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Mapping of Forested Wetland: Use of Seasat Radar Images to Complement Conventional Sources

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CONTENTS

ILLUSTRATIONS

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ABSTRACT

Distinguishing forested wetland from dry forest using aerial photographs has been handicapped because photographs often do not reveal the presence of water below the tree canopies. Images obtained during the summer months of 1978 by the Seasat satellite's L-band (23-cm) radar reveal forested wetland as patterns of high radar reflection in the Atlantic coastal plain between Maryland and Florida. Potential exists for Seasat radar images to complement aerial photographs in the compiling of maps of wetland. A test was conducted with four experienced photointerpreters which revealed that interpretation accuracy was significantly higher when the Seasat radar images were used than when only conventional sources were utilized. The bases of reference, that is, the maps made from conventional sources, were from the U.S. Geological Survey (USGS) series on Land Use and Land Cover, which shows Forested Wetland among its categories.

INTRODUCTION

The purpose of this investigation was to evaluate the advantage of using Seasat radar images to complement aerial photographs for compiling maps of forested wetland as distinguished from dryland forest.

The U.S. Geological Survey (USGS) has been concerned with nationwide mapping of land use and land cover, as well as with traditional mapping. This mapping is done by interpreting aerial photographs and other source materials. Unless the right kind of photographs, taken preferably during the leafless spring flood period, are available, it is difficult to see through tree canopies to detect the standing water that normally distinguishes wetland forest from dryland forest, a distinction made on many of the Survey's maps. Forested wetland patterns are shown in both the large-scale topographic map series and the land use and land cover map series. In one case of the topographic map series, the Alaska maps bear in their margins a caveat stating that only the very wettest areas are shown with the Wetland symbol.

Fitzpatrick-Lins, in her statistical test of map accuracies, found in some maps of land cover, notably in Maine and Georgia, that the identification of Forested Wetland (category 61)[1] fell below the 85 percent accuracy level (Fitzpatrick-Lins,

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[1] Forested Wetland (category 61 on the USGS maps of land use and land cover) is defined as wetlands dominated by woody vegetation and includes seasonally flooded bottomland, hardwoods, mangrove swamps, and forests fringing bogs (Anderson and others, 1976). Wetlands are those areas where the water table is at, near, or above the land surface for a significant part of most years. The hydrologic regime is such that aquatic or hydrophytic vegetation usually is established.

1980, and Anderson and others, 1976). The most common problem was discriminating between dry forest and wet forest. Yet of all the categories on land cover maps, seasonally flooded land is particularly important to planners in government or business, as well as to the general public.

It should be noted that the identification of Nonforested Wetland (category 62) as distinguished from Forested Wetland (category 61) has rarely been a problem for photointerpreters since Nonforested Wetland normally has a distinctive appearance, for example, tidal channels. This type of identification is not considered in this investigation.

BACKGROUND

In order to map Forested Wetlands accurately, one must have either (1) photographs that reveal flooded areas beneath the forest leaf canopy, or (2) images that distinguish wetland forest from dryland forest because of some characteristic of vegetation. It is possible that Seasat radar images may augment either of the above. This is a new application of the L-band (23-cm) synthetic-aperture radar from space, which may do what the mapping camera cannot do.

Radar is known to be especially sensitive to differences in dielectric constant of surface materials and shows intense return or backscatter from some wet forested areas. During the past 15 years, a number of investigators have reported detecting a greater radar reflection from wetland forest than from dryland forest. By far the most work was done with airborne radar operating in the X-, K-, and L-wavelength bands. The low depression angle, that is, less than 25 degrees downward from horizontal, used with radar mounted in aircraft, resulted in high return from surface irregularities and only limited penetration of vegetation. In the case of Forested Wetland, the energy of the radar wave striking the tree canopy probably was attenuated by the branches before reflecting off the wet surface beneath. Nevertheless, greater radar reflection from some forested area believed to have been flooded at the time of overflight has been noted (American Society of Photogrammetry, 1975, p. 997).

Some early studies have been done using Seasat images to reveal wetland forest, notably by Harold MacDonald and others at the University of Arkansas and by Wayne Mooneyhan and his associates at the Slidell, La., facility of the National Aeronautics and Space Administration (NASA). Both worked on sites in the lower Mississippi Valley area; neither had contemporaneous ground truth. Mooneyhan (1979) investigated the value of integrating data from a Seasat radar tape when analyzing data from multispectral Landsat tapes. MacDonald and others (1980) had colleagues in the field after the satellite overpass trying to determine the environmental conditions which might have caused the higher reflection from wetland forest.

In their work on the Blackwater Marshes along the eastern shore of the Chesapeake Bay, Krohn and others (1983) found wet forests generally reflect more radar energy than dry forests, which agrees with observations by other investigators. However, in their test site on the Chickahominy flood plain, east of Richmond, they found at least one forest of water tupelo (Nyassa aquatica), a typical southern swamp forest type, that reflected less radar energy than the neighboring dry forests. This particular stand of tupelo was bordered on two sides by a new water impoundment and a new road embankment of an interstate highway. Some disruption of normal hydrologic conditions may have occurred. The near total absence of undergrowth also seemed a bit unusual. It is apparent that more study is needed on these phenomena.

