FL68009

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Reprinted from:
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
Earth Resources Aircraft Program, Status Review
Volume III
Hydrology, Oceanography, and Sensor Studies
Presented at the NASA Manned Spacecraft Center
Houston, Texas, September 16 to 18, 1968

United States Department of the Interior
Geological Survey

FL68009

Tallahassee, Florida

1969

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ABSTRACT

Results are presented of a continuing effort in the application of remote-sensing data as a tool in hydrobiological investigations in the Everglades and coastal regions of south Florida. Panchromatic, color, color infrared, and multiband photographs used individually and in combination show gross, as well as detailed, features that permit evaluation of water resources. Hydrologic features such as depth and size of basins and drainage patterns are easily measured or observed from the photographs. The distribution of aquatic and semiaquatic plants serves as an indicator of hydrologic conditions. Examples are the occurrence of red and black mangrove trees along the tropical shorelines of Florida, which would indicate the mean high-water level; also, the particular reflections on photographs from algal mats and emergent aquatic plants allow for the delineation of the fresh-water/brackish-water interface. These observations have been made even from orbital photography at an altitude greater than 150 miles. Multiband imagery shows potential in extracting the spectral signatures of willow and fig trees and cattail marshes in the Everglades. The findings have transfer value to other marsh, swamp, and coastal regions of the United States.

INTRODUCTION

Recent technological developments in the field of remote sensing have opened broad vistas in the study of natural sciences. This report describes the strides that have been made in applying remote-sensing technology to hydrobiological investigations in the subtropical and tropical aquatic environments of south Florida. The type and extent of developments in south Florida have been inseparably linked to the historic water-related physiographic features of the region — the Everglades, Big Cypress Swamp, and the mangrove and coastal glades (fig. 23-1). The principal bodies of water along the coast are the Atlantic Ocean, Biscayne Bay, Florida Bay, and the Gulf of Mexico.

The use of remote sensors in earth resources studies has gained impetus in approximately the past 5 years; and, as might be expected in a new endeavor, literature dealing specifically with water resources and ecological applications is scant. A search of the literature that is still continuing began with the initiation of this investigation 2 years ago and has resulted in a compilation of more than 90 references (listed in the section of this report entitled "Bibliography") that have been used to formulate the objectives and approach for this investigation in Florida. These references generally indicate the potential that remote sensing has in solving problems of a hydrobiological nature. It is noteworthy that the investigators in the new field of remote sensing are rapidly approaching the stage where interpretative examples limited to small study sites will be replaced by large-scale applications, often with assistance of data collected from suborbital and orbital vehicles.

DATA-COLLECTION SUMMARY

NASA has completed three missions over the flight lines that were established for this investigation in south Florida (fig. 23-2). The following types of data were collected in these missions: color, color infrared (IR), and multiband photography and ultraviolet (UV), IR, and radar imagery. Other data collected for this investigation were multiband imagery by the University of Michigan and IR color photography by the U.S. Geological Survey. Table 23-I summarizes the information collected, including sensors used, spectral wave lengths monitored, and display formats of data.

The continuing study by the U.S. Geological Survey began in December 1966. The overall objective of the program is to test the feasibility of using remote-sensing data from low (1000 feet) to orbital (>100 miles) altitudes as a tool in locating, identifying, and quantitatively interpreting hydrologic and biologic features in the shallow inland and coastal aquatic communities of south Florida. Characteristics such as depth and size of hydrologic basins, areal extent of sawgrass marshes, and species composition of plant communities will be defined and mapped, either automatically or semiautomatically, to serve as an aid to hydrobiological investigations and the development, management, and conservation of two of the primary resources of the earth — water and biological communities.

The experimental approach of this investigation is based on the evaluation of all the types of remote-sensing data that are collected for the Earth Resources Aircraft Program on a currently operational basis by NASA. Initially, data were collected for evaluation at low altitudes, especially between 2000 and 5000 feet. The remote sensors that show the greatest potential will then be used at successively higher altitudes to determine the upper limits of their usefulness in detecting selected target features on the ground. Results from this investigation will be useful in suggesting types of remote-sensing data that should be collected in high-altitude and orbital space vehicles for hydrobiological interpretations.

Data collected specifically for other studies have utility in this investigation. Since 1964, the Phoenix Research Unit of the Water Resources Division of the U.S. Geological Survey obtained approximately 4000 frames of color and color IR photography in Everglades National Park, in portions of Biscayne Bay, and in the Loxahatchee National Wildlife Refuge (conservation area 1 in fig. 23-3) in cooperation with the National Park Service and the U.S. Fish and Wildlife Service. Also, Lake Okeechobee and much of the urbanized southeast coast, including the shoreline, have been covered by panchromatic photography in recent years by various federal and local governmental agencies. The panchromatic photographs are generally available for use upon request and may be valuable later as an aid to making interpretations over large areas from remote-sensing data collected at orbital or suborbital altitudes.

In general, the data collected by NASA have been suitable for interpretative work. A small percentage of the data was useless as a result of direct obstruction by cloud cover or poor reflectance resulting from marginal lighting conditions.

TEST SITES, OBJECTIVES, AND INTERPRETATION METHODS

As this investigation progressed, it became obvious that hydrobiological remote-sensing sites should be restricted in size and should be easily accessible for conducting ground-truth observations. Discussions with others in the Earth Resources Aircraft Program have indicated that, in many instances, flight lines have been too long, which resulted in data too extensive to handle easily. Therefore, one test site typifying the Everglades has been chosen for extensive work in the remote-sensing studies. Three small secondary coastal test sites were added (in Biscayne Bay, in Florida Bay, and in the Shark River Estuary) because they contain hydrobiological features that are absent from the primary inland test site. These four test sites (fig. 23-3) are ideal for testing the propositions and hypotheses of the investigation. A discussion of the characteristics of the test sites follows.

Seven-Mile Road

Seven-Mile Road (fig. 23-4), the principal test site in the Everglades, is approximately 7 miles long by 4 miles wide and includes the following features that favored its selection:

1. The test site contains numerous hydrobiological features essential to recognition feasibility in the interpretative work: sloughs (shallow, slowly moving rivers), intermittent ponds, alligator holes (fig. 23-5), manmade lakes and canals, and a portion of a large water impoundment, conservation area 3A (fig. 23-3). The biological communities in the test site include tree islands (semiterrestrial tree and shrub communities called heads and terrestrial tropical hardwood communities called hammocks), sawgrass marshes or wet prairies, cattail marshes, fireflag marshes, and algal mats in the intermittent ponds. A wide range of animals, including fish, deer, alligators, and wading birds, inhabit the aquatic and terrestrial environments.

2. The test site located in northern Everglades National Park is protected from manmade change. Thus, the same flight line can be covered each time to provide monitoring for seasonal and annual fluctuations in natural conditions without cultural changes in the landscape.

3. A straight road in the center of the test site facilitates flying.

4. The road in the test site provides for easy accessibility for ground-truth examination of the hydrological and biological features.

5. Irregularities in the normal pattern of the road (wide parking areas, culverts, etc.) serve as specific identifiable points from which natural target features can be identified. This solves a problem that often arises during interpretation in locating known ground features on data formats, especially in cases in which features appear in geometrically distorted shapes or as abstract images.

6. The researchers are familiar with the features of the study site from other investigations that have been conducted in its vicinity. This includes a knowledge of water flows, water quality characteristics, sediments, and the species composition of the plant communities.

7. A 100-foot tower located near the southern end of the test site (fig. 23-6) affords a vantage point for taking photographs and making ground-truth observations and allows for unobstructed views of the flat topography.

The main objective at this test site is to obtain spectral signatures and electronically generated maps of selected features, including alligator holes, inundated and dry ponds, wet prairies (where sawgrass is the dominant emergent plant), and willow, cocoplum, and fig trees.

Biscayne Bay

Biscayne Bay, the test site along the Atlantic shoreline, is a shallow semienclosed estuary. One of the main features used for recognition studies at this test site is the attached, submerged beds of aquatic plants, including various grasses and algae (fig. 23-7). The detailed interpretation of the character of the bottom (littoral zone) is important for species identification in ecological studies. The littoral flora provides shelter and food for juvenile sport and game fish, shrimp, and other commercial species. The occurrence and distribution of plants can serve as an index of pollution by indicating the state of biological well-being of an estuary. The pollutants range from pesticides to overheated water. Excessive temperature, caused by heated effluent from electric generating plants powered by nuclear energy, are a potential problem in Florida and other states. One such plant is under construction near the test site. Another problem is the turbidity caused by dredge and fill operations. Either excessive temperature or turbidity can destroy plant beds and sessile animals, including corals and sponges, and hence diminish or even destroy natural communities and the commercial and sports fisheries of an area.

Another point of interest is the fresh ground-water discharge into the bay. In places, the discharge breaks out in sufficient strength to form springs — subcircular ponds a few feet in diameter (ref. 23-1). Thermal contrasts between the cool water in the springs and the surrounding warm bay water can be sensed here remotely. Infrared imagery has already served as a tool for detecting fresh-water springs off the coast of Hawaii (ref. 23-2) and in the discovery of a large spring off the coast of northeast Florida (Kohout, oral communication). Submarine springs have a worldwide distribution (ref. 23-3), and some have potential for providing a supply of fresh water in regions where it is scarce.

In many instances, the zonation or distribution of plants in the vicinity of an intertidal zone can serve to indicate the mean high-water level, as well as other levels that may be of interest. A specific zonation of tropical trees occurs along the undeveloped shorelines of Biscayne Bay and along the other south-Florida coasts. The typical zonation pattern is red mangrove (*Rhizhophora mangle* L.) through the intertidal zone, black mangrove (*Avicennia nitida* Jacq.) in the upper tidal reaches, and buttonwood (*Conocarpus erectus* L.) in the supratidal region. The delineation and mapping of these species can be valuable to those concerned in planning and in settling problems relating to the legal definitions of shorelines or mean high-water lines that concern ownership or the seaward limit allowable for land fill and bulkhead lines.

Initially, it is proposed that an experiment be conducted at this test site to delineate the mean high-water line on a strip photomosaic map of the shoreline. A line parallel to the shore should stand out as the interface between the mangroves and buttonwood. The reflectance characteristics can be established by using multiband imagery (data to be collected). The procedure in obtaining print-outs of individual plant species based on their particular spectral signatures is discussed later in this report.

Other phenomena of interest that could eventually be examined at this test site in relation to remote-sensing applications are (1) tidal movements, flushing, and salinity distribution in the bay and (2) surveys of storm or hurricane damage to the flora and fauna of the littoral and intertidal regions and to the trees along the coast.

Florida Bay

The Florida Bay location (fig. 23-3) has many features in common with the Biscayne Bay Test Site, including submerged beds of vegetation and a mangrove coastline. Florida Bay is shallower on the average and, as a result of incomplete tidal flushing, maintains a higher salinity with hypersaline conditions (approaching twice the salinity of sea water) occurring in the dry season from November to May. However, this test site was selected because it has the following particular features that will be examined for spectral characteristics: (1) offshore mudflats, (2) brackish water marshes, and (3) perennially fresh-water marshes.

Figure 23-8 illustrates a method used by W. J. Schneider of the U.S. Geological Survey (ref. 23-4) and the authors to interpret and map these features on a color IR photograph. Better discrimination and more specific delineation of features by semiautomatic methods is hypothetically possible now with the aid of multiband imagery. An experiment is planned in which print-outs from multiband imagery (data to be collected) of each discriminated feature will be overlaid on a rectified photomosaic base (or on a base prepared from rectified orbital photographs). Maps of the hydrobiological features along the coasts of the United States and other countries would be valuable in fisheries and wildlife management and for planning coastal urban and industrial developments in such a way that the productivity of primary coastline areas will remain unimpaired. Figure 23-9 is a model of such a map, portraying the major hydrobiological units of Everglades National Park.

