A MULTISCALED MODEL OF SOUTHWESTERN WILLOW FLYCATCHER BREEDING HABITAT

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Abstract: The southwestern willow flycatcher (SWFL; *Empidonax traillii extimus*) is an endangered songbird whose habitat has declined dramatically over the last century. Understanding habitat selection patterns and the ability to identify potential breeding areas for the SWFL is crucial to the management and conservation of this species. We developed a multiscaled model of SWFL breeding habitat with a Geographic Information System (GIS), survey data, GIS variables, and multiple logistic regressions. We obtained presence and absence survey data 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) 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 that 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 SWFL. We will use the multiscaled model to map SWFL breeding habitat in Arizona, prioritize future survey effort, and examine changes in habitat abundance and quality over time.

JOURNAL OF WILDLIFE MANAGEMENT 67(4):774–788

Key words: Arizona, *Empidonax traillii extimus*, GIS, habitat selection, landscape, neighborhood analysis, predictive modeling, riparian vegetation, southwestern willow flycatcher.

The 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 1995, Marshall 2000). The SWFL is a Neotropical migrant that breeds exclusively in riparian vegetation from near sea level to 2,700 m in elevation (Marshall 2000). Arizona contains approximately one-third of SWFL breeding territories (Sogge et al. 2000), and over 95% of these are located between 140 and 1,400 m elevation (Paradzick et al. 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 et al. 1987) and livestock grazing (Belsky et al. 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 (U.S. Fish and Wildlife Service 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 (Arizona Game and Fish Department, unpublished data), 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,

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Vander Haegen et al. 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 also can 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 on vegetation and landscape features found at or around the site (0.09–72 ha).

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 (Fig. 1). The U.S. 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 (Fig. 1) at the confluence of the Bill Williams, Big Sandy, and Santa Maria rivers. The U.S. Bureau of Land Management managed the eastern section of the test area as a wilderness area, while the Arizona Game and Fish Department 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

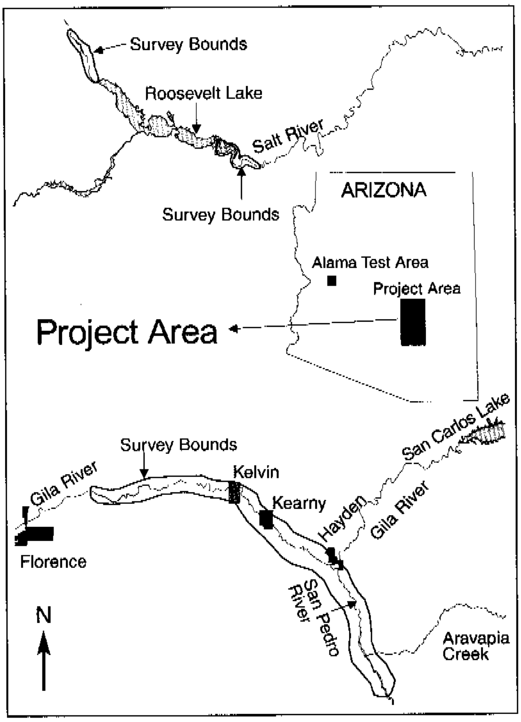

Fig. 1. A map of our project area in Arizona, USA, showing locations of the 3 survey areas: Tonto Creek, Salt River, and Gila/San Pedro rivers. The location of Alamo test area is shown on the map inset.

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 et al. 2001).

METHODS

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 potentially suitable SWFL breeding habitat was delineated on aerial photographs and topographic maps, and nest locations were recorded. Potentially 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 et al. 1997). Habitats considered unsuitable (Sogge et al. 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 think 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.

Presence–absence surveys for SWFL followed a standardized protocol (Sogge et al. 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–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 et al. 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 et al. 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 et al. 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) and encompass the project area (8,848 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 on 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 et al. 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, seral stage) that may influence habitat selection (Sogge et al. 1997, Sogge and Marshall 2000) because they could not be accurately extracted from TM imagery.

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 et al. 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

Table 1. Predictor variables used to characterize vegetation and floodplain features at or around southwestern willow flycatcher (SWFL) breeding and nonuse sites in south-central Arizona, USA, 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) of 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

nonriparian 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 zero and classes 10–12 (raw NDVI >0.336) were set to 1.

