Commentary

The Role of the Private Sector in GIS

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THERE ARE EIGHT MAJOR CATEGORIES OF BUSINESS that support GIS technology and together constitute the GIS industry:

- GIS software
- Specialized GIS hardware
- Spatial data suppliers
- Consulting, development, and system integration
- Data conversion
- Remote sensing, aerial photography, and photointerpretation
- Surveying, GPS and geodetic control
- Mapping and field data acquisition

Although there is overlap between all categories, functionally, they may be generalized into three categories: (1) research and development, (2) technology distribution, and (3) supply of data.

Research and development is typically done by the software and hardware suppliers, and sometimes by consulting and system integration companies. Although most is funded by governments, especially from defense budgets, much of the actual work is done by private contractors. Beyond the early R&D stage, the influence of the private sector is even stronger as entrepreneurial minds imagine new ways of using the technology developed for government. There are several variations on this basic theme in GIS history, where the pattern has been repeated over and over again.

Intergraph Corporation began business in 1969 with a $5,000 Army purchase order that soon led to innovations in missile guidance using interactive graphics (Schonrock, 1988). Imagining other applications for the technology, the company a few years later convinced the city of Nashville, Tennessee, that it should be working interactively to digitize its street maps rather than batch processing with punched cards, and began a new local government GIS industry. The U.S. Department of the Interior's MOSS GIS was developed virtually 100 percent by contractors, as was the agency's earlier Analytical Mapping System (AMS). Even earlier, USDA- and NASA-funded contracts produced numerous software packages that marked various stages of evolution toward what we now call GIS. Although difficult to document, it is inevitable that the program code from many of these evolved into commercial systems under other names, effectively masking the fact that much of their development was government funded. But legal issues aside, it was the private sector that made the software available, along with enabling technologies such as microcomputers, CD-ROM, and workstations, that made it all possible.

In the free world, rapidly expanding as a result of the momentous political changes in the USSR and eastern Europe over the past year, GIS technology is growing at a rate on the order of 30 percent annually and is expected to equal the U.S. market in size in 1992 (Gartzen and Hale, 1991). Based on total worldwide GIS-related sales of $2.4 billion in 1990 (Parker, 1991), the industry will grow to almost $9 billion by 1995. More rapid growth, up to 60 percent by some informal estimates, would produce a $25 billion industry in the same period. Note that all this growth is forecast to occur in the private sector. To be sure, much of it will respond to public needs, but it is industry that will make it happen.

The distribution of technology involves people, on both the sending and receiving ends. There is substantial economic incentive to getting GIS into use, especially in the software business, but there are real human limits to how fast the technology can be distributed. Number one may be simple ignorance on the part of current job holders in organizations that could benefit from using GIS. Technology has passed many of them by, and only when their positions pass on to younger generations, will GIS and other computer-based methods come into routine use.

But, even if they all retired tomorrow, there would not be enough GIS-literate job seekers to take their places. There aren't enough even now, and the demand for them is forecast to grow (Figure 1). The universities appear unable to generate the interest in GIS that is needed in the GIS-using disciplines. Educators often have difficulty getting new technologies into established curricula, and the diversity of GIS may be its own worst enemy. A GIS course sequence in a forestry, planning, engineering, or marketing curriculum can be a tough sell to a conservative faculty, for example. "Put it in the Geography Department?" If there isn't a geography department, or if the geography faculty is not versed in GIS, this conventional advice is meaningless.

Private industry can help this situation with the most powerful influence of all – money. By seeking and hiring GIS-fluent graduates, or even funding research or academic chairs, the private sector can have a significant influence on the direction of GIS education, but the funds must be carefully placed. One university in the author's experience had a GIS training facility, complete with computers, software, and furnishings, given to it free of charge by a U.S. federal agency. Within two years the lab had been appropriated by a faculty committee for other purposes, and the small GIS faculty had resigned. What happened? A complete lack of leadership at the college level, fighting among departments, and ambivalent administration combined to totally smother the vision that created the facility.

The third industry category, spatial data supply, represents a continuing need of GIS users and an opportunity for GIS businesses. There are two service parts to the business, the im-

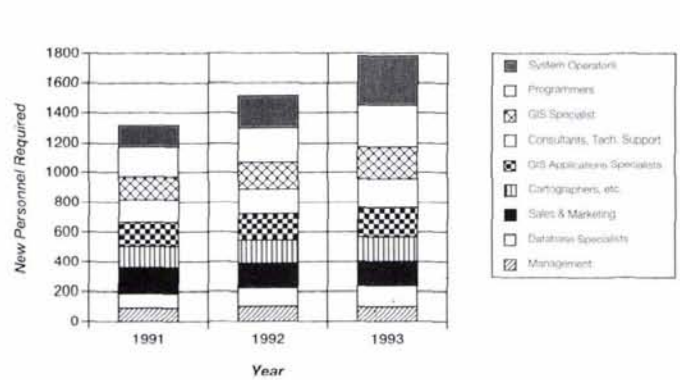

FIG. 1. Estimated GIS industry new personnel requirements for the years 1991-1993 (from *GIS World* magazine GIS Industry Survey, April 1991).

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provement and marketing of government data, and the digitizing of map data on contract for specific customers.

In the U.S., a large amount of digital cartographic data is available in the public domain inexpensively. Both the U.S. Geological Survey and U.S. Bureau of the Census supply various types of spatial data with virtually complete coverage of the country. Numerous other agencies provide more specialized data on specific subjects or in specific geographic areas. However, the original form of the data is often less than optimum for GIS use. This situation has led to an industry of data suppliers that add value to the government products in various ways, improving consistency, accuracy, coverage, or packaging.

A third category, digitizing maps on speculation, actually is a product supply business, and it is creating libraries of "off-the-shelf" spatial databases. Data are becoming a commodity and this is very significant because it allows the sometimes very high cost of data to be spread among users, and that can reduce GIS implementation cost substantially.

