Validating a Florida Scrub Jay Habitat Suitability Model, Using Demography Data on Kennedy Space Center

Brean W. Duncan, David R. Breininger, Paul A. Schmalzer, and Vickie L. Larson

Abstract
*A habitat suitability index (HSI) model for the Florida Scrub Jay (*Aphelocoma coerulescens coerulescens*) was tested using a geographic information system for the Tel-4 study site on Kennedy Space Center, Florida. The model used suitability graphs that quantify habitat preference with respect to a given variable to produce spatial estimates of Florida Scrub Jay habitat suitability. Habitat suitability of each habitat patch was dependent on its characteristics and the characteristics of its surroundings. A coverage containing three years of demographic data was overlaid on the HSI coverage. Areal correspondence measures and statistical testing were then performed. Correlation coefficients between modeled data and demographic data ranged between 0.60 and 0.87. Spatial residual analysis also showed agreement between the model and demography data. All measures of model performance suggested that the model accurately predicted habitat suitability for the Tel-4 study site.*

Introduction
The main purpose of geographic information systems (GIS) is to process spatial information (Berry, 1993). Ecologists have been modeling processes that involve spatial information since the early development of their discipline (Holdridge, 1947; Whittaker, 1956; Curtis, 1959). However, use of GIS technology by ecologists has been limited and represents a relatively untapped potential for ecological modeling of spatial processes (Hunsaker *et al.*, 1993). With the aid of today's remote sensing and GIS technology, opportunities exist to further develop and test environmental modeling techniques that can readily be applied to environmental management.

Many threatened and endangered wildlife species and their habitats are being adversely affected by human disturbance. It is increasingly important to understand the habitat requirements, delineate the remaining suitable habitat, and effectively manage those units for the survival of these species. Habitat-based modeling techniques can identify remaining potential habitat and predict spatial habitat suitability. The modeling techniques should incorporate existing knowledge of species-habitat relationships, be reproducible, and provide a quantitative measure of habitat suitability.

Habitat suitability index (HSI) modeling is a common approach to modeling wildlife-habitat relationships (Morrison *et al.*, 1992). The methodology was developed to support habitat evaluation procedures (HEP) used by the United States Fish and Wildlife Service (USFWS) (USFWS, 1980a; USFWS, 1980b). HEP/HSI modeling was designed to document and quantify the quality and quantity of available habitat for selected wildlife species. The procedure is based on the habitat unit (HU) which is derived by multiplying habitat quality (an index ranging from 0.0 to 1.0) by habitat quantity (area). This modeling technique has potential for use with many wildlife habitats and species (Lancia *et al.*, 1982; Cook and Irwin, 1985; Verner *et al.*, 1986; Pereira and Itami, 1991; Schulz and Joyce, 1992; Morrison *et al.*, 1992).

Although there are many HSI models, few have been validated or tested appropriately (Lancia *et al.*, 1982; Cole and Smith, 1983; Breininger *et al.*, 1991; Thomasma *et al.*, 1991; Morrison *et al.*, 1992). The importance of validation is discussed in the published literature (Verner *et al.*, 1986; Morrison *et al.*, 1992), but available data are often inadequate to support validation (Schamberger and O'Neil, 1986). Few if any published HSI model validation efforts have utilized long-term demography data.

HSI model validation efforts date back to the early 1980s. The most recent validation efforts have utilized advanced statistical techniques, but all primarily used frequency and density data. Lancia *et al.* (1982) tested an HEP model predicting the distribution of bobcats (*Felis rufus*) against frequency of use within vegetation patches by six radio-telemetered bobcats. Cook and Irwin (1985) tested and revised a pronghorn (*Antilocarpa americana*) HSI model using field data from 28 winter ranges. Pronghorn densities assumed to reflect habitat quality were correlated with HSI values to achieve test results. Laymon and Barrett (1986) tested HSI models for the Spotted Owl (*Strix occidentalis*), Marten (*Martes americana*), and Douglas' squirrel (*Tamiasciurus douglasii*). Presence-absence and density data were used for validation of the models. They also discussed some of the problems associated with testing HSI models. Laymon and Reid (1986) tested HSI values against radio-telemetered locations of Spotted Owls. They also performed a sensitivity analysis related to grid-cell resolution and HSI validation. Pereira and Itami (1991) used multivariate techniques coupled with habitat use data to validate an HSI model for the Mt. Graham red squirrel (*Tamiasciurus hudsonicus grahamensis*) in Arizona. Thomasma *et al.* (1991) tested a fisher (*Martes pennanti*) habitat model using frequency data and logistic

Dynamac Corporation, Mail Code: DYN-2, Kennedy Space Center, FL 32899.

Photogrammetric Engineering & Remote Sensing,
Vol. 61, No. 11, November 1995, pp. 1361–1370.

0099-1112/95/6111–1361$3.00/0

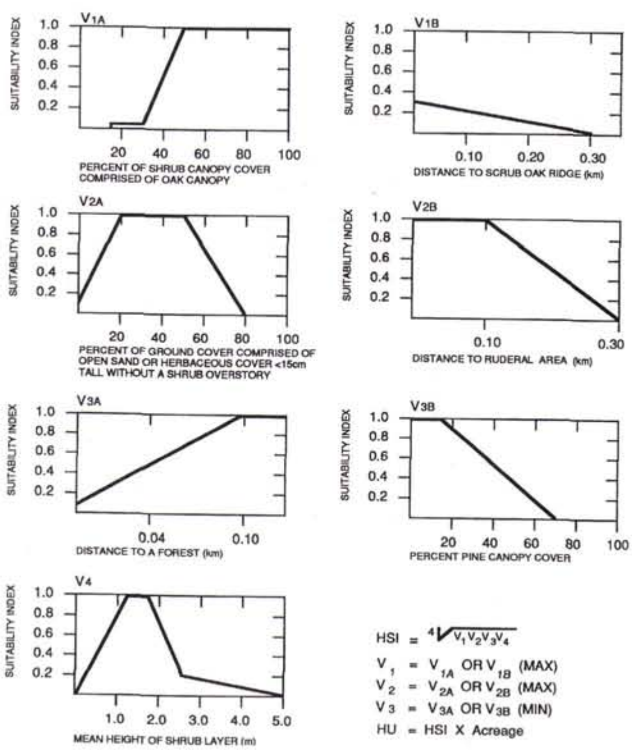

Figure 1. The Florida Scrub Jay habitat model. The suitability graphs describe the relationship between each variable and its suitability index. Two equations are also listed: one combines the variables into the final habitat suitability index map and the other computes habitat units for any desired area (acreage).

discriminant analysis to evaluate the importance of each model variable.