We used GRID focal functions (Environmental Systems Research Institute [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 nonriparian features from the riparian-vegetation density grid. Last, 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 et al. 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) 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 1 of 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 on 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 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 that 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.

Multiscaled, Multivariate Analysis.—Our multiscaled, multivariate analysis found 3 covariates (NDVIBEST, FLOODPL, NDVISTD) that were significantly associated with breeding-site occurrence within different-sized neighborhoods, but model fit was better in smaller-sized neighborhoods (Fig. 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.

Table 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, USA, 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.

	Nonuse group			Breeding group				
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.

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.

The best subset of predictor variables (Table 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 4.4 times more likely to contain breeding activity. At an interme-

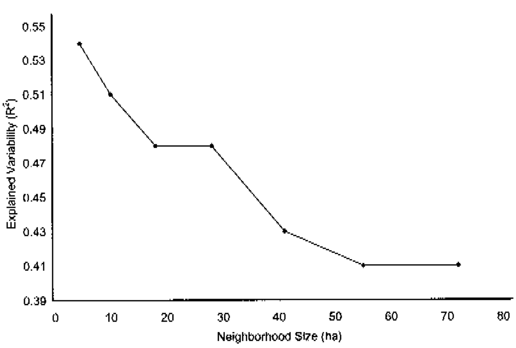

Fig. 2. The amount of explained variability (R^2) in southwestern willow flycatcher (SWFL) breeding-site occurrence, as determined with multiple logistic regression, within 7 different-sized neighborhoods (4.5–72 ha) around breeding and nonuse sites. In this analysis, NDVI (relative density of green 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.

Table 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, USA. 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.

diate scale (4.5 ha), for each 10% of neighborhood covered in dense vegetation (NDVI = 12), likelihood of breeding activity increased by 1.6 times. Furthermore, each unit of increase in NDVISTD increased likelihood of breeding activity by 1.9 times. We found a significant positive association between FLOODPL12 and the likelihood of breeding activity.

Habitat Mapping and Accuracy Assessment

Project Area: 1999.—The model identified 5,294 ha of potential breeding habitat in the project area, with each cell assigned a probability of breeding-site occurrence between 1 and 98% (Fig. 3). Amount (ha) of potential breeding habitat was inversely related to 5 probability classes (Fig. 4A), with 61% of potential breeding habitat within the first class and 6% within the fifth class. In contrast, nest density increased in each probability class (Fig. 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 on what probability cutpoint was examined (Fig. 4C). When all potentially 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.

Project Area: 1995–1998 and 2000–2001.—When we overlaid breeding-site locations from 1995–1998 (Fig. 5A) or 2000–2001 (Fig. 5B) on 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 (Fig. 5C) and 2000–2001 (Fig. 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 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 identified 1,403 ha of potential breeding habitat in Alamo test area (Fig. 6), with each cell assigned a probability of breeding activity between 1 and 98%. The amount (ha) of potential breeding habitat was inversely related to 5 probability classes (Fig. 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 (Fig. 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.

