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Application of Landsat Imagery to Shoreline Erosion

Areas susceptible to erosion in Croatan and Pamlico Sounds, North Carolina were identified.

Abstract: *Landsat imagery from a 5-year time span has been used to study water circulation patterns on Croatan Sound and Pamlico Sound, North Carolina, as the patterns relate to erosion of the mainland shoreline. Evidence of probable attack by the sound waters on the shoreline has been correlated with a recent aerial photographic study of shoreline erosion. Approximately one-half of the Landsat images used in the study showed evidence of attack upon each of the several points studied. Landsat imagery, with its repetitive nature together with the accumulated images, provides a relatively inexpensive tool for rapid evaluation of potential for erosion along mainland shores of estuaries.*

Introduction

Shoreline erosion on the mainland side of Croatan Sound, Pamlico Sound, and along portions of Albemarle Sound are of more than academic interest (e.g., Bellis *et al.*, 1975). The erosional process involves both attack on the land areas during periods of high wave activity and removal of material from beaches adjacent to the mainland. Shoreline erosion occurs chiefly because of the application of the kinetic energy of moving water to the shoreline. This application can come in the form of wave attack on the land and/or currents flowing parallel to the shoreline. If it is possible to determine where the energy is being applied on a consistent basis, then it should be possible utilizing Landsat together with other appropriate data to make predictions about the probability of erosion along a given stretch of the shoreline. Such information can be useful in designing experiments for actual measurement of the erosion and for guiding planning and management decisions where other forms of information may not be available.

Various methods of making inventories of shoreline changes are possible, use of old maps and aerial photographs being among the most common (e.g., Langfelder *et al.*, 1968; Stirewalt and Ingram, 1974; Bellis *et al.*, 1975). However, coverage of entire coastlines with aerial photography on a consistent, repetitive basis has not always been undertaken because of the costs, and when photography is available, often it is at widely spaced and irregular intervals. For those areas where aerial photography is limited in quantity, it appears that Landsat imagery provides a useful tool for sampling the coastline on a systematic basis and for identifying areas of potential erosion. Pluhowski (1976), for example, describes turbidity plumes derived from shoreline erosion on Lake Ontario.

The resolution of the Landsat imagery does not allow recognition of shoreline changes of less than about 100 metres, and the changes within the last five years on Croatan and Pamlico sounds have been less than this value (Stirewalt and Ingram, 1974). Thus, the usefulness of the Landsat imagery lies in providing clues to the hydrodynamics of the system causing the erosion and to the frequency with which certain patterns of water flow and associated erosion occur.

The well-known synoptic coverage of the imagery allows an investigator to study not only the shoreline within the approximately 100 metre limit of the imagery resolution but also evidence relating to circulation patterns within the water bodies (Welby, 1975, 1977). Thus, the investigator can evaluate evidence concerning water movement with relation to the shoreline. In addition to clues about the movement of suspended sediment, the imagery supplies information on the presence of shoal areas. The repetitive coverage of the imagery makes possible the acquisition, over a given period of time, of a much larger sample of the ever-changing water circulation patterns than is economically feasible through application of conventional aerial photography or through current-meter studies.

Fifty-three potentially usable images (30 percent or less cloud cover) exist from approximately 134 possible instances of imaging of the study area from both Landsat-1 and Landsat-2 (EROS Data Center, personal communication). Of these, 11 are cloud-free and 24 have less than 10 percent cloud cover. The images studied represent an 8 percent sample of the total theoretically possible number of images and approximately 30 percent of potentially usable imagery.

A variety of wind and tidal conditions are represented for the times of imagery acquisition; within the study area the lunar tides are less than six inches (NOAA). Interpretations made from the imagery concerning points of attack on the shoreline were compared with an aerial photographic study of the mainland side of Croatan Sound (Stirewalt and Ingram, 1975) and, in the course of the study, other points of probable attack were noted.

The chief purpose of the work has been to demonstrate the efficacy of the technique so that it can be applied elsewhere. Discussion of the physical oceanographic relations required to explain the water circulation recorded by the imagery is beyond the scope of the investigation. Singer and Knowles (1975) have documented the complexities of water movement in Croatan Sound and have demonstrated the importance of surface wind influence on water flow in Croatan Sound, Roanoke Sound, and Oregon Inlet. Persistent southwest winds can bring about a southerly water flow through Croatan Sound and Roanoke Sound, and wind speeds as low as 5 kt exert considerable influence on water circulation in the North Carolina sounds.

Imagery Used

The study is based upon 16 images covering northeastern North Carolina. They were chosen essentially at random, having been used in conjunction with other remote sensing studies; the time period from which the imagery was selected extends from August 1972 through early March 1977. This number represents a 30 percent sample of the potentially usable images and approximately 50 percent of the images with 0 to 10 percent cloud cover.

