MAPPING AND MONITORING SOUTHWESTERN WILLOW FLYCATCHER BREEDING HABITAT IN ARIZONA: A REMOTE SENSING APPROACH

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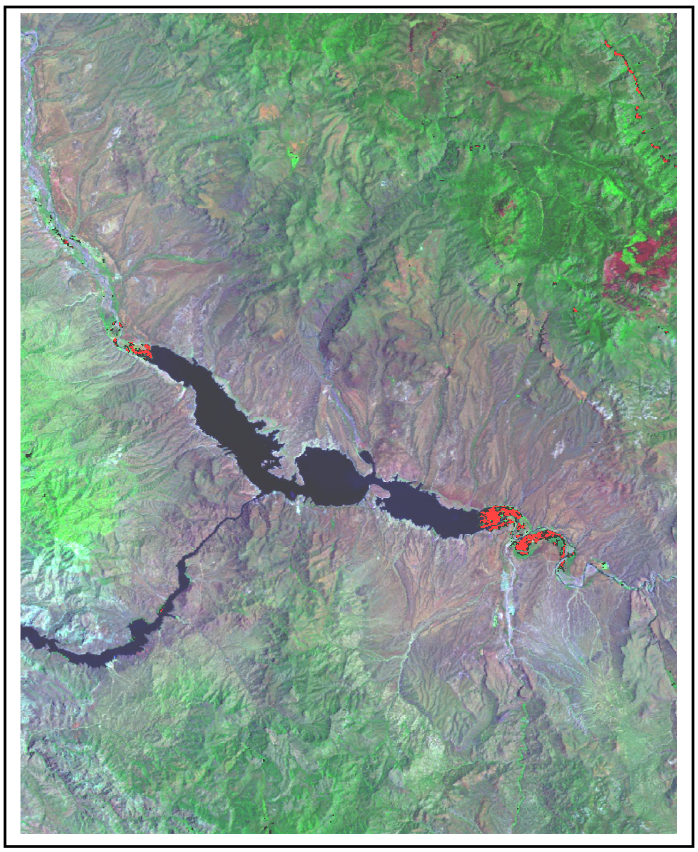

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FORWARD

One of the primary research needs identified by leading southwestern willow flycatcher (SWFL; *Empidonax traillii extimus*) researchers was to identify the current distribution and extent of riparian vegetation that could contain suitable breeding habitat across the Southwest. It was this goal that prompted a cooperative project between the Arizona Game and Fish Department (AGFD) and the U.S. Bureau of Reclamation (USBR) to develop a Geographic Information System (GIS) based model that would be useful across broad areas. In 1999, we began the development of a GIS-based model using past survey and nest data from Roosevelt Lake and the San Pedro River/Gila River confluence area. In 2002, we finalized the model and the results were published in the Journal of Wildlife Management (67:774-778). This manuscript is reproduced in Chapter 1, and provides the background of model development and testing. It is our intent, and we greatly encourage, that other researchers improve upon this first attempt at discerning patterns of SWFL habitat selection across multiple scales.

Once the model was complete, we began the task of mapping SWFL breeding habitat throughout the state (Chapter 2). The results provided the first approximation of possible breeding habitat statewide. While it is a snapshot in time, it serves as a basis for prioritizing future surveys and a reference to compare future conditions. We provided the results on CD for researchers and managers as a tool to view specific areas of the state. As part of USBR mitigation actions at Roosevelt Lake, we also used the model to quantify habitat change over time (Chapter 3). The results highlight the spatial and temporal dynamics of riparian systems, and generate ideas for future SWFL research at Roosevelt Lake, and other riparian areas throughout the state.

We believe the model will be useful for several years, but as the habitat changes, model results will become obsolete. The GIS-based model is a first step in identifying possible SWFL breeding habitat in Arizona and we hope it will spur discussions and encourage a broad-scale perspective related to conservation of SWFL and their habitat. One of the most important points to consider for each chapter and the CD, is that the model delineates *predicted* (possible) suitable breeding habitat. These areas may or may not be occupied or contain the conditions that SWFL require during the breeding season (for example, suitable tree species, vegetation structure, water, surrounding habitats). These terms (predicted and possible) should not be confused with "potential" habitat that is extensively used in other SWFL publications and by researchers when referring to a riparian system that does not currently have all components needed to provide conditions suitable for SWFL, but which could – if managed appropriately – develop these components over time. A model is an approximation of the real world; managers should use all tools available (for example, vegetation and habitat maps, on-the-ground surveys, aerial photographs, and expert knowledge) when estimating habitat quality and needs for SWFL conservation and recovery.

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NOTE: The reproduction, as it appears here, has been altered from its published form. The term "potential," in the original manuscript was changed to predicted or possible breeding habitat when it refers to habitat delineated by the GIS model. The term "potential" was retained when it referred to habitat that does not currently have all components needed to provide conditions suitable for SWFL, but which could - if managed appropriately - develop these components over time. This allowed consistent use of terms among all 3 chapters, and would reduce confusion with other published literature.

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EXECUTIVE SUMMARY

The southwestern willow flycatcher (*Empidonax traillii extimus*) is an endangered songbird whose habitat has declined dramatically over the last century. Understanding habitat selection patterns and the ability to predict breeding areas for the flycatcher is crucial to the management and conservation of this species. We developed a multiscaled model of flycatcher breeding habitat with a Geographic Information System (GIS), survey data, GIS variables, and multiple logistic regressions. Presence and absence survey data were obtained from a riverine ecosystem and a reservoir delta in south-central Arizona, USA, in 1999. We extracted the GIS variables from satellite imagery and digital elevation models to characterize vegetation and floodplain within the project area. We used multiple logistic regressions within a cell-based (30 × 30 m) modeling environment to (1) determine associations between GIS variables and breeding-site occurrence at different spatial scales (0.09-72 ha) and (2) to construct a predictive model. Our best model explained 54% of the variability in breeding-site occurrence with the following variables: vegetation density at the site (0.09 ha), proportion of dense vegetation and variability in vegetation density within a 4.5 ha neighborhood, and amount of floodplain or flat terrain within a 41 ha neighborhood. The density of breeding sites was highest in areas the model predicted to be most suitable within the project area and at an external test site 200 km away. Conservation efforts must focus on protecting not only occupied patches, but also surrounding riparian forests and floodplain to ensure long-term viability of flycatchers. We will use the multiscaled model to map flycatcher breeding habitat in Arizona, prioritize future survey effort, and examine changes in habitat abundance and quality over time.

CHAPTER 1

A MULTISCALED MODEL OF SOUTHWESTERN WILLOW FLYCATCHER BREEDING HABITAT

James R. Hatten and Charles E. Paradzick

INTRODUCTION

The Southwestern Willow Flycatcher (SWFL) is a federally endangered subspecies of the willow flycatcher with a breeding distribution in 6 states: Arizona, California, Colorado, Nevada, New Mexico, and Utah (Unitt 1987; U.S. Fish and Wildlife Service (USFWS) 1995; Marshall 2000). The SWFL is a neotropical migrant that breeds exclusively in riparian vegetation from near sea level to 2700 m in elevation (Marshall 2000). Arizona contains approximately one-third of SWFL breeding territories (Sogge and others 2000), and over 95% of these are located between 140 and 1400 m elevation (Paradzick and others 2000) in riparian forests dominated by Freemont cottonwood (*Populus fremontii*), Goodding willow (*Salix gooddingii*), and tamarisk (*Tamarix ramosissima*). Changes in flow regimes in the last century, as a result of river channelization, impoundment and diversion, and groundwater withdrawal, have created a less favorable environment for regeneration of cottonwoods and willows (Stromberg 1993). Introduction of nonnative tamarisk (Graf 1982; Hunter and others 1987) and livestock grazing (Belsky and others 1999) have further altered riparian habitats. The Governor's Riparian Habitat Task Force (1990) estimated that over 90% of riparian forests have been degraded in Arizona. The precipitous decline in riparian forests throughout the Southwest is a major cause in the decline of SWFL populations (USFWS 1995).

Locating populations and protecting habitats are important steps in SWFL management. Biologists have spent over 22,000 hr since 1993 surveying riparian areas in Arizona for SWFL (Paradzick and Woodward 2003), yet large expanses remain unsurveyed. Impediments include Arizona's vast size (295,159 km^2), remoteness, rugged topography, and restricted access to private lands. Therefore, developing remote sensing tools that delineate suitable breeding habitat statewide may prove valuable in lieu of extensive, slow, and costly ground-based surveys. Techniques in remote sensing coupled with a GIS can assist with bird-habitat analyses and the development of habitat suitability models (Lyon 1983; Palmeirim 1988; Vander Haegen and others 2000). Spatial (GIS) models can identify sensitive habitats, prioritize survey efforts, and have predictive value outside their original development area. The use of satellite imagery can also reduce costs associated with aerial photography and ground-based mapping efforts (Aronoff 1989).

Our goals were to discern patterns of habitat selection by SWFL at multiple spatial scales and develop a GIS-based model for mapping SWFL breeding habitat in Arizona. To do so, we set 3 objectives: (1) construct a breeding-site suitability model, (2) produce a breeding-site suitability map, and (3) determine model accuracy. We also evaluated whether the model could be extrapolated outside the project area, thereby providing information to resource managers for inventorying, monitoring, restoration, recovery plans, and conservation opportunities.

Concurrent with modeling, we tested our hypothesis that SWFL select breeding sites based upon vegetation and landscape features found at or around the site (0.09-72 ha).

METHODS

STUDY AREA

To develop the model, we used SWFL survey data obtained from 8 km of riparian habitat along Tonto Creek, 11 km along the Salt River, and 80 km along the San Pedro and Gila rivers in south-central Arizona, USA, collectively called the project area (Figure 1.1). The U.S. Department of Agriculture Forest Service managed Tonto Creek and Salt River on the west and east ends of Roosevelt Lake (660 m elevation); while private, federal, and state landowners managed the Gila and San Pedro river corridors. Elevation ranged from 680 m near the town of Mammoth on the San Pedro River to 480 m at a diversion dam on the Gila River. We tested the model 200 km outside the project area near Alamo Lake, at approximately 350 m elevation (Figure 1.1) at the confluence of the Bill Williams, Big Sandy, and Santa Maria rivers. The U.S. Department of Interior Bureau of Land Management managed the eastern section of the test area as a wilderness area, while the Arizona Game and Fish Department (AGFD) managed the western portion as a wildlife area.

Riparian habitat within the project and test areas was located within the Sonoran Desertscrub biome, surrounded by Arizona Upland subdivision vegetation (Brown 1994). Paloverde (*Cercidium* spp.) and cacti (*Opuntia* spp.) desert associations dominated the upland vegetation communities. Riparian habitat has been classified as Sonoran Riparian Deciduous Forest (Minckley and Brown 1994). Dominant riparian tree and shrub species included Freemont cottonwood, Goodding willow, mesquite (*Prosopis* spp.), seepwillow (*Baccharis salicifolia*), and tamarisk. Riparian habitat occurred as spatially heterogeneous patches in all areas. Plant species composition and vegetation structure (both horizontal and vertical) ranged greatly within and among patches (Paradzick and others 2001).

MODEL DEVELOPMENT

Southwestern Willow Flycatcher Surveys

Pilot breeding surveys of SWFL were conducted in 1995-1996 at a subset of occupied and unoccupied patches within the project area. We followed up with a project-wide survey (1997-1998) in which possibly suitable SWFL breeding habitat was delineated on aerial photographs and topographic maps, and nest locations were recorded. Possibly suitable breeding habitats included patches >10 m wide and >3 m tall that were dominated by cottonwood, willow, or tamarisk, with dense vegetation in the patch interior (Sogge and others 1997). Habitats considered unsuitable (Sogge and others 1997; Sogge and Marshall 2000) included monotypic stands of mesquite, short (<3 m), sparse tamarisk, and gallery forest (>20 m tall) that lacked dense mid and understory vegetation. We continued to survey for breeding SWFL between 1999 and 2001 in areas that were believed suitable in 1997-1998, plus any areas previously thought unsuitable but that subsequently became suitable. Due to our intensive survey efforts each year, we believe that little suitable breeding habitat was left unsurveyed and few breeding sites were missed. In our study, breeding site refers only to a location that contained an active SWFL nest, while a nonuse site refers to a location that did not contain a SWFL nest regardless of the habitat it was in.

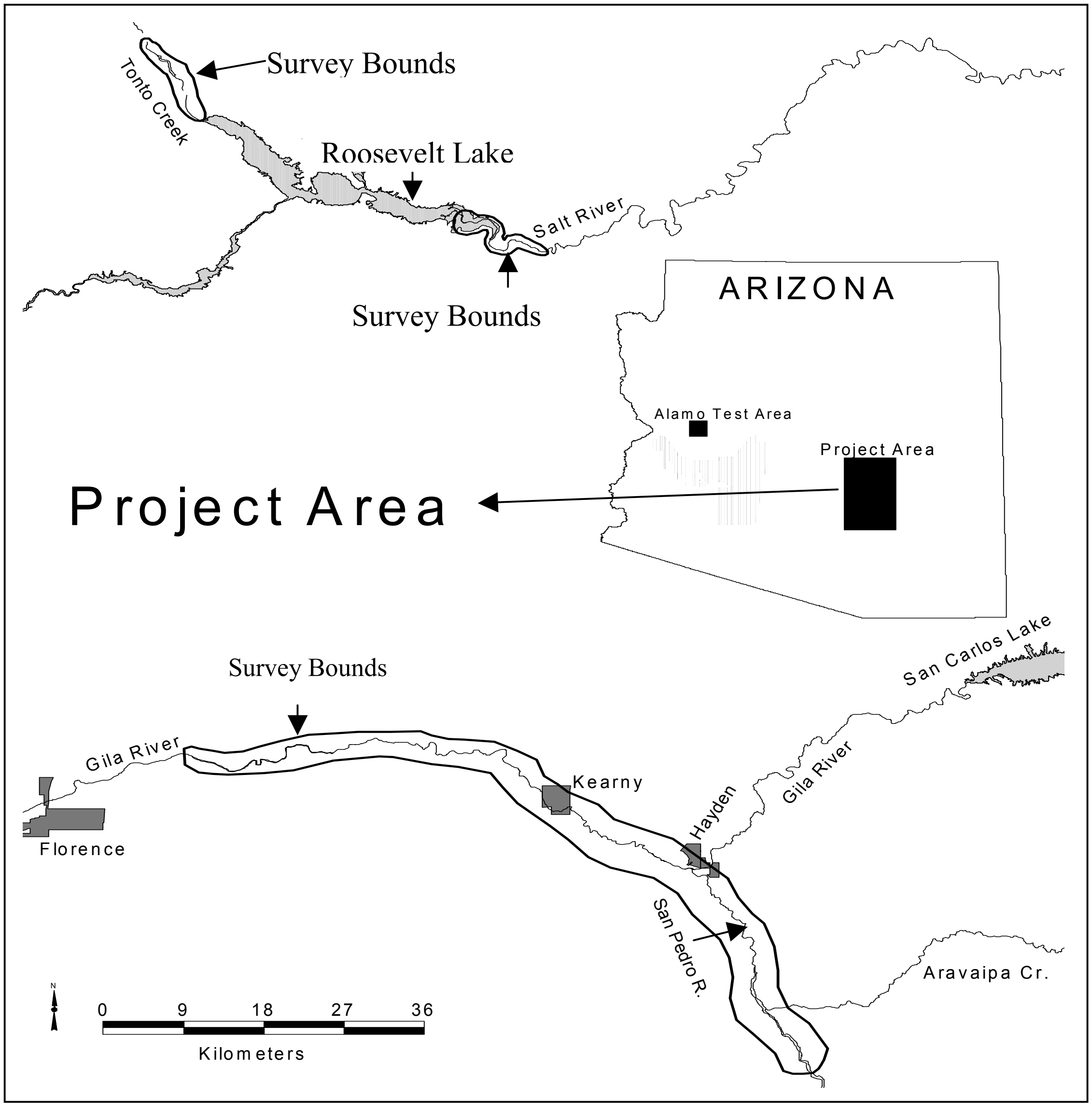

Figure 1.1. A map of our project area in Arizona, showing locations of the 3 survey areas: Tonto Creek, Salt River, and Gila/San Pedro rivers. The location of Alamo test area is shown on the map inset.

Presence/absence surveys for SWFL followed a standardized protocol (Sogge and others 1997). We conducted a minimum of 3 surveys using tape-playback of the SWFL primary song to elicit vocalizations. Surveyor(s) walked through habitat broadcasting SWFL vocalizations every 20-30 m. Surveyors made numerous passes through wide patches to thoroughly cover all existing habitat. At least 1 survey was conducted within each of 3 survey periods: 15-31 May, 1-21 June, and 22 June to 10 July. When a SWFL was detected, we intensively searched the patch to document pairing and locate nesting attempts. Following the breeding season in mid- to late August, we recorded all nests using geographic positioning units.

Retrospective Sampling

We used presence/absence data obtained from our SWFL surveys to test our hypothesis because retrospective data work well with multiple logistic regression, require a smaller sample size, and are well suited for exploratory analysis (Ramsey and others 1994). Retrospective sampling provided a practical way to examine our survey data and is well suited for animals that exhibit preferences for rare habitat types (Ramsey and others 1994). We compared vegetation and floodplain characteristics around breeding sites with a control group comprised of randomly selected nonuse sites from the project area. We did not survey the randomly selected nonuse (unoccupied) sites because they were either in areas that had already been surveyed, and found to be empty, or in areas considered unsuitable for breeding.

We examined habitat association at multiple spatial scales (Ripple and others 1991) by characterizing vegetation and floodplain features within different-sized neighborhoods (0.3-72 ha concentric circles) of breeding and nonuse sites. We characterized fine scales as 0.09-1.1 ha, which corresponds to SWFL territory size (Sogge 2000). The lower value was bounded by the 30-m resolution limits of Landsat Thematic Mapper (TM) imagery. We selected intermediate (2.5-28 ha) and coarse scales (41-72 ha) to characterize riparian forest patch(es) and floodplains, respectively. We used both univariate and multivariate logistic regression to determine associations between predictor variables and SWFL breeding activity.

Variable Appraisal and Selection

We developed a set of predictor (GIS) variables with fine resolution and broad scope to characterize vegetation and floodplain features at multiple scales (Table 1.1) and encompass the project area (8848 km^2). Vegetation and floodplain features were characterized in discrete 30 × 30 m cells (0.09 ha) obtained from TM imagery and digital elevation model (DEM) data, respectively. We focused upon predictor variables extractable from TM or DEM data because these variables could be created for any region of the state. We examined vegetation density, edge habitat, and proximity to patch boundaries because these are thought to be important to SWFL (Sogge and others 1997; Sogge and Marshall 2000), and width of floodplain because it can influence riparian plant community establishment and persistence (Szaro 1990; Stromberg 1993). We did not examine 3 variables (distance to water, vegetation species, or seral stage) that may influence habitat selection (Sogge and others 1997; Sogge and Marshall 2000) because they could not be accurately extracted from TM imagery.

Table 1.1. Predictor variables used to characterize vegetation and floodplain features at or around southwestern willow flycatchers (SWFL) breeding and nonuse sites in south-central Arizona, during 1999. Breeding sites (0.09 ha) contained a SWFL nest and nonuse sites (0.09 ha) did not. We extracted vegetation variables from Landsat Thematic Mapper imagery (30 m resolution), and floodplain (area) from digital elevation models (30 m resolution).

Variable	Definition
NDVI	Relative density (12 interval classes) green vegetation at site
DISTANCE	Distance (m) between site and patch boundary (NDVI = 0)
NDVIBEST1	Amount (ha) of densest vegetation within a 0.3-ha neighborhood
NDVIBEST2	Amount (ha) of densest vegetation within a 1.1-ha neighborhood
NDVIBEST3	Amount (ha) of densest vegetation within a 2.5-ha neighborhood
NDVIBEST4	Amount (ha) of densest vegetation within a 4.5-ha neighborhood
NDVIBEST6	Amount (ha) of densest vegetation within a 10-ha neighborhood
NDVIBEST8	Amount (ha) of densest vegetation within a 18-ha neighborhood
NDVIBEST10	Amount (ha) of densest vegetation within a 28-ha neighborhood
NDVIBEST12	Amount (ha) of densest vegetation within a 41-ha neighborhood
NDVIBEST14	Amount (ha) of densest vegetation within a 55-ha neighborhood
NDVIBEST16	Amount (ha) of densest vegetation within a 72-ha neighborhood
NDVISTD1	Standard deviation in NDVI within a 0.3-ha neighborhood
NDVISTD2	Standard deviation in NDVI within a 1.1-ha neighborhood
NDVISTD3	Standard deviation in NDVI within a 2.5-ha neighborhood
NDVISTD4	Standard deviation in NDVI within a 4.5-ha neighborhood
NDVISTD6	Standard deviation in NDVI within a 10-ha neighborhood
NDVISTD8	Standard deviation in NDVI within a 18-ha neighborhood
NDVISTD10	Standard deviation in NDVI within a 28-ha neighborhood
NDVISTD12	Standard deviation in NDVI within a 41-ha neighborhood
NDVISTD14	Standard deviation in NDVI within a 55-ha neighborhood
NDVISTD16	Standard deviation in NDVI within a 72-ha neighborhood
FLOODPL12	Amount (ha) of floodplain or flat area within a 41-ha neighborhood
FLOODPL14	Amount (ha) of floodplain or flat area within a 55-ha neighborhood
FLOODPL16	Amount (ha) of floodplain or flat area within a 72-ha neighborhood

Geographic Information System Variables

We created riparian-vegetation density grids (0.09 ha cells) for the project and test areas with TM imagery and ERDAS IMAGINE software (Pouncey and others 1999). The TM images were taken October 1999 during a cloud-free period: scene TM-3637 covered the project area and TM-3836 the external test area. Riparian-vegetation density grids were created in a 4-step process: (1) we calculated the Normalized Difference Vegetation Index (NDVI), which correlates with relative density and biomass of green vegetation (Avery and Berlin 1992) within 2 km of perennial/intermittent waters; (2) we used the ISODATA algorithm (Tou and Gonzalez 1974) to cluster NDVI into 12 interval-scaled classes; (3) we overlaid NDVI classes and satellite imagery to find the best cutpoint between riparian and upland vegetation; and (4) we used the ISODATA routine to cluster riparian forest into 12 interval-scaled density classes. Creating an interval-scaled variable of the raw NDVI values (-0.522 to 0.63) made the values simpler to query and display, and made finding cutpoints easier. The cutpoint separating riparian and non-riparian vegetation was between NDVI classes 8 and 9 (raw NDVI cutpoint = 0.126). In the multivariate modeling stage, we converted NDVI into a binary variable where the first 9 riparian NDVI classes (raw NDVI values 0.127 to 0.336) were set to 0 and classes 10-12 (raw NDVI >0.336) were set to 1.

We used GRID focal functions (ESRI 1992) to characterize vegetation and floodplain features within 0.3 to 72 ha circular neighborhoods and stored results from each operation in a separate grid. We used FOCALSUM function to calculate proportion of neighborhood covered in dense vegetation by counting all neighborhood cells equal to NDVI class 12 (raw NDVI >0.413), the densest vegetation class. We used SLOPE and FOCALSUM functions on the DEM to identify floodplain (ha) because it was incised and flatter (slope <2.5°) than its surroundings. We used EUCDISTANCE function to identify distance between riparian and non-riparian features from the riparian-vegetation density grid. Lastly, we used FOCALSTD function to characterize heterogeneity in vegetation density and edge habitat by calculating standard deviation among the 12 NDVI classes. We rationalized that edge habitat should increase heterogeneity in riparian vegetation density because of the sharp contrasts between dense riparian vegetation, barren floodplain, upland areas, and sparsely vegetated riparian forest.

STATISTICAL ANALYSIS

To create a database for hypothesis testing and modeling, we adjusted for spatial and temporal autocorrelation (Legendre 1993) because sites were tightly clustered ($\bar{x}$ = 57 m, SD = 38 m). We corrected for temporal autocorrelation by using a single year (1999) of survey data because SWFL have high patch fidelity (up to 78%) between years (Luff and others 2000). We adjusted for spatial autocorrelation by randomly selecting breeding (n = 71) and nonuse (n = 136) sites >100 m apart, stratified by NDVI. We selected more nonuse sites to characterize unoccupied habitat because most of the project area was unoccupied and we expected more variability among these sites (Kvamme 1985). We attributed each site with surrounding vegetation and floodplain characteristics and compared group (breeding vs. nonuse) means with the Mann-Whitney U-test (Sokal and Rohlf 1969). We used nearest neighbor index (Boots and Getis 1988; Chou 1997) to identify patterns of dispersion in breeding sites because neighborhood effects should be considered if clustering is evident (Chou and Soret 1996).

We used logistic regression to identify habitat associations and to develop a model for predicting probability of breeding-site occurrence. We examined the scale of predictor variables with a quartile analysis (Hosmer and Lemeshow 1989), and model fit during the development stage with Nagelkerke statistic (Nagelkerke 1991), a classification table (Norusis 1999), and Hosmer and Lemeshow Test (Hosmer and Lemeshow 1989). Predictor variables (Table 1.1) were eliminated before the multivariate stage if their association with breeding activity was weak (P > 0.15). We selected a P-value >0.05 in the univariate analysis because of the exploratory nature of our analysis, not wanting to exclude variables from the multivariate analysis too early. All qualifying variables were incorporated into a multivariate analysis and their contributions examined with forward and backward stepping and the likelihood ratio test (Hosmer and Lemeshow 1989). We minimized the number of variables entered into the multivariate analysis to 5 per subset by examining a single neighborhood size for each neighborhood variable (FLOODPL, NDVISTD, NDVIBEST); we also included the DISTANCE and NDVI variables. This technique enabled us to compare results of different model runs without adjusting for model richness.