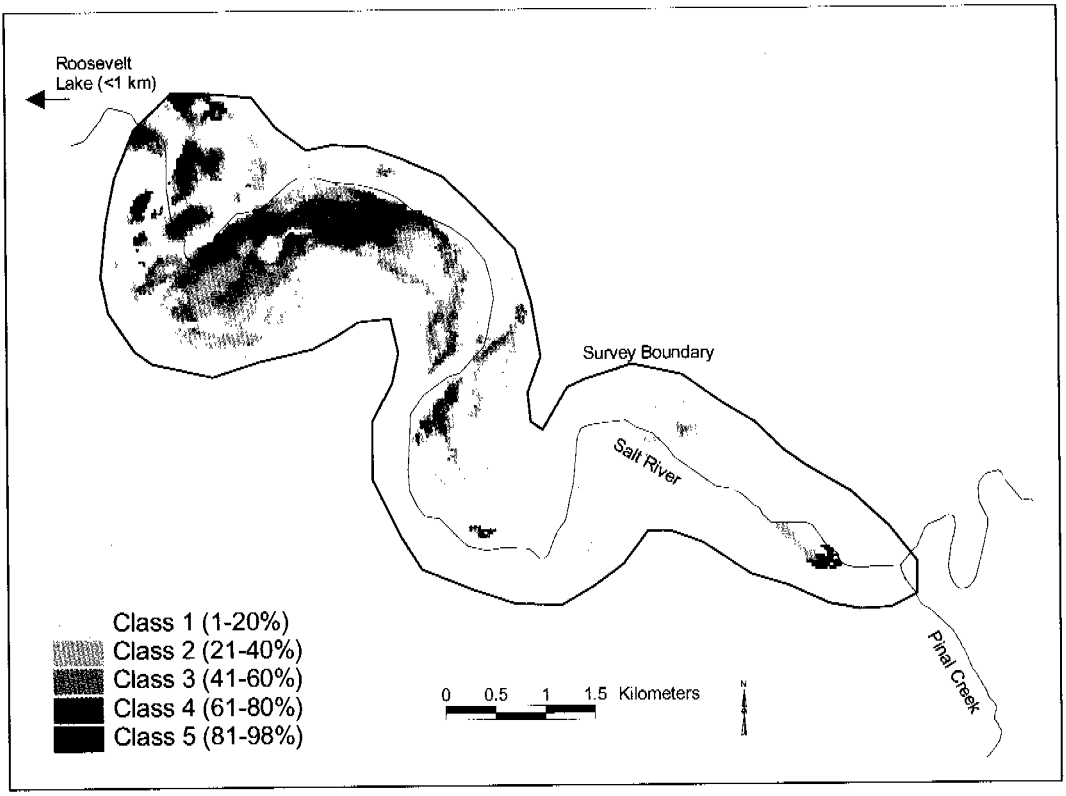

Fig. 3. A southwestern willow flycatcher (SWFL) breeding-site suitability map of Salt River, Arizona, USA, survey area in 1999 produced from a GIS-based model, logistic regression, digital elevation models, and Thematic Mapper imagery. Probability of breeding-site occurrence ranged from 1 to 98%, which we reclassified into 1 of 5 probability classes.

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 (Fig. 7C) at Alamo Lake, compared with 21% in the project area. Ninety percent of breeding sites at Alamo Lake were above the 40% cutpoint, compared with 79% in the project area, occupying 16% of potentially 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 also was 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

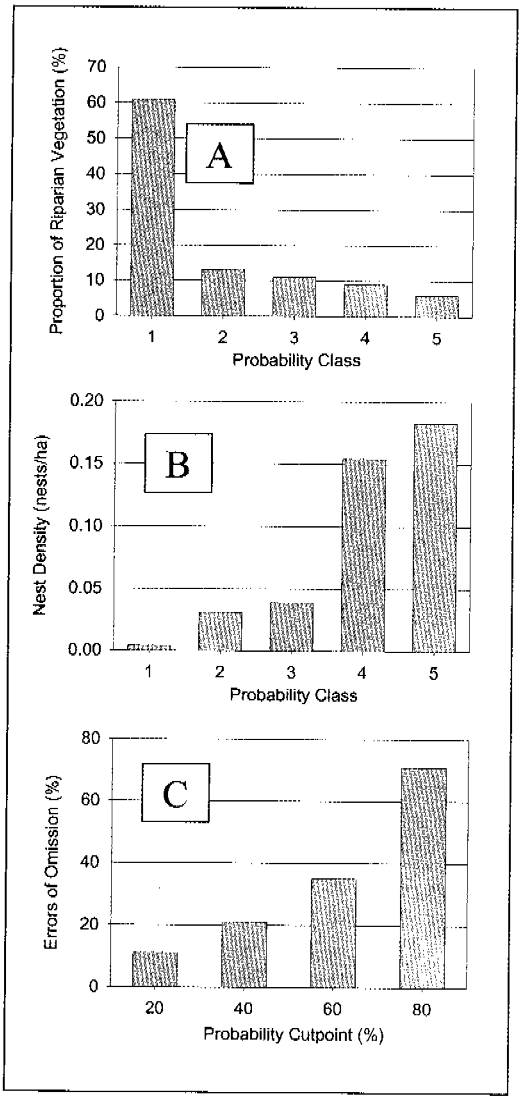

Fig. 4. The proportion of potential breeding habitat (A) and nest density (B) within 5 probability classes, produced from a GIS-based model within our project area (Arizona, USA) in 1999, and omission error at different probability cutpoints (C). Nest density was calculated from control sites (nests) 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.

song perches (Sedgwick and Knopf 1992) or foraging opportunities (Barlow and McGillivray 1983, Sedgwick 2000, Sogge 2000).