Spatial data are obviously critical to the use of GIS technology for any purpose. There is, therefore, a business opportunity in providing it and a potentially large and long term industry growing around it. However, there are serious hazards in depending too heavily on much of the data available through today's technology for certain demanding applications, because of a lack of knowledge of the error contained in them. Both the original source materials, frequently maps, and the digitizing steps required to store and use them in the GIS, are sources of error of such importance that they are being pursued as the top priority research topic of the National Center for Geographic Information and Analysis (Goodchild, 1990).

The cost of virtually error-free data would surely stifle this vibrant industry, even if it was possible to produce it. For some applications, construction for example, very accurate data may be worth a high cost, but for others, like planning, it would be a waste of resources. This is an area where industry and academia could work together profitably to create and promote data error standards related to specific applications.

The private GIS industry is growing, and with good reason. There is an increasing demand around the world for GIS technology that can only be filled by business. Although I would not characterize the industry as being in a state of chaos, there certainly is a broad, fluid mix of approaches and solutions to GIS applications for the user to choose from, and that can be bewildering to the newcomer. But, that state is normal for new technologies, especially one with only the tip of its future showing above the surface today. Below the surface there exists a potential for a true computing revolution based on spatial data processing that is as extensive as spatial data itself, which is all around us. Optimistic, but realistic, recognition of this point was made at the recent GISDEX conference in Washington, D.C., by IBM Vice President, Gerald W. Ebker who said, "GIS will be as common in the future as word processing is today."

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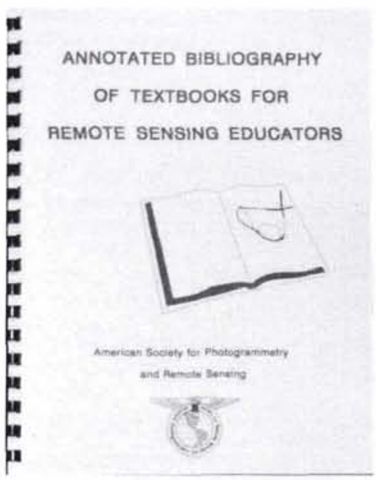

Mapping Florida Scrub Jay Habitat for Purposes of Land-Use Management

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ABSTRACT: Geographical information system (GIS) applications were used to map areas of primary and secondary Florida Scrub Jay habitat on Kennedy Space Center (KSC) using vegetation and soils maps. Data from field studies were used for accuracy assessment and evaluating the importance of mapping classes. Primary habitat accounts for 15 percent of the potential habitat and contained 57 percent of the Florida Scrub Jay population on KSC. Proximity analysis identified potential population centers, which were 44 percent of the potential habitat and contained 86 percent of the population. This study is an example of how remote sensing and GIS applications can provide information for land-use planning, habitat management, and the evaluation of cumulative impacts.

INTRODUCTION

REMOTE SENSING AND GEOGRAPHIC INFORMATION SYSTEM (GIS) applications have been used for mapping habitat of several avian and mammalian species (Barnard *et al.*, 1981; Craighead *et al.*, 1986; Scepan *et al.*, 1987; Young *et al.*, 1987; Shaw and Atkinson, 1990). Many of these studies were an intermediate step in a program to refine habitat maps.

The size of the Florida Scrub Jay (*Aphelocoma coerulescens coerulescens*) population has declined by half in the last century due to habitat destruction and degradation (Cox, 1984). This subspecies has been listed as threatened by the U.S. Fish and Wildlife Service (USFWS). The largest population occurs on the John F. Kennedy Space Center (KSC) (Cox, 1984; Breininger, 1989). Federal agencies with jurisdiction in Florida Scrub Jay habitat are mandated by the Endangered Species Act of 1973, as amended (16 U.S.C. 1531 *et seq.*), to consider effects on the Florida Scrub Jay population from their operations. This requires knowledge of a project site and its significance to the population.

The first objective of this study was to apply remote sensing and GIS techniques to map areas that vary according to their habitat potential for Florida Scrub Jays, recognizing that comprehensive field surveys could not be performed. Field studies revealed much variation in Florida Scrub Jay density across the KSC (Breininger, 1981; Breininger, 1989; Breininger and Smith, 1989; Breininger and Schmalzer, 1990). Animal populations are often maintained by a subset of the total area used by the population, due to differences in habitat suitability across the landscape (Wiens and Rotenberry, 1981; Pulliam, 1988; Pulliam and Danielson, in press). Habitat suitability models can be used in environmental impact studies (Williams, 1988; O'Neil *et al.*, 1988). Relying on models, remote sensing and GIS applications can provide information to evaluate habitat suitability across large areas (Lyon, 1983; Payne and Long, 1986; Ormsby and Lunetta, 1987; Stenback *et al.*, 1987; Agee *et al.*, 1989; Heinen and Lyon, 1989).

There has been a proliferation of habitat suitability models, but most have not been adequately tested (Lancia *et al.*, 1982; Cole and Smith, 1983). Model development or testing is often based on densities or information from sightings or radiotracking; these data are not always accurate indicators of habitat suitability (Van Horne, 1983; Hobbs and Hanley, 1990). Despite problems, habitat modeling shows promise for the management of wildlife diversity (Verner *et al.*, 1986; Davis *et al.*, 1990). Assumptions used for mapping and accuracy assessment must be carefully considered because GIS applications can generate seemingly accurate maps with little knowledge of true spatial relationships (Burrough, 1986; Berry, 1987).

Most accuracy assessments of wildlife habitat maps do not measure actual habitat suitability; long-term study of population dynamics is needed to quantify suitability (Van Horne, 1983; O'Connor, 1986; Hobbs and Hanley, 1990) and is beyond the scope of most mapping applications. Accuracy assessments use indicators of habitat suitability such as vegetation cover type (Miller and Conroy, 1990), sightings (Agee *et al.*, 1989), or measures of animal abundance (Cannon *et al.*, 1982; Lyon, 1983). Additional problems include the feasibility of acquiring enough field samples to test what proportion of sites are classified correctly (Cannon *et al.*, 1982), and the quantification of commission errors (Hodgson *et al.*, 1988), because it can not always be determined whether an animal has never or will never use a site.