A project in cooperation with the National Park Service is underway to portray accurately the coastline, estuaries, rivers, brackish and fresh-water marshes, major sloughs, and tree islands of the park. Delineations, as shown in the model, will be made from a completed photomosaic base (of approximately 1000 panchromatic photographs) that measures 6 feet square. The completed map will contain far more details and better accuracy than any standard published coastal or inland maps of Florida. The quadrangle-type sheets that will be prepared from the experimental map will be used primarily for inventories of the resources of the park, plant and wildlife management practices, research studies in the natural sciences, and navigational aids.

Florida Bay and environs is an excellent region for examining the potential of remote sensing in the management of certain botanical and wildlife resources. For example, the National Park Service is concerned about the diminishing numbers of the American crocodile (Crocodylus acutus Cuvier) along the northeast coast of Florida Bay and the Florida Keys, which contains the only crocodiles in the United States. The U.S. Fish and Wildlife Service has designated the crocodile as a peripheral species (ref. 23-5). A peripheral species is "one whose occurrence in the United States is at the edge of its natural range and which is rare or endangered within the United States although not in its range as a whole. Special attention is necessary to assure retention in our Nation's fauna."

The decline in numbers of crocodiles in south Florida has resulted largely from wanton killing and the destruction of their habitat by man. The females prepare their nests on sandy (sometimes marly) beaches, and only beaches such as those in Everglades National Park and the National Wildlife Refuges of the Florida Keys are protected.

Beach sites suitable for crocodile (and, incidentally, for sea turtle) nesting are under another threat — the encroachment of a rapidly growing exotic tree, Australian pine (Casuarina). This nuisance tree is well adapted to sea coasts where, given the opportunity, it will turn a barren beach into a forest. Australian pine also thrives inland where it competes with and replaces indigenous plant communities (fig. 23-10). The National Park Service attempts to keep this tree out of Everglades National Park.

Multiband imagery and supporting ground-truth data will be collected in and near the Florida Bay Test Site for, among other purposes, determining the reflectance patterns that characterize and expose the Australian pine and the nesting locations of the crocodile. Eventually, a detailed map will be prepared of the distribution of these features for the use of management and research biologists.

Shark River Estuary

Shark River Estuary is a test site in a brackish-water zone, sandwiched between the upper fresh-water and the lower marine regions. The test site is near the center of the Shark River that has its headwaters in the Everglades and its mouth in the Gulf of Mexico. The river channels in the test site are 10 to 20 feet deep and are lined by red, black, and white mangroves; buttonwood; and other tropical trees. Ponds and marshes, ranging from brackish water to marine, are interspersed in the forested land areas among the stream channels. Extensive hydrological and limited biological data are collected monthly in a transect along the Shark River. These data, valuable for ground-truth purposes, include determinations of dissolved oxygen, chlorinity, nitrate and phosphate species, temperature, turbidity, water levels, and planktonic organisms. Remote-sensing applications to the detection and description of water quality characteristics will be examined at this test site.

Over the years, wading-bird rookeries (fig. 23-11) have been established at known localities in the general vicinity of the test site. In some years, tens of thousands of wood ibises, white ibises, egrets, and other birds in these rookeries prepare nests and raise their young on aquatic animals captured from miles around in shallow streams, ponds, and marshes. The wood ibis seems to be a key avian species in that its failure or success in forming rookeries each year is usually indicative of the availability of aquatic animals for food and of the suitability of hydrologic conditions necessary for all grope-feeding birds.

At present, surveys in Everglades National Park are made of rookery areas, and birds are counted visually from a low-flying aircraft (William B. Robertson, Jr., NPS, oral communication). Various remote-sensing data will be collected from high altitudes (perhaps >10 000 feet) over this test site and nearby regions to determine the possibility of eventually conducting synoptic bird surveys with high accuracy at a reasonable cost. Because the targets (in this case, birds) are only approximately a foot in diameter when resting and have similar physical features when viewed from above, species recognition may be difficult or impossible. Plotting the numbers and locations of birds, however, seems a realistic goal if a remote-sensing system with high object resolution is used. Periodic plotting over the years would indicate the failure or success of rookeries to form and the locations of aquatic communities that are commonly used for feeding.

The four remote-sensing test sites were specifically selected for two basic reasons:

1. The test sites have hydrobiological features representative of south Florida, yet the chosen areas are small. Little time is spent

during interpretation sessions in looking through the rolls of collected data. Experience has taught that storing and handling excessive amounts of format materials creates time-consuming problems for the interpreter in matching registered phenomena with ground-truth features.

2. Ground-truth data have been collected at each test site, largely as a byproduct from other research activities that are in progress or have been completed in and near the test sites. The data compiled for use in remote-sensing experiments concern depths and quality of water, hydrologic boundaries, and the composition and areal distribution of plant and certain animal species.

Photographic and scanner transparencies and prints are viewed for interpretation with the aid of a combination light table and stereoscope (fig. 23-12) designed and constructed by Antonio Jurado (U.S. Geological Survey cartographer). The instrument has spools and winders adapted for displaying rolls of 9- by 9-inch and 70-millimeter data formats. The Itek nine-lens camera yields groups of nine photographs that are easily viewed simultaneously with this instrument. Two fluorescent lights on arms swing into position for illumination from above when viewing prints. The stereoscope is utilized for preliminary three-dimensional viewing of overlapping photography. Appropriate pairs of photographs are selected for use with a mechanical stereoplotter for such purposes as preparing rectified illustrations of ground-truth features, making detailed maps for research or management purposes, and accurately measuring the sizes and heights of certain features such as a tree canopy.

Multispectral imagery data for this investigation are collected and processed by the University of Michigan. The staff of the University of Michigan Willow Run Laboratories is assisting the authors in developing the means for identifying and mapping the spectral signatures of selected hydrological and biological targets. The procedures for signatures extraction, analysis, and generation of decision imagery will be explained in the following section.

DISCUSSION OF DATA

Panchromatic, Color, and Color IR Photography

Photographic systems have been and continue to be the most widely applied sensors in hydrology and biology.

Panchromatic photography has been valuable in portraying features, as indicated by a concurrent investigation in cooperation with the National Park Service in Everglades National Park. The objectives of the study are to document the extent of changes that have occurred in the distribution and composition of plant communities in the Shark River Slough between 1940 and 1964 and to determine whether the botanical changes were related to a difference in the hydrologic regimen. Panchromatic photographs from 1940, 1952, and 1964 were obtained for the study. Three basic types of plant communities were recognizable on the photographs that were taken at altitudes greater than 10 000 feet: tree and shrub associations, wet prairies (primarily sawgrass marshes), and shallow intermittent ponds. These communities were accurately outlined from the photographs onto rectified models (fig. 23-13) with the aid of a mechanical stereoplotter.

Although suitable for the described study, black and white photography has serious limitations. Panchromatic photographs, even taken with fine-grained film at elevations as low as 2000 feet, lack the resolution power necessary to give definition to such details as the genera of plants in the communities. Interestingly, during surveillance flights by helicopter, the authors required flight altitudes of 500 feet and lower to identify most plant genera visually.

Color and color IR photography are ideally suited to some types of water resources studies. Color IR photography is particularly useful for hydrologic interpretations, as exemplified in figure 23-14. The illustrated model was prepared from a color IR photograph taken at an altitude of 4700 feet in the vicinity of the observation tower in the Seven-Mile Road. As demonstrated by the model, color IR photography distinguishes between those shallow intermittent ponds that are dry and those that are inundated, a definition undiscernable in color and panchromatic photography. Also, land-water interfaces are sharply portrayed by color IR photography in marshes and along coastlines. Vegetation is displayed strikingly with color IR photography, but color IR photography is inferior to color photography for taxonomic identification in Everglades plant communities. The shades of the colors (pinks and reds) designating vegetation vary from one batch of color IR film to the next. Other factors, such as the intensity of illumination and the exposure setting of the camera, influence the color tones. The false colors themselves make it difficult for the botanist to identify ordinarily recognizable (in color photographs) genera or species.

In summary, color IR photography, used in conjunction with color or panchromatic aerial photography, greatly reinforces the skill of the researcher in the photointerpretation of certain aquatic and biological features.

MULTIBAND PHOTOGRAPHY

The emphasis of this investigation has been and will continue to be in multiband sensing. As Charles F. Cooper (ref. 23-6) has stated, "Real progress in remote measurement for ecological purposes will almost certainly require multiband sensors whose outputs can be compared directly and electronically. Single wave length imagery, no matter how sophisticated, will in general give information that will do no more than supplement the data extractable from high quality aerial photographs."

Multiband photographic data were collected along flight paths covering the four tests sites and other selected regions of the Everglades and Florida and Whitewater Bays (fig. 23-2). The nine-lens camera was used by NASA to collect the multiband photographs. The range of the electromagnetic spectrum that was sensed covers the lower limit of available UV that can be transmitted by the lens (approximately 0.350μ) to the upper range of the near IR region to which black and white IR film is sensitive (approximately 0.900μ). The film-filter combinations employed yielded data in each of eight bands that were more or less 0.100μ wide (fig. 23-15). The ninth, a wider band, sensed the range of the near IR region to which the film was sensitive (0.670μ to 0.900μ). The sets of simultaneous photographs were examined to establish whether this technique can serve as a way to detect detailed information relating to the quality of water, to distinguish among different species of vegetation, and to distinguish among different aquatic communities.

Of particular interest was an experiment to test for the detection in water of turbidity and color from an organic acid. Two water impoundments (test plots in fig. 23-16) were created by enclosing two areas (approximately 50 by 120 feet) inside an artificial lake with polyethylene sheeting supported vertically by wooden stakes. A fairly uniform stretch of the lake was chosen near the road where the water was approximately 1.5 feet deep. The water surrounding the impoundments served as the control for the experiment. Tannic acid was added to one tank to test whether any of the bands could detect the weak color imparted to the water by the acid. Tannic acid, in combination with a variety of other complex organic acids, imparts color to certain natural bodies of water in south Florida, especially in coastal rivers and in mangrove swamps.

Unfortunately, the aircraft drifted slightly away from the flight path and failed to collect data over the test plot with tannic acid.

Bentonite, a clay, was added to the second test plot immediately prior to the overflight (fig. 23-16) and created an average turbidity of approximately 17 mg/liter in the water impoundment, while the turbidity of the surrounding water was 10 mg/liter. The slightly higher turbidity is noticeable in the bands within the visible part of the spectrum and, especially, in the 0.490μ to 0.570μ band. The three IR bands failed to discriminate between the two turbidities in the test and control areas.

Besides turbidity, spectral reflectances of the hydrological and botanical features designated in figure 23-16 were examined in each of the nine multiband photographs. These features, especially water depth, show marked changes in detectability and tonal contrast in the different wavelength bands.

Other sets of multiband photographs collected over the four test sites were examined and evaluated, and the following conclusions were drawn about the potential of multiband photography in the field of hydrobiology.

1. Multiband photographs fail to distinguish specific botanical features. For example, the various species of trees in a tree island or the various aquatic plants in a marsh are indistinguishable from one another.

2. The widths of the bands that were used (~0.100μ) apparently span segments of the spectrum that are too large to detect the subtle variations in reflectivity patterns found among natural features.

3. Photographic processing of data is tedious and time consuming because it involves considerable guesswork in combining bands and in using color filters to prepare prints for study; producing test strips of prints for proper illumination for tonal balance from the enlarger; developing, fixing, washing and drying prints; and so forth. In short, the format is difficult for the scientist to handle.

4. On the positive side, multiband photographs can be viewed stereoscopically. Multiband photographs are geometrically true if rectified, as opposed to the geometrical distortion of landforms that occurs with multiband scanner imagery with the present state of the art.

