Mexico. Studies in Avian Biology 26:91-95.

_____, J. Agyagos, D.M. Finch, T. McCarthey, J. Uyehara, and M.J. Whitfield. 2000. Research needs. Pages 119-127 *in* D.M. Finch and S.H. Stoleson, editors. Status, ecology, and conservation of the southwestern willow flycatcher. Gen. Tech. Rep. RMRS-GTR-60. USDA Forest Service, Rocky Mountain Research Station, Ogden, Utah, USA.

Story, M. and R.G. Congalton. 1986. Accuracy assessment: a user's perspective. Photogrammetric Engineering and remote sensing. 52:397-399.

Stromberg, J.C. 1993. Fremont cottonwood-Gooding willow riparian forests:a review of their ecology, threats, and recovery potential. Journal of the Arizona Academy of Science. 26:97-110.

_____. 1998a. Dynamics of Fremont cottonwood (*Populus fremontii*) and saltcedar (*Tamarix chinensis*) populations along the San Pedro River, Arizona. Journal of Arid Environments. 40:133-155.

_____. 1998b. Functional equivalency of salt cedar (*Tamarix chinensis*) and remont cottonwood (*Populus fremontii*) along a free-flowing river. Wetlands 18:675-686.

_____, J. Fry, and D.T. Patten. 1997. Marsh development after large floods in an alluvial, arid-land river. Wetlands 17:292-300.

_____, R. Tiller, and B. Richter. 1996. Effects of groundwater decline on riparian vegetation of semiarid regions: the San Pedro, Arizona. Ecological Applications 6:113-131.

Unitt, P. 1987. *Empidonax traillii extimus*: an endangered subspecies. Western Birds 18:137-162.

U.S. Fish and Wildlife Service. 1995. Final rule determining endangered status for the southwestern willow flycatcher. February 17, 1995. Federal Register 60(38):10694-10715.

_____. 2002. Southwestern willow flycatcher (Empidonax traillii extimus) - Final recovery plan. U.S. Fish and Wildlife Service, Albuquerque, New Mexico, USA.

Van Horne, B. 1983. Density as a misleading indicator of habitat quality. Journal of Wildlife Management 47:893-901.

Verner, J., M.L. Morrison, and C.J. Ralph. 1986. Wildlife 2000: modeling habitat relationships of terrestrial vertebrates. University of Wisconsin Press, Madison, Wisconsin, USA.

Walsberg, G.E. 1981. Nest-site selection and radiative environment of the warbling vireo. Condor 83: 86-88.

Ward, J.V., K. Tockner, U. Uehlinger, and F. Malard. 2001. Understanding natural patterns and processes in river corridors as the basis for effective river restoration. Regulated Rivers: Research and Management 17:311-323.

Ward, M.P. and S. Schlossberg. 2004. Conspecific attraction and the conservation of territorial songbirds. Conservation Biology 18:519-525.

Weller, D.E. 1987. A reevaluation of the –3/2 power rule of plant self-thinning. Ecological Monographs 57:23-43.

Wiens, J.A. 1977. On competition and variable environments. American Scientist 65:590-597.

_____. 1989. Spatial scaling in ecology. Functional Ecology 3:385-397.

_____. 2002. Riverine landscapes: taking landscape ecology into the water. Freshwater biology. 47:501-515.

_____., 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.

_____, N.C. Stenseth, B.Van Horne, and R.A. Ims. 1993. Ecological mechanisms and landscape ecology. Oikos 66:369-380.

Wood, M.L. 1997. Historical channel changes along the lower San Pedro River, southeastern Arizona. Open-File Report, Arizona Geological Survey 97-21.

Zar, J.H. 1999. Biostatistical analysis. Prentice Hall, Upper Saddle River, New Jersey, USA.

CHAPTER 2

INFLUENCE OF PATCH-SCALE HYDROGEOMORPHIC CONDITIONS ON SOUTHWESTERN WILLOW FLYCATCHER HABITAT SUITABILITY ALONG THE LOWER SAN PEDRO AND GILA RIVERS, ARIZONA

ABSTRACT

Recovery of many endangered bird species requires knowledge that links habitat selection patterns to environmental conditions and ecological processes that create and sustain suitable breeding habitat. In arid-land riparian systems, hydrogeomorphic conditions influence vegetation floristic and structure characteristics, which in turn affect forest patch suitability for sensitive species such as the southwestern willow flycatcher (SWFL; *Empidonax traillii extimus*). To examine plant-hydrogeomorphic relationships for SWFL, I linked patch-scale characteristics found important to breeding habitat selection to local hydrological and geomorphic conditions on a free-flowing river (San Pedro) and a regulated river (Gila) in central Arizona. I found that 4 of the 5 key patch-scale vegetation variables measured were associated with water availability and patch inundation rate. Foliage density at 7 – 9 m showed the strongest pattern: density increased with higher water tables and low annual water table fluctuation in both cottonwood-willow (C-W) and tamarisk (TAMA) dominated patches. Other key variables showed C-W or TAMA-specific relationships with hydrogeomorphic conditions. Slight variations in hydrogeomorphic conditions altered forest-patch

vegetation and suitability for SWFL, highlighting the importance of hydrology for restoration and conservation of breeding habitat for the bird.

INTRODUCTION

In arid-land riparian ecosystems variation in surface flow and groundwater have great influence on floristic composition and structure of the vegetation (Graf 1988, Stromberg et al. 1991, Hughes 1994, Stromberg et al. 1996, Cooper et al. 1999, Merritt and Cooper 2000). For wildlife species that have highly specialized habitat needs, alteration of the underlying biological and physical conditions that create and sustain particular vegetation features can profoundly affect habitat use (Scott et al. 2003) and potentially reduce reproductive rates, which could influence population persistence. In the arid-southwest, dramatic changes to the rivers due to dams and water diversions, channelization, and groundwater withdrawal have caused direct loss and significant alteration to riparian plant communities (Poff et al. 1997, Stromberg et al. 2004). These changes have lead to the precipitous decline of some native taxa (Minckley and Douglas 1991) including the SWFL (U.S. Fish and Wildlife Service 1995). In order to conserve and restore breeding-ground habitat for the SWFL there is a critical need for research that identifies local and landscape-level hydrological and geomorphic conditions that support breeding-habitat features (Kus and Sogge 2003).

The SWFL is a neotropical migratory songbird that breeds within dense thickets along rivers and delta areas of reservoirs in Arizona, California, Colorado, New Mexico, Nevada, and Utah (U.S. Fish and Wildlife Service 1995, Sogge et al. 2003). Other causes for its decline were identified by the U.S. Fish and Wildlife Service (1995) as loss of wintering ground habitat, cowbird parasitism, and invasive plants (e.g., tamarisk [*Tamarix spp*.], Russian olive [*Elaeagnus angustifolia*]). Primarily caused by landscape level changes in hydrological regimes and land use, tamarisk has become abundant along many southwestern rivers and has replaced cottonwood-willow (*Populus* spp. –*Salix* spp.) forests along some (Stromberg et al. 1996, Everitt 1998, Tickner et al. 2001, Sher et al. 2000, Lite and Stromberg *in review*). It was thought at the time of listing that tamarisk had negative effects on flycatcher fitness; however, current research by U.S. Geological Survey and Arizona Game and Fish Department in Arizona suggests that some populations utilizing tamarisk are stable or increasing (Tudor et al. *in review*[b]), that physiological conditions of SWFL are similar between native and tamarisk habitats (Owen and Sogge 2002), and that the insect foodbase within tamarisk patches do not limit recruitment or survival (Drost et al. 2003, Durst 2004).

A primary focus of the SWFL Recovery Plan (U.S. Fish and Wildlife Service 2002) is to protect and restore riparian habitat suitable for flycatchers. While it emphasizes the need to protect and restore native dominated habitats, it also recognizes the role tamarisk now plays in a large part of the SWFL breeding range. While research has addressed habitat selection, tree species preference, and identified key vegetation components in different parts of the birds range (see McKernan and Braden 2001, Allison et al. 2003, Hatten and Paradzick

2003, Stoleson and Finch 2003), little information is available that directly links specific breeding-patch vegetation characteristics with environmental conditions.

In general, structural and floristic traits of riparian vegetation have been tied to local topographic features, such as height above and lateral distance to the low flow channel (thalweg), and tied to hydrologic features, such as permanence of surface flow and depth and variation of groundwater, which influence disturbance frequency and water availability (Hupp and Osterkamp 1985, Harris 1987, Cooper et al. 2003, Lite et al. *in press*). For example, high water availability in a patch can increase tree vigor and growth rate (Horton et al. 2001a, b), thereby influencing patch conditions. Within pioneer floodplain forests, slight variations in local hydrogeomorphic conditions could alter patch floristic and structural characteristics, and affect suitability of vegetation to SWFL.

Primary objectives of this Chapter were to 1) identify the specific environmental variables that are related to vegetational determinants of SWFL patch selection, and to contrast hydrogeormorphic conditions between 2) SWFL occupied and unoccupied patches within floristic patch types, 3) tamarisk-dominated and cottonwood-willow dominated SWFL occupied patches, and 4) SWFL occupied patches on reaches of a free-flowing river and of a dammed and flow-regulated river. I hypothesized that groundwater depth and inundation frequency both would influence SWFL patch quality; that occupied patches would have shallow groundwater tables, greater inundation frequency, and higher stream flow permanence than unoccupied patches; that tamarisk-dominated patches would be sustained by deeper groundwater depths than for cottonwood-willow patches; and that variation in hydrogeomorphic conditions between rivers at cottonwood-willow occupied patches will not differ, while conditions at occupied tamarisk patches will differ (because tamarisk can persist at a greater range of conditions).

This chapter is part of a larger study that had two overall goals: 1) describe patch-scale SWFL habitat selection patterns for the population located near the Gila/San Pedro River confluence (Chapter 1); and 2) define the fluvial geomorphic and hydrologic conditions at patch (Chapter 2) and basin scales (Chapter 3) that create and sustain these habitat components. This chapter links the SWFL habitat selection results from the first objective to patch-level hydrogeomorphic relationships. Results of this analysis can be coupled with landscape level plant-hydrogeomorphic relationships to assess ecological conditions on SWFL habitat across multiple spatial scales (Chapter 3). The study was conducted on a large population (>130 territories) of SWFL in Arizona (Paradzick and Woodward 2003) that nest near the confluence of the free-flowing San Pedro River, and regulated Gila River. The use of habitat by SWFL on both drainages provides an opportunity to quantify environmental influences on nesting habitat suitability in both cottonwood-willow and tamarisk patches and two contrasting flow regimes.

STUDY AREA

This study was conducted along the San Pedro and Gila rivers in south-central Arizona (Fig. 2-1). The San Pedro River is one of the few remaining free-flowing streams in the Sonoran Desert, and supports long stretches of cottonwood-willow forests (Tellman et al. 1997); in contrast, Coolidge Dam impounds the Gila River affecting the flow regime, and much of the riparian forest is dominated by tamarisk (*Tamarix ramosissima*) (Chapter 3).

Both reaches are low gradient (0.002-0.005 mm^{-1}) alluvial rivers. Channel sediments consist of cobbles, pebbles, gravels, and sand; overbank sediments are dominated by sand, silt, and clay-sized material (Huckleberry 1994, 1996). Floodplain vegetation varies among and within drainages and is dominated by Fremont cottonwood (*P. fremontii*), Goodding willow (*S. gooddingii*), and tamarisk. Other abundant species included velvet mesquite (*Prosopis velutina*), seepwillow (*Baccharis salicifolia*), and burrobrush (*Hymonoclea monogyra*). Primary land and water uses within the area include agriculture, mining, and livestock production.

Gila River

Gila River project area (43 linear km) began 35 km downstream of Coolidge Dam near Dripping Springs Wash and ended 3 km downstream of the Florence-Kelvin highway bridge (Fig. 2-1). Elevation ranged from 536 - 600 m. The Gila River watershed drains 46,648 km^2, of which 13,273 km^2 is below Coolidge Dam. Coolidge Dam was completed in 1928, creating San Carlos Lake, primarily to store and release water for agricultural purposes downstream of the study area. Between 1993 – 2003, releases for farming generally began in March and continued through September. Upstream of the dam, the river is largely unregulated, but small surface water diversions and groundwater pumping withdraw water for agriculture, mining, and municipal uses.

San Pedro River

The San Pedro River project area (30 km) began 5 km downstream of the town of Mammoth and ended at the confluence with the Gila River (Fig. 2-1). Elevation ranged from 585 - 680 m. The watershed, near the confluence, drains 11,533 km^2. The lower San Pedro River flows south to north with its headwaters in Mexico and is largely unregulated. Small water diversions and groundwater withdrawal for agricultural and mining occur along the river. In the last decade, conservation efforts have removed two large farms from production (Haney 2002), and the San Manuel Mine (15 km upstream of the project area) has reduced groundwater withdrawals.

METHODS

Vegetation Measurements

To assess the plant-hydrogeomorphic relationships, I used floristic and structural characteristics found to be significant predictors of SWFL occupancy at the patch scale: 1) density of young (5.5 – 15 cm dbh) willow or tamarisk trees; 2) presence of saturated soil or standing water near the patch; 3) canopy cover and foliage volume; and 4) forest abundance within 4.5 ha surrounding the patch.

These nesting habitat characteristics were similar, albeit more specific, to those identified in other research along the Gila and lower San Pedro rivers (Allison et al. 2003, Hatten and Paradzick 2003) and other drainages (Brown 1988, Sogge and Marshall 2000, Stoleson and Finch 2003). The vegetation variables were measured at 20 willow flycatcher occupied and 20 unoccupied patches, with 10 occupied and 10 unoccupied patches per drainage. A patch was defined as a stand of trees with similar floristic and physiognomic characteristics, and with similar floodplain topography (see Chapter 1). Occupied patches were located using standardized protocol surveys (Sogge et al. 1997), and unoccupied patches were potentially suitable for nesting based on qualitative habitat descriptions by Sogge et al. (1997).

SWFL Patch Vegetation.— I sampled approximately 10% of the area of each patch using randomly placed 5 x 20 m quadrats. Within each quadrat, I measured canopy cover (using a spherical densiometer) and foliage volume at the corners and center of each quadrat. I used the line intercept method described by Mills et al. (1991) to measure foliage volume between 7 - 9 m, the interval above SWFL average nest height (4 – 6 m) in the study area (Smith et al. 2002, 2003). To characterize floristic composition, I identified to species and counted all stems taller than breast height (1.5 m) in each quadrat. I grouped stems into 5 size classes based on diameter at breast height (dbh), and I focused on tamarisk and willow stems in the 5.5 – 15 cm class. I calculated basal area ($cm^2/100m^2$) by multiplying number of stems by the midpoint of the size class

(10.25 cm). Each variable was averaged across the quadrat and patch. Based on size class-age relationships developed by Stromberg (1998a) on the San Pedro River, the 5-cm interval represents 2 – 3 years of growth for cottonwood and willow, and 7 years for tamarisk. Thus, stand age for trees 5.5 - 15 cm is estimated to be between 2 - 9 yrs and 7 - 21 yrs, for cottonwood-willow and tamarisk respectively.

Patches were grouped into two floristic types - cottonwood-willow (C-W) and tamarisk (TAMA) dominated - based on a cluster analysis (Johnson and Wichern 2002) using total basal area of the 5 dominant tree and shrub species (cottonwood, willow, tamarisk, mesquite, and seepwillow) for each patch (see Chapter 1 for more detail).

4.5-ha Neighborhood Sampling.— I visually delineated major patch types based on growth form and size class following Grossman et al. (1998) in a 150 x 300 m rectangular plot overlaid on SWFL occupied and unoccupied patches (see Chapter 1). I calculated the percentage of forest (>60% cover of >5 m tall trees) within the neighborhood.

Environmental Sampling

Topography.— I characterized the location (height above and distance to the thalweg) of the 20 patches (10 per drainage), half of which intersected occupied willow flycatcher patches and half of which intersected unoccupied patches using floodplain transects. These transects were also used to calculate inundation rates (see below), and in a separate analysis, delineate floodplain vegetation abundance and diversity (Chapter 3). This subset of patches (20 of the 40) was representative of the vegetation and hydrologic conditions along each river segment. Transects were placed perpendicular to the river, extended across the pioneer-riparian vegetation zone (generally dominated by cottonwood, willow, and tamarisk), and ended at higher terraces dominated by mesquite, upland plants, or agricultural lands. This zone is essentially similar to the floodplain zone, defined as the area that includes the active channel and surfaces deposited by the present flow regime (Graff 1988). The floodplain transects were surveyed using a laser transit to determine elevation and distance from channel thalweg to each patch (Harrelson et al. 1994). The remaining 20 patches not falling on a floodplain transect also were surveyed using the laser transit.

Stage - Discharge Calculation.— For floodplain transects, I estimated stream discharge that would inundate each occupied or unoccupied patch. I calculated stage-discharge relationships using the program WinXSPRO Channel analyzer (Grant et al. 1998); floodplain surface elevations, lateral distance to thalweg, channel slope, and an estimate of Mannings N (channel roughness) were inputs into the program. Slope was estimated using elevation contours from USGS 7.5 minute topographic maps. To determine roughness coefficients, I followed the same methodology as Lite (2003); I divided transects into 3 zones (i.e., thalweg-channel and 2 floodplain surfaces), characterized vegetation form and density along each floodplain zone, and assigned coefficient values based on published values. Because transect placement was based on flycatcher occupancy, not all assumptions of the WinXSPRO model may have been met (e.g., uniform flow, constant channel geometry, and discontinuities in flow); similarly each lateral floodplain surface (patch) was assumed level and slope breaks were not recorded. However, model results (i.e., inundation frequency of each floodplain surface) were similar to Lite (2003), who conducted flow-modeling analyses on the lower San Pedro River, and to observed flooding events between 1995 – 2003.

Inundation Frequency.— For each floodplain transect, I calculated patch inundation rates between 1994 – 2003. Flow data input for the analysis depended on transect location. For San Pedro River transects, I used the stage-discharge relationship and flood return intervals (i.e., expected frequency of various flood magnitudes) obtained from Pope et al. (1998) and Lite (2003) based on a historic gage located on the lower San Pedro River near the town of Winkelman to determine number of years that each patch was expected to be inundated between 1994 - 2003. On the Gila River, 9 of 10 transects were located downstream of the San Pedro River confluence. For these transects, I used flow records from the Kelvin gage (Table 2-1). For the one transect located upstream of the confluence, I used the Coolidge Dam gage because it was not affected by San Pedro River inflows. For all calculations, I assumed that channel topography and vegetation community were similar throughout the period modeled (1994 – 2003). However, channel form might have changed in response to smaller floods (post-1993), and model output could be affected by change in distribution and abundance of vegetative growth in the floodplain over time. These changes can affect sediment deposition, fluvial surface height, and roughness coefficients, which can alter model output.

Surface Water Permanence.— I mapped presence of surface flow or standing water using GPS during the last week of June (which is typically the driest time of the year) along the entire San Pedro River study reach in 2001 - 2003. I measured distance of surface flow (perennial) and dry streambed (intermittent) using ArcView software (ESRI 2002). I calculated the median number of years SWFL occupied or unoccupied patches within each floristic patch type were adjacent to a flowing stream segment. On the Gila River, because flows had been maintained by releases from Coolidge Dam I did not map stream permanence. However in 2002 – 2003, flow releases were reduced, and water was intermittent along the river in June and the extent of surface flow appeared to decline through summer in both years.

Groundwater Monitoring.— I installed 9 piezometers (shallow groundwater monitoring wells) and I used 7 existing piezometers (maintained by the Nature Conservancy) to monitor depth to groundwater. On the Gila River, 2 were within occupied willow flycatcher patches and 2 were near (< 50 m) unoccupied patches. On the San Pedro River, 5 were located within occupied patches and 7 near unoccupied patches. The distribution among rivers and between occupied and unoccupied patches reflected landowner permission to install and monitor the wells. Readings at wells not located within patches were corrected for elevation differences using a laser transit. Wells were monitored monthly, generally read in the middle of the month, from summer 2001 through August 2003. Water table fluctuation was calculated as maximum change in depth between January - June during 2002 or 2003.

Statistical Analysis.—- Relationships between environmental conditions and patch-scale vegetation variables were analyzed with Spearman rank order correlations, using data pooled across rivers (Objective 1). Mean values of environmental attributes were compared between unoccupied and occupied patches within rivers (Objective 2), between C-W and TAMA patches within rivers (Objective 3), and occupied patches between rivers (Objective 4) using two-tailed Mann-Whitney U-tests. All statistical analyses were conducted using SPSS 11.5. Unless otherwise noted values reported are mean ± 1 sd.

RESULTS

Relationships between Hydrogeomorphic Variables and Patch Quality

Over all SWFL occupied and potentially suitable unoccupied patches, hydrogeomorphic characteristics were correlated to 4 of the 5 key vegetation structural characteristics that are associated with flycatcher habitat selection (Table 2-2). Basal area of young (5.5 - 15 cm dbh) tamarisk increased with greater inundation discharge and lower frequency of inundation, but was not related to groundwater depth or fluctuation. Basal area of young willow increased as patch inundation discharge decreased, inundation rates increased, and as ground water depth became shallower. Foliage volume at 7 - 9 m above ground increased with shallower and less fluctuation in groundwater depths. Average canopy cover was not correlated to any hydrogeomorphic variable. The amount of forest in the 4.5-ha area surrounding the patch increased as groundwater became shallower.