The second objective was to use existing data for a preliminary accuracy assessment of Florida Scrub Jay habitat maps. Empirical testing developed from the GIS application could not be done in a timely manner without requiring biological assumptions that were possibly invalid. Instead, long-term reproductive success and survival studies will be used to evaluate the habitat maps. The third objective was to estimate the contribution of mapping class types to the Florida Scrub Jay population and estimate the spatial variability of habitat potential within each mapping class, using existing field data.

BACKGROUND

Florida Scrub Jays live in territories defended year-round by a permanently monogamous breeding pair (Woolfenden and Fitzpatrick, 1984). The Florida Scrub Jay is a disjunct race that differs from the various western subspecies by having helpers. These helpers are usually offspring of previous breeding seasons which remain in their natal territory for at least one year. They participate in nest and territory defense, and in the care of young (Woolfenden and Fitzpatrick, 1984).

Habitat requirements of Florida Scrub Jays include the need for open sandy spaces, a sufficient cover of scrub oaks (*Quercus* spp.), little or no tree cover, and a suitable shrub height (Westcott, 1970; Woolfenden, 1974; Breininger, 1981; Cox, 1984). Densities are highest in scrub and slash pine flatwoods where oak canopy cover exceeds 50 percent; areas with oak cover less than 30 percent have few Florida Scrub Jays (Breininger, 1981; Cox, 1984). Within scrub and slash pine flatwoods on KSC, mean oak cover is 78 percent (optimal) on well drained soils and 22 percent (marginal) on poorly drained soils (Breininger *et al.*, 1988). Densities in coastal strand are low because few scrub oaks occur there (Stout, 1980), but Florida Scrub Jays will use coastal strand where it is adjacent to scrub (Breininger, 1981) or coastal woodlands (Simon, 1986).

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Habitat potential is an important mapping criterion because habitat suitability changes with time since fire (Cox, 1984; Woolfenden and Fitzpatrick, 1984; Breininger *et al.*, 1988). There are unburned areas not occupied by Florida Scrub Jays that would become suitable if they were burned (Westcott, 1970; Cox, 1984; Woolfenden and Fitzpatrick, 1984) because fires usually affect structural features and not scrub oak occurrence (Schmalzer and Hinkle, 1987). Scrub oak cover is the best indicator of a site's potential to be suitable habitat for Florida Scrub Jays (Westcott, 1970; Cox, 1984; Woolfenden and Fitzpatrick, 1984), but we have been unable to reliably map scrub oaks over large areas. The use of vegetation and soils maps provides a method to map potential habitat and population centers of Florida Scrub Jays.

Areas dominated by scrub oaks occur as narrow linear features among marginal habitat. Florida Scrub Jays occupy large territories (Woolfenden and Fitzpatrick, 1984) relative to patches of optimal habitat. Areas that can be managed as population centers need to be identified because this is where industrial development would have the most impact. The structure of optimal habitat allows Florida Scrub Jays to scan their surroundings for long distances (Woolfenden and Fitzpatrick, 1984), which is important for the detection of predators, especially hawks (McGowan and Woolfenden, 1989). Human development within population centers can result in a discontinuous fuel structure that often burns poorly (Breininger and Schmalzer, 1990) and has a tall shrub layer (Breininger *et al.*, 1988) that interferes with the ability to spot hawks. Mortality of adult Florida Scrub Jays has been high and reproductive success has been poor in tall, disturbed areas (Breininger and Smith, unpublished data).

Most of KSC has been subdivided into fire management units (FMUs) that allows specific fire management prescriptions for each unit. The evergreen nature of scrub oaks makes them less prone to burn than adjacent habitats that have a high cover of flammable grasses and forbs (Webber, 1935) or saw palmetto (Schmalzer and Hinkle, 1987; Breininger *et al.*, 1988). Repeated prescribed fires during dry weather patterns could burn habitat dominated by scrub oaks more frequently than is suitable for Florida Scrub Jays (Breininger *et al.*, 1988).

STUDY SITE

Lands and lagoons of KSC comprise 57,000 ha in Brevard and Volusia counties located along the east coast of central Florida. Most of KSC is on northern Merritt Island which forms a barrier island complex with the adjacent Cape Canaveral. Temperate and subtropical plant associations that include closed forests, open woodlands, scrub communities, and marshes dominate the landscape (Sweet *et al.*, 1980). Scrub and slash pine flatwoods, which are similar to scrub but have an open canopy of slash pine, occupy most upland areas. In scrub and slash pine, saw palmetto dominates the wet end of the gradient and scrub oaks dominate the dry end; in most areas dominance is mixed (Schmalzer and Hinkle, 1987; Breininger *et al.*, 1988). Marshes and woodlands are found in low areas that are interspersed throughout the scrub or slash pine.

METHODS

HABITAT MODEL

Primary habitat of Florida Scrub Jays was defined as all scrub and slash pine occurring on well drained soils; secondary habitat was defined as scrub and slash pine occurring on poorly drained soils. Also included in secondary habitat was coastal strand where scrub or coastal woodlands was within 300 m, which is the width of an average territory (Woolfenden and Fitzpatrick, 1984).

Large areas that represent potential population centers were identified as a combination of all primary habitat, secondary habitat within 300 m of primary habitat, and ruderal habitat within 100 m of primary habitat. Primary habitat usually occurs as narrow strips, so that Florida Scrub Jay territories occupying primary habitat often include secondary habitat (Breininger and Smith, 1989). The width of an average territory (300 m) was considered to represent a suitable buffer of secondary habitat surrounding primary habitat. In areas where ruderal and primary habitat coincide, Florida Scrub Jay territories extend into ruderal areas as far as 100 m (Breininger and Smith, 1989). This was assumed to be an adequate distance to identify ruderal areas as being part of potential population centers.