There are a number of theories as to the reason for high radar reflection from wetland forest, but so far no scientific proof that applies in all ground conditions. Engheta and Elachi (1981) produced a mathematical model which supports the belief of MacDonald and others (1980) that vertical trees standing in water cause a double reflection of the radar energy and increased back-scatter. Field observations indicate that it may also be the vegetative branch structures or leaf characteristics which cause greater return. The difference in dielectric constant between wet and dry soil may also contribute. Hanson and Moore (1976) found that the greater the depression angle downward, the greater the difference in radar energy return from moist soils versus dry soils.

In compiling land cover maps, the image interpreter recognizes best those patterns which are comprehensible in relation to the total environment. Better understanding is needed of the environmental phenomena that cause high radar return from wetland forest.

SEASAT AND ITS RADAR IMAGES

Seasat was launched on June 28, 1978, to test the utility of microwave sensors for remote sensing of the Earth's oceans (Ford and others, 1980). Of the five sensors aboard this spacecraft, one was a synthetic-aperture imaging radar (SAR). Before failure due to a short circuit on October 10, 1978, the radar had imaged approximately 100 million square kilometers. Nearly all of the United States was imaged by this one satellite's radar. The Satellite Data Services Division of the National Oceanographic and Atmospheric Administration (NOAA), Washington, D.C. 20232, has been distributing Seasat film and data products. All of these data are presently available as optically processed film strips; many Seasat images are available as digitally processed frames produced by the Jet Propulsion Laboratory and sent to NOAA for distribution.

The Seasat Imaging Radar was an L-band (23.5-cm) synthetic-aperture radar using H-H polarization, that is, horizontal transmission, horizontal reception, and had a resolution of 25 meters, which was relatively high for a satellite sensor (Pravdo and others, 1983).

The images used in this investigation were nearly all digitally processed. The digitally processed images appear superior to the optically processed film strips both in geometry and gray-scale uniformity, as well as being easier to handle since each is a single page-sized film tranparency.

It was thought that because of the Seasat radar's steep downward look, combined with the ability of the radar energy in the L-band wavelengths to penetrate some distance through vegetation, that some distinctive radar return from Forested Wetland might be found.

Early in this investigation an attempt was made to utilize Seasat radar to detect Forested Wetland between beach ridges just north of the mouth of the Columbia River in the State of Washington. This attempt was frustrated by the saturated, intense return from the steep landforms. It was learned that the Seasat radar should be used only on level or nearly level areas if vegetation or moisture conditions are the primary targets to be detected. The steepness of the look angle should help make Seasat radar images promising information sources for this purpose when obtained over nearly level terrain.

METHODS

Statistical measurements were made to determine degree of agreement between (1) a wetland map made from interpretation of a Seasat radar image and (2) the same type of map made using conventional sources only. The preparation for the measurements are described below.

Test Sites

Four test sites were selected, each representing a different climatic environment and possessing a different wetness condition at the time of Seasat's pass. The geology, soils, and landforms also differ between the four sites. The sites selected were in eastern Maryland, eastern North Carolina, southeastern Georgia, and in southern Florida (fig. 1). A fifth site, the lower Pearl River in Mississippi/ Louisiana had been planned, but work on it was postponed because of lack of ground truth comparable with the other sites. All sites used are on the Atlantic coastal plain or in Florida in order to avoid problems of high topographic relief. A total of 40 specific test segments were selected in the (1) Pocomoke River area of Maryland, (2) Currituck County, N.C.., (3) Ridgeville 7½-minute Quadrangle, Ga., and (4) Fisheating Creek area, Florida. The term "segment" is used because in nearly all cases they were pieces of linear riparian forest patterns.

A minimum sample size of 40 test segments was needed before a test for accuracy could be performed (Rosenfield and Melley, 1980). These test sites were selected because of the availability of both Seasat radar images and good quality ground truth, primarily from the U.S. Fish and Wildlife Service's National Wetland Inventory (NWI). Map sources are listed in the "References" section of this report.

Comparative Data

Comparative data may be defined as that collateral information used to gain understanding of the actual conditions on the ground. The sources of comparative data were in all cases off-the-shelf and ordered afterwards to match as much as possible the conditions existing at the time of the Seasat pass. Detailed mapping of vegetation associations had been done for the NWI for the three southernmost sites, and these associations were not likely to change. Excellent color infrared aerial photographs were available for the northernmost site. All other readily available maps and small-scale images/photographs were obtained for the four sites. The northern three sites were later field-checked. The existing USGS land use and land cover maps for the southernmost sites had been made in close coordination with the State of Florida's wetland office in Tallahassee and should be relatively accurate. The patterns of Forested Wetland mapped by USGS around Fisheating Creek matched the NWI patterns very closely.

Additional sources were used to help understand the radar patterns. Weather records (NOAA) and stream gage data (USGS) were obtained for the days before, during, and after the Seasat pass. Unfortunately, they were measured close to but not at the sites themselves.

