Harold F. Hennigar
Virginia Institute of Marine Science
The College of William and Mary
Gloucester Point, VA 23062

Quantification of Changes in Coastal Topography Using Simple Parallax Measurements*

Changes in dune topography were determined with a precision ranging from 0.5 to 0.9 metres from photography ranging in scale from 1:6000 to 1:24,000.

Introduction

Coastal processes have long been studied using aerial photography (Shepard, 1950; Sonu, 1964; Dolan and Vincent, 1973). Much of this early work has been qualitative due to the inability to obtain field measurements concomitant with the aerial photography. Shoreline erosion and accretion have been measured using aerial photography (Wanless and El Ashry, 1968; Langfelder *et al.*, 1973); however, standards for measuring erosion and accretion have only recently been compiled (Tanner, 1978). Sequential aerial photography has been used to quantify changes in shoreline orientation and overwash distribution (Zeigler and Ronne, 1957; Boc and Langfelder, 1977; Hosier and Cleary, 1977). These studies measured changes in shoreline erosion and accretion and were not concerned with information available on the photography dealing with the vertical dimension, namely, changes in topography.

This paper illustrates how changes in coastal topography can be measured using existing aerial photography and simple parallax measurements. Currituck Spit, the northernmost portion of the North Carolina Outer Banks, was selected as the study area primarily because there have been large changes in dune morphology and topography over a relatively short time span (Figure 1). Furthermore, sequential stereo photographic coverage of most of the Spit is available since the late 1930's. There are currently no topographic maps of the region, which necessitates measuring topography on the aerial photographs. The most recent maps of the region date back to 1940 and contain no topographic information. Many of the dunes in the area are migrating inland at rates of up to 13 m per year (Gutman, 1978; Hennigar, 1979). A study of dune morphological changes revealed a pattern extant over the entire study area in which large, actively migrating, sand hills or medaños are transformed into stable, vegetated parabolic dunes over a period of 35 years (Hennigar,

Abstract: *Simple parallax measurements revealed major changes in dune topography over a relatively short time span on Currituck Spit, Virginia-North Carolina. Dunes can migrate over 12 m per year and exhibit topographic changes on the order of metres per year. While these changes have not been recorded on any topographic map revisions, parallax measurements delineated these changes in topography to an accuracy of ±0.5 m. Because topography on existing topographic maps is rarely revised, maps of highly dynamic coastal areas may contain inaccurate topographic information.*

* VIMS Contribution No. 911

Photogrammetric Engineering and Remote Sensing,
Vol. 46, No. 1, January 1980, pp. 71-75.

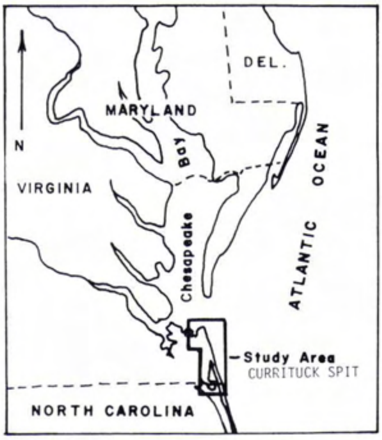

FIG. 1. Location of study area.

1979). Consequently, topography is continually being modified. Whereas topography of fastland areas may exhibit changes on the order of centimetres per century, topographic changes in the coastal zone are in metres per year. Obviously, the use of existing topographic maps in coastal dune areas for topographic information is not justified for more than a few years after publication of the maps.

For this study, topography of a single dune, known locally as Penny's Hill, was measured through time as the dune metamorphosed from a medaño into a parabolic dune.

METHOD OF STUDY

Stereo aerial photographic coverage of Penny's Hill was available for three dates at different scales (1955, 1:20,000; 1961, 1:6,000; 1975, 1:24,000). The 1955 and 1961 photography was available as 9 by 9-inch black-and-white prints while the 1975 imagery was available as 9 by 9-inch color infrared transparencies. A mirror stereoscope and a parallax bar were used to obtain parallax measurements.

In order to ascertain the precision of the parallax measurements, one point, chosen at random, was measured on each set of imagery. The parallax of each test point was measured twenty times over different occasions after the stereo pair had been aligned and fastened down. Table 1 summarizes these measurements. By this procedure, a reliable estimate was obtained of the variance of the population of parallax measurements. A Student's t-test was applied to determine whether minor differences in measured elevation could be considered to be significantly different.