Accuracy assessments of primary and secondary habitat maps were performed using existing data on scrub oak cover. The model of potential habitat suitability is based on average Florida Scrub Jay densities (Breininger 1981) in different scrub oak cover classes (Figure 1). This model is being tested using long-term studies of reproductive success and survival.

REMOTE SENSING AND GIS ANALYSIS

All analyses for defining these habitats were run with ERDAS 7.3 GIS software (ERDAS, 1987) on a Compaq 386 25 MHz computer. Aerial photography provided the necessary resolution to map vegetation types. Vegetation on KSC is frequently represented by narrow, linear polygons because of the ridge and swale topography that is characteristic of the landscape. Season has little influence on the appearance of scrub and slash pine because the shrubs that dominate these habitats are evergreen. Fifty vegetation and land-use types were interpreted from November, 1979 aerial color infrared photography (ACIR) at 1:12,000 scale (Provancha *et al.*, 1986). Scrub and slash pine were distinct with respect to texture and color on aerial photographs. Some areas of saw palmetto scrub had a lighter appearance and more uniform texture than oak scrub, which frequently had a dark red signature. However, most areas had an intermediate appearance and, because mesic shrubs also had a red signature, it was not possible to accurately map oak scrub across large areas. Soils data were taken from USDA Soil Conservation Service soils survey maps (1:20,000 scale) of Brevard (Huckle *et al.*, 1974) and Volusia (Baldwin *et al.*, 1980) counties. Soils and vegetation/land-use themes were gridded into a database with a

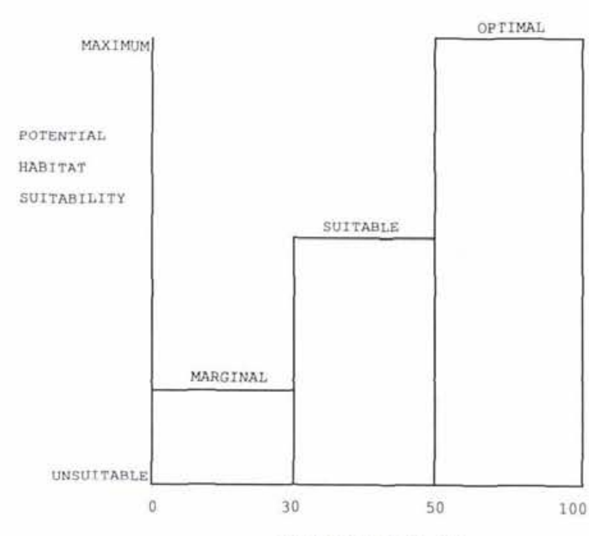

FIG. 1. Potential habitat suitability based on average Florida Scrub Jay densities in different scrub oak cover classes (Breininger, 1981).

pixel resolution of 22 m. This pixel size allowed the identification of small, isolated wetlands found within scrub and slash pine. Boundaries of FMUs (Fire Management Plan, Merritt Island National Wildlife Refuge, Titusville, Florida) were transferred to 1:24,000-scale topographic quadrangle maps and digitized using 22-m pixel resolution.

Coastal strand, disturbed scrub, oak/palmetto scrub, and slash pine were recorded as potential habitat from the KSC vegetation map (Figure 2). Hereafter, oak/palmetto scrub and disturbed scrub are referred to as scrub. The following soils types were recoded as well drained soils based on their descriptions (Huckle *et al.*, 1974; Baldwin *et al.*, 1980) : Astatula, Bulow, Canaveral sand, Canaveral urban complex, Cocoa sand, Daytona sand, Orsino, Palm Beach, Paola, Pomello, Quartzipsamments, St Lucie, and Welaka. Remaining soil types were recorded as poorly drained. Coastal strand was separated from the file of potential habitat by a recoding function. The ERDAS routine MATRIX was used to develop a file of primary habitat (slash pine and scrub that coincided with well drained soils) and secondary habitat without coastal strand (slash pine and scrub that coincided with poorly drained soils). A file was developed that included all pixels within 308 m of scrub and coastal woodlands using proximity analysis. A search distance of 308 m was used because it was the closest possible distance to 300 m, given a pixel size of 22 m. This file was overlaid with the coastal strand file to develop a file of coastal strand classified as secondary habitat. An overlay was then performed to develop a file of all secondary habitat (Figure 2, Step 8).

Proximity analysis was used to generate a map of potential Florida Scrub Jay population centers. All pixels that were within 308 m of primary habitat were incorporated into a new GIS file that was then overlaid with secondary habitat to create a file of secondary habitat adjacent to primary habitat. The KSC vegetation map was recorded to develop a file of ruderal habitat. Overlay analysis was used to overlay the ruderal habitat file with a file of all pixels within 110 m of primary habitat (110 m is the closest search distance possible to 100 m given the pixel size) to develop a file of ruderal habitat adjacent to scrub oak vegetation (Figure 2, Step 13). A preliminary file of all population centers was developed by combining primary habitat, adjacent secondary habitat, and adjacent ruderal habitat into one file. Contiguity analysis was used to delete isolated pixels classified as population centers that were assumed to be too small. This was done by clumping all pixels classified as population centers that were connected to each other, and then eliminating regions that were only one pixel in size (0.05 ha).

