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SPOT SATELLITE IMAGERY FOR MAPPING KIRTLAND'S WARBLER WINTERING HABITAT IN THE BAHAMAS

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The endangered Kirtland's warbler (*Dendroica kirtlandii*) is restricted in its breeding range to only 6 counties of the northern Lower Peninsula of Michigan (Payne 1983). Most research and management efforts aimed at increasing population levels have focused on the breeding grounds. Intensive efforts to control limiting factors have resulted in increased reproductive success, improved nesting habitat, and increased habitat area (Shake and Mattson 1975). Nevertheless, populations of breeding warblers have failed to increase.

Kirtland's warblers winter in the Caribbean, primarily in the Bahama Islands (Mayfield 1960, Radabaugh 1974, Walkinshaw 1983). Because loss of wintering habitat may be responsible for population declines in some migrant Parulids (see Keast and Morton 1980), investigations of Kirtland's warbler wintering ecology are being conducted. Early systematic searches for the species in the Bahamas generally were unsuccessful, although recent investigations have determined that the Kirtland's warbler uses transient, early-successional habitats dominated by lantana (*Lantana* spp.) (P. W. Sykes, U.S. Fish and Wildl. Serv., Athens, Ga., pers. commun.). Observations of the warbler generally have been restricted to habitat areas 2–3 ha in size or larger. Because these vegetative communities are subject to successional changes, searches for the warbler are hampered by a lack of current information on habitat distribution. These problems are compounded by the size of the archipelago and the remoteness of many of the potential sites. Aerial photographs and vegetation maps either are outdated or nonexistent, and costs associated with obtaining current aerial photographs can be prohibitive.

Satellite imagery has been shown to be effective for regional habitat/land use mapping because of its area coverage, cost, availability, and ease of interpretation (Best 1982, Welch 1985). It therefore may provide a reasonable alternative to aerial photographs for habitat mapping over large areas, especially when the image data are supplemented with limited ground truth information. This study was conducted to determine whether digital image data collected by the French Systeme Probatoire d'Observation de Terre (SPOT-1) satellite (SPOT Image Corp., 1984; use of trade names does not imply U.S. Government endorsement of commercial products) could be used to provide an initial reconnaissance of locations of vegetative communities typical of Kirtland's warbler wintering habitat in the Bahama Islands. This information could then be used to facilitate the efforts of field investigators studying the winter ecology of this endangered species.

METHODS

A 25-km² area containing known Kirtland's warbler wintering habitat located near Governors Harbour, Eleuthera Island, Bahamas was selected as the study site. The area contains a number of vegetation covers dominated by broadleaf evergreens, with scattered areas of agriculture, mangrove (*Rhizophora* spp.), beach, and urban/residential.

SPOT HRV2 multispectral imagery centered at 24°59'49"N, 76°17'56"W and collected on 21 April 1986 were obtained. The image data were recorded in green (0.50–0.59 μm), red (0.61–0.68 μm), and near-infrared (0.79–0.89 μm) spectral bands with a spatial resolution of 20 m. A supervised digital classification was performed on a 238-pixel by 270-line subset of the SPOT multispectral data using an ERDAS image processing system at the Center for Remote Sensing and Mapping Science, University of Georgia, Athens. In the classification process, training sets were selected with reference to available ground information including 1:25,000 scale topographic/land use maps (Dep. Lands and Surveys, Nassau, Bahamas 1975) and recent field data (P. W. Sykes, U.S. Fish and Wildl. Serv., Athens, Ga., unpubl. data) and visual interpretation of the image data. Seven classes were designated: (1) *General Agriculture*, and other areas of bare soil (e.g., roads, residential, etc.); (2) *Lantana*, early successional areas resulting from agricultural abandonments with low-growing shrubs of the genus *Lantana* spp. as the dominant vegetative type; (3) *Low Coppice*, midsuccessional areas containing broadleaf evergreen shrubs of moderate height (≤2 m) and density; (4) *High Coppice*, very dense late successional area containing broadleaf evergreen shrubs of greater height (2–6 m); (5) *Coconut*, plantations of *Cocos nucifera*; (6) *Beach*, primarily sandy shorelines; and (7) *Grasses*, including pastures and other grassland areas.