5. The relatively small size of a multilens camera (as compared to a multiband scanner system) is ideally suited for use in orbital vehicles, where bulk and weight factors are vital.

Multiband Imagery

Multiband imagery (tape recorded) was collected over the Seven-Mile Road Test Site with the University of Michigan optical-mechanical scanner in September 1967. Although the University of Michigan scanner is designed for obtaining data in 18 bands simultaneously in the wavelength interval of 0.32μ to 14.0μ, data in only 10 bands were collected in the interval of 0.40μ to 14.0μ.

The signals in these bands are collected in such a manner that groups of bands in exact registration can be mixed or processed electrically for preliminary spectral discrimination studies.

Each of the 10 tape-recorded channels was reproduced on 70-millimeter film strips in postflight playback. These continuous film strips (fig. 23-17) have a calibrated relationship between the video signal voltage from the magnetic tape and film tone through a 16-step linear voltage scale (P. G. Hasell, Jr., University of Michigan, written communication).

In the initial processing of the Everglades data, a simple technique, termed "the light pencil" (ref. 23-7), was used to obtain a quick estimate of whether particular objects (for example, willow trees, fig trees, or cattail marshes) can be easily recognized, or if not, to consider the use of a more powerful technique. The light pencil consists of two oscilloscopes, a photomultiplier tube, and a camera assembly. Two channels of video data from the multispectral scanner are supplied to an X-Y cathode-ray oscilloscope (CRO), and a two-color pattern is produced wherein various objects appear as bright blobs on the CRO. The operator can determine which object corresponds to a given blob by pointing the photomultiplier tube (the pencil) at the blob, and a map of the object is drawn on the slow-creep CRO. The map of the object can be photographed there or with an auxiliary camera and CRO. Marshall states (ref. 23-7), "If the object is not uniquely resolved or appears too close to another object blob, other spectral channels may be tried until satisfactory separation is obtained."

The light-pencil technique was used on a scene of the south end of the Seven-Mile Road Test Site. A ground-truth map was prepared to illustrate the distribution of trees, marshes, and shallow sloughs in the scene (fig. 23-18).

A series of objects was characterized and photographed for comparison with the ground-truth objects. The most promising print-out depicted the distribution of willow trees in the test scene (fig. 23-19). Blobs were printed out that compared with the larger clumps of willow trees. The smaller groups in the scene were undetected, indicating the need for processing to define the reflectance characteristics of the species better.

Geometrical distortion caused some of the blobs to fall outside the ground-truth positions, but these rectification problems can be easily corrected.

For comparison, figure 23-20 shows the results of an unsuccessful print-out in which spectral discrimination of objects was incomplete. The strangler fig and cattail marsh are jointly displayed in the central region of the scene but not in the left portion of the scene. Further processing is necessary to resolve the two natural objects uniquely.

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TABLE 23-I.- SUMMARY OF INSTRUMENTS EMPLOYED AND CHARACTERISTICS OF THE MAJOR DATA COLLECTED FOR THE REMOTE-SENSING INVESTIGATION BY THE U.S. GEOLOGICAL SURVEY IN SOUTH FLORIDA

Information collected	Instrument and wave band(s) sensed	Format
UV reflectance images from lateral scanning	Passive UV modified AAS (NASA) 2900 to 400 Å — 1st channel	35-mm film strip
Color and near IR, color IR photographs	RC-8 camera (NASA), Modified K-17 camera (U.S.G.S.) Color: 0.4μ to 0.7μ Color IR: 0.7μ to 0.9μ	9-inch-square frame (Ektachrome film) (Kodak color IR film)
Multiband photographs	Itek 9-lens camera (NASA) 0.35μ to 0.46μ; 0.425μ to 0.54μ; 0.49μ to 0.57μ; 0.54μ to 0.64μ; 0.58μ to 0.66μ; 0.63μ to 0.72μ; 0.67μ to 0.90μ; 0.75μ to 0.90μ; and 0.775μ to 0.90μ	70-mm film frame (3 images on each of 3 films photographed simultaneously)
Multiband images from lateral scanning	Unclassified optical-mechanical scanner (Univ. of Michigan) 0.40μ to 0.44μ; 0.50μ to 0.52μ; 0.55μ to 0.58μ; 0.62μ to 0.66μ; 0.8μ to 1.0μ; 1.0μ to 1.4μ; 1.5μ to 1.8μ; 2.0μ to 2.6μ; 4.5μ to 5.5μ; and 8.0μ to 14.0μ.	70-mm film strip (Band signals can be mixed or processed electronically.)
Radar reflectivity to some depth	Ryan radar scatterometer (NASA), 13.3 GHz	Line trace (magnetic tape)

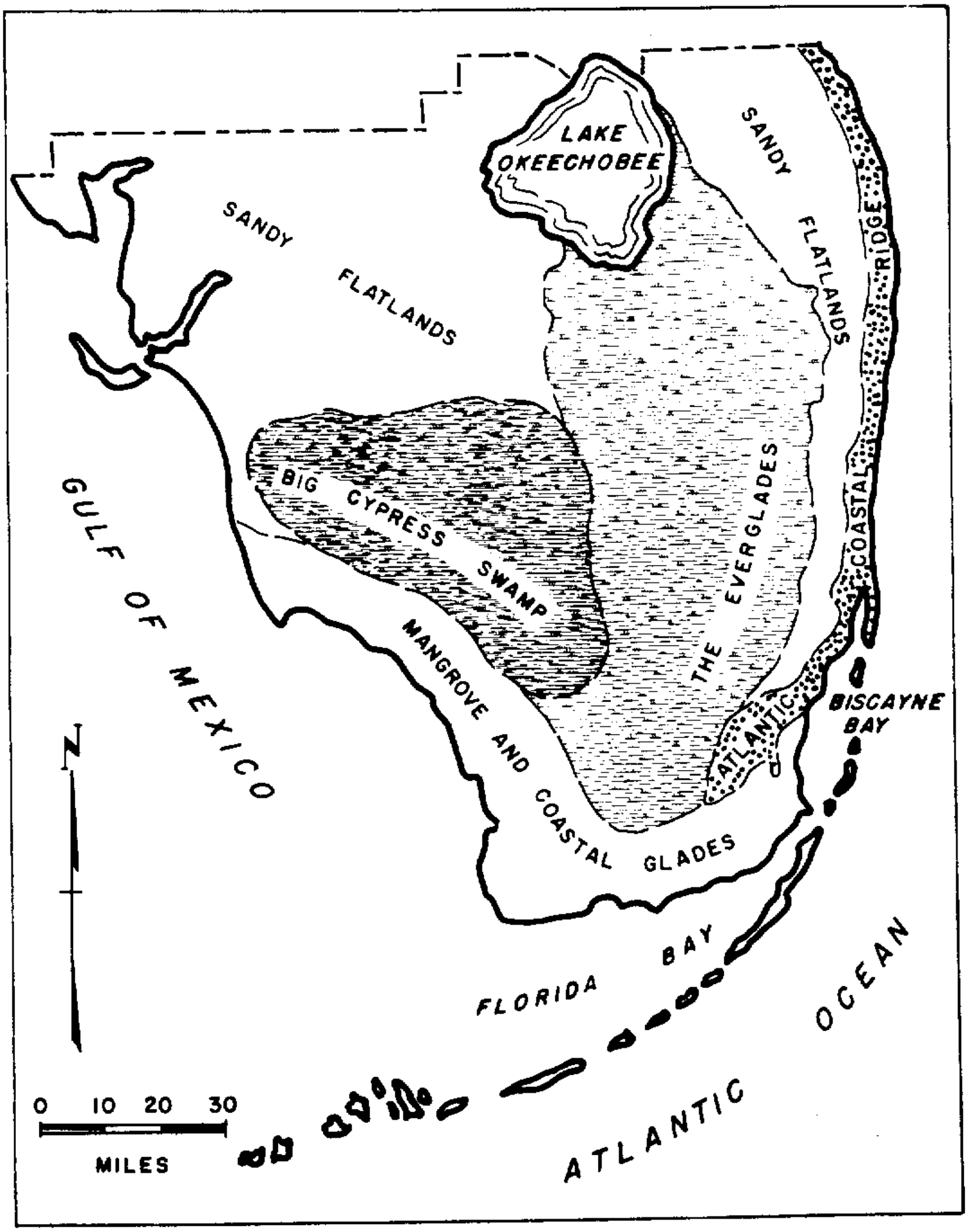
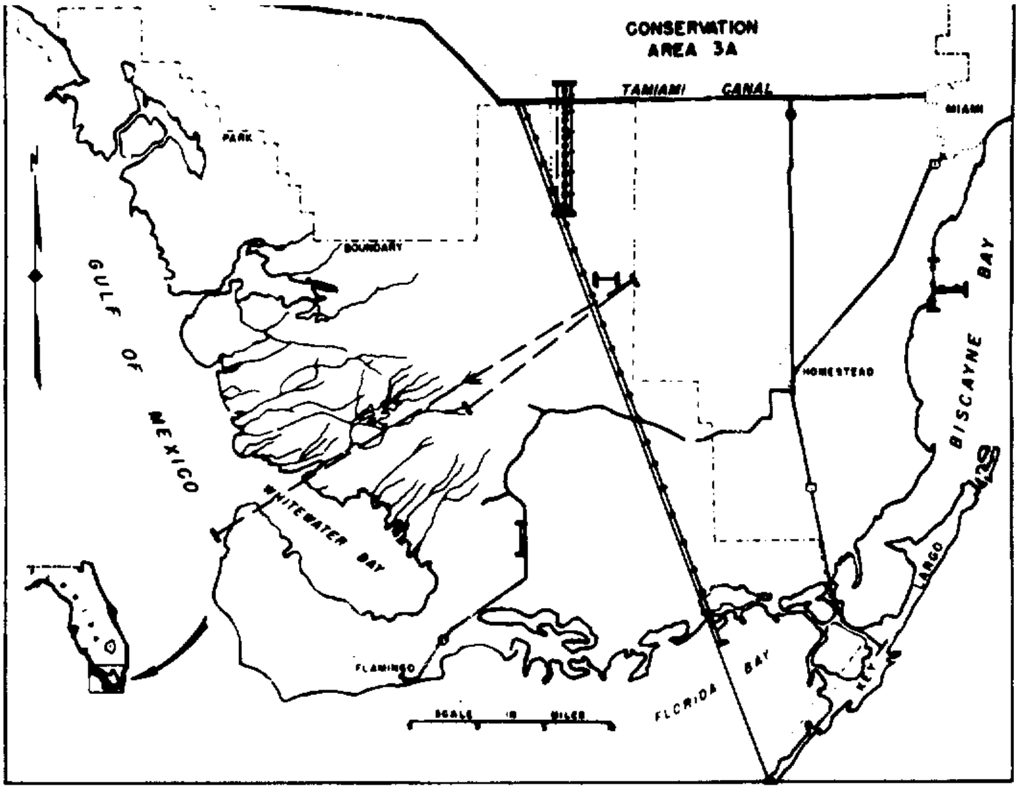


Figure 23-1.- Map of southern Florida showing physiographic divisions.



Explanation:

Flight line symbol	Mission Date	Conducted by	Types of data collected	Flight elevation(s)
	May 1966	NASA	Color, color IR, and multiband photography and UV, IR, and radar imagery	Most flight lines at 3000 and 7000 feet
	Dec. 1966	NASA		
	June 1967	NASA		
	Sept. 1967	Univ. of Michigan	Multiband imagery	500, 2000, and 10 000 feet
	April 1968	U.S. Geological Survey	Color IR photography	2000 feet

Figure 23-2.- Summary of missions and data collected for the remote-sensing investigation by the U.S. Geological Survey in south Florida.

