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REMOTE SENSING - WETLANDS

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Remote Sensing - Wetlands

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Coastal wetlands present an extremely harsh physical environment in which a variety of organisms survive. That is, despite their subjection to periodical wet and dry conditions as a result of tidal inundation and to alternating warm and cold cycles daily, the coastal wetlands provide one of the most biologically and ecologically valuable habitats presently known (Reimold and Linthurst, 1973). Estuaries, for example, serve as a nursery ground for marine organisms by providing food and protection from larger predators. The wetlands also serve as a physical barrier to protect the coast from severe erosion during coastal storms and hurricanes.

There exists a variety of scientific methodologies to examine and study the importance and complexity of these wetland systems. Fornes and Reimold (1973), Reimold et al. (1972), and Thompson et al. (1973) have considered remote sensing technology as applicable to several specific wetland problems. It will be the purpose of this paper to summarize and examine multiple uses of remote sensing of wetlands and their potential applications to similar systems.

Boundary Mapping

Remote sensing has been employed for wetlands boundary mapping. These boundaries are usually dependent on a particular tidal datum (Figure 1). The datum planes most often selected are mean low and mean high water.

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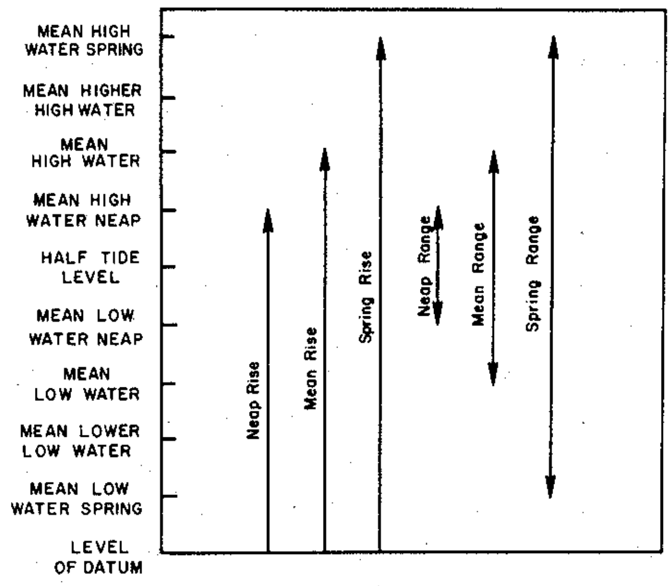


Fig. 1. Tidal datums. Mean low water springs is the average level of the low waters that occur at the times of spring tides; Mean lower low water is the average height of the lower low waters at a place; Mean low water is the average height of all low waters at a place; Half-tide level is the level midway between mean high water and mean low water; Mean higher high water is the average height of the higher high waters of each day; and Mean high water springs is the average level of the high waters that occur at the time of spring tides.

Fornes and Reimold (1973) have considered three different methods to locate mean high water in a tidal salt marsh. Conventional surveying, color infrared photography, and thermal imagery were all employed. It was concluded that of the three techniques, the low level (1:5000 scale) color infrared photography was most useful to delineate plant species and/or plant primary production differences which were associated with mean high water determinations. They also reported that a tidal water level recorder (tide gauge) was essential nearby the wetland area in which mean high water is to be mapped. In the system considered, mean high water level varied as much as 50 cm in height within a four mile horizontal distance. Using proper ground control, locally determined mean high water and photogrammetric interpretation, the color infrared aerial photographic method was considered comparable to conventional surveying methodology.

Latham (1973) has utilized color photography to locate the lines of low water and high water on shore face sand beaches in eastern Florida. High water was established by the "flotsam jetsam" line left from the highest reach of the tide. Low water was delineated using photography flown at low water as predicted from tide tables and tide recorders. To further differentiate this line of water vs sand, black and white infrared photography was also employed (Guth, 1972). The latter method provided more satisfactory results when the photography was flown simultaneously with low tide predictions.