Comparative Data Map of Wetland Forest

As base data for testing the interpretability of the Seasat radar, a map of Forested Wetland was made of each test site. For the southernmost three sites, the NWI's map of Palustrine Forest (category PFO) and Palustrine Scrub and Shrub (PSS) was used as the primary source. A map was compiled for each site using the NWI's

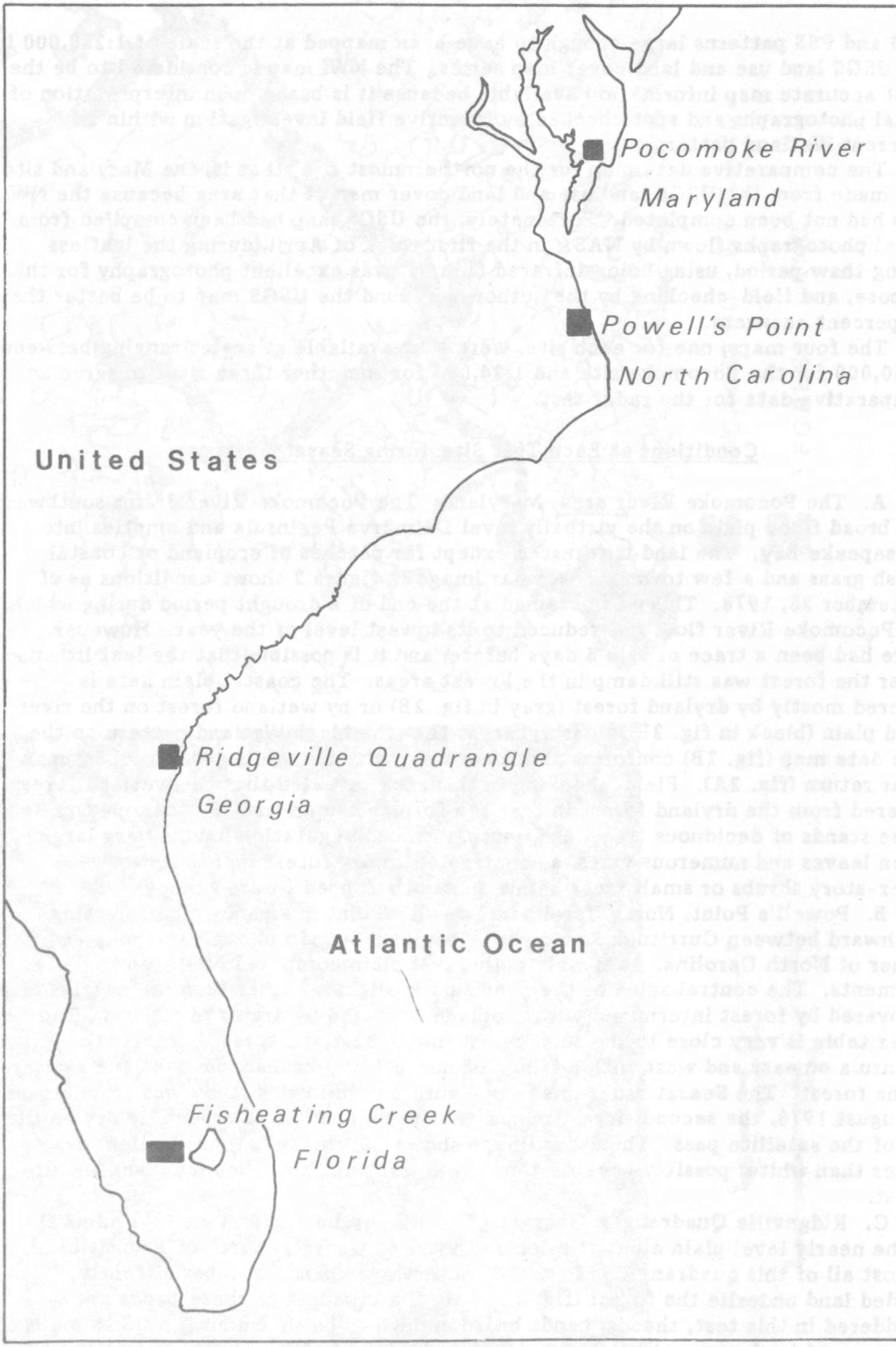

Figure 1.--Index map showing test sites used for land cover interpretation from Seasat radar images.

PFO and PSS patterns large enough to have been mapped at the scale of 1:250,000 in the USGS land use and land cover map series. The NWI map is considered to be the most accurate map information available because it is based upon interpretation of aerial photographs and spot checked by intensive field investigation within the apparent Wetland patterns.

The comparative data map for the northernmost site, that is, the Maryland site, was made from the USGS land use and land cover map of that area because the NWI map had not been completed. Fortunately, the USGS map had been compiled from aerial photographs flown by NASA in the first week of April, during the leafless spring thaw period, using color-infrared film. It was excellent photography for this purpose, and field-checking by the author has found the USGS map to be better than 95-percent accurate.