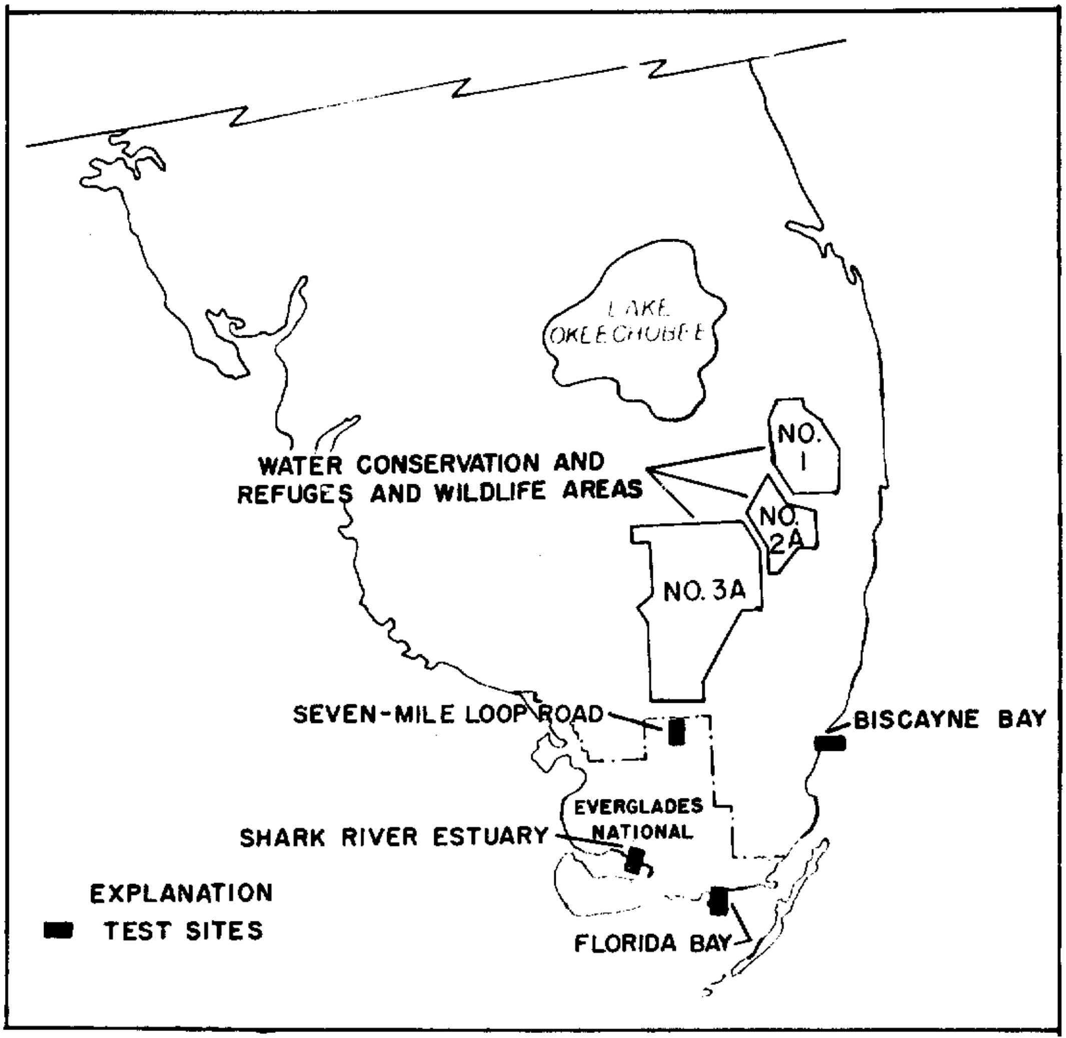


Figure 23-3.- Locations of remote-sensing test sites for hydrobiological interpretations in south Florida.

Figure 23-4.- Photomosaic of the Seven-Mile Road Test Site in Everglades National Park. The test site is approximately 7 miles long by 4 miles wide and contains typical Everglades communities.

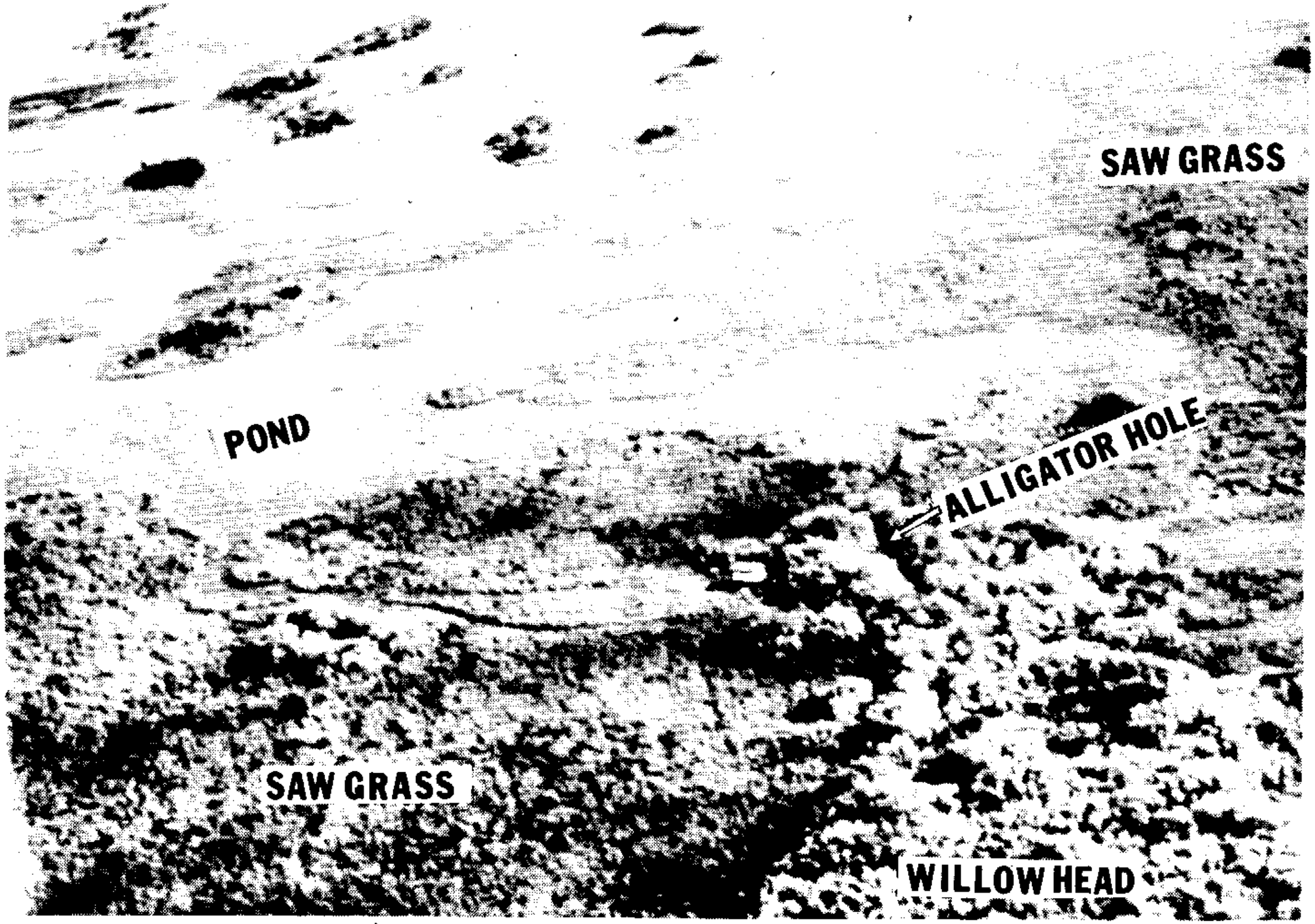


Figure 23-5.- Aerial view of the fresh-water Everglades during the wet (rainy) season. The darker elevated areas (upper left) are tree islands or "heads" that are interspersed among the shallow intermittent ponds and sawgrass marshes.

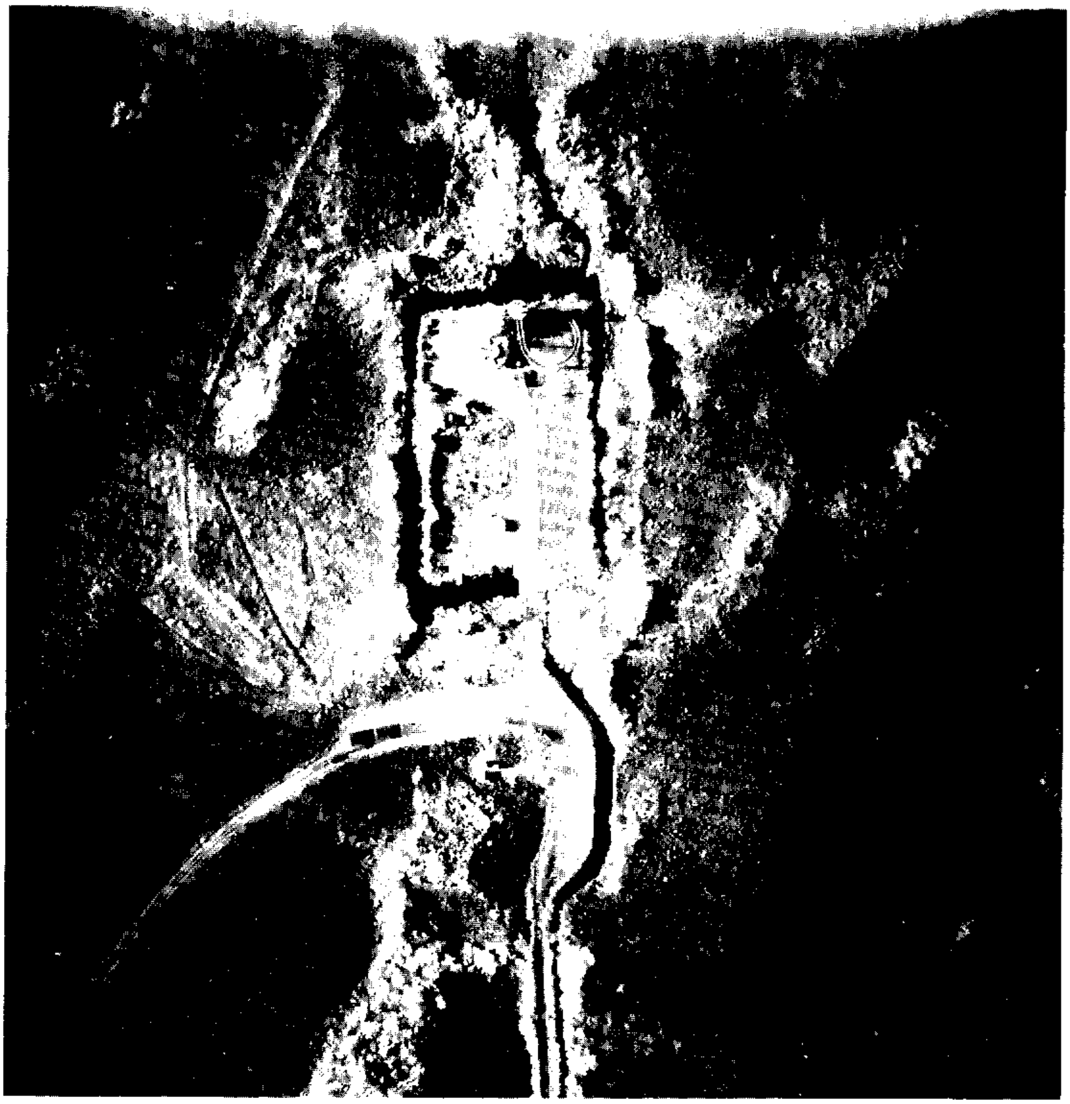


Figure 23-6.- Southern end of Seven-Mile Road Test Site showing observation tower and surrounding glades.