Another use of remote sensing is currently being explored by the U. S. Geological Survey. They are creating prototype typographic maps which will delineate not only wetland from high land, but will also delineate other boundaries such as wetland vegetation. These maps are being prepared using a Bausch & Lomb Zoom Transfer Scope and color infrared photography at various scales.

Vegetation Differentiation

A number of recent papers have considered differentiation of wetland plant species using remote sensing. Wobber and Anderson (1972) have used multiband imagery to characterize different plant species in New Jersey and Maryland estuarine marshes. Reimold et al. (1972) have utilized color infrared photography at scales of 1:2500 to 1:40000 to differentiate vegetative stands of common salt marsh plants including: *Spartina alterniflora*, *Spartina cynosuroides*, *Juncus roemerianus*, *Salicornia virginica*, *Distichlis spicata*, *Borrichia frutescens*, *Scirpus* sp. and *Typha* sp. Gallagher et al. (1972), for example, have employed infrared imagery in the 2.0 to 3.5 micron band to distinguish between *Spartina* and *Juncus*. Using adequate ground truth observations, it was possible to identify the vegetative distribution patterns most easily using the color infrared imagery at 1:5000.

Gallagher and Reimold (1973) utilized color infrared photography at scales of both 1:10000 and 1:40000, and color photographs at 1:24000 to discriminate vegetative differences in wetland areas that extended from sea water to fresh water. In the fresher water zones they found the color infrared photography taken in the summer months, and the color photography taken in the winter months, to be most useful for species differentiation.

Using color photography (Kodak Type 2445) at a scale of 1:24000 exposed at low water 2 December 1972, one of us (RAL) has initiated production of vegetation maps of the wetlands directly onto USGS topographic maps. Using a light table and acetate overlays, the interpretation is accomplished simultaneously with acquisition of the necessary ground truth. Areas differentiated include base mud areas, spoil areas, vegetated areas of *Spartina alterniflora*, *Juncus roemerianus*, *Salicornia virginica*, and minor mixed plant species combined. A sample of this type of vegetation

mapping (Figure 2) results in a vegetation map for the user group which can be taken into the field. This is designed for user groups conducting land planning, resource inventory, civil engineering and scientific research.

Production Patterns

In addition to patterns in imagery associated with plant species differences, Reimold et al. (1973) and others have recently differentiated variations in plant production. The most common plant in the estuarine wetlands of the Atlantic coast, *Spartina alterniflora*, is one of the most productive plants known (Odum, 1959). Reimold (1971) initiated studies to determine the feasibility of using remote sensors to differentiate between various degrees of primary production of *Spartina*. Reimold et al. (1972) employed Kodak Type 2443 color infrared photography at scales from 1:2500 to 1:10000 to discriminate four different production patterns in *Spartina alterniflora*. Using an 1100 hectare salt marsh watershed in coastal Georgia, it was documented that production patterns could be associated with color intensities on the film. By computing the areal distribution of the different production zones, an integrated mean primary productivity value was obtained. The four color zones, red, light red, blue red, and blue, corresponded respectively with different primary production values of those zones based on ground truth production measurements in the *S. alterniflora*.

Gallagher et al. (1972) have shown that not only color infrared imagery but also infrared imagery in the 8.0 to 12.5 micron range is useful for distinguishing between different *S. alterniflora* production classes. The infrared imagery however is not as reliable as color infrared photography.

Thompson et al. (1973) summarizes the numerous remote sensing media related to plant primary production patterns, i.e., seasons, climatic