Most 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 et al. 1996). The 4 systems we investigated all have large watersheds (1,800–46,000 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 et al. 2001). These patterns suggest that SWFL prefer large, active floodplains that support development of young, wide, and dense stands of riparian vegetation similar to presettlement patterns of cottonwood–willow communities that were spatially and temporally dynamic (Graf 1982, Auble et al. 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 et al. 1987, Chou and Soret 1996, Vander Haegen et al. 2000). Five percent of breeding sites within the project area (1999) and 2% in the Alamo Lake test area fell outside of all potentially suitable areas (classes 1–5) and were errors of omission. Some breeding-site misclassification probably 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 deter-

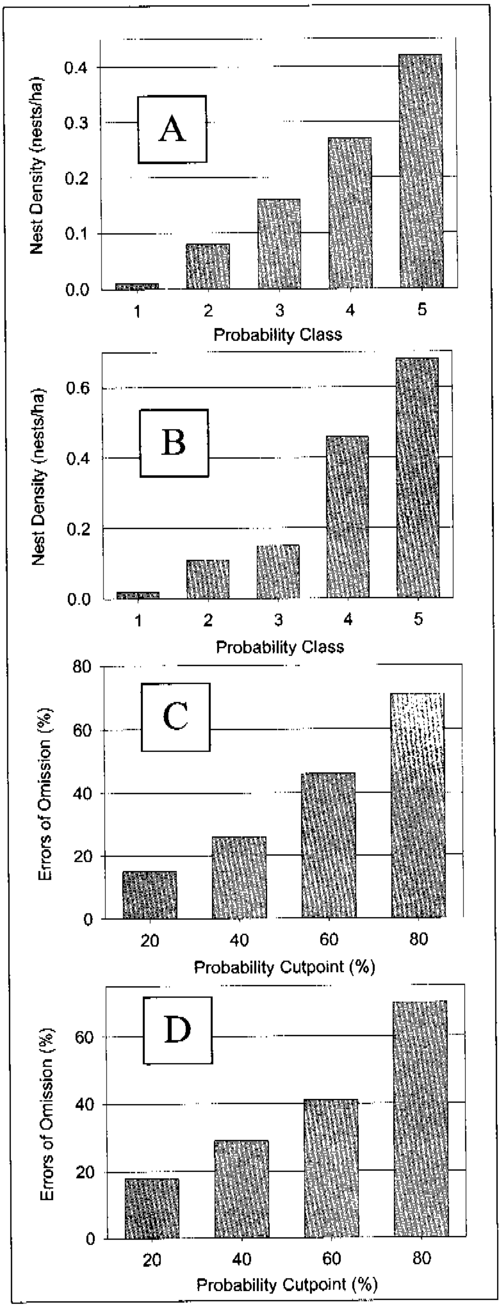

Fig. 5. We assessed the temporal accuracy of the 1999 model by overlaying 398 southwestern willow flycatcher breeding sites identified between 1995 and 1998, and 601 between 2000 and 2001, within the project area. Model fit was examined with nest density 1995–1998 (A) and 2000–2001 (B) within 5 probability 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.

mined 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 (1,900 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 on 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 potential 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 potential 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 1,500 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 with-