The four maps, one for each site, were thus available at scales ranging between 1:250,000 for the Pocomoke site and 1:24,000 for the other three sites to serve as comparative data for the radar test.

Conditions at Each Test Site during Seasat Overpass

A. The Pocomoke River area, Maryland: The Pocomoke River drains southward in a broad flood plain on the virtually level Delmarva Peninsula and empties into Chesapeake Bay. The land is forested except for patches of cropland or coastal marsh grass and a few towns. The radar image in figure 2 shows conditions as of September 25, 1978. This was obtained at the end of a drought period during which the Pocomoke River flow was reduced to its lowest level of the year. However, there had been a trace of rain 3 days before, and it is possible that the leaf litter under the forest was still damp in the lowest areas. The coastal plain here is covered mostly by dryland forest (gray in fig. 2B) or by wetland forest on the river flood plain (black in fig. 2B). It is apparent that the black Wetland pattern on the base data map (fig. 2B) conforms almost exactly with the white pattern of intense radar return (fig. 2A). Field-checking in this area revealed that the wetland forest differed from the dryland forest in that the former had an irregular canopy top, dense stands of deciduous trees, and unusual ground vegetation having very large green leaves and numerous vines, as contrasted to dry forest leaf litter and lower-story shrubs or small trees below a smooth-topped forest canopy.

B. Powell's Point, North Carolina: Powell's Point is a peninsula projecting southward between Currituck Sound and Albemarle Sound near the northeastern corner of North Carolina. It is a virtually level plain composed of Recent sediments. The central spine of the peninsula is slightly higher than its margins and is covered by forest intermixed with cropland bordered by drainage ditches. The water table is very close to the surface. A line of wetland forest borders the peninsula on east and west with a fringe of nonforested herbaceous Wetland seaward of the forest. The Seasat radar image in figure 3 used in this study was from a pass in August 1978, the second-dryest month that year, and it was especially dry on the day of the satellite pass. The radar image shows the forest patches as light gray rather than white, possibly because they are in fact marginal between wet and dry forest.

C. Ridgeville Quadrangle, Georgia: The Ridgeville Quadrangle (7½ minute) is on the nearly level plain along the central coast of Georgia, north of Brunswick. Almost all of this quadrangle is forested. Interwoven bands of intermittently flooded land underlie the forest (fig. 4). Only the broadest of these bands are considered in this test, that is, bands broad enough to be shown on the USGS maps of land use and land cover at a scale of 1:250,000. Rain had just started to fall at the time of Seasat overpass in an otherwise dry August 1978. The radar reveals a great many white or light gray linear patterns, some quite narrow.