These areas of known land use/cover were interactively delineated on the satellite image and used to train the computer to recognize specific classes of features based on their spectral characteristics. After each sample was selected, a quick-look classification highlighted those pixels which were spectrally similar to the sample set. If too many pixels appeared incorrectly classified, the sample was refined or new samples taken and the process repeated. Most sample sizes ranged from 40 to over 200 pixels. However, to adequately sample rare land classes, multiple small samples were taken. A maximum likelihood classifier then was used with the final training sets to assign a class value to each pixel (Am. Soc. Photogrammetry 1983:1045). A 1:10,000 scale land use/habitat map was produced from the classified image (Fig. 1).

Stereo color infrared aerial photographs (1:10,000) of the study area were recorded on 3 June 1987 at an altitude of 1,524 m. These photos were analyzed using a Bausch & Lomb SIS 95 stereoscope by a photointerpreter experienced in vegetation identification. A detailed 1:10,000 scale land use/habitat map was produced with a minimum mapping unit of 10 m^2 on the ground (1 mm^2 on photo) (Fig. 2). Due to the higher spatial resolution of the aerial photographs, 7 additional classes could be identified: (8) *Casuarinas*, areas having *Casuarina* spp. as the dominant vegetative type; (9) *Mangrove*, dense tidal thickets dominated by *Rhizophora* spp.; (10) *Pond*, open freshwater areas; (11) *Residential*, includes buildings and other manmade structures; (12) *Scrub/shrub*, open early successional areas dominated by species other than *Lantana* spp., often sparsely vegetated; (13) *Swamp*, vegetated fresh and brackish water areas; and (14) *Roads*.

The accuracy of the digital classifications was assessed by comparison with the photo-interpreted land use/habitat maps using a stratified, systematic unaligned random sampling scheme (Yeates 1974, Fitzpatrick-Lins 1980). The entire study area was subdivided into 1.5-ha cells, and a sample point was randomly selected within each cell. This ensured that all portions of the map were sampled with equal frequency and that habitat areas of suitable size would be included. At each of 460 sample points, the land use class derived from the satellite image was compared to the class interpreted from the aerial photographs. Confusion matrices showing the relationship between correct and incorrect classifications were constructed and percent accuracy of the SPOT classification determined (Lillesand and Kiefer 1979:477).

RESULTS AND DISCUSSION

SPOT digital classification correctly classified Kirtland's warbler habitat (*Lantana* spp.) with a high degree of accuracy (88%). However, overall classification accuracy was only 69%. This lower accuracy is explained by characteristics inherent in SPOT imagery. First, several classes that are distinct on the aerial photographs have similar spectral signatures on the digital image. For example, roads, agricultural areas, and residential areas have similar spectral reflectance and can only be distinguished visually through context rather than spectral reflectance. Second, pixels lying on the boundary between 2 classes can only be classified by SPOT as one or the other, whereas the aerial photo interpreter can accurately differentiate habitat types in areas with high type interspersion.

To minimize complications caused by spectrally similar classes, we grouped similar classes in both the digital classifications and photo interpretations. These included: agriculture/beach/bare, lantana, low coppice/high coppice, coconut/grasses, and other. Regrouping these classes increased the overall classification accuracy to 83% (Table 1). Identification of areas predominated by lantana remained at 88%, resulting in an omission error of only 12%. The commission error for lantana was 36% (Table 1). However, due to the reconnaissance nature of our study, errors of commission are less important than errors of omission in that sites of commission errors can be eliminated quickly during subsequent ground inventories.