Differences between Occupied and Unoccupied Patches, Cottonwood-Willow and Tamarisk Patches, and Rivers

Geomorphic Variables.— San Pedro River occupied C-W forest patches were closer, both vertically and horizontally, to the stream thalweg than unoccupied C-W patches (Table 2-3). Too few unoccupied C-W patches were present on the Gila River to allow comparison with occupied C-W patches. There was no within-river elevation difference between TAMA occupied and unoccupied patches, but along both rivers, mean distance to the stream channel from occupied TAMA patches was greater than unoccupied TAMA patches. However, variability was high and the results were not statistically significant.

On both rivers, TAMA occupied patches were on higher surfaces than C-W occupied patches. The maximum elevation of TAMA occupied patches was 7 m above the thalweg (and located adjacent to channel) on the Gila River. Gila River SWFL occupied and unoccupied patches were located on higher fluvial surfaces (3.79 m ± 1.43) compared to San Pedro River occupied and unoccupied patches (1.78 m ± 0.83).

Inundation Discharge and Frequency.— On the San Pedro River TAMA and C-W occupied habitat tended to be inundated at lower stream discharges than either unoccupied patch types (Table 2-3). Occupied patches were inundated more frequently across rivers and habitat types when flow records (Gila River) or return intervals (San Pedro River) were applied.

All C-W occupied patches on the San Pedro River were estimated to be inundated annually between 1994 - 2003, whereas TAMA occupied habitat had a median inundation rate of 4.5 yrs (Table 2-3). Three occupied patches on the Gila River were inundated once during the 1995 flood event, and two were not inundated during the study period. A portion of one C-W occupied patch (GS12) on the Gila River may have been inundated again during the 2000 flood event. Stream discharge to inundate both occupied and unoccupied C-W and TAMA patches was greater on the Gila River than for the San Pedro River (Table 2-3).

Surface and Groundwater Availability.— San Pedro River stream permanence between 2001 - 2003 was higher at occupied patches than unoccupied patches, and at C-W occupied patches than TAMA occupied patches (Gila River permanence was not recorded). Occupied patches were closer to the water table than unoccupied patches within floristic patch types (Table 2-3, Fig. 2-2). Maximum water depth at all occupied patches also was shallower than unoccupied patches (except for ARVI on the San Pedro River; see below). Fluctuation in water levels at occupied patches tended to be less than at unoccupied patches and was statistically significant for C-W patches (Table 2-3).

Occupied C-W patches tended to be closer to the water table than occupied TAMA patches but the difference was not significant, due to the ARVI patch. On the San Pedro River, one C-W occupied patch (ARVI) was dominated by old (>30 cm) cottonwood trees with a dense tamarisk understory. For this patch, mean water depth was –2.58 m (± 0.40), whereas the mean water level at the 2 remaining C-W patches, dominated by young cottonwood and willow trees, was -1.07 m (± 0.32).

Because of low number of wells in each patch type on the Gila River it was not possible to statistically test depth to groundwater differences among patch types, and between rivers. However, depth to groundwater generally followed the pattern of patch elevation differences. C-W and TAMA occupied habitat tended to have deeper groundwater depths on the Gila River compared to the San Pedro River. Interestingly, the one C-W occupied patch (GS12) on the Gila River had depth to groundwater greater than all TAMA occupied patches and two of the C-W occupied patches on the San Pedro River (Fig. 2-2).

DISCUSSION

The riparian habitat that is selected for nesting by SWFL is sensitive to relatively small variations in stream hydrology, as evidenced by correlations between vegetation structure variables and hydrogeomorphic variables, and differences in depth to groundwater, inundation frequency, and stream permanence between occupied and unoccupied patches. Of the 5 key vegetation structure variables previously found to be linked with SWFL patch selection

(Chapter 1), 4 were related with at least one hydrogeomorphic variable. Of these, depth and fluctuation in groundwater showed the strongest relationships with 3 of the 5 variables: foliage density at 7 – 9 m, willow stem density, and amount of forest in the 4.5-ha neighborhood. These structural variables have also been found to be significant predicators of habitat use at coarser (Hatten and Paradzick 2003) and finer (Allison et al. 2003) scales.

Surface Water and Vegetation.— Lateral gradients in elevation and distance to thalweg and in depth to groundwater have been related to lateral gradients in both floristic and structural community traits (Hupp and Osterkamp 1985, Hughes 1994). Lite et al. (*in press*) found that vegetation biomass (canopy cover, basal area, foliage volume, stem density) tended to be higher at lower elevations and moister sites (closer to the water table) across the floodplain. I found similar patterns for the dense patches preferred by flycatchers. Both C-W and TAMA occupied patches (which on average were denser than unoccupied patches) were closer to groundwater than unoccupied patches. However, I did not find that occupied TAMA patches (which also were on average denser than unoccupied patches) were closer (in elevation or distance) to the stream than unoccupied tamarisk patches. This pattern may reflect my methods to select patches because I did not sample a wide range of tamarisk patches that were unsuitable for SWFL nesting (e.g., dense sapling stands < 5 m tall).

Occupied willow patches tended to be closer to the stream channel than occupied tamarisk patches, with this location resulting in higher frequency of patch inundation compared to TAMA patches. A study of patch distribution patterns on the San Pedro River found that tamarisk patches were a similar distance from the channel as cottonwood-willow patches, but occurred on higher surfaces (Bagstad et al. *in press*). This spatial segregation of tamarisk and willow patches may be due to physiological and morphological adaptations to withstand flood-disturbance (Karrenberg et al. 2002). Willows produce both vertical and horizontal root systems that anchor the plant during floods, have high rate of root and stem growth, and have highly flexible branches that do not break in fast-moving flood waters (Horton and Clark 2001, Karrenberg et al. 2002). Others have suggested that tamarisk has less tolerance for surviving flood disturbance (Levine and Stromberg 2001, Vandersande et al. 2001, Tallent-Halsell and Walker 2002), shifting it to higher floodplain surfaces. Alternatively, tamarisk may have a broad tolerance range but is competitively reduced from the wetter sites by competition from willows or cottonwoods (Sher et al. 2000, 2002, Sher and Marshall 2003).

Surface Water and SWFL.— Stream permanence and inundation frequency may directly influence SWFL habitat selection and reproduction. Inter-relationships between hydrogeomorphic conditions, vegetation, and other habitat attributes (e.g., insect abundance, humidity) makes it difficult to tease apart ultimate and proximate effects on SWFL nesting behavior and reproductive rates, but Johnson et al. (1999) hypothesized that SWFL will not nest in absence of flowing water based on nest studies on the Rio Grande River, New Mexico. Most, but not all, occupied patches on the San Pedro River were adjacent to surface flow during the breeding season, and flow in the Gila River was maintained by dam releases except for 1999, and 2002 - 2003. The population on the Gila River declined by 70% between 1997 – 2003 (McCarthey et al. 1998, Smith et al. 2004), suggesting that this hypothesis should be more fully explored, especially as it relates to water management on rivers.

Cain et al. (2003) found that prolonged flood inundation restricted land predator access to willow flycatcher (*E. trailli*) and yellow warbler (*Dendrocia petechia*) nests in Sierra Nevada meadows. Tudor et al. (*in review*[a]) identified both terrestrial [e.g., kingsnake, spotted skunk, and spiny lizard) and avian (e.g., Cooper's hawk, western screech-owl) species as SWFL nest predators in the project area. While population-level reproductive rates have been assessed for SWFL on the Gila and lower San Pedro rivers (Tudor et al. *in review*[b]), detailed analysis that examines both vegetative attributes as well as hydrogeomorphic factors (i.e., stream permanence, inundation rates) at the patch and nest-scales on predation rates and nest success needs to be completed. This research could also examine predator diversity and abundance between C-W and TAMA patches, and evaluate flood inundation as a factor that might mediate predator densities and influence nest success.

Groundwater.— As noted above, 3 of the 5 vegetation structure variables were related to depth and fluctuation in groundwater. Others have shown that sites with rapid declines or highly fluctuating water tables can cause reduced stem growth, leaf desiccation, branch dieback, and in severe conditions, crown die back and mortality, in cottonwood, willow, and tamarisk (Busch and Smith 1995, Cleverly et al. 1997, Smith et al. 1998, Scott et al. 1999, Horton et al. 2001a,b). For SWFL, maintenance of dense foliage by a high water table might benefit reproductive rates by increased shade (Walsberg 1981) and cover from avian predators (Martin and Roper 1988). Also, high soil moisture content and greater plant transpiration might create more favorable (i.e., cooler, higher humidity) within-patch microclimate conditions.

Occupied cottonwood-willow and tamarisk patches had maximum depth to groundwater of 1.7 and 3.4 m, respectively. These results were within the ranges reported by other researchers for young cottonwood, willow, and tamarisk trees (Stomberg 1993a, Stomberg et al. 1993, Stromberg et al. 1996, Stromberg 1998a). Scott et al. (1999) suggested groundwater fluctuations of >1m could destroy cottonwood, and plants experiencing gradual declines up to 0.5 m can show deleterious affects. Impacts can be exacerbated due to lateral rather than vertical root growth during high stable water levels that can leave roots stranded above available soil moisture during rapid water table declines (Shafroth et al. 2000). Water tables fluctuated within occupied patches between 0.5 – 1.0 m, and in one patch (GS12) water tables declined below 2 m, the maximum depth reported under young cottonwood or willow stands along the upper San Pedro River (Fig 2-2; Stromberg et al. 1996). At GS12, on the Gila River, cottonwood and willow mortality was evident in 2002 - 2003, which reduced stand density, canopy cover, and patch suitability for nesting. In 2004, no birds were detected in GS12 (Munzer et al. 2005), which had been occupied in 2001 by 5 pairs. Field observations in 2003 – 2004 suggested that water stress impacts to vegetation were greater on the Gila River than San Pedro River; however, because vegetation sampling occurred in 2001, and patches were not resampled, direct effects of declining water tables on vegetation and SWFL habitat suitability was not captured.

Other Considerations

I assumed that vegetation measured during the study was associated with current environmental conditions; however, this may not be true if vegetation is adjusting to new hydrogeomorphic conditions (e.g., drought), impacted by other abiotic factors not measured, or has been influenced by recent or ongoing human activities (Stromberg et al. 1991, Stromberg 1993b, Tabacchi et al. 1996, Bagstad et al. *in review*). Similarly, vegetation structure and floristic composition is constrained by coarser-scale conditions, such as elevation, gradient, and river basin geology (Stromberg 1993b, Dixon et al. 2002, Lite 2003). Two local factors that have likely influenced patch-scale floristic and structural characteristics of riparian vegetation in the study area, but which I did not measure, include livestock grazing and soil salinity.

Along the San Pedro River, recent (<5 yrs) conservation measures have reduced the distribution and abundance of livestock in some areas. On the Gila River, field observations (1995 – 2003) suggest that livestock were present throughout the study reach. Livestock grazing can alter plant community composition and structural characteristics (Belsky et al. 1999, Krueper et al. 2003, Scott et al. 2003). However, Stoleson and Finch (2001) note that highly managed fall-winter livestock grazing in New Mexico had no significant negative impact SWFL nest success, incidence of cowbird parasitism, or habitat selection. Under highly managed conditions, short-term impacts may not be detrimental to nesting SWFL, but long-term influences on the temporal availability of SWFL nesting habitat is unknown. Second, soil salinity has been reported to influence riparian plant community dynamics (Busch and Smith 1995). Tamarisk has a higher tolerance for saline soils than cottonwood and willow (Busch and Smith 1995, Smith et al. 1998, Schmidt 2003). Soil salinity rates are low in the San Pedro River floodplain (Bagstad et al. *in press*) but may be high along the Gila River and thus could influence the composition of riparian patches used by SWFL.

MANAGEMENT IMPLICATIONS

The highest priority for conservation of the SWFL is protection of existing occupied breeding habitat (U.S. Fish and Wildlife Service 2002). In the short-term, maintenance of functional SWFL habitat will require sustaining hydrogeomorphic conditions that conserve key vegetation components (i.e., dense foliage, stem densities) but also serve to maintain other important habitat conditions (e.g., near-patch surface water, within-patch soil moisture). Opportunities to protect instream flows and maintain or increase water tables at occupied sites should be viewed as essential as direct protection of land and forest stands. A better understanding is needed of the relationships between watershed conditions and local hydrological characteristics. For example, groundwater models for the San Pedro River, that link groundwater withdrawal to depression of groundwater tables and stream surface flows can aid managers in prioritizing conservation actions (Haney 2002).

Managers seeking to restore SWFL habitat should assess patch-scale hydrological conditions, along with other local site factors (e.g., soil salinity, grazing pressure) to determine adequate floristic composition for restoration. If willow cannot be supported due to deep groundwater tables, and interruption of fluvial processes that support recruitment, the site may be more appropriate for restoration of other native flora (e.g., mesquite). At some sites, where tamarisk occurs, hydrological processes are highly altered, and large-scale removal and maintenance is not feasible, managers could look for opportunities to utilize the tree, and alter patch characteristics to benefit wildlife including the SWFL. For example, flood irrigation in conjunction with selective removal and interspersed planting of native trees to create high vertical and horizontal foliage heterogeneity throughout the patch could increase available habitat niches for a diversity of wildlife species. Use of exotic species for restoration purposes is not a novel concept (Ewel and Putz. 2004). More research and project planning is needed before *a priori* deciding to remove tamarisk in areas where hydrological conditions limit cottonwood and willow survival (Anderson 1998, Stromberg *in review*).

To accomplish long-term conservation of the SWFL and other riparian obligate species, information is needed to link habitat requirements across multiple spatial scales to environmental conditions, primarily hydrologic features of the landscape, and the ecological process that create and sustain key habitat features. Both landscape scale and local-scale data will aid development of sound land-conservation and water-management plans (Verner et al. 1986, Graf et al. 2002, Kus and Sogge 2003). There has been a recent interest by riparian ecologists to link fluvial processes to vegetation patterns to avian community dynamics (Scott et al. 1999). Along the San Pedro River, Lite and Stromberg (*in press*) identified hydrologic thresholds that maintain abundant cottonwood-willow stands with high age-class diversity, and Stromberg (1998b) has evaluated physiognomic similarities and differences between cottonwood-willow and tamarisk patches. Coupling similar research with fish and wildlife habitat needs, would allow an ecosystem approach to conservation of native fauna, including SWFL.

Table 2-1. San Pedro River and Gila River USGS stream gage descriptions.

Gage	Gage Number	River	Location
Redington	09472000 09472050	San Pedro	40 km upstream from study area
Kelvin	09474000	Gila	Downstream end of study area
Coolidge Dam	09469500	Gila	At dam 35 km upstream from study area

Table 2-2. Correlation (Spearman's rho) between vegetation structural traits and hydrologic variables measured at willow flycatcher occupied and unoccupied patches on the Gila and lower San Pedro rivers, Arizona.

	Inundation discharge (n=21)	No. years patch inundated 1994 – 2003 (n=20)	Mean depth to groundwater[1] (n=16)	Groundwater Fluctuation (n=16)	Maximum depth to groundwater[1] (n=16)
Young[2] tamarisk basal area	0.48	-0.47	--	--	--
Young willow basal area	- 0.46	0.44*	0.60	--	0.52
Average canopy cover	--	--	--	--	--
Foliage volume 7 - 9m	--	--	0.60	- 0.58	0.48*
% forest in 4.5-ha neighborhood[3]	NA	NA	0.51	--	0.46*

[1]depth to groundwater represented with negative numbers; therefore a positive r value indicates an increase in a biotic variable at shallower groundwater depth
[2] young defined as trees 5.5 – 15 cm dbh
[3] Inundation discharge and patch inundation rate could not be estimated for this variable because all floodplain surfaces in the neighborhood were not measured. Groundwater depth and variation for this variable is a relative measure of water table depth in neighborhood.
* $p < 0.1$, all others $p < 0.05$

Table 2-3. Geomorphic and hydrologic variables measured in 2001-2003 at willow flycatcher occupied (O) and unoccupied (U) habitat patches on the Gila and lower San Pedro rivers, Arizona. Unless noted values for each variable include (N), mean, ± 1sd.

	Gila River				San Pedro River			
	Cottonwood-willow		Tamarisk		Cottonwood-willow		Tamarisk	
Variable	O	U	O	U	O	U	O	U
Elevation above thalweg (m)	(1) 2.54	(0)	(9) 3.6 ± 1.8	(10) 4.1 ± 1.1	(6) 1.3 ± 0.6**	(5) 2.0 ± 0.4	(4) 2.4 ± 0.3	(5) 1.7 ± 1.3
Distance to stream channel (m)	(1) 269	(0)	(9) 53 ± 72	(10) 29 ± 40	(6) 1 ± 2**	(5) 73 ± 47	(4) 211 ± 205	(5) 91 ± 103
Inundation discharge (m^3s^{-1})	(1) 261	(0)	(4) 1034 ± 683	(5) 1092 ± 771	(3) 27 ± 29*	(2) 268 ± 93	(2) 180 ± 6	(4) 591 ± 807
Median number of years patch inundated	1	(0)	1	0	10	3	4.5	2
Median number years with surface flow	--	--	--	--	(6) 3	(5) 1	(4) 1.5	(5) 0

Table 2-3 (continued). Geomorphic and hydrologic variables measured in 2001-2003 at willow flycatcher occupied (O) and unoccupied (U) habitat patches on the Gila and lower San Pedro rivers, Arizona. Unless noted values for each variable include (N), mean, ± 1sd.

	Gila River				San Pedro River			
	Cottonwood-willow		Tamarisk		Cottonwood-willow		Tamarisk	
Variable	O	U	O	U	O	U	O	U
Groundwater depth (m)	(1) - 2.32	(0)	(1) - 2.71	(2) -4.76 ± 0.43	(3) - 1.59 ± 0.80*,[a]	(5) - 2.39 ± 0.33	(2) - 1.94 ± 0.30*	(3) - 2.63 ± 0.36
Min / Max groundwater depth (m)	(1) - 1.77 - 2.93	(0)	(1) - 2.16 - 3.42	(2) -3.79 -5.75	(3) - 0.36 [a] - 3.31	(5) - 1.67 - 3.20	(2) - 1.21 - 2.49	(3) - 1.86 - 3.12
Groundwater fluctuation (m)	(1) 0.67	(0)	(1) 0.58	(2) 0.99 ± 0.69	(3) 0.65 ± 0.26**	(5) 0.71 ± 0.16	(2) 0.62 ± 0.37	(3) 0.68 ± 0.18

* $p < 0.1$; ** $p < 0.05$ – Kruskal-Wallis Test for difference between means of occupied and unoccupied patches within habitat types and within river.

[a] one of the cottonwood-willow patches was dominated by mature (>25 cm) cottonwood trees with an understory of tamarisk, the two remaining patches were dominated by young (5 - 15.5 cm) willow; mean depth to groundwater at the willow patches was -1.07 m ± 0.32 (Min/Max: -0.36 - 1.70 m; fluctuation: 0.51 m ± 0.14).

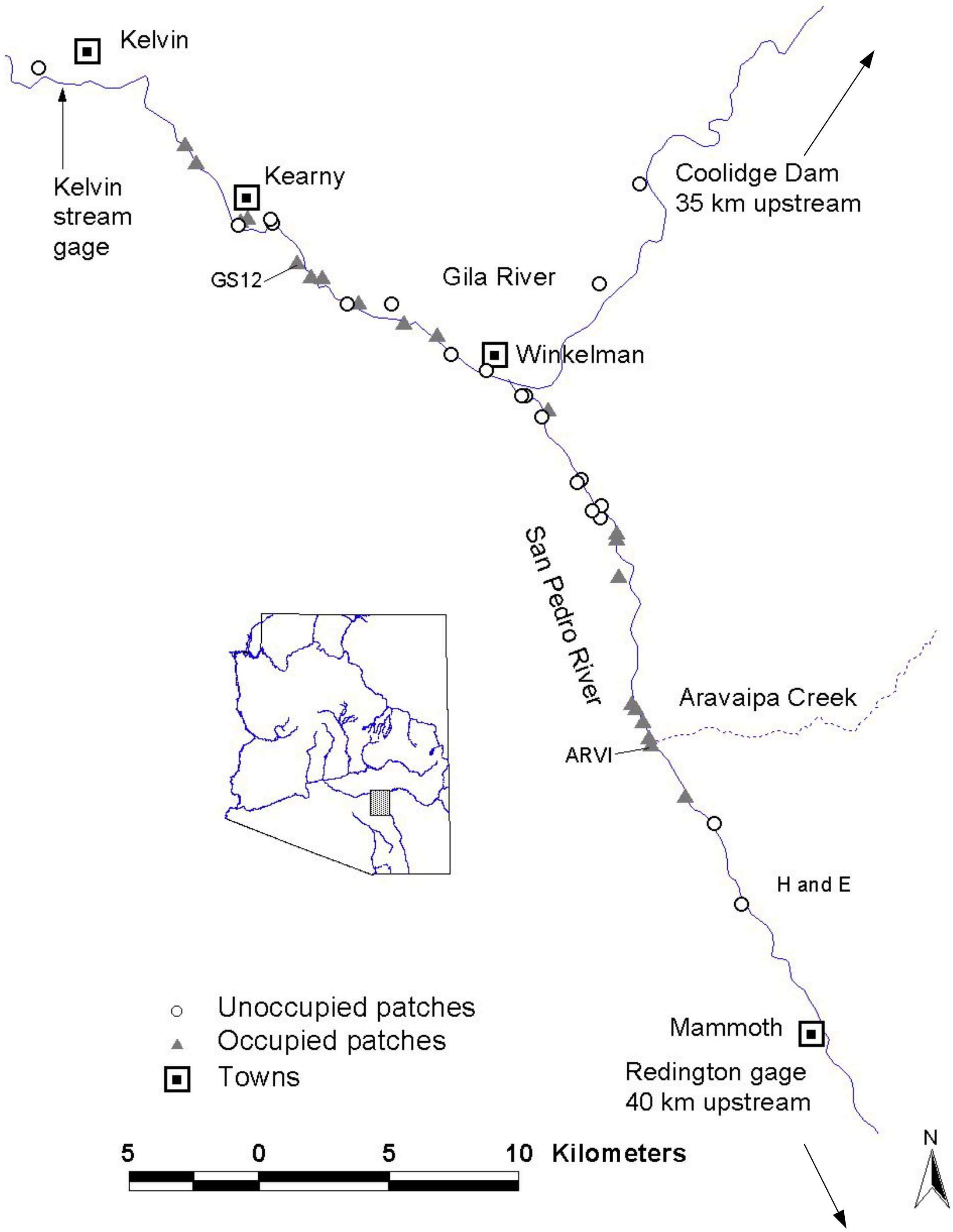


Fig. 2-1. Map of project area showing Gila River and lower San Pedro River confluence in southeastern Arizona. Individual sites mentioned in text are identified on map.