The present research used GIS techniques to validate an existing HSI model, (Breininger, 1992) for the threatened Florida Scrub Jay (*Aphelocoma coerulescens coerulescens*), using demographic data collected over three consecutive years. Our primary objectives were to determine the effectiveness of the model's predictive capability and to determine if the modeled suitability is related to known demographic information. Most model testing is based on densities, information from sightings, or radiotracking; these data are not always accurate indicators of habitat suitability (Van Horne, 1983; Hobbs and Hanley, 1990). These papers suggest that other demographic variables such as mean survivorship and mean production should be combined with density to measure habitat quality.

Background

Florida Scrub Jay

One of the largest remaining populations of the threatened Florida Scrub Jay is found on Kennedy Space Center (KSC) (Cox, 1984; Breininger, 1989). Florida Scrub Jays live in large territories (average size of 10 hectares) defended year-round by permanently monogamous breeding pairs and nonbreeding Scrub Jays that help with nesting activities and detection of predators (Woolfenden and Fitzpatrick, 1984). Florida Scrub Jays prefer sites with sandy openings and scrub oaks, with few or no trees, in areas that are periodically burned (Westcott, 1970; Woolfenden, 1974; Breininger, 1981; Cox, 1984; Woolfenden and Fitzpatrick, 1991). Optimal habitat often occurs as patches in a landscape matrix dominated by other shrub species and marshes (Breininger *et al.*, in press). The characteristics (i.e., composition and height) of the matrix are important, even though much of the habitat within the matrix is seldom used by Scrub Jays (Breininger *et al.*, in press). For example, a matrix containing forests or urban areas reduces the quality of a landscape whereas a habitat matrix of scrub oaks and recently burned palmetto-lyonia and swale marshes is best.

Florida Scrub Jay habitat suitability varies temporally and spatially within and among landscapes. The habitat potential of patches and landscapes depends upon inherent characteristics (e.g., soils, elevation) that allow sites to support scrub oak vegetation needed by Florida Scrub Jays (Breininger *et al.*, 1991; Schmalzer and Hinkle, 1992b). Areas without scrub oaks may be occupied but may represent population sinks (areas where mortality exceeds reproductive success) (Pulliam *et al.*, 1992). Areas with wide patches of scrub oaks may be population sources (areas where reproduction exceeds mortality), if they have had a favorable fire history (Woolfenden and Fitzpatrick, 1991; Breininger *et al.*, in press). Even in optimal conditions, demography is affected by stochastic events so that source areas do not have successful reproduction and survival each year and sink areas can be successful occasionally. Consequently, patterns in demographic success that are related to habitat often require a combination of data from several years to reveal habitat influence on demography (Breininger *et al.*, in press).

HSI Model

An HSI model was developed to quantify the quality of Florida Scrub Jay habitat for use in environmental planning and habitat management at KSC (Breininger, 1992). The model was derived from studies beginning in 1978 at KSC and other studies outside of KSC. A complete discussion of the model, including its assumptions and limitations, can be found in Breininger (1992).

The HSI model consists of four variables critical to defining Florida Scrub Jay habitat suitability: proximity and amount of scrub oak cover, proximity and amount of open space, proximity and amount of tree canopy cover, and mean height of shrub layer (Figure 1). The model assumes that habitat suitability is an approximate average of the conditions described by these four variables. However, the model assumes that too few nearby scrub oaks or too many trees will make the habitat unsuitable. Each variable is described by a suitability index. The suitability index graphs describe the relationship between the variables, and their suitability value ranges between 0.0 and 1.0. The first three variables have two parts (a and b). Each part is treated as if it were a separate variable until the HSI values are computed. The equations used to calculate the HSI values and habitat units (HUs) are at the bottom of Figure 1. For a complete discussion on HSI modeling, see USFWS (1980a; 1980b; 1981).

Tel-4 GIS Database

An extensive spatial database has been compiled in ARC/INFO (Environmental Systems Research Institute, Inc., 1991) for the Tel-4 long-term study site on KSC. The database contains environmental and demographic Florida Scrub Jay coverages compiled from remote sensing and field derived data (Breininger *et al.*, in press). This database provided the foundation for the HSI modeling in this paper.

Study Site

KSC comprises 57,000 ha in Brevard and Volusia counties located along the east coast of central Florida. The Tel-4 study site is a 295 ha area located near the southern boundary of KSC. The vegetation of the Tel-4 study site is comprised of pine flatwoods and scrub communities. Well drained upland sites are dominated by scrub oaks (*Quercus spp.*), while mesic shrubs (e.g., *Serenoa repens, Lyonia spp., Ilex sp.*) dominate poorly drained sites (Schmalzer and Hinkle, 1992b). A sparse canopy of slash pine (*Pinus elliotii*) and interspersed swale marshes are found throughout the study site. The scrub communities found within the study site are fire-adapted and fire-maintained, with species that resprout after fire. *Pinus elliotii* is an obligate seeding species but survives some fires.

Methods

Spatial Suitability Index Mapping

Each of the model variables was mapped using ARC/INFO software Version 6.1. The HSI model was followed as explicitly as possible; therefore, all buffer distances and suitability values discussed below were a direct result of the model (Breininger, 1992). Variable V1A was produced by selecting open oak, oak, oak-palmetto, and palmetto-lyonia categories from the Tel-4 Florida Scrub Jay habitat map and writing them to a new coverage. An attribute called V1A was added to the polygon attribute table (PAT), and a suitability index value was assigned for each polygon based on the V1A variable of the model. The open oak and oak categories by definition had scrub oak cover greater than or equal to 51 percent and received a value of 1.0 assigned to the attribute V1A in the PAT file. The oak-palmetto habitat type contained 31 to 50 percent scrub oak cover and V1A received a value of 0.5. Palmetto-lyonia contained less than 30 percent scrub oak cover and the V1A attribute received a value of 0.05. All other categories have no scrub oak cover and received a V1A value of 0.0. Variable V1B was created by buffering the coverage containing large ridge features (well drained soil with elevation between 1 and 2 metres) and writing them to a new coverage. A new item, V1B, was added to the buffer coverage, and suitability values were assigned to it based on the median of each class. The 0- to 100-metre buffer received a suitability value of 0.25, the 100- to 200-metre buffer was assigned 0.15, the 200- to 300-metre buffer was given a value of 0.05, and anything greater than 300 metres from a ridge received a value of 0.0.

Variable V2A was created by selecting each of the scrub habitat types from the habitat map and writing each one to a new coverage. An item, V2A, was added to the PAT, and the open oak polygons received a value of 1.0; all other scrub categories had few openings and received a value of 0.1. To create variable V2B spatially, the ruderal habitat (mowed grass) type wider than 12 metres was written to a new coverage. Buffers were produced around the ruderal areas for 0 to 100 metres, 100 to 200 metres, and 200 to 300 metres. Suitability values for the added item V2B were 1.0 for buffers of 0 to 100 metres, 0.75 for 100 to 200 metres, 0.30 for 200 to 300 metres, and 0.0 for everything greater than 300 metres.