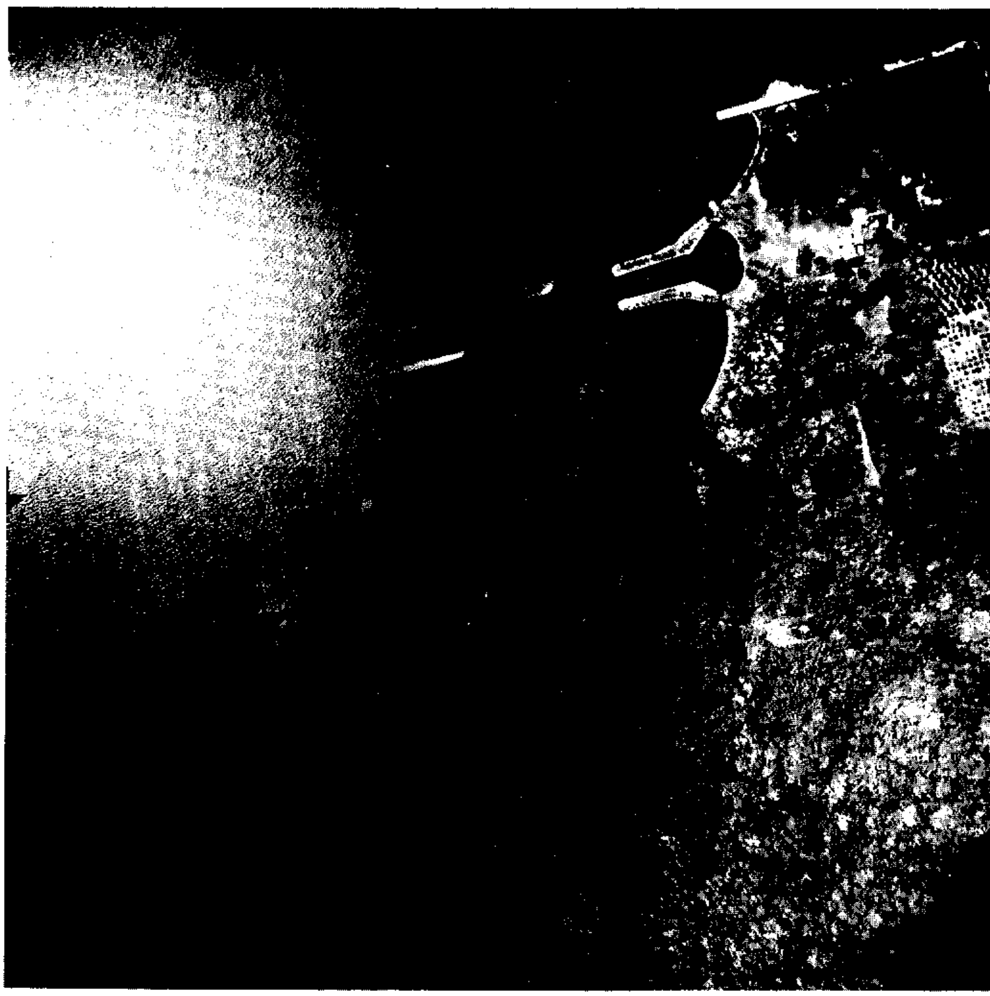


Figure 23-7.- Aerial photograph showing portion of Biscayne Bay Test Site. Arrow points to a transition, parallel to shore, between two sea grasses, Diplanthera (dark) and Thalassia (light). The transition line results from biological zonation largely influenced by ground-water discharge. A zone of red mangrove trees follows along the irregular shoreline.

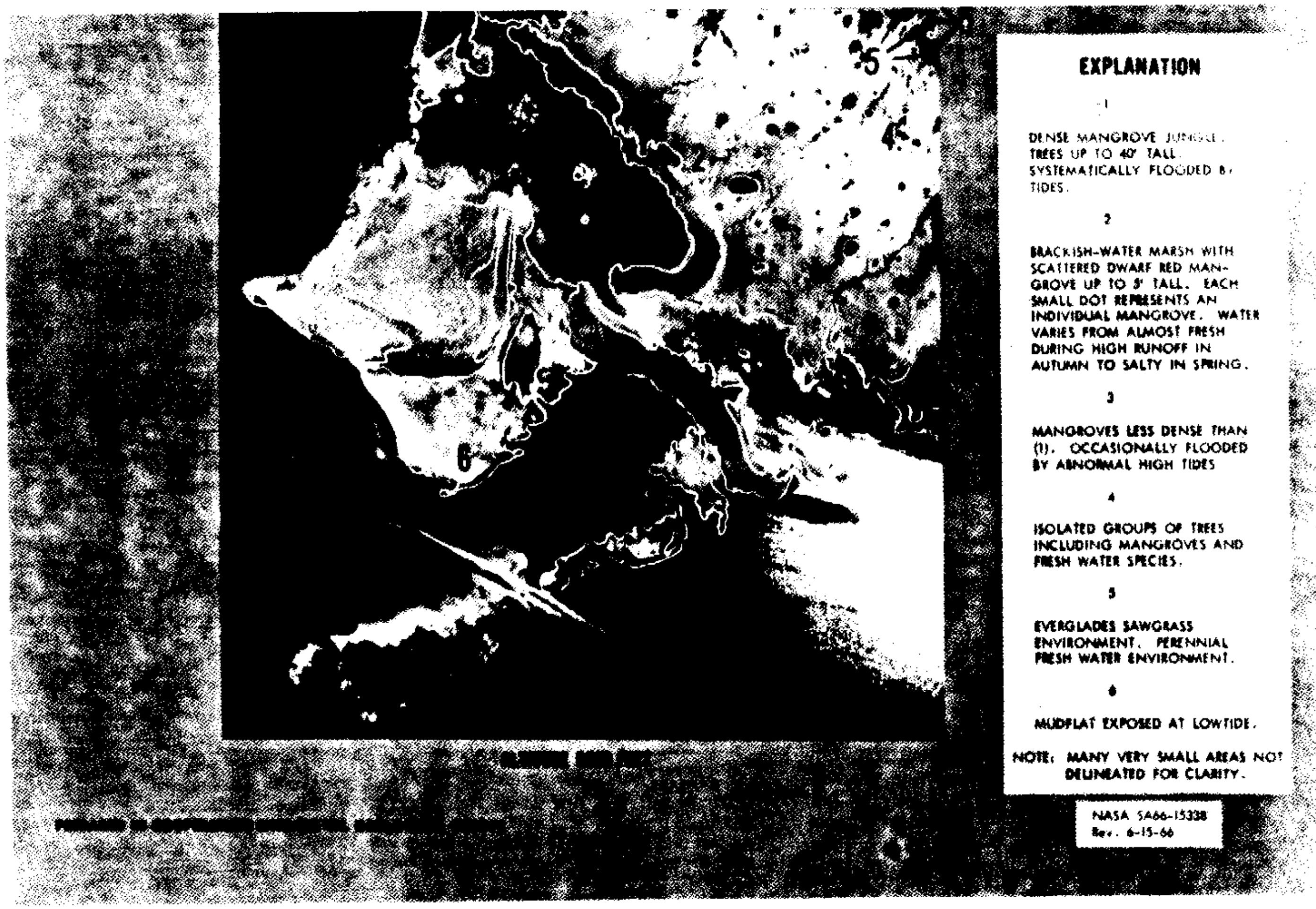


Figure 23-8.- Coastal vegetation in the Florida Bay Test Site.

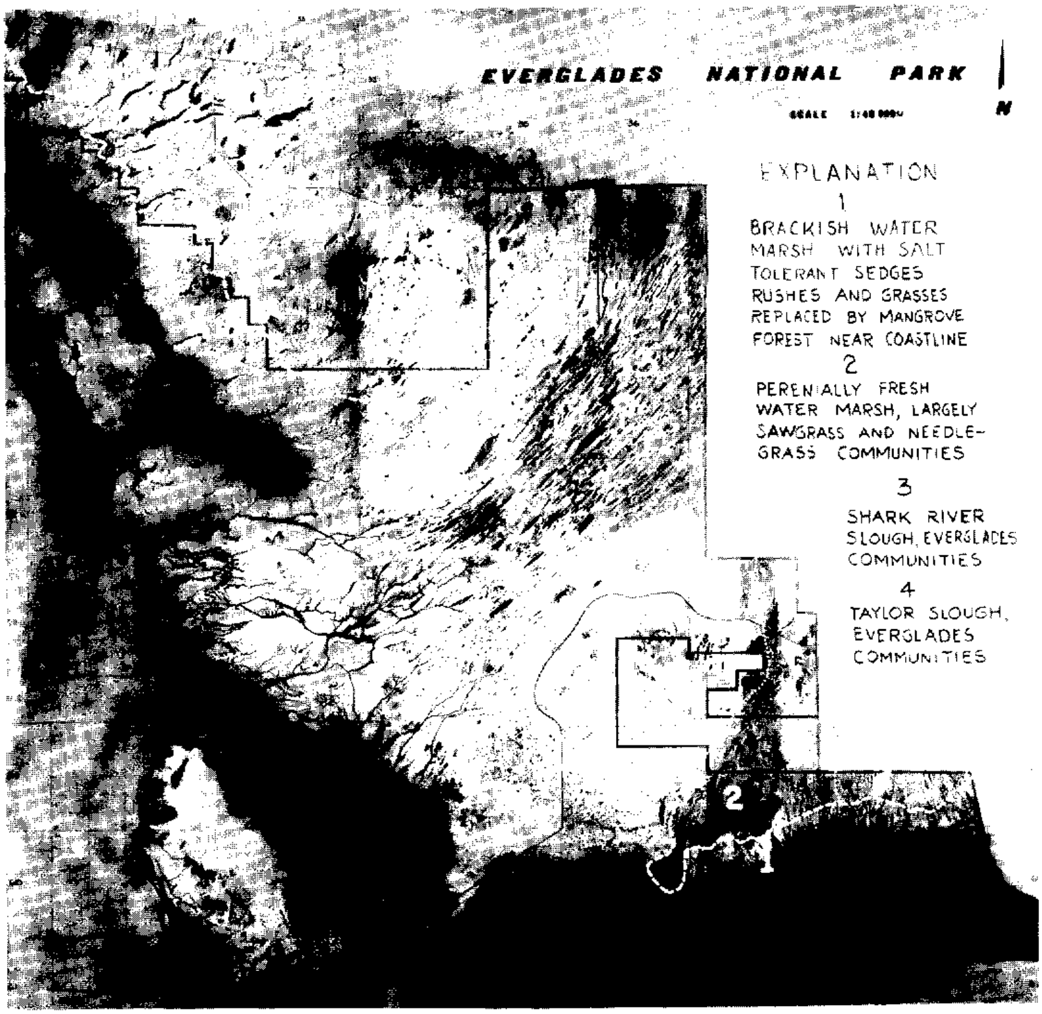


Figure 23-9.- Illustrative model of map to be prepared from photomosaic of panchromatic aerial photographs showing major hydrobiological units of Everglades National Park.

Figure 23-10.- Australian pine, a rapidly growing exotic tree that has become a nuisance in south Florida. The tree overruns crocodile nesting sites along the coast and replaces indigenous plant communities inland. Multiband imagery will be used to display the distribution of Australian pine and of beaches suitable for crocodile nesting.