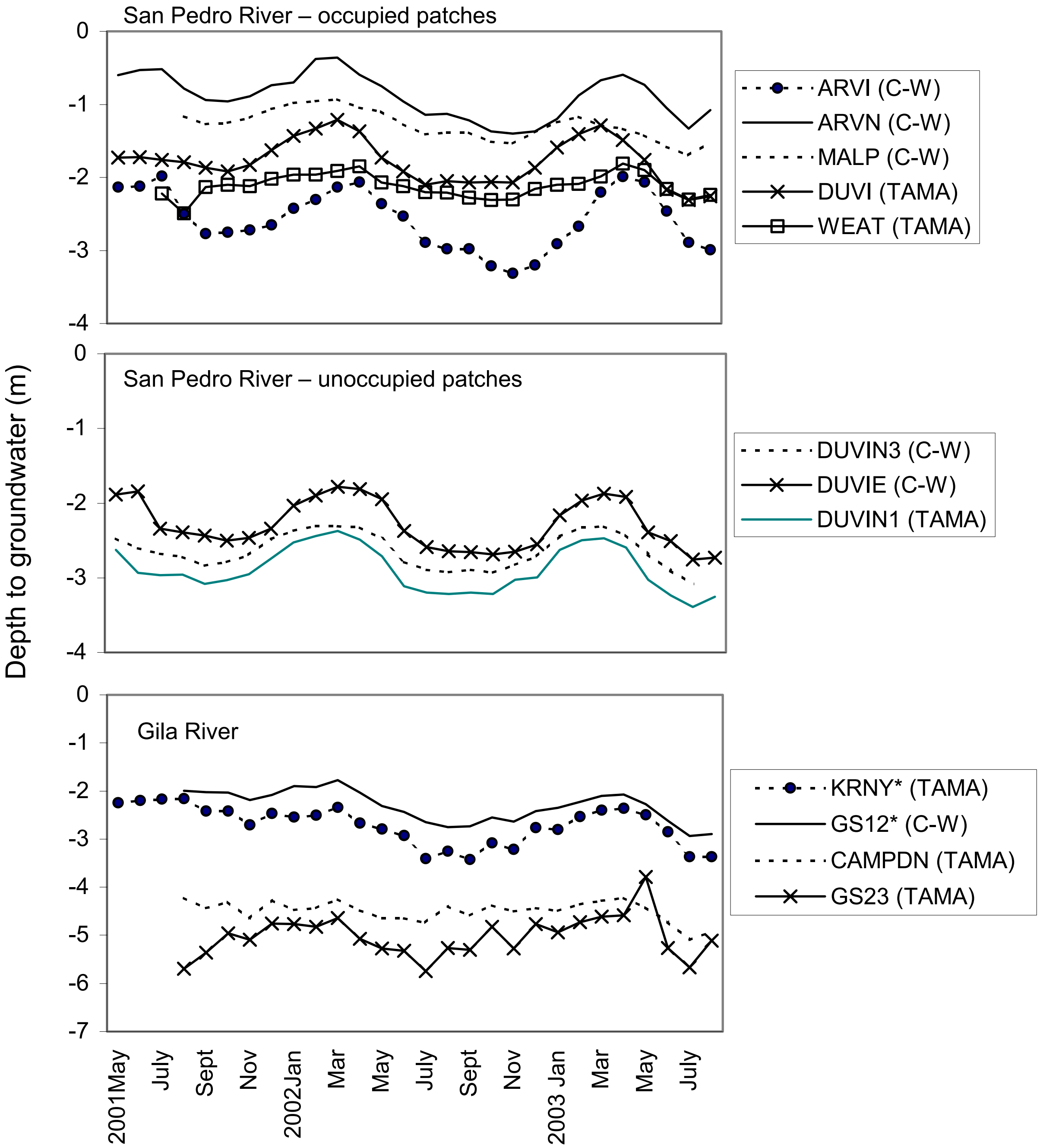


Fig. 2-2. Depth to groundwater at willow flycatcher occupied cottonwood-willow (C-W) and tamarisk (TAMA) dominated patches from May 2001 – August 2003 along the Gila and lower San Pedro rivers. Four unoccupied patches on San Pedro River not shown but fall within range depicted. Gila River occupied sites marked with asterisks. Note: ARVI was classified as C-W due to predominance of large (>25cm) cottonwood trees; mid- and understory was dominated by smaller (5.5 – 15 cm) tamarisk trees.

LITERATURE CITED

Allison, L.J., C.E. Paradzick, J.W. Rourke, and T.D. McCarthey. 2003. A characterization of nesting and non-nesting plots for southwestern willow flycatchers in central Arizona. Studies in Avian Biology 26:81-89.

Anderson, B. 1998. The debate over tamarisk: the case for salt cedar. Restoration and Management Notes 16:130-134.

Bagstad, K.J., S.J. Lite, and J.C. Stromberg. *In press*. Vegetation and hydro-geomorphology of riparian patch types of a dryland river. Western North American Naturalist.

Belsky, A.J., A. Matzke, and S. Uselman. 1999. Survey of livestock influences on stream and riparian ecosystems in the western United States. Journal of Soil and Water Conservation 54: 419-431.

Brown, B.T. 1988. Breeding ecology of a willow flycatcher population in Grand Canyon, Arizona. Western Birds 19:25-33.

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

Cain, J.W., M.L. Morrison, and H.L. Bombay. 2003. Predator activity and nest success of willow flycatchers and yellow warblers. Journal of Wildlife Management 67:600-610.

Cleverly, D.J., D.M. Merritt, D.C. Andersen, and R.A. Chimner. 1997. Invasive capacity of *Tamarix ramosissima* in a Mohvae Desert floodplain: the role of drought. Oecologia 11:12-18.

Cooper, D.J., D.C. Anderson, and R.A. Chimner. 2003. Multiple pathways for woody plant establishment on floodplains at local to regional scales. Journal of Ecology 91:182-196.

_____, D.M. Merritt, D.C. Andersen, and R.A. Chimner. 1999. Factors controlling the establishment of Fremont cottonwood seedlings on the upper Green River, USA. Regulated Rivers: Research and Management 15:419-440.

Dixon, M.D., M.G. Turner, and C. Jin. 2002. Riparian tree seedling distribution on Wisconsin River sandbars: controls at different spatial scales. Ecological Monographs 72:465-485.

Drost, C.A., E.H. Paxton, M.K. Sogge and M.J. Whitfield. 2003. Food habitats of the southwestern willow flycatcher during the nesting season. Studies in Avian Biology 26:96-103.

Durst, S.L. 2004. Southwestern willow flycatcher potential prey base and diet in native and exotic habitats. MS Thesis, Northern Arizona University, Flagstaff, Arizona, USA.

ESRI. 2002. ArcView 8. Environmental Systems Research Institute, Inc. Redlands, California, USA.

Everitt, B.L. 1998. Chronology of the spread of tamarisk in the central Rio Grande. Wetlands 18:658-668.

Ewel, J.J., and F.E. Putz. 2004. A place for alien species in ecosystem management. Frontiers in Ecology 7:354-360.

Graf, W.L. 1988. Fluvial processes in dryland rivers. Springer-Verlag, New York.

_____, J. Stromberg, and B. Valentine. 2002. Rivers, dams, and willow flycatchers: summary of their science and policy connections. Geomorphology. 47:169–188.

Grant, G.E., J.E. Duval, G.J. Koerper, and J.L. Fogg. 1998. WinXSPRO: a channel cross-section analyzer; user manual. U.S. Department of Agriculture, Forest Service, Rock Mountain Forest and Range Experimental Station. Prepared by West Consultants, Inc. San Diego, California, USA.

Grossman, D.H., D. Faber-Langendoen, A.S. Weakly, M. Anderson, P. Bourgeon, R. Crawford, K. Goodin, S. Landaal, K. Metzler, K.D. Patterson, M. Pyne, M. Reid, and S.L. Sneddon. 1998. International classification of ecological communities: terrestrial vegetation of the United States. Volume I. The National Vegetation Classification System: development, status, and applications. Nature Conservancy, Arlington, Virginia, USA.

Haney J.A. 2002. Groundwater modeling and biodiversity conservation on the Lower San Pedro River. *Southwest Hydrology* 1:8.

Harrelson, C.C., C.L. Rawlins, and J.P. Potyondy. 1994. Stream channel reference sites: an illustrated guide to field technique. Gen. Tech, Rep.

RM-245. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experimental Station.

Harris, R.R. 1987. Occurrence of vegetation on geomorphic surfaces in the active floodplain of a California alluvial stream. American Midland Naturalist 118:393-405.

Hatten, J.R., and C.E. Paradzick. 2003. A multiscaled model of southwestern willow flycatcher breeding habitat. Journal of Wildlife Management 67:774-788.

Horton, J.L., and J.L. Clark. 2001. Water table declines alters growth and survival of *Salix gooddingii* and *Tamarix chinensis* seedlings. Forest Ecology and Management 140:239-247.

_____, T.E. Kolb, and S.C. Hart. 2001a. Physiological response to groundwater depth varies among species and with river flow regulation. Ecological Application 11:1046-1059.

_____, _____, and _____. 2001b. Responses of riparian trees to interannual variation in ground water depth in a semi-arid river basin. Plant, Cell and Environment 24:293-304.

Huckleberry, G. 1994. Contrasting channel response to floods on the middle Gila River, Arizona. Geology 22:1083-1086.

_____. 1996. Historical channel changes on the San Pedro River, southeastern Arizona. Arizona Geological Survey, Tucson, AZ, USA. Open File Report 96-15.

Hughes, F.M.R. 1994. Environmental change, disturbance, and regeneration in semi-arid floodplain forests. Pages 321-345 *in* A.C. Millington and K. Pye editors. Environmental change in drylands: biogeographical and geomorphological perspectives. John Wiley and Sons Ltd., New York, New York, USA.

Hupp, C.L., and W.R. Osterkamp. 1985. Bottomland vegetation distribution along Passage Creek, Virginia, in relation to fluvial landforms. Ecology 66:670-681.

Johnson, K., P. Mehlhop, C. Black, and K. Score. 1999. Reproductive failure of endangered southwestern willow flycatchers on the Rio Grande, New Mexico. Southwestern Naturalist 44:226-231.

Johnson, R.A., and D.W. Wichern. 2002. Applied multivariate statistical analysis. Prentice-Hall, Inc. Upper Saddle River, New Jersey, USA.

Karrenberg, S., P.J. Edwards, and J. Kollmann. 2002. The life history of Salicaceae living in the active zone of floodplains. Freshwater Biology 47:733-748.

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

Kus, B.E., and M.K. Sogge. 2003. Status and distribution – introduction. Studies in Avian Biology 26:3–4.

Levine, C.M., and J.C. Stromberg. 2001. Effects of flooding on native and exotic plant seedlings: implications for restoring south-western riparian forests by manipulating water and sediment flows. Journal of Arid Environments 49:111-113.

Lite, S.J. 2003. San Pedro River vegetation across water availability and flood intensity gradients. Ph.D. dissertation, State University, Tempe, Arizona.

_____, and J.C. Stromberg. *in press*. Surface and ground-water thresholds for maintaining *Populus - Salix* forests, San Pedro River, Arizona. Biological Conservation.

_____, and _____. *in review*. Variations in woody vegetation across water availability and flood intensity gradients along the semi-arid San Pedro River, Arizona.

_____, K.J. Bagstad, and J.C. Stromberg. *in press*. Riparian plant richness and abundance along lateral and longitudinal gradients of water stress and flood disturbance, San Pedro River, Arizona, USA. Journal of Arid Environments.

Mahoney, J.M., and S.B. Rood. 1998. Stream flow requirements for cottonwood seedling recruitment – an integrated model, Wetlands 18:634-645.

Martin, T.E., and J.J. Roper. 1988. Nest predation and nest-site selection of a western population of hermit thrush. Condor 90:51-57.

McCarthey, T.D., C.E. Paradzick, J.W. Rourke, M.W. Sumner, and R.F. Davidson. 1998. Arizona partners in flight southwestern willow flycatcher 1997 survey and nest monitoring report. Nongame and Endangered Wildlife Program Technical Report 130. Arizona Game and Fish Department, Phoenix, Arizona, USA.

McKernan, R.L., and G. Braden. 2001. Status, distribution, and habitat affinities, of southwestern willow flycatcher along the lower Colorado River Year-4 (unpublished report). San Bernardino County Museum, Redlands, California, USA.

Merritt, D.M., and D.J. Cooper. 2000. Riparian vegetation and channel change in response to river regulation: a comparative study of regulated and unregulated streams in the Green River Basin, USA. Regulated Rivers: Research and Management 16:543-564.

Mills, G.S., J.B. Dunning, and J.M. Bates. 1991. The relationship between breeding bird density and vegetation volume. Wilson Bulletin 103:468-479.

Minckley, W.L., and M.E. Douglas. 1991. Discovery and extinction of western fishes: a blink of the eye in geologic time. Pages 3-17 *in* W.L. Minckley and J.E. Deacon editors. Battle against extinction: native fish management in the American West. University of Arizona Press, Tucson, Arizona, USA.

Munzer, O., Smith, A.B., H.C. English, and A.A. Tudor. 2005. Southwestern willow flycatcher 2004 survey and nest monitoring report. Nongame and Endangered Wildlife Program Technical Report 244. Arizona Game and Fish Department, Phoenix, Arizona, USA.

Owen, J.C., and M.K. Sogge. 2002. Physiological condition of southwestern willow flycatchers in native and saltcedar habitats. U.S. Geological Survey report to the Arizona Department of Transportation, Phoenix, Arizona, USA.

Paradzick, C.E., and A.A. Woodward. 2003. Distribution, abundance, and habitat characteristics of southwestern willow flycatchers (*Empidonax traillii extimus*) in Arizona, 1993 – 2000. Studies in Avian Biology 26:22–29.

Poff, N.L., J.D. Allan, M.B. Bain, J.R. Karr, K.L. Prestegaard, B.D. Richter, R.E. Sparks, and J.C. Stromberg. 1997. The natural flow regime – a paradigm for river conservation and restoration. Bioscience 47:769-784.

Pope, G.L., P.D. Rigas, and C.F. Smith. 1998. Statistical summaries of streamflow data and characteristics of drainage basins for selected streamflow-gaging stations in Arizona through water year 1996. Water-Resources Investigations Report 98-4225. Tucson, Arizona, USA.

Schmidt, K.M. 2003. Relationship of salinity and depth to the water table on *Tamarix* spp. (saltcedar) growth and water use. Masters Thesis. Texas A&M University. College Station, Texas.

Scott, M.L., P.B. Shafroth, and G.T. Auble. 1999. Reponses of riparian cottonwoods to alluvial water table declines. Environmental Management 23:347-358.

_____, S.K. Skagen, and M.F. Merigliano. 2003. Relating geomorphic change and grazing to avian communities. Conservation Biology 17:284-296.

Shafroth, P.B., J.C. Stromberg, and D.T. Patten. 2000. Woody riparian vegetation response to different alluvial water table regimes. Western North American Naturalist 60:66-76.

Sher, A.A., and D.L. Marshall. 2003. Seedling competition between *Populus deltoids* (Salicaceae) and exotic *Tamarix ramosissima* (Tamaricaceae) across water regimes and substrate types. 2003. American Journal of Botany 90:413-422.

_____, D.L. Marshall, and J.P. Taylor. 2002. Establishment patterns of native *Populus* and *Salix* in the presence of invasive nonnative *Tamarix*. Ecological Applications 12:760-772.

_____, _____, and S.A. Gilbert. 2000. Competition between native *Populus deltoids* and invasive *Tamarix ramosissima* and implications for reestablishing flooding disturbance. Conservation Biology 14:1744-1754.

Smith, A.B., A.A. Woodward, P.E.T. Dockens, J.S. Martin, and T.D. McCarthey. 2003. Southwestern willow flycatcher 2002 survey and nest monitoring report. Nongame and Endangered Wildlife Program Technical Report 210. Arizona Game and Fish Department, Phoenix, Arizona, USA.

_____, C.E. Paradzick, A.A. Woodward, P.E.T. Dockens, and T.D. McCarthey. 2002. Southwestern willow flycatcher 2001 survey and nest monitoring report. Nongame and Endangered Wildlife Program Technical Report 191. Arizona Game and Fish Department, Phoenix, Arizona, USA.

_____, P.E.T. Dockens, A.A. Tudor, H.C. English, and B.L. Allen. 2004. Southwestern willow flycatcher 2003 survey and nest monitoring report. Nongame and Endangered Wildlife Program Technical Report 233. Arizona Game and Fish Department, Phoenix, Arizona, USA.

Smith, S.D., D.A. Devitt, A. Sala, J.R. Cleverly, and D.E. Busch. 1998. Water relations of riparian plants from warm desert regions. Wetlands 18:687-696.

Sogge, M.K., and R.M. Marshall. 2000. A survey of current breeding habitats. Pages 43-56 *in* D. M. Finch, and S. H. Stoleson, editors. Status, ecology, and conservation of the southwestern willow flycatcher. Gen. Tech. Rep. RMRS-GTR-60. USDA Forest Service, Rocky Mountain Research Station, Ogden, Utah, USA.

_____, R.M. Marshall, S.J. Sferra, and T.J. Tibbitts. 1997. A southwestern willow flycatcher natural history summary and survey protocol. National Park Service Cooperative Studies Unit. USGS Colorado Plateau Research Station – Northern Arizona University, Flagstaff, Arizona, USA. NRTR-97/12.

_____, S.J. Sferra, T.D. McCarthey, S.O. Williams, and B.E. Kus. 2003. Distribution and characteristics of southwestern willow flycatcher breeding sites and territories: 1993 – 2001. Studies in Avian Biology 26:5–11.

Stoleson, S.H., and D.M. Finch, 2001. Southwestern willow flycatchers in the Cliff-Gila Valley, New Mexico – landscape-level effects on density, reproduction, and cowbird parasitism. Summary report on the 2000 field season (unpublished report). USDA Forest Service, Rocky Mountain Research Station, Albuquerque, New Mexico, USA.

Stoleson, S.H., and D.M. Finch. 2003. Microhabitat use by breeding southwestern willow flycatchers on the Gila River, New Mexico. Studies in Avian Biology 26:91-95.

Stromberg, J.C. 1993a. Fremont cottonwood-goodding willow riparian forests: a review of their ecology, threats, and recovery potential. Journal of the Arizona-Nevada Academy of Science. 26:97-110.

_____. 1993b. Instream flow models for mixed deciduous riparian vegetation within a semiarid region. Regulated Rivers: Research and Management 8:225-235.

_____. 1998a. Dynamics of Fremont cottonwood (*Populus fremontii*) and saltcedar (*Tamarix chinensis*) populations along the San Pedro River, Arizona. Journal of Arid Environments. 40:133-155.

_____. 1998b. Functional equivalency of salt cedar (*Tamarix chinensis*) and Fremont cottonwood (*Populus fremontii*) along a free-flowing river. Wetlands 18:675-686.

_____, B.D. Richter, D.T. Patten, and L.G. Wolden. 1993. Response of a Sonoran riparian forest to a 10-year return flood. Great Basin Naturalist 53:118-130.

_____, D.T. Patten, and B.D., Richter. 1991. Flood flows and dynamics of Sonoran riparian forests: 2:221-235.

_____, M. Briggs, C. Gourley, M. Scott, P. Shafroth, and L. Stevens. Human alterations of riparian ecosystems. 2004. Pages 99 -126. *in* M.B, Baker, P.F. Ffolliot, L.F. Debano, and D.G. Neary, editors. Riparian areas of the Southwestern United States: hydrology, ecology, and management. Lewis Publishers, Inc., Boca Raton, Florida, USA.