Variable V3A was produced by selecting the forest category polygons from the habitat map and writing them to a new coverage. Buffers for 0 to 50 metres, 50 to 100 metres, and greater than 100 metres were added to the coverage. The suitability values added to the item V3A were 0.25 for buffers of 0 to 50 metres, 0.75 for 50 to 100 metres, and 1.0 for greater than 100 metres. Variable V3B was produced by using the overstory coverage from the Tel-4 database. This coverage contained five overstory categories produced by photointerpretation from a 1:2,200-scale color infrared aerial photograph. The first category was no overstory coverage at all, the second was savanna (1 to 15 percent canopy cover), the third was sparse woodland (16 to 40 percent), the fourth was dense woodland (41 to 65 percent), and the fifth was forest (greater than 65 percent). Item V3B was added, and a suitability value of 1.0 was given to areas of no overstory and savanna, 0.7 to sparse woodland, 0.4 to dense woodland, and 0.0 to forests.

Variable V4 was produced by utilizing fire maps from the Tel-4 database and field derived data predicting scrub height with time since fire. A regression model was built to predict mean scrub oak height with time since fire. A 27-year dataset was constructed by combining scrub oak height data from different studies at various sites at KSC (Schmalzer and Hinkle, 1992a; Schmalzer and Hinkle, 1992b). To determine mean height of palmetto-lyonia with time since fire, we utilized field data collected at the Tel-4 study site. Because of the small sample size, palmetto-lyonia data were averaged for each burn class (time since fire category) instead of using a regression. Fire maps were overlaid with scrub categories and copied to a new coverage. A new item called V4 was added to this coverage, and suitability values were added based on the predicted vegetation height.

HSI Map

Following the formulae at the bottom of Figure 1, we overlaid the V1 coverages, the V2 coverages, and the V3 coverages to produce one coverage for each variable. New items V1, V2, and V3 were added to each of the coverages. The maximum value between V1A and V1B was selected for each polygon and written to item V1. The same was performed for V2 and V3, but V3 used the minimum value.

We then combined the four variable coverages into an HSI coverage, and a geometric mean for each polygon was calculated. The HSI coverage PAT data were loaded into Quatro Pro (Borland International, Inc., 1992) where geometric means were calculated, and the results were input back into the HSI coverage in an item called HSI. Boundaries between like HSI values were dissolved to form the final HSI coverage.

Demographic Data

A coverage containing Florida Scrub Jay demography data from 1989 to 1991 was used to validate the HSI model. The 1989, 1990, and 1991 territories were overlayed to produce a combined territory coverage resulting from the intersection of three years of territory boundaries. Three demographic measures were used for evaluating the model. The first metric was density (number of birds / suitable habitat area in each territory), averaged over the three years of study. Performance was the second metric; it was produced by adding the number of surviving breeders to the number of yearlings produced (birds approximately one year old). The product of density, juvenile production (birds approximately 60 to 90 days old), and breeder survival was the third metric. For more information regarding the demography data, see Breininger *et al.* (in press). Spurious sliver polygons (smaller than 1/3 ha) created from territory overlays were removed from

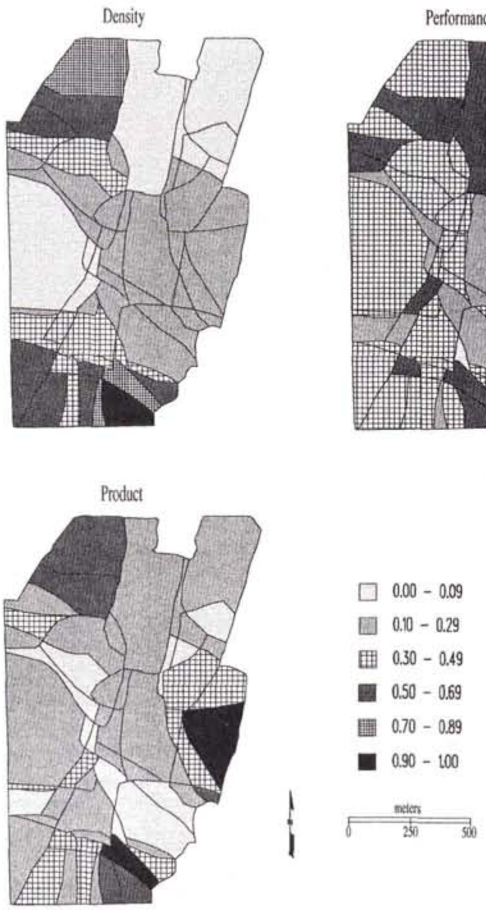

Figure 2. The standardized demographic data for the common territory areas (areas containing three years of Florida Scrub Jay demography data) for the Tel-4 study site on Kennedy Space Center, Florida.

the coverage. Marsh areas were overlaid on the demographic coverage and set to 0.0 for all variables. Each demographic measure was standardized to range from 0.0 to 1.0.

Model Validation

The common territory polygons were overlaid on the HSI coverage, and areas outside of the common territory polygons were dropped from the resulting coverage. HSI habitat units were calculated by multiplying the HSI value of each habitat polygon by its area and summing those results for each common territory area. Demographic habitat units were created by multiplying the standardized demographic value by the area of common territory polygons.

The demography habitat units were run through the Spatial Analysis Module (SAM) for ARC/INFO (Ding and Fotheringham, undated) to look for spatial dependence using the Moran's I statistic (Cliff and Ord, 1973). The Kolmogrov-Smirnoff test was used to determine if the data differed significantly from a normal distribution (SPSS Inc., 1990). Spearman rank correlation coefficients were calculated after determining that the data departed from normality (SPSS Inc., 1990).

Model Residuals

Model residual coverages were produced in ARC/INFO. Standardized HSI habitat units were subtracted from standardized field demography habitat units to produce spatial residual coverages of the common territory areas. Spatial model residuals were also produced for oak scrub habitat within the common territory areas. This was performed because oak scrub represented the habitat actually used by the Florida Scrub Jays, whereas the remaining habitat represented a matrix that received little use (Breininger *et al.*, in press).

Results

HSI Mapping

The suitability of each model variable for the Florida Scrub Jay was predicted spatially in Plate 1. Each variable has a unique pattern that was incorporated into the final HSI coverage (Plate 2).

About half of the habitat in the study site was predicted to have extremely little or no suitability (0.00 to 0.09)(Plate 2). Most (91 percent) of this area is contained in one large polygon. The majority of the study site (79.5 percent) had an HSI value below 0.5. The remainder of the study area (20.5 percent) had an HSI value greater than 0.5. The polygons predicted to be of the highest value to the Florida Scrub Jay were mostly small polygons and were spread throughout the study site. Most of the habitat between these optimal patches was composed of suitable habitat or swale marsh and not forest or other unsuitable habitat which would negatively impact habitat suitability. Within the common territory areas, the proportion of habitat with an HSI value below 0.5 was 65 percent. The proportion of HSI values above 0.5 was 35 percent.