The images were studied in black-and-

Table 1. Activity Classification

1. *Direct Attack*
   The moving water appears to be impinging directly upon the shoreline. The patterns seen on the imagery suggest that the water mass is moving from a position directly offshore against the shoreline.
2. *Alongshore Water Movement*
   The main movement of the water along a particular stretch of the shoreline is parallel to the shoreline. Presumably current eddies associated with any turbulence are attacking the shoreline.
3. *Offshore Sediment Transport*
   There is evidence that sediment is being carried away from the shoreline as an identifiable plume. The tonal changes indicate that the suspended material becomes increasingly disperse with increasing distance from the shore.
4. *No Clear-Cut Evidence*
   For those images included in this class the reflectances indicate the presence of very little highly reflective suspended material in the water.
   Also included in this class are instances of a general dispersion of suspended material parallel to the shoreline but for which there appears to be little evidence for more than a general, diffuse suspension of sediment close to shore. Experience indicates that in general the water is relatively calm and little erosion can be expected to be occurring along the shoreline at the instant of imaging.

white format on a light table and in a color additive viewer. Color 35 mm slides of the viewer screen were also studied as an aid in the interpretation. Subtle color changes and tonal differences were utilized as guides to the current activity at the instant of imaging during the interpretation of the imagery. Patterns of apparent stream lines were noted and used in the interpretations.

A four-fold classification of the apparent water impact along the shore was devised. Each stretch of the shoreline studied was interpreted in terms of this classification. A summary description of each of the four classes is given in Table 1. In some cases an individual image indicates that the activity at a particular point can be placed in two of the classes. For example, there can be evidence of direct attack on one part of a shoreline stretch and evidence of off-shore sediment transport on another.

Results

Figure 1 shows the general study area. The specific shoreline reaches which have been studied are labeled on the figure. Bluff Point, Gibbs Points, and Long Wretch Point were chosen specifically for study because Stirewalt and Ingram (1975) had described the history of erosion at each of them. Sow Island Point was also used in the study for the same reason, although the total number of images used to study this point are fewer than for the other points. Stumpy Point and Long Shoal Point were included in the study because the imagery suggested that erosion and sediment transport away from these two points was important. Table 2 summarizes the data.

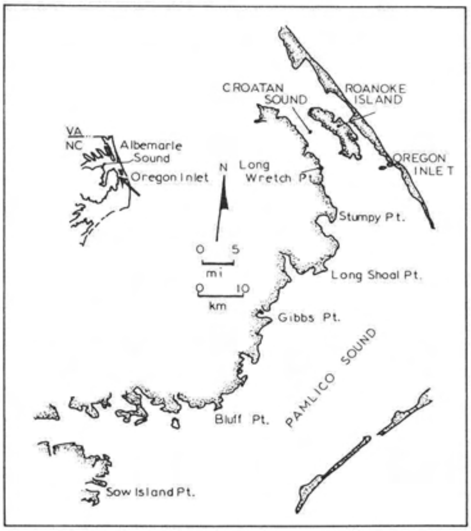

Fig. 1. Study locations, Croatan Sound and Pamlico Sound, North Carolina.

Long Wretch Point

Stirewalt and Ingram (1975) indicate that the net erosion on both the north and south sides of this point has been up to 10 ft/yr. Of the 16 images studied, ten show some evidence of erosion from the point. Direct attack accounts for four of these, and two images show sediment being moved offshore. Two of the images, 1 February 1977 (Figure 2) and 9 March 1977, show particularly well the movement of Albemarle Sound water through Croatan Sound as a well-defined entity. These images also show the apparent drag effect of this mass of water on the western shoreline of Croatan Sound. Singer and Knowles (1975, p. 102) describe the tendency of southward flow through Croatan Sound to hug its western shore. It seems probable that there is associated with this type of movement turbulence which could aid in erosion of the northern shore of Long Wretch Point.

Gibbs Point

Stirewalt and Ingram (1975) indicate that the bulk of the erosion on this point has taken place on its south side at the rate of approximately 3.5 ft/yr between 1939 and 1971. Image interpretation suggests that for approximately 50 percent of the time there is some sort of attack on the southern side of the point. Evidence of sediment transport

Table 2. Comparison of Erosion Rates and LANDSAT Interpretation

Location	Total Images Used	Approx. Erosion Rate (Stirewalt & Ingram)	Direct Attack	Alongshore	Offshore Transport	No Evid.
Long Wretch Pt.	16	10 ft/yr	4	6	2	4
Gibbs Pt.	16	3.5 ft/yr	7	2	4	2
Bluff Pt.	14	6 to 45 ft/yr	1	4	4	5
Sow Island Pt.	4	up to 3 ft/yr			4	
Stumpy Pt.	16	NO DATA	1	6	4	5
Long Shoal Pt.	16	NO DATA	1	5	6	4

FIG. 2. Movement of water from Albemarle Sound through Croatan Sound. White area north of Roanoke Island is ice. 1 = Long Wretch Point, 2 = Stumpy Point, 3 = Roanoke Island. Landsat-2 image, 2741-14485-5, 1 February 1977. Wind from west at estimated 5-10 kt midway in ebb cycle at Oregon Inlet.