HABITAT MAPPING AND ACCURACY ASSESSMENT

We used GRID to calculate and map the probability of breeding-site occurrence within 0.09 ha cells. The model assigned each cell a probability between 1 and 98%, which we reclassified into 1of 5 probability classes: (1) 1-20%, (2) 21-40%, (3) 41-60%, (4) 61-80%, and (5) 81-98%. We assessed model fit and accuracy within the project area with 159 control sites from 1999. Controls were breeding sites not used in model development and were between 1 and 5 cells (30-150 m) from the breeding sites used in model development. We used density of nests among the 5 probability classes as our measure of fit, reasoning that higher-probability habitat should contain more breeding sites. We also tested temporal and spatial accuracies of the model retrospectively and prospectively by overlaying breeding sites collected 1995-1998 (n = 398) and 2000-2001 (n = 601) within the project area, and 51 breeding sites (1999-2000) outside the project area at Alamo Lake. We developed new input grids for Alamo Lake, ran the model with the same coefficients, and created a new breeding-site suitability map. We did not adjust for spatial or temporal autocorrelation in the control sites used in accuracy assessment because we were interested in nest density among the 5 probability classes through both space and time.

Model accuracy depended upon a movable probability cutpoint that we used to delineate suitable and unsuitable habitat from the probability grid. For example, if the probability cutpoint was set at 50%, all cells with ≤50% probability were considered unsuitable and cells >50% suitable. We created binary grids from probability cutpoints at 20% intervals (20, 40, 60, 80%) and overlaid control sites to determine errors of omission (Story and Congalton 1986). Breeding sites that fell outside of predicted suitable cells (≤ cutpoint) were listed as errors of omission. Model accuracy was then defined as percent of control sites falling within habitat delineated as suitable.

RESULTS

STATISTICAL ANALYSIS

Univariate Analysis

Mean floodplain and vegetation characteristics found at or around breeding sites were significantly larger than the nonuse group, except for variation in vegetation density within 0.3 to 2.5 ha neighborhoods (Table 1.2). The statistical significance of the univariate logistic regression models mirrored the Mann-Whitney tests; only variation in vegetation density within 0.3 to 2.5 ha neighborhoods was insignificant. Breeding sites on average contained 76% denser vegetation than nonuse sites and were 24% farther from patch boundaries. Nearest neighbor analysis found breeding sites were significantly clustered ($z = 26.8$, $P < 0.001$) within each survey area and over the entire project area, emphasizing the need to examine neighborhood effects (Chou and Soret 1996). Compared with the nonuse group, neighborhoods surrounding breeding sites contained 200-600% more dense vegetation (NDVI = 12), 10-25% more variation in vegetation density, and 18% more floodplain or flat terrain.

Table 1.2. Average floodplain and vegetation characteristics found at or around southwestern willow flycatcher (SWFL) breeding (n = 71) and nonuse (n = 136) sites in south-central Arizona, during 1999, comparison of group means (Mann-Whitney test for 2 independent samples), and significance of univariate logistic regression models for SWFL breeding activity. Breeding sites (0.09 ha) contained a SWFL nest and nonuse sites (0.09 ha) did not.

Variable[a]	$\bar{x}$	Median	CV	$\bar{x}$	Median	CV	P[b]	P[c]
NDVI	5.9	5.0	0.68	10.4	12.0	0.27	<0.001	<0.001
DISTANCE	82.6	60.0	0.79	102.5	90.0	0.60	0.004	0.040
NDVIBEST1	0.1	0	2.21	0.2	0.3	0.75	<0.001	<0.001
NDVIBEST2	0.1	0	2.09	0.6	0.5	0.66	<0.001	<0.001
NDVIBEST3	0.3	0	1.90	1.1	1.2	0.64	<0.001	<0.001
NDVIBEST4	0.5	0	1.86	1.8	1.7	0.64	<0.001	<0.001
NDVIBEST6	1.0	0.3	1.71	3.3	3.4	0.62	<0.001	<0.001
NDVIBEST8	1.7	0.6	1.58	5.0	4.8	0.66	<0.001	<0.001
NDVIBEST10	2.6	1.0	1.45	7.0	6.1	0.69	<0.001	<0.001
NDVIBEST12	3.4	1.4	1.39	8.7	6.8	0.71	<0.001	<0.001
NDVIBEST14	4.6	2.5	1.32	10.9	8.4	0.72	<0.001	<0.001
NDVIBEST16	5.7	3.1	1.28	13.0	10.3	0.72	<0.001	<0.001
NDVISTD1	1.7	1.0	0.75	1.6	1.0	1.15	0.114	0.670
NDVISTD2	2.3	1.0	0.55	2.4	2.0	0.76	0.653	0.460
NDVISTD3	2.7	3.0	0.46	3.0	3.0	0.62	0.135	0.170
NDVISTD4	3.0	3.0	0.41	3.3	4.0	0.50	0.029	0.100
NDVISTD6	3.3	3.0	0.35	4.0	4.0	0.31	<0.001	<0.001
NDVISTD8	3.5	4.0	0.33	4.2	4.0	0.23	<0.001	<0.001
NDVISTD10	3.6	4.0	0.32	4.5	5.0	0.15	<0.001	<0.001
NDVISTD12	3.6	4.0	0.32	4.5	5.0	0.14	<0.001	<0.001
NDVISTD14	3.7	4.0	0.31	4.6	5.0	0.13	<0.001	<0.001
NDVISTD16	3.8	4.0	0.31	4.6	5.0	0.13	<0.001	<0.001
FLOODPL12	25.5	29.4	0.53	30.1	32.4	0.34	0.041	0.013
FLOODPL14	34.7	39.7	0.52	40.4	43.0	0.35	0.042	0.022
FLOODPL16	44.2	50.1	0.51	50.9	52.7	0.36	0.047	0.034

[a]Variable definitions: NDVI = relative density of green vegetation at site; DISTANCE = distance between each site and patch boundary; NDVIBEST = amount (ha) of densest vegetation within a neighborhood; NDVISTD = standard deviation in NDVI within a neighborhood; FLOODPL = amount (ha) of floodplain or flat area within a neighborhood. Numbers represent neighborhood sizes: 1 = 0.3 ha, 2 = 1.1 ha, 3 = 2.5 ha, 4 = 4.5 ha, 6 = 10 ha, 8 = 18 ha, 10 = 28 ha, 12 = 41 ha, 14 = 55 ha, 16 = 72 ha.

[b]Significance of Mann-Whitney test.

[c]Significance of univariate logistic regression model

Multiscaled, Multivariate Analysis

Our multiscaled, multivariate analysis found 3 covariates (NDVIBEST, FLOODPL, and NDVISTD) that were significantly associated with breeding-site occurrence within different-sized neighborhoods, but model fit was better in smaller-sized neighborhoods (Figure 1.2). The first 3 neighborhoods (0.3–2.5 ha) were excluded from the multiscaled analysis because NDVISTD was insignificant at those scales (P > 0.15) in the univariate analysis. DISTANCE was highly significant in the univariate analysis, but insignificant in the multivariate analysis at any scale. Vegetation density (NDVI) was a significant predictor in each variable subset, NDVISTD was significant at >2.5 ha, FLOODPL was significant between 41 and 72 ha, and NDVIBEST was significant at <28 ha.

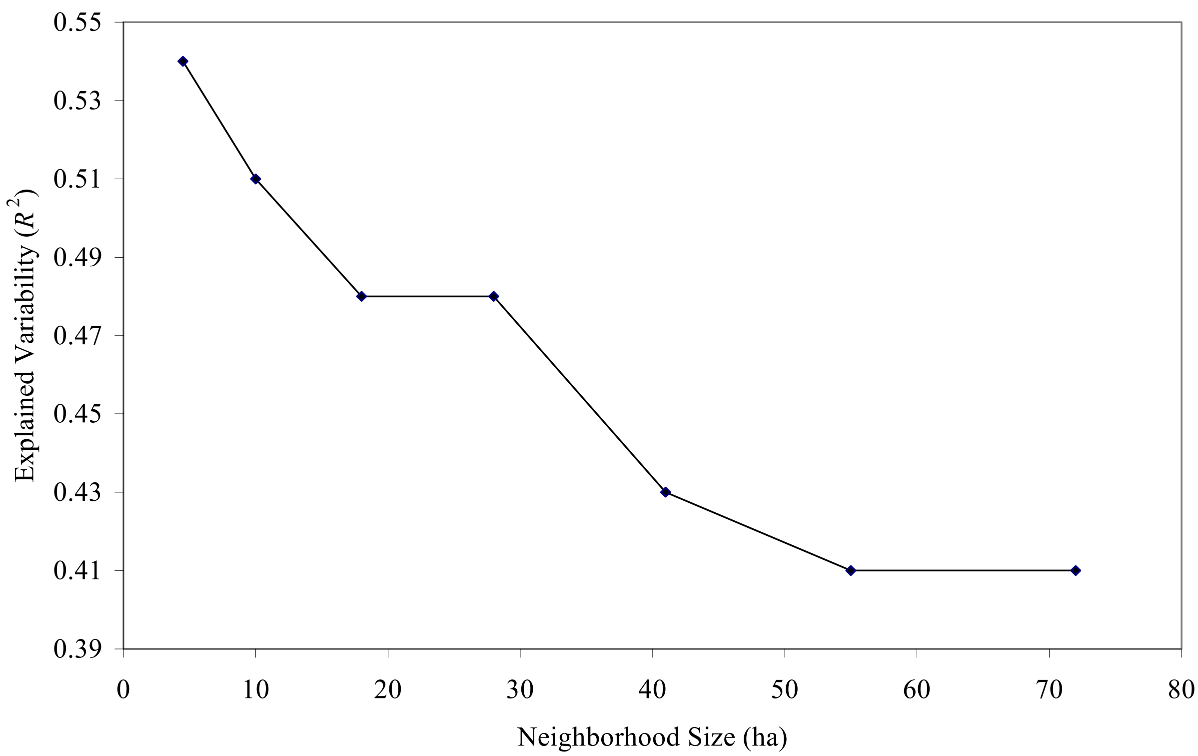

Figure 1.2. Amount of explained variability (R^2) in southwestern willow flycatcher breeding-site occurrence, as determined with multiple logistic regression, within 7 different-sized neighborhoods (4.5-72 ha) around breeding and nonuse sites. In this analysis, NDVI (relative density of green vegetation at site) and FLOODPL12 (amount of floodplain or flat area within a 41-ha neighborhood) were constants, while a different-sized neighborhood was examined for the 2 vegetation variables (NDVISTD [standard deviation of NDVI] and NDVIBEST [amount of densest vegetation]) in each of the 7 model runs.

The best subset of predictor variables (Table 1.3) explained 54% of variability in breeding-site occurrence and produced a good fit with data used in model development (Hosmer and Lemeshow Test: $P = 0.27$). The covariate NDVIBEST4 entered the model first and explained 38% of variability, followed by NDVISTD4 (8%), NDVI (5%), and FLOODPL12 (3%). We found no significant interactions between covariates, so we interpreted the odds ratio for each vegetation variable. At the finest scale (0.09 ha), cells that contained dense vegetation (NDVI > 9) were 440% more likely to contain breeding activity. At an intermediate scale (4.5 ha), for each 10% of neighborhood covered in dense vegetation (NDVI = 12), likelihood of breeding activity increased by 160%. Furthermore, each unit of increase in NDVISTD increased likelihood of breeding activity by 190%. We found a significant positive association between FLOODPL12 and the likelihood of breeding activity.

Table 1.3. Multivariate logistic regression model obtained from southwestern willow flycatcher (SWFL) data. The model was created from retrospective survey data (71 breeding sites and 136 nonuse sites) collected during 1999 in south-central Arizona. Breeding sites contained a SWFL nest and nonuse sites did not. We did not interpret the odds ratio for FLOODPL12 because some of the floodplain might have been confused with flat areas within the neighborhood.

Variable	Coefficient	SE	G	Odds Ratio	*P*
NDVI[a]	1.483	0.48	9.6	4.4	0.002
NDVIBEST4[b]	0.098	0.02	29.6	1.6[e]	<0.001
FLOODPL12[c]	0.034	0.01	8.7	NA	0.003
NDVISTD4[d]	0.648	0.16	19.5	1.9	<0.001
Constant	–6.074	0.98	64.5	0.0	<0.001

[a]Relative density (12 interval classes) of green vegetation at site; modeled as a binary variable: NDVI classes 1-9 = 0 (raw NDVI < 0.336) and NDVI classes 10-12 = 1 (raw NDVI > 0.336)

[b]Amount (ha) of densest vegetation within a 4.5 ha neighborhood; modeled as a continuous variable.

[c]Amount (ha) of floodplain or flat area within a 41 ha neighborhood; modeled as a continuous variable.

[d]Standard deviation in NDVI within a 4.5 ha neighborhood; modeled as a continuous variable.

[e]Odds ratio calculated in 10% increments

HABITAT MAPPING AND ACCURACY ASSESSMENT

Project Area: 1999

The model predicted 5294 ha of breeding habitat in the project area, with each cell assigned a probability of breeding-site occurrence between 1 and 98% (Figure 1.3). Amount (ha) of predicted breeding habitat was inversely related to 5 probability classes (Figure 1.4A), with 61% of predicted breeding habitat within the first class and 6% within the fifth class. In contrast, nest density increased in each probability class (Figure 1.4B), with 0.005 nests/ha in the first class and 0.18 nests/ha in the fifth class.

The accuracy of the model, as determined from errors of omission, depended upon what probability cutpoint was examined (Figure 1.4C). When all predicted suitable breeding habitat was considered (classes 1-5), 5% of nest sites fell outside the suitable envelope, but all were within 1 cell (30 m) of predicted suitable habitat, indicating possible positional error. At a 20% probability cutpoint, we found an 11% omission error, increasing to 21% at a 40% cutpoint, 35% at a 60% cutpoint, and 71% at an 80% cutpoint. The juxtaposition of cells showed a clear pattern of spatial autocorrelation with higher- and lower-probability cells clumped together in a patch-like arrangement. Around Roosevelt Lake, higher-probability breeding habitat was located closer to lake inlets near the water line. Within the Gila/San Pedro river corridor, higher-probability breeding habitat was associated with wider floodplains, demonstrated by lower-probability breeding habitat within the canyon-constrained reach west of the town of Kelvin.

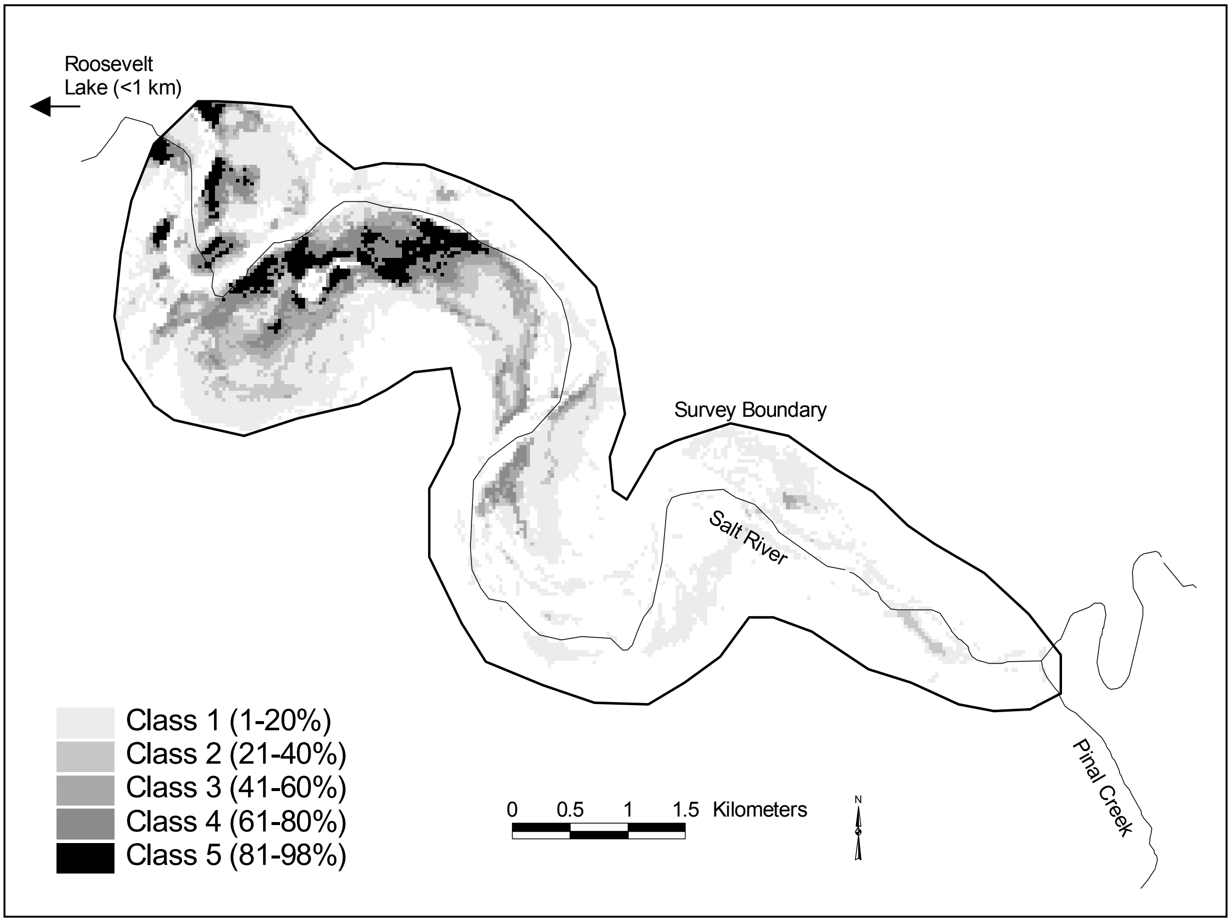

Figure 1.3. A southwestern willow flycatcher breeding-site suitability map of Salt River, Arizona, survey area in 1999 produced from a GIS-based model, logistic regression, digital elevation models, and Thematic Mapper imagery. Probability of breeding-site occurrence ranged from 1 to 98%, which we reclassified into 1 of 5 probability classes.

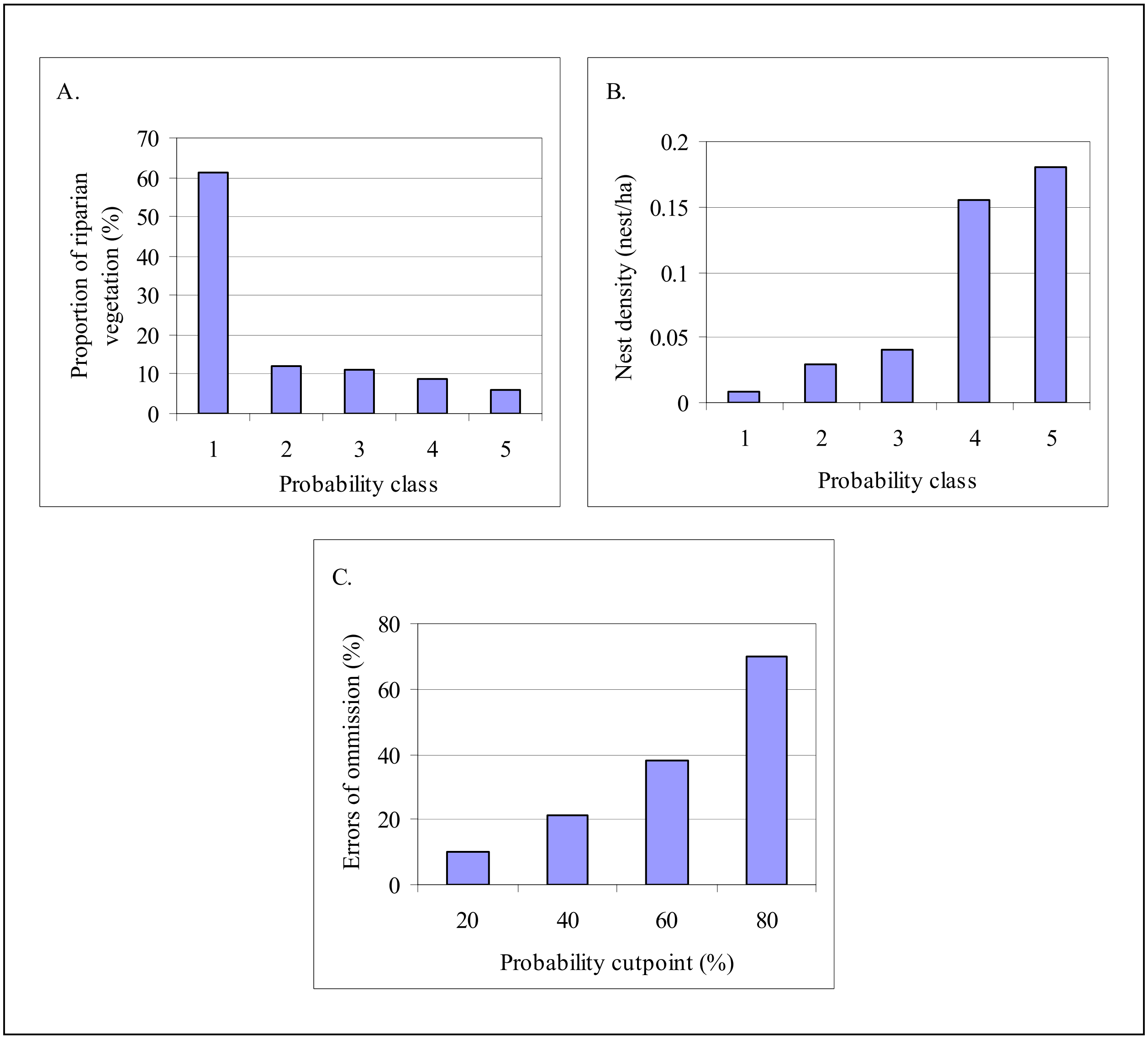

Figure 1.4. The proportion of predicted breeding habitat (A) and nest density (B) within 5 probability classes, produced from a GIS-based model within our project area (Arizona, USA) in 1999, and omission error at different probability cutpoints (C). Nest density was calculated from control sites (nests) not used in model development. The 5 classes divide the probability of breeding activity, as determined from the model, into 20% increments, while errors of omission refer to the number of nests found outside the suitability envelope. Cells with probabilities less than or equal to the probability cutpoint were considered unsuitable, while cells with values greater than the probability cutpoint were considered suitable.

Project Area: 1995-1998 and 2000-2001

When we overlaid breeding-site locations from 1995-1998 (Figure 1.5A) or 2000-2001 (Figure 1.5B) upon the 1999 probability map, nest density increased exponentially in higher probability classes for each time interval. When we considered the entire suitability envelope (probability classes 1-5), errors of omission were 8% within both time frames. Furthermore, errors of omission during 1995-1998 (Figure 1.5C) and 2000-2001 (Figure 1.5D) were similar at each 20% cutpoint.

Our temporal analysis documented movement in SWFL between 1995 and 2001. Some of the 2000-2001 breeding sites were >1 km from previously occupied habitat, but they were located in areas the model predicted to be suitable in 1999. This was demonstrated at Roosevelt Lake's 2 inlets (Salt and Tonto), where immature, unoccupied tamarisk and Goodding willow identified as suitable in 1999 became occupied 1-2 years later. Examining the data, some areas that were predicted suitable in 1999 but contained no breeding sites, had nests in 1995-1998. The most

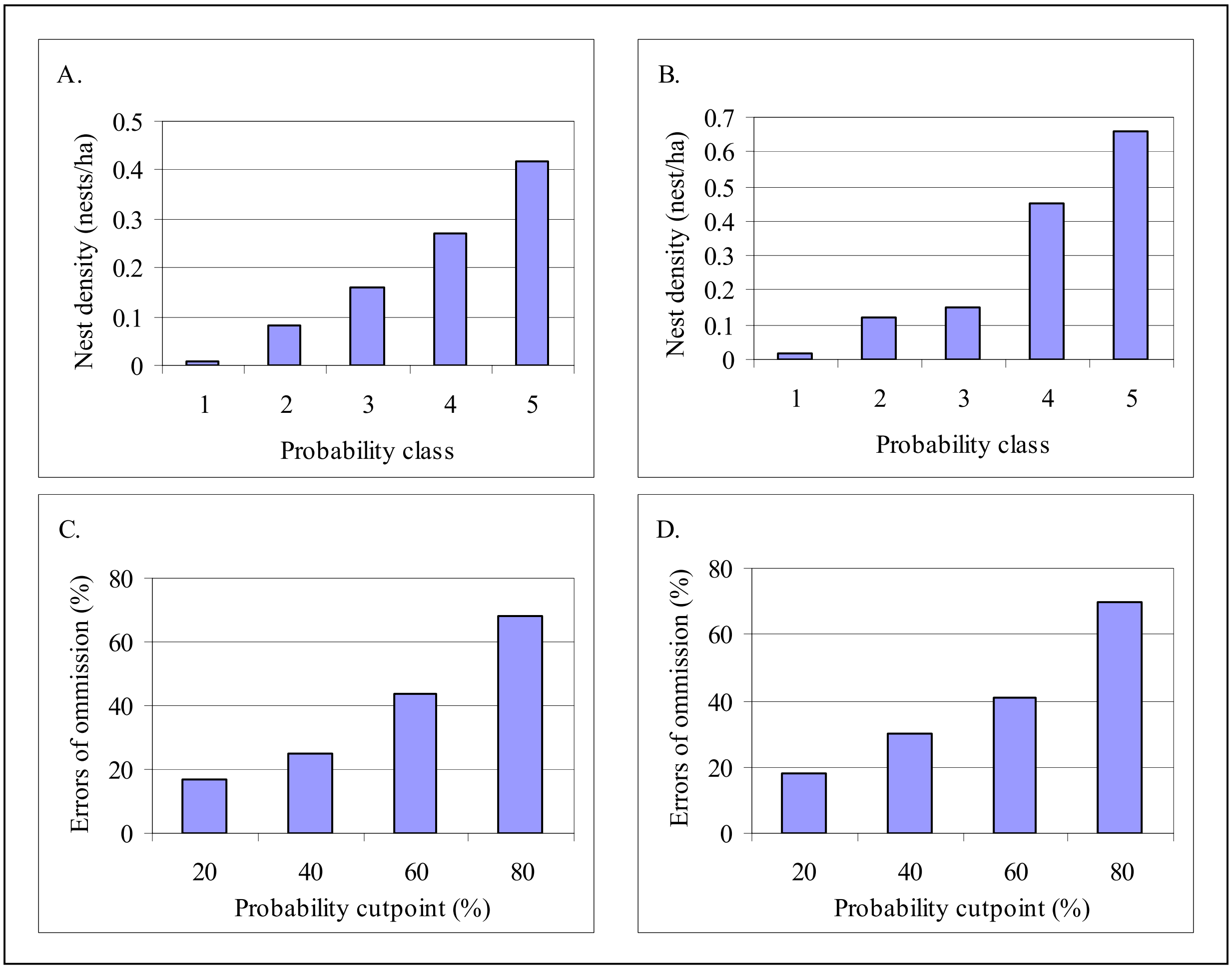

Figure. 1.5. We assessed the temporal accuracy of the 1999 model by overlaying 398 southwestern willow flycatcher breeding sites identified between 1995 and 1998, and 601 between 2000 and 2001, within the project area. Model fit was examined with nest density 1995-1998 (A) and 2000-2001 (B) within 5 probability classes. Model accuracy was determined by omission errors between 1995-1998 (C) and 2000-2001 (D) at 20% probability cutpoints. Cells with probabilities less than or equal to the probability cutpoint were considered unsuitable, while cells with values greater than the probability cutpoint were considered suitable.

pronounced movement occurred within Roosevelt Lake's 2 inlets (Salt and Tonto), where SWFL appeared to move from older riparian habitat (>9 yr old) to younger riparian habitat (<9 yr old).