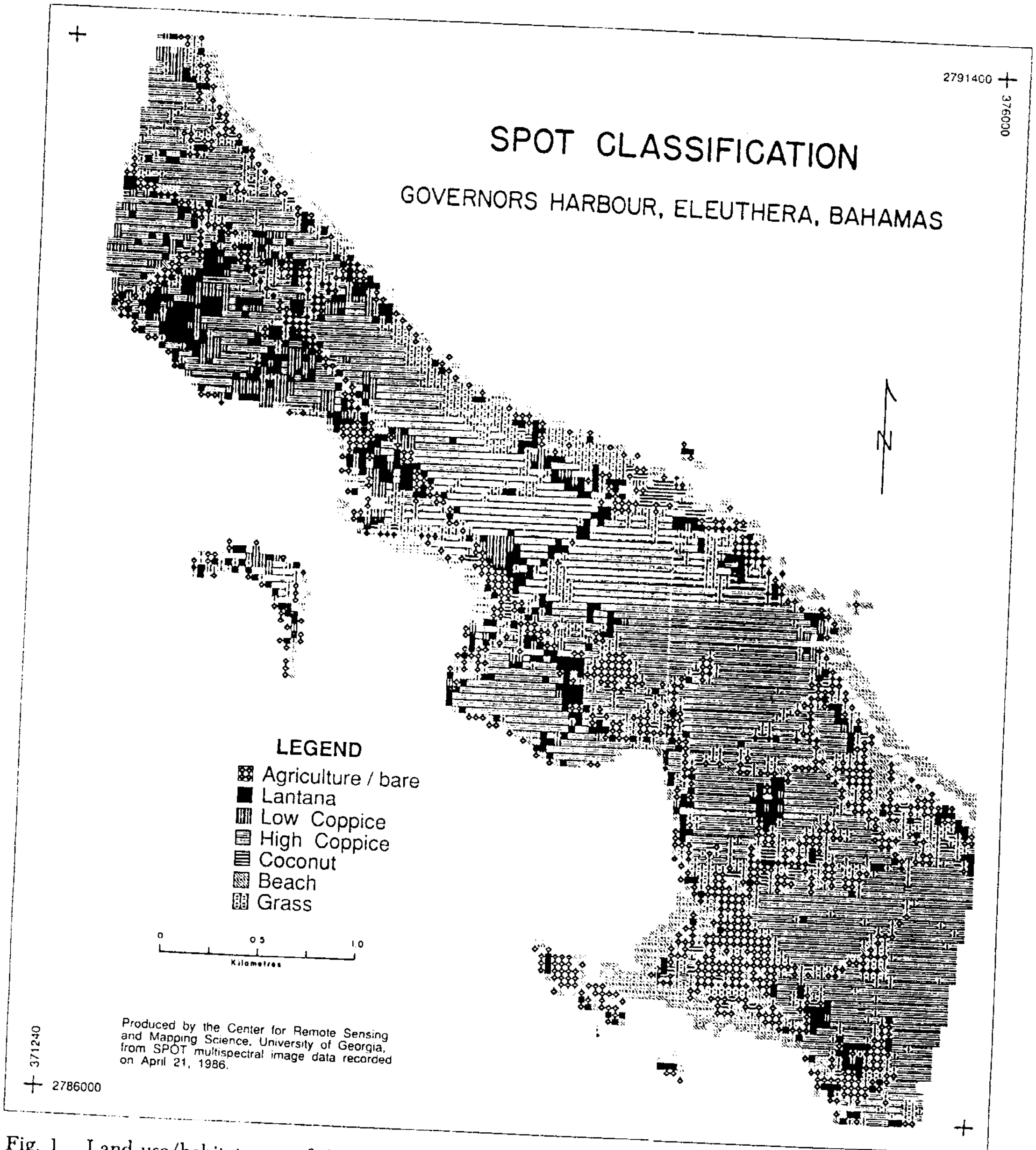
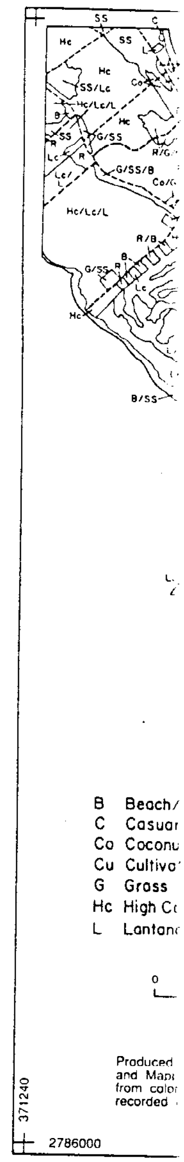


Fig. 1. Land use/habitat map of Governors Harbour, Eleuthera Island, Bahamas, prepared by digital classification of SPOT multispectral data.