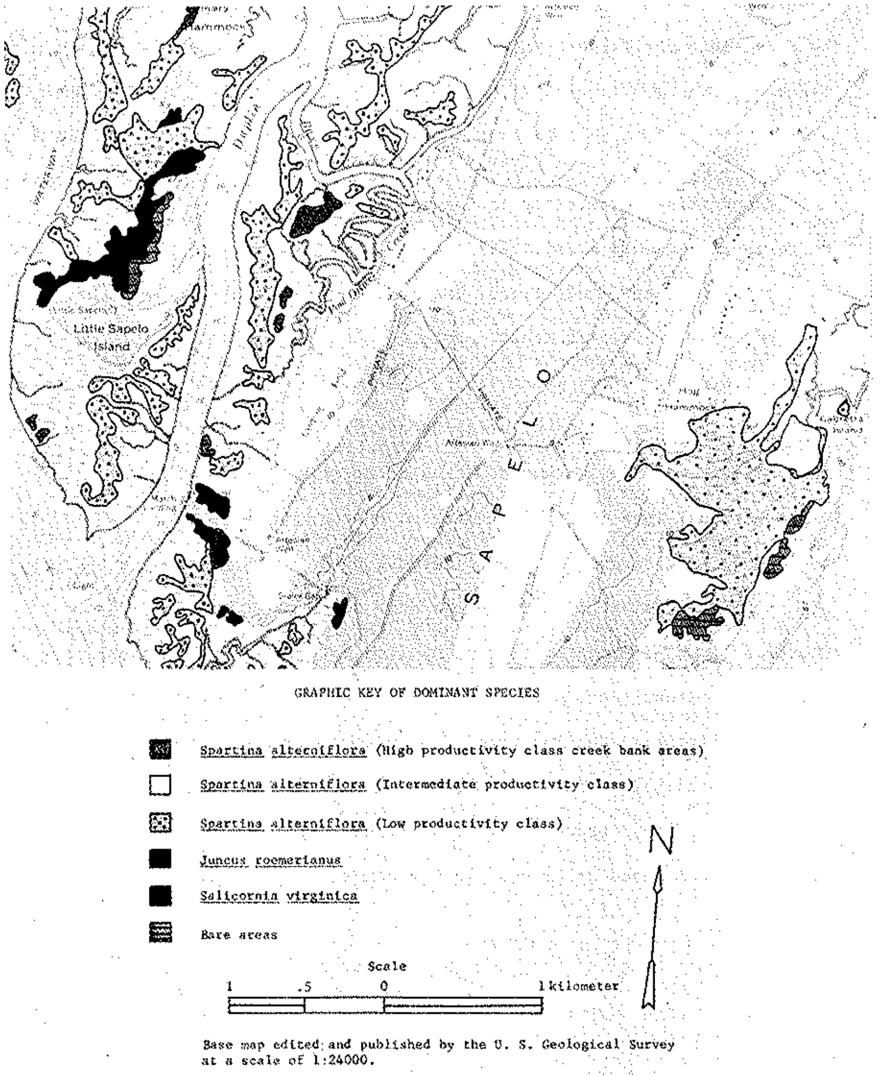


Fig. 2. Vegetation map of a coastal Georgia estuary produced by mea of color photography and USGS topographic maps.

conditions, etc. For optimum results it was ascertained that the remote sensing of wetlands primary production requires cloud-free days, a solar angle of 40° to 60°, low tide, and maximum annual standing biomass of those plant species under consideration.

Predicting the plant primary production of wetlands as well as the distribution of plant species is currently utilized by the Department of Transportation, and the Army Corps of Engineers officials. Construction of highways and maintenance of waterways is now being done with a minimal impact to the potential primary production of the wetlands due to these new applications of remote sensing technology. In several states (including New Jersey) vegetation boundaries are now being used as a property line between private and public land ownership.