Model Validation

The standardized demographic coverages are shown in Figure 2. A very small proportion of the common territory areas have high demographic values (Table 1). The majority of the demographic data exist in the low to mid values. The performance measure, however, is closer to a normal distribution than the other two measures. No autocorrelation was found among the demographic habitat units (Table 2); therefore, correlations could be performed without bias.

The results from the Kolmogrov-Smirnoff normality test revealed lack of normality in both the HSI and the demographic habitat units ($P < 0.001$). Spearman rank correlation coefficients were calculated between the HSI and demographic habitat units. The HSI HUs vs. density HUs were the weakest of the correlations ($r = 0.60$, $P < 0.001$). The HSI HUs vs. performance HUs were the strongest of the correla-

TABLE 1. STANDARDIZED DEMOGRAPHY DATA FOR THE TEL-4 STUDY SITE AT KENNEDY SPACE CENTER, FLORIDA. PROPORTIONS ARE BY CATEGORY INSIDE THE COMMON TERRITORY AREA (THE AREA CONTAINING THREE YEARS OF DEMOGRAPHY DATA).

Demographic Category	Density (%)	Performance (%)	Product (%)
0.00–0.09	31.5	0.3	15.0
0.10–0.29	34.5	17.0	54.5
0.30–0.49	12.5	52.5	14.0
0.50–0.69	12.5	26.0	11.0
0.70–0.89	7.0	0.0	0.0
0.90–1.00	2.0	4.0	5.5

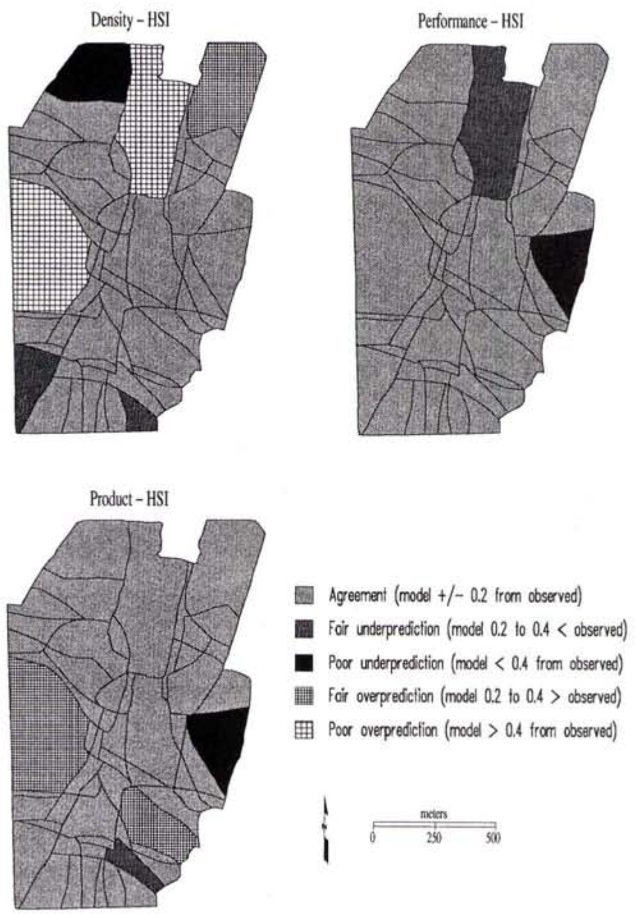

Figure 3. The spatial residual coverages for the Tel-4 study site on Kennedy Space Center, Florida. These coverages were produced by subtracting the standardized habitat suitability index habitat unit predictions from the standardized field demography habitat units for the common territory areas (areas containing three years of Florida Scrub Jay demography data).

tions ($r = 0.87$, $P < 0.001$) and the HSI HUs vs. product HUs correlation was also significant ($r = 0.75$, $P < 0.001$).

Model Residuals

Spatial model residuals are shown for the common territory areas in Figure 3. The residual coverages show the spatial locations and magnitude of agreement and disagreement between the model and the demographic data. The proportions of agreement (Table 3) follow the same trend as the correlation coefficients listed above. Performance had the highest proportion of agreement, followed by the product measure and density had the least area in agreement.

Spatial model residuals for scrub oak habitat within the common territory areas are shown in Plate 3. Scrub oak habitat makes up 25 percent of the common territory area. Performance had the highest amount of agreement with the HSI coverage, the next highest level of agreement was the product, and density had the least agreement (Table 3). The proportions of the common territory residuals and the scrub oak residuals were very similar. The largest difference between any common territory area proportion and the same scrub oak category proportion was 5 percent.

Discussion

Model Performance

The Florida Scrub Jay HSI model was able to predict accurately the habitat suitability for the Tel-4 study area at KSC. This was evident by simple areal correspondence and statistical testing.

The model's prediction of habitat suitability correlated well with the density, product, and performance measures of demography. Density had the lowest correlation with the model of all the demographic measures. Density is widely

Table 2. The Moran's (I) Autocorrelation Results for the Demographic Habitat Units (HU). The Moran (I) Column Shows the Actual Value of (I) Ranging Between 1 (Positive Autocorrelation) and −1 (Negative Autocorrelation). The E (I) Column is the Expected (I) Value, the Varn (1) Columns Are the Variance Values of (I) Under the Assumptions of Normality and Randomness, Respectively. The Znormal and Zrandom Columns Show the Normal Deviates Under the Assumption of Normality and Randomness, Respectively. The Z Values are Compared to a Normal Distribution at the 0.05 Significance Level to Reject or Except the Null Hypothesis of no Autocorrelation (Cliff and Ord, 1973).

Demography	Moran (I)	E (I)	Varn (I)	Varr (I)	Znormal	Zrandom
Density HU	−0.048	−0.017	0.005	0.006	−0.427	−0.418
Performance HU	0.039	−0.017	0.005	0.006	0.778	0.760
Product HU	0.013	−0.017	0.005	0.006	0.412	0.403

Table 3. Spatial Residual Analysis Results for the Tel-4 Study Site on Kennedy Space Center, Florida. Proportions Represent Residuals Produced by Subtracting the Modeled Standardized Habitat Units (HUs) from Standardized Field Demography Habitat Units for the Common Territory Areas (First Three Columns) and Scrub Oak Habitat within the Common Territory Areas (Last Three Columns). The Common Territory Areas Represent the Areas that Contained Three Years of Demographic Data.

	% Common Territory Area			% Scrub Oak Area		
	Density	Performance	Product	Density	Performance	Product
Agreement	64	87	80	62	85	79
Fair underprediction	4	9	1	6	9	1
Poor underprediction	5	4	4	10	6	6
Fair overprediction	7	0	15	3	0	14
Poor overprediction	20	0	0	19	0	0

Agreement = Modeled HU value was plus or minus 0.2 from observed standardized demography HU value.
Fair underprediction = Modeled HU value was 0.2 to 0.4 less than observed standardized demography HU value.
Poor underprediction = Modeled HU value was less than 0.4 from observed standardized demography HU value.
Fair overprediction = Modeled HU value was 0.2 to 0.4 greater than observed standardized demography HU value.
Poor overprediction = Modeled HU value was greater than 0.4 from observed standardized demography HU value.