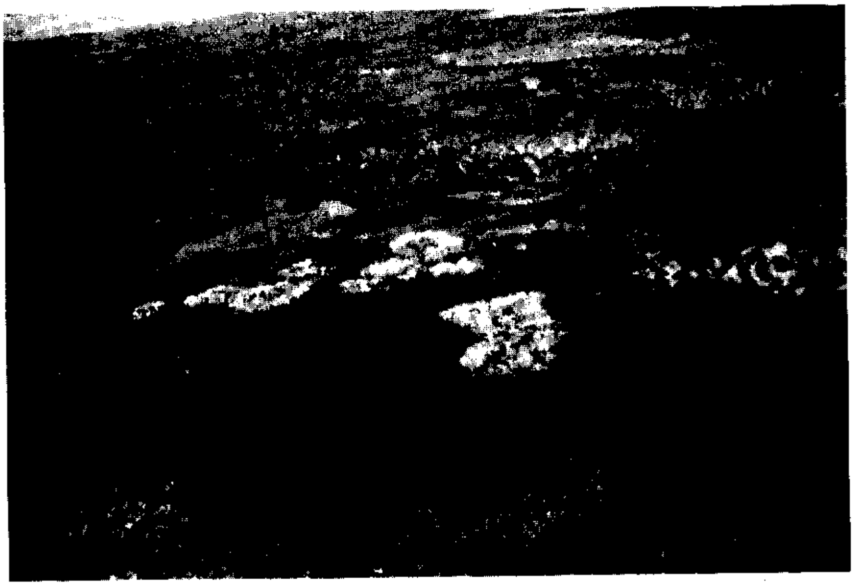


Figure 23-11.- Aerial view of a bird rookery in a southwestern estuary of Everglades National Park. The hundreds of wood storks and white ibises are visible as white spots on the islands near the center of the photograph. The possible use of the remote-sensing techniques for conducting synoptic surveys of wading birds will be investigated.

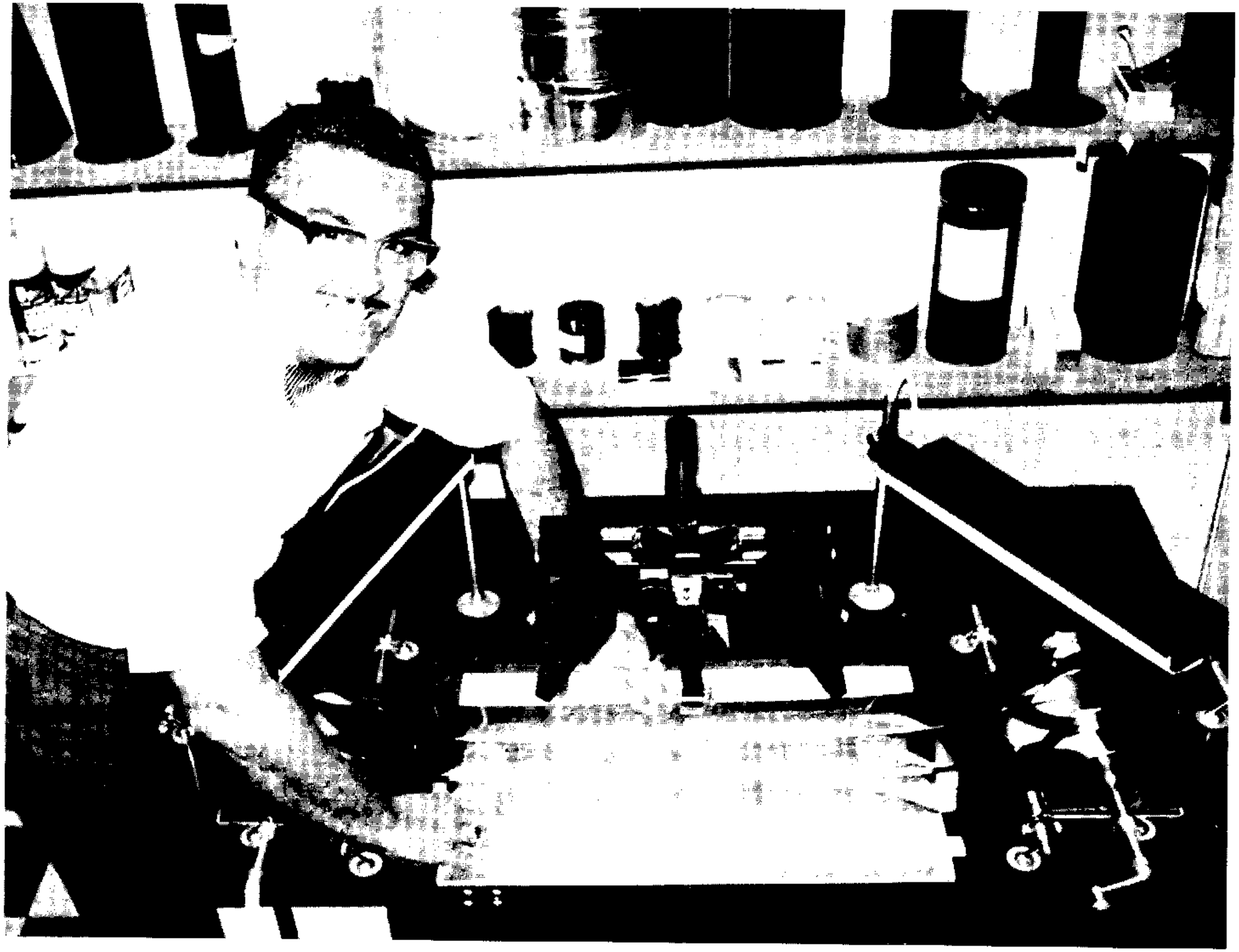


Figure 23-12.- Combination light table and stereoscope designed for viewing photographic and scanner transparencies and prints. The manually operated instrument handles 9-inch and 70-millimeter format rolls and is adapted for the simultaneous viewing of groups of nine multiband photographs from a nine-lens camera.

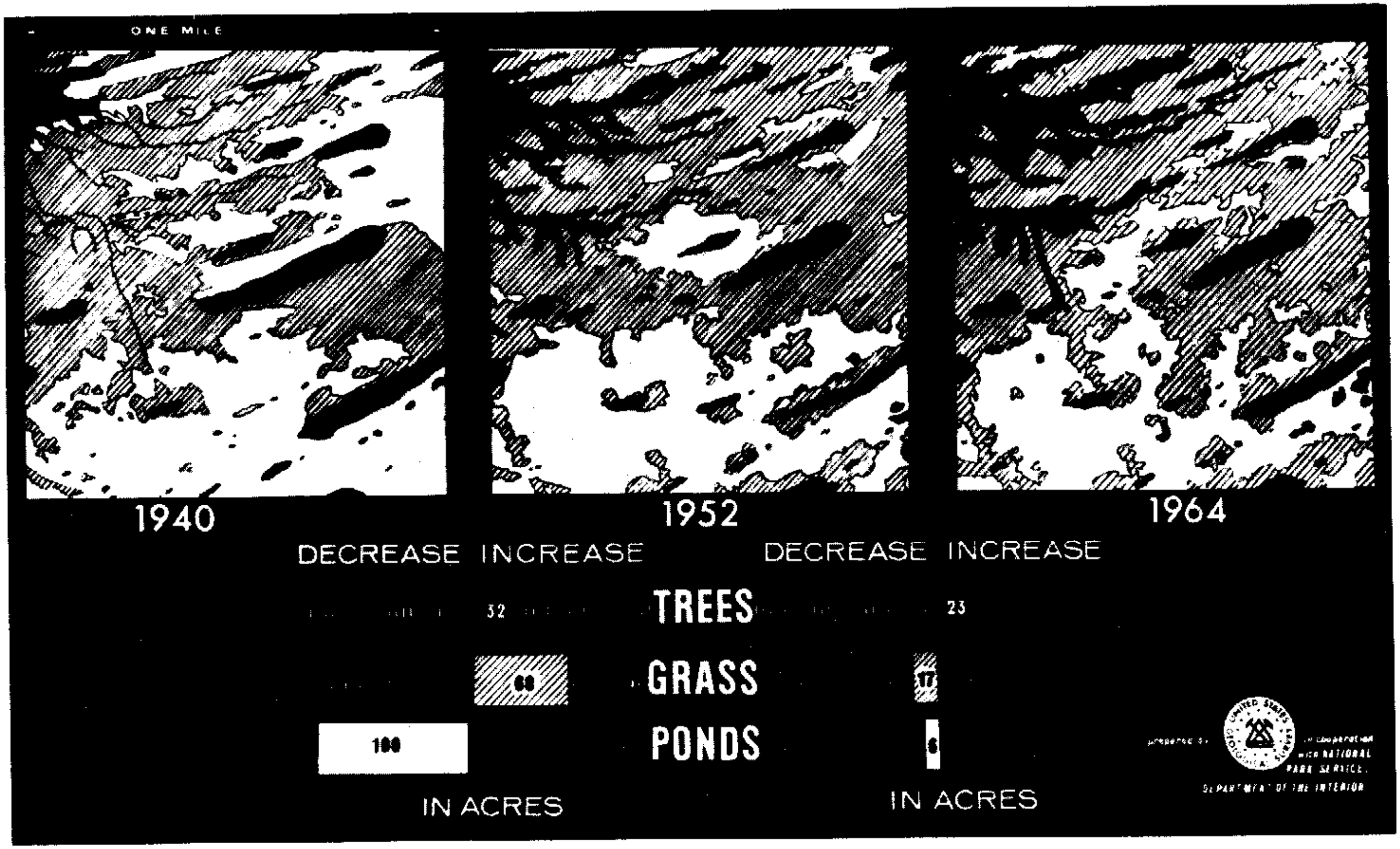
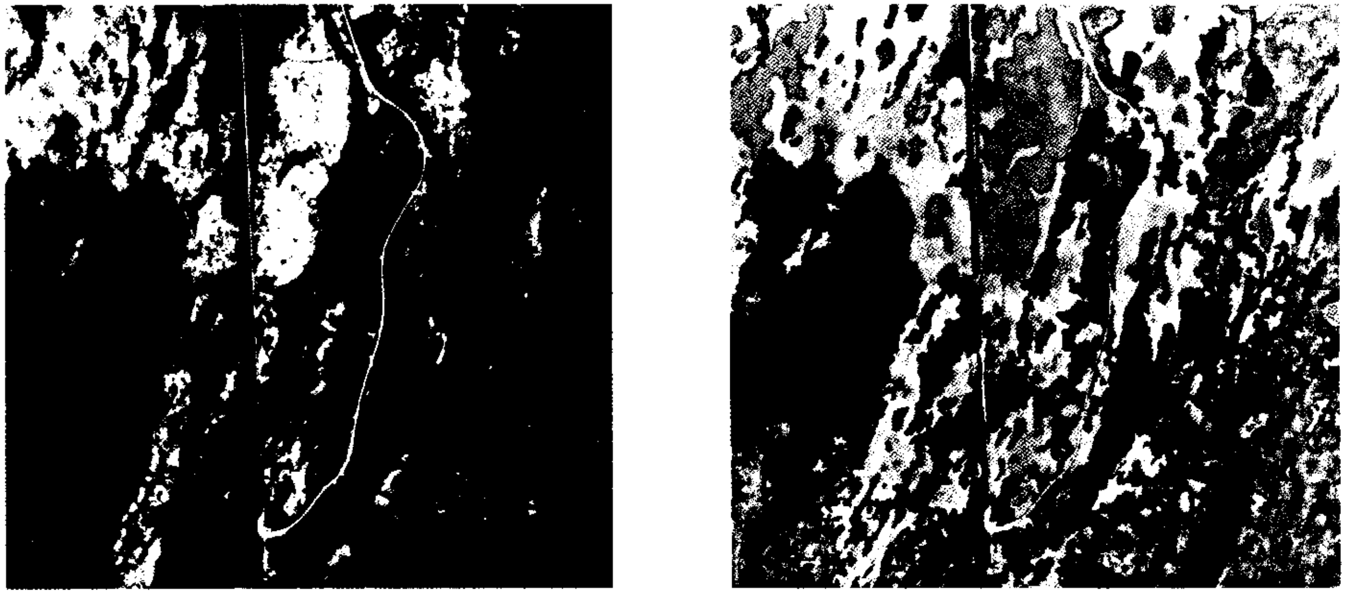


Figure 23-13.- Models prepared with a stereoplotter from panchromatic aerial photographs depicting changes that occurred in plant communities in a square-mile study plot in Shark River Slough between 1940 and 1964.