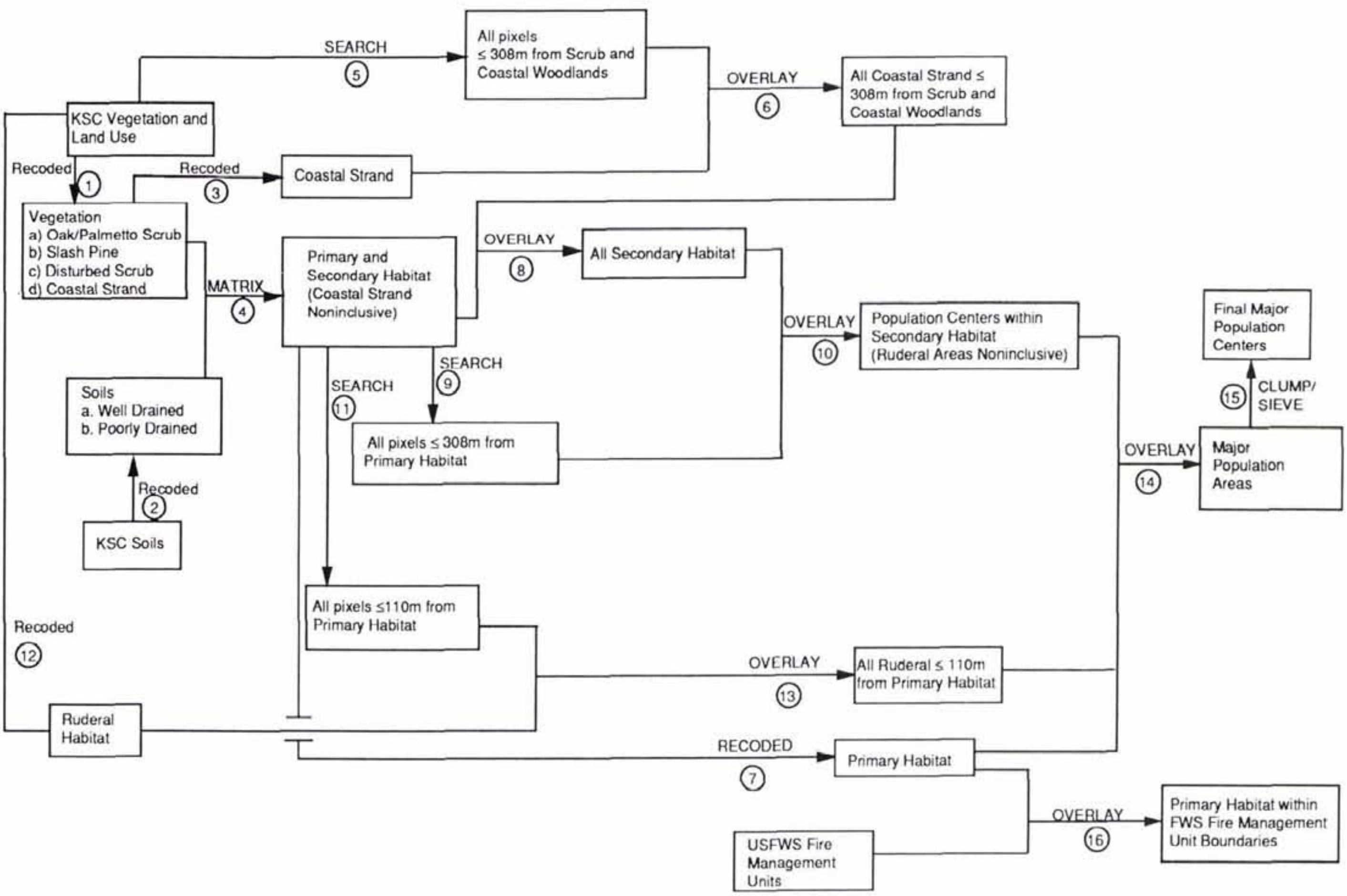

FIG. 2. Florida scrub jay GIS habitat mapping model. The overlay of well drained soils with scrub and slash pine was used to identify primary habitat. The overlay of poorly drained soils with scrub and slash pine was used to identify secondary habitat within scrub and slash pine. Coastal strand adjacent to areas with scrub oaks was used to identify additional secondary habitat. Potential population centers were defined as all primary habitat and adjacent secondary and ruderal habitat greater than one pixel in size. An overlay of fire management unit boundaries and primary habitat was used to identify the acreage of primary habitat outside fire management units and the fire management units most important to the Florida Scrub Jay population.

Primary habitat within FMUs was identified by an overlay of primary habitat and a file of FMU boundaries.

FIELD STUDIES

Data for estimating map accuracy and the contribution of mapping classes (primary habitat, secondary habitat within population centers, secondary habitat outside population centers) was derived from a stratified random design of 73 stations located in slash pine, disturbed scrub, and oak/palmetto scrub (Breininger, 1989). Measurements of oak canopy cover collected from each station were used to identify the habitat as optimal, suitable (but not optimal), or marginal, based on the model in Figure 1. Percent oak cover was determined by a modification of the point intercept method (Mueller-Dombois and Ellenberg, 1974; Hayes *et al.*, 1981; Breininger *et al.*, 1988). Eight lines of four points each were radiated from a point at the center of each station. At every point, the presence or absence of oak was determined. The number of points having oak divided by the total number of points gave an estimate of oak cover.

The variable distance circular plot method (Reynolds *et al.*, 1980) was used to estimate Florida Scrub Jay densities for each station. Stations were sampled eight times between March 1986 and February 1987 (Breininger, 1989).

ACCURACY ASSESSMENT

The map accuracy of primary (potentially optimal habitat) and secondary habitat was determined using an error matrix (Card, 1982; Story and Congalton, 1986) where the reference data were based on stations having optimal (greater than 50 percent) oak cover or less than optimal oak cover as determined from field measurements. The classified data were derived from stations mapped as occurring in primary habitat or secondary habitat. Errors of commission for primary habitat were defined as the number of stations classified as primary habitat when they actually had oak cover that was less than 50 percent. Errors of omission were defined as stations not classified as primary habitat that had 50 percent or greater oak cover. Overall accuracy was determined as the number of correct classifications divided by 73.

RELATIVE IMPORTANCE OF HABITAT TYPES TO FLORIDA SCRUB JAYS

The total number of Florida Scrub Jays within primary habitat, secondary habitat within population centers, and secondary habitat outside population centers was determined by multiplying the average density for each habitat type by the acreage of the type to compare the contribution of each type to the total population.