_____, R. Tiller, and B. Richter. 1996. Effects of groundwater decline on riparian vegeation of semiarid regions: the San Pedro, Arizona. Ecological Applications 6:113-131.

Tabachi, E., A. Planty-Tabacchi, M.J. Salinas, and H. Decamps. 1996. Landscape structure and diversity in riparian plant communities: a longitudinal comparative study. Regulated Rivers: Research and Management 12:367-390.

Tallent-Hassell, N.G., and L.R. Walker. 2002. Responses of *Salix gooddingii* and *Tamarix ramosissima* to flooding. Wetlands 22:776-785.

Tellman, B., R. Yarde, and M.G. Wallace. 1997. Arizona’s changing rivers: how people have affected the rivers. Issue Paper #19, Water Resources Research Center, College of Agriculture, University of Arizona, Tucson Arizona, USA.

Tickner, D.P., P.G. Angold, A.M. Gurnell, and J.O. Mountford. 2001. Riparian plant invasions: hydrogeomorphological control and ecological impacts. Progress in Physical Geography 25:22-52.

Tudor, A.A., P.E.T. Dockens, D.K. Bolen, and T.D. McCarthey. *in review*[a]. Predators of southwestern willow flycatcher nests in Arizona: identification using video cameras. Submitted to Journal of Field Ornithology.

_____, E. H. Paxton, and C.E. Paradzick. *in review*[b]. Demography of southwestern willow flycatchers in central Arizona. Submitted to the Condor.

U.S. Fish and Wildlife Service. 1995. Final rule determining endangered status for the southwestern willow flycatcher. February 17, 1995. Federal Register 60(38):10694-10715.

_____. 2002. Southwestern willow flycatcher (*Empidonax traillii extimus*) - Final recovery plan. U.S. Fish and Wildlife Service, Albuquerque, New Mexico, USA.

Vandersande, M.W., E.P. Glenn, and J.L. Walworth. 2001. Tolerance of five riparian plants from the lower Colorado River to salinity drought and inundation. Journal of Arid Environments 49:147-159.

Verner, J., M.L. Morrison, and C.J. Ralph. 1986. Wildlife 2000: modeling habitat relationships of terrestrial vertebrates. University of Wisconsin Press, Madison, Wisconsin, USA.

Walsberg, G.E. 1981. Nest-site selection and radiative environment of the warbling vireo. Condor 83:86-88.

CHAPTER 3

BASIN-SCALE HYDROLOGY, VEGETATION, AND PATCH SELECTION BY THE SOUTHWESTERN WILLOW FLYCATCHER ALONG THE LOWER SAN PEDRO AND GILA RIVERS, ARIZONA

ABSTRACT

The southwestern willow flycatcher (*Empidonax traillii extimus*, SWFL) is an endangered riparian obligate songbird whose habitat has been greatly altered by large-scale damming, flow diversion, and groundwater pumping that substantially changed hydrology, riparian vegetation, and nesting habitat quality. To develop long-term conservation strategies for the bird, mangers need data that links river processes to breeding habitat suitability. I assessed the relationships between hydrogeomorphic conditions (surface and groundwater hydrology) and riparian vegetation, and assessed SWFL patch selection patterns, along the free-flowing lower San Pedro River and the regulated Gila River in southeastern Arizona. Riparian forest near the confluence of these rivers supports one of the largest concentrations of SWFL in the subspecies range. Results indicated that the Gila River has low floristic and structural diversity, and an abundance of tamarisk (*Tamarix ramosissima*) forest, compared to the free-flowing San Pedro River, which had high patch floristic and structural diversity with co-dominant cottonwood-willow (*Populus* spp. – *Salix* spp.) and tamarisk forest. On the San Pedro River, SWFL selection patterns suggested that willow

forest was used more than expected, tamarisk less often than expected, and cottonwood in equal proportion based on availability. On the Gila River, most of the limited cottonwood-willow patches were utilized but were too sparse to allow for determination of selection. Substantial alteration to the hydrograph and interruption of the fluvial processes by regulation has probably caused low structural diversity on the Gila River, and could limit temporal availability of SWFL nesting habitat. Preference for willow forest on the San Pedro River highlights the need to further examine the impact to SWFL of plant community shifts from cottonwood-willow to tamarisk forest. For land and water managers, conservation and restoration of SWFL breeding habitat should consider hydrogeomorphic conditions across multiple scales including the influence of basin-scale hydrology on riparian floodplain forests and its constraint on local patch vegetation structure and floristic characteristics.

INTRODUCTION

In arid-land riparian systems, the flood regime is the primary mechanism governing erosion, deposition, and channel morphological changes that influence inundation rates, disturbance frequencies, and broad vegetation patterns across the floodplain (White 1979, Hughes 1994, Poff et al. 1997). These basin-scale processes constrain local hydrogeomorphic variability, which influence riparian community floristic and structural composition (Stromberg 1993b, Ward et al. 2001, Dixon et al. 2002, Lite 2003). Characteristics of a flood regime, including magnitude, frequency, timing, and duration, can vary widely between river reaches, depending on factors such as watershed size, stream gradient, and presence of flow-regulating dams, and can influence forest traits such as mean tree age and stem density (Lite 2003). Stream flow rates and floodplain groundwater depths also vary between river reaches, depending on factors such as depth to bedrock and extent of alluvial groundwater pumping or stream flow diversion, and influence traits including composition and structure of the floodplain forests (Lite and Stromberg *in press*). On regulated systems, alteration of base-flow can produce channel geomorphic changes, influence surface and groundwater availability, and alter the vegetation community (Graf 1982, Dominick and O'Neil 1998, Friedman et al. 1998, Shafroth et al.1998).

Along some lower elevation rivers in the southwest, changes in hydrology in concert with other environmental stressors (e.g., overgrazing) have contributed to shifts in the riparian plant community from native species to exotic dominated systems (Stromberg 1993a, Stromberg et al. 1996, Everitt 1998, Tickner et al. 2001, Sher et al. 2002, Lite and Stromberg *in press*). One of the most conspicuous changes has been decline of Fremont cottonwood – Goodding willow (*Populus* fremontii – *Salix gooddingii*) forest from some rivers, with a contemporaneous increase in tamarisk (*Tamarix* spp.). Tamarisk, an exotic tree from Eurasia (Crins 1989), is often well adapted to the new hydrologic regime caused by dewatering or regulation (Graf 1982, 1988, Everitt 1998, Stromberg 1998a). Tamarisk has deeper roots, can extract water from the unsaturated soil, and can tolerate a much wider range of groundwater levels than cottonwood or willow (Busch and Smith 1995, Devitt et al. 1997, Shafroth et al. 2000). Where tamarisk has increased in abundance, some have suggested that it can have deleterious impacts on native flora and fauna (Hunter et al. 1987, Brock 1994). Others have found that the functional role of tamarisk is variable among rivers (Stromberg 1998b, Fleishman et al. 2003), and impacts might be more complex and result in alteration but not necessarily declines in flora and fauna richness or diversity (Bagstad et al. *in press,* Shafroth et al. *in press*). An additional complicating factor of tamarisk management is its use as nesting habitat by SWFL, a federally listed endangered species.

In Arizona, the central portion of the songbirds breeding range, the bird nests in riparian communities that vary from native dominated patches to extensive monotypic stands of tamarisk along major rivers and delta areas of reservoirs (Paradzick and Woodward 2003). While tamarisk was listed as a factor contributing to the species decline (U.S. Fish and Wildlife Service 1995), managers now recognize the functional role tamarisk forest plays for SWFL in many riparian areas that support large breeding populations (U.S. Fish and Wildlife Service 2002, Paradzick and Woodward 2003). Additionally, recent research suggests that SWFL tamarisk does not negatively influence population viability (Tudor et al. *in review*, Owen and Sogge 2002, Durst 2004). While some nest-site studies have reported that the species (*E. traillii traillii*, McCabe 1991) and the southwestern subspecies (Stoleston and Finch 2003) may select against willow for other substrates (e.g., tamarisk) when available, no selection studies have been conducted at basin scales. For managers, understanding broad-scale SWFL selection patterns and the influence of fluvial processes and hydrological conditions on floristic composition and structure of riparian forest that may limit available breeding habitat within the floodplain can aid development of conservation and restoration strategies.

The objectives of this study were 1) to compare patch abundance and diversity between a free-flowing and regulated river that support SWFL, 2) to contrast hydrogeomorphic conditions among pioneer forest patch types within and between rivers, 3) to determine whether SWFL use of a patch type was greater than expected based on patch availability, and 4) to thoroughly describe the flow regimes of the reaches of the free-flowing and regulated rivers that support SWFL.

This Chapter is part of a larger study that had two overall goals: 1) describe patch-scale SWFL habitat selection patterns for the population located near the Gila/San Pedro River confluence (Chapter 1); and 2) define the fluvial geomorphic and hydrologic conditions at patch (Chapter 2) and basin scales (Chapter 3) that create and sustain these habitat components. Results of this analysis were discussed in conjunction with patch level plant-hydrogeomorphic relationships (Chapter 2) to assess ecological conditions on SWFL habitat across multiple spatial scales. The study was conducted on a large population (>130 territories) of SWFL in Arizona (Paradzick and Woodward 2003) that nest near the confluence of the free-flowing San Pedro River, and regulated Gila River. The use of habitat by SWFL on both drainages provides an opportunity to quantify environmental influences on nesting habitat availability and basin-scale selection patterns in both cottonwood-willow and tamarisk patches influenced by two contrasting flow regimes.

STUDY AREA

This study was conducted along the San Pedro and Gila rivers in southeastern Arizona (Fig. 3-1). The San Pedro River is one of the few remaining free-flowing streams in the Sonoran Desert, and supports long stretches of cottonwood-willow forests (Tellman et al. 1997); in contrast, Coolidge Dam impounds the Gila River affecting the flow regime, and much of the riparian forest is dominated by tamarisk. Both reaches are low gradient (0.002-0.005 mm^{-1}) alluvial rivers. Channel sediments consist of cobbles, pebbles, gravels, and sand; overbank sediments are dominated by sand, silt, and clay-sized material (Huckleberry 1994, 1996). Primary land and water uses within the area include agriculture, mining, and livestock production.

Gila River

Gila River project area (43 linear km) began 35 km downstream of Coolidge Dam near Dripping Springs Wash and ended 3 km downstream of the Florence-Kelvin highway bridge (Fig. 3-1). Elevation ranged from 536 - 600 m. The Gila River watershed drains 46,648 km^2, of which 13,273 km^2 is below Coolidge Dam. Coolidge Dam was completed in 1928, creating San Carlos Lake, primarily to store and release water for agricultural purposes downstream of the study area. Between 1993 – 2003, releases for farming generally began in March and continued through September. Upstream of the dam, the river is largely unregulated, but small surface water diversions and groundwater pumping withdraw water for agriculture, mining, and municipal uses.

San Pedro River

The San Pedro River project area (30 km) began 5 km downstream of the town of Mammoth and ended at the confluence with the Gila River (Fig. 3-1). Elevation ranged from 585 - 680 m. The watershed, near the confluence, drains 11,533 km^2. The lower San Pedro River flows south to north with its headwaters in Mexico and is largely unregulated. Small water diversions and groundwater withdrawal for agricultural and mining occur along the river. In the last decade, conservation efforts have removed two large farms from production (Haney 2002), and the San Manuel Mine (15 km upstream of the project area) has reduced groundwater withdrawals.

Climate: Flooding and Drought

There are three main types of storms that cause floods in central Arizona: 1) winter and early spring Pacific systems; 2) summer monsoon floods caused by intense local rainfall from storms moving northward from the Gulf of California and Mexico; and, 3) late summer or fall storms due to Eastern pacific tropical storms (Huckleberry 1994). The latter has caused major flood events on the Gila River (Huckleberry 1994). In recent history, two large flood events occurred in these central Arizona rivers: October 1983 and January - February 1993.

Huckleberry (1994) described the 1993 flood as the most dramatic channel-widening event on the Gila River since 1905 (peak discharge within the project area was 2120 m^3s^{-1}). The flood destabilized bank and terrace vegetation, caused significant bank erosion and deposition, and produced channel avulsion. Wood (1997) reports similar occurrences (scouring and bank erosion) due to the 1993 flood on the lower San Pedro River. While the early 1990's were wet, the southwest experienced a severe drought during the latter part of the decade and during the study period (2001 – 2003), (http://www.drought.unl.edu/). Below average rainfall began in late 1999, and drought persisted throughout the study. Total rainfall was less than the long-term average for 22 of the 29 months of the study (May 2001 – August 2003).

METHODS

Floodplain Transects

Transect Selection.— I characterized the riparian plant community along 20 floodplain transects (10 per drainage), half of which intersected occupied willow flycatcher patches and half of which intersected unoccupied patches. All riparian floodplain forest potentially suitable for SWFL nesting was surveyed following a standardized protocol to locate occupied patches (Sogge et al. 1997, Smith et al. 2002,2003). Unoccupied patches were delineated for other project objectives (See Chapters 1 and 2). A patch was defined as a stand of trees with similar floristic and physiognomic characteristics, and with similar floodplain topography (see Chapter 1). This subset of patches was representative of the vegetation and hydrologic conditions along each river segment. Transects were placed perpendicular to the river, extended across the pioneer-riparian vegetation zone (generally dominated by cottonwood, willow, and tamarisk), and ended at higher terraces dominated by mesquite, upland plants, or agricultural lands. This zone is essentially similar to the floodplain zone, defined as the area that includes the active channel and surfaces deposited by the present flow regime (Graff 1988). The floodplain transects were surveyed using a laser transit to determine elevation and distance from channel thalweg to each patch (i.e., floodplain surface) (Harrelson et al. 1994).

Vegetation Measurements.— Along each transect, I visually delineated major vegetation patch types based on growth form, dominant plant species, dominant size class of trees, and fluvial surfaces. I recorded width of each patch and I measured dbh of 2 trees representing the most common age class. Patches were grouped into 6 main categories based on structure type, following Grossman et al. (1998): 1) grass-forb land; 2) shrubland (>25% canopy cover of <5 m tall trees or multistemmed shrubs); 3) woodland (25 - 60% canopy cover of >5 m tall trees); 4) forest (>60% cover of >5 m tall trees); 5) water/stream channel; and, 6) open (<25% vegetative cover). Forest and woodland patches were further categorized into 4 size/age classes using dbh measurements and size-age class regression described above: <5.5 cm (sapling), 5.5 - 15 cm (young), 15 – 25 cm (mature), >25 cm (old).

Transects were combined to estimate diversity of riparian plant community patch types for each river using the Shannon-Wiener diversity index (H') (Zar 1999). There were 37 different patches types, which I collapsed into 13 categories to calculate total diversity of patch types. I collapsed patch types into 6 and 11 categories to analyze floristic and structural diversity, respectively.

Hydrogeomorphic Sampling

Stage - Discharge Calculation.— I estimated stream discharge that would inundate each patch. I calculated stage-discharge relationships using the program WinXSPRO Channel analyzer (Grant et al. 1998); patch elevation, lateral distance to thalweg, channel slope, and an estimate of Mannings N (channel roughness) were inputs into the program. Slope was estimated using elevation contours from USGS 7.5 minute topographic maps. I followed the same methodology as Lite (2003) to estimate Mannings N values for each transect. Because transect placement was based on flycatcher occupancy, not all assumptions of the WinXSPRO model may have been met (e.g., uniform flow, constant channel geometry, and discontinuities in flow); similarly each lateral floodplain surface (patch) was assumed level and slope breaks were not recorded. However, model results (i.e., inundation frequency of each floodplain surface) were similar to Lite (2003), who conducted flow-modeling analyses on the lower San Pedro River, and to observed flooding events between 1995 – 2003.

Inundation Frequency.— I calculated patch inundation rates and percent of floodplain inundated between 1994 – 2003. Flow data input for the analysis depended on transect location. For San Pedro River transects, I used the stage-discharge relationship and flood return intervals (i.e., expected frequency of various flood magnitudes) obtained from Pope et al. (1998) and Lite (2003) based on a historic gage located on the lower San Pedro River near the town of Winkelman to determine number of years that each patch was expected to be inundated between 1994 - 2003. On the Gila River, 9 of 10 transects were located downstream of the San Pedro River confluence. For these transects, I used flow records from the Kelvin gage (Table 3-1). For the one transect located upstream of the confluence, I used the Coolidge Dam gage because it was not affected by San Pedro River inflows. For all calculations, I assumed that channel topography and vegetation community were similar throughout the period modeled (1994 – 2003). However, channel form might have changed in response to smaller floods (post-1993), and model output could be affected by change in distribution and abundance of vegetative growth in the floodplain over time. These changes can affect sediment deposition, fluvial surface height, and roughness coefficients, which can alter model output.

Surface Water Permanence.— I mapped presence of surface flow or standing water using GPS during the last week of June (which is typically the driest time of the year) along the entire San Pedro River study reach in 2001 - 2003. I measured distance of surface flow (perennial) and dry streambed (intermittent) using ArcView software (ESRI 2002). On the Gila River, because flows had been maintained by releases from Coolidge Dam I did not map stream permanence. However in 2002 – 2003, flow releases were reduced, and water was intermittent along the river in June and the extent of surface flow appeared to decline through summer in both years.

Groundwater Monitoring.— I installed 9 piezometers (shallow groundwater monitoring wells) and I used 7 existing piezometers (maintained by the Nature Conservancy) to monitor depth to groundwater (Fig. 3-1). On the San Pedro River, 5 were located within occupied patches and 7 near unoccupied patches. The distribution among rivers, between occupied and unoccupied patches, and among transects reflected landowner permission to install and monitor the wells. For each river, wells were combined to estimate variation in groundwater depth over time. Depth to groundwater at each patch was estimated along 10 floodplain transects that bisected an occupied or unoccupied patch that contained a well (4 on the Gila River, and 6 on the San Pedro River). Mean groundwater depth was calculated as the difference between the land surface and water elevation at the associated well. Wells were monitored monthly, generally read in the middle of the month, from summer 2001 through August 2003. Water table fluctuation was calculated as maximum change in depth between January - June during 2002 or 2003. Relationships between Gila River flows and groundwater depths were analyzed with Spearman rank order correlations, to determine if groundwater depth varied contemporaneously with stream flow rate. No analysis was completed on the lower San Pedro River due to the 40 km distance of the closest stream gage.

Stream Hydrograph Data.— I used stream flow records obtained from U.S. Geological Survey (USGS) website (http://waterdata.usgs.gov/az/nwis/rt) for five stream gages (Table 3-1) to estimate peak discharges and seasonal variation in the hydrograph. For the Gila River study area, I used the Kelvin gage located near the downstream end of the reach (Fig. 3-1). To examine the influence of the dam and its operation on the hydrograph, I compared flow records from the Calva gage located 36 km upstream of Coolidge Dam to the Kelvin gage. For the lower San Pedro River, I combined records of two gages near Redington located approximately 40 km upstream of the study reach (Table 3-1). While flood attenuation and tributary inputs may affect stream discharge in the study area, these gages represented the best available data to show overall trends in the hydrograph.

Statistical Analysis.— Patch type diversity was not statistically compared between rivers, because data were pooled across transects within rivers; but patch type abundance (Objective 1) and the hydrogeomorphic conditions among the three pioneer patches (Objective 2) were compared within and between rivers using Krusal-Wallace univariate tests. This nonparametric test, analogous to an ANOVA, was used to assess the statistical differences of hydrogeomorphic variables among the 3 pioneer forest patch types (i.e., cottonwood, willow, tamarisk) because sample size was low, and most variables had non-normal distributions. If differences were found, I conducted post-hoc analyses using Mann-Whitney U-tests to identify which forest patch types differed. I used the I compared graphs of abundance of each pioneer patch types within each basin to the patches used by the SWFL to assess if each was used greater than expected based on availability (Objective 3). All statistical analyses were conducted using SPSS 11.5. Unless otherwise noted values reported are mean ± 1 sd.

RESULTS

Vegetation Community

Gila River was dominated (66% of total floodplain) by tamarisk, whereas on the San Pedro River, tamarisk patches (30%) co-occurred with cottonwood (29%) and willow (7%) patches (Fig. 3-2). The Gila River had lower structural (i.e., growth form and size class) diversity (H' = 1.90) compared to the San Pedro River (H' = 2.08) and much lower floristic diversity (H' = 0.49) compared to the San Pedro River (H' = 1.36). Gila River vegetation structure and growth form was dominated by mature (23%) and young (23%) forest, shrubland (21%), and grass/forb land (11%). Sapling forest comprised (1%) of the floodplain, and no old forest patches were delineated. San Pedro River plant community had similar abundance of young forest (22%) and shrubland (21%) as the Gila River, but less mature forest (13%), and greater old (9%) and sapling (4%) forest.