Alamo Lake Test Area: 1999-2000

The spatial model predicted 1403 ha of breeding habitat in Alamo test area (Figure 1.6), with each cell assigned a probability of breeding activity between 1 and 98%. The amount (ha) of predicted breeding habitat was inversely related to 5 probability classes (Fig. 1.7A), with 76% located in class 1 and 4% in class 5. As with the project area, density of breeding sites increased in higher probability classes (Figure 1.7B), with 0.0009 nests/ha in class 1 and 0.25 nests/ha in class 5. Model fit deviated slightly from expected since the fourth probability class had greater breeding-site density (0.27 nests/ha) than the fifth class (0.25 nests/ha), but breeding-site density did increase in the first 4 classes.

Overall model accuracy (classes 1-5) was better at Alamo Lake (98%) than the project area (95%), with only 1 breeding site falling outside predicted suitable habitat. Furthermore, we had 10% omission error below the 40% cutpoint (Figure 1.7C) at Alamo Lake, compared with 21% in the project area. Ninety percent of breeding sites at Alamo Lake were above the 40% cutpoint,

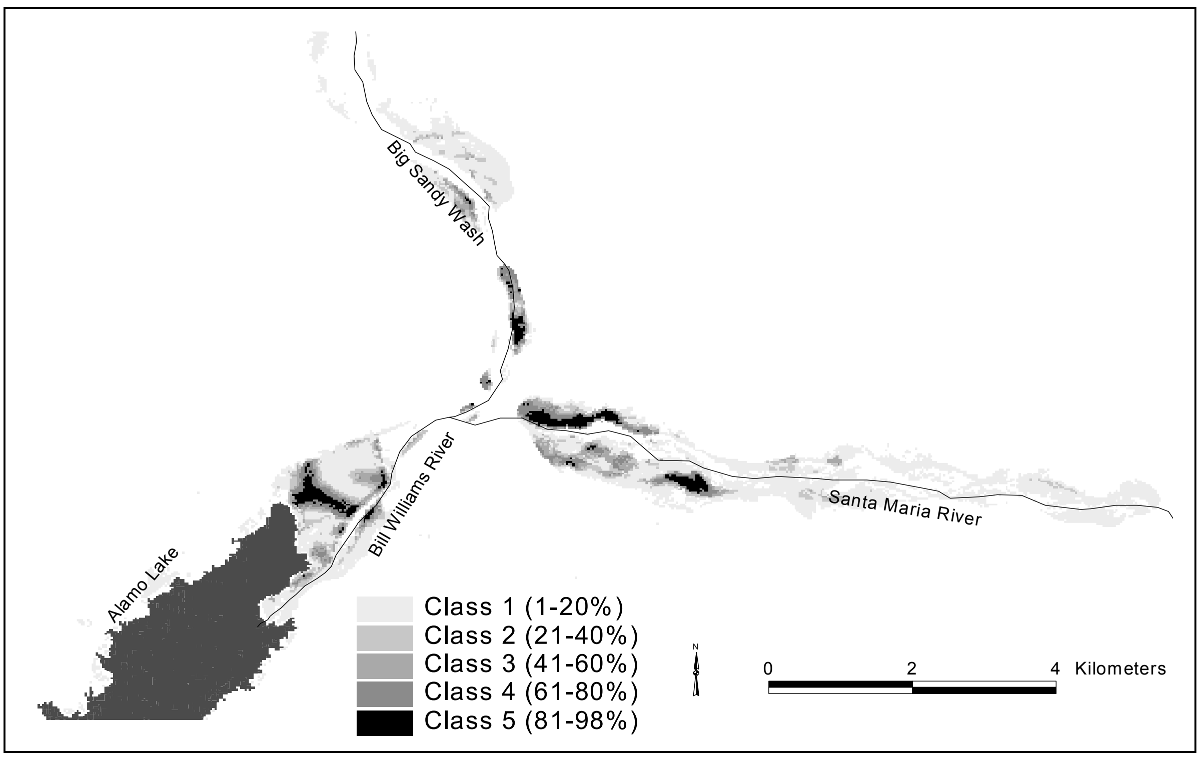

Figure 1.6. A southwestern willow flycatcher breeding-site suitability map of the Alamo Lake, Arizona test area that was produced from a GIS-based model developed 200 km to the southeast. The GIS-based model used logistic regression, digital elevation models, and TM imagery to map the probability of breeding-site occurrence. Probabilities ranged from 1 to 98%, which we reclassified into 1 of 5 probability classes.

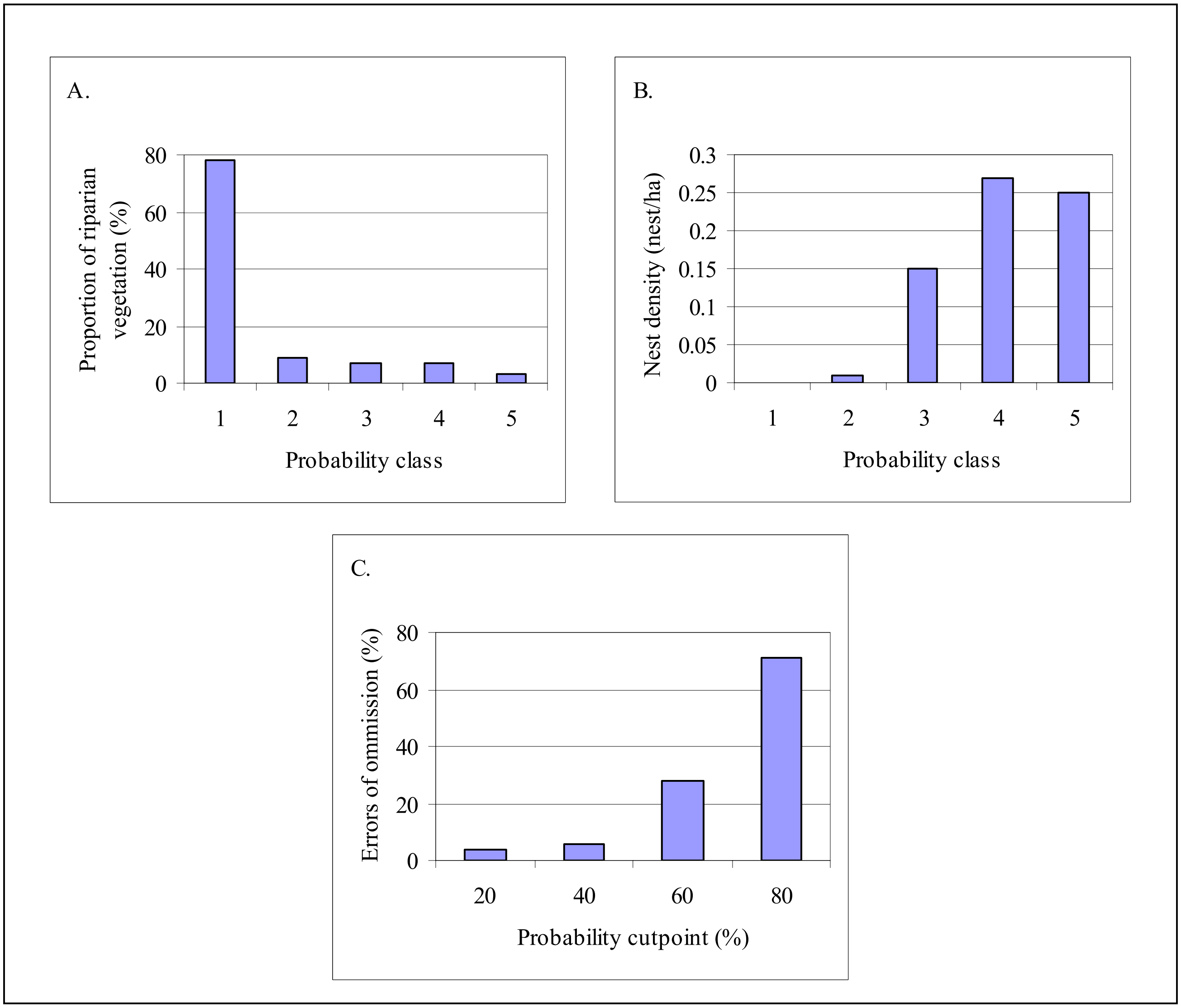

Figure 1.7. The proportion of predicted suitable breeding habitat (A) and density of nest sites (B) within 5 probability classes, produced from a GIS-based model developed 200 km to the southeast in 1999, and omission errors at different probability cutpoints (C). The 5 classes divide the probability of breeding activity, as determined from the model, into 20% increments, while errors of omission refer to the number of nests found outside the suitability envelope. Cells with probabilities less than or equal to the cutpoint were considered unsuitable, while cells with values greater than the cutpoint were considered suitable.

compared with 79% in the project area, occupying 16% of predicted suitable breeding habitat. Similar to the project area, we found pronounced spatial autocorrelation among 5 probability classes, with higher-probability breeding habitat located closer to the lake inlet.

DISCUSSION

HABITAT ASSOCIATIONS

Southwestern willow flycatcher breeding activity and nest density were greater in dense riparian vegetation, a pattern supported by qualitative descriptions of breeding habitat throughout the subspecies' range (Sogge and Marshall 2000). Dense vegetation may benefit offspring production through enhanced concealment from predators (Martin and Roper 1988) and/or a more favorable microclimate (Walsberg 1981). The adaptive significance of localized vegetation parameters has been well studied in avian species (Anderson and Shugart 1974; Larson and Bock 1986; Martin 1992; Clark and Shutler 1999), but intermediate and coarse-scale habitat characteristics have received less attention. We suspect that dense patches of vegetation within a 4.5 ha neighborhood provide refuge, dispersal, and foraging habitat for juvenile and adult SWFL, and might be important to their long-term survival (Lehmkuhl 1984; Lande 1987). Variation in vegetation density within a 4.5 ha neighborhood was also significantly associated with SWFL breeding activity and increased wherever dense riparian vegetation abutted barren floodplain. Selection of edge habitat at a 4.5 ha scale may be important to territorial males by increasing availability of exposed song perches (Sedgwick and Knopf 1992) or foraging opportunities (Barlow and McGillivray 1983; Sedgwick 2000; Sogge 2000).

The majority of breeding sites (96%) found between 1995 and 2001 were located in wide floodplain or flat areas >41 ha, with the remainder (4%) located in relatively confined channels (8-15 ha) located at Alamo Lake and Kelvin. We are uncertain why larger floodplains increased the likelihood of breeding sites, but the reason is probably because topography and fluvial-geomorphic processes play a significant role in riparian plant establishment (Scott and others 1996). The 4 systems we investigated all have large watersheds (1800-46,000 km^2), thus in areas where floodplain was constricted, less area would be available for riparian plant establishment and higher flood velocities through these reaches may limit persistence. Generally in wide, low gradient rivers located in the arid Southwest, dense stands of immature or small trees dominate the middle of the floodplain, while young saplings occur near the active channels and older trees around the outer edges (Stromberg 1993). During 1996-2001, we recorded color-banded flycatchers moving from more senescent patches to younger habitats that regenerated during receding water levels at Roosevelt Lake and in flood-scoured areas along the San Pedro River (Paradzick and others 2001). These patterns suggest that SWFL prefer large, active floodplains that support development of young, wide, and dense stands of riparian vegetation similar to pre-settlement patterns of cottonwood-willow communities that were spatially and temporally dynamic (Graf 1982; Auble and others 1994; Minckley and Brown 1994; Busch and Smith 1995).

MODEL SCOPE AND ACCURACY

Accuracy of the multiscaled model compared favorably with other bird-habitat models developed with remote sensing and GIS, and validated with presence/absence survey data (Lyon 1983; Hodgson and others 1987; Chou and Soret 1996; Vander Haegen and others 2000). Five percent of breeding sites within the project area (1999) and 2% in the Alamo Lake test area fell outside of all predicted suitable areas (classes 1-5) and were errors of omission. Some breeding-site misclassification probability resulted from misalignment of nest locations and TM imagery since imagery had 36 m positional error. Consequentially, some breeding sites located near patch boundaries appeared to be located outside of the riparian patch when they were really inside.

Two factors one might wish to consider when examining the accuracy of the model are map accuracy and the relative scarcity of SWFL. We assessed model accuracy, not map accuracy, and a difference exists between how they are determined and interpreted (Story and Congalton 1986). We used breeding sites to determine model accuracy because breeding sites eliminated uncertainty about the suitability of a location, but did not determine what percent of mapped (modeled) habitat was actually suitable breeding habitat (map accuracy). Therefore, some portion of the cells that were predicted suitable will be unsuitable, but what percentage is currently unknown. Furthermore, the probability of finding a breeding site in a cell predicted suitable will vary annually depending on the population of SWFL. During the 1999 season, one would have to have searched 171 ha (1900 cells) to find a nest in class 1; 22 ha (244 cells) in class 2; 13 ha (144 cells) in class 3; 5 ha (55 cells) in class 4; and 3.5 ha (39 cells) in class 5.

Omission errors increased as the probability cutpoint was raised because less riparian habitat was considered suitable by the model. Selecting the best probability cutpoint depends upon the objectives of the resource manager. For our purposes, a 40% cutpoint appears favorable because it contained only 21% omission error in the project area and 10% in Alamo test area. Furthermore, a 40% cutpoint reduced the area of predicted breeding habitat (as determined from the model) by 76% in the project area and 84% in the Alamo test area. Further work needs to be done to improve the GIS-based model to reduce the area of predicted breeding habitat while minimizing omission errors.

A small difference (3%) in overall model accuracy (classes 1-5) between project (95%) and test areas (98%), located 200 km apart, provided evidence the model coefficients can be extrapolated. However, additional testing of the model in a wider range of habitats will be necessary to fully understand its utility and limitations. For example, the model was developed and tested in areas with large floodplains and extensive stands of riparian vegetation, characteristics that may be absent in other parts of the subspecies' range. Furthermore, the model was developed in an arid landscape where significant spectral contrast existed between upland and riparian vegetation, below 1500 m elevation, and within 2 km of perennial or intermittent waters. Such constraints limit extrapolation of the model to deserts of southwestern United States and Mexico adjacent to perennial or intermittent waters.

ADDITIONAL RESEARCH NEEDS

The impact of tamarisk needs to be clarified because it was present in varying abundance within each survey area (Paradzick and others 2001), but the U.S. Fish and Wildlife Service (1995) listed tamarisk as a factor in the decline of SWFL. We caution that habitat use does not imply reproductive viability and our analysis did not examine the influence of predictor variables on SWFL reproductive rates (Van Horne 1983; Powell and Steidl 2000). However, survey and nest monitoring data suggest that both the Roosevelt and Gila/San Pedro Confluence populations are stable or increasing (Paradzick and others 2001).

Managers would benefit if the vegetation variables we found to be important were linked to traditional habitat measurements (for example, canopy cover, basal area, mean vegetation height, tree species, seral stage, distance to water, edge habitat, forest fragmentation), thereby providing a bridge between modeled and field data. Within occupied patches in the project area, SWFL select nesting sites that contain dense vegetation at 3-5 m above ground, are closer to canopy breaks and water, and are associated with specific species and size classes of riparian trees compared to non-nesting plots (Allison and others 2003). Failure to include these attributes limits the model's ability to consider the full range of habitat parameters. Combining traditional ground-based habitat measurements at the nest and patch scale with model results will provide a more comprehensive picture of SWFL habitat selection. Similarly, influence of behavioral traits (clumping and site fidelity) on site selection needs to be explored (Sogge 2000); such traits could lead to high densities in some patches while similar habitat remains unoccupied.

Additional research is necessary to explain the ecological significance of breeding-site dispersion (see Gates and Gysel 1978; Schieck and Hannon 1993), patch size and arrangement, and proximity of breeding sites to perennial–intermittent streams or land use classes (for example, agricultural, urban). Lastly, additional research is necessary to clarify the structural characteristics and biological significance of the NDVISTD variable. We know from GIS overlays that NDVISTD increased where dense riparian forest abutted barren floodplain, but our multiscaled analysis produced different patterns in variability depending on the size of neighborhood examined. Such scale-dependent patterns suggest that researchers should examine habitat features at multiple scales to gain a better understanding of their biological significance to SWFL.

MANAGEMENT IMPLICATIONS

Prioritizing Surveys

The multiscaled model is an important tool for managers because it can rank and map predicted breeding habitat outside the area where the model was developed. Identifying lower-probability breeding habitat (≤40%) for SWFL is important because this habitat accounted for 74-84% of riparian forest and contained lower breeding-site density. This identification is very relevant in Arizona because the state's vast size makes habitat and breeding surveys time consuming and expensive. Managers can prioritize surveys based upon an area's suitability ranking, surveying the most suitable areas first and less suitable areas as resources permit. The distribution of predicted breeding habitat was clumped, not random or dispersed, enabling crews to sweep areas with higher probability quickly and efficiently to locate occupied habitat and develop SWFL population estimates. Additionally, for the first time we can map possible habitat in private lands and remote areas that may never be visited, gaining valuable insight for management and conservation purposes.

Habitat Change Detection

An exciting but untried application of the model is assessing changes in SWFL breeding habitat over time. Changes in quality and abundance of breeding habitat along mainstem-rivers and lake deltas could be assessed at fixed time intervals or retrospectively since 1984 when TM imagery became available. Landsat is an ideal platform for change detection since it passes over the same place every 16 days, imaging the Earth in 185 km swaths (Aronoff 1989). Thus, the model could provide important information for assessing impacts of land management activities that would be difficult to quantify on the ground. Change detection could be done in a simulated fashion (before the change happens), by manipulating imagery to reflect a proposed change, or by running the model before and after an activity. Additionally, the model could generate habitat information across significant portions of the subspecies' range by assessing changes in habitat within 1 or more TM scenes. However, change detection will require careful attention to time of year and location because the structural and chemical properties of deciduous riparian vegetation change seasonally, and are affected by geography.

Multiscaled Approach

Southwestern willow flycatcher breeding habitat was comprised of landscape and vegetation features found at different spatial scales (0.09-41 ha), which further supports a multiscaled approach to species-habitat analyses and management (Gutzwiller and Anderson 1987; Kotliar and Wiens 1990; Wiens and others 1993; Saab 1999). While 2 intermediate-scale variables (NDVIBEST4 and NDVISTD4) explained 5.6 times more variability in breeding-site occurrence than fine- or coarse-scale variables combined, model fit improved when all 3 scales were included. This improved fit suggests that SWFL breeding habitat is a spatially nested hierarchy with floodplain nurturing and supporting a mosaic of patches that contain breeding sites. Thus, managers should consider habitat components and their juxtaposition at multiple spatial scales.

Proactive Management

Managers can take a proactive approach toward conservation and management of SWFL by identifying and protecting occupied and unoccupied breeding habitat across the species' range. Unoccupied areas offer refuge when SWFL are displaced from breeding sites and may be important stopover points for migrating SWFL or other willow flycatcher subspecies. The USFWS (1995) took an important first step by attempting to conserve extant SWFL populations and their habitat. Our multiscaled model with ground verification can assist managers by identifying both occupied and unoccupied habitat throughout Arizona.

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CHAPTER 2

APPLICATION OF A SOUTHWESTERN WILLOW FLYCATCHER GIS-BASED HABITAT MODEL: AN ESTIMATE OF BREEDING HABITAT IN ARIZONA, 2001

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EXECUTIVE SUMMARY

The southwestern willow flycatcher (*Empidonax traillii extimus*), a neotropical migrant, was listed as an endangered species in 1995. One of the crucial information gaps needed to conserve and recover the bird was a map of suitable breeding habitat within Arizona. We used a published GIS-based habitat model that incorporates variables extracted from 30 m resolution Landsat Thematic Mapper (TM) imagery and digital elevation maps to delineate suitable habitat in Arizona. We applied the model in riparian areas <1525 m elevation that contained perennial or intermittent stream flow using 2001 TM imagery and digital elevation maps. Model output included a 30 x 30 m grid-format map with the probability (1-98%) of each cell containing suitable breeding habitat. We grouped probabilities into 5 classes by 20% increments based on the published model: class 1 (<20%) had low probability of containing suitable habitat, and class 5 (>80%) had higher probability. The model identified 398,300 ha that could contain suitable willow flycatcher breeding habitat (probability classes 1-5). However, 94.6% of riparian area mapped had low probability (classes 1-2) of containing breeding habitat, whereas 3.4% was identified as higher probability habitat (classes 4-5). The Gila River Basin contained the greatest amount of higher probability breeding habitat in the state. Land managers and researchers can use these results to identify flycatcher habitat across the state, allowing for better informed decisions when prioritizing future surveys efforts, habitat restoration, and habitat protection.

CHAPTER 2

APPLICATION OF A SOUTHWESTERN WILLOW FLYCATCHER GIS-BASED HABITAT MODEL: AN ESTIMATE OF BREEDING HABITAT IN ARIZONA, 2001

Patrick E.T. Dockens, Charles E. Paradzick, and James R. Hatten

INTRODUCTION

One of the primary research needs to further recovery efforts for the endangered southwestern willow flycatcher (SWFL; *Empidonax traillii extimus*) is to determine the current distribution and extent of riparian habitat (Stoleson and others 2000). Such data, coupled with surveys, can help refine our knowledge of SWFL distribution and abundance, unoccupied possibly suitable habitat, and lead to a better understanding of habitat limitations. This need is crucial in Arizona because the state lies in the central portion of the bird's range and contains >30% of the known rangewide population. In addition, there has been a precipitous decline in flycatchers in the last century (Unitt 1987; Sogge and others 2003). The population decline has been primarily attributed to the loss and degradation of riparian forest in the Southwest. Over 90% of riparian habitat has been lost or severely altered in Arizona over the last century (Governor's Riparian Habitat Task Force 1990; U.S. Fish and Wildlife Service [USFWS] 1995). Thus, locating and protecting the remaining stands of riparian habitat, possibly suitable for breeding SWFL in Arizona, are high conservation and recovery priorities (USFWS 2002).

While much work has been done to locate SWFL in Arizona through surveys beginning in 1993, much of the riparian habitat within the state remains unsurveyed (Paradzick and Woodward 2003). Due to cost and resource constraints, it would be impractical to survey all riparian habitat in the state in any one year. To overcome similar challenges for other species and in other areas, spatial (GIS) habitat models have been designed and used to identify sensitive habitats (Palmeirim 1988; Rosenberry and Sudkamp 1998), prioritize survey efforts to locate occupied habitat (Conner 2002), and predict species abundance and distribution across large areas (Avery and Haines-Young 1990). One of the primary reasons we developed and tested the GIS-based habitat model (Chapter 1; Hatten and Paradzick, 2003) was to predict locations of suitable habitat and prioritize survey efforts. The SWFL GIS-based habitat model (Chapter 1) used SWFL nest location data, variables extracted from Landsat Thematic Mapper (TM) imagery, digital elevation maps (DEM), and multiple logistic regression to rank breeding habitat suitability <1524 m elevation (see Chapter 1 for more discussion on the model). Variables extracted from satellite-based imagery were easily applied to broad areas, unlike aerial photos, or expensive ground-based vegetation mapping.

The second step in delineating possible habitat, and the goal for this project, was to extrapolate the GIS-based model statewide. Extrapolation was restricted to areas with high spectral contrast between riparian habitat and upland vegetation (Chapter 1). This excluded riparian vegetation communities above 1500 m, specifically montane wet meadows and shrub willow patches surrounded by pine and conifer forests. However, Paradzick and Woodward (2003) noted that only 3 of the 92 known occupied sites (<95% of SWFL territories) located between 1993-2000 were above 1500 m elevation. Thus, the GIS-based model is ideally suited for lower elevation riparian communities (Sonoran riparian deciduous forest [Brown 1994]) that contain the majority of nesting SWFL in Arizona. The primary riparian tree species used by SWFLs in this community, are Fremont cottonwood (*Populus fremontii*), Goodding willow *(Salix gooddingii*), and tamarisk (*Tamarisk* spp.). These are primarily phreatophytic trees, dependent on shallow groundwater and found along perennial and intermittent streams (Stromberg 1993). This association with the presence of groundwater allowed us to further reduce the project area by eliminating ephemeral streams or washes from consideration.