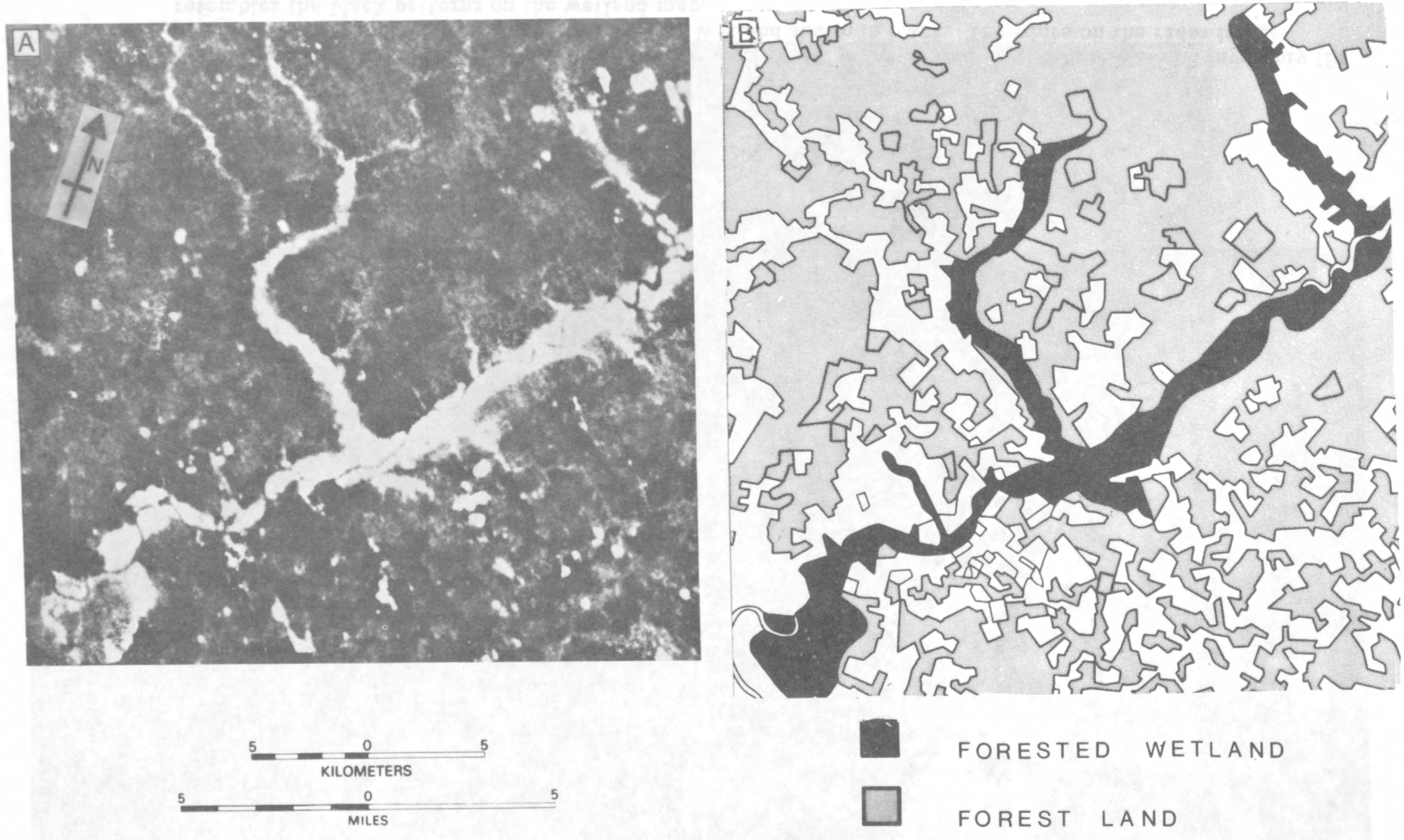

Figure 2.--Comparison of Seasat synthetic-aperture radar image (A) with a map of land cover in the Pokomoke River area with Forested Wetland shown in black (B) reveals a similarity in an easily seen pattern. The radar return from this Forested Wetland is very intense, i.e., white. The area shown is the lower Pocomoke River Valley east of Chesapeake Bay in Maryland (U.S. Geological Survey, 1977).