SWFL Patch Selection

Of pioneer riparian forest available to flycatchers in each basin, 19% and 18% was occupied on the Gila and San Pedro rivers, respectively. On the Gila

River, SWFL nested predominantly within the most abundant forest type (tamarisk), whereas, on the San Pedro River, willow was used more frequently, tamarisk less frequently, and cottonwood as frequently as expected based on amount of available habitat (Fig. 3-3). Of the forest patches occupied on the Gila River, 44% and 43% were classified as young or mature forest, respectively, whereas on the San Pedro River, occupied habitat was distributed more equitably among age classes: 35% young, 27% old, 20% sapling, and 14% mature. Those patches characterized as mature or old had abundant large (>20 cm) cottonwood trees, but also had dense mid-story layers of willow or tamarisk.

Hydrology of the Free-flowing and Regulated Rivers

Surface Water Hydrology.— On the Gila River, flood magnitude and frequency recorded in the study area (Kelvin gage) has been reduced compared to unregulated flows upstream of Coolidge Dam (Fig. 3-4). Small to medium floods were diminished by as much as 70% between 1994 – 2003. The largest flood recorded at the Kelvin gage following the 1993 event was 558 m^3s^{-1} recorded in 1995. This same flood event above Coolidge Dam peaked at 1826 m^3s^{-1}. During the 1995 flood and the October 2000 flood (218 m^3s^{-1}) the gage at Coolidge Dam showed releases <1 m^3s^{-1} indicating storage of flood runoff in San Carlos Reservoir. The highest flow released from Coolidge dam between 1994 – 2003 was 113 m^3s^{-1}. Thus, peak flood flows between 1994 – 2003 recorded at the Kelvin gage were largely due to San Pedro River flow inputs into the Gila River.

While flood magnitude was diminished, irrigation releases (March - September) in 1994 – 1998 and 2001 (Fig. 3-5) increased monthly mean flow 3-fold on the Gila River ($\bar{x}$ = 22 m^3s^{-1} ± 9) within the study area compared to flow upstream of Coolidge Dam ($\bar{x}$ = 7 m^3s^{-1} ± 10). In 1999 - 2000 and 2002 - 2003 irrigation releases from Coolidge Dam were reduced ($\bar{x}$ = 5 m^3s^{-1} ± 6). However, March – June releases continued to be greater than inflow into San Carlos Lake until 2003 when releases were equal to inflow (1 - 2 m^3s^{-1}).

On the San Pedro River, the hydrograph followed a seasonal pattern of runoff. High flows were recorded in winter-spring, late summer (monsoon floods), and fall. Lowest flows occurred in June-July prior to monsoon storm runoff. Linear distance of surface flow in late June on the San Pedro River declined by 11.5 km between 2001 (18.5 km) and 2003 (7.0 km) (Appendix A). Stream segments near Aravaipa Creek and Malpais Hill along the San Pedro River appeared to be gaining reaches and consistently had surface flow. Stream segments near the upstream end (H&E), a middle portion (PZ Ranch), and an area in the last third (Indian Hills) of the study area were dry all three years.

On the San Pedro River, there was no difference between the total abundance of pioneer forest (45% ± 20, n = 4) measured at transects located within perennial reaches compared to forest (51% ± 19, n = 6) on intermittent reaches. Of all pioneer riparian forest, there was a trend of greater abundance of willow (12% ± 9) and tamarisk (20% ± 23) on perennial reaches compared to intermittent reaches (3% ± 6, 12% ± 11, willow and tamarisk forest respectively), but the differences were not statistically significant. Cottonwood forest abundance was similar between perennial and interrupted reaches, 20% ± 22 and 23% ± 21 respectively.

Floodplain Topography and Patch Inundation Rates.— Gila River had greater topographic relief over the lateral extent of the floodplain compared to the San Pedro River. The pioneer riparian patches ranged from 0.2 – 8.53 m above thalweg compared to the San Pedro River, which ranged from 0.26 - 3.91 m. Gila River mean patch elevation (2.63 m ± 1.92) was greater than San Pedro River patches (1.44 m ± 0.84). Gila River had a single thread low flow channel (Fig. 3-6a). Altered channel morphology and reduced flood flows caused less frequent overbank flooding on the Gila River compared to the San Pedro River (Fig. 3-7). The unregulated San Pedro River had a compound channel (i.e., one low flow meandering channel nested within a larger system of braided channels) (Fig. 3-6b); small flood events (<1-yr) produced flow in secondary channels and small portions of the floodplain (Figs. 3-6b, 3-7).

San Pedro River willow forest patches were at lower elevations, closer to the channel, and inundated by less stream flow than tamarisk and cottonwood forest patches, which were located at similar floodplain locations (Fig. 3-8). Gila River willow and cottonwood forest patches tended to be at similar positions on the floodplain, and were lower in elevation and inundated at less stream discharge than tamarisk forest patches. However, there was no difference in distance to stream channel among the three forest patch types.

Between rivers, there was no difference ($p > 0.1$) in hydrogeomorphic variables measured (distance to edge, elevation, or inundation discharge) at willow forest patches (Fig. 3-8). Cottonwood forest was located on higher floodplain surfaces on the Gila River ($p < 0.05$) than the San Pedro River, but distance to stream channel and inundation discharge did not differ. Tamarisk forest patches showed the greatest variation between rivers - both elevation and inundation discharge were higher on the Gila River than San Pedro river ($p < 0.01$). However, there was no between river difference ($p > 0.1$) in distance to stream channel.

Groundwater Depth and Fluctuation.— Groundwater levels followed a seasonal pattern on both rivers (Fig. 3-9). Water levels were shallow in January - April and deep in July - November on both rivers. Summer (July-August) water levels at all wells on the San Pedro River, except for one, declined over the study period. A similar pattern occurred on the Gila River; water levels declined over time at 3 wells, and one well showed no decline. Mean monthly water fluctuations did not differ between the Gila River (0.20 m ± 0.15) and the San Pedro River (0.15 m ± 0.18). Monthly water level readings were positively correlated to mean monthly surface flow records at 3 of the 4 wells on the Gila River (Table 3-2). No analysis was conducted on the San Pedro River due to a lack of stream gage records within study reach. On the Gila River, mean groundwater depth was shallower at willow forest patches than tamarisk. There were too few cottonwood forest patches to test groundwater depth differences among patch types, but it appeared that depths were similar to willow and shallower that tamarisk (Fig 3-8). On the San Pedro River, willow forest had significantly shallower groundwater depths than cottonwood or tamarisk.

DISCUSSION

SWFL Habitat Selection

Basin-level variation in hydrological conditions between the Gila and San Pedro rivers resulted in distinct differences in vegetation floristic and structural characteristics across the landscape. Despite this contrast, SWFL nested on both rivers, but on San Pedro River SWFL seemed to select willow forest greater than expected based on its availability. On the Gila River, hydrological alterations favored establishment of tamarisk over cottonwood and willow; SWFL could be fully utilizing the small amount of C-W habitat, but due to small sample size it was not possible to accurately determine whether preferential selection was occurring.

This was the first study to examine SWFL plant species preferences at a coarse (drainage) scale, and our results differ from some of those conducted at smaller spatial scales. In contrast to the findings for the San Pedro River, Sogge (2000) and Stoleson and Finch (2003) reported SWFL selecting against willow for nest placement when other tree species (e.g., tamarisk and box elder) were present. However, Allison et al. (2003) found that SWFL were more likely to use areas within a patch that contained willow trees than those that did not. Similar scale-dependent habitat affinities have been described for other bird species, with patterns at coarse (e.g., basin) scales often reflecting preferences for broad vegetation community types or vegetation structure relationships rather than preference or avoidance of individual tree species (Bergin 1992, Powell and Steidl 2002, Pidgeon et al. 2003). More research is needed on other drainages in the SWFL's range at the patch and nest-site scale to determine whether there are robust scale-dependent patterns.

River Basin Considerations

Interaction of surface and groundwater hydrology and channel morphology has influenced the riparian plant community and available SWFL nesting habitat on each river. Gila River was dominated by tamarisk forest, with low structural and species diversity compared to the San Pedro River, a pattern similar to other regulated and unregulated systems (Merrit and Cooper 2000, Sher et al. 2000, Scott et al. 2003). Lite et al. (*in press*) suggested that greater patch type diversity and abundance is related to increased water availability (surface and groundwater) and flood disturbance.

Floods and Fluvial Processes.— Structural diversity can be high in the riparian landscape if there are an abundance of growth forms present (e.g., patches vegetated by shubs and by trees) or if there are an abundance of tree age classes present. High structural diversity on the San Pedro River thus partly reflects high frequency of recruitment of pioneer riparian trees; Stromberg (1998a) estimated that the floods that enable cottonwood-willow recruitment events on the San Pedro River have occurred on average once every 5 years in the last 36 years. A high degree of spatial diversity in the landscape can translate into temporal habitat continuity for birds such as SWFL that select for particular size or age classes of trees. Thus, young stands of willow or tamarisk have been available to and used by SWFL for nesting over the long-term on the San Pedro River (see Phillips 1948, Unitt 1987, Paradzick and Woodward 2003).

Low structural diversity on the Gila River likely reflects the interruption of fluvial processes by flow alteration, with plant recruitment now restricted to only those years or periods following large flood events. In addition, in systems managed for agricultural releases, floodplain surfaces available for plant colonization are often at low elevation and can be subsequently eroded or inundated, thereby destroying new germinants (Cooper et al. 1999) and limiting the creation of pioneer forest patches. Thus, SWFL nesting habitat on the Gila River may be available on more of a boom-and–bust cycle compared to more continual availability on the San Pedro River.

In arid-land river systems, moderate to large floods remove and deposit sediment, alter channel location and form, and scour and remove vegetation, which provides areas for riparian plant colonization (Hughes 1994). Following the large scouring flood event in 1993 (Huckleberry 1994), small floods were captured in the reservoir and summer base-flows were increased for irrigation on the Gila River. Higher base-flows tend to expand the low-flow channel, and change a braided or compound system to a single thread meandering river following expansion of riparian forest and loss of disturbance (Williams and

Wolman 1984, Graff 1988, Stromberg 1993b, Graf et al. 2002, Shafroth et al. 2002), similar to the channel pattern observed on the Gila River, but not the free-flowing San Pedro River. In the short-term these changes caused reduced over-bank flooding and patch disturbance, which could directly influence within-patch environmental conditions (e.g., soil moisture, humidity, predator density). But over the long-term, interruption of hydrological processes could alter the riparian community, and could limit the temporal availability of suitable SWFL nesting habitat.

Surface Flows.— Timing and rate of irrigation flow recession also can influence cottonwood-willow patch development. Flows that recede in late summer-early fall and decline at a greater rate than the natural hydrograph can favor establishment of tamarisk over cottonwood and willow due to plant phenological (seed dispersal timing) and morphological differences (Mahoney and Rood 1998, Shafroth et al. 2000). In low elevations of Arizona, cottonwood and willow produce seed between late February - April, and March - June, respectively, whereas, tamarisk produces seed mid-March - October (Warren and Turner 1975, Shafroth et al. 1998). Natural flow conditions on the San Pedro River would have exposed wetted soil in spring, and again in late summer following monsoon storms, compared to irrigation reductions in early fall on the Gila River (Fig. 3-5). Such differences could have contributed to the dominance of tamarisk on the Gila River, and a co-dominant community on the San Pedro River.

Groundwater.— Lite and Stromberg (*in press*) developed a hydrologic threshold model using stream flow permanence, depth to groundwater, and groundwater fluctuation for sites along the San Pedro River to predict riparian plant community shifts from cottonwood-willow, to co-dominance, to tamarisk dominated. At the patches I examined on the San Pedro River, the hydrological parameters were within their thresholds for co-dominance of cottonwood, willow, and tamarisk, supporting their model. At the Gila River, the deeper groundwater conditions at the Gila River may favor the dominance of tamarisk.

Groundwater depth and decline rate can affect within-patch conditions by causing tree stress and mortality, and can affect patch development by influencing seedling survivorship. During early life stages sharp water table declines could favor tamarisk over cottonwood and willow (Mahoney and Rood 1998, Scott et al. 1999, Shafroth et al. 2000). Impacts to young and adult riparian pioneer trees can be exacerbated during rapid water table declines due to lateral rather than vertical root growth during long periods of high stable water levels (Shafroth et al. 2000). Rapid declines in stream or groundwater during the growing season can cause reduced foliage density and crown dieback and mortality (Busch and Smith 1995, Cleverly et al. 1997, Smith et al. 1998, Scott et al. 1999, Horton and Clark 2001, Horton et al. 2001a,b) altering breeding habitat quality. However, established tamarisk patches might be less affected by flow reduction and declines in groundwater tables than cottonwood-willow patches due to their ability to draw water from the unsaturated soil zone (Busch and Smith 1995, Devitt et al. 1997, Shafroth et al. 2000).

I found no difference between monthly rates of groundwater decline between the Gila and San Pedro rivers during two years of measurement, but these results may not be representative of longer-term conditions. Patterns of groundwater fluctuation should be measured under a broader range of managed flow conditions, such as during irrigation releases, to better document impacts of flow regulation on SWFL nesting habitat.

Salinity.— Shifts from cottonwood-willow to tamarisk forest could be in part due to tamarisk's higher tolerance for saline soils (Busch and Smith 1995, Walker and Smith 1997, Smith et al. 1998, Vandersande et al. 2001, Schmidt 2003). However, recent research has suggested that salinity concentration due to tamarisk exudation of salt could be mediated by frequent floodplain inundation (Bagstad et. al. *in press*). Thus, on the Gila River low frequency of floodplain inundation coupled with high tamarisk abundance might have elevated salt concentrations and in turn further limited cottonwood-willow germination and survival contributing to shifts in plant species composition.

Livestock Grazing.— While fluvial processes can greatly influence riparian plant communities in the southwest, livestock grazing can also impact plant community structure and floristic composition. Direct affects of over utilization by livestock and other large ungulates can alter streambank stability and channel morphology, cause declines in plant cover and biomass, simplify or reduce foliage diversity and volume, and cause shifts in plant community composition (Rickard and Cushing 1982, Reichenbacher 1984, Belsky et al. 1999, Robertson and Rowling 2000, Baker et al. 2005). These vegetative changes have been linked to lower avian abundance and species diversity (Taylor 1982, Krueper et al. 2003, Scott et al. 2003). Similarly, reductions in foliage volume can decrease cover from predators, which may cause higher predation rates lowering nesting success and reproductive output (Ammon and Stacey 1997). Reaches of the San Pedro and Gila rivers were grazed during the study or the recent past (< 5 yrs), which probably influenced vegetative traits of SWFL occupied and unoccupied patches. Some research suggests that properly managed livestock grazing do not directly reduce SWFL nesting success or reproductive output (Stoleson and Finch 2001), but no research has been conducted on long-term affects of grazing to SWFL nesting habitat availability due to changes in riparian plant community floristic composition or patch structure as described above.

Linking Basin and Local Scale Hydrogeomorphic Conditions

Studies of SWFL habitat selection patterns across multiple spatial scales identified key structural and floristic vegetation characteristics and floodplain features (Hatten and Paradzick 2003, Allison et al. 2003). These habitat features are shaped by hydrogeomorphic processes and conditions at both basin and local scales (Bendix 1994, Dixon et al. 2002, Cooper et al. 2003) but in general basin scale geology and fluvial conditions act to constrain local environmental conditions (Ward et al. 2001).

Hatten and Paradzick (2003) noted that breeding sites tended to be spatial autocorrelated (i.e, clumped). This pattern may reflect variation in floodplain hydrogeomorphic conditions. Hatten and Paradzick (2003) found that SWFL were associated with broad floodplains at coarse spatial scales (>40 ha), which they hypothesized allowed growth of dense wide stands of forest compared to narrow canyon bound reaches. Lite et al. (*in press*) studied vegetation patterns over most of the San Pedro River (from Mexican border to Gila River confluence, 180 km) and found that density of young trees increased at downstream sites as a function of site elevation and flood disturbance. Similarly, Lite and Stromberg (*in press*) correlated plant community shifts from forest to woodland and shrubland to declines in water table depths and stream surface flow permanence. These data coupled with findings that occupied patches and greater abundance of tamarisk and willow forest tended to be associated with perennial reaches, suggest that fluvial geomorphic conditions limit the spatial distribution and abundance of available SWFL breeding habitat along rivers over broad-scales.

Within these forested reaches, SWFL habitat is further constrained by slight variations in floodplain topography and water availability that influence patch-scale vegetation structure and floristic characteristics (Lite et al. *in press*, Chapter 2). High foliage density preferred by SWFL was correlated to high water tables and occupied patches tended to have higher inundation rates than unoccupied patches, which caused higher flood disturbance frequency and may have improved within-patch soil moisture conditions for nesting birds (Chapter 2). Additionally, occupied patches were associated with surface water, which could reflect improved vegetative conditions (higher foliage density) or greater local insect abundance increasing reproductive success. Allison et al. (2003) found within-patch vegetative differences in nest locations compared to random sites. Generally, nest sites had higher abundance of young stems, were closer to water, and had greater canopy cover directly over the nest but were also closer to canopy openings than nonuse sites. These within-patch variations could be associated with fine-scale differences in hydrogeomorphic conditions. For example, small within-patch topography differences, which may influence water availability, could lead to spatially uneven tree distributions, resulting in areas with higher stem densities more suitable for SWFL nesting sites. While we now have a solid understanding of relationships between hydrogeomorphic conditions and SWFL breeding habitat suitability across spatial scales, more research is needed to test these findings on other rivers in the region and also to link hydrogeomorphic conditions to breeding habitat availability across temporal scales.

MANAGEMENT IMPLICATIONS

Land and water management differences between the San Pedro River and Gila River serve as an example of anthropogenic influence on riparian plant community and SWFL nesting habitat. Along the San Pedro River, the free-flowing nature of the stream, and conservation efforts to reduce groundwater pumping and limit livestock grazing, has maintained an abundant cottonwood-wilow forest plant community with high floristic and structural diversity, which supports a great number of bird species, including SWFL and other sensitive species (e.g., yellow-billed cuckoo). On the Gila River, regulated flow for agricultural use has reduced habitat diversity, but SWFL have been documented successfully nesting along the river since surveys began in 1995 (Paradzick and Woodward 2003). While little data exists concerning the abundance and distribution of SWFL on the Gila River prior to 1995, suitable nesting habitat has probably fluctuated in response to large disturbance events (e.g., 1993). Because of the rivers proximity to the lower San Pedro River, a stronghold for the species since they were first described in 1940 (Phillips 1948), SWFL have probably used Gila River habitat when it is available. The recent trend for declining SWFL abundance on the Gila River speaks to the high temporal variability in riverine forest habitat suitability for SWFL, and the trend highlights the importance of ecological processes (i.e, flood disturbance) and floodplain conditions (i.e., elevated groundwater table) to create and sustain suitable nesting habitat.

Many western state water managers face similar issues with SWFL and other riparian or aquatic species that have been impacted by dam operations and groundwater withdrawal (Briggs 1991, Rood et al. 2003, Stromberg et al. 2004). In some cases, impacts to species result in water operations being dictated by the Endangered Species Act (Stromberg et al. 2004). Developing riparian conservation strategies can be complex, and managers must consider the environmental, political, and social constraints of the system (Wissmar and Beschta 1998). However, opportunities exist to find cooperative solutions to provide society with much needed water and allow for conservation of habitat (Levine and Stromberg 2001, Stromberg 2001). There has been a recent interest by riparian ecologists to model vegetation responses to alternative flow regimes (Auble et al. 1994, Richter et al. 1998, Richter and Richter 2000, Pettit et al. 2001, Ward et al. 2001). For example, on the Rio Grande River, ecologists teamed with water managers to stimulate natural recruitment of riparian vegetation (Taylor et al. 1999). Managers cleared tamarisk to provide bare-soil sites and reshaped floodplain terraces, which allowed a dam-released flood pulse to produce overbank flooding and encouraged plant establishment. On the Gila River, within the study area, managers could evaluate the potential for similar restoration efforts: water could be made available from San Carlos Lake for periodic flooding, cottonwood-willow seed sources are available, and the San Pedro River provides smaller and more frequent flood pulses and delivers sediment to the system (see Sher et al. 2000, Sher and Marshall 2003). Such action would be inline with the SWFL Recovery Plan (USFWS 2002), which recommends, as the highest priority, to protect existing occupied habitat and restore habitat near extant populations.

In some cases, societal needs may constrain our ability to adjust flow regimes for ecosystem purposes. Without flushing flows or suitable groundwater regimes conservation of native riparian habitat is difficult or in some cases not sustainable without ongoing maintenance (Anderson 1998, Barrows 1998). There has been much effort under way in the west to remove tamarisk and restore native communities (http://www.tamariskcoalition.org/index.html) and some projects are directed at SWFL (DeLoach et al. 2000). However, many of the efforts might fail in the long-term because underlying environmental stressors that limit recruitment of native plants have not been addressed (Briggs et al. 1994, Stromberg et al. *in review*). If the goal of a restoration project is to provide habitat for the SWFL, I suggest first examining the site from a watershed perspective to determine large-scale influences on vegetation (e.g., flow alteration, sediment inputs), and second, identify local environmental parameters (e.g., groundwater depth, salinity levels, grazing pressures) at the site to determine if suitable nesting habitat can be sustained.