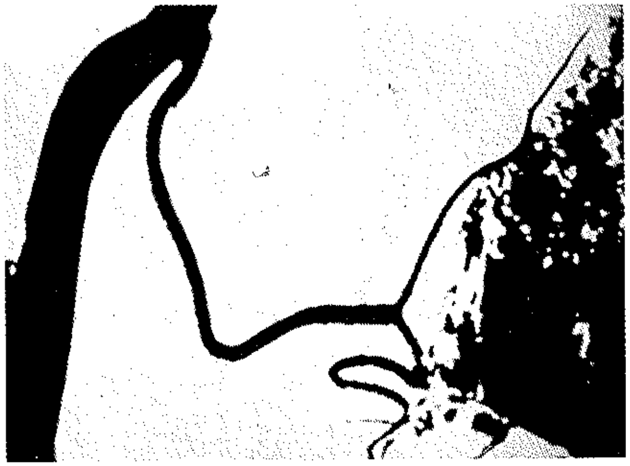
Water Movement

In the wetlands, the movement of water within the intertidal zone is of interest to multiple disciplines. Using infrared imagery obtained with a Bendix LN-3 thermal mapper outfitted with a mercury cadmium teluride crystal and filtered to record in the 8.0 to 12.5 micron portion of the spectrum, it has been possible to successfully record intertidal water movement. By acquiring this imagery at precisely low water in mid-afternoon during the summer seasons, variations in gray tone patterns can easily be observed. With the use of a Datacolor System Color Densitometer, Model 701, density slicing revealed different levels of water as documented by the gray tones of both wetter cooler, and dryer warmer areas. Figure 3 depicts the sequence related to density slicing and tidal inundation. Figure 3a depicts an estuarine intertidal area where the tidal stream is white, and the intertidal zone is black. First, the smaller streams fill partially with water as the tide rises (Figures 3b and 3c). Then they begin to overflow at the stream head (Figures 3d, 3e, 3f). Finally, as the tide continues to rise, the water at the head of the small streams flood back toward the main channel. The areas remaining high and dry (black) in Figure 3h are the natural levees which are only inundated during the high spring tides. All of this was accomplished by density slicing one image taken at low water. Subsequent flights at hourly intervals after low water, using black and white infrared photography, document the reality of this remote means of following intertidal water movement.

This new technique may be used to replace dye studies which also document intertidal hydrography of the wetlands. Planners and engineers working in the wetlands must strive not to obstruct the intertidal movement of water necessary to sustain the wetlands. Through the use of techniques such as those cited above, remote sensing can quickly document water flow of wetland marshes so there can be an awareness of the importance of water movement before any alterations which may obstruct it can take place.

Location and Field Orientation

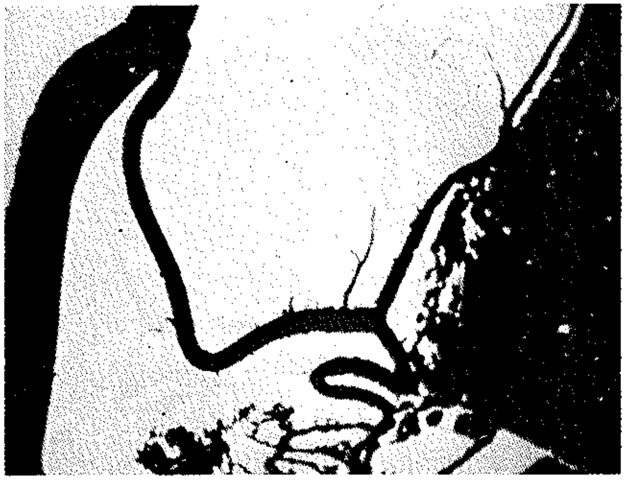
Remote sensing has become an extremely useful aid in field work. Because of the relatively low cost of good quality color and black and white photography, many user groups are routinely using photography to aid in their field work. Surveyors, geologists, biologists, chemists and others are routinely using photographic prints to document their position in the field. The photography is engaged extensively in the wetland areas because of their relative inaccessibility, i.e., vegetation three meters tall, soft mud, and numerous streams, make the estuarine wetlands extremely treacherous. Sample sites, field collection areas, survey points, and access planning are all more easily accomplished using comprehensive photographic coverage. Due to the absence of a tree canopy, the area



a) Low water

b) Initial tidal rise after low water

Fig. 3. Successive density sliced images depicting tidal flooding patterns of a Georgia estuary from a period of low water through and including a state of high water.