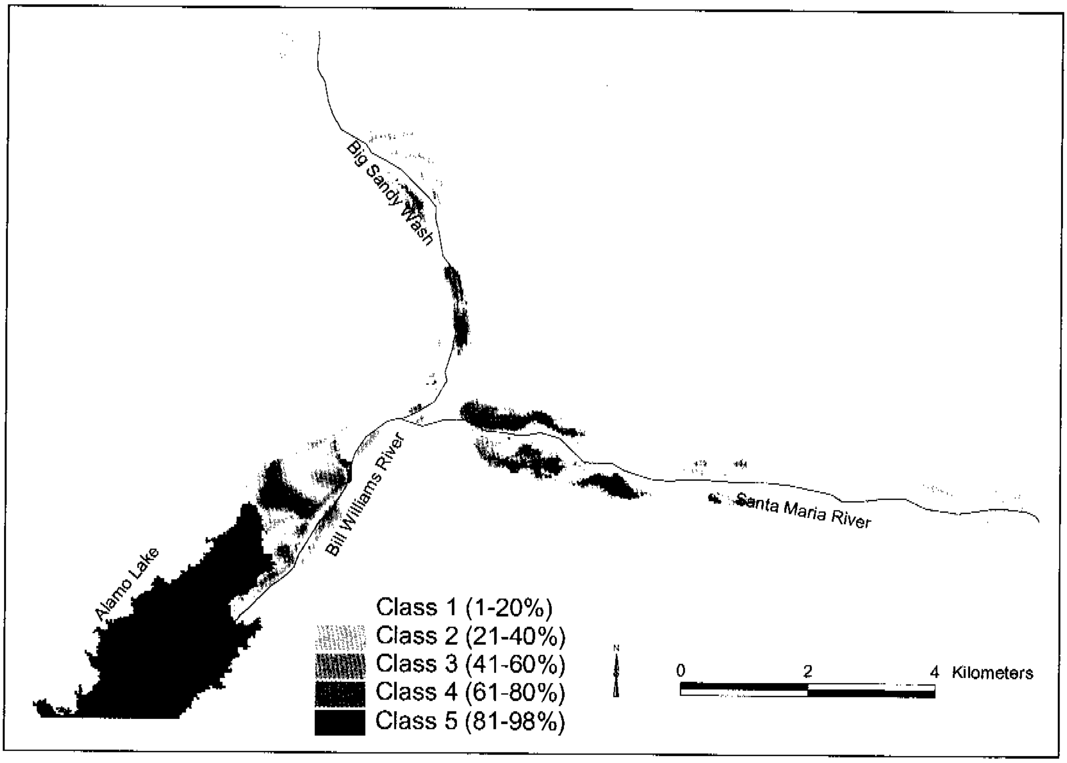

Fig. 6. A southwestern willow flycatcher (SWFL) breeding-site suitability map of Alamo test area, Arizona, USA, that was produced from a GIS-based model developed 200 km to the southeast. The GIS-based model used logistic regression, digital elevation models, and Thematic Mapper imagery to map the probability of breeding-site occurrence. Probabilities ranged from 1 to 98%, which we reclassified into 1 of 5 probability classes.

in each survey area (Paradzick et al. 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 et al. 2001).

Managers would benefit if the vegetation variables we found to be important were linked to traditional habitat measurements (e.g., 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 et al. 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 (e.g., agricultural, urban). Last, additional research is necessary to clarify the structural characteristics and biological significance of the NDVISTD variable.

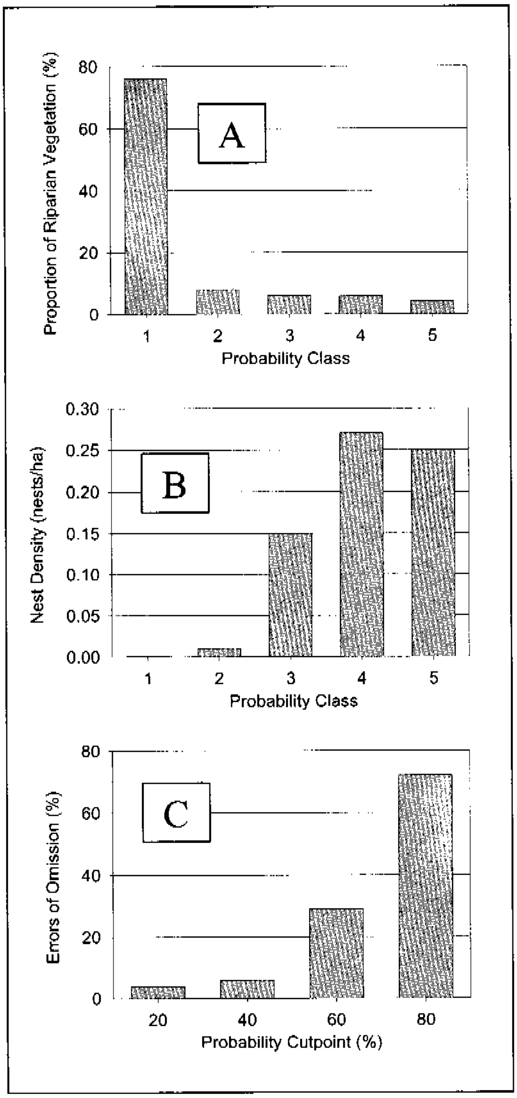

Fig. 7. The proportion of potential breeding habitat (A) and density of nest sites (B) within 5 probability classes, produced from a GIS-based model developed 200 km to the southeast in 1999, and omission errors at different probability cutpoints (C). The 5 classes divide the probability of breeding 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.