TABLE 1. PRECISION OF PARALLAX MEASUREMENTS OF ONE POINT ON EACH STEREO PAIR

Parallax Measurements of One Point on Each Stereo Pair			
	1955 (mm - #)	1961 (mm) - (#)	1975 (mm) (#)
	0.78 - 2	0.19 - 4	0.33 - 1
	0.79 - 2	0.20 - 4	0.34 - 3
	0.80 - 3	0.21 - 8	0.35 - 7
	0.81 - 8	0.22 - 2	0.36 - 5
	0.82 - 4	0.23 - 1	0.37 - 3
	0.83 - 1	0.24 - 1	0.38 - 1
Mean	0.81 mm	0.21 mm	0.35 mm
Standard Deviation	0.01 mm	0.01 mm	0.01 mm

Points on the dune used for elevation calculations were measured at least five times and the mean of the parallax measurements was used to calculate the elevation according to

$$\Delta h = \frac{\Delta p H}{b}$$

where b = photo base (mm),
H = flying height (m),
Δh = difference in elevation (m), and
Δp = parallax difference (mm).

Measurements of each point, although obtained at one sitting, were not biased by memory effects since the vernier scale on the parallax bar was randomly changed between measurements. This was done for all points measured.

Elevations are given as heights above the surrounding plain rather than above sea level. This arbitrary datum was chosen in order that heights could be calculated with respect to measurements obtained at the base of the dune. This was done because changes in topography relative to the surrounding plain were considered to be more significant for this study. The dune itself is located in the center of a sparsely vegetated plain which highlighted the dune and made parallax measurements much easier to obtain.

A referenced grid system was drawn on clear acetate and overlayed on the imagery. Parallax measurements were obtained through the sheet of acetate so that they could be digitized and drawn at a common scale with minimum errors in the location of elevations on the dune.

Table 2 contains the parallax measurements obtained for two points on the 1975 imagery. The elevations were calculated to be 2.2 m and 3.1 m. Although the means of the parallax measurements differ

TABLE 2. RESULTS OF STUDENT'S T-TEST SHOWING THE ABILITY OF PARALLAX MEASUREMENTS TO DISCRIMINATE BETWEEN SIMILAR ELEVATIONS

	Pt. A (mm)	Pt. B (mm)
	0.32	0.29
	0.32	0.28
	0.31	0.29
(1975 DATA)	0.31	0.30
	0.32	0.30
	0.31	0.30
	0.32	
Mean	0.32	0.29
Calculated average height above base of dune	2.2 m	3.1 m

H_0: Mean A = Mean B
T = 5.9
d.f. = 11

H_0 is rejected at $P < 0.005$. Therefore, the calculated heights are significantly different.

only by 0.03 mm, a Student's t-test revealed that the height difference is significant at $P < 0.005$. A t-test of points on the other imagery sets revealed that differences in elevation of as little as 0.5 m could be distinguished.

Errors in parallax due to differences in scale were not considered to be significant (Johnson, 1957; Pope, 1957). Since present relief in the area is less than 25 m, changes in scale (maximum of 3.0 percent) within each photograph were neglected and, because Penny's Hill is small (diameter approximately 300 m), parallax measurements were obtained within a small area of each photograph (e.g., 25 cm²). Parallax errors caused by tip and tilt of the aircraft were not considered to be significant since tip and tilt were less than ±3 degrees.

RESULTS

Figure 2 graphically illustrates the metamorphosis of Penny's Hill from a medaño into a parabolic dune. It is important to note that, while maximum height decreased from 11 m to less than 7 m, the dune slipface also migrated more than 120 m toward the southwest. This gives an average annual migration rate of more than 6 m per year. An analysis of the changes revealed that adjacent vegetation was the major factor responsible for the transformation of Penny's Hill. Vegetation in 1955 (Figure 2) consisted of grass and shrubs less than 2 m high. As a result, offshore westerly winds, which are dominant, were the main force shaping the morphology of the dune as vegetation exerted little effect on the wind. As a forest succeeded the grasses and shrubs and increased in height to 10 m, the vegetation decreased surface wind velocity to the point where Penny's Hill fell within the wind shadow of the forest (Figure 2). As a result, onshore easterly winds assumed prime importance in shaping the dune.