The spatial heterogeneity of scrub oak cover and Florida Scrub Jay density was evaluated for each of the mapping classes to estimate how much of each type was important for Florida Scrub Jays. The proportion of the mapping class actually used by Florida Scrub Jays was estimated from the proportion of stations where at least one Florida Scrub Jay was sighted during at least one of eight visits to the station. Oak cover field measurements collected from the stations were used to classify each station as optimal, suitable but not optimal, or marginal (Figure 1). The proportion of stations classified in each of these habitat suitability classes was determined for each habitat type.

Statistics were used (SPSS, 1988) to test whether oak cover and Florida Scrub Jay densities were different between primary and secondary habitat and between secondary habitat inside and outside population centers. An alpha level of 0.05 was used for all statistical tests. The Kolmogorov-Smirnov goodness of fit test determined whether oak cover and Florida Scrub Jay densities had a normal distribution. Oak cover was normally distributed, and t-tests were used to test for oak cover differences. Variance was not significantly different between classes at the 95 percent level; pooled variance estimates were used for comparisons between primary and secondary habitat and for comparisons between secondary habitat inside and outside population centers. Florida Scrub Jay densities were not normally distributed and nonparametric Mann-Whitney U-Wilcoxon rank sum tests were used to test for differences between primary and secondary habitats and between secondary habitat inside and outside population centers.

RESULTS AND DISCUSSION

Primary habitat comprised only 2 percent of all KSC lands and 15 percent of all scrub and slash pine, but 57 percent of the total KSC Florida Scrub Jay population was accounted for within this habitat type (Table 1). Plate 1 shows that these well drained areas were interspersed with poorly drained areas. Areas mapped as potential population centers contained 86 percent of the population and 44 percent of all scrub and slash pine (Figure 3). Primary habitat had significantly higher Florida Scrub Jay densities and oak cover than secondary habitat.

Approximately 69 ha of coastal strand were within areas classified as secondary habitat. The estimate of the total number of Florida Scrub Jays maintained by this habitat was 14, derived by multiplying this acreage by 0.20 jays per hectare, which is a density estimate for this habitat type (Breininger, 1981).

Sixty-five stations were classified correctly, resulting in an

TABLE 1. SPATIAL HETEROGENEITY OF HABITAT AND CONTRIBUTION OF MAPPING CLASSES TO THE FLORIDA SCRUB JAY POPULATION ON JOHN F. KENNEDY SPACE CENTER.

Characteristics	Primary Habitat	Secondary habitat: Within population centers	Secondary habitat: Outside population centers
Acreage (ha)	1600	3185	5986
Percent of scrub and slash pine[a]	15	30	55
Average Florida Scrub Jay density[b]	31[c]	8[d]	2
Population estimate	1240	637	299
Percent of population[e]	57	29	14
Number of stations	16	29	28
Mean oak cover (%)	72[f]	23[g]	25
Percent of habitat occupied by Florida Scrub Jays	94	62	25
Percent of habitat with opitmal oak cover[h]	69	7	4
Percent of habitat with suitable oak cover[i]	19	38	46
Percent of habitat with marginal oak cover[j]	12	55	50

[a]Acreage of habitat divided by the acreage of all scrub and slash pine (10,771 ha) multiplied by 100
[b]Birds/40 ha
[c]Primary habitat had a significantly higher ($p \leq 0.05$) density than all secondary habitat
[d]Secondary habitat within population centers had a significantly higher ($p \leq 0.05$) density than secondary habitat outside population centers
[e]Population estimate for the habitat type divided by the total population for scrub and slash pine (2,176 birds)
[f]Oak cover was significantly greater ($p \leq 0.05$) in primary habitat that secondary habitat
[g]Oak cover was not significantly different between the two classes of secondary habitat
[h]Greater than or equal to 50% oak cover
[i]30–49% oak cover
[j]Less than 30% oak cover