c) Water fills smaller streams

d) Water overflows at stream heads

Fig. 3. (Cont.) Successive density sliced images depicting tidal flooding patterns of a Georgia estuary from a period of low water through and including a state of high water.

e) Water fills surrounding stream head areas

f) Water flows back toward main channel

Fig. 3. (Cont.) Successive density sliced images depicting tidal flooding patterns of a Georgia estuary from a period of low water through and including a state of high water.

g) Final flooding before high water

h) High water

Fig. 3. (Cont.) Successive density sliced images depicting tidal flooding patterns of a Georgia estuary from a period of low water through and including a state of high water.

satisfactorily lends itself to photographic interpretation. Not only second and third generation blue line prints but also color photographic prints are used in wetlands operations. Since USGS topographic maps do not indicate any relief for wetlands but simply classify them as "swamps" or "marshes", photographs are an invaluable tool in wetlands operations.

Comparative Analyses

In the wetlands one is often interested in assessing change over unit time. Change associated with land water areas, areal extent of vegetation changes with season, and changes in scene as depicted by various remote sensing media, are all of interest. For ecological considerations, it is important to know the areal extent of vegetation and production patterns in the wetlands which may be associated with resultant changes elsewhere within the system. Changes in the same scene as depicted by different remote sensing media reveal different phenomenon. Thompson et al. (1973) document differences of resolution in evaluating coastal resources using color, color infrared, black and white infrared, and black and white photography, as well as various windows in the infrared spectrum. Wobber and Anderson (1972) have documented the various comparative features using multiband imagery to consider wetland resources. Carter and Anderson (1972) have employed various bands of ERTS I imagery for wetlands vegetation mapping, and then compared it to information learned from low level photography of the same area. Recent work by Pfeiffer et al. (1973) considers differences in spectral reflectance of wetlands scenes and optimum remote sensing media for differentiation and comparison.

Comparative analysis is also useful in land use planning. Historical photography over a given time interval will record the influence of nature on a shoreline. The shore may build and then erode with a twenty or even fifty year periodicity. The comparative photography permits assessment of these features prior to potential development or alteration. Documentation of hurricane flooding patterns in the coastal wetlands is invaluable to future generations. Lines and property can be spared by wise land use revealed through comparative analysis of remote sensing imagery.

Landform Analysis

Features such as shoreline location, beach erosion and wave runup are all features of the landform which can be documented and contrasted by remote sensing. Color infrared photography (1:40000) has been used to document the former theoretical location of a major stream channel (Figure 4). Subsequent ground truth analysis using geological interpretative methodology has documented that this is, indeed, the old course of the stream. Old stream meanders presently cut off are visible using color infrared photography. Other geological features of wetlands such as drainage patterns, soil moisture, and beach and shoreline ridges are discernable using photography. Side looking airborne radar recently flown over coastal Georgia reveals different wetlands features, including watersheds, as well as microchanges, which to date have not been adequately explained by ground truth analysis.

Water Pollution Analyses

Infrared imagery in the 8.0 to 12.5 micron band has been extensively used in recent years to follow thermal loading in the wetlands. With the advent of an energy crisis, heat, the waste product of energy transformation, will become even a greater environmental pollutant than it is presently. Assuming that warmer water within a defined area of generally cooler water is warmer because something has been added to it, e.g., heat, nutrients, waste materials, etc., then the thermal imagery detection of