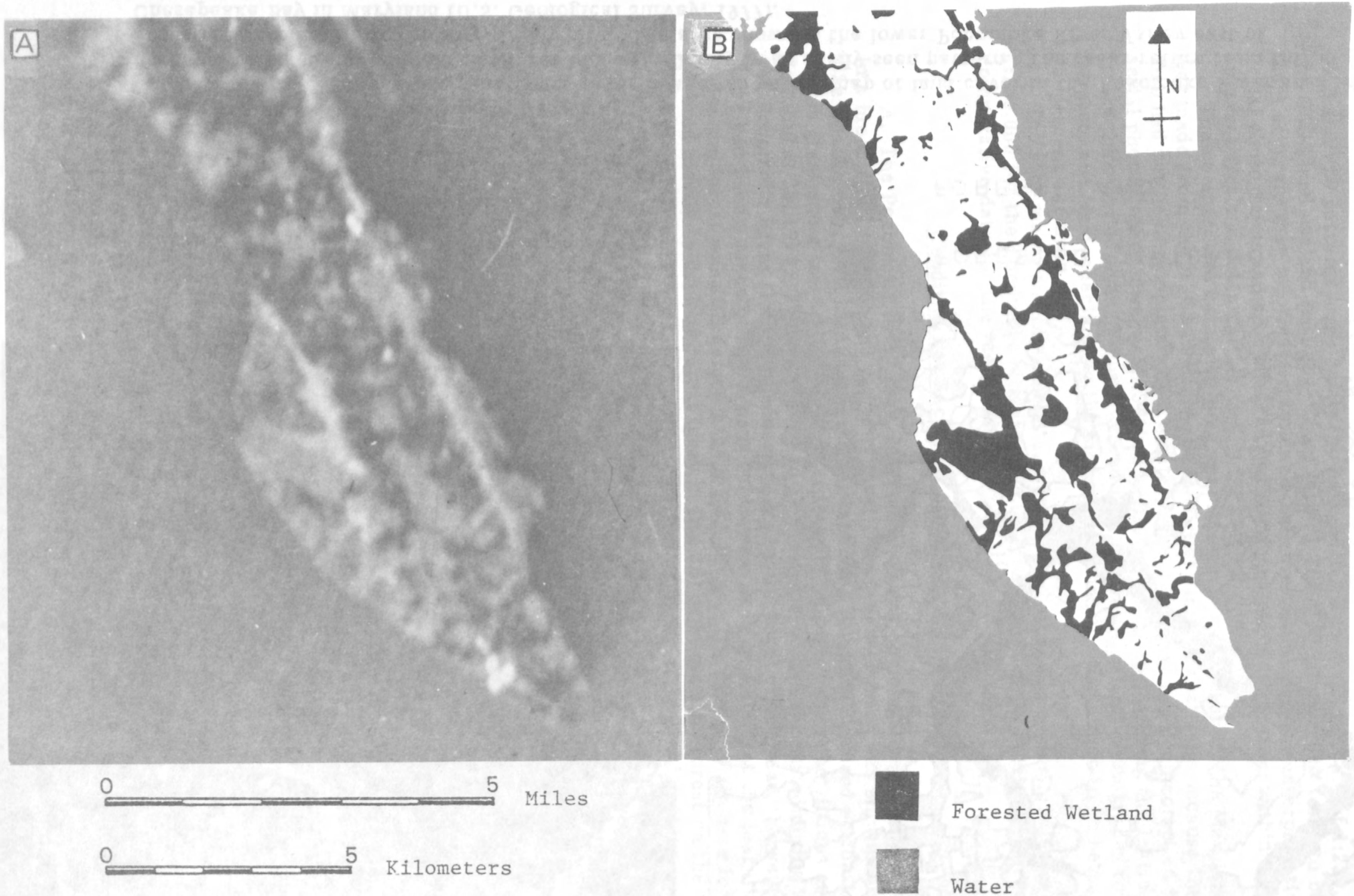

Figure 3.--Comparison of Seasat synthetic aperture radar image (A) with a map based on National Wetland Inventory (B) of Powell's Point, North Carolina with Forested Wetland shown in black. The white on the radar image resembles the black patterns on the wetland map.

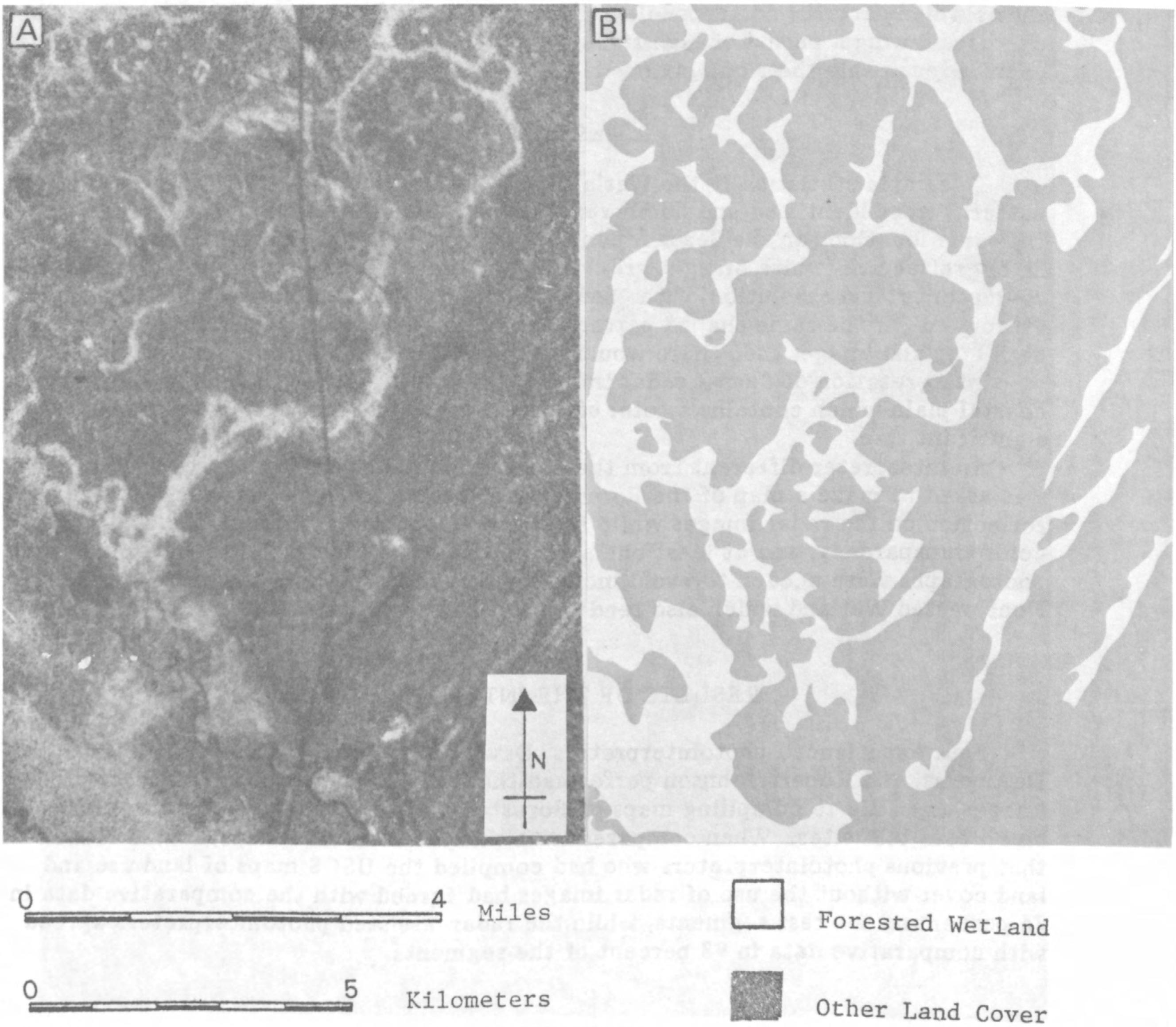

Figure 4.--Comparison of Seasat synthetic aperture radar image (A) with a map based upon the National Wetland Inventory (B) of the Ridgeville Quadrangle, Georgia, with Forested Wetland shown in white.