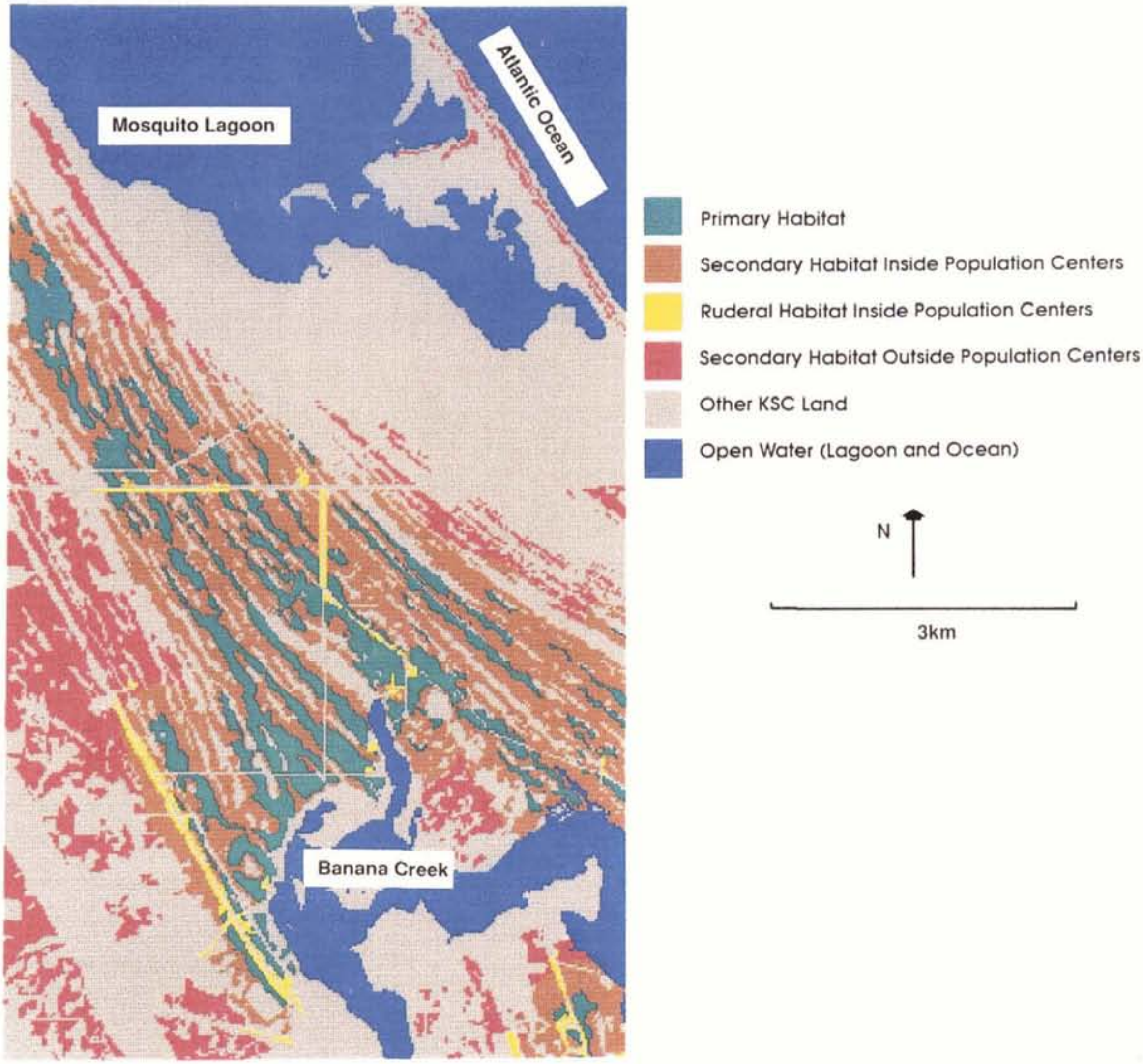

PLATE 1. Primary Florida scrub jay habitat, secondary habitat inside population centers, ruderal habitat inside population centers, and secondary habitat outside population centers. Horizontal and vertical lines are roads.

overall mapping accuracy of 89 percent (Table 2). This is similar to accuracy estimates obtained for maps of kestrel habitat (Lyon, 1983) and wood stork foraging habitat (Hodgson *et al.*, 1988). Errors of omission for optimal habitat were due to three stations with high scrub oak cover that occurred in poorly drained areas instead of primary habitat. Their vegetation and surface soil characteristics were similar to primary habitat, but these patches were small. Soil inclusions are often not treated as distinct soils mapping units because of their small size; they can significantly contribute to mapping errors in GIS applications (Walsh *et al.*, 1987). Errors of commission within primary habitat were associated with five stations that occurred in recently burned areas (less than three years post-fire). Oak cover is reduced for at least three years after fire (Schmalzer and Hinkle, 1987). We believe that all stations located within primary habitat were correctly classified as having potential to be optimal and that all primary habitat is potentially important to Florida Scrub Jays. Only one station within primary habitat was unoccupied by Florida Scrub Jays; this area was unburned for at least 25 years.

Scrub oak cover was not significantly different at the 95 percent level between the two types of secondary habitat (Table 1). Proximity to primary habitat may explain why Florida Scrub Jay densities were significantly higher at the 95 percent level in secondary habitat within population centers than densities outside population centers. Secondary habitat should provide a buffer to primary habitat, enhancing the opportunity for fires to burn into primary habitat. Corridors of secondary habitat that connect population centers are especially important given the poor dispersal abilities of the Florida Scrub Jay (Woolfenden, 1970; Woolfenden and Fitzpatrick, 1984).

Almost half of the secondary habitat had oak cover that was either suitable or optimal and was capable of supporting Florida Scrub Jays. Secondary habitat provides for a population that is larger than would be maintained by primary habitat alone; larger populations are less susceptible to catastrophic events, epidemics, and inbreeding (Soule, 1987). It is not known how long Florida Scrub Jay populations would persist if no primary habitat were available. Animal populations often include population sinks (areas where mortality rates exceed net reproduction), but long-term persistance of these populations is dependent on source areas (where reproduction exceeds mortality) that provide individuals to subsidize the sink (Howe *et al.*, in press; Pulliam and Danielson, in press). The identification of sources and their management is crucial to persistance of populations;