Mapping Kirtland's warbler habitat on larger, more diverse Bahamian islands using satellite imagery will necessitate more intensive ground truth data and additional habitat classifications. It is unlikely, however, that the accuracy of determining lantana habitat types would be reduced greatly because its spectral signature appears to be relatively distinct.

Certainly land use/habitat mapping can best be performed through conventional interpre-



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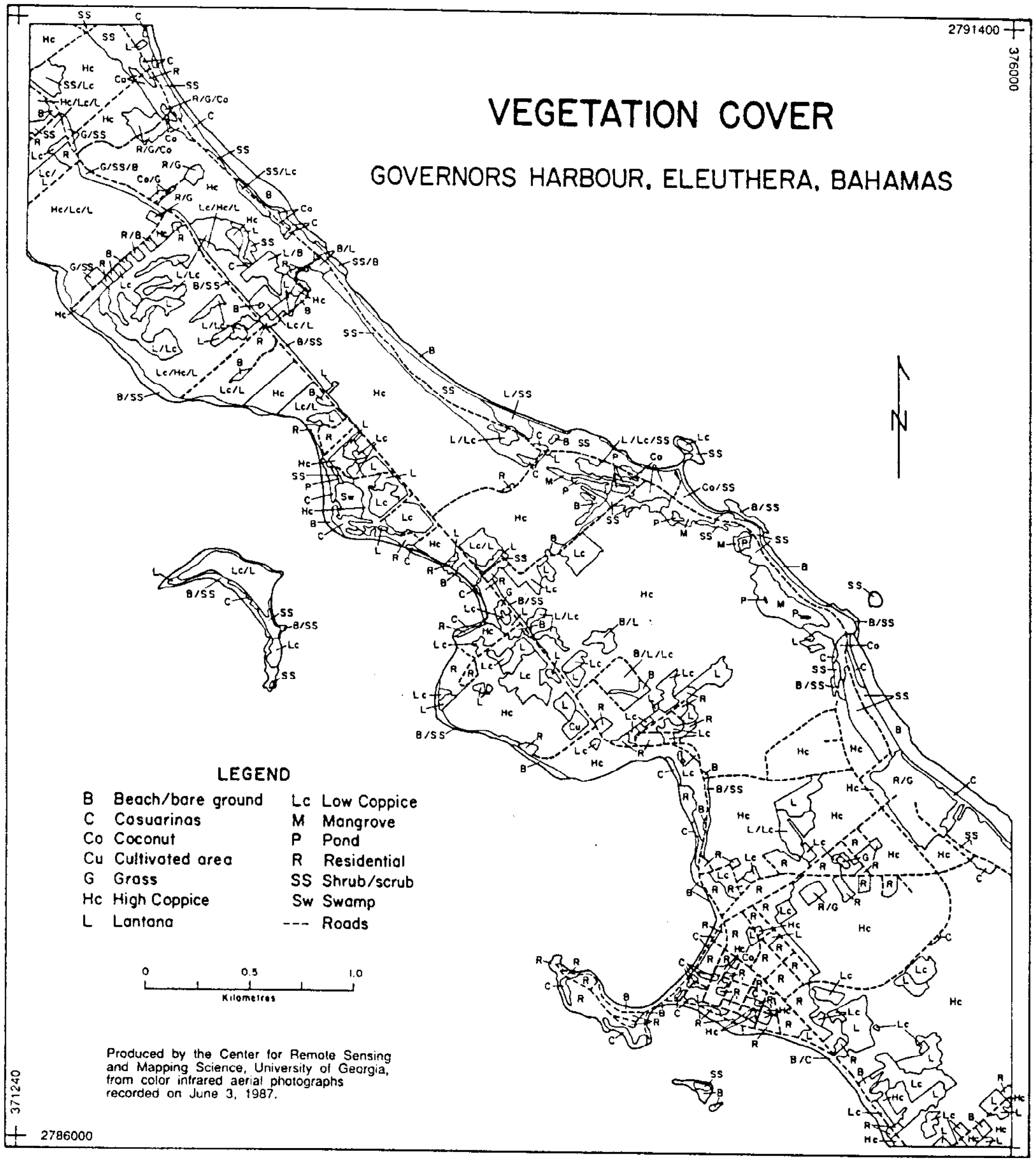