EXPLANATION

TREE ISLAND
SAW GRASS MARSH
WILLOW BRUSH
SHALLOW POND, INUNDATED
SHALLOW POND, DRY

Figure 23-14.- An illustrated model prepared from color IR photograph taken in the Seven-Mile Road Test Site.

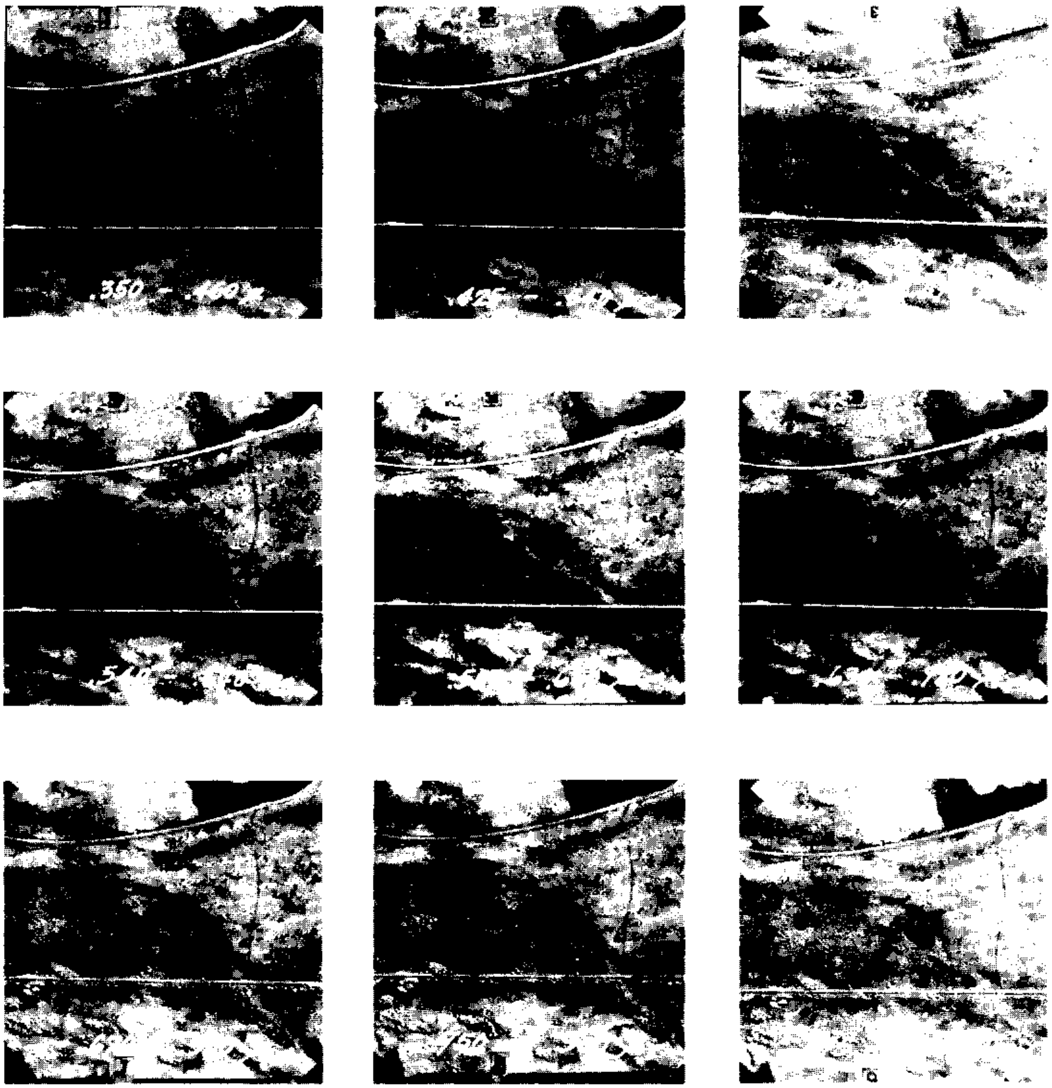


Figure 23-15.- A multiband panel assembled from photographs obtained simultaneously by the Itek nine-lens multiband camera. Significant changes in tonal contrast of selected hydrological and botanical features (fig. 23-17) can be seen in the different wavelength bands.

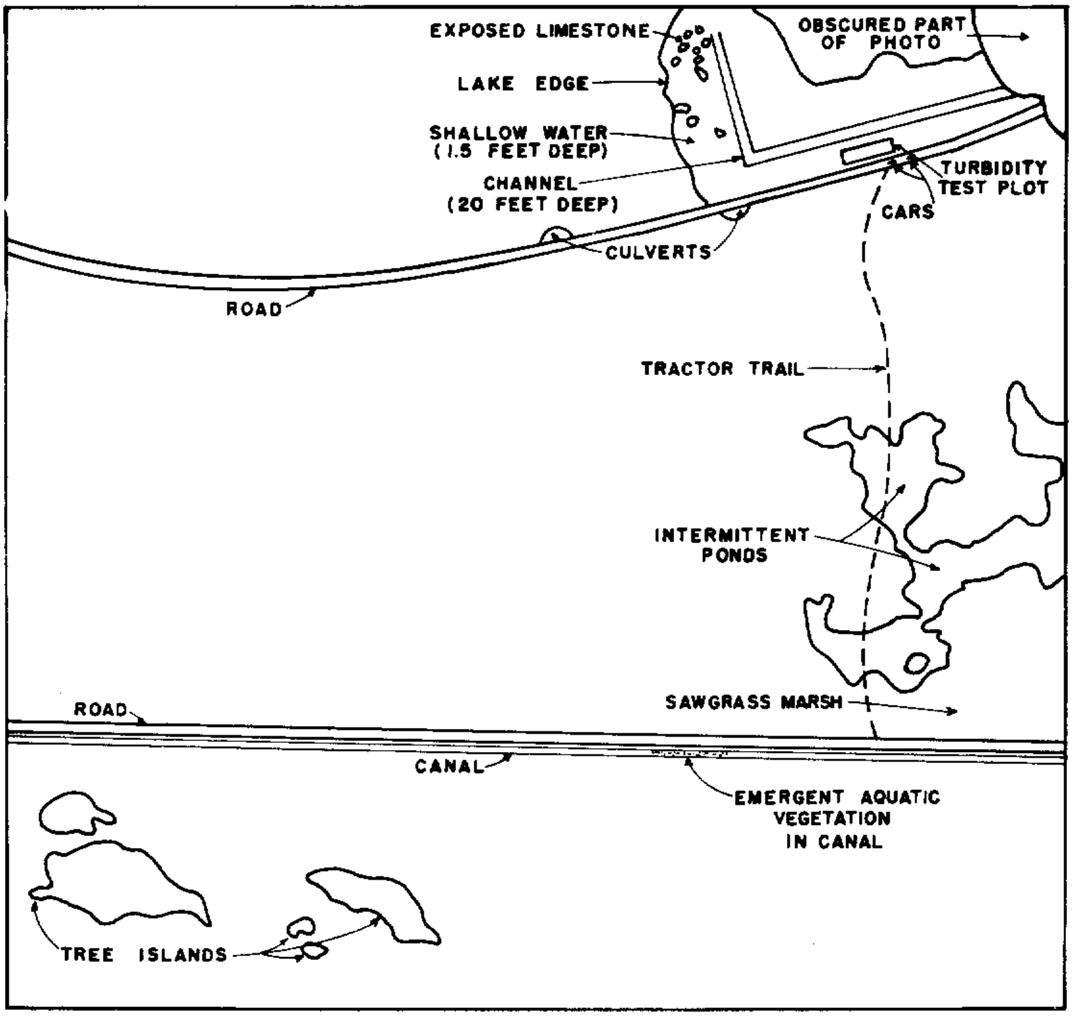


Figure 23-16.- Ground-truth map of region covered in the nine multiband photographs of figure 23-15.

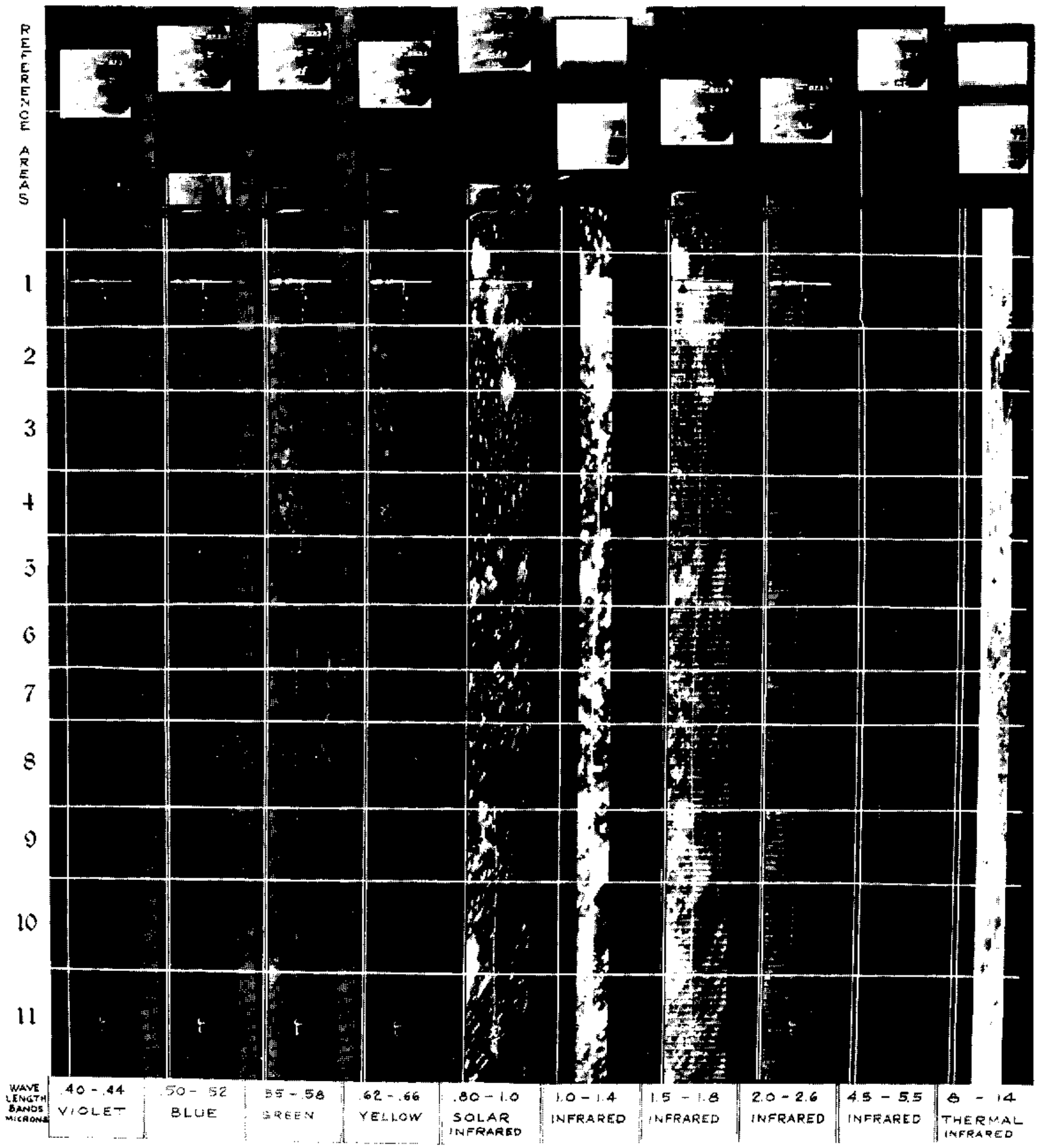


Figure 23-17.- Film strip reproductions of multiband imagery collected over the Seven-Mile Road Test Site in Everglades National Park. The film strips were produced from tape-recorded video signals from an airborne multispectral imaging scanner by the University of Michigan. Many of the bands are collected so that signals are registered and can be mixed or processed electrically for the spectral discrimination of hydrobiological features.