We determined in Chapter 1 that model accuracy is high; that is, most of the SWFL nests in the project area were encompassed by habitat that was predicted suitable by the model. However, knowledge of map accuracy (habitat which is predicted suitable by the model and actually is suitable SWFL habitat) is lacking. While SWFL occupancy and reproductive success are the ultimate parameters to judge habitat quality, we used published literature and expert knowledge to make an assessment of the predicted suitable habitat in the field. We focused on characteristics that could easily be estimated and are important to SWFL: patch size and arrangement, floristic composition, vegetation structure, and presence of water (Sogge and others 1997; Allison and others 2003; Paradzick and Woodward 2003).

Thus, for this project, we had 2 main objectives: (1) run the model on statewide imagery to delineate predicted suitable breeding habitat, and (2) determine the map accuracy of the model (map accuracy is reflected by errors of commission or when the model identified habitat as suitable even though it was not). With the results, we hope to provide managers and researchers the ability to effectively and efficiently identify possible SWFL breeding habitat across the state. Use of this model will allow for better informed decisions when prioritizing conservation and preservation efforts, including surveys, habitat restoration, and habitat protection.

METHODS

STUDY AREA

Within Arizona we identified riparian areas <1524 m in elevation that occurred along perennial/intermittent waters (that is, streams, lakes, reservoirs, and cienegas). We used a GIS to buffer the riparian areas by 1.6 km from the center of the waterway to exclude much of the surrounding upland vegetation while still capturing wide riparian forests located along the larger mainstem rivers. The area modeled for suitable SWFL habitat encompassed 8.5% (25,103 km^2) of Arizona (Figure 2.1).

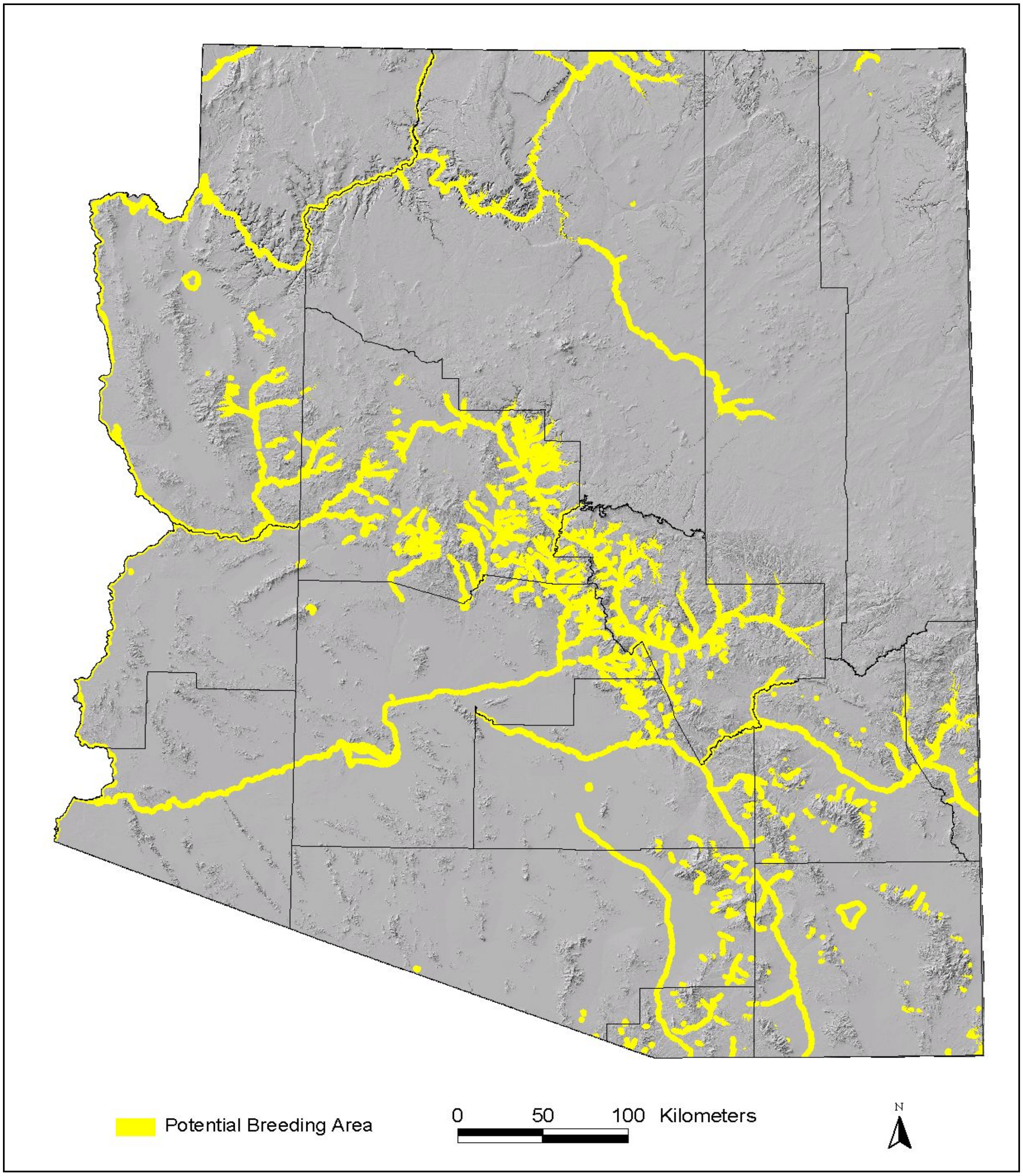

Figure 2.1. Areas that might support southwestern willow flycatcher breeding habitat were identified with a GIS by buffering perennial/intermittent waters <1524 m elevation by 1.6 km. Only areas within the buffer were included in the model.

MAP DEVELOPMENT

We used the same 4 predictor variables to characterize vegetation and floodplain features at multiple scales described in Chapter 1. We used a statewide TM image mosaic and a statewide DEM to build GIS layers. The 2001 TM imagery was terrain corrected (the 1999 imagery was not), which we expected to decrease positional error. The images were tonal matched because the Normalized Difference Vegetation Index (NDVI) is sensitive to solar illumination angle and image processing. We acquired TM imagery scenes between May 23 and June 3, 2001 (Table 2.1), a period with little difference in solar illumination angle, and performed a histogram match on bands 3 and 4 for all images. We conducted a tonal-contrast sensitivity analysis by comparing model results obtained from a single TM scene with those obtained from the same scene after mosaicking the whole state together. The tonal-contrast sensitivity analysis showed the GIS-based model could be run on a single TM mosaic provided the scenes were tonally adjusted with a histogram match.

Table 2.1. Date and time TM imagery was acquired for statewide application of southwestern willow flycatcher habitat model.

Scene ID[a]	Date	Time[b]
LT5038034036001143	May 23, 2001	17:49:36
LT5038037000114310	May 23, 2001	17:50:24
LT5036034036001145	May 25, 2001	17:37:17
LT5036037038001145	May 25, 2001	17:38:17
LT5039034035001150	May 30, 2001	17:55:42
LT5039036000115010	May 30, 2001	17:56:17
LT5037034036001152	June 1, 2001	17:43:33
LT5037037038001152	June 1, 2001	17:44:33
LT5035035037001154	June 3, 2001	17:31:36
LT5035038000115410	June 3, 2001	17:32:24

[a] Scene ID is a USGS designation.
[b] Time is Greenwich Mean Time (GMT).

We used the GIS-based model to create a statewide SWFL breeding habitat map with the same techniques outlined in Chapter 1. A GIS layer (30 x 30 m cells) was created that was populated with the probability (1-98%) of the cell containing SWFL breeding habitat. As described in Chapter 1, we reclassified the probability into 5 classes (approximately 20% per class), 1 having the lowest and 5 the highest probability of a cell containing suitable SWFL breeding habitat.

We quantified the amount of predicted breeding habitat within 16 hydrologic basins and 85 subbasins by overlaying the U.S. Geological Survey (USGS) Hydrological Unit Code (HUC) boundaries and the 5 probability classes produced from the model. The HUC boundaries were convenient because they allowed us to examine our results at different hydrologic scales, ranging from whole or major portions of basins (HUC code: Subacc ID), such as Salt or Little Colorado river basins, to subbasins (HUC code: Subacccat ID) such as the Agua Fria or Hassayampa river basins. We also overlaid model results on 7.5’ USGS topographic quadrangles to identify at a finer scale, higher probability (classes 4-5) breeding habitat.

ACCURACY ASSESSMENT

We examined model accuracy at 3 probability cutpoints (40% [classes 3-5], 60% [classes 4-5], 80% [class 5]) by overlaying 375 nest sites collected in 2001 (AGFD unpublished data) from 3 study sites: Roosevelt Lake, Alamo Lake, and the confluence of the San Pedro and Gila rivers (see Chapter 1 for explanation of probability cutpoints, pg. 13). We determined errors of omission at the 3 probability cutpoints. Errors of omission are when the model incorrectly identifies suitable habitat as unsuitable. We also examined temporal accuracy of the model by overlaying 1128 nest locations collected between 2000 and 2002 (AGFD unpublished data) from the study sites at Roosevelt Lake and the confluence of the San Pedro and Gila rivers to look for overlap with the model's predicted suitable habitat. Additionally, we examined model accuracy by overlaying 547 patches occupied by resident SWFLs reported by AGFD and statewide surveyors between 1993 and 2002. Occupied patches were converted (drawn) into a polygon layer in a GIS using estimates of occupied area delineated by surveyors in the field on 7.5' USGS topographic maps. Surveyors were required to submit these maps showing patch location and survey routes when reporting their data to AGFD and the USFWS (Sogge and others 1997). We determined accuracy by examining the spatial intersection of occupied patches with the model's probability classes. Patches that had no high probability classes (classes 4-5) intersecting them were considered errors of omission. We also quantified errors of omission in SWFL occupied patches using different year subsets: 1993-2002 (n = 547), 1997-2001 (n = 446), and 2001 (n = 72) to examine temporal accuracy of the model.

To calculate errors of commission, when the model identified habitat as suitable when it was not, we ground truthed predicted suitable breeding habitat. We first created 5000 random points stratified by probability class within the entire study area. Because time and resources were limited, we focused (>50% of points sampled) on higher quality habitat (classes 4-5). This focus helped us identify the vegetation types or habitat features the model was misidentifying as suitable. We also limited our ground truth points to public lands (federal, state, municipal) because we did not have the resources to obtain permission letters from all private landowners. We completed habitat evaluations at 95 random points.

At each random point, an experienced willow flycatcher surveyor, with no knowledge of the predicted model classification, visually estimated habitat characteristics: presence of water; grazing intensity (indicated by presence of sign of grazing, for example, hoof prints, fresh dung, or trampled vegetation); vegetation structure, density, and species composition; and forest patch size and configuration (Appendix 2.3). The field observer used these data to assess the habitat as unsuitable, potentially suitable (within 1-5 years from time of observation) and suitable. Floodplain width, the type of flow, and the probability class predicted by the model were entered in the office after ground truthing was completed. We grouped potentially suitable and suitable habitat for the error assessment because we expected that the spectral differences between potentially suitable habitat and suitable were not large enough for the model to accurately distinguish. Field scores and model classes were compared using an error matrix (Story and Congalton 1986) to provide errors of commission and overall accuracy.

RESULTS

Of the 8.5% of Arizona that was modeled, 3983 km^2 (15.9% of the study area) was predicted suitable breeding habitat. Most (90.5%) predicted habitat was classified in the lowest probability class (class 1). Class 2 was 4.1% of predicted habitat, and the remaining classes were fairly constant (2.0% class 3; 1.8% class 4; and 1.6% class 5).

The Gila River Basin contained a disproportionate amount (>55%) of high probability habitat (class 4-5) in the state (Figure 2.2). At a finer scale, a large amount of predicted habitat was identified near San Carlos Reservoir, including the lower sections of the San Carlos River and 20 km upstream from the reservoir along the Gila River (Figure 2.3). The section of the Gila River draining the Agua Fria and Hassayampa river basins (Subacc 701) contained 1891 ha of class 4-5 habitat, followed by the San Pedro River Basin (1600 ha). High probability habitat was concentrated near reservoirs (San Carlos Reservoir and Roosevelt Lake), and along larger rivers (Gila, San Pedro, Salt, and Verde rivers) while being unevenly distributed along the 85 smaller drainages (Appendix 2.1).

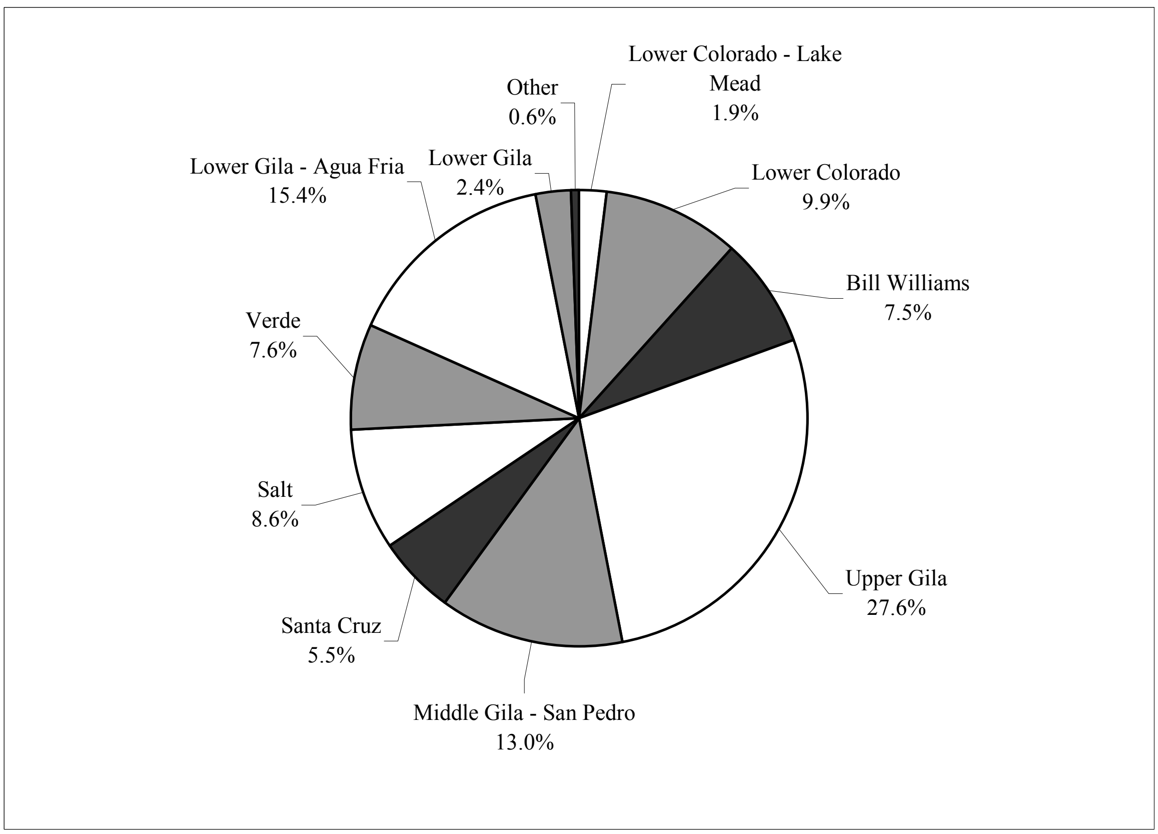

Figure 2.2. Distribution of high probability (class 4-5) southwestern willow flycatcher breeding habitat in 2001 among subbasins <1524 m elevation in Arizona (percentage shown is classes 4-5 ha/classes 1-5 ha). Total amount of high probability habitat was 12,298 ha.

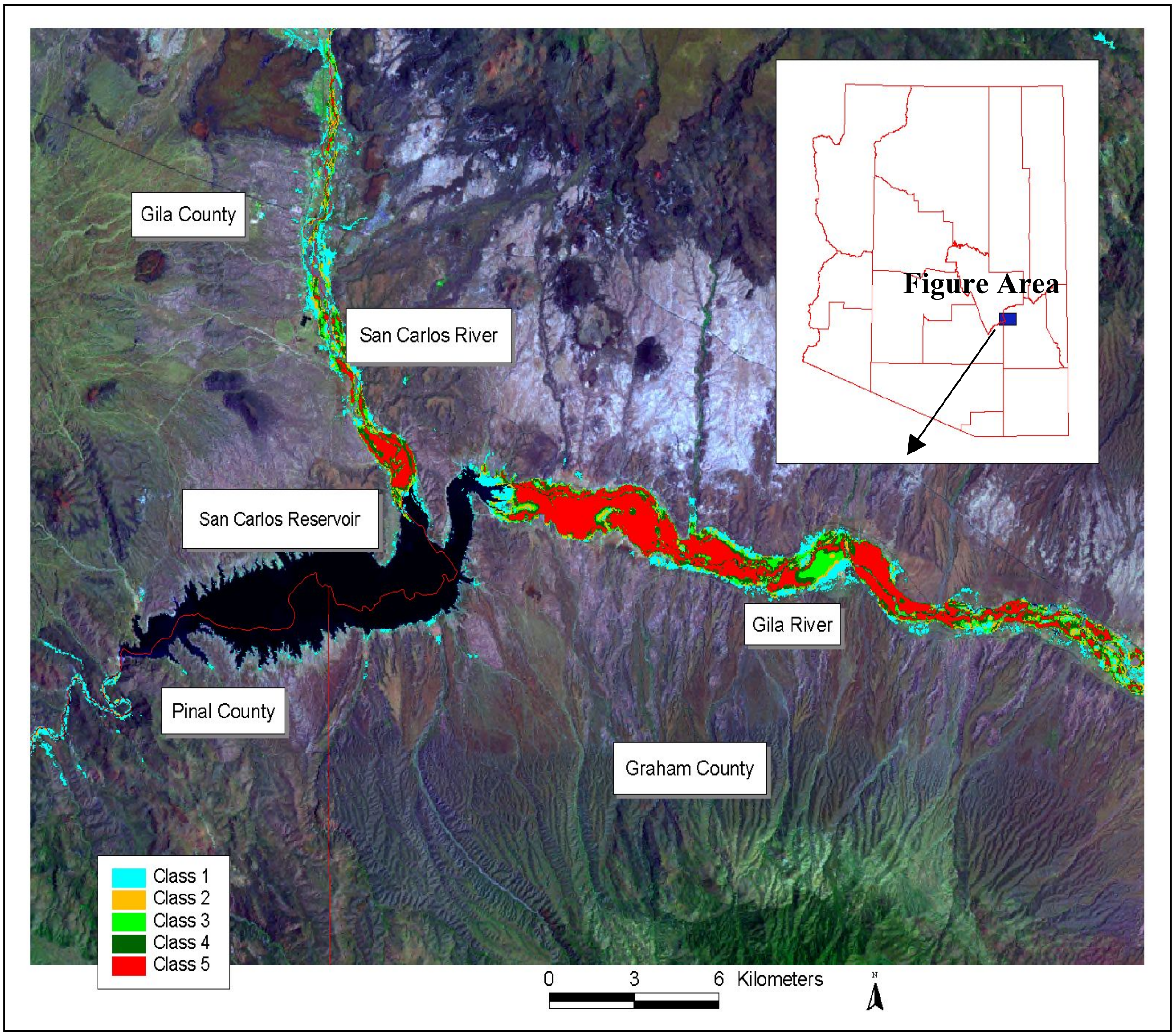

Figure 2.3. High probability (classes 4-5) southwestern willow flycatcher breeding habitat near San Carlos Reservoir in east-central Arizona, 2001.

Overlaying high probability habitat on 7.5' quadrangles (Figure 2.4; Appendix 2.2) showed that Dewey Flat, located at the Gila River inlet to San Carlos Reservoir, contained approximately twice as much high probability habitat (1121 ha) as any other quadrangle. Three other areas with extensive stands of habitat were identified: the confluence of the lower San Pedro and Gila rivers; lower Colorado River near Cibola National Wildlife Refuge, and the Gila River west of Phoenix.

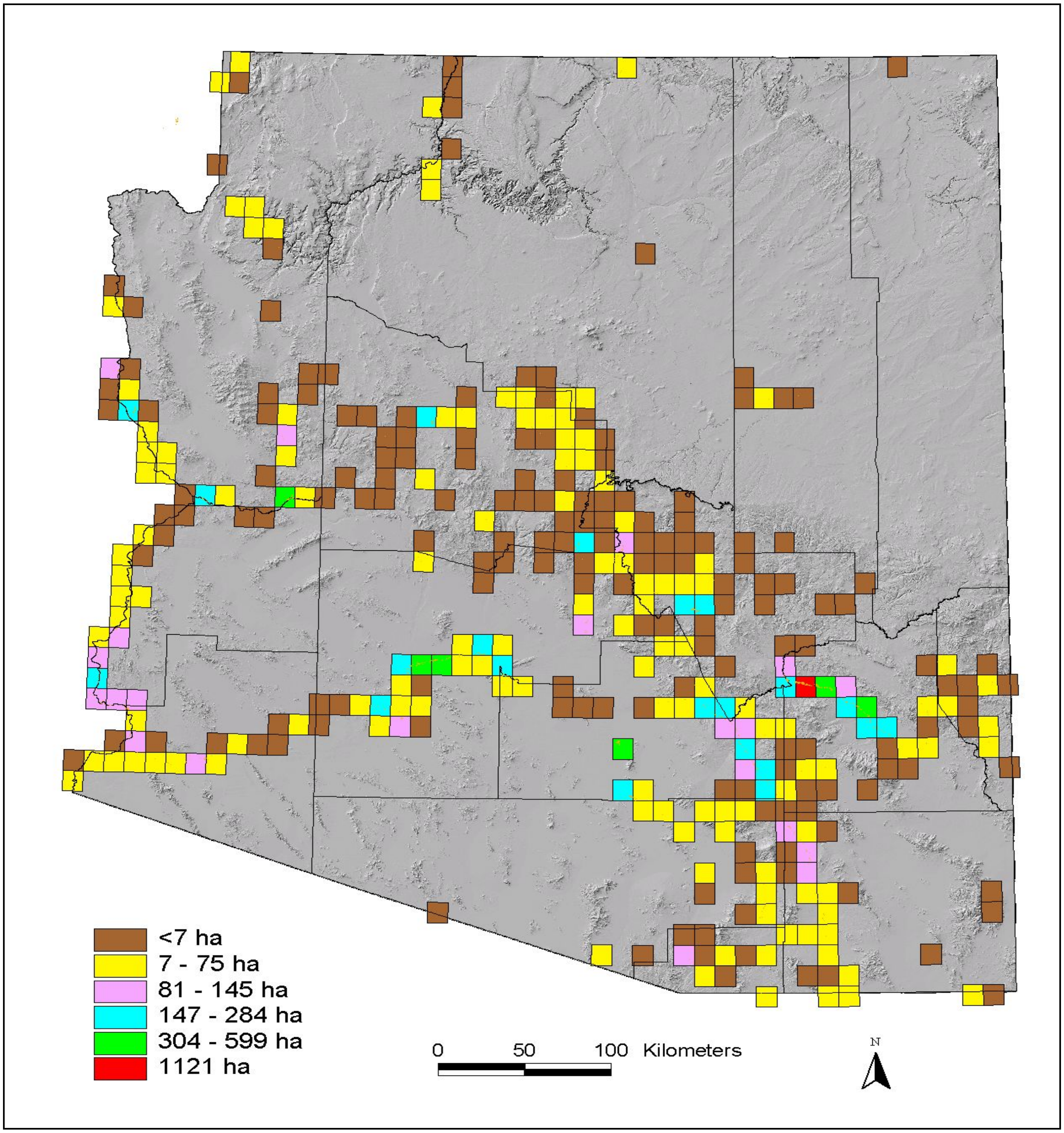

Figure 2.4. Distribution of high probability (classes 4-5) southwestern willow flycatcher breeding habitat within 7.5' quadrangles in Arizona, 2001.

MODEL ACCURACY

Overall accuracy (classes 1-5) for 2001 nests was 96.5% (Table 2.2). Error increased as the lower probability classes were not considered suitable. For example, if the user only surveyed class 5 habitat, 30% of the habitat containing nests in 2001 would not have been searched. Whereas, if all classes were searched, <4% of the habitat containing nests in 2001 would not have been searched. When we applied a temporal component using 2000-2002 nests, model accuracy (using classes 1-5) decreased to 94.1%. The error rates (using classes 1-5) for SWFL occupied patches were similar to nests: 1993-2002 occupied patches = 90.3%; 1997-2002 occupied patches = 91.9%; 2001 occupied patches = 93.1%.

Table 2.2. Southwestern willow flycatcher habitat model accuracy (based on 2001 TM imagery) calculated using nest locations and occupied patches in Arizona.

SWFL occurrence data	N	% nests or occupied habitat not identified by the model as suitable (errors of omission) by habitat class(es)[a]			
		1-5	3-5	4-5	5
2001 Nests[b]	375	3.5	4.3	10.9	29.3
2000-2002 Nests[b]	1128	5.9	9	18	37
1993-2002 Occupied Patches[c]	547	9.7	21	29	47
1997-2002 Occupied Patches[c]	446	8.1	16.4	24.7	42.6
2001 Occupied Patches[c]	72	6.9	11.1	18.1	36.1

[a] The model does not correctly identify habitat that is known to be suitable, causing errors of omission.
[b] Collected at Roosevelt Lake, Alamo Lake, and the confluence of the San Pedro and Gila rivers.
[c] Collected statewide.

MAP ACCURACY

Map accuracy (errors of commission) increased in higher probability classes (Table 2.3). We lacked the resources to check each class with the same amount of effort, and chose to focus primarily on the upper probability classes, so results should be considered preliminary. Our results are consistent with the pattern observed in Chapter 1, with fewer classification errors in higher probability classes. Map accuracy, like model accuracy, is dependant on what probability cutpoint is selected (for further explanation of cutpoints, see Chapter 1, pg. 13). If researchers survey all class 5 habitat (80% cutpoint) in the state, approximately 20% of the habitat would be unsuitable for SWFL, and based on model accuracy (Table 2.2), they would miss approximately 30% of nests. However, if researchers surveyed all class 3-5 habitat (40% cutpoint), 32% would be unsuitable habitat, but <5% of SWFL would be missed.