The speed at which changes in dune morphology can occur has been dramatically illustrated and this raises several important questions.

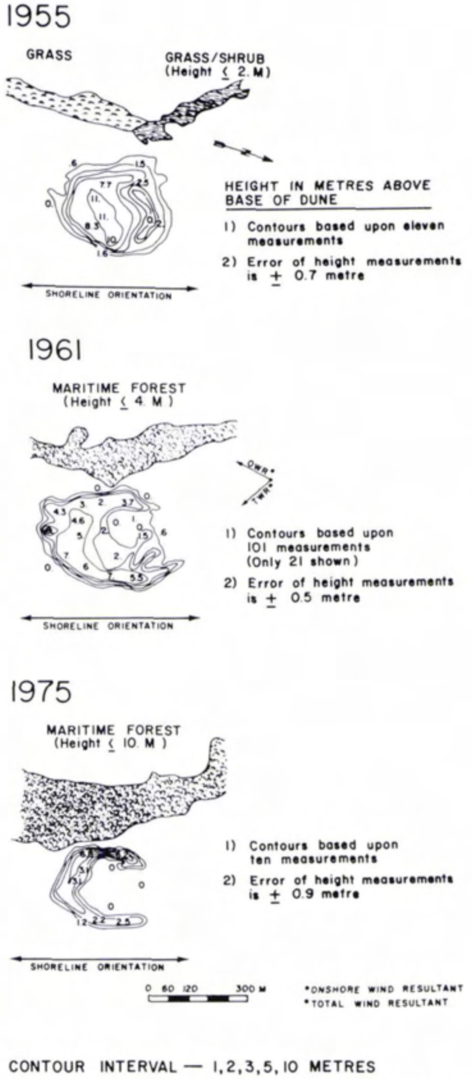

FIG. 2. Temporal changes in the morphology of Penny's Hill.

Discussion

United States Geological Survey topographic maps are periodically updated and only cultural changes are shown. Topography is not revised as often; thus, topography shown on many old maps of coastal dune areas is inaccurate.

Topographic maps exist for undeveloped False Cape State Park in Virginia; however, the last revision was in 1973 and did not update topography. The topography shown on the map was compiled in 1952, and since that time every medaño which existed in 1952 has metamorphosed into a parabolic dune and migrated many tens of metres. Planners rely on existing topographic maps when choosing access routes into the Park in order that roads will be planned so that they take the route which exhibits the least environmental impact. Access routes laid out using existing topographic maps will be invalid because the entire surface of the Park has undergone dramatic changes in all three dimensions. Roads planned to bypass dunes may now cut right through them, with a resulting adverse impact on the ecology of the entire park.

In other areas, parcels of land platted on level ground may now be at the crest of a dune migrating at more than 10 m per year. Clearly, the concept of a "mobile home" must take on entirely new dimensions.

The techniques used in this study are neither new nor sophisticated. Foresters rely on parallax measurements to estimate the volume of marketable timber because many areas are inaccessible and the cost of a field survey is prohibitive (Moessner and Choate, 1964). Geologists use parallax measurements to measure the dip of rock units visible on aerial photographs (Miller, 1961). River currents have been measured using parallax measurements (Cameron, 1952).

The application of this technique to the coastal zone can produce information on topographic changes which might otherwise be neglected. In coastal areas where topographic map revisions are to be undertaken, spot checks of elevations should be made prior to map production to determine if the changes are significant enough to warrant a complete map revision. The coastal geomorphologist, who often uses aerial photography in his work, can utilize this technique to measure changes in dune morphology.

Simple parallax measurements cannot approach the precision of the various plotters available, but when one considers the expense involved, the technique becomes very attractive, despite its limitations. A mirror stereoscope can be purchased for approximately $400.00, while a parallax bar costs less than $250.00. At the current price of existing black-and-white imagery, a 100-kilometre reach of coast could be examined for less than $1,000.00 (exclusive of labor costs). Given the simplicity and low cost of this technique, it is obvious that it represents a significant tool for measuring topographic changes in the coastal zone.

Conclusions

- Topography shown on existing topographic maps of coastal dune areas may not be accurate because coastal morphology exhibits changes on the order of metres per year, both laterally and vertically.
- Simple parallax measurements of dune areas, both in coastal and desert regions, can be used to obtain topographic information from existing aerial photography. This can aid in the better understanding of the various physical processes at work in these areas and possibly lead to better management decisions.