Where stressors cannot be alleviated, and where long-term costs for maintenance of native habitat are cost prohibitive, tamarisk could be used solely or in combination with planted native species, to provide functional SWFL nesting habitat. Use of exotic species for restoration or conservation purposes is not a novel concept (Ewel and Putz 2004). Similarly, others have explored the functional role tamarisk can play in the riparian plant community (Stromberg 1998b), and its use as habitat for a number of species (Ellis 1995, Fleishman et al. 2003). One could use SWFL habitat needs and the corresponding hydrogeomorphic conditions provided here as a starting point to assess baseline vegetation conditions, and structure restoration activities to target appropriate environmental constraints.

Table 3-1. San Pedro River and Gila River USGS stream gage descriptions.

Gage	Gage Number	River	Location
Redington	09472000 09472050	San Pedro	40 km upstream from study area
Kelvin	09474000	Gila	Downstream end of study area
Coolidge Dam	09469500	Gila	At dam 35 km upstream from study area
Calva	09466500	Gila	36 km upstream of Coolidge Dam

Table 3-2. Correlation (Spearman's rho) between monthly groundwater levels recorded May 2001 – September 2003 and mean monthly flow recorded at the Kelvin stream gage on the Gila River, Arizona.

Well Location	Number of months (n)	Correlation coefficient	P value
Kearny	29	0.73	0.00
GS12	26	0.71	0.00
CAMP	26	0.61	0.00
GS23	26	0.27	0.19
Sites combined	29	0.44	0.02

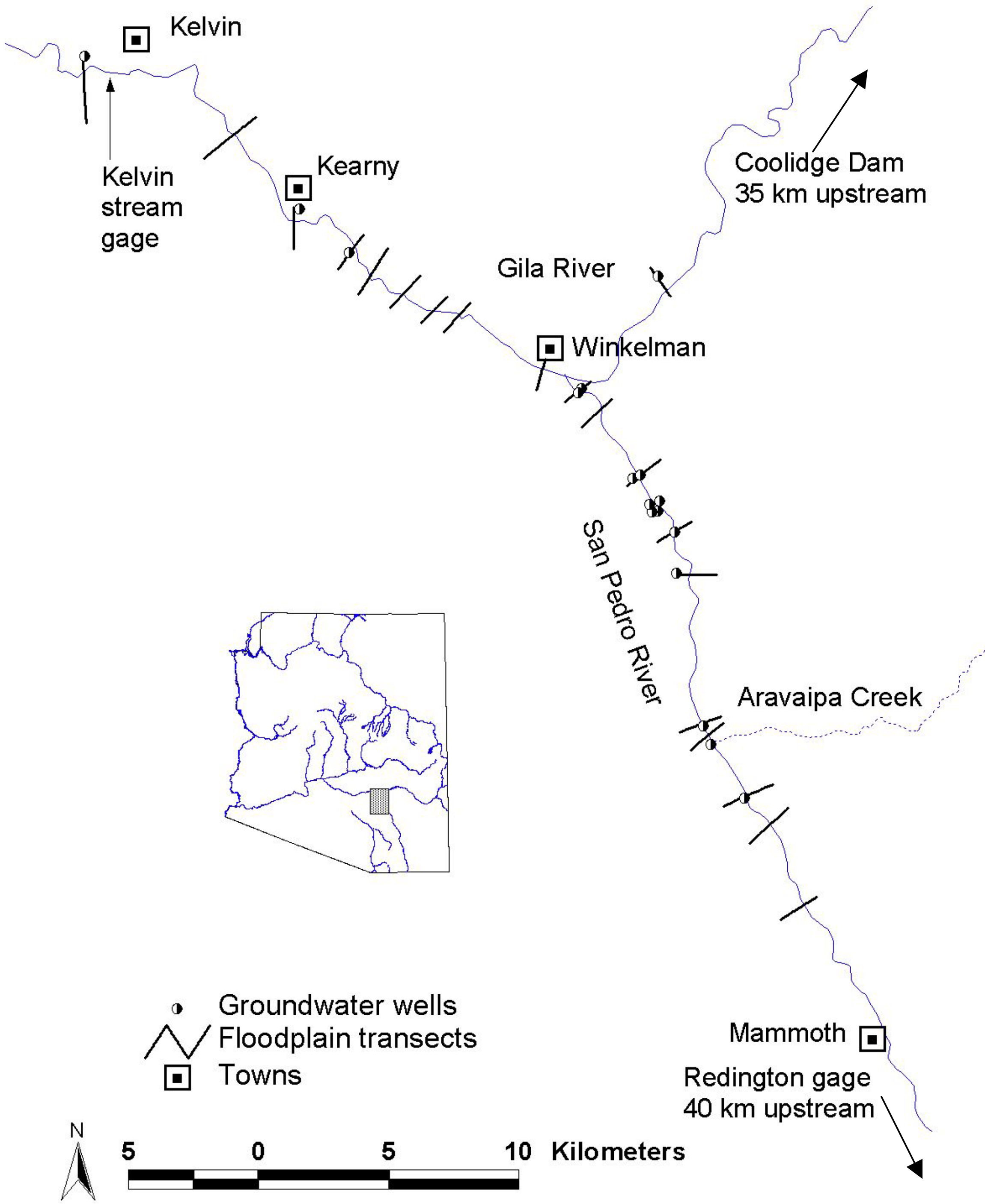


Fig. 3-1. Map of project area showing Gila River and lower San Pedro River confluence, groundwater well locations, and floodplain transect locations in southeastern Arizona (transect lengths are not to scale).

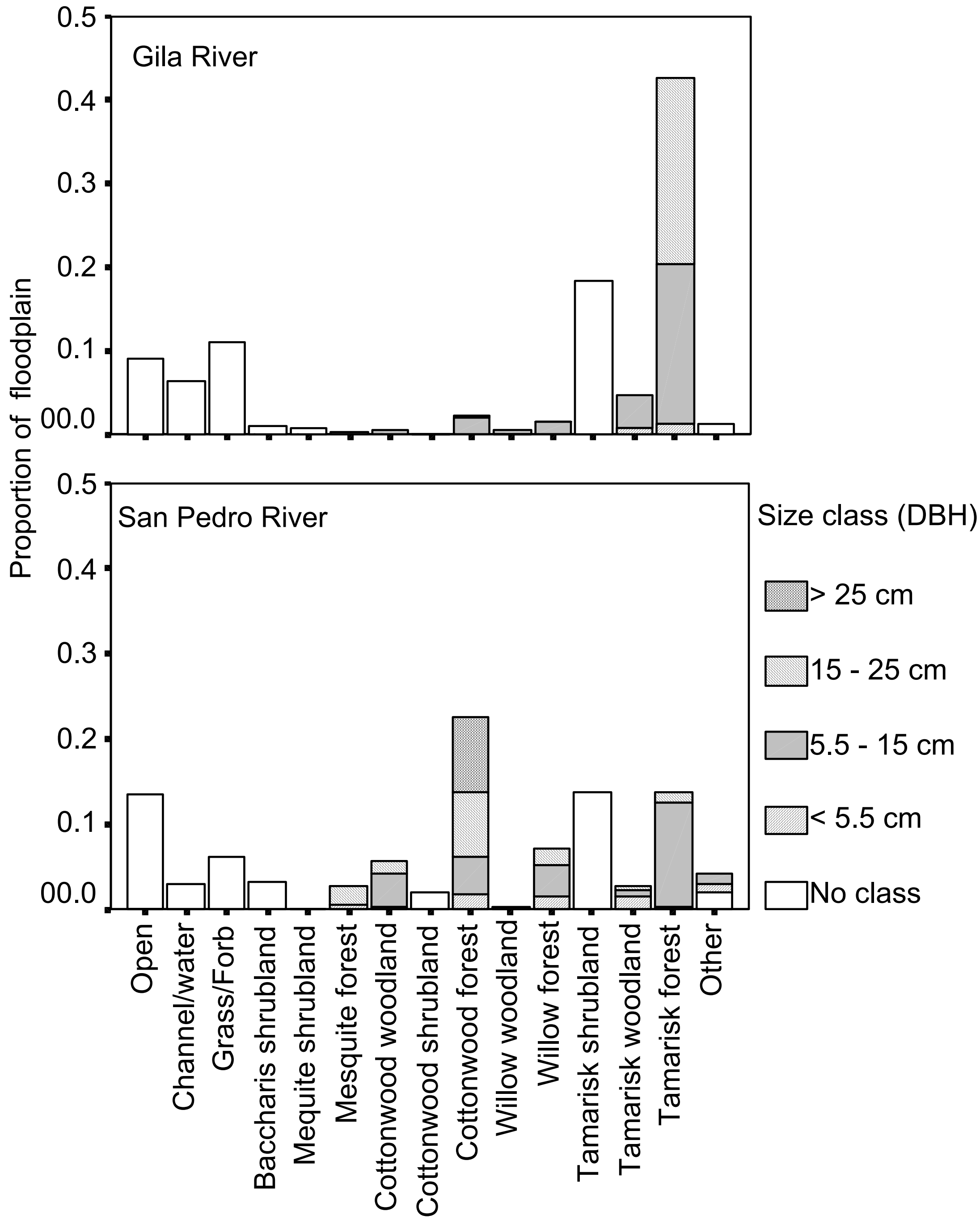


Fig. 3-2. Vegetation community composition and structure on the Gila and lower San Pedro rivers based on 10 floodplain cross-sections on each river, 2002.

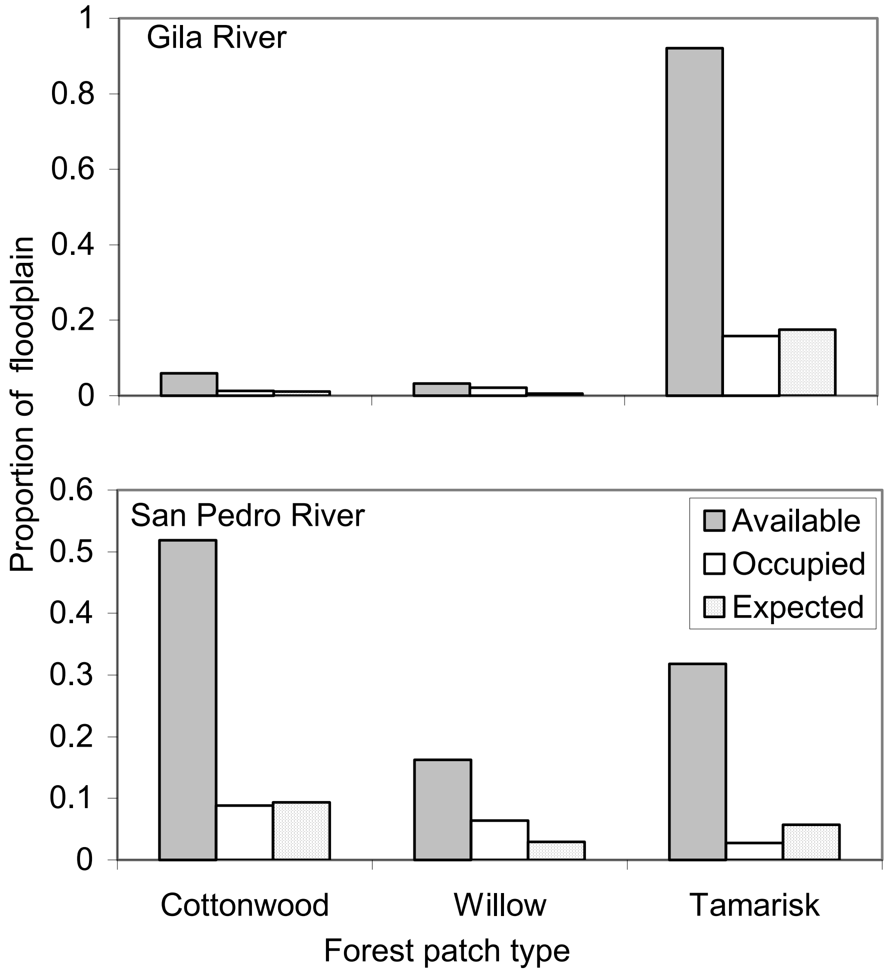


Fig. 3-3. Proportion of floodplain available by forest patch type, proportion occupied by willow flycatchers, and the proportion expected to be occupied on the Gila and lower San Pedro rivers, 2001-2002.

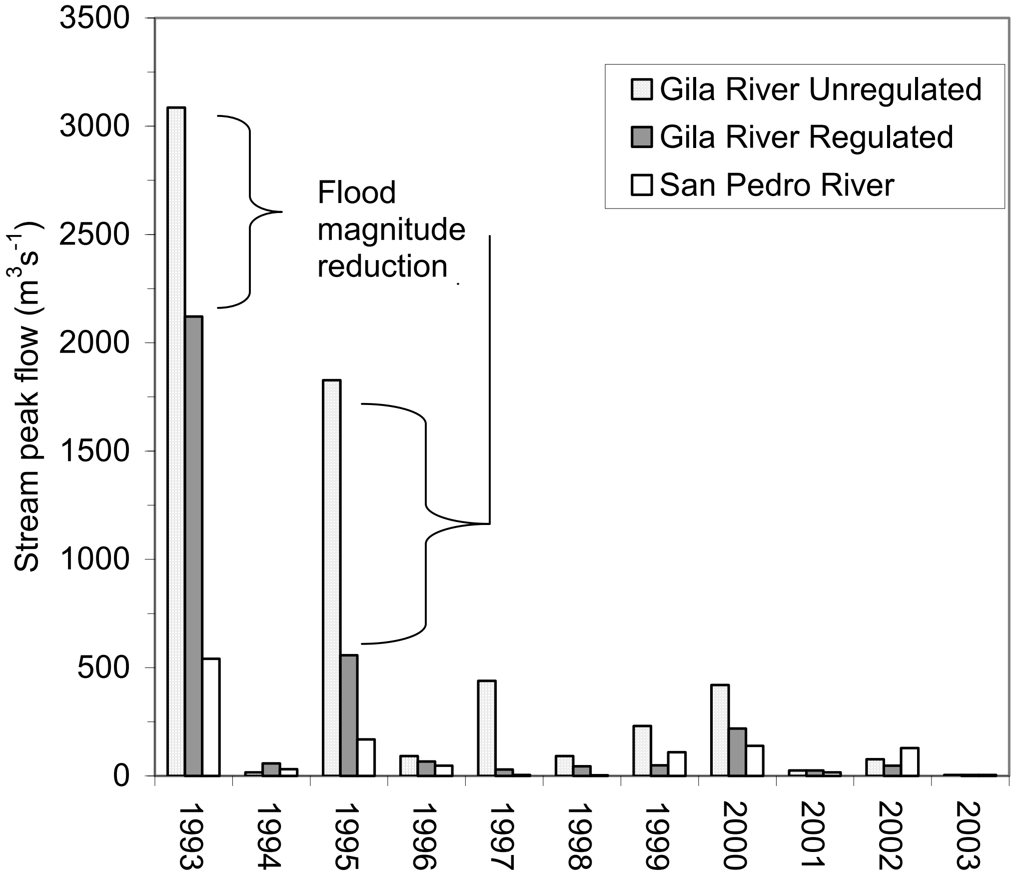


Fig. 3-4. Annual peak flows for the regulated portion of the Gila River study area 35 km downstream of Coolidge Dam (data recorded at USGS Kelvin stream gage), the unregulated reach of the Gila River recorded 36 km upstream of the Dam (USGS Calva stream gage). and the unregulated San Pedro 40 km upstream of the study area (USGS Redington stream gages).

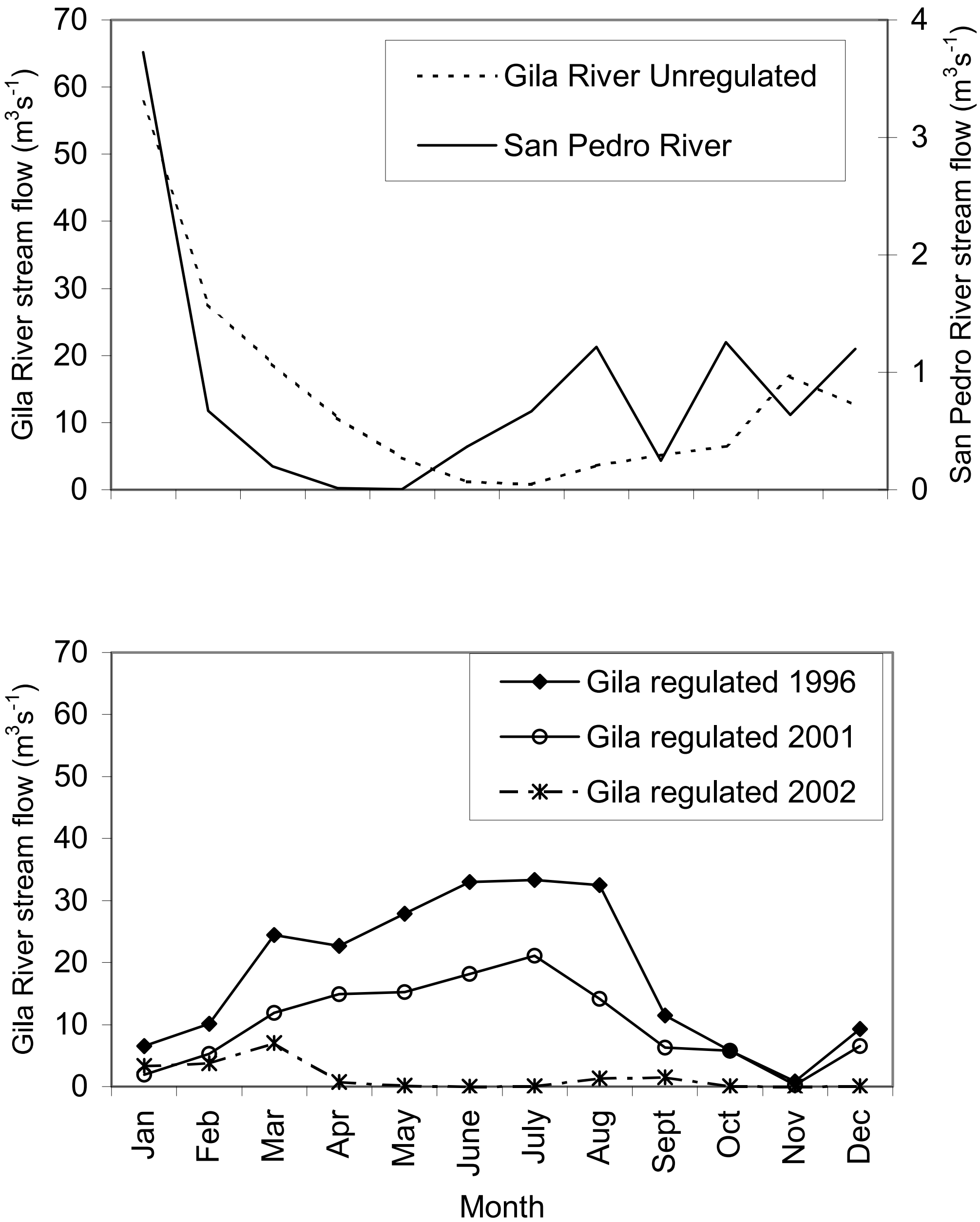


Fig. 3-5. Top graph shows mean monthly flow from 1993 – 2003 on the unregulated portion of the Gila River upstream of Coolidge Dam (Calva gage), and San Pedro River (secondary y-axis) measured at the Redington gage. Bottom graph shows regulated flows for selected years downstream of Coolidge Dam on the Gila River measured at the Kelvin gage.

Fig. 3-6 (following 2 pages). Surveyed cross-sections for two Gila River transects (a) and two San Pedro River transects (b) showing vegetation patches and modeled river stages for selected floods recorded on the Gila River and selected return interval flows on the San Pedro River (see Fig 6 for return interval discharges). Bold horizontal lines with square symbols indicate location of SWFL occupied patch. X and Y axes are, respectively, distance and elevation in meters.