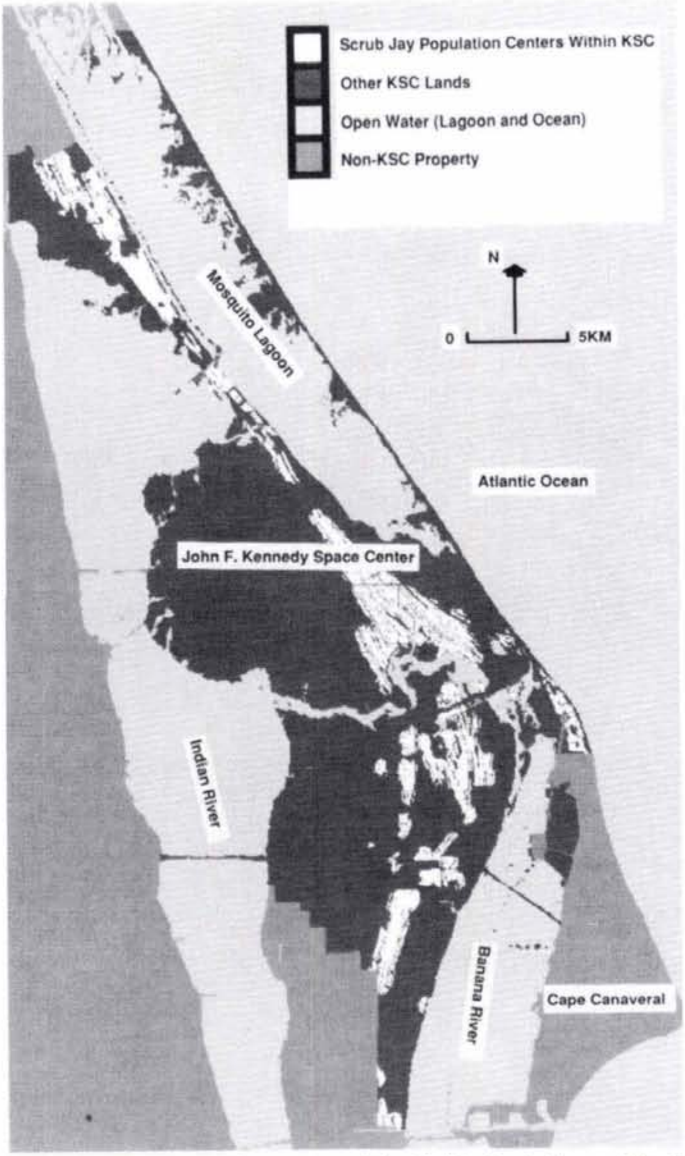

FIG. 3. Potential population centers of the Florida Scrub Jay on John F. Kennedy Space Center. Horizontal and vertical lines are roads.

TABLE 2. ERROR MATRIX FOR MAPPING PRIMARY AND SECONDARY HABITAT.[a]

	Map Category		
True Category[b]	Primary Habitat	Secondary Habitat	Totals
Greater Than or Equal to 50% Oak Cover	11	3	14
Less Than 50% Oak Cover	5	54	59
Totals	16	57	73

[a]Overall mapping accuracy = 89% [the number of stations classified correctly as primary habitat (11) plus the number of stations correctly classified as secondary habitat (54) divided by the total number of stations (73) multiplied by 100]
[b]Based on field measurements of 73 stations

this is an important consideration for habitat mapping applications.

This GIS application provides a map of potential Florida Scrub Jay population centers that can be used to minimize human disturbance to areas important for sustaining the Florida Scrub Jay population. Cumulative impacts across the landscape can also be evaluated using GIS applications (Johnston *et al.*, 1988). Habitat lost to construction can be digitized to assess the impact from individual projects relative to the total habitat available. Files of many projects can be combined to quantify cumulative losses. Wildlife management problems arise when entire populations are maintained by source areas that are small, relative to the total habitat occupied by the population (Pulliam, 1988; Pulliam and Danielson, in press), but are not treated as separate mapping classes. A project site may appear insignificant, relative to the remaining habitat, but could be a source of individuals for a large area. This may be an especially important consideration for rare patches of good habitat located outside population centers.

Planning of habitat management practices can also be enhanced by GIS applications (Heinen and Mead, 1984). Eleven percent of primary habitat was found outside FMUs; this habitat is likely to become unsuitable if not burned. Thirteen of 33 FMUs that included scrub contained 96 percent of all the primary habitat. The FMUs are responsible for the viability of the KSC Florida Scrub Jay population and should be managed accordingly. The GIS analysis also found that primary habitat was typically less than one-third of the areas within an FMU and was adjacent to vegetation types such as marsh and palmetto flats that are more flammable. Controlled burn prescriptions will need to be written carefully to avoid burning primary habitat too frequently.

Remote sensing and GIS applications can be used to monitor habitat changes (Hodgson *et al.*, 1988; Leckenbey *et al.*, 1985). Fires, pine cover, and openings in the shrub layer are examples of parameters that can be mapped, but evaluating their effects on Florida Scrub Jays requires other remote sensing applications and a better understanding of habitat influences on reproduction and survival. Long-term study of reproduction and survival of color-banded birds is necessary to distinguish between habitat conditions suitable or unsuitable for maintenance of sustainable populations. The ability to develop maps of features that influence habitat suitability is likely to proceed at a faster pace than the ability to quantify how reproductive success and survival of Florida Scrub Jays varies with these features. The combination of demographic studies, remote sensing, and GIS applications provide an enhanced opportunity to test and refine habitat mapping.

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Forum

Remote Sensing of Leaf Water Stress

Warren B. Cohen's article, "Response of vegetation indices to changes in three measures of leaf water stress," published in the February 1991 issue of *Photogrammetric Engineering & Remote Sensing* (57(2):195–202) contains an error in the calculation of the Leaf Water Content Index (LWCI). Cohen indicated that the LWCI was negatively correlated with measures of water stress such as leaf relative water content (RWC) or absolute water content. However, LWCI was originally formulated by Hunt *et al.* (1987) to be equal to RWC and hence should be positively correlated with RWC. We found that Cohen presented the reciprocal of the LWCI, thus explaining the negative correlation.

The Corrected LWCI is positively correlated to relative water content (pooled data) with an r of 0.77, which is highly significant with 52 degrees of freedom. The regression line is LWCI = 0.80 + 0.20 RWC. However, both the intercept and slope are significantly different from the expected values of 0.0 and 1.0, respectively, so the hypothesis that LWCI equals RWC is rejected.

A key assumption in the development of LWCI is that the reflectance of a dry leaf (RWC = 0.0) in the 1.55- to 1.65-μm waveband (Thematic Mapper band 5) can be approximated by the reflectance in the 0.76- to 0.90-μm waveband (Thematic Mapper band 4) for a fresh leaf (RWC = 1.0). These results are explained by sensitivity analyses performed by Hunt and Rock (1989) and suggest that reflectances in the 1.55- to 1.65-μm waveband for dry leaves were less than reflectances in the 0.76- to 0.90-μm waveband for fresh leaves. Cohen's data covered a range of RWC from 0.7 to 1.0, so reflectances for dry leaves were not obtained. Although the corrected LWCI is positively correlated with RWC, LWCI is not equal to RWC as hypothesized by Hunt *et al.* (1987) when assumptions are made about the spectral properties of dry leaves. Following Hunt and Rock (1989), we conclude LWCI is not a practical vegetation index of leaf water stress because it requires reflectances at two known RWC, one for the leaf while fresh and one while dry.

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