D. Fisheating Creek area, Florida: Fisheating Creek flows southeastward into the west corner of Lake Okeechobee in south-central Florida. Surface drainage throughout this level area is poor and mostly irregular in pattern. Wetland vegetation abounds in many forms, normally as shrubs or herbs. However the NWI mappers reported Forested Wetland, as did the USGS land cover mappers, in and near the flood plain of Fisheating Creek (fig. 5B). The Seasat radar image (fig. 5A) shows white patterns corresponding closely to the NWI patterns. The Seasat pass occurred during a period of high stream runoff during the wettest month of the year. Presumably the flood plain was wet if not underwater.

Test of Interpreters

To sample statistically the Wetland patterns, segments of the Forested Wetland patterns were identified and numbered. These segments were to be compared with the same locations on the Seasat radar image to see if agreement exists with the highly reflective (white or light gray) areas on the radar image. Because of the 25-meter ground resolution of the Seasat image, mapping of small patterns was not attempted. If the same shaped pattern existed in essentially the same location on both map and image, then there would be agreement for that segment of Wetland.

Interpretation of Seasat radar images was performed for regions of the Atlantic coastal plain which contains a total of 40 test areas of Forested Wetland of significant size.

An interpreter different from the one who compiled the comparative data map was asked to make a map of the Forested Wetlands as seen as the areas of very high reflection on the radar images while referring to topographic maps, Landsat MSS color transparency, and at least one aerial photograph for each site. The maps and photographs were needed to avoid including manmade features and some types of Nonforested Wetland which also tend to have a bright return.

RESULTS OF THE INTERPRETATION

Four experienced photointerpreters, David Wolf, Thomas Johnson, Robert DeAngelis, and Robert Johnson performed the test of interpretation of Seasat radar images as an aid to compiling maps of Forested Wetland. Each interpreter worked on all four test sites. When compared with comparative data maps, it was found that previous photointerpreters who had compiled the USGS maps of land use and land cover without the use of radar images had agreed with the comparative data in 75 percent of the test segments, while the radar-assisted photointerpreters agreed with comparative data in 93 percent of the segments.

STATISTICAL TESTS

The statistical tests consisted of two parts. First, the findings of the four interpreters were compared for agreement with each other. Second, the findings from the radar interpretation were compared with the findings of previous photointerpreters who did not have radar images to complement their conventional sources. The hypothesis tested in this latter case related to whether there was a significant difference between the two sets of findings.