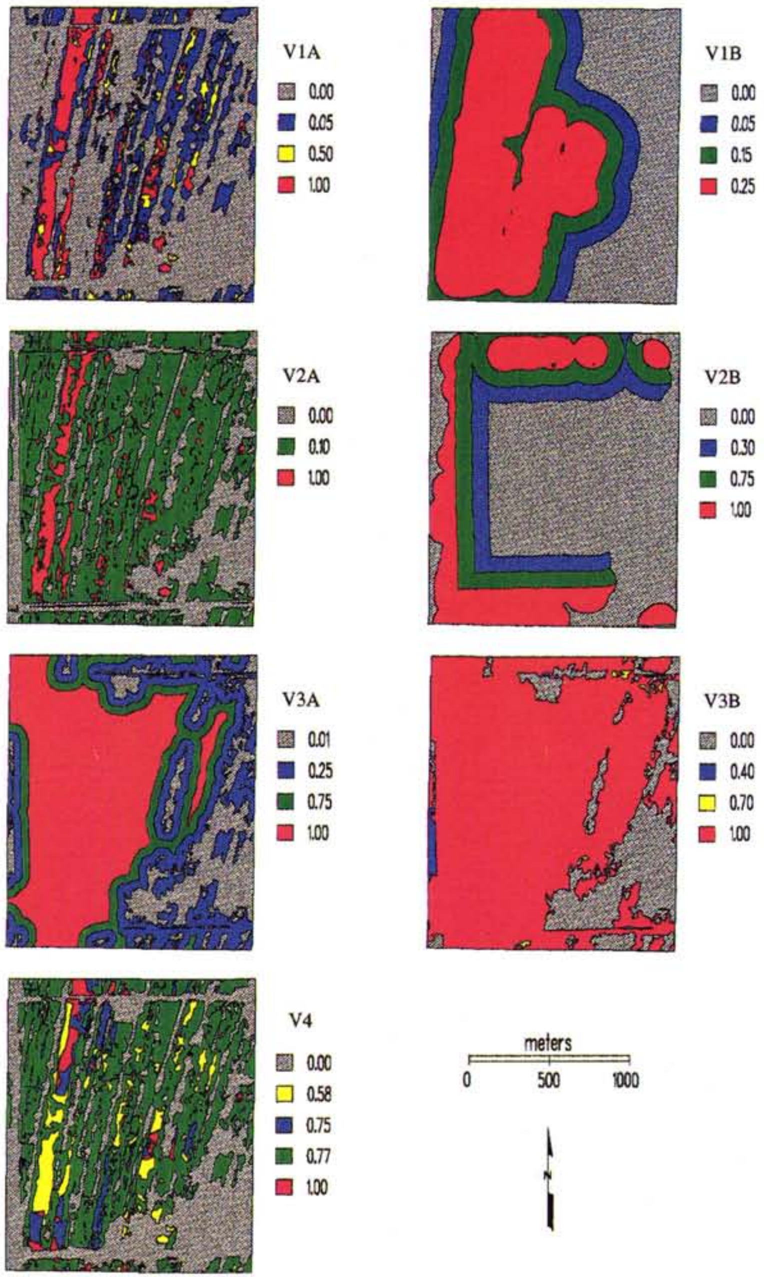

Plate 1. The spatial suitability indexes mapped for each variable in the Tel-4 study site on Kennedy Space Center, Florida. Suitability values ranging from 1.0, greatest suitability, to 0.0, lowest suitability.

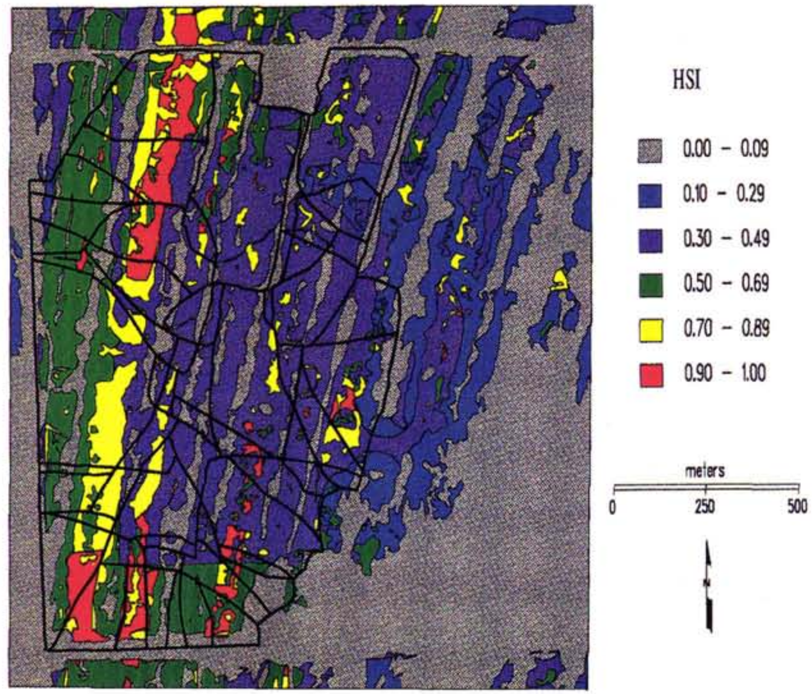

Plate 2. The habitat suitability index map with the common territory areas (areas containing three years of Florida Scrub Jay demography data) overlaid for the Tel-4 study site on Kennedy Space Center, Florida.