Table 2.3. Southwestern willow flycatcher predicted breeding habitat map accuracy based on ground truthing of sites in Arizona, 2003.

Habitat model prediction class	Total sites ground truthed	Ground truthed field assessment		Errors of commission by class[a]	Accuracy by class[b]
		Not suitable	Suitable or potentially suitable		
5	42	12	30	28.6%	79%
4	27	11	16	40.7%	67.7%
3	16	7	9	43.7%	56.3%
2	8	4	4	50.0%	50.0%
1	2	2	0	100%	0.0%

[a] The model identified habitat as suitable when it was not, causing errors of commission, shown as percentage of sites predicted as suitable but were not.
[b] Accuracy adjusted for burned areas and/or management changes, shown as percentage of sites that were identified as suitable by the model and were deemed suitable in the field.

Commission errors in high-elevation riparian areas were often associated with vegetation communities comprised of oak (*Quercus* spp.), juniper (*Juniperus* spp.), pine (*Pinus* spp.), sycamore (*Plantanus wrightii*), manzanita (*Arctostaphylos* spp.) or hackberry (*Celtis* spp.). In contrast, low-elevation commission errors were most frequently associated with mesquite (*Prosopis* spp.) forests, desert broom (*Baccharis sarothroides*), or creosote (*Larrea tridentata*) shrubs. The shrub misclassifications were areas with dense shrublands and few or no trees. One commission error was ornamental landscaping trees in a city park. Two of the errors were the result of a management change after the 2001 imagery was acquired, which allowed an irrigation water catchment basin to dry out defoliating trees and reducing forest cover (Table 2.4).

Table 2.4. Southwestern willow flycatcher GIS-based habitat model commission error types, Arizona, 2003.

Habitat model class	Error type (number of sites)					
	Near upper elevation limit	Mesquite or riparian shrubs	Xeric shrubs (creosote)	Burned areas	Management change	City park
5	5	0	2	3	1	1
4	4	2	2	2	1	0
3	4	2	1	0	0	0
2	1	3	0	0	0	0
1	1	0	0	1	0	0

DISCUSSION

HABITAT MAPPING

Our application of the GIS-based SWFL habitat model provides the first inventory of possible breeding habitat on a statewide scale. Consistent with results from model development and testing in Chapter 1, as the probability class increased, the amount of habitat predicted suitable decreased. This relationship gives managers the ability to prioritize future survey effort in areas with the greatest chance of finding suitable habitat and SWFL. We overlaid survey routes from 2000-2003 on a subset of areas with large quantities of predicted suitable habitat to show how the imagery could be used to identify areas with predicted suitable habitat that have not been surveyed adequately (Table 2.5). The model can also be used to identify areas with conservation potential, where there is potential for habitat restoration (that is nearest high quality habitat), or used to evaluate degradation and destruction of habitat (see Jenkins and others 2003, Sanchez-Azofeifa and others 2001). The SWFL recovery plan (USFWS 2002) identifies population goals for a number of regions throughout the species' range; the model could be used to identify habitat within regions for protection and help to secure the SWFL population in Arizona.

Table 2.5. A partial list of priority (to be surveyed) southwestern willow flycatcher (SWFL) survey areas in Arizona. (High probability SWFL breeding habitat [classes 4-5]).

River basin	7.5' Quadrangle	Area
Colorado River	Page	West of Page
	Mount Manchester	North of Topock on the Fort Mohave Indian Reservation
	Palo Verde	County Park
Gila River	Citrus Valley West, Citrus Valley East, Smurr	West of Tres Rios, Painted Rock Reservoir
	Laveen, Montezuma Peak, Pima Butte	South and west of South Mountain
	San Carlos, San Carlos Reservoir, Dewey Flat, Calva	San Carlos River where it enters the reservoir upstream to Geronimo
	York	East of confluence with San Francisco River
Verde River	Granite Reef Dam, Fort McDowell	North of confluence with Salt River
	Chalk Mountain	Sycamore Creek by Sheep's Bridge
	Horner Mountain	South of confluence with West Clear Creek
	Chino Valley North	Williamson Valley, north of Prescott
Santa Cruz	Samaniego Hills	South of Picacho Peak
	Picacho Reservoir	Picacho Reservoir
San Pedro	Kielberg Canyon	Several stretches upstream of canyon

The model provides a snapshot in time of predicted suitable habitat. The largest concentration of predicted suitable habitat occurred at San Carlos Reservoir. In 2001, the reservoir was 22 m below conservation pool, suggesting that large portions of the habitat could be with sufficient runoff and storage, a process similar to the fluctuations in habitat availability at Roosevelt Lake (Chapter 3), and Lake Mead (McKernan and Braden 1998). Along rivers and streams, habitat is also highly dynamic. Large floods in 1984 and 1993 removed riparian vegetation along many of Arizona's rivers (Huckleberry 1994). Thus, if we had selected post-flood imagery in 1993, a very different picture of available breeding habitat would have been obtained. For example, in the early and mid 1990's along the San Pedro River, SWFL were primarily found in forest patches located on higher terraces that survived the 1993 flood (Sferra and others 1997). SWFL occupied and bred at these sites in the late 1990's, and subsequently colonized trees that reestablished within the scoured channel (Paradzick and others 2000; Luff and others 2000, Paradzick and Woodward 2003), demonstrating that reoccurring disturbances (whether by natural flood, drought, or reservoir inundation and drawdown, see Chapter 3) influence the distribution and abundance of SWFL breeding habitat in any one year. With satellite imagery available from the past, and with future research, we will be better able to describe riparian ecosystem dynamics;

knowledge that would provide insight into the mechanisms that create and sustain SWFL breeding habitat on temporal and spatial scales.

MODEL ACCURACY

An unexpected result of our modeling effort was the discovery that the GIS-based model performed better on a statewide scale than in the original project area (see Chapter 1), with fewer nests (3.5%) outside the probability envelope (classes 1-5) in 2001 than in 1999 (5%). In general statistical models do not perform as well when extrapolated outside their original development area. One of the most likely reasons the GIS-based model performed better in 2001 was the use of terrain corrected TM imagery provided by the USGS. In 1999, many of the omission errors were caused when nest sites on the periphery of the habitat appeared to be outside of the predicted suitable area when they were actually just misaligned on TM imagery that had lower positional accuracy. Our results indicate that the GIS-based model might continue to improve if higher resolution multispectral imagery were used to recalibrate the model at a future date.

Our effort to determine map accuracy found more commission than omission errors, which is expected when comparing these 2 statistics (Story and Congalton 1986). Commission errors tend to be larger because classification errors are not independent, that is, errors that occur in one class usually impact another class as well. Thus, the less accurate one class performs, the more errors will be found in other classes. We refer to our map accuracy assessment as a preliminary effort because funds were lacking to collect a sufficient number of samples among classes to develop class confidence intervals. Furthermore, stratification of probability classes by elevation, plant communities, and watershed will be necessary to accurately identify map errors in the different probability classes. In all likelihood, map accuracy of low elevation sites will likely be different than high elevation sites, and wide floodplains might provide different results than sites in narrow valleys. Thus, our map accuracy (by class and overall) is only a preliminary estimate used to provide insight into sources of modeling error.

The collection of field data in 2003 to validate a habitat model created with 2001 TM imagery made ground truthing problematic. For example, 6 of the field validation sites burned between 2001 and 2003. When these sites were removed from the data set, the overall accuracy increased to 54.4%. Map errors due to burns between the date of the imagery acquisition and ground truthing further highlight the dynamic nature of riparian habitats. In addition to fire and floods, other perturbations such as water diversions, drought, and land clearing for agriculture or municipal uses, can have substantial effects on the vegetation community and suitability for nesting SWFL. Due to the dynamic nature of riparian habitat, and to avoid increasing errors as the timeframe expands, the model could be improved by using current TM imagery. The model could be reapplied at a fine scale using 1 or 2 TM images, which would reduce the cost and time to update habitat suitability maps. Re-running the model on the latest TM imagery may also identify areas that are changing drastically (see Chapter 3 for added discussion on change detections).

Errors of the model include failing to identify suitable habitat (errors of omission) or identifying habitat as suitable when it is not (errors of commission; Jenkins and others 2003). Because we did not ground truth habitat class 0, we do not know how much suitable habitat was misclassified as unsuitable, but errors of omission indicate that the error would be very small for this class.

Ground truthing found that errors of commission were much more common than errors of omission. This may be attributed to several possibilities: 1) positional error during ground truthing (due to faulty reading on hand-held GPS units), 2) habitat degradation to the point of unsuitability after the model was run, or 3) inability of the model to differentiate between suitable and unsuitable plant species and growth form (tree or shrub). The most common errors appeared to be the misclassification of dense juniper or riparian shrubs as suitable breeding habitat. Applying a variable width buffer around the riparian area could minimize these misclassifications and thereby lower error rates. A variable width buffer would expand around large riparian forests and decrease where floodplains are narrow. Lowering the upper elevation boundary to exclude pinyon/juniper communities would also decrease errors generated where the model is having difficulties differentiating between riparian and non-riparian habitats.

Image resolution limits the model's ability to discriminate between plant species, thus dense mesquite bosques or riparian shrublands (for example, *Bacharris* spp.) will continue to pose problems. While not frequently used, SWFL have been documented nesting in mesquite forests (McKernan and Braden 1998; Smith and others 2003). These areas had standing water during the breeding season, possibly making the patch more attractive to SWFLs. Existing knowledge of SWFL habitat selection patterns and further research could be used to refine the model. Also, continued ground truthing to test for errors of commission could expose additional weaknesses or strengths of the model.

MODEL USE LIMITATIONS

There are several limitations when using the model as a conservation tool. The model output shows predicted suitable habitat, not suitable or occupied habitat, and there is a clear distinction. Our preliminary accuracy assessment highlighted that not all predicted suitable habitat is actually suitable. Thus, in areas where detailed knowledge of habitat or occupancy is needed, the model could be used as a first approximation of possible habitat. Managers could then use all available data to determine suitability, such as aerial photographs, vegetation covers or maps, expert knowledge and field visits. Floristic and structural characteristics such as plant species composition, stand age, presence of water, canopy cover, and vertical foliage density, have all been identified as important in differentiating between suitable and unsuitable habitat (Allison and others 2003; Stoleson and Finch 2003). Incorporating fine-scale habitat characteristics after applying the model as a landscape filter will provide a two-tiered approach to habitat classification and help bridge the gap between coarse- and fine-scaled data.

Additionally, some areas that are known to be occupied were not classified in a higher probability class (class 4-5). Grand Canyon occupied patches (near confluence of the Little Colorado and Colorado rivers) were predicted to be in a lower probability class (class 2), with no class 4-5 habitat nearby. This is probably due to the model input parameters that incorporate the amount of dense habitat and floodplain in 4.5 ha surrounding a 30 x 30 m cell. Thus, a narrow isolated occupied patch in the bottom of a steep canyon could be overlooked if all model classes are not considered during survey prioritization.

The model only predicts suitable nesting habitat and does not predict all habitat used by nesting SWWF. Nesting habitat is one part of a larger matrix of habitat used by SWWF during the migration and breeding seasons. Therefore, this model should not be used as a means of calculating amount of habitat. Further refinement of this model with additional research on habitat use by SWWF may provide the ability to calculate amount of habitat.

Future Research

The formulation of a linkage between the model and demographic research would be a powerful tool, enabling researchers to conduct population viability analysis. Conservation planning would benefit greatly from understanding the degree to which these fragmented patches and small populations are connected, and how improvement or degradation of habitat would affect the population as a whole. Also, by using statewide imagery and change detection techniques (see Chapter 3), patterns of habitat availability throughout the state could be determined over longer time frames (decades). This information would provide insight into the distribution and abundance patterns we see today, and aid in making future management decisions.

As identified in Chapter 1, habitat selection occurs on many spatial scales. Predicting SWFL habitat across the landscape could be greatly improved by combining selection patterns at landscape, patch, and nest-site scales. Linking the scales would not only refine the model, but also improve our understanding of habitat preferences of the SWFL and enhance our opportunities to recover the species. Studies could be done on high-elevation habitat (>1500 m) regarding the applicability of the model to include potential and suitable habitat within montane forests. Similarly, the model could be applied to low-elevation habitats in other states to identify priority survey areas and conservation sites. In addition to contributing to the knowledge and conservation of SWFLs, models could be created and applied to other riparian obligate species of concern in Arizona such as yellow-billed cuckoo (*Coccyzus americanus*) and Yuma clapper rail (*Rallus longirostris yumanensis*), allowing managers to focus conservation efforts on multiple species across large spatial scales.

Recommendations

1. Continue map accuracy assessment by ground truthing in all probability classes.
2. Form a workgroup of SWFL experts to:
    a. Review current literature and research to identify habitat characteristics that could be incorporated into the model, such as:
        i. Forest stand age or size class
        ii. Tree species
        iii. Stream flow and distance to surface water
        iv. GIS masks to exclude unsuitable habitat (for example agricultural, city parks, pinyon/juniper stands)
    b. Explore available covers or technology to characterize habitat features identified above:
        i. Maps or GIS layers of perennial/intermittent/ephemeral and important waters of Arizona
        ii. New 4 - 20 m resolution multi-spectral imagery
        iii. Side-looking radar to map canopy roughness

        iv. Using consecutive TM scenes to estimate forest age and plant species composition
c. Redevelop model with improvements
    i. Test new model in same areas as original model and compare results
    ii. If appropriate, apply and validate new model statewide
d. Consider developing different models for riverine versus delta (reservoir) systems
e. Develop and test methods to model high elevation habitat

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Appendix 2.1. Hectares of high probability (classes 4-5) southwestern willow flycatcher breeding habitat in Arizona identified by the GIS-based model using 2001 satellite imagery, grouped by basin and drainage.

Subbasin (Subacc)	Drainage	HUC ID Subacccat	Prob 4 ha	Prob 5 ha	Total ha	Drainage km^2
Lower Colorado – Lake Mead (100)	Marble Canyon	15010001	0.0	0.0	0.0	3791
	Grand Canyon	15010002	0.2	0.0	0.2	6615
	Kanab	15010003	11.7	6.1	17.8	4415
	Havasu Canyon	15010004	22.1	5.1	27.2	7590
	Lake Mead	15010005	103.4	29.5	132.9	4056
	Grand Wash	15010006	1.7	0.2	1.9	2179
	Hualapai Wash	15010007	0.9	0.0	0.9	4041
	Fort Pierce Wash	15010009	0.0	0.0	0.0	3897
	Lower Virgin	15010010	33.0	21.7	54.7	1288
	Detrital Valley	15010014	0.0	0.0	0.0	1743
	Total:		**173.0**	**62.6**	**235.6**	**39,616**
Little Colorado (200)	L. Colorado Headwaters	15020001	0.0	0.0	0.0	1874
	Upper Little Colorado	15020002	0.0	0.0	0.0	4168
	Carrizo Wash	15020003	0.0	0.0	0.0	863
	Zuni	15020004	0.0	0.0	0.0	1878
	Silver	15020005	0.0	0.0	0.0	2454
	Upper Puerco	15020006	0.0	0.0	0.0	1436
	Lower Puerco	15020007	0.0	0.0	0.0	2938
	Middle Little Colorado	15020008	7.4	3.1	10.4	6469
	Leroux Wash	15020009	0.0	0.0	0.0	2071
	Chevelon Canyon	15020010	7.1	0.1	7.2	2145
	Cottonwood Wash	15020011	0.0	0.0	0.0	4170
	Corn – Oraibi	15020012	0.0	0.0	0.0	2316
	Polacca Wash	15020013	0.0	0.0	0.0	2799
	Jadito Wash	15020014	0.0	0.0	0.0	2677
	Canyon Diablo	15020015	0.0	0.0	0.0	3044
	Lower Little Colorado	15020016	1.8	0.4	2.2	6230
	Dinnebito Wash	15020017	0.0	0.0	0.0	1852
	Moenkopi Wash	15020018	0.0	0.0	0.0	6937
	Total:		**16.3**	**3.5**	**19.8**	**56,319**
Lower Colorado (301)	Havasu – Mohave Lakes	15030101	213.8	222.2	436.1	3138
	Sacramento Wash	15030103	2.6	0.3	2.9	3465
	Imperial Reservoir	15030104	435.4	282.1	717.5	3886
	Bouse Wash	15030105	0.0	0.0	0.0	4209
	Tyson Wash	15030106	0.0	0.0	0.0	1899
	Lower Colorado	15030107	45.5	13.8	59.2	165
	Yuma Desert	15030108	0.4	0.0	0.4	1640
	Total:		**697.7**	**518.3**	**1216.0**	**18,402**

Appendix 2.1. Hectares of high probability (classes 4-5) southwestern willow flycatcher breeding habitat in Arizona identified by the GIS-based model using 2001 satellite imagery, grouped by basin and drainage.

Subbasin (Subacc)	Drainage	HUC ID Subacccat	Prob 4 ha	Prob 5 ha	Total ha	Drainage km^2
Bill Williams (302)	Big Sandy	15030201	150.0	71.4	221.4	5574
	Burro	15030202	3.0	0.0	3.0	1846
	Santa Maria	15030203	87.7	130.6	218.3	3710
	Bill Williams	15030204	206.6	277.7	484.3	2785
	Total:		**447.2**	**479.7**	**926.9**	**13,915**
Upper Gila (400)	Upper Gila – Mangas	15040002	28.3	12.6	40.9	1396
	Animas Valley	15040003	0.0	0.0	0.0	38
	San Francisco	15040004	32.0	5.7	37.6	2430
	Upper Gila – San Carlos Reservoir	15040005	1127.3	2017.9	3145.2	7206
	San Simon	15040006	1.6	0.0	1.6	5214
	San Carlos	15040007	99.4	72.0	171.4	2763
	Total:		**1288.5**	**2108.2**	**3396.7**	**19,047**
Middle Gila – San Pedro – Wilcox (501-502)	Middle Gila	15050100	574.9	486.7	1061.6	9079
	Willcox Playa	15050201	5.9	0.0	5.9	4335
	Upper San Pedro	15050202	262.9	62.0	324.9	4629
	Lower San Pedro	15050203	761.9	507.2	1269.1	5128
	Total:		**1030.6**	**569.3**	**1599.8**	**14,091**
Santa Cruz (503)	Upper Santa Cruz	15050301	145.4	52.5	197.8	5742
	Rillito	15050302	99.8	29.6	129.4	2421
	Lower Santa Cruz	15050303	66.7	56.9	123.6	3729
	Brawley Wash	15050304	89.6	132.2	221.9	3612
	Aguirre Valley	15050305	0.0	0.0	0.0	2027
	Santa Rosa Wash	15050306	0.0	0.0	0.0	3182
	Total:		**401.5**	**271.2**	**672.7**	**20,713**
Salt (601)	Black	15060101	4.4	0.2	4.6	3243
	White	15060102	1.4	0.0	1.4	1651
	Upper Salt	15060103	283.0	331.6	614.5	5584
	Carrizo	15060104	0.0	0.0	0.0	1829
	Tonto	15060105	148.8	101.0	249.8	2712
	Lower Salt	15060106	131.0	55.6	186.7	3405
	Total:		**568.5**	**488.3**	**1056.9**	**18,423**
Verde (602)	Big Chino – Williamson Valley	15060201	107.6	123.1	230.7	5587
	Upper Verde	15060202	196.5	46.9	243.4	6467
	Lower Verde	15060203	316.4	139.0	455.4	5101
	Total:		**620.5**	**309.0**	**929.4**	**17,156**
Upper Colorado – Dirty Devil (700)	Lower Lake Powell	14070006	14.8	12.2	26.9	3740
	Paria	14070007	0.0	0.0	0.0	958
	Total:		**14.8**	**12.2**	**26.9**	**4699**

Appendix 2.1. Hectares of high probability (classes 4-5) southwestern willow flycatcher breeding habitat in Arizona identified by the GIS-based model using 2001 satellite imagery, grouped by basin and drainage.

Subbasin (Subacc)	Drainage	HUC ID Subacccat	Prob 4 ha	Prob 5 ha	Total ha	Drainage km^2
Lower Gila – Aqua Fria (701)	Lower Gila	15070101	1030.4	792.2	1822.6	5355
	Agua Fria	15070102	30.6	3.4	34.0	6300
	Hassayampa	15070103	16.6	12.2	28.8	3702
	Centennial Wash	15070104	2.6	3.2	5.9	5033
	Total:		**1080.2**	**811.1**	**1891.3**	**20,390**
Lower Gila (702)	Lower Gila River	15070201	176.0	117.1	293.1	10919
	Tenmile Wash	15070202	0.0	0.0	0.0	3127
	San Cristobal Wash	15070203	0.0	0.0	0.0	4066
	Total:		**176.0**	**117.1**	**293.1**	**18,111**
Rio Sonoyta – Rio De La Conception (801)	San Simon Wash	15080101	0.0	0.0	0.0	5578
	Rio Sonoyta	15080102	5.2	1.2	6.4	1099
	Tule Desert	15080103	0.0	0.0	0.0	1016
	Total:		**5.2**	**1.2**	**6.4**	**7963**
Chinle Creek (802)	Chinle	15080200	0.0	0.0	0.0	332
	Lower San Juan – Four Corners	14080201	0.0	0.0	0.0	621
	Chinle	14080204	0.5	0.0	0.5	10154
	Lower San Juan	14080205	0.0	0.0	0.0	1559
	Total:		**0.5**	**0.0**	**0.5**	**12,666**
Rio De Bavispe (803)	Whitewater Draw	15080301	0.5	0.0	0.5	3066
	San Bernadino Valley	15080302	16.9	8.4	25.3	1012
	Total:		**17.4**	**8.4**	**25.7**	**4078**
Arizona Totals:			**6537.9**	**5760.1**	**12,297.7**	**285,589**

Appendix 2.2. Hectares of high probability (classes 4-5) southwestern willow flycatcher breeding habitat in Arizona identified by the GIS-based model using 2001 satellite imagery, grouped USGS by 7.5' topographic quadrangle. (See Figure 2.4 for locations of quadrangles with ≥ class 4 habitat.)

7.5' Quadrangle	Ha	7.5' Quadrangle	Ha
Agua Caliente	0.5	Bylas	88.0
Amado	5.6	Calva	599.1
Apache Butte	2.0	Cameron SE	2.2
Apache Maid Mountain	0.5	Camp Verde	53.4
Arivaca	4.3	Campo Bonito	3.5
Arlington	284	Cane Springs Mountain	3.0
Armer Mountain	10.9	Casner Butte	32.2
Arrastra Mountain SE	0.1	Castaneda Hills SW	34.7
Artesia	5.1	Castle Rock	23.6
Artillery Peak	304.1	Chalk Mountain	163.4
Avondale SE	32.6	Cherry Spring Peak	2.9
Avondale SW	35.6	Chino Valley North	19.3
Aztec NW	16.7	Chino Valley South	0.5
Aztec Peak	66.4	Christmas	13.0
Azure Ridge	1.9	Chrysotile	5.2
Baldy Mountain	0.6	Cibecue	5.9
Bard	5.7	Cibola	138.2
Bartlett Dam	1.3	Citrus Valley East	54.0
Bassett Peak	1.7	Citrus Valley West	185.9
Bat Cave	54.7	Clark Ranch	151.7
Beckers Butte	0.4	Clarkdale	23.4
Bee Canyon	36.6	Clear Creek Reservoir	3.0
Benson	38.2	Clear Water Spring	1.1
Big Maria Mountains NE	8.7	Cleator	0.7
Big Maria Mountains SE	21.6	Clifton	3.1
Black Canyon City	4.2	Columbine Falls	46.8
Blackwater	2.3	Cooks Mesa	0.7
Bloody Basin	2.3	Copper Mountain	6.5
Blythe	33.1	Copperplate Gulch	8.0
Blythe NE	56.5	Cordes Junction	1.4
Bob Thompson Peak	13.9	Cornville	5.7
Bonita Spring	50.0	Coronado Mountain	0.4
Booger Canyon	43.9	Cotton Center	15.7
Boulder Mountain	2.3	Cotton Center NW	6.0
Brandenburg Mountain	7.4	Cottonwood	3.4
Buckeye	461.2	Cross Roads	1.7
Buckhead Mesa	0.4	Crown King	8.2
Buckhorn Mountain	3.1	Cumero Canyon	3.2
Buehman Canyon	0.2	Cypress Butte	3.2
Burro Mesa	1.6	Dagger Peak	1.2
Buzzard Roost Mesa	2.1	Date	0.1

Appendix 2.2. Hectares of high probability (classes 4-5) southwestern willow flycatcher breeding habitat in Arizona identified by the GIS-based model using 2001 satellite imagery, grouped USGS by 7.5' topographic quadrangle. (See Figure 2.4 for locations of quadrangles with ≥ class 4 habitat.)