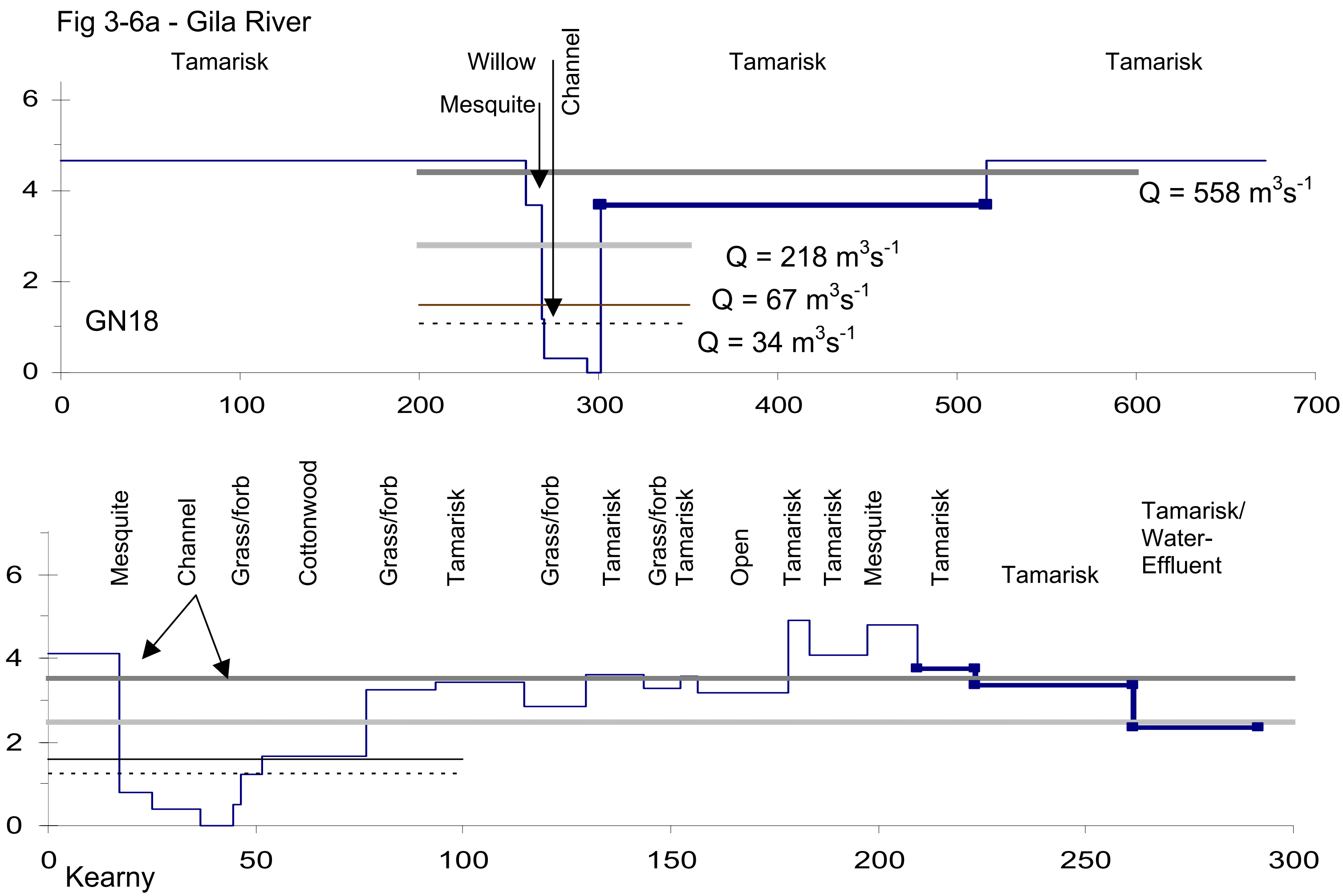
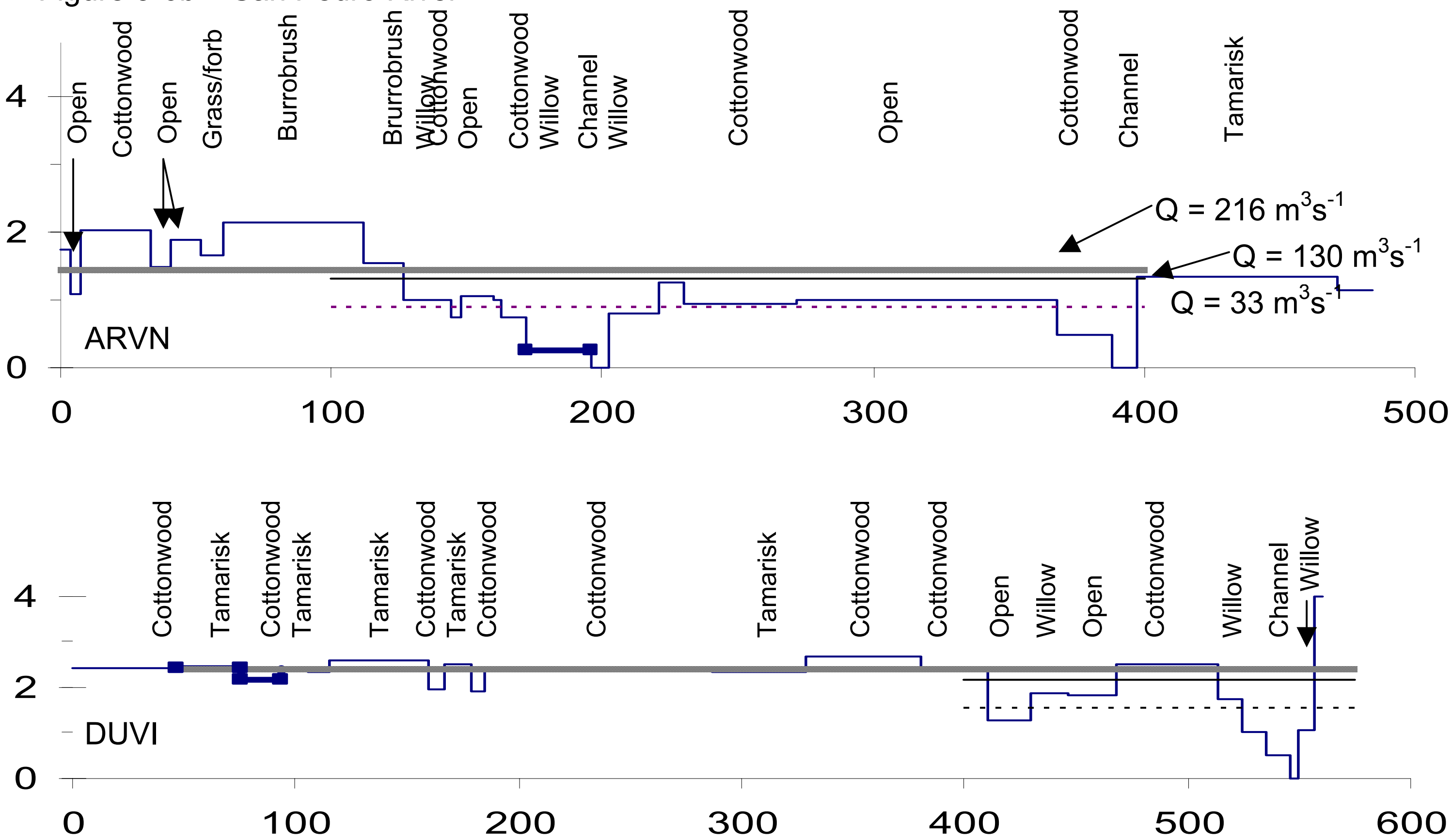


Fig 3-6a - Gila River
Tamarisk
Willow
Mesquite
Channel
Tamarisk
Tamarisk
6
4
2
0
GN18
Q = 558 m^{3}s^{-1}
Q = 218 m^{3}s^{-1}
Q = 67 m^{3}s^{-1}
Q = 34 m^{3}s^{-1}
0
100
200
300
400
500
600
700
Mesquite
Channel
Grass/forb
Cottonwood
Grass/forb
Tamarisk
Grass/forb
Tamarisk
Grass/forb
Tamarisk
Open
Tamarisk
Tamarisk
Mesquite
Tamarisk
Tamarisk
Tamarisk/
Water-
Effluent
6
4
2
0
0
Kearny
50
100
150
200
250
300

Figure 3-6b – San Pedro River



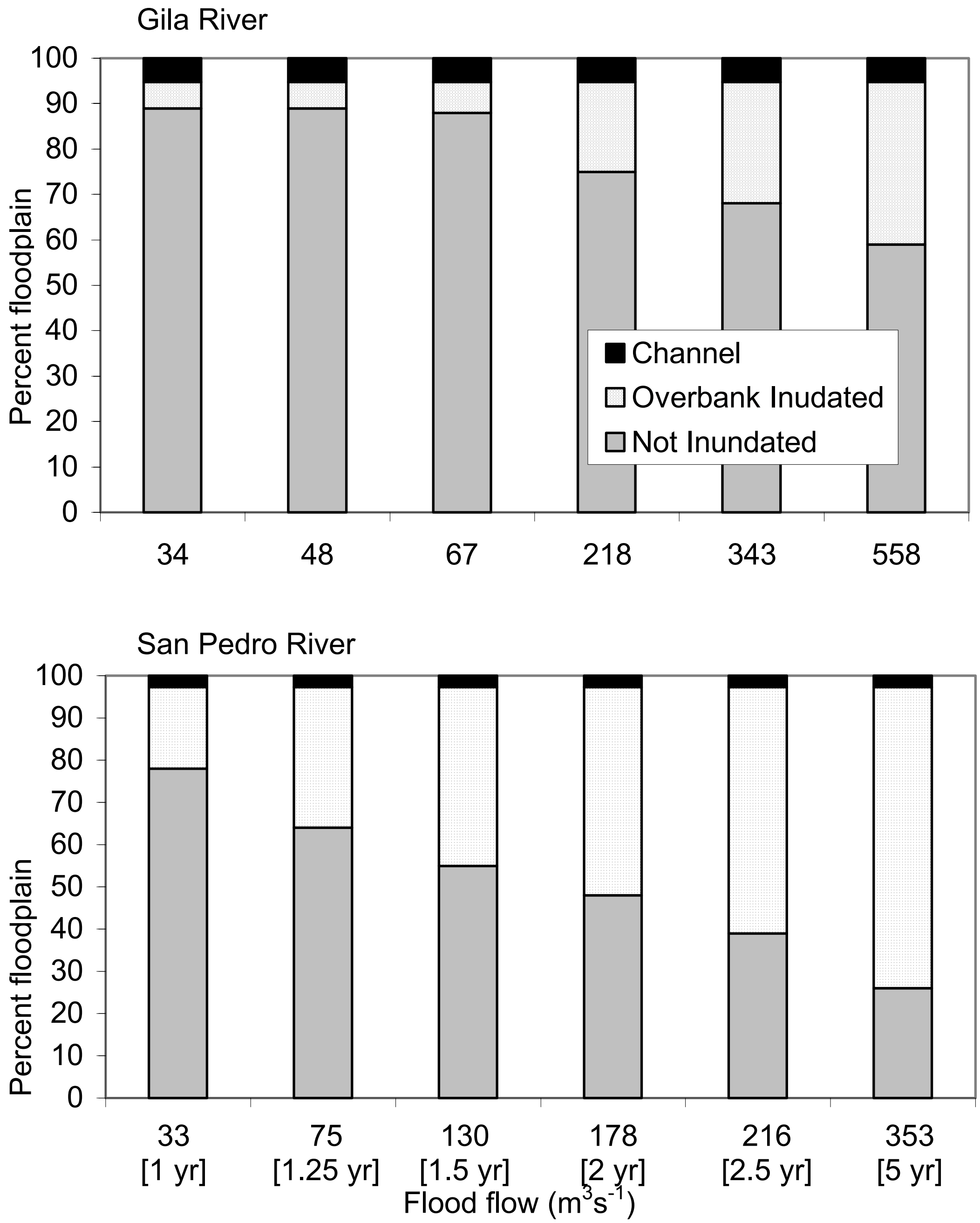
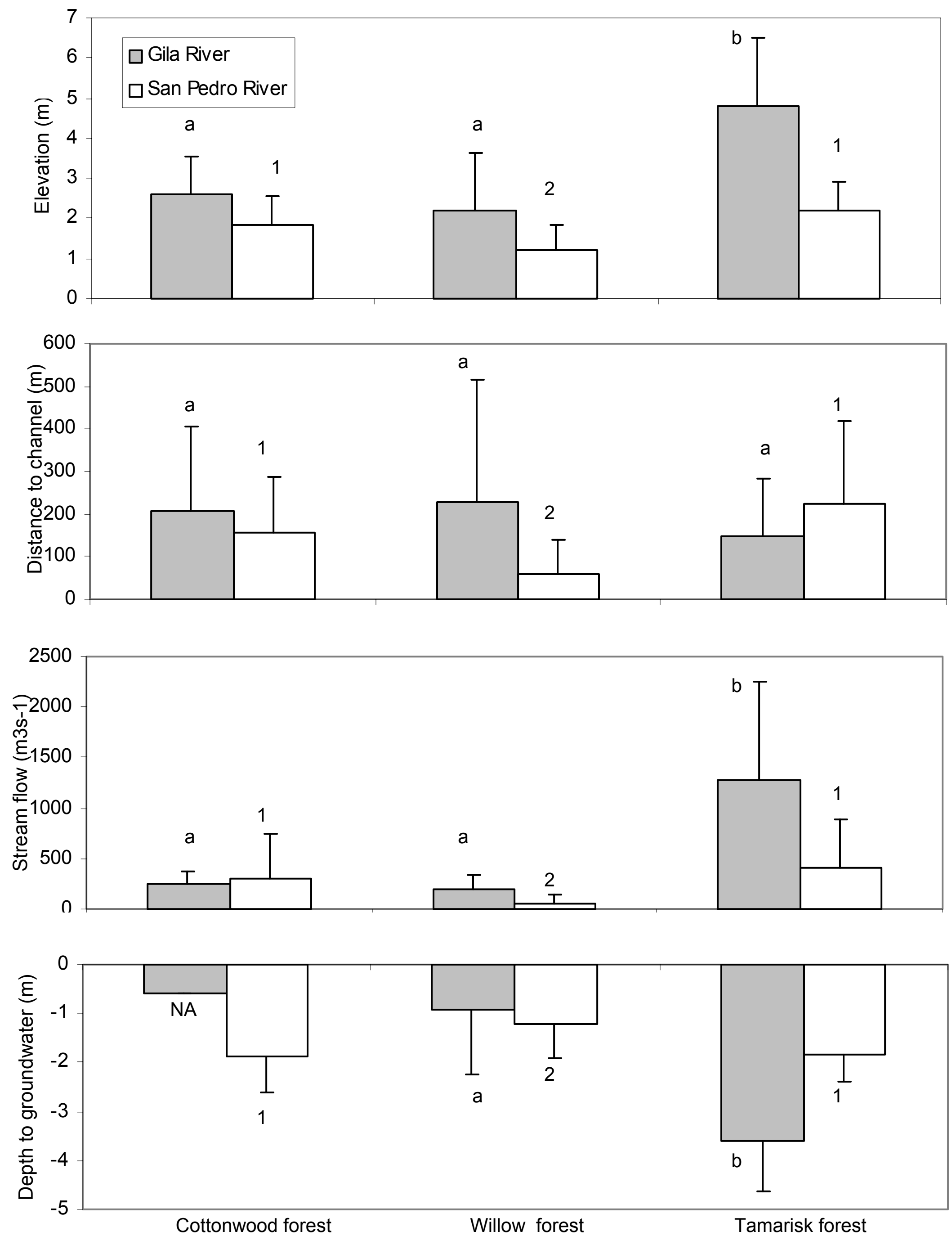


Fig. 3-7. Percent floodplain-channel complex inundated based on range of peak flow records for the Gila River between 1994 – 2003, and discharge for specific flood return intervals (noted within brackets) on the San Pedro River, Arizona.

Fig. 3-8 (following page). Distance to channel, floodplain elevation, patch-inundation discharge, and depth to groundwater for cottonwood, willow, and tamarisk forest on the Gila and lower San Pedro rivers. Letters represent differences ($p < 0.05$) among forest patch types on the Gila River (similar letters indicate no difference). Numbers represent lower San Pedro River patch differences. (NA = too few samples to calculate statistic).


Gila River
San Pedro River
Elevation (m)
Distance to channel (m)
Stream flow (m3s-1)
Depth to groundwater (m)
NA
Cottonwood forest
Willow forest
Tamarisk forest

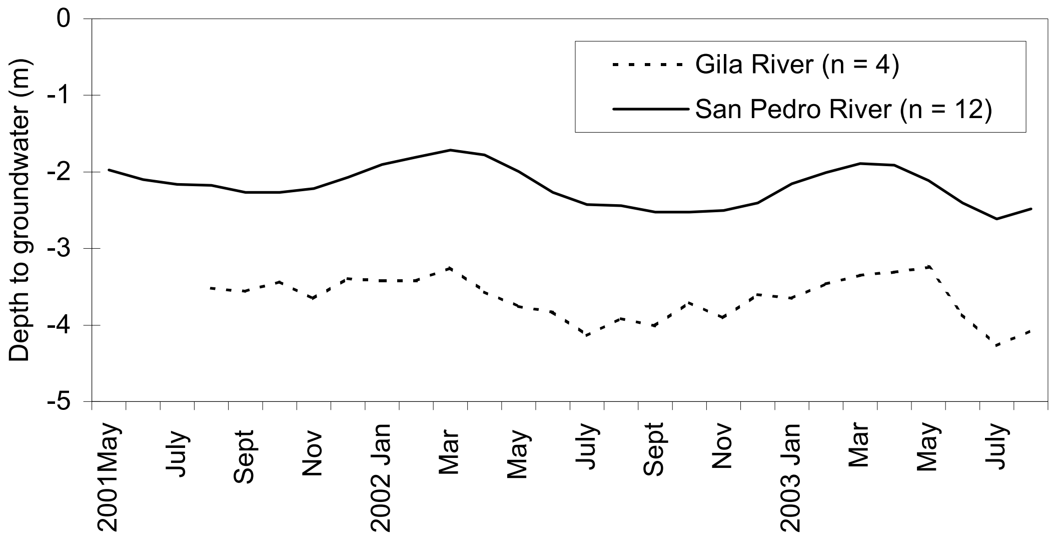


Fig. 3-9. Depth to groundwater measured at wells located on the lower San Pedro River and Gila River between May 2001 – August 2003.

LITERATURE CITED

Allison, L.J., C.E. Paradzick, J.W. Rourke, and T.D. McCarthey. 2003. A characterization of nesting and non-nesting plots for southwestern willow flycatchers in central Arizona. Studies in Avian Biology 26:81-89.

Ammon, E.M. and P.B. Stacey. 1997. Avian nest success in relation to past grazing regimes in a montane riparian system. Condor 99:7-11.

Anderson, B. 1998. The debate over tamarisk: the case for salt cedar. Restoration and Management Notes 16:130-134.

Auble, G.T., J.M. Friedman, and M.L. Scott. 1994. Relating riparian vegetation to present and future stream flows. Ecological Applications 4:544-554.

Baker, B.W., H.C. Ducharme, D.C.S. Mitchell, T.R. Stanley, and H.R. Peinett. 2005. Interaction of beaver and elk herbivory reduces standing crop of willow. Ecological Applications 15:110-118.

Bagstad, K.J., S.J. Lite, and J.C. Stromberg. *In press*. Vegetation and hydro-geomorphology of riparian patch types of a dryland river. Western North American Naturalist.

Barrows, C. 1998. The debate over tamarisk: the case for wholesale removal. Restoration and Management Notes 16:135-1139.

Belsky, A.J., A. Matzke, and S. Uselman. 1999. Survey of livestock influences on stream and riparian ecosystems in the western United States. Journal of Soil and Water Conservation 54: 419-431.

Bendix, J. 1994. Scale, direction, and pattern in riparian vegetation-environment relationships. Annals of the Association of American Geographers 84:652-665.

Bergin, T.M. 1992. Habitat selection by the western kingbird in western Nebraska: a hierarchical analysis. Condor 94:903-911.

Briggs, M. 1991. Riparian ecosystem restoration in arid lands. Univ. of Arizona Press. Tucson, Arizona, USA.

Briggs, M.K., B.A. Roundy, and W.W. Shaw. 1994. Trial and error: assessing the effectiveness of riparian revegetation in Arizona. Restoration and Manangement Notes 12:160-167.

Brock, J.H. 1994. *Tamarix* spp. (salt cedar) an invasive exotic woody plant in arid and semi-arid riparian habitats of Western USA. Pages 27-44 *in* L.C. de Waal, L.E. Child, P.M. Wade, and J.H. Brock, editors, Ecology and management of invasive riverside plants. John Wiley and Sons Ltd., West Sussex, England.

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

Cleverly, D.J., D.M. Merritt, D.C. Andersen, and R.A. Chimner. 1997. Invasive capacity of *Tamarix ramosissima* in a Mohvae Desert floodplain: the role of drought. Oecologia 11:12-18.

Cooper, D.J., D.C. Anderson, and R.A. Chimner. 2003. Multiple pathways for woody plant establishment on floodplains at local to regional scales. Journal of Ecology 91:182-196.

_____, D.M. Merritt, D.C. Andersen, and R.A. Chimner. 1999. Factors controlling the establishment of Fremont cottonwood seedlings on the upper Green River, USA. Regulated Rivers: Research and Management 15:419-440.

Crins, W.J. 1989. The Tamaricaceae in the southwestern United States. Journal of the Arboretum 70:403-425.

DeLoach, C.J., R.I. Carruthers, J.E. Lovich, T.L. Dudley, and S.D. Smith. 2000. Ecological interactions in the biological control of saltcedar (*Tamarix* spp.) in the United States: toward a new understanding. Pages 819-873 *in* N. R. Spencer, editor. Proceedings of the X International Symposium on Biological Control of Weeds. 4 - 14 July, 1999, Montana State University, Bozeman, Montana.

Devitt, D.A. J.M. Piorkoski, S.D. Smith, J.R. Cleverly, and A. Sala. 1997. Plant water relations of *Tamarix ramosissima* in response to the imposition and alleviation of soil moisture stress. Journal of Arid Environments 36:527-540.

Dixon, M.D., M.G. Turner, and C. Jin. 2002. Riparian tree seedling distribution on Wisconsin River sandbars: controls at different spatial scales. Ecological Monographs 72:465-485.