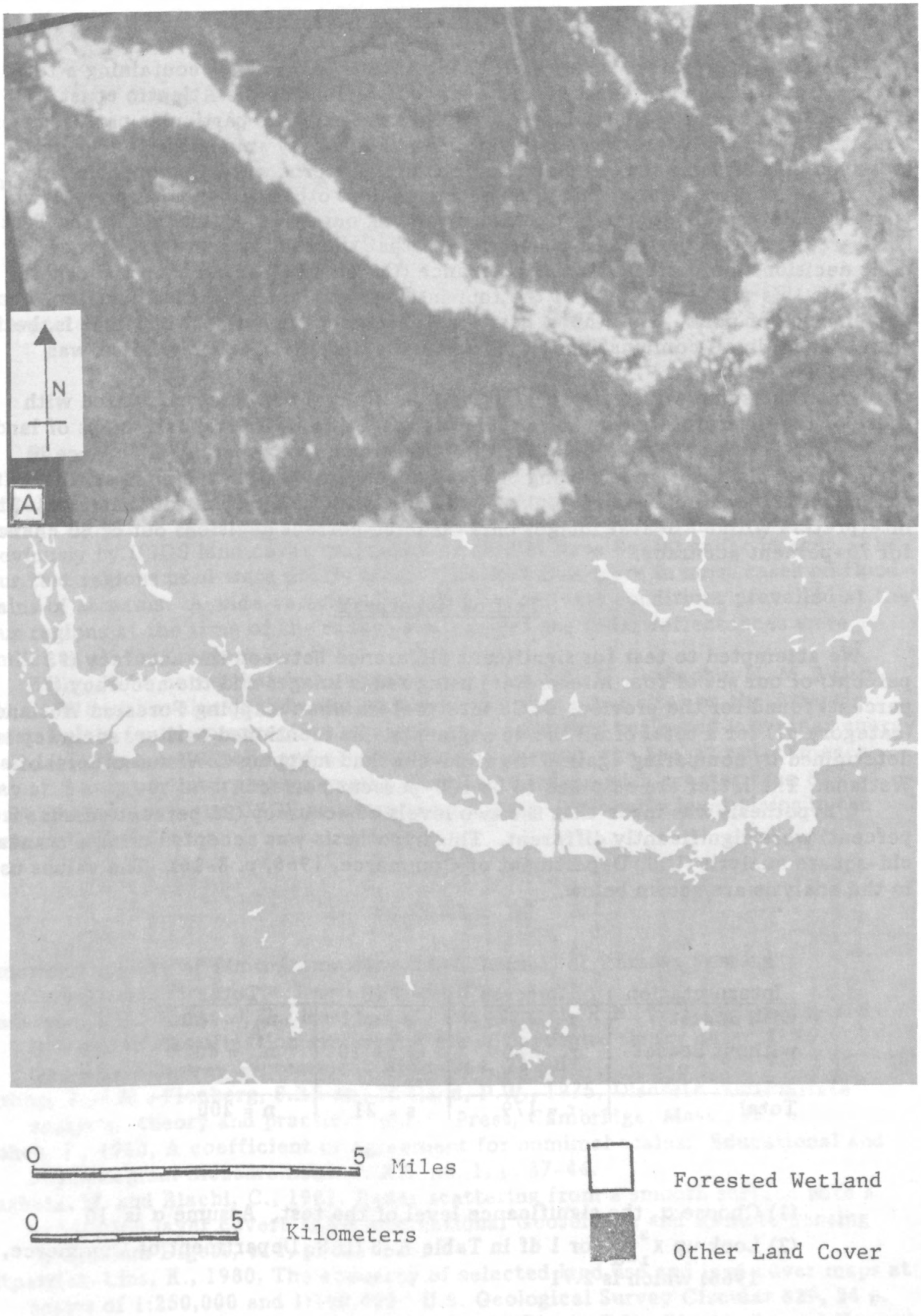

Figure 5.--Comparison of Seasat synthetic aperture radar image (A) with a map based on National Wetland Inventory (B) of Fisheating Creek area, Florida with Forested Wetland shown in white.

Cohen's Kappa Test for Agreement

The four interpreters were asked to interpret radar images containing a total of 40 Forested Wetland segments spread over four regions of the Atlantic coast. Hence, 160 decisions were made as to whether or not these particular patterns were Forested Wetland. There was some variation in accuracy among the four people, mostly due to differences of opinion as to which patterns were of mappable size. Before we compared these four interpreters against other sets of interpreters, we wanted to determine degree of agreement among our four. A Cohen's Kappa Test for Agreement was performed which showed that the four interpreters agreed in their decisions more often than mere chance (Cohen, 1960 and Bishop and others, 1975). In this test, the scores of the four interpreters were compared by all combination of pairs. The Kappa Test for Agreement proved positive, that is, better than chance, in all combinations. This also indicated that the experiment was repeatable.

When the summarized findings of our four interpreters were compared with those of the interpreters who had previously made the USGS standard maps of land use and land cover, it was found that the two sets had an apparent difference in accuracies. The interpreters using Seasat images agreed with the comparative data for the 40 test segments in 149 out of 160 decisions or 93 percent of the cases. The interpreters without Seasat images only made 30 correct decisions out of 40 chances for 75-percent accuracy.

Test of Hypothesis

We attempted to test for significant difference between the accuracy (93 percent) of our set of four interpreters using radar images and the accuracy (75 percent) found for the previous USGS interpreters when mapping Forested Wetland (category 61) for a total of all the 40 segments. As mentioned earlier, accuracy is determined by comparing against the field-checked mapping (NWI and others) of Wetland. The latter are assumed to be 100-percent correct.

A hypothesis was made that the two levels of accuracy (93 percent versus 75 percent) were significantly different. This hypothesis was accepted using a standard chi-square analysis (U.S. Department of Commerce, 1966, p. 8-16). The values used in the analysis are shown below.

Interpretation	Success	Fail	Total
with Seasat	$r_A = 149$	$s_A = 11$	$n_A = 160$
without Seasat	$r_B = 30$	$s_B = 10$	$n_B = 40$
Total	$r = 179$	$s = 21$	$n = 200$

(1) Choose α, the significance level of the test. Assume α is .10

(2) Look up $\chi^2_{1-\alpha}$ for 1 df in Table A-3 (U.S. Department of Commerce, 1966) which is 2.71

(3) Compute $\chi^2 = \dfrac{n(|r_{AB}^{s} - r_{BA}^{s}| - \frac{n}{2})^2}{n_A^{r} n_B^{s}}$

which calculates to approximately 9.

(4) If $\chi^2 > \chi^2_{1-\alpha}$ conclude a difference.

Since 9 is greater than 2.71, we conclude that there is a difference in the interpretation quality between the two sets of interpreters.

CONCLUSIONS

Based upon 40 test segments of Forested Wetland in different regions of the Atlantic coastal plain from Maryland to Florida, it was determined statistically that photointerpreters who use Seasat radar images to complement their conventional sources should be able to map Forested Wetland more accurately than done previously by USGS land cover mappers who did not have Seasat radar images. The four test regions used were nearly level. The Wetlands were in most cases on flood plains of streams. A wide variety of climatic or wetness conditions prevailed at the four regions at the time of the radar pass, and yet the radar reflectances were similar in all four regions.

It should be noted that in a separate investigation, M. D. Krohn, N. M. Milton, and D. B. Segal evaluating the use of Seasat radar on other sites on the Atlantic coastal plain found an exception where Forested Wetland reflected less radar energy than dryland forest (Krohn and others, 1983). However, the Seasat radar images may still help our interpreters to map Forested Wetland with greater than 85-percent accuracy--the USGS program requirement--on nearly level plains in the eastern United States.

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