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 potential 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 on an area's suitability ranking, surveying the most suitable areas first and less suitable areas as resources permit. The distribution of potential breeding habitat was clumped, not random or dispersed, enabling crews to sweep high-potential areas quickly and efficiently to locate occupied habitat and develop SWFL population estimates. Additionally, for the first time we can map habitat potential 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 et al. 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 U.S. Fish and Wildlife Service (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.

ACKNOWLEDGMENTS

We thank M. W. Sumner, who was crucial in the formation and fieldwork for this project. We thank the 1996–2000 Arizona Game and Fish Department (AGFD) seasonal biologists who collected field data. We thank A. A. Woodward, D. A. Gryskiewicz, S. S. Rosenstock, S. S. Germaine, S. J. Sferra, M. K. Sogge, and 2 anonymous reviewers for comments that improved this manuscript. This work was supported by the U.S. Bureau of Reclamation (Contract No. 98-FC-32-0050), the U.S. Bureau of Land Management (AAA990008-4), Arizona's Nongame Wildlife Checkoff, and the AGFD Heritage Fund.

LITERATURE CITED

ALLISON, L. A., C. E. PARADZICK, J. W. ROURKE, AND T. D. MCCARTHEY. 2003. A characterization of vegetation in nesting and non-nesting plots for southwestern willow flycatchers in central Arizona. Studies in Avian Biology 26:22–29.

ANDERSON, S. H., AND H. H. SHUGART. 1974. Habitat selection of breeding birds in an east Tennessee deciduous forest. Ecology 55:828–837.

ARONOFF, S. 1989. Geographic information systems: a management perspective. WDL Publications, Ottawa, Ontario, Canada.

AUBLE, G. T., J. M. FRIEDMAN, AND M. L. SCOTT. 1994. Relating riparian vegetation to present and future streamflows. Ecological Applications 4:544–554.

AVERY, T. E., AND G. L. BERLIN. 1992. Fundamentals of remote sensing and airphoto interpretation. Fifth edition. Macmillan Publishing Company, New York, New York, USA.

BARLOW, J. C., AND W. B. MCGILLIVRAY. 1983. Foraging and habitat relationships of the sibling species willow flycatcher (*Empidonax traillii*) and alder flycatcher (*E. alnorum*) in southern Ontario. Canadian Journal of Zoology 61:1510–1516.

BELSKY, A. J., A. MATZKE, AND S. USELMAN. 1999. Survey of livestock influences on stream and riparian ecosystems in the western United States. Journal of Soil and Water Conservation 54:419–431.

BOOTS, B. N., AND A. GETIS. 1988. Point pattern analysis. Sage Publications, Beverly Hills, California, USA.

BROWN, D. E., editor. 1994. Tropical-subtropical desertlands. Pages 180–221 *in* Biotic communities of the southwestern United States and northwestern Mexico. University of Utah Press, Salt Lake City, Utah, USA.

BUSCH, D. E., AND S. E. SMITH. 1995. Mechanisms associated with decline of woody species in riparian ecosystems of the southwestern U.S. Ecological Monographs 65:347–370.

CHOU, Y. 1997. Exploring spatial analysis in Geographic Information Systems. OnWord Press, Santa Fe, New Mexico, USA.

———, AND S. SORET. 1996. Neighborhood effects in bird distributions, Navarre, Spain. Environmental Management 20:675–687.

CLARK, R. G., AND D. SHUTLER. 1999. Avian habitat selection: pattern from process in nest-site use by ducks? Ecology 80:272–287.

ENVIRONMENTAL SYSTEMS RESEARCH INSTITUTE (ESRI). 1992. Cell-based modeling with GRID. ESRI, Redlands, California, USA.

GATES, J. E., AND L. W. GYSEL. 1978. Avian nest dispersion and fledging success in field–forest ecotones. Ecology 59:871–883.

GOVERNOR'S RIPARIAN HABITAT TASK FORCE. 1990. Final report and recommendations: Executive Order 89–16 Streams and Riparian Resources in Arizona. Phoenix, Arizona, USA.