Dominick, D.S., and M.P. O'Neil. 1998. Effects of flow augmentation on stream channel morphology and riparian vegetation: Upper Arkansas River Basin, Colorado. Wetlands 18:591-607.

Durst, S.L. 2004. Southwestern willow flycatcher potential prey base and diet in native and exotic habitats. MS Thesis, Northern Arizona University, Flagstaff, Arizona, USA.

Ellis, L.M. 1995. Bird use of saltcedar and cottonwood vegetation in the Middle Rio Grande Valley, New Mexico, U.S.A. Journal of Arid Environments 30:339-349.

ESRI. 2002. ArcView 8. Environmental Systems Research Institute, Inc. Redlands, California, USA.

Everitt, B.L. 1998. Chronology of the spread of tamarisk in the central Rio Grande. Wetlands 18:658-668.

Ewel, J.J., and F.E. Putz. 2004. A place for alien species in ecosystem management. Frontiers in Ecology 7:354-360.

Fleishman, E., N. McDonal, R. Mac Nally, D.D. Murphy, J. Walters, and T. Floyd. 2003. Effects of floristics, physiognomy, and non-native vegetation on riparian bird communities in a Mohave Desert Wash. Journal of Animal Ecology. 72:484-490.

Friedman, J.M., W.R. Osterkamp, M.L. Scott, and G.T. Auble. 1998. Downstream effects of dams on channel geometry and bottomland vegetation: regional patterns in the Great Plains. Wetlands 18:619-633.

Graf, W.L. 1982. Tamarisk and river-channel management. Environmental management 6:283-296.

_____. 1988. Fluvial processes in dryland rivers. Springer-Verlag, New York.

_____, J. Stromberg, and B. Valentine. 2002. Rivers, dams, and willow flycatchers: summary of their science and policy connections. Geomorphology. 47:169–188.

Grant, G.E., J.E. Duval, G.J. Koerper, and J.L. Fogg. 1998. WinXSPRO: a channel cross-section analyzer; user manual. U.S. Department of Agriculture, Forest Service, Rock Mountain Forest and Range

Experimental Station. Prepared by West Consultants, Inc. San Diego, California, USA.

Grossman, D.H., D. Faber-Langendoen, A.S. Weakly, M. Anderson, P. Bourgeon, R. Crawford, K. Goodin, S. Landaal, K. Metzler, K.D. Patterson, M. Pyne, M. Reid, and S.L. Sneddon. 1998. International classification of ecological communities: terrestrial vegetation of the United States. Volume I. The National Vegetation Classification System: development, status, and applications. Nature Conservancy, Arlington, Virginia, USA.

Haney J.A. 2002. Groundwater modeling and biodiversity conservation on the Lower San Pedro River. *Southwest Hydrology* 1:8.

Harrelson, C.C., C.L. Rawlins, and J.P. Potyondy. 1994. Stream channel reference sites: an illustrated guide to field technique. Gen. Tech, Rep. RM-245. Fort Collins, Colorado, USA: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experimental Station.

Hatten, J.R., and C.E. Paradzick. 2003. A multiscaled model of southwestern willow flycatcher breeding habitat. Journal of Wildlife Management 67:774-788.

Horton, J.L., and J.L. Clark. 2001. Water table declines alters growth and survival of *Salix gooddingii* and *Tamarix chinensis* seedlings. Forest Ecology and Management 140:239-247.

_____, T.E. Kolb, and S.C. Hart. 2001a. Physiological response to groundwater depth varies among species and with river flow regulation. Ecological Application 11:1046-1059.

_____., _____, and _____. 2001b. Responses of riparian trees to interannual variation in ground water depth in a semi-arid river basin. Plant, Cell and Environment 24:293-304.

Huckleberry, G. 1994. Contrasting channel response to floods on the middle Gila River, Arizona. Geology 22:1083-1086.

_____. 1996. Historical channel changes on the San Pedro River, southeastern Arizona. Arizona Geological Survey, Tucson, AZ, USA. Open File Report 96-15.

Hughes, F.M.R. 1994. Environmental change, disturbance, and regeneration in semi-arid floodplain forests. Pages 321-345 *in* A.C. Millington and K. Pye editors. Environmental change in drylands: biogeographical and geomorphological perspectives. John Wiley and Sons Ltd., New York., New York, USA.

Hunter W.C., B.W. Anderson, and R.D. Ohmart. 1987. Avian community structure changes in mature floodplain forest after extensive flooding. Journal of Wildlife Management 51:495-502.

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

Levine, C.M., and J.C. Stromberg. 2001. Effects of flooding on native and exotic plant seedlings: implications for restoring south-western riparian forests by manipulating water and sediment flows. Journal of Arid Environments 49:111-113.

Lite, S.J. 2003. San Pedro River vegetation across water availability and flood intensity gradients. Ph.D. dissertation, State University, Tempe, Arizona, USA.

_____, and J.C. Stromberg. *in press*. Surface and ground-water thresholds for maintaining *Populus - Salix* forests, San Pedro River, Arizona. Biological Conservation.

_____, K.J. Bagstad, and J.C. Stromberg. *in press*. Riparian plant richness and abundance along lateral and longitudinal gradients of water stress and flood disturbance, San Pedro River, Arizona, USA. Journal of Arid Environments.

Mahoney, J.M., and S.B. Rood. 1998. Stream flow requirements for cottonwood seedling recruitment – an integrated model, Wetlands 18:634-645.

McCabe, R.A. 1991. The little green bird: ecology of the willow flycatcher. Rusty Rock Press, Madison Wisconsin, USA.

Merritt, D.M., and D.J. Cooper. 2000. Riparian vegetation and channel change in response to river regulation: a comparative study of regulated and unregulated streams in the Green River Basin, USA. Regulated Rivers: Research and Management 16:543-564.

Owen, J.C., and M.K. Sogge. 2002. Physiological condition of southwestern willow flycatchers in native and saltcedar habitats. U.S. Geological Survey report to the Arizona Department of Transportation, Phoenix, Arizona.

Paradzick, C.E., and A.A. Woodward. 2003. Distribution, abundance, and habitat characteristics of southwestern willow flycatchers (*Empidonax traillii extimus*) in Arizona, 1993 – 2000. Studies in Avian Biology 26:22–29.

Pettit, N.E., R.H. Froend, and P.M. Davies. 2001. Identifying the natural flow regime and the relationship with riparian vegetation for two contrasting western Australian rivers. Regulated Rivers Research and Management 17:201-215.

Phillips, A.R. 1948. Geographic variation in *Empidonax traillii*. Auk 65:507-514.

Pidgeon, A.M., V.C. Radeloff, and N.E. Mathews. 2003. Landscape-scale patterns of black-throated sparrow (*Amphispiza bilineata*) abundance and nest success. Ecological Applications 13:530-542.

Poff, N.L., J.D. Allan, M.B. Bain, J.R. Karr, K.L. Prestegaard, B.D. Richter, R.E. Sparks, and J.C. Stromberg. 1997. The natural flow regime – a paradigm for river conservation and restoration. Bioscience 47:769-784.

Pope, G.L., P.D. Rigas, and C.F. Smith. 1998. Statistical summaries of streamflow data and characteristics of drainage basins for selected streamflow-gaging stations in Arizona through water year 1996. Water-Resources Investigations Report 98-4225. Tucson, Arizona.

Powell, B.F., and R.J. Steidl. 2002. Habitat selection by riparian songbirds breeding in southern Arizona. Journal of Wildlife Management 66:1069-1103.

Reichenbacher, F. 1984. Ecology and evolution of southwestern riparian plant communities. Desert Plants6:15-23.

Richter, B.D., and H.E. Richter. 2000. Prescribing flood regimes to sustain riparian ecosystems along meandering rivers. Conservation Biology 14:1467-1478.

_____, J.V. Baumgartner, D.P. Braun, and J. Powell. 1998. A spatial assessment of hydrologic alteration within a river network. Regulated Rivers: Research and Management 14:329-340.

Rickard, W.H. and C.E. Cushing. 1982. Recovery of streamside woody vegetation after exclusion of livestock grazing. Journal of Range Management 35:360-361.

Robertson, A.I. and R.W. Rowling. 2000. Effects of livestock grazing on riparian zone vegetation in an Australian dryland river. Regulated Rivers: Research and Management 16:527-541.

Rood, S.B., C.R. Gourley, E.M. Ammon, L.G. Heki, J.R. Klotz, M.L. Morrison, D. Mosely, G.G. Scoppettone, S. Swanson, and P.L. Wagner. 2003. Flows for floodplain forests: a successful riparian restoration. Bioscience 53:647-656.

Schmidt, K.M. 2003. Relationship of salinity and depth to the water table on *Tamarix* spp. (saltcedar) growth and water use. Masters Thesis. Texas A&M University. College Station, Texas, USA.

Scott, M.L., P.B. Shafroth, and G.T. Auble. 1999. Reponses of riparian cottonwoods to alluvial water table declines. Environmental Management 23:347-358.

_____, S.K. Skagen, and M.F. Merigliano. 2003. Relating geomorphic change and grazing to avian communities. Conservation Biology 17:284-296.

Shafroth, P.B. J.R. Cleverly, T.L. Dudley, J.P. Taylor, C. van Riper, E.P. Weeks, and J. N. Stuart. *In press*. Control of *Tamarix* in the western United States: implications for water salvage, wildlife use, and riparian restoration. Environmental Management.

_____, G.T. Auble, J.C. Stromberg, and D.T. Patten. 1998. Establishment of woody riparian vegetation in relation to annual patterns of stream flow, Bill Williams River, Arizona. Wetlands 18:577-590.

_____, J.C. Stromberg, and D.T. Patten. 2000. Woody riparian vegetation response to different alluvial water table regimes. Western North American Naturalist 60:66-76.

_____, _____, and _____. 2002. Riparian vegetation response to altered disturbance and stress regimes. Ecological Applications 12:107-123.

Sher, A.A., and D.L. Marshall. 2003. Seedling competition between *Populus deltoids* (Salicaceae) and exotic *Tamarix ramosissima* (Tamaricaceae) across water regimes and substrate types. 2003. American Journal of Botany 90:413-422.

_____, _____, and J.P. Taylor. 2002. Establishment patterns of native *Populus* and *Salix* in the presence of invasive nonnative *Tamarix*. Ecological Applications 12:760-772.

_____, _____, and S.A. Gilbert. 2000. Competition between native *Populus deltoids* and invasive *Tamarix ramosissima* and implications for reestablishing flooding disturbance. Conservation Biology 14:1744-1754.

Smith, A.B., A.A. Woodward, P.E.T. Dockens, J.S. Martin, and T.D. McCarthey. 2003. Southwestern willow flycatcher 2002 survey and nest monitoring report. Nongame and Endangered Wildlife Program Technical Report 210. Arizona Game and Fish Department, Phoenix, Arizona, USA.

_____, C.E. Paradzick, A.A. Woodward, P.E.T. Dockens, and T.D. McCarthey. 2002. Southwestern willow flycatcher 2001 survey and nest monitoring report. Nongame and Endangered Wildlife Program Technical Report 191. Arizona Game and Fish Department, Phoenix, Arizona, USA.

Smith, S.D., D.A. Devitt, A. Sala, J.R. Cleverly, and D.E. Busch. 1998. Water relations of riparian plants from warm desert regions. Wetlands 18:687-696.

Sogge, M.K. 2000. Breeding season ecology. Pages 57-70 *in* D.M. Finch and S.H. Stoleson, editors. Status, ecology, and conservation of the southwestern willow flycatcher. Gen. Tech. Rep. RMRS-GTR-60. USDA Forest Service, Rocky Mountain Research Station, Ogden, Utah, USA.

_____, R.M. Marshall, S.J. Sferra, and T.J. Tibbitts. 1997. A southwestern willow flycatcher natural history summary and survey protocol. National Park Service Cooperative Studies Unit. USGS Colorado Plateau Research Station – Northern Arizona University, Flagstaff, Arizona, USA. NRTR-97/12.

Stoleson, S.H., and D.M. Finch, 2001. Southwestern willow flycatchers in the Cliff-Gila Valley, New Mexico – landscape-level effects on density, reproduction, and cowbird parasitism. Summary report on the 2000 field season (unpublished report). USDA Forest Service, Rocky Mountain Research Station, Albuquerque, New Mexico, USA.

_____, and _____. 2003. Microhabitat use by breeding southwestern willow flycatchers on the Gila River, New Mexico. Studies in Avian Biology 26:91-95.

Stromberg, J.C. 1993a. Fremont cottonwood-goodding willow riparian forests: a review of their ecology, threats, and recovery potential. Journal of the Arizona-Nevada Academy of Science. 26:97-110.

_____. 1993b. Instream flow models for mixed deciduous riparian vegetation within a semiarid region. Regulated Rivers: Research and Management 8:225-235.

_____. 1998a. Dynamics of Fremont cottonwood (*Populus fremontii*) and saltcedar (*Tamarix chinensis*) populations along the San Pedro River, Arizona. Journal of Arid Environments. 40:133-155.

_____. 1998b. Functional equivalency of salt cedar (*Tamarix chinensis*) and Fremont cottonwood (*Populus fremontii*) along a free-flowing river. Wetlands 18:675-686.

_____. 2001. Restoration of riparian vegetation in the south-western United States: importance of flow regimes and fluvial dynamism. Journal of Arid Environments 49:17-34.

_____, M. Briggs, C. Gourley, M. Scott, P. Shafroth, and L. Stevens. Human alterations of riparian ecosystems. 2004. Pages 99 -126. *in* M.B, Baker, P.F. Ffolliot, L.F. Debano, and D.G. Neary, editors. Riparian areas of the Southwestern United States: hydrology, ecology, and management. Lewis Publishers, Inc., Boca Raton, Florida. USA.

_____, R. Tiller, and B. Richter. 1996. Effects of groundwater decline on riparian vegeation of semiarid regions: the San Pedro, Arizona. Ecological Applications 6:113-131.

_____, S. Lite, C. Paradzick. *In review*. Tamarisk and river restoration along the San Pedro and Gila rivers. Published in Conference Proceedings – Biodiversity and Management of the Madrean Archipelago II: Connecting Mountain Islands and Desert Seas. May 11-15, 2004. Tucson, Arizona, USA.

Taylor, D.M. 1986. Effects of cattle grazing on passerine birds nesting in riparian habitat. Journal of Range Management 39:254-258.

Taylor, J.P., D.B. Wester, and L.M. Smith. 1999. Soil disturbance, flood management, and riparian woody plant establishment in the Rio Grande floodplain. Wetlands 19:372-382.

Tellman, B., R. Yarde, and M.G. Wallace. 1997. Arizona's changing rivers: how people have affected the rivers. Issue Paper #19, Water Resources Research Center, College of Agriculture, University of Arizona, Tucson Arizona, USA.

Tickner, D.P., P.G. Angold, A.M. Gurnell, and J.O. Mountford. 2001. Riparian plant invasions: hydrogeomorphological control and ecological impacts. Progress in Physical Geography 25:22-52.

Tudor, A.A., E. H. Paxton, and C.E. Paradzick. *in review*. Demography of southwestern willow flycatchers in central Arizona. Submitted to the Condor.

Unitt, P. 1987. *Empidonax traillii extimus*: an endangered subspecies. Western Birds 18:137-162.

U.S. Fish and Wildlife Service. 1995. Final rule determining endangered status for the southwestern willow flycatcher. February 17, 1995. Federal Register 60(38):10694-10715.

_____. 2002. Southwestern willow flycatcher (*Empidonax traillii extimus*) - Final recovery plan. U.S. Fish and Wildlife Service, Albuquerque, New Mexico.

Vandersande, M.W., E.P. Glenn, and J.L. Walworth. 2001. Tolerance of five riparian plants from the lower Colorado River to salinity drought and inundation. Journal of Arid Environments 49:147-159.

Walker, L.R., and S. Smith. 1997. Impacts of invasive plants on community and ecosystems properties. Pages 69-86. *in* J.O. Luken and J, W. Thieret, *editors*. Assessment and management of plant invasions. Springer-Verlag, New York, New York. USA.

Ward, J.V., K. Tockner, U. Uehlinger, and F. Malard. 2001. Understanding natural patterns and processes in river corridors as the basis for effective river restoration. Regulated Rivers: Research and Management 17:311-323.

Warren, D.K., and R.M. Turner. 1975. Saltcedar (*Tamarix chinensis*) seed production, seedling establishment, and response to inundation. Journal of Arizona-Nevada Academy of Science 10:135-144.

White, P.S. 1979. Pattern, process, and natural disturbance in vegetation. The Botanical Review 45:229-299.

Williams, G.P., and M.G. Wolman. 1984. Downstream effects of dams on alluvial rivers. U.S. Geological Survey Professional Paper 1286. Washington, D.C.

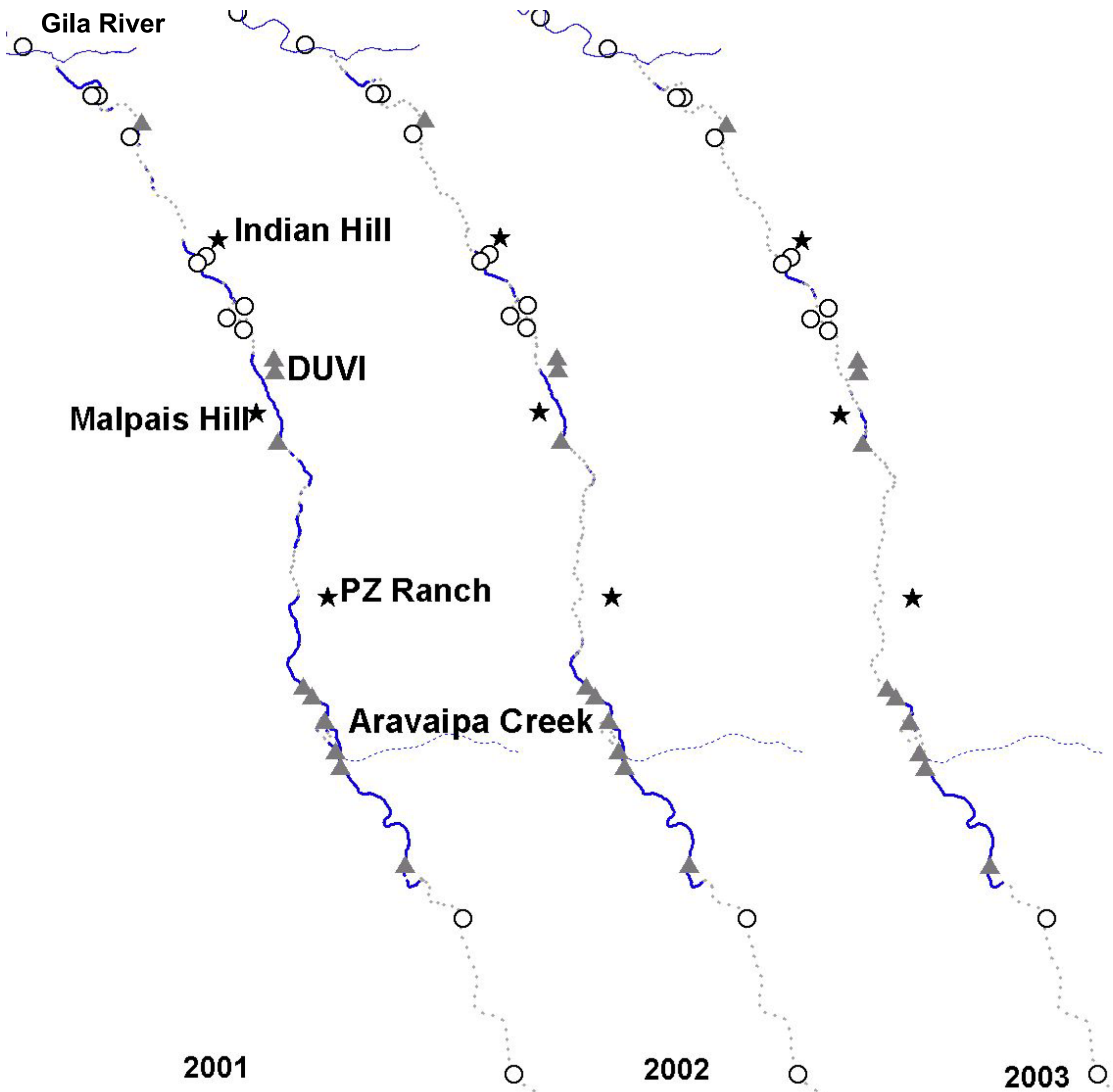
Wissmar, R.C., and R.L. Beschta. 1998. Restoration and management of riparian ecosystems: a catchment perspective. Freshwater Biology 40:571-585.

Wood, M.L. 1997. Historical changes along the lower San Pedro River, southeastern Arizona. Arizona Geological Survey Open-File Report 97-21.

Zar, J.H. 1999. Biostatistical analysis. Prentice Hall, Upper Saddle River, New Jersey, USA.

APPENDIX A

MAP OF PERENNIAL AND INTERMITTENT STREAM FLOW DELINEATED DURING THE LAST WEEK OF JUNE ON THE LOWER SAN PEDRO RIVER, 2001 - 2003



	Stream flow (km)	
Year	Perennial	Interrupted
2001	18.5	15.4
2002	11.8	22.1
2003	7.0	26.9