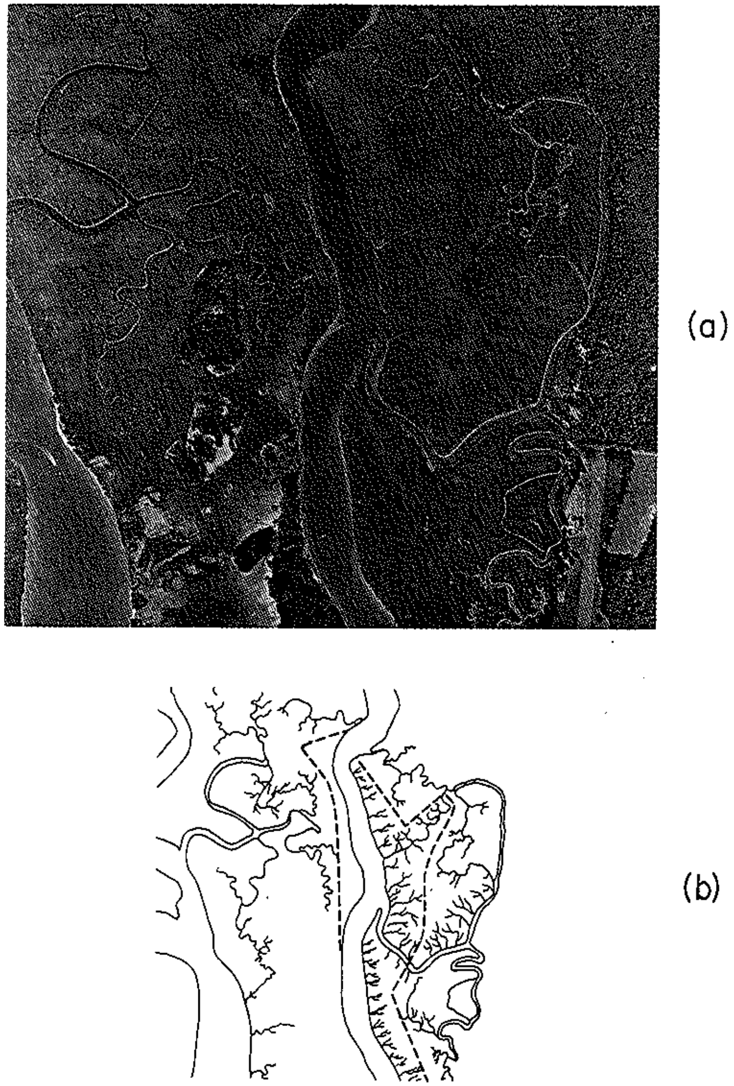


Fig. 4. Black and white aerial photograph (a) documenting the present course of a major stream channel in coastal Georgia along with a visual interpretation (b) of the same area, defining the former stream channel by a dotted line.

heat in waters of the wetlands serves as a reliable means of identifying potential water pollution. Ground truth observations at the sites of thermal discharge can assess other pollutants not able to be remotely sensed.

The biota also serve as a reliable indicator of water pollution. Algae, for example, normally present in low concentrations in the water column will, with the addition of large amounts of nutrients, bloom. This bloom generates a green cast to the water color which is discernable on color photography and color infrared photography. Conversely, when high concentrations of toxic substances are added to the waters, death of the nekton occurs. Therefore, a potential fish kill is easily discernable and the source of pollution can be documented on color aerial photography.

Pollutants affect the water by heating, adding toxic and nontoxic substances, adding suspended solids, and removing dissolved oxygen. Another aspect of remotely sensed water pollution is the observation of an added suspended sediment, or silt load, into the water, which is easily discernable from black and white aerial photography.

Baseline Conditions

One of the ultimate uses of remote sensing in the wetlands is assessing and documenting baseline conditions. A developer may wish to document the ecological health of the wetlands prior to exploitation. A prospective property owner may wish to know the influence nature has on wetlands, as well as precise boundaries before a purchase is consumated.

Quality remote sensing products will enable many user groups to document wetlands for numerous purposes. To date we have assisted in documenting the areal extent, vegetative zones, plant production, and general ecological health of wetlands in a number of places on the eastern seaboard. Land use planners, developers, and conservationists alike are interested in factual documentation of the conditions today, i.e., baseline. Adequate remote sensing imagery of the wetlands today will not only document their present condition, but will mitigate their survival in a pristine condition in the future.

Not all the wetland could or should be left in the hands of nature alone. Using remote sensed information, decisions can rationally be reached regarding the ultimate fate of wetlands. Indeed the technology of remote sensing will find increased use in the consideration of our nation's wetlands.

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