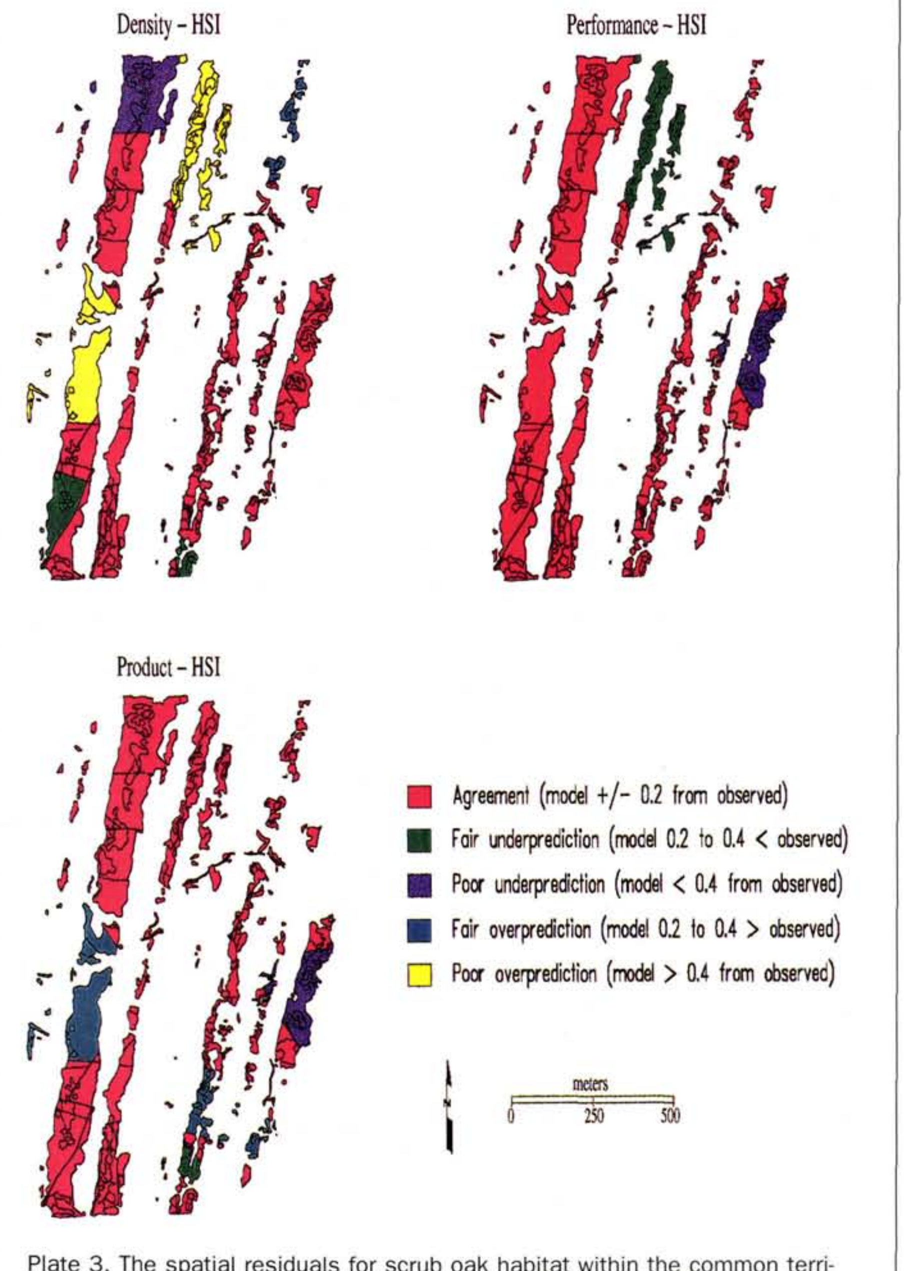

Plate 3. The spatial residuals for scrub oak habitat within the common territory areas (areas containing three years of Florida Scrub Jay demography data). These coverages were produced by subtracting the standardized habitat suitability index habitat unit predictions from the standardized field demography habitat units in the Tel-4 study site on Kennedy Space Center, Florida.

used for evaluating model performance and is the easiest demographic parameter to measure. The problem is that densities alone do not always accurately predict habitat quality, because areas with high densities can be population sinks (Van Horne, 1983).

The correlation between performance and HSI model output was the highest of all demographic measures. Areas with high demographic performance correspond to potential population sources where reproduction exceeds mortality rates (Breininger *et al.*, in press). Areas without patches of high quality habitat were potential population sinks where mortality exceeded reproductive success. This information suggests that the model is a good predictor of habitat where breeders are surviving and young Scrub Jays are potentially produced. The product measure, although not the strongest correlation value, was also an important indicator of the model's predictive capability. The product of density, reproductive success, and breeder mortality is considered by some to be a better measure of habitat quality than density alone (Van Horne, 1983). To receive a high product value, each individual measure must be strong; therefore, it is a good measure of habitat quality and suitability.

The results from the residual analysis also show the strength of the HSI model's predictive capability. For the majority of the common territory area and the area dominated by scrub oak vegetation, the model and demography data agree. Smaller proportions of disagreement (areas of residual) are also observed. The residual proportions for areas dominated by scrub oak vegetation are very similar compared to the study area residuals. The largest difference in any of the proportions is 5 percent, which suggests that the model does not predict oak scrub any differently than habitat in the common territory areas.

Characteristics of the Model and the Validation Process

Because of the Florida Scrub Jay's habitat requirements, the HSI model is designed to work at the patch and landscape scale. This is important because many previous habitat mapping applications failed to predict the suitability of scrub landscapes for the Florida Scrub Jay. They often have minimum mapping units that are too large to detect the small, critical patches of habitat that make landscapes suitable for Jays (Breininger *et al.*, in press). This model is designed to use large-scale coverages (such as the Tel-4 habitat map with a minimum mapping unit of 20 m^2) and retain the small, valuable patches of habitat within them. The majority of the Tel-4 HSI coverage is comprised of large polygons with low values made up of matrix habitats. The polygons containing high HSI values occur throughout the study site and contain small patches of critical oak scrub habitat. The model would have classified additional matrix habitats as unsuitable, if the critical oak scrub patches had not been nearby.

Demography data collected over a longer duration than three years would be preferred when establishing habitat quality. For this application, however, validating the model is our objective, so it is important that the model and test data be consistent. Coverages in the Tel-4 database were produced from aerial photos and field work collected concurrently. Thus, the model and demography data were produced by the same environmental conditions that prevailed during this time. Because of the detail required in each variable for this model, it would be difficult to produce a model representative of a longer time frame given the frequent occurrence of fire and the associated structural response by vegetation (Schmalzer and Hinkle, 1992a).

One problem in using territory coverages to test the model is that Florida Scrub Jay territories are very large and are often comprised mostly of marginally suitable habitat. Other confounding influences are related to bird quality, which may also influence demographic success (Fitzpatrick and Woolfenden, 1988). Bird quality may be one of the reasons for the poor underprediction for the same territory polygon in both the performance and product residual coverages (Figure 5). Birds occupying this territory have produced young and have been successful each year (Breininger *et al.*, in press). The habitat in this territory is high quality but does not appear to be better than other quality habitat in other territories. Each year the pair in this territory was one of the earliest to nest; early nests often have the highest success (Woolfenden and Fitzpatrick, 1984). Alternatively, the patch of high quality scrub occupied by this pair was separated from other areas of quality scrub by marginal habitat. This marginal habitat may have buffered the pair from intense territory disputes with other families that frequently occurred along long ridges of high quality habitat, thus improving their potential to produce young.

Implications and Future Work

There are many ways that this model can be applied (e.g., Boolean logic modeling, neural network modeling, etc.) to expedite its operational use. Because modeling the Tel-4 study site was the initial application of the model, we attempted to apply the model as explicitly as possible. The model was run in ARC/INFO using existing commands with no exploration of alternate methods. Demography data have proven that the model, applied literally, provides reasonable estimates of habitat suitability in the Tel-4 study area.