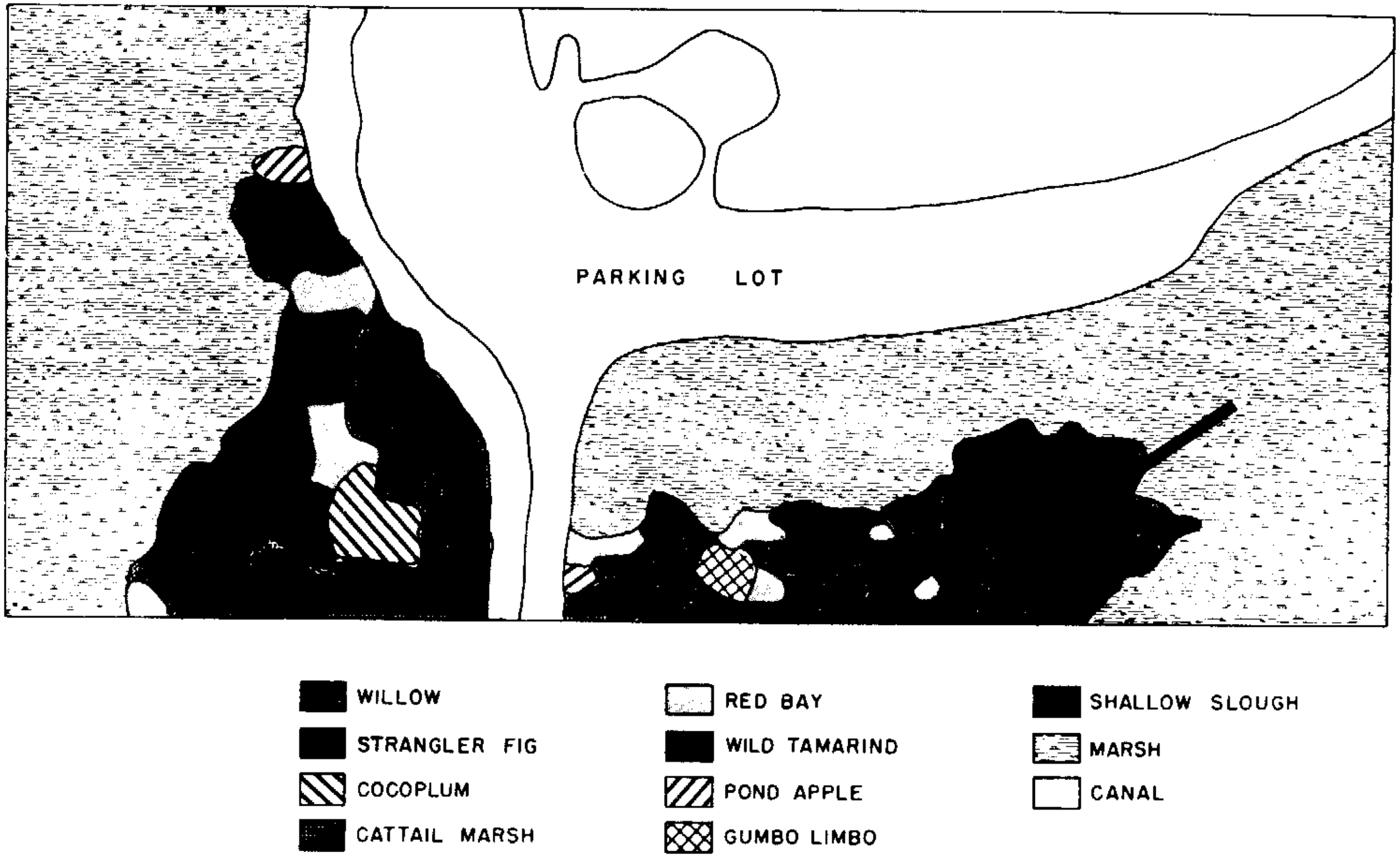


Figure 23-18.- Ground-truth map for spectral discrimination studies with multiband imagery of hydrobiological features in the south end (fig. 23-6) of the Seven-Mile Road Test Site.

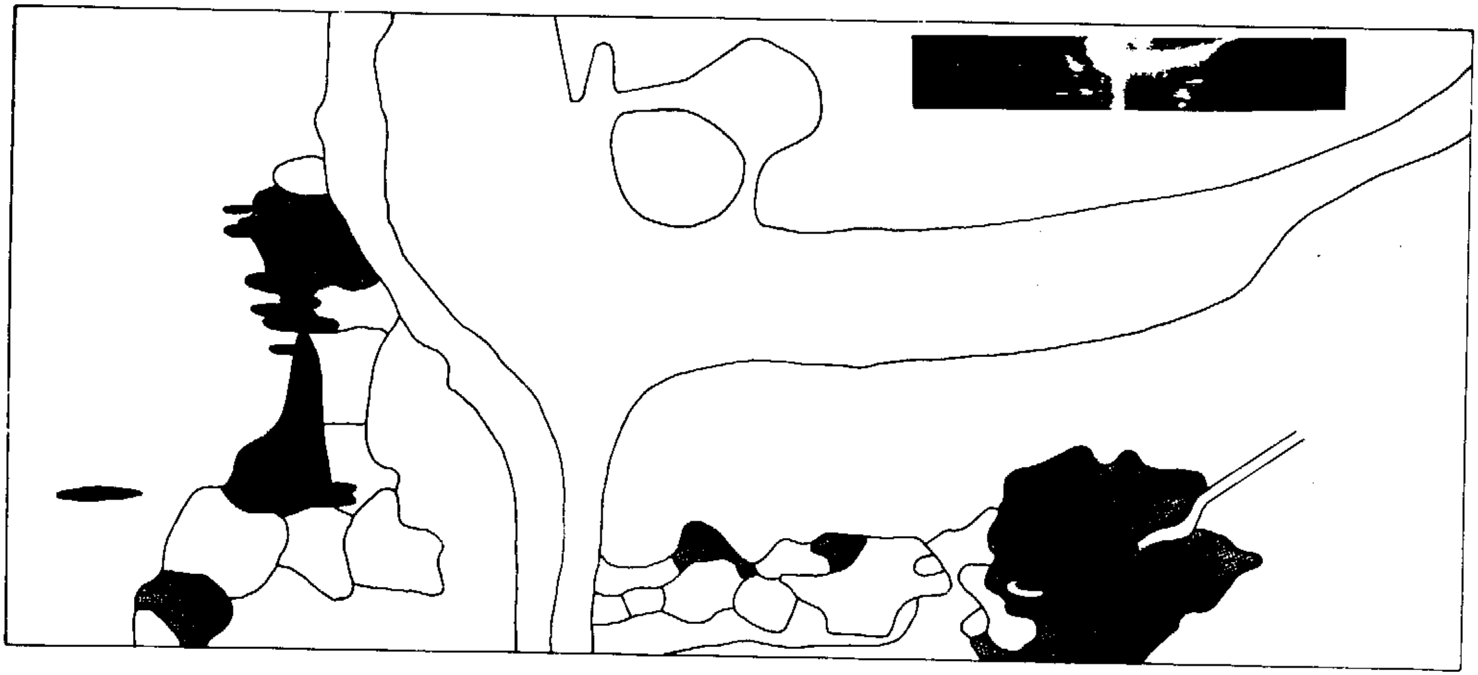


Figure 23-19.- Electronic print-out of willow trees from two channels of multiband imagery superimposed on an Everglades ground-truth test site (fig. 23-18). Further processing is necessary to better define the reflectance characteristics of willow and to eliminate the geometrical distortion of the print-outs. (Note that the smallest groups of willow (gray) were undetected and that some of the print-out "blobs" (black ovals representing willow) fall outside the true ground-truth positions.) The inset shows the print-out format — a photograph of the oscilloscope display.

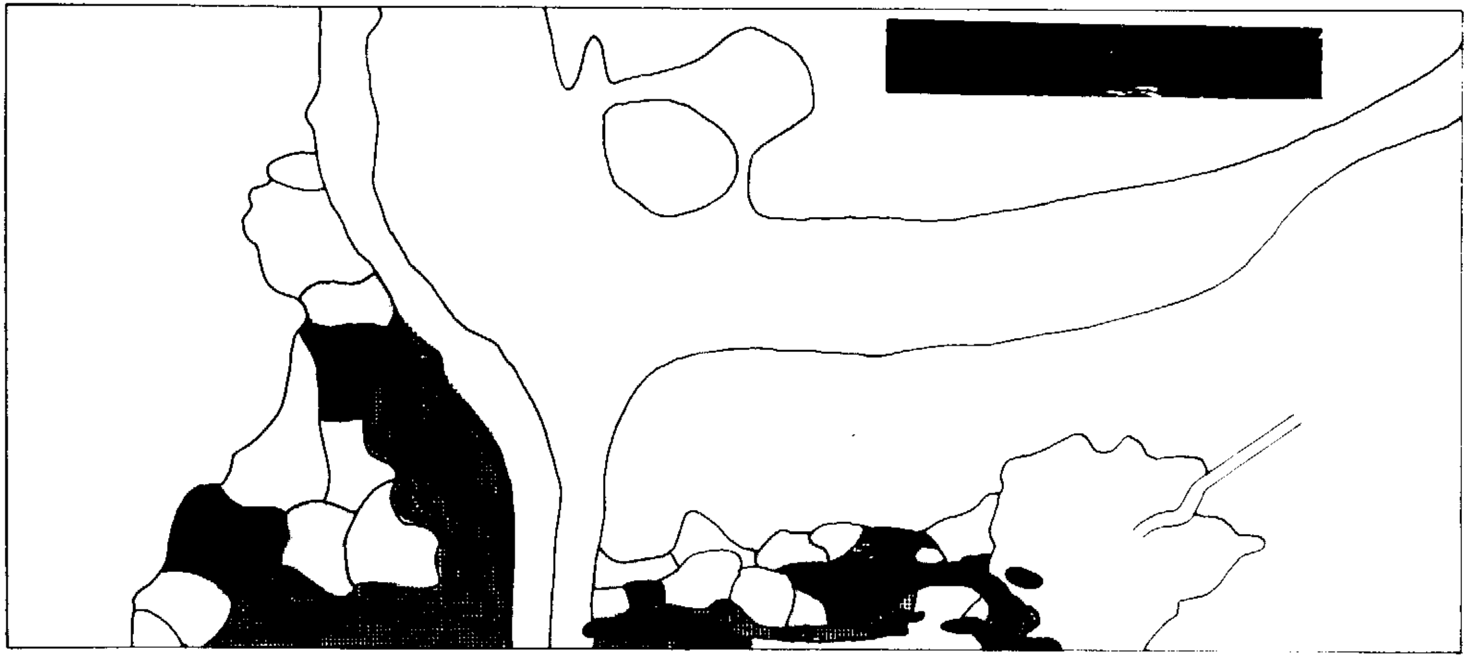


Figure 23-20.- Electronic print-out representing an incomplete discrimination between two objects. The strangler fig and cattail marsh are jointly displayed in the central region but not in the left portion of the scene. Further processing is necessary to resolve the two natural objects uniquely.