7.5' Quadrangle	Ha	7.5' Quadrangle	Ha
Dateland	0.3	Gonzales Wash	0.7
Davis Dam SE	4.8	Governors Peak	5.9
Dendora Valley	16.8	Granite Reef Dam	87.8
Devils Hump	1.3	Grayback	8.5
Devils Slide Rapids	16.6	Grays Well NE	0.6
Dewey Flat	1120.7	Greenback Creek	65.0
Diamond Butte	0.5	Greenwood Peak	29.2
Dix Creek	30.8	Growler	10.2
Dome	5.9	Gunsight Canyon	2.5
Double Buttes	4.6	Gunsight Point	1.9
Dudleyville	136.8	Guthrie	5.1
Dugas	1.2	Happy Valley	0.5
Duncan	1.2	Harden Cienega	1.4
Eden	218.3	Harrison Canyon	3.3
Elbow Canyon	3.5	Hassayampa	458.5
Empire Ranch	2.5	Haunted Canyon	9.5
Estler Peak	0.7	Havasu Falls	9.2
Eureka Ranch	7.0	Havasu Lake	16.2
Fairbank	14.0	Hayden	150.2
Findlay Tank	14.7	Hereford	28.5
Fishtail Mesa	0.2	Hibbard	7.2
Florence Junction	21.3	Hillside	2.6
Florence SE	1.5	Hookers Hot Springs	5.6
Forks Butte	1.1	Horn	1.0
Fort Grant	2.5	Horner Mountain	5.0
Fort McDowell	65.0	Horse Mesa Dam	0.6
Fort Thomas	321.9	Horseshoe Dam	3.5
Fortuna	12.5	Hot Tamale Peak	7.7
Four Peaks	9.0	Huachuca City	23.8
Fowler	11.3	Hyder	1.8
Fredonia	0.2	Imperial Reservoir	68.9
Fritz Canyon	0.9	Inspiration	0.2
Gadsden	12.9	Iron Mountain	44.0
Galleta Flat East	88.4	Jaynes	16.9
Galleta Flat West	0.3	Joseph City	3.2
Gene Wash	2.1	Kayler Butte	0.7
Geronimo	251.6	Kearny	165
Gila Bend	4.3	Kennedy Peak	12.0
Gila Butte	1.5	Kielberg Canyon	54.3
Gila Butte SE	0.4	Kirkland	22.5
Gisela	0.7	Klondike	1.3

Appendix 2.2. Hectares of high probability (classes 4-5) southwestern willow flycatcher breeding habitat in Arizona identified by the GIS-based model using 2001 satellite imagery, grouped USGS by 7.5' topographic quadrangle. (See Figure 2.4 for locations of quadrangles with ≥ class 4 habitat.)

7.5' Quadrangle	Ha	7.5' Quadrangle	Ha
Knob Hill	0.1	Mule Wash	87.1
La Paz Mountain	12.2	Muleshoe Ranch	0.5
Laguna Dam	102.7	Munds Mountain	1.5
Lake Havasu City North	17.8	Munds Park	34.6
Lake Havasu City South	13.9	Mustang Mountains	28.9
Lake Montezuma	8.1	Natural Corral	0.3
Land	62.3	Needles	284.1
Laveen	215	Needles NE	7.7
Leslie Canyon	0.5	Needles NW	6.9
Lewis Springs	29.6	Needles SW	0.9
Ligurta	33.0	New River	1.0
Lion Mountain	10.4	New River Mesa	0.1
Littlefield	24.1	Nicksville	1.0
Lochiel	7.5	North Butte	48.0
Lone Star Mountain	3.2	North Peak	16.4
Lookout Mountain	205.1	Oak Creek Ranch	0.6
Loy Butte	5.4	Oak Grove Canyon	3.6
Malpais Mesa	0.5	Oatman Mountain	5.4
Mammoth	108	O'Donnel Canyon	13.8
Marana	23.3	Oracle	1.3
Martin Mountain	2.1	Oro Valley	9.5
Mazatzal Peak	122.9	Page	26.9
Mcfadden Peak	62.6	Page Springs	18.1
Meddler Wash	247.6	Palmerita Ranch	74.8
Menagers Lake	6.4	Palo Verde	55.8
Mesquite	35.3	Parker	2.9
Mexican Water	0.5	Parker SE	0.2
Miller Peak	0.2	Parker SW	38.6
Mitchell Peak	1.5	Patagonia	33.3
Mitchell Peak	1.5	Paulden	1.3
Monkeys Head	276.8	Payson South	3.8
Montezuma Peak	52.5	Penitentiary Mountain	0.4
Mormon Flat Dam	7.8	Peppersauce Wash	148.9
Mount Bigelow	12.7	Perkinsville	7.1
Mount Davis	0.8	Perryville	12.5
Mount Graham	0.8	Picacho	125.5
Mount Hopkins	3.1	Picacho NW	146.9
Mount Hughes	0.8	Picacho Reservoir	314.2
Mount Lemmon	11.9	Picacho SW	141.9
Mount Manchester	144.7	Picture Mountain	0.5
Mule Hoof Bend	2.4	Pilgrim Wash	3.4

Appendix 2.2. Hectares of high probability (classes 4-5) southwestern willow flycatcher breeding habitat in Arizona identified by the GIS-based model using 2001 satellite imagery, grouped USGS by 7.5’ topographic quadrangle. (See Figure 2.4 for locations of quadrangles with ≥ class 4 habitat.)

7.5’ Quadrangle	Ha	7.5’ Quadrangle	Ha
Pima	186.7	Simmons	217.0
Pima Butte	36.0	Smith Mesa	0.1
Pinal Peak	0.3	Smurr	137.2
Pinyon Mountain	5.5	Sombrero Peak	1.3
Portal	1.2	Sontag Mesa	0.2
Portal Peak	0.5	Soza Canyon	127.4
Poston	2.6	Soza Mesa	35.6
Prescott	0.5	Spencer Canyon	2.9
Presumido Peak	10.0	Spirit Mountain NE	0.5
Promontory Butte	1.3	Spirit Mountain NW	10.4
Quartermaster Canyon	12.0	Spring Mountain	23.9
Red Hill SW	113.2	Spring Water Canyon	48.2
Red Rock	37.9	Stark	7.8
Redington	3.2	Strawberry	17.1
Reid Valley	2.2	Sullivan Buttes	10.4
Reno Pass	72.0	Supai	18.0
Rhodes Peak	4.5	Swansea	5.0
Rincon Peak	19.6	Sycamore Basin	8.6
Rio Rico	9.2	Sycamore Point	0.4
Roll	2.0	Table Mountain	0.5
Rover Peak	0.9	Tacna	25.9
Sabino Canyon	7.9	Tanque Verde Peak	0.3
Sacaton	1.0	Teapot Mountain	2.3
Safford	32.0	Texas Hill	1.1
Sahuarita	0.8	Thatcher	4.6
Saint David	32.0	The Narrows	41.0
Salt River Peak	4.8	Theba	22.9
Sam Powell Peak	5.6	Thorn Peak	0.5
Samaniego Hills	199.4	Tolleson	213.1
San Bernardino Ranch	24.9	Tonto Basin	34.8
San Carlos	104.3	Topock	57.9
San Carlos Reservoir	255.4	Tubac	81.4
San Cayetano Mountains	2.6	Tucson SW	11.5
San Jose	28.5	Tule Mesa	11.0
Scratch Canyon	1.4	Tule Wash	21.7
Sedona	34.0	Vail	4.1
Seepage Mountain	2.1	Valentine	0.9
Sheep Basin Mountain	1.3	Velasquez Butte	3.5
Sheldon	15.4	Verde Hot Springs	1.4
Sheridan Mountain	6.2	Walker Mountain	9.2
Signal	1.0	Walnut Grove	0.2

Appendix 2.2. Hectares of high probability (classes 4-5) southwestern willow flycatcher breeding habitat in Arizona identified by the GIS-based model using 2001 satellite imagery, grouped USGS by 7.5' topographic quadrangle. (See Figure 2.4 for locations of quadrangles with ≥ class 4 habitat.)

7.5' Quadrangle	Ha	7.5' Quadrangle	Ha
Warm Springs SW	1.1	Willow Mountain SE	1.0
Wellton	58.8	Wilson Mountain	35.6
West Of Guadalupe Canyon	0.4	Windy Hill	164.8
West Of Marana	16.9	Winkelman	89.2
Wet Bottom Mesa	1.4	Winslow	2.3
White Horse Lake	0.6	York	19.2
Whiteriver	1.4	Young	1.2
Wickenburg	16.6	Yuma East	26.4
Wikieup	131.0	Yuma West	20.3
Wildhorse Mountain	83.7		

Appendix 2.3. A southwestern willow flycatcher GIS-based habitat model ground-truthing evaluation form.

Habitat Evaluation Form-GIS Model Accuracy Assessment

Random Point # ________________
UTM's: n_ _ _ _ _ _ _ e_ _ _ _ _ _
Drainage______________________
S_totsit ______________________
SWIFL Detected? : Yes / No

Evaluation Date ____________
Datum ___________________
Evaluator _________________
7.5' Quad Name________________
Status: Resident / Migrant/ Unknown

<table>
<tr><td>Floodplain (office)</td><td colspan="2">Slope: ____________
Width: ____________</td></tr>
<tr><td>Presence of water:</td><td>Stream Flow or Reservoir Water present

Yes No

Perennial Intermittent Ephemeral
(if known)</td><td>Supplemental Water

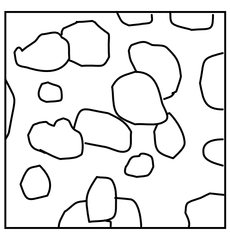
__1__Agricultural Runoff
__2__Sewage / Effluent
__3__Other - list: _______________</td></tr>
<tr><td colspan="3">Comments on presence of water:
____
____
____</td></tr>
<tr><td>Grazing Impact</td><td colspan="2">__0__ No Sign
__1__Light impacts (little sign, little/no visible impact to vegetation)
__2__Moderate impacts (significant sign, dung, prints, visible impact on vegetation)
__3__Severe impacts (heavy sign, dung, prints, altering plant community)</td></tr>
<tr><td>Overall Patch (site) Morphology</td><td colspan="2">__1__Thin and Linear: <20 m wide X >30m -- < 50 m long.
__2__Wide with breaks: >20m X >50m long
__3__Wide and contiguous: >20m X >50m long</td></tr>
<tr><td>Spatial distribution of patches:</td><td colspan="2">__1__Multiple patches various degrees of suitability
__2__Multiple patches all approximately equal in suitability
__3__One patch – grades into unsuitable habitat</td></tr>
</table>

<table>
<tr><td>Vegetation Floristics:
(see back for four letter codes)</td><td>Tree/Shrub Species:
_ _ _ _, _ _ _%
_ _ _ _, _ _ _%
_ _ _ _, _ _ _%
_ _ _ _, _ _ _%</td><td colspan="2">Comments: ____________</td></tr>
<tr><td>Vegetation Structure</td><td>**Canopy Cover:**
__1__ 0 %
__2__ 1-25 %
__3__ 26-50 %
__4__ 51-75 %
__5__ 76-100 %</td><td>**Average Canopy Height:**
__1__0-3 m
__2__3-10 m
__3__10-15 m
__4__15+ m</td><td>**Size class of most abundant tree/shrub species (dbh)**
__1__ 0-5.5 cm
__2__ 5.6-15 cm
__3__ 15.1-30 cm
__4__ 30.1+ cm</td></tr>
<tr><td colspan="2">**In Field Scored Habitat Classification:**
__1__ Unsuitable
__2__ Potential Short Term (1-5 years)
__3__ Suitable</td><td>**Photo Numbers:**
N: ____________
S: ____________
E: ____________
W: ____________</td><td>**Model Probability Class:**
__0__ Not Suitable
__1__Low Probability
__2__
__3__
__4__
__5__High Probality</td></tr>
</table>

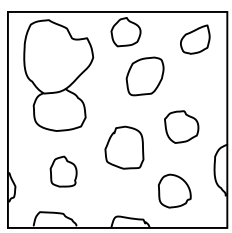
Four Letter Vegetation Floristic Codes

Code	Common	Genus	Species	Code	Common	Genus	Species
ACSP	Acacia Species	*Acacia*	spp.	PRGL	Honey Mesquite	*Prosopis*	*glandulosa*
FRVE	Arizona Ash	*Fraxinus*	*velutina*	PTTR	Hoptree	*Ptelea*	*trifoliata*
ALOB	Arizona Alder	*Alnus*	*oblongifolia*	AMFR	Indigobush	*Amorpha*	*fructicosa*
ROAR	Arizona Rose	*Rosa*	*arizonica*	JUSP	Juniper	*Juniperus*	spp.
PLWR	Arizona Sycamore	*Platanus*	*wrightii*	WETL	Marsh (Sedges, Rushes)		
JUMA	Arizona Walnut	*Juglans*	*major*	PRSP	Mesquite	*Prosopis*	spp.
PLSP	Arroweed / Marsh Fleabane	*Pluchea*	spp.	SAME	Mexican Elder	*Sambucus*	*mexicana*
POSP	Aspen Species	*Populus*	spp.	PICE	Mexican Pinyon Pine	*Pinus*	*cembroides*
BARE	Bare Ground			MISC	Miscellaneous		
LOIN	Bearberry Honeysuckle	*Lonicera*	*involucrata*	ALTE	Mountain Alder	*Alnus*	*tenuifolia*
SABE	Bebb Willow	*Salix*	*bebbiana*	POAN	Narrowleaf Cottonwood	*Populus*	*angustifolia*
SANI	Black Willow	*Salix*	*nigra*	RONE	New Mexico Locust	*Robinia*	*neomexicana*
ACNE	Boxelder	*Acer*	*negundo*	QUSP	Oak Species	*Quercus*	spp.
SCSP	Bullrush	*Scirpus*	spp.	OTHR	Other		
HYMO	Burroweed (Burrobrush)	*Hymenoclea*	*monogyra*	PASP	Palo Verde	*Parkinsonia*	spp.
CEOC	Buttonbush	*Cephalanthus*	*occidentalis*	PIED	Pinyon Pine	*Pinus*	*edulis*
TYSP	Cattail	*Typha*	*spp.*	PIPO	Ponderosa Pine	*Pinus*	*ponderosa*
PHCO	Common Reed	*Phragmites*	*communis*	SABO	Red Willow (Bonpland)	*Salix*	*bonplandiana*
SAEX	Coyote / Sandbar Willow	*Salix*	*exigua*	ELAN	Russian Olive	*Elaeagnus*	*angustifolia*
LASP	Creosote	*Larrea*	spp.	SAEX	Sandbar / Coyote Willow	*Salix*	*exigua*
TYSP	Cattail	*Typha*	*spp.*	ATSP	Saltbush	*Atriplex*	spp.
PHCO	Common Reed	*Phragmites*	*communis*	TASP	Salt Cedar (TACH, TAAP)	*Tamarix*	spp. (*chinensis / aphylla)*
SAEX	Coyote / Sandbar Willow	*Salix*	*exigua*	CASP	Sedge	*Carex*	spp.
LASP	Creosote	*Larrea*	spp.	BASP	Seep Willow	*Baccharis*	spp. *(salicifolia / glutinosa)*
BASA	Desert Broom	*Baccharis*	*sarothroides*	PISP	Spruce Species	*Picea*	spp.
CHLI	Desert Willow	*Chilopsis*	*linearis*	PRPU	Screwbean Mesquite	*Prosopis*	*pubescens*
POFR	Fremont Cottonwood	*Populus*	*fremontii*	RHSP	Sumac	*Rhus*	spp.
SAGE	Geyer Willow	*Salix*	*geyeriana*	TASP	Tamarisk (TACH, TAAP)	*Tamarix*	spp. *(chinensis / aphylla)*
SAGO	Goodding Willow	*Salix*	*gooddingii*	MOMI	Texas Mulberry	*Morus*	*microphylla*
GRAS	Grass			FRVE	Velvet Ash	*Fraxinus*	*velutina*
COLY	Greystone	*Condalia*	*lycioides*	PRVE	Velvet Mesquite	*Prosopis*	*velutina*
CERE	(Netleaf Hackberry)	*Celtis*	*reticulata*	MOAL	White Mulberry	*Morus*	*alba*

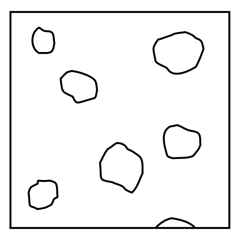
Sketch Map of Area (Mark areas of interest, location of bird(s) w/UTMs, location of water, and any additional comments)



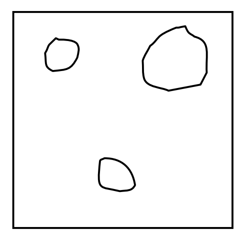
~60% Cover
Closed Canopy
Continuous



~40% Cover
Open Canopy
Discontinuous



~25% Cover
Dispersed Canopy



~10% Cover
Sparse Canopy

CHAPTER 3

SOUTHWESTERN WILLOW FLYCATCHER HABITAT CHANGE DETECTION ANALYSIS: ROOSEVELT LAKE, ARIZONA, 1985-2001

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EXECUTIVE SUMMARY

The southwestern willow flycatcher (*Empidonax traillii extimus*) was listed as endangered in 1995 due in part to alteration and destruction of riparian habitat caused by dams and water diversions. However, much occupied flycatcher habitat currently occurs within reservoirs in the Southwest, including a large population at Roosevelt Lake, in central Arizona. In 1997, the U.S. Bureau of Reclamation increased the height of Roosevelt Dam, and if lake levels rise, to this increased capacity, waters will inundate and might destroy flycatcher breeding habitat. However, over the long-term, lakeside vegetation may periodically be available as nesting habitat for the bird because habitat fluctuates in response to water management and precipitation runoff. To quantify the variation of available breeding SWFL habitat on a temporal scale, the Arizona Game and Fish Department and U.S. Bureau of Reclamation used a published GIS-based habitat model that incorporates variables extracted from 30 m resolution Landsat Thematic Mapper (TM) imagery and digital elevation maps to delineate suitable habitat at Roosevelt Lake between 1985-2001. We applied the model in the 2 major rivers feeding the lake (Salt River and Tonto Creek inflows) using 1985, 1990, 1995, and 2001 TM imagery and digital elevation maps. The abundance of predicted breeding habitat was greatest in 1990 and 2001 corresponding to periods when lake levels were low. During high lake levels, 1985 and 1995, habitat was destroyed in lower lake elevations. Salt River inflow consistently had more available breeding habitat than Tonto Creek inflow. However, Tonto Creek inflow had greater amount of habitat above the new lake capacity that might not be destroyed if water levels rise. Slowly receding lake levels may allow growth of large stands of suitable breeding habitat, but this habitat is destroyed during periodic inundation. Over the time frame of the study, this process, in some degree, mimicked the natural flood cycle and allowed recruitment of trees. Water managers could use knowledge of these processes at Roosevelt Lake and other reservoirs to conserve, restore, and protect flycatcher breeding habitats.

CHAPTER 3

SOUTHWESTERN WILLOW FLYCATCHER HABITAT CHANGE DETECTION ANALYSIS: ROOSEVELT LAKE, ARIZONA, 1985 - 2001

Charles E. Paradzick and James R. Hatten

INTRODUCTION

In the southwestern United States much of the riparian forest has been eliminated or severely altered due to dams, water diversions, and groundwater withdrawal (Governor's Riparian Habitat Task Force 1990). These projects have both an immediate effect on habitats and long-term impacts that can alter the processes that create and sustain riparian forests. Forest loss has reduced the available habitat for the southwestern willow flycatcher (SWFL; *Empidonax traillii extimus*), a federally endangered migratory songbird, that historically nested in willow thickets along rivers and streams in Arizona, California, Colorado, New Mexico, Nevada, and Utah (Unitt 1987). The species distribution and abundance has been reduced to 221 sites rangewide, and Arizona contains approximately one third of these (Sogge and others 2003). Riparian forest near the town of Winkelman (confluence of the lower San Pedro and Gila rivers) and Roosevelt Lake harbor 36% and 35% of the territories within the state, respectively (Paradzick and Woodward 2003).

In areas where suitable breeding habitat still occurs, it is both spatially and temporally dynamic. Episodic floods are a significant driver of riparian forest ecology (Stromberg and others 1991). These perturbations scour and remove vegetation, reshape and expose floodplain sediment, and stimulate Fremont cottonwood (*Populus fremontii*) and Goodding willow *(Salix gooddingii*) germination and recruitment. This process is the mechanism that drives the successional patterns that create a mosaic of different floristic and structural vegetation patches that vary both laterally and longitudinally along the floodplain. When dams impound rivers, this process is interrupted. Downstream of the control structure the flow regime, or hydrograph (the magnitude, frequency, duration, and timing of flow), is altered affecting the underlying environmental conditions (Graf and others 2002). This alteration leads to changes in the distribution, abundance, and composition of riparian forests (Poff and others 1997; Graf and others 2002). An altered hydrograph in southwestern stream systems often increases the abundance and distribution of tamarisk (*Tamarix* spp.), a nonnative tree, while decreasing the prevalence of cottonwood/willow patches (Fenner and others 1985; Busch and Smith 1995; Everitt 1998). Similarly, water levels in the storage area upstream of dams fluctuate in response to release patterns and inputs of runoff. Levels may fluctuate daily, seasonally, or remain fairly constant over time. Patterns of water fluctuation (inundation or recession) can have disturbance effects that mimic in varying degrees the disturbance cycle of a natural hydrograph. These fluctuations alter the riparian forest communities located along the margins and inlets of the lake, influencing the assemblage of animals that use these communities, including the federally endangered SWFL.

In 1995, the U.S. Bureau of Reclamation (USBR) increased the height of Roosevelt Dam by 23.5 m (77 ft), which would raise the conservation pool to a new lake elevation of 656 m (2152 ft). Temporary storage of water as emergency flood control could occur above this elevation, but water would be released within 20 days. The resulting Biological Opinion (U.S. Fish and Wildlife Service [USFWS] 1996) identified that the action would negatively affect the SWFL because increased water levels would inundate and destroy occupied nesting habitat in the 2 main inlets. While the additional storage space will increase lake levels over the long-term, short-term fluctuations in response to precipitation runoff, drought, or regulated flow releases by managers will still occur and alter the available habitat for the SWFL. A portion of the action to assess the effects on SWFL required USBR to measure and monitor the distribution and abundance of SWFL habitat at the lake over time. Managers would use the data to monitor the long-term regional effects of the change in operating criteria of the modified Roosevelt Dam and lake, and to gauge the effectiveness of replacement habitat and other management actions.

We used a Geographic Information System (GIS)-based SWFL habitat model (Chapter 1; Hatten and Paradzick 2003) to accomplish this Biological Opinion requirement. The model uses GIS, SWFL survey and nest data, GIS variables extracted from 30 m resolution satellite imagery and digital elevation data, and multiple logistic regression to predict suitable breeding habitat within low elevation riparian areas. The use of GIS-based models and satellite Landsat Thematic Mapper (TM) imagery to monitor temporal habitat change (including wetland and riparian areas) is well established (see Ozesmi and Bauer 2002). The benefits of using the SWFL GIS-based model include: 1) the model was created and tested using SWFL data from Roosevelt Lake; 2) it is cost effective compared to labor intensive on-the-ground vegetation monitoring; 3) it is repeatable in the future as long as up-to-date Landsat TM imagery is available; and, 4) it allows retrospective assessment of habitat back to 1982 when Landsat TM imagery became available. Limitations of the model are that it provides an estimate of habitat that might be suitable for SWFL based on remotely sensed data. Therefore, other environmental variables (that is, tree species, seral stage, distance to water, fine-scale habitat parameters) or bird-related parameters (that is, dispersal and colonization patterns) affecting habitat suitability and occupancy rates are not included. Thus it does not include all habitat that SWFL may need or use during the breeding season. However, the benefits of using the model outweigh the limiting factors for monitoring broad patterns of habitat change over time, as long as, the results are viewed accordingly, as an approximation of available model-predicted breeding habitat, not the actual area occupied or the total area needed by SWFL.

METHODS

STUDY AREA

We modeled temporal change in habitat within the 2 delta inflows to Roosevelt Lake: Tonto Creek inflow and Salt River inflow (Figure 3.1). We delineated both study areas into specific lake elevation gradients to measure habitat availability and change for lake managers. The elevation groupings were <651 m (< 2136 ft), 651-656 m (2136-2152 ft), and >656 m (>2152 ft), which reflected the ordinary high-water line before dam construction, the area to be periodically inundated by the new dam height, and the area above the new high-water mark, respectively.

Tonto Creek inflow project area for this analysis was a 2000 ha riverine and delta area formed by an interrupted perennial stream flowing from the Mollogon Rim southward into Roosevelt Lake. The stream collects runoff from a 1620 km^2 watershed. Within the study area the stream often flows during the spring months into early summer, but may dry during late June before heavy precipitation from summer monsoons (July-August) provide additional flow. Salt River inflow project area is a 1500 ha riverine and delta area formed by perennial river flow that drains portions of the Mollogon Rim and White Mountains. The stream collects runoff from an 11,100 km^2 watershed. Land uses and habitat characteristics are described in more detail in Chapter 1. Water level elevations for Roosevelt Lake were acquired from U.S. Bureau of Reclamation (2001) and S.Sferra (pers. comm.).