Acknowledgments

This project was supported in part by a Grant-In-Aid of Research from Sigma Xi.

Robert J. Byrne, Carl H. Hobbs, III, and John C. Munday reviewed the original manuscript.

References

Boc, S. J., and J. Langfelder, 1977. *An Analysis of Beach Overwash Along North Carolina's Coast.* Report No. 77-9. North Carolina State/University of Raleigh, 17 p.

Cameron, H. L., 1952. The Measurement of Water Current Velocities by Parallax Methods. *Photogrammetric Engineering,* Vol. 21, No. 1.

Dolan, R., and L. Vincent, 1973. Coastal Processes. *Photogrammetric Engineering,* Vol. 39, No. 2, p. 255-260.

Gutman, A. L., 1978. *The Interaction of Eolian Sand Transport, Vegetation, and Dune Geomorphology, Currituck Spit, Virginia-North Carolina.* M.A. Thesis. College of William and Mary, Williamsburg, Va., 190 p.

Hennigar, H. F., 1979. *Historical Evolution of Coastal Sand Dunes on Currituck Spit, Virginia-North Carolina.* M.A. Thesis. College of William and Mary, Williamsburg, Va., 121 p.

Hosier, P. E., and W. J. Cleary, 1977. Cyclic Geomorphic Patterns of Washover on a Barrier Island in Southeastern North Carolina. *Environmental Geology,* Vol. 2, p. 23-31.

Johnson, E. W., 1958. Effect of Photographic Scale on Precision of Individual Tree-Height Measurements. *Photogrammetric Engineering,* Vol. 24, No. 1, p. 142-152.

Langfelder, J., D. Stafford, and M. Amein, 1968. *A Reconnaissance of Coastal Erosion in North Carolina*. Dept. of Civil Engineering, N.C. State University at Raleigh, N.C.

Miller, V. C., 1961. *Photogeology*. McGraw-Hill Book Company, Inc., New York, 248 p.

Moessner, K. E., and G. A. Choate, 1966. Terrain Slope Estimation. *Photogrammetric Engineering*, Vol. 32, No. 1, p. 67-75.

Pope, R., 1957. The Effect of Photoscale on the Accuracy of Forest Measurements. *Photogrammetric Engineering*, Vol. 23, No. 5, p. 869-873.

Shephard, F. P., 1950. Photography Related to Investigation of Shore Processes. *Photogrammetric Engineering*, Vol. 16, p. 756-769.

Sonu, C. J., 1964. Study of Shore Processes With Aid of Aerial Photogrammetry. *Photogrammetric Engineering*, Vol. 30, No. 6, p. 932-941.

Tanner, W. F. (editor), 1978. *Standards for Measuring Shoreline Changes*. Coastal Research and Dept. of Geology, Florida State University, Talahassee, 87 p.

Wanless, H. R. and M. T. El-Ashry, 1968. Photointerpretation of Shoreline Changes Between Cape Hatteras and Fear (North Carolina). *Marine Geology*, Vol. 6.

Zeigler, J. M., and F. C. Ronne, 1957. Time-Lapse Photography—An Aid to Studies of the Shoreline. *Naval Research Review*, O.N.R., April, 1957.

(Received 23 February 1979; accepted 16 July 1979)

Notice to Contributors

1. Manuscripts should be typed, double-spaced on $8\frac{1}{2} \times 11$ or $8 \times 10\frac{1}{2}$ white bond, on *one* side only. References, footnotes, captions—everything should be double-spaced. Margins should be $1\frac{1}{2}$ inches.
2. Ordinarily *two* copies of the manuscript and two sets of illustrations should be submitted where the second set of illustrations need not be prime quality; EXCEPT that *five* copies of papers on Remote Sensing and Photointerpretation are needed, all with prime quality illustrations to facilitate the review process.
3. Each article should include an abstract, which is a *digest* of the article. An abstract should be 100 to 150 words in length.
4. Tables should be designed to fit into a width no more than five inches.
5. Illustrations should not be more than twice the final size: *glossy* prints of photos should be submitted. Lettering should be neat, and designed for the reduction anticipated. Please include a separate list of captions.
6. Formulas should be expressed as simply as possible, keeping in mind the difficulties and limitations encountered in setting type.

Journal Staff