Running the model in its current form is very time and labor intensive. Methods of isolating and adjusting the most important variables such as sensitivity analysis (Stoms *et al.*, 1992) and variable priority setting (Saaty, 1985) are needed to refine and facilitate application of the model for management issues at KSC. The model, when easily applied, can be used for site assessments in scrub habitat and scrub mitigation projects among other applications. Oak dominated scrub is a very valuable resource that is under tremendous pressure from human activities. To manage this resource effectively, it is essential to have accurate, high quality, working models that are thoroughly and appropriately tested.

This first test of the model showed that it can be used to quantitatively compare habitat suitability among patches in a landscape. There are still remaining questions about the models capability that need investigation. The model is currently being tested in a larger, less dynamic landscape that has been studied for six years to determine how well the model distinguishes population sources from sinks. This is important to evaluate the model's ability to identify areas and habitat conditions essential for Florida Scrub Jay population persistence. Additional empirical data are also needed to test individual model assumptions such as the arrangement of open space. The final HSI model inputs make little distinction between natural openings in scrub and the open ruderal edges. It is possible for higher predation rates to occur along ruderal edges because predators can systematically patrol them (Yosef, 1994). Natural openings contained within scrub occur in a complex spatial arrangement that may make them less susceptible to predation. These are critical tests needed to define the breadth of applications that are appropriate for habitat suitability modeling.

Acknowledgments

This study was funded by NASA, under contracts NAS10-11624 and NAS10-12180. We thank Dr. William M. Knott, III, and Burton Summerfield, Biomedical Operations Office, for their support and assistance. We thank Rebecca B. Smith and Donna M. Oddy for assistance in collecting nesting data. We would also like to thank Dr. Frank Davis, Dr. Mike Goodchild, Dr. Bernie Engel, Douglas L. Britt, and several anonymous reviewers for their helpful comments.

References

Berry, J.K., 1993. Cartographic Modeling: The Analytical Capabilities of GIS, *Environmental Modeling with GIS* (M.F. Goodchild, B.O. Parks, and L.T. Steyaert, editors), Oxford University Press, Oxford, New York, pp. 58–74.

Borland International, Inc., 1992. *Quatro Pro V4.0*, Borland International, Inc., Scotts Valley, California.

Breininger, D.R., 1981. *Habitat Preferences of the Florida Scrub Jay (Aphelocoma coerulescens coerulescens) on Merritt Island National Wildlife Refuge, Florida*, M. S. thesis, Florida Institute of Technology, Melbourne, Florida, 159 p.

———, 1989. A New Population Estimate for the Florida Scrub Jay on Merritt Island National Wildlife Refuge, *Florida Field Naturalist*, 17:25–31.

———, 1992. *Habitat Model for the Florida Scrub Jay on John F. Kennedy Space Center*, NASA Technical Memorandum No. 107543, Kennedy Space Center, Florida, 95 p.

Breininger, D.R., V.L. Larson, B.W. Duncan, R.B. Smith, D.M. Oddy, and M.F. Goodchild, (in press). Landscape Patterns of Florida Scrub Jay Habitat Use and Demographic Success, *Conservation Biology*.

Breininger, D.R., M.J. Provancha, and R.B. Smith, 1991. Mapping Florida Scrub Jay Habitat for Purposes of Land-Use Management, *Photogrammetric Engineering & Remote Sensing*, 57:1467–1474.

Cliff, A.D., and J.K. Ord, 1973. *Spatial Autocorrelation*, Pion Limited, London, 266 p.

Cole, C.A., and R.L. Smith, 1983. Habitat Suitability Indices for Monitoring Wildlife Populations-An Evaluation, *48th North American Wildlife Conference*, pp. 367–375.

Cook, J.G., and L.L. Irwin, 1985. Validation and Modification of a Habitat Suitability Model for Pronghorns, *Wildlife Society Bulletin*, 13:440–448.

Cox, J.A., 1984. *Distribution, Habitat, and Social Organization of the Florida Scrub Jay, with a Discussion of the Evolution of the Cooperative Breeding in New World Jays*, Ph.D. dissertation, University of Florida, Gainsville, Florida, 259 p.

Curtis, J.T., 1959. *The Vegetation of Wisconsin*, University of Wisconsin Press, Madison, Wisconsin, 657 p.

Ding, Y., and A.S. Fotheringham, undated. *A Spatial Analysis Module for ARC/INFO: The SAM Module*, National Center for Geographic Information and Analysis, State University of New York at Buffalo, New York.

Environmental Systems Research Institute, Inc., 1991. *ARC/INFO Command Reference and Users Guides 6.0, The Geographic Information System Software*, Redlands, California.

Fitzpatrick, J.W., and G.E. Woolfenden, 1988. Components of Lifetime Reproductive Success in the Florida Scrub Jay, *Reproductive Success* (T. H. Clutton-Brock, editor), The University of Chicago Press, Chicago, pp. 305–320.

Holdridge, L.R., 1947. Determination of World Plant Formations from Simple Climatic Data, *Science*, 105:367–368.

Hobbs, N. T., and T. A. Hanley, 1990. Habitat Evaluation: Do Use/Availability Data Reflect Carrying Capacity? *Journal of Wildlife Management*, 54:515–522.

Howe, R.W., G.J. Davis, and V. Mosca, 1991. The Demographic Significance of "Sink" Populations, *Biological Conservation*, 57: 239–255.

Hunsaker, C.T., R.A. Nisbet, D.C. Lam, J.A. Browder, W.L. Baker, M.G. Turner, and D.B. Botkin, 1993. Spatial Models of Ecological Systems and Processes: The Role of GIS, *Environmental Modeling with GIS* (M.F. Goodchild, B.O. Parks, and L.T. Steyaert, editors), Oxford University Press, Oxford, New York, pp. 248–264.

Lancia, R.A., S.D. Miller, D.A. Adams, and D.W. Hazel, 1982. Validating Habitat Quality Assessment: An example, *47th North American Wildlife Conference*, pp. 96–110.

Laymon, S.A., and R.H. Barrett, 1986. Developing and Testing Habitat-Capability Models: Pitfalls and Recommendations, *Modeling Habitat Relationships of Terrestrial Vertebrates* (J. Verner, M.L. Morrison, and C.J. Ralph, editors), University of Wisconsin Press, Madison, Wisconsin, pp. 87–91.

Laymon, S.A., and J.A. Reid, 1986. Effects of Grid-Cell Size on Tests of a Spotted Owl HSI Model, *Modeling Habitat Relationships of Terrestrial Vertebrates* (J. Verner, M.L. Morrison, and C.J. Ralph, editors), University of Wisconsin Press, Madison, Wisconsin, pp. 93–96.

Morrison, M.L., B.G. Marcot, and R.W. Mannan, 1992. *Wildlife-Habitat Relationships, Concepts and Applications*, University of Wisconsin Press, Madison, Wisconsin, 343 p.