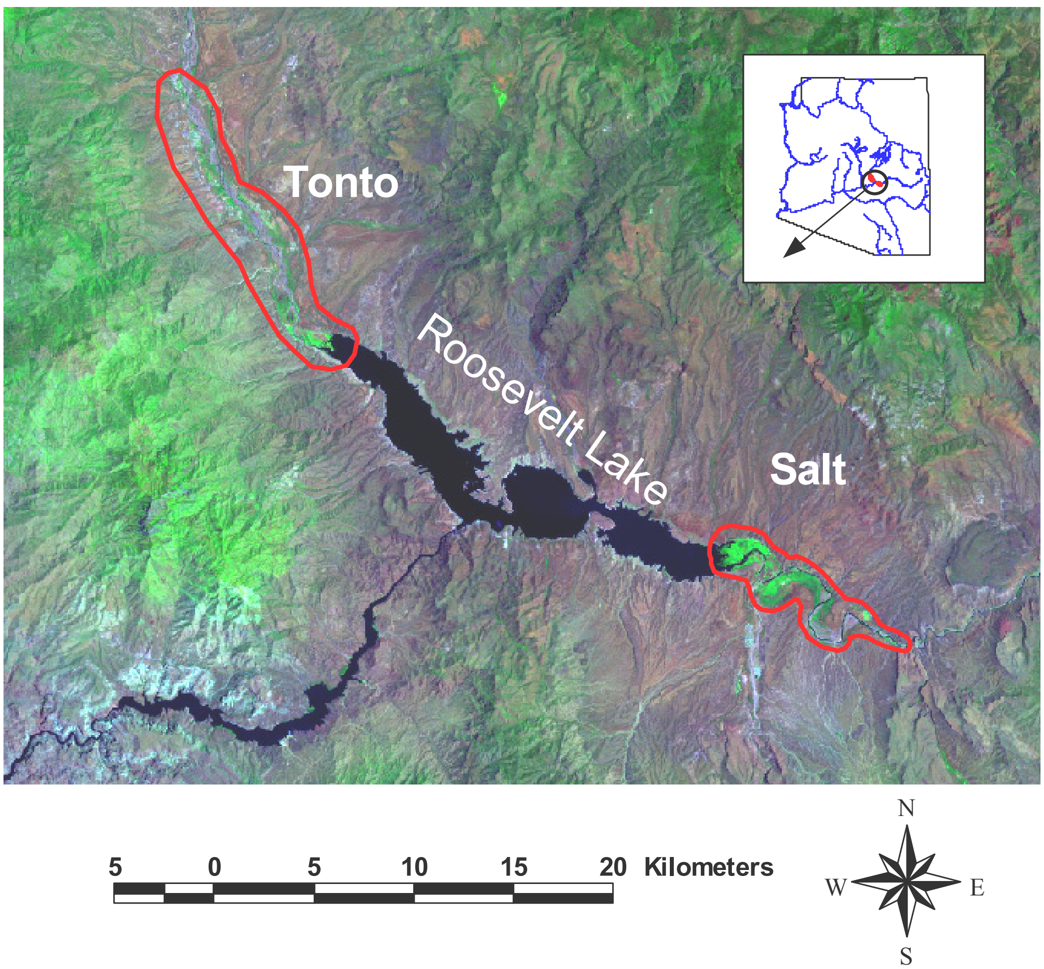

Figure 3.1. Study area showing Salt River inflow and Tonto Creek inflow deltas at Roosevelt Lake, Arizona.

CHANGE DETECTION

We used the GIS-based model described in Chapter 1 to quantify changes in possible SWFL breeding habitat over 16 years. We acquired Landsat TM 30 m resolution imagery from 4 years: 1985, 1990, 1995, and 2001. Each image was taken during a cloudless period of mid-June. The same image processing procedures identified in Chapter 1 were used to assure tonal match and quality. We did not assess atmospheric differences in imagery among years, or correct for changes in the gain or biases of Landsat over the time frame of the study due to logistic and funding constraints. However, we believe model error due to these concerns was low because imagery was taken in June each year (i.e., generally a month with low humidity-prior to monsoon storms), Normalized Difference Vegetation Index (NDVI) was grouped into large classes, and we only considered ≥2 probability class changes as a between year change in predicted breeding habitat suitability (see below). Ignoring small changes reduced the chance that results were due to differences in solar illumination angle between 2 time periods, which might affect the NDVI variable.

We calculated the amount of predicted suitable habitat each year, grouped these probabilities into 5 classes (see Chapter 1), and determined the change in suitability between years within the 2 study areas. Because statewide modeling results (see Chapter 2) found that the top 2 probability classes (60% cutpoint; class 4-5) contained 89% of nest sites, we focused on the variation in these higher probability habitat classes.

We mapped changes in habitat suitability by overlaying model outputs from different years and calculating changes in the 5 probability classes. We created a new 30 x 30 m grid in GIS populated with change values for each time series. Change values ranged from -5 to 5 depending on the magnitude and direction of change. Cells with a negative value had a decrease in predicted breeding habitat, while cells with a positive value had an increase in predicted habitat. For example, cells with a value of -5 decreased from Class 5 to Class 0 between 2 time periods, while cell values of 5 changed from Class 0 to Class 5. In contrast, cells with a 0 value remained unchanged, while changes of 1 or -1 would have changed by 1 probability class. Because we were evaluating 5-year increments, we were most interested in large scale habitat changes; therefore, we considered cell values with small changes (-1 or 1) as unchanged in our analysis.

RESULTS

Predicted suitable breeding habitat fluctuated in both deltas over time (Table 3.1, Appendix 3.1). The greatest extent of available habitat occurred in 2001 and 1990, which corresponded with low water levels at the lake (Figure 3.2). Salt River inflow consistently had a higher proportion of high probability breeding habitat than Tonto Creek inflow; 10 and 14% of the total riparian area at Salt River inflow was delineated high probability habitat in 1995 and 2001, respectively. The proportion of high probability habitat at Tonto Creek inflow reached a maximum of 5% in 1990. Change detection maps show that while much of the variation in habitat was within the fluctuating reservoir pool at both sites, habitat developed in similar areas between high and low water years: 1985-1990; and 1995-2001 (Appendix 3.1).

Habitat change within elevation zones varied between Salt River inflow and Tonto Creek inflow (Figures 3.3 and 3.4; Appendix 3.2). While the lowest band (<651 m; 2136 ft) had the greatest fluctuation in both areas, Tonto Creek inflow showed 2 similar peaks in 1990 and 2001. In contrast, Salt River inflow had less predicted breeding habitat in 1990 than in 2001. Between 651-656 m (2136-2152 ft) elevations, Salt River inflow predicted breeding habitat peaked in 1990 and then declined, whereas Tonto Creek inflow peaked in 1995. A small increase of habitat at Salt River inflow occurred in 1990 in the highest elevation (>656 m, 2152 ft) but relative to other elevations showed little habitat development or variation over time. At Tonto Creek inflow, a significant amount of habitat developed at the higher elevation zone relative to other zones. Thus, habitat appears to be more evenly distributed among elevation zones at Tonto Creek inflow compared to Salt River inflow, where it is concentrated in the 2 lowest zones.

Table 3.1. Amount of predicted suitable southwestern willow flycatcher breeding habitat (ha) between 1985-2001 at Roosevelt Lake, Arizona.

Area	Year	Not Suitable	Predicted Suitable Habitat Classes					
			Lower Probability			Higher Probability		
		Class 0	Class 1	Class 2	Class 3	Class 4	Class 5	Sum Classes 4-5
Tonto Creek inflow	1985	2042	344	41	29	13	3	16
	1990	1916	324	67	51	61	52	113
	1995	1572	718	67	42	47	26	73
	2001	1742	495	84	56	45	49	94
Salt River inflow	1985	2547	273	80	50	51	41	92
	1990	2260	248	96	104	145	188	333
	1995	2341	414	63	55	74	93	167
	2001	2075	315	110	93	136	312	448
Total	1985	4589	617	121	79	64	44	108
	1990	4176	572	163	155	206	240	446
	1995	3913	1132	130	97	121	119	240
	2001	3817	810	194	149	181	361	542

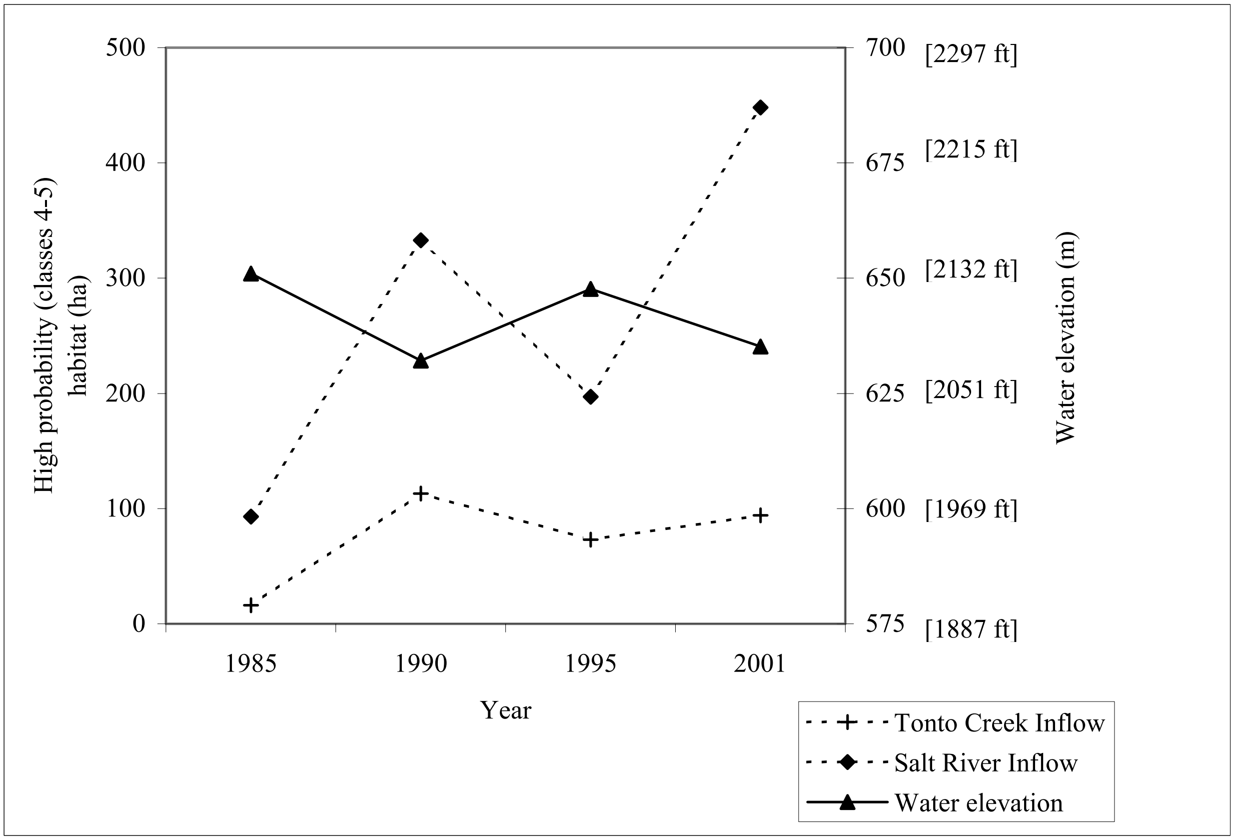

Figure 3.2. Amount (ha) higher probability (classes 4-5) southwestern willow flycatcher breeding habitat and corresponding reservoir water level elevation at Roosevelt Lake from 1985-2001. (Water elevations in feet provided in brackets on Y axis)

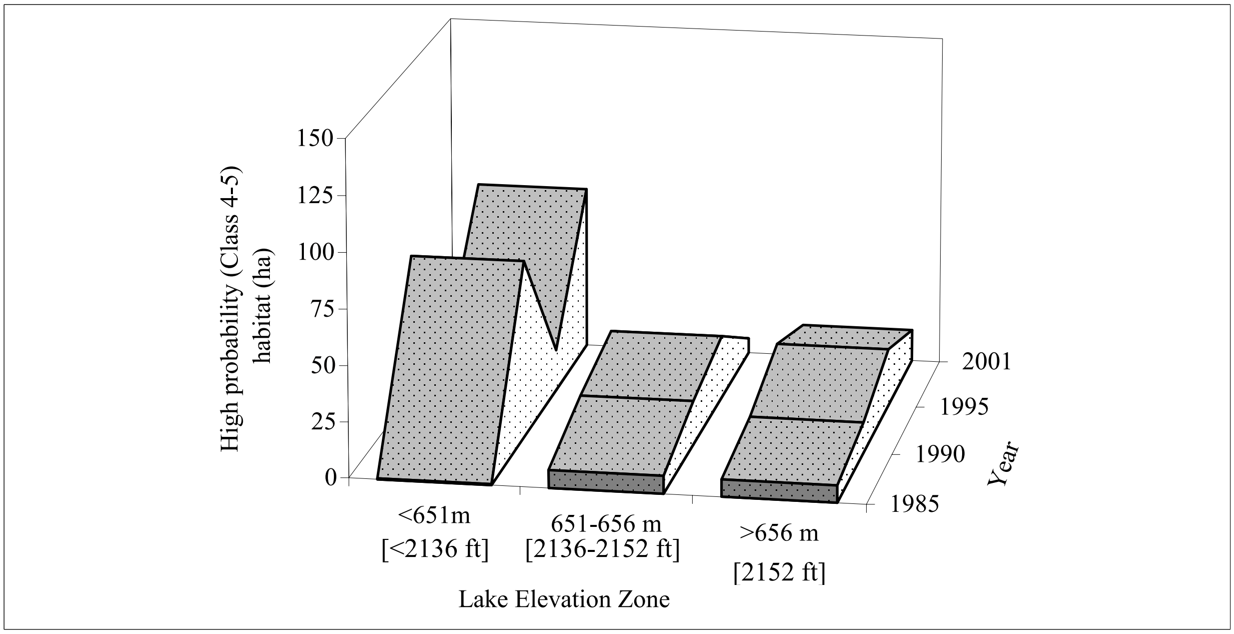

Figure 3.3. Amount (ha) of higher probability (Classes 4-5) southwestern willow flycatcher breeding habitat within 3 elevation zones at Tonto Creek inflow to Roosevelt Lake, Arizona, between 1985-2001.

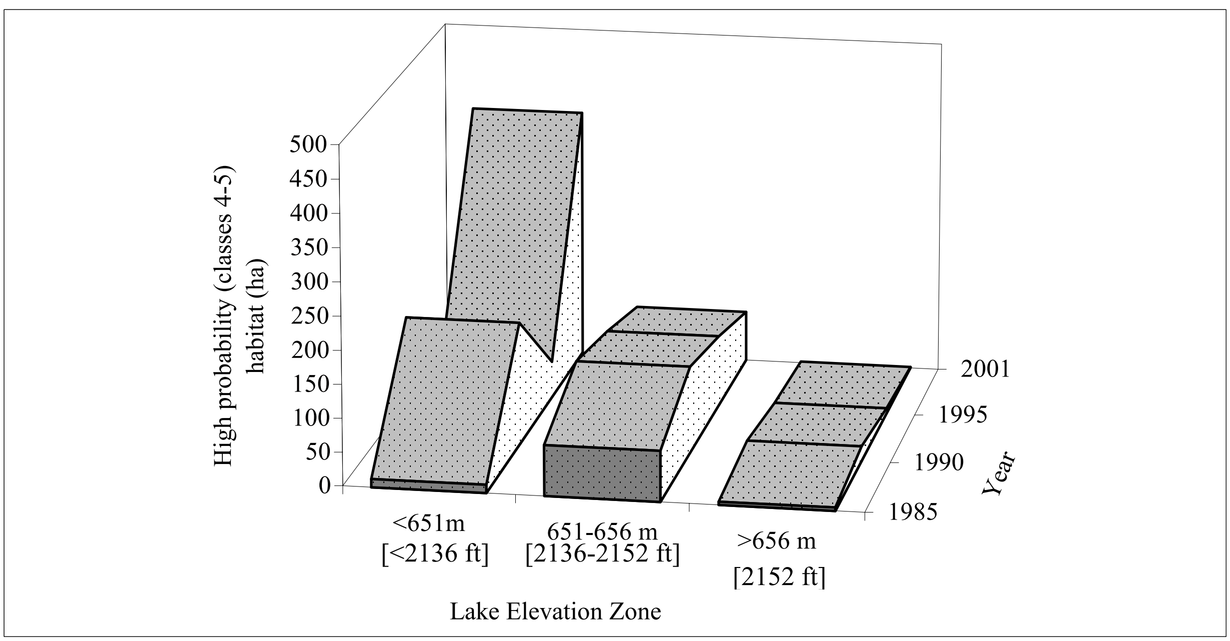

Figure 3.4. Amount of higher probability (Classes 4-5) southwestern willow flycatcher breeding habitat within 3 elevation zones at Salt River inflow to Roosevelt Lake, Arizona, between 1985-2001.

DISCUSSION

HABITAT EFFECTS

Reservoir habitats are important breeding areas for southwestern willow flycatchers throughout their range (for example, Alamo Lake, Lake Mead, and San Carlos, Arizona; Lake Isabella, California; and Elephant Butte, New Mexico [Marshall 2000]). However, little research has been done to identify the hydrological processes that create and sustain SWFL habitat in reservoir systems, information that could aid managers when considering lake level manipulations (see Warren and Turner 1975; Franz and Bazzaz 1977). For example, during flycatcher surveys at Roosevelt Lake, we observed that patch floristics varied longitudinally along the riparian delta. Dense stands of willow were interspersed between stands of monotypic tamarisk, suggesting that certain environmental conditions favored willow establishment over tamarisk as lake levels declined. Specifically, the frequency, timing, and duration of drawdown need to be explored to determine its affect on plant community assemblages. Drawdown during early spring and summer, when cottonwood and willow are producing seed, might allow for their establishment at suitable floodplain sites rather than tamarisk, which produces seed later in the growing season (Figure 3.5).

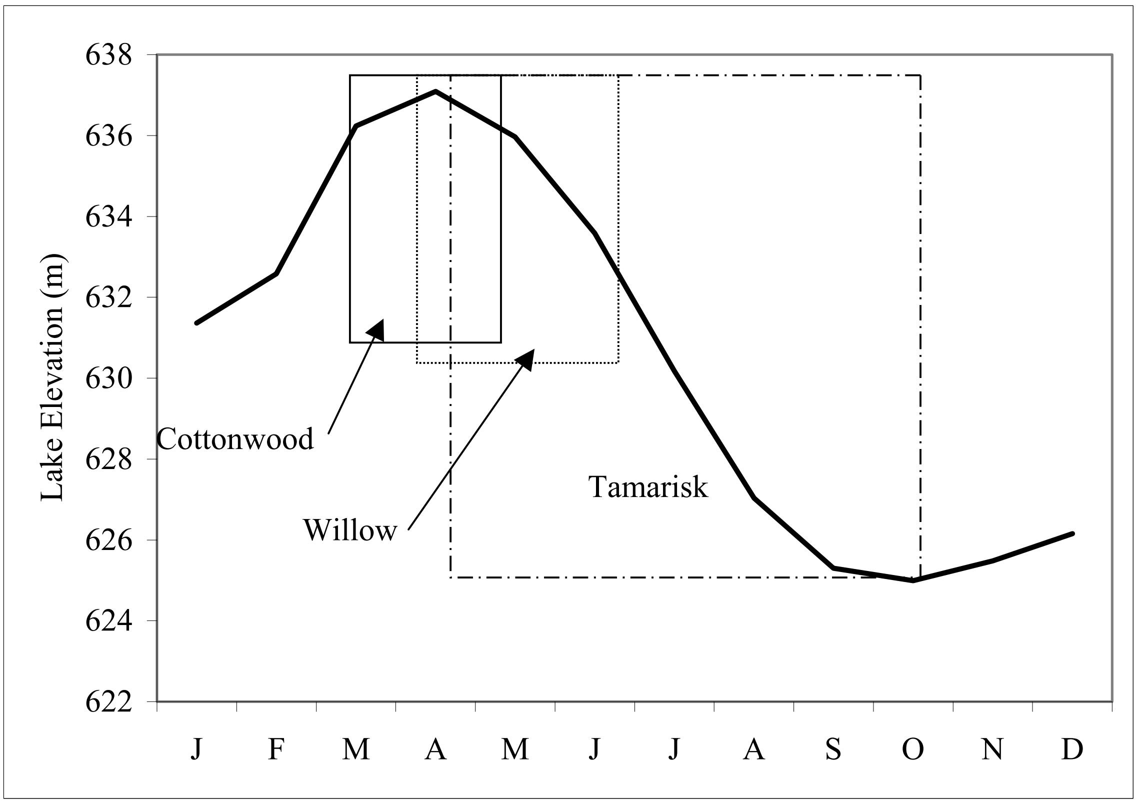

Figure 3.5. Seed-dispersal months (boxes) for 3 riparian tree species overlaid on Roosevelt Lake water elevations in 2001 (solid bold line). Note the greater chance for tamarisk establishment as water levels decline late in the growing season. Seed-dispersal data from Shafroth and others (1998) study on the Bill Williams River, west-central Arizona.

Drawdown rates might also affect the size and structure of riparian forest patches that develop, influencing patch occupancy and flycatcher reproductive success. Similarly, other riparian obligates (for example, bald eagle [*Haliaeetus leucocephalus*], yellow-billed cuckoo [*Coccyzus americanus occidentalis*]) that are of concern to Roosevelt Lake managers would benefit from an increase of cottonwood and willow trees.

Fluctuating water levels at Roosevelt Lake appear to be the disturbance mechanism responsible for recruitment and growth of SWFL nesting habitat. Declining water levels expose alluvium, which is colonized by pioneer tree species (willow, cottonwood, and tamarisk). In areas where germination occurs, seedlings are able to establish and grow, provided that declining water levels do not exceed root growth, desiccating the plant. In systems with natural flow regimes, Stromberg and others (1991) documented that recruitment of cottonwood and willow were associated with high flow events (>7 yr return interval) in the spring, fall, or winter preceding germination, and flows during the year of establishment were small. These conditions produced a cohort of trees approximately each decade. In reservoirs, riparian tree recruitment could occur each year if water level declines expose bare alluvium during the spring and early summer allows cottonwood-willow recruitment through early fall for tamarisk recruitment. This pattern would produce successively younger stands in lower lake elevations. However, if water levels are constant with no flood flows, habitats could senesce and grow out of suitability. Recent SWFL habitat selection studies at Roosevelt Lake and along the Gila/San Pedro rivers (AGFD unpublished data; Allison and others 2003) found that SWFL are associated with young (4-10 yr) forest habitats. These temporal patterns highlight the balance between periodic disturbance (inundation) within the lake deltas and declining water levels (allowing recruitment) that create and sustain younger forest stands preferred by SWFL.

In addition to the rate and timing of drawdown, other environmental characteristics affect plant species germination and growth. Tonto Creek inflow, while greater in area, had consistently less predicted breeding habitat than Salt River inflow between 1985 and 2001. The mechanism limiting the extent of breeding habitat at Tonto Creek inflow is unknown, but it may be due to local geomorphic characteristics (lake-bed slope, channel or floodplain size, soil substrates), hydrology (groundwater relationships, upstream diversions), or land uses (grazing intensity, upstream gravel mining). These characteristics may limit the growth of breeding habitat above the new high-water line of the lake and highlights the importance of identifying limiting factors to determine if replacement habitat could develop when lake levels rise.

Potential Population Effects

SWFL populations increased between 1997 and 2002 at Roosevelt Lake (Smith and others 2003; Paradzick and Woodward 2003) and the increase paralleled the expansion of new breeding habitat as lake levels declined. Color-banded birds from upstream and higher lake-bed elevation forest patches were recorded colonizing newly established forest (Koronkiewicz and others 2002). However, initial analysis of reproductive rates for the Roosevelt population suggests that births compensate for mortality, but are not high enough to add significantly to the population (AGFD unpublished data). Thus, we need better estimates of fecundity, adult and juvenile survivorship, and rates of immigration to clearly determine population dynamics and predict responses to inundation. If immigration has caused some of the increase, and Roosevelt habitat is drawing birds from other nearby populations (for example, San Carlos Reservoir, Winkelman, and Verde River), there could be an exacerbated effect on the range wide population if the lake fills to maximum capacity during the breeding season.

In 2001, 15.5 ha of predicted suitable breeding habitat were detected above the new high water level. Without additional localized refuge habitat some birds might be unable to locate suitable nesting habitat, find mates, or produce young, potentially limiting an entire year's cohort if lower lakebed elevation habitat were lost. SWFL have shown high site fidelity in the past with 70% of known surviving birds returning to Roosevelt Lake in 2002 (Koronkiewicz and others 2002). However, research has also shown that birds can successfully relocate to other breeding areas and produce young both within and between years. (Luff and others 2000; AGFD unpublished data). Also, partial inundation of trees during the breeding season may not preclude nesting if sufficient substrate occurs above water levels. SWFLs at Lake Mead nested within inundated patches until tree fall began destroying nests during the breeding season (McKernan and Braden 1998). Continued banding and monitoring at Roosevelt Lake will help determine the effects on flycatchers when lake levels rise.

Model Limitations

The GIS model and estimates of predicted breeding habitat are derived from remote sensing data; therefore not all habitat components known to be important to flycatcher habitat selection (for example, tree species and size class, and distance to water) were assessed (but see Research Needs below). Similarly, because the model predicts breeding habitat, fluctuations in bird abundance and distribution due to demographic (reproductive rates) and environmental (drought) factors are unknown.

While the GIS-based model eliminates observer biases or varying methodologies inherent in vegetation studies done over long time scales by different researchers, variation in TM imagery or data processing procedures could also influence results. For example, as mentioned in the Methods section, between year atmospheric conditions and satellite image degradation should be assessed and corrected. We caution that if the model is used to determine future trends in habitat change at Roosevelt Lake (or in other areas), these issues should be considered.

Research Needs

As noted above, the relationship between geomorphology, hydrology, and riparian plant ecology needs to be assessed to better understand how riparian tree germination, establishment, and survival occur in reservoir systems. These processes affect the spatial and temporal patterns of habitat availability at Roosevelt Lake, affect the SWFL population that occurs there, and has the potential to influence range wide population dynamics.

Using multiple images within a year, one might be able to assess plant species composition across the landscape based on phenology of riparian tree species. Variation among riparian plant species in spring leaf expansion and fall leaf drop could be tied to changes in NDVI. This technique could be especially useful to discern between the primary SWFL nesting substrates (tamarisk and willow) and unsuitable nesting substrates (mesquite forests, *Baccharis* spp.

shrublands). Additionally, using images over multiple years, one could estimate plant age and be able to assess physiognomic attributes of the vegetation. Inclusion of these parameters could help refine the model and more accurately predict possible breeding habitat across the landscape.

The GIS-based model may also be used to explore the relationship between fluvial processes within different systems (for example, regulated flow compared to natural flow streams) and the associated temporal changes in riparian forests. Additionally, the GIS-based model could be used in any suitable riparian area (see Chapter 1) where the objective is to assess change in predicted breeding habitat over time including but not limited to: other reservoirs and stream reaches, restoration projects, assessment of certain land uses, and evaluation of site potential for acquisition and protection.