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

GUTZWILLER, K. J., AND S. H. ANDERSON. 1987. Multiscale associations between cavity-nesting birds and features of Wyoming streamside woodlands. Condor 89:534–548.

HODGSON, M. E., J. R. JENSEN, H. E. MACKEY, JR., AND M. C. COULTER. 1987. Remote sensing of wetland habitat: a wood stork example. Photogrammetric Engineering and Remote Sensing 53:1075–1080.

HOSMER, D. W., AND S. LEMESHOW. 1989. Applied logistic regression. First edition. John Wiley & Sons, New York, New York, USA.

HUNTER, W. C., R. D. OHMART, AND B. W. ANDERSON. 1987. Status of breeding riparian-obligate birds in southwestern riverine systems. Western Birds 18:10–18.

KOTLIAR, N. B., AND J. A. WIENS. 1990. Multiple scales of patchiness and patch structure: a hierarchical framework for the study of heterogeneity. Oikos 59:253–260.

KVAMME, K. L. 1985. Determining empirical relationships between the natural environment and prehistoric site locations: a hunter–gatherer example. Pages 208–238 *in* C. Carr, editor. For concordance in archaeological analysis. Westport Publishers, Kansas City, Kansas, USA.

LANDE, R. 1987. Extinction thresholds in demographic models of territorial populations. American Naturalist 130:624–635.

LARSON, D. L., AND C. E. BOCK. 1986. Determining avian habitat preference by bird-centered vegetation sampling. Pages 37–43 *in* J. Verner, M. L. Morrison, and C. J. Ralph, editors. Wildlife 2000: modeling habitat relationships of terrestrial vertebrates. University of Wisconsin Press, Madison, Wisconsin, USA.

LEGENDRE, P. 1993. Spatial autocorrelation: trouble or new paradigm? Ecology 74:1659–1673.

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

LUFF, J. A., E. H. PAXTON, K. E. KENWOOD, AND M. K. SOGGE. 2000. Survivorship and movements of southwestern willow flycatchers in Arizona–2000. U.S. Geological Survey, Colorado Plateau Field Station Report, Flagstaff, Arizona, USA.

LYON, J. G. 1983. Landsat-derived land-cover classifications for locating potential kestrel nesting habitat. Photogrammetric Engineering and Remote Sensing 49:245–250.

MARSHALL, R. M. 2000. Population status on breeding grounds. Pages 3–11 *in* D. M. Finch and S. H. Stoleson, editors. Status, ecology, and conservation of the southwestern willow flycatcher. U.S Forest Service General Technical Report RMRS-60.

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

———, AND J. J. ROPER. 1988. Nest predation and nest-site selection of a western population of the hermit thrush. Condor 90:51–57.

MINCKLEY, W. L., AND D. E. BROWN. 1994. Wetlands. Pages 223–301 *in* D. E. Brown, editor. Biotic communities of the southwestern United States and northwestern Mexico. University of Utah Press, Salt Lake City, Utah, USA.

NAGELKERKE, N. J. D. 1991. A note on a general definition of the coefficient of determination. Biometrika 78:691–692.

NORUSIS, M. J. 1999. SPSS regression models 10.0. SPSS, Chicago, Illinois, USA.

PALMEIRIM, J. M. 1988. Automatic mapping of avian species habitat using satellite imagery. Oikos 52:59–68.

PARADZICK, C. E., R. F. DAVIDSON, J. W. ROURKE, M. W. SUMNER, A. W. WARTELL, AND T. D. MCCARTHEY. 2000. Southwestern willow flycatcher 1999 survey and nest monitoring report. Arizona Game and Fish Department Nongame and Endangered Wildlife Program Technical Report 151.

———, AND A. A. WOODWARD. 2003. Distribution, abundance, and habitat characteristics of southwestern willow flycatchers (Empidonax traillii extimus) in Arizona, 1993–2000. Studies in Avian Biology 26:22–29.

———, T. D. MCCARTHEY, R. F. DAVIDSON, J. W. ROURKE, M. W. SUMNER, AND A. B. SMITH. 2001. Southwestern willow flycatcher 2000 survey and nest monitoring report. Arizona Game and Fish Department Nongame and Endangered Wildlife Program Technical Report 175.