FIG. 3. Offshore movement of suspended sediment from Stumpy Point area. 1 = Stumpy Point, 2 = Long Shoal Point, 3 = Roanoke Island, 4 = Oregon Inlet. Landsat-2 image, 2363-15003-5, 20 January 1976. Flood tide at Oregon Inlet, with 5-10 kt winds from south-southwest and west for 9 hours prior to image.

away from the point was found on approximately 25 percent of the images.

BLUFF POINT

Because of cloud cover only 14 images could be used for study of Bluff Point. One of the images showed evidence of direct attack upon the point, and, in contrast, four of the images showed offshore transport, chiefly from the eastern side of the point. A like number of the images indicated some sort of longshore transport.

Stirewalt and Ingram (1975) suggest that much of the erosion that took place between 1939 and 1971 occurred in conjunction with two hurricanes, one in 1958 and one in 1962. Because erosion has not been uniform along the point, they give a range of erosion rates for the 33-year period, from 6.5 ft/yr to 45 ft/yr. However, the sample of images used in this study seems to support the concept that normal erosion along the southshore of Bluff Point is associated more with alongshore currents than with direct attack, and it is assumed that a lower rate of erosion is associated with the currents flowing approximately parallel to the shore than with storm induced direct attack.

SOW ISLAND POINT

Several of the images cover Sow Island Point, and there is a consistent pattern of sediment streaming from the point eastward for several kilometres. A shoal area extends southeastward from the point into Pamlico Sound.

STUMPY POINT

Evidence concerning the effects of Croatan Sound water upon the shoreline of Stumpy Point shows that alongshore movements and sediment transport offshore (Figure 3) comprise over two-thirds of the activity. Little direct attack upon the point is suggested, and for approximately one-third of the images there is no unequivocal evidence that either erosion or deposition is transpiring. An unidentified resident of the area has indicated that extensive erosion has taken place over the last 30 or so years (R. Holman, personal communication). From its position on the shoreline of Pamlico Sound Stumpy Point should be attacked directly only when winds are blowing from the southeasterly quadrant on a rather consistent basis.

LONG SHOAL POINT

A straight, south-facing shoreline is characteristic of this particular point. The Landsat imagery indicates a predominance of water movement from the south and alongshore movement in a clockwise direction. Much of the evidence for erosion at this

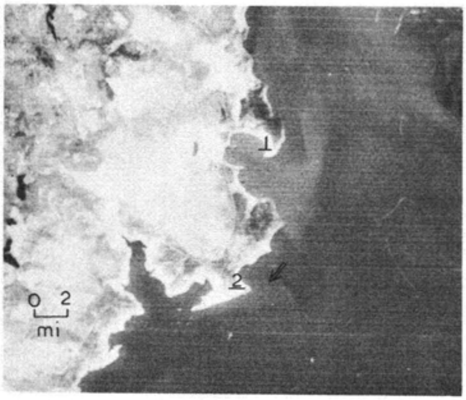

FIG. 4. Offshore transport of suspended sediment, Long Shoal Point. 1 = Stumpy Point, 2 = Long Shoal Point. Landsat-2 image, 1205-15150-5, 13 February 1973.

point consists of plumes extending eastward from the easternmost corner of the point (Figure 4). In some cases the plume is turned to the northeast; in other cases it continues as a narrow area of high reflectance on the imagery in an almost eastward direction; and in still other cases the plume turns southeastward and apparently disperses. There is a prominent shoal extending eastward from the eastern edge of the point. In only one image is there clearly a direct attack on the point. Four of the images show no evidence which might indicate that erosion is occurring.

Discussion

Interpretation of Landsat imagery can assist in regional studies of shoreline erosion potential. Its most important contribution, perhaps, lies in its use for identifying shoreline reaches and points which are particularly susceptible to attack because of repeated impingement of currents and waves on the shoreline. The imagery not only provides a means for identifying the areas, but it also is a potential method for sampling the frequency of the impingement. From the data used in this study it appears that conditions favorable for shoreline erosion occur between 60 and 70 percent of the time along parts of Pamlico Sound and Croatan Sound.

Knowledge of the strength of the current and wave activity at the time of imaging cannot be determined from the Landsat data. However, the application direction of the forces can be inferred from the imagery and their frequency can be sampled. Strength of the attack must be estimated from meteorological information. Geomorphic information contained on the imagery can aid in the interpretation.

It should be possible to measure in a summary manner the suspended sediment concentrations that are associated with shoreline attack. Where identifiable plumes leaving an eroding area are imaged, it should be possible to use the imagery to estimate the concentrations of suspended sediment being transported away from the eroding shoreline stretch (e.g., Bartolucci *et al.*, 1977). From this type of information it may be possible to improve estimates of the volume of material being eroded.

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