Recommendations

1. Model Improvement
    a. Develop and test a model using information only from Roosevelt Lake
    b. Review current literature and research to identify habitat characteristics that could be incorporated into the model (see Chapter 2 Recommendations)
    c. Explore available covers or technology to characterize habitat features identified in b. (see Chapter 2 Recommendations)
    d. Consider evaluating and correcting for illumination angle and satellite degradation
2. Model extrapolation
    a. Run the model in future years and develop predicted breeding area/SWFL abundance ratio to better evaluate population effects of lake level fluctuations.
        i. If changes are made to the model, imagery for all years, including years in this report (1985, 1990, 1995, 2001) will need to be reevaluated to make results consistent and interpretable.
    b. Use the change detection technique on other systems
        i. The TM scene used in this report also contains portions of the San Pedro/Gila River Confluence, San Carlos Reservoir, and portions of the Verde River.
            1. The model could be used to explore available habitats in these areas over the last 2 decades.
            2. The model could be used to explore how hydrogeomorphic processes affect SWFL breeding habitat over a two decade time period. One could compare fluctuations in SWFL breeding habitat among reservoirs (Roosevelt, San Carlos, possibly Bartlett and Horseshoe Reservoirs), regulated river reaches (Gila below Coolidge Dam, Verde River below Bartlett Dam), and an unregulated river (Lower San Pedro River).
3. Population Effects
    a. Link numbers of SWFL and movement data with change in habitat over time.
    b. Contrast SWFL population distribution and abundance with other riparian areas (see 2.b.i).

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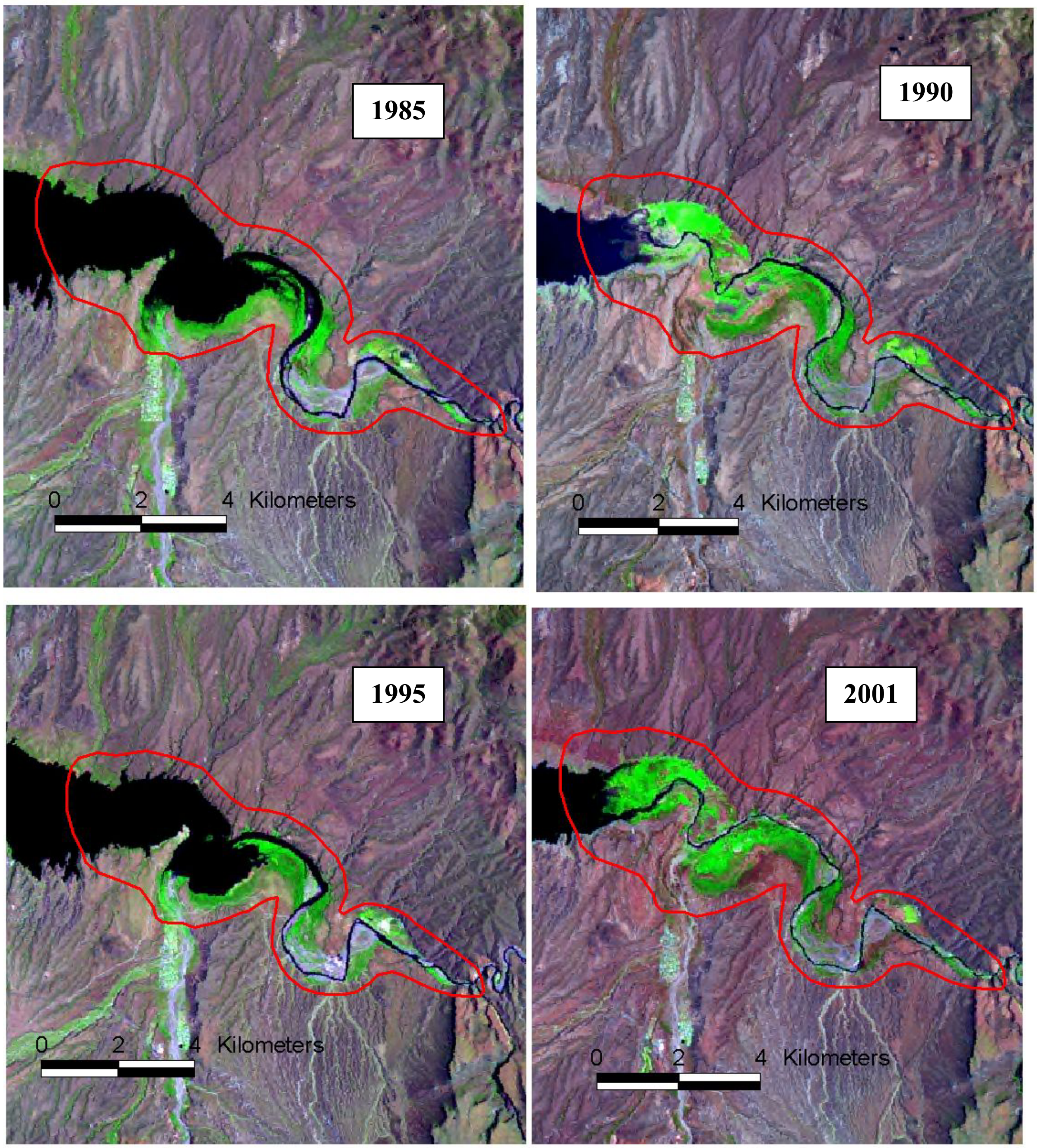
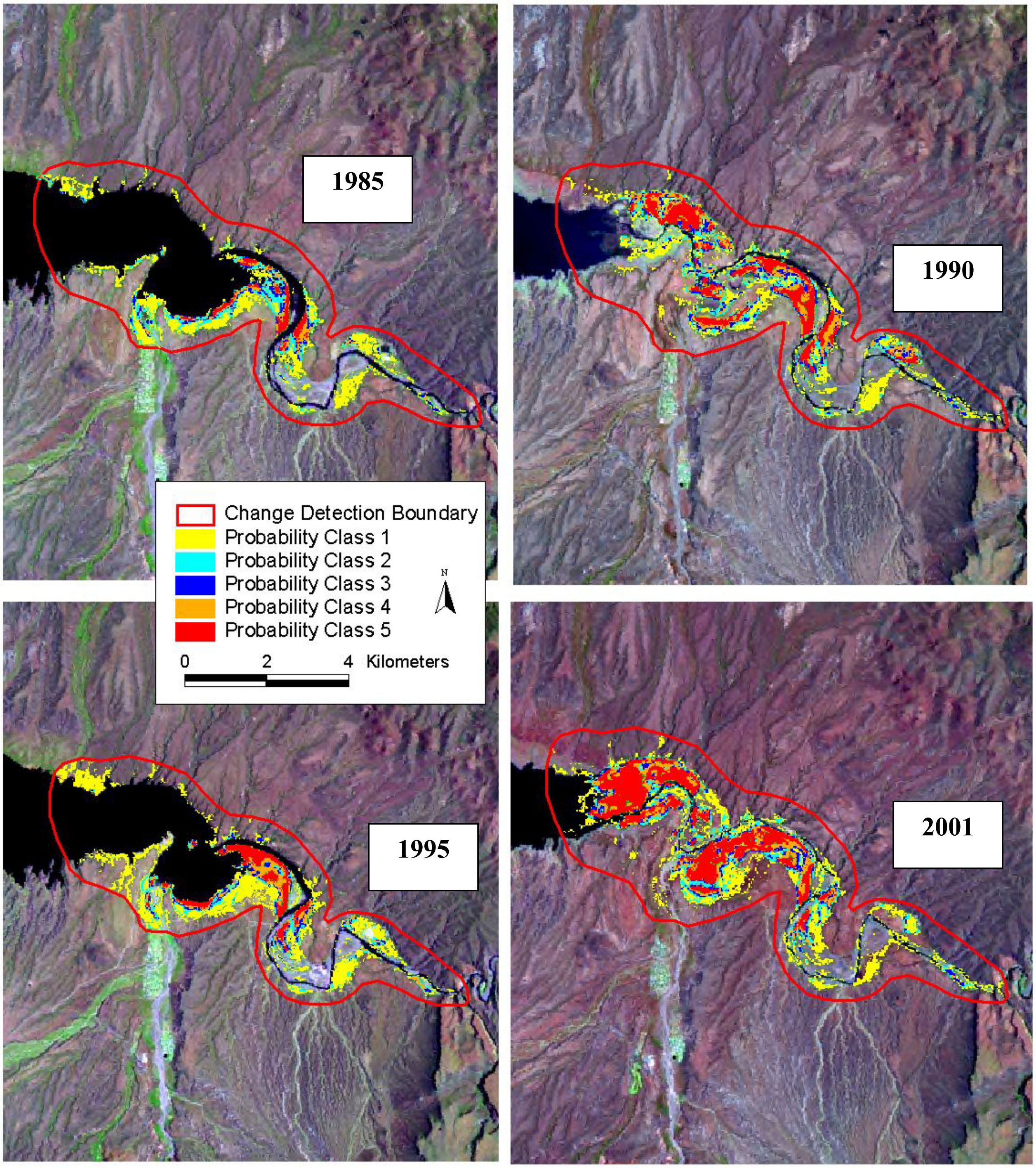
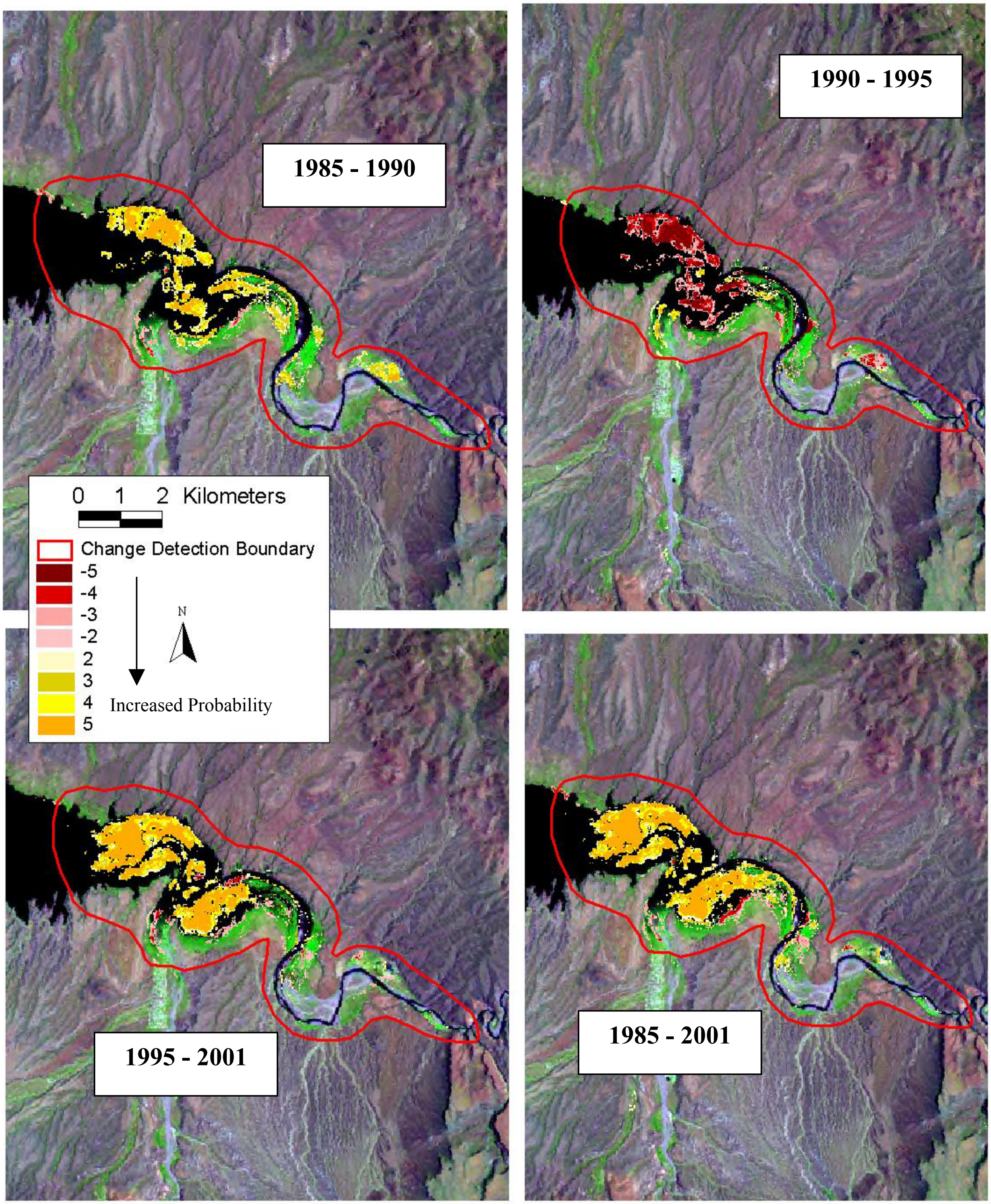
Appendix 3.1. Time series (1985-2001) maps showing Landsat Thematic Mapper images; predicted southwestern willow flycatcher breeding habitat, and change in predicted habitat suitability between time series for Salt River inflow and Tonto Creek inflow to Roosevelt Lake, Arizona. (see descriptive captions below images).



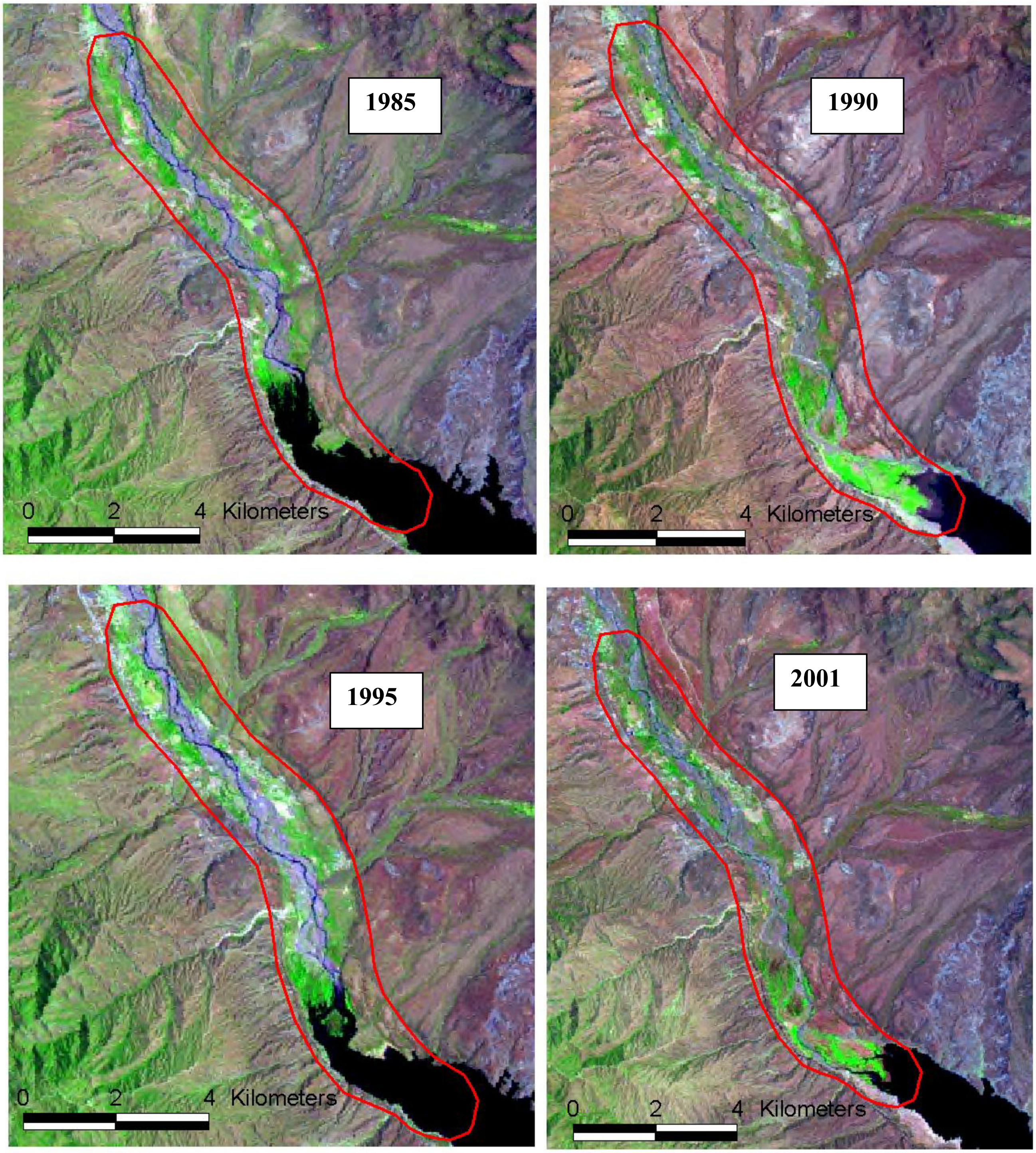
Salt River inflow: TM images acquired during the second week of June 1985, 1990, 1995, and 2001.



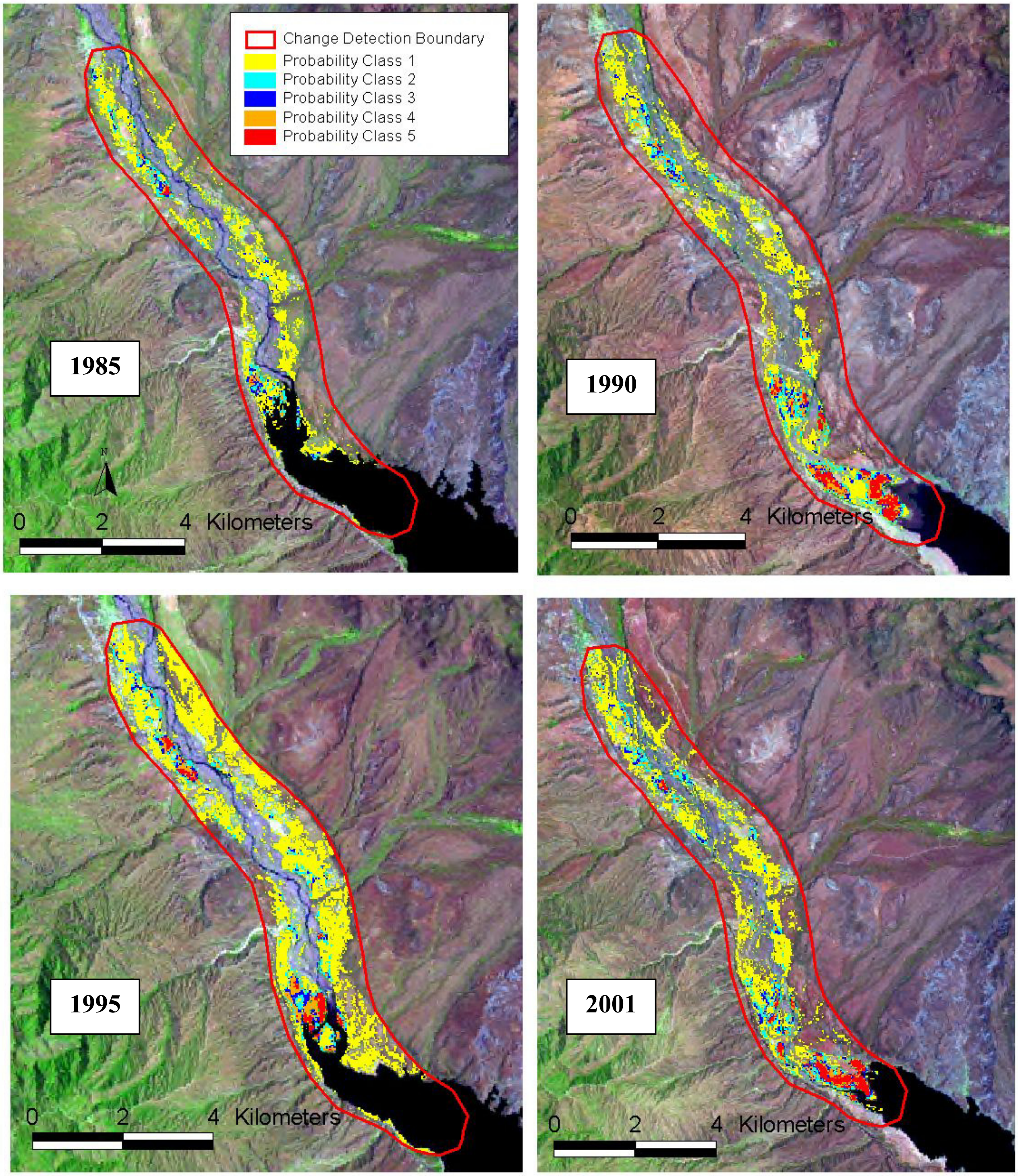
Salt River inflow: predicted suitable SWFL breeding habitat in 1985, 1990, 1995, and 2001. Probability divided into 5 suitability classes: 1 (lowest potential) to 5 (highest potential).



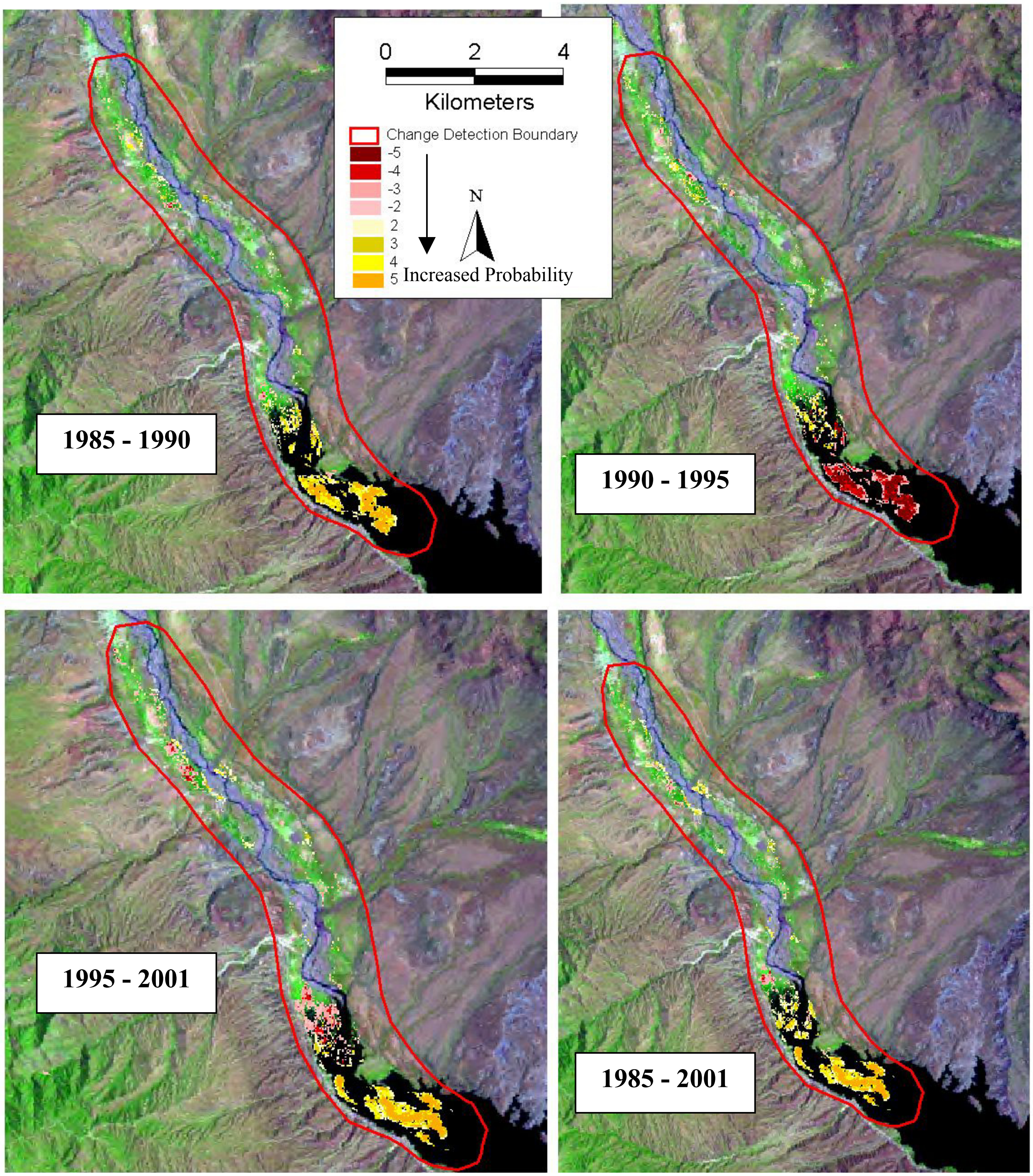
Salt River inflow: change in predicted habitat suitability between years. Higher values (see legend) indicate an increase in the probability class of breeding habitat, while larger negative values indicate a decrease in the probability class of breeding habitat.



Tonto Creek inflow: TM images acquired during the second week of June 1985, 1990, 1995, and 2001.



Tonto Creek inflow: predicted suitable SWFL breeding habitat in 1985, 1990, 1995, and 2001. Probability divided into 5 suitability classes: 1 (lowest potential) to 5 (highest potential).



Tonto Creek inflow: change in predicted habitat suitability between years. Higher values (see legend) indicate an increase in the probability class of breeding habitat, while larger negative values indicate a decrease in the probability class of breeding habitat.

Appendix 3.2. Southwestern willow flycatcher predicted suitable breeding habitat (class 4-5) (ha) within 3 lake elevation zones at Tonto Creek inflow and Salt River inflow to Roosevelt Lake, Arizona.

Area	Lake Elevation	Predicted breeding habitat (ha) per year			
		1985	1990	1995	2001
Salt River inflow	< 651 m (<2136 ft)	12.3	182.2	54.3	371.8
	651-656 m (2136-2152 ft)	75.3	128.8	105.3	74.8
	> 656 m (>2152 ft)	4.9	22.1	7.8	1.3
Tonto Creek inflow	< 651 m (<2136 ft)	0.4	79.3	18.2	73.3
	651-656 m (2136-2152 ft)	8	19.8	28.4	6.7
	< 656 m (>2152 ft)	7.7	13.9	26	14.2