POUNCEY, R., K. SWANSON, AND K. HART. 1999. ERDAS field guide. Fifth edition. ERDAS, Inc., Atlanta, Georgia, USA.

POWELL, B. F., AND R. J. STEIDL. 2000. Nesting habitat and reproductive success of southwestern riparian birds. Condor 102:823–831.

RAMSEY, F. L., M. MCCRACKEN, J. A. CRAWFORD, M. S. DRUT, AND W. J. RIPPLE. 1994. Habitat association studies of the northern spotted owl, sage grouse, and flammulated owl. Pages 189–209 *in* N. Lange, L. Ryan, L. Billard, D. Brillinger, L. Conquest, and J. Greenhouse, editors. Case studies in biometry. John Wiley & Sons, New York, New York, USA.

RIPPLE, W. J., D. H. JOHNSON, K. T. HERSHEY, AND E. C. MESLOW. 1991. Old-growth and mature forests near spotted owl nests in western Oregon. Journal of Wildlife Management 55:316–318.

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

SCHIECK, J. O., AND S. J. HANNON. 1993. Clutch predation, cover, and the overdispersion of nests of the willow ptarmigan. Ecology 74:743–750.

SCOTT, M. L., J. M. FRIEDMAN, AND G. T. AUBLE. 1996. Fluvial process and establishment of bottomland trees. Geomorphology 14:327–339.

SEDGWICK, J. A. 2000. Willow flycatcher (*Empidonax traillii*). No. 533 *in* A. Poole and F. Gill, editors. The birds of North America. The Birds of North America, Philadelphia, Pennsylvania, USA.

———, AND F. L. KNOPF. 1992. Describing willow flycatcher habitats: scale perspectives and gender differences. Condor 94:720–733.

SOGGE, M. K. 2000. Breeding season ecology. Pages 57–70 *in* D. M. Finch and S. H. Stoleson, editors. Status, ecology, and conservation of the southwestern willow flycatcher. U.S. Forest Service General Technical Report RMRS-60.

———, AND R. M. MARSHALL. 2000. A survey of current breeding habitats. Pages 43–56 *in* D. M. Finch and S. H. Stoleson, editors. Status, ecology, and conservation of the southwestern willow flycatcher. U.S. Forest Service General Technical Report RMRS-60.

———, ———, S. J. SFERRA, AND T. J. TIBBITTS. 1997. A southwestern willow flycatcher natural history summary and survey protocol. NRTR-97112. National Park Service Cooperative Studies Unit, U.S. Geological Survey Colorado Plateau Research Station, Northern Arizona University, Flagstaff, Arizona, USA.

———, S. J. SFERRA, T. MCCARTHEY, S. O. WILLIAMS, AND B. E. KUS. 2000. Southwestern willow flycatcher breeding site and territory summary–1999. U.S. Geological Survey, Colorado Plateau Field Station, Northern Arizona University, Flagstaff, Arizona, USA.

SOKAL, R. R., AND F. J. ROHLF. 1969. Biometry. Second edition. W. H. Freeman, San Francisco, California, USA.

STORY, M., AND R. G. CONGALTON. 1986. Accuracy assessment: a user's perspective. Photogrammetric Engineering and Remote Sensing 52:397–399.

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

SZARO, R. C. 1990. Southwestern riparian plant communities: site characteristics, tree species distributions, and size-class structures. Forest Ecology and Management 33/34:315–334.

TOU, J. T., AND R. C. GONZALEZ. 1974. Pattern recognition principles. Addison-Wesley, Reading, Massachusetts, USA.

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

U.S. FISH AND WILDLIFE SERVICE. 1995. Final rule determining endangered status for the southwestern willow flycatcher. U.S. Federal Register 60:10694–10715.

VANDER HAEGEN, W. M., F. C. DOBLER, AND D. J. PIERCE. 2000. Shrubsteppe bird response to habitat and landscape variables in eastern Washington, U.S.A. Conservation Biology 14:1145–1160.

VAN HORNE, B. 1983. Density as a misleading indicator of habitat quality. Journal of Wildlife Management 47:893–901.

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

WIENS, J. A., N. C. STENSETH, B. VAN HORNE, AND R. A. IMS. 1993. Ecological mechanisms and landscape ecology. Oikos 66:369–380.

Received 8 March 2002.
Accepted 7 July 2003.
Associate Editor: Kelly.