Pereira, J.M., and R.M. Itami, 1991. GIS-Based Habitat Modeling Using Logistic Multiple Regression: A Study of the Mt. Graham Red Squirrel, *Photogrammetric Engineering & Remote Sensing*, 57:1475–1486.

Pulliam, H.R., 1988. Sources, Sinks, and Population Regulation, *American Naturalist*, 132:652–661.

Pulliam, H.R., J.B. Dunning, and J. Liu, 1992. Population Dynamics in Complex Landscapes: A Case Study, *Ecological Applications*, 2:165–177.

Saaty, T.L., 1985. *The Analytic Hierarchy Process: Planning, Priority Setting, Resource Allocation*, McGraw-Hill, New York, 287 p.

Schamberger, M.L., and L.J. O'Neil, 1986. Concepts and Constraints of Habitat-Model Testing, *Modeling Habitat Relationships of Terrestrial Vertebrates* (J. Verner, M.L. Morrison, and C.J. Ralph, editors), University of Wisconsin Press, Madison, Wisconsin, pp. 5–10.

Schmalzer, P.A., and C.R. Hinkle, 1992a. Recovery of Oak-Saw Palmetto After Fire, *Castanea*, 57:158–173.

———, 1992b. Species Composition and Structure of Oak-Saw Palmetto Scrub Vegetation, *Castanea*, 57:220–251.

Schulz, T.T., and L.A. Joyce, 1992. A Spatial Application of a Marten Habitat Model, *Wildlife Society Bulletin*, 20:74–83.

SPSS, Inc., 1990. *SPSS/PC V2.0 Base Manual*, SPSS, Inc., Chicago, Illinois.

Stoms, D.M., F.W. Davis, and C.B. Cogan, 1992. Sensitivity of Wildlife Habitat Models to Uncertainties in GIS Data, *Photogrammetric Engineering & Remote Sensing*, 58:843–850.

Thomasma, L.E., T.D. Drummer, and R.O. Peterson, 1991. Testing The Habitat Suitability Index Model For the Fisher, *Wildlife Society Bulletin*, 19:291–297.

U.S. Fish and Wildlife Service, 1980a. *Habitat as a Basis for Environmental Assessment (HEP)*, Ecological Services Manual 101, U.S. Department of Interior, Fish and Wildlife Service, Division of Ecological Services, Government Printing Office, Washington, D.C., 26 p.

———, 1980b. *Habitat Evaluation Procedures (HEP)*, Ecological Services Manual 102, U.S. Department of Interior, Fish and Wildlife Service, Division of Ecological Services, Government Printing Office, Washington, D.C., 84 p. plus appendices.

———, 1981. *Standards for the Development of Habitat Suitability Index Models*, Ecological Services Manual 103, U.S. Department of Interior, Fish and Wildlife Service, Division of Ecological Services, Government Printing Office, Washington, D.C., 68 p. plus appendices.

Van Horne, B., 1983. Density as a Misleading Indicator of Habitat Quality, *Journal of Wildlife Management*, 47:813–901.

Verner, J., M.L. Morrison, and C.J. Ralph, 1986. *Wildlife 2000, Modeling Habitat Relationships of Terrestrial Vertebrates*, The University of Wisconsin Press, Madison, Wisconsin.

Westcott, P.A., 1970. *Ecology and Behavior of the Florida Scrub Jay*, Ph.D. dissertation, University of Florida, Gainsville, Florida, 84 p.

Whittaker, R.H., 1956. Vegetation of the Great Smoky Mountains, *Ecological Monographs*, 22:1–44.

Woolfenden, G.E., 1974. Nesting and Survival in a Population of Florida Scrub Jays, *Living Bird*, 12:25–49.

Woolfenden, G.E., and J.W. Fitzpatrick, 1984. *The Florida Scrub Jay: Demography of a Cooperative-Breeding Bird*, Monographs in Population Biology No. 20, Princeton University Press, Princeton, New Jersey, 407 p.

———, 1991. Florida Scrub Jay Ecology and Conservation, *Bird Pop-*

ulations (C.M. Perrins, J.D. Lebreton, and G.J.M. Hirons, editors), Oxford University Press, New York, pp. 542–565.

Yosef, R., 1994. The Effects of Fencelines on Reproductive Success of Loggerhead Shrikes, *Conservation Biology*, 8:281–285.

Brean W. Duncan

Brean W. Duncan received the B.A. (1988) and M.S. (1990) degrees in Geography from the University of California Santa Barbara. He is a Physical Geographer with the Dynamac Corporation at Kennedy Space Center, Florida. His research interests include using remote sensing, geographic information systems, and global positioning systems for habitat/wildlife modeling and spatial analysis.

Dave Breininger

Dave Breininger received a B.S. degree in Marine Biology (1978) and an M.S. degree in Ecology (1981) from the Florida Institute of Technology. He is a conservation biologist with the Dynamac Corporation at Kennedy Space Center, Florida. His current studies combine field data on endangered and threatened species with remote sensing data using GIS, population models, and landscape trajectories.

Paul A. Schmalzer

Paul A. Schmalzer received a B.A. degree in biology from Western Maryland College, (1976) and the M.S. (1978) and Ph.D. (1982) degrees in ecology from the University of Tennessee. He is a plant ecologist with the Dynamac Corporation at Kennedy Space Center, Florida. His current research interests include effects of fire on vegetation and soils; restoration of scrub ecosystems; distribution, structure, composition, and dynamics of barrier island plant communities; and effects of Space Shuttle launches on vegetation and soils.

Vickie L. Larson

Vickie L. Larson received a B.S. degree in biological oceanography (1986) and an M.S. degree in ecology (1992) from the Florida Institute of Technology. As an ecologist with Dynamac Corporation at Kennedy Space Center, she has studied the conservation and management of scrub ecosystems with specific emphasis on Florida Scrub Jay demography and habitat requirements. Other interests include the application of GIS/RS in understanding ecosystem function and natural community conservation and restoration.

Notice!

Candidates for ASPRS Vice President

This will be the only notice you will receive regarding the Official Nomination for the office of ASPRS Vice President for 1996 and the requirements for nomination by petition.

The ASPRS Nominating Committee is pleased to announce its candidates for the office of Vice President, ASPRS to take office in April 1996.

- Thomas M. Lillesand, Madison, Wisconsin
- James V. Taranik, Reno, Nevada

Additional nominations for Vice President from academia shall be submitted to the Executive Director, 5410 Grosvenor Lane, Suite 210, Bethesda, Maryland 20814-2160, no later than 14 weeks prior to the day of the 1996 Annual Meeting. These nominations must be made by a nominating letter signed by not less than 250 voting members and must contain a biographical sketch of the nominee.

Deadline for nominations by petition: **17 January 1996.**

ASPRS Nominating Committee: Marilyn M. O'Cuilinn, Vincent V. Salomonson, Stanley A. Morain, Clifford W. Greve, and Maurice O. Nyquist, chair.