Fig. 2. Land use/habitat map of Governors Harbour, Eleuthera Island, Bahamas, prepared by visual interpretation of low-level color infrared photographs.

tation of large-scale color infrared aerial photographs. These photographs allow a skilled photointerpreter to recognize detailed land-use categories with minimal error. Finer discrimination among adjoining types also is possible. Photointerpretation, however, can be costly and time-consuming, especially for large areas. In addition, recent photographs either may not be available or difficult and expensive to obtain. For example, costs of aerial photographs of our 25-km² study site were 2.2 times that of the SPOT image data. Costs of aerial

Table 1. Confusion matrix comparing generalized SPOT and photo-interpreted land use/habitat classification, Eleuthera Island, Bahama, 1986.

Aerial photo classes	SPOT digital classes: AG	LA	LC/HC	CG/GR	Total correct	Omission error
Agric./Beach/Bare/Roads/Residential (AG)	85	3	6	12	85/106 (80%)	20%
Lantana spp. (LA)	0	37	4	1	37/42 (88%)	12%
Low/High coppice (LC/HC)	6	12	255	2	255/275 (93%)	7%
Coconut/Grasses (CG/GR)	0	1	0	6	6/7 (86%)	14%
Other	8	5	13	4	0/30 (0%)	100%
Total					383/460 (83%)	
Commission error	14%	36%	8%	76%		

photo interpretation and mapping for our study area averaged approximately 10 times the cost of producing a digital classification from the SPOT image. On larger study areas, however, acquisition costs per km^2 of both aerial photographs and SPOT imagery would be reduced. Because an individual SPOT scene encompasses 3,600 km^2, satellite data costs potentially could be reduced to a very nominal amount, while aerial photo acquisition of a similar area may remain prohibitive. Other cost factors requiring consideration include obtaining the necessary equipment and personnel for photo interpretation versus image processing, or contracting for those services.

CONCLUSION

The vegetation type favored by Kirtland's warblers is an early-successional stage, and information about its distribution becomes obsolete in a few years. Therefore, most published maps are no longer useful during field investigations. The accuracy of habitat type delineation in this study suggests that in many situations, land use/habitat maps suitable for use in initial reconnaissance during field studies can be produced quickly using standard digital classification techniques and SPOT multispectral image data. Its utility is maximized in remote or poorly mapped areas where direct access is logistically difficult and recent aerial photographs do not exist. Additionally, digital classification allows quantification of warbler habitat over large areas and also may be used to determine temporal changes in habitat distribution.

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THE SUITABILITY OF THE COMMON LOON AS AN INDICATOR SPECIES

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Indicator species are used widely to monitor environmental conditions (Thomas 1972) despite inherent problems in the indicator species concept and recent criticisms (Landres et al. 1988, Temple and Wiens 1989). The selection of species and the population measurements used in assessments are important parts of an effective indicator species program. Some programs, for example, the U.S. Forest Service's management indicator species program (Code of Federal Regulations 1983:64), are confounded by selection criteria (e.g., game species and nongame species of special interest) that have little to do with the ecological attributes of indicators. Additionally, failure to identify the most important population parameters for assessment may result in meaningless data or faulty conclusions.

Loons (*Gavia* spp.) are generally considered to be good indicators of high quality lacustrine habitats and are used as indicators in some studies and monitoring programs. For example, the common loon (*Gavia immer*) is a management indicator species on 6 national forests in the western Great Lakes region (Table 1) where changes in its populations are expected to indicate the effects of management activities. On some forests it represents other species from the same biological community and is expected to reflect changes in their populations also.

In this paper I evaluate the suitability of the common loon as an indicator species and discuss the limitations of population measurements commonly used to assess the status of loon populations and the quality of habitats it