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Beach Changes and Management Options for Nauset Barrier Beach and Orleans Town Beach, Cape Cod, MA: Report to the Town of Orleans

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David G. Aubrey and William Robertson V

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Technical Report

Funding was provided by the Town of Orleans and the Andrew W. Mellon Foundation.

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Department of Geology and Geophysics
Woods Hole Oceanographic Institution
Woods Hole, MA 02543

Presented to:

Paul Fulcher
Parks and Recreation Superintendent
Town of Orleans, MA 02653

April 1998

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Approved for Distribution:

William B. Curry, Chair
Department of Geology and Geophysics

EXECUTIVE SUMMARY

The present study investigated the shoreline and dune changes occurring along Nauset Barrier Beach system during the past sixty years, based on examination of aerial photographs, charts, and other data sources. This study updates the previous studies by scientists from the Woods Hole Oceanographic Institution, from the past forty years or more.

Significant changes have occurred to the barrier beach and dune systems of Nauset during the fifteen intervening years since the last major study of the system. The barrier and shoreline in general has continued to retreat, at rates varying from 1 to 10 feet per year, depending on location. The barrier beach in general has eroded at a faster rate than the shoreline to the south near Pochet Neck. The dunes have undergone strong changes as well. Nearly all the dunes along South Spit have eroded away during storms, so the new profile of the South Spit is extremely low lying and storm waves overtop it frequently. Overwash has resulted in more rapid migration of South Spit towards the west, into Nauset Harbor, closing off South Channel which separates the Spit from New Island. Dunes to the south, towards the Orleans Town Beach, also have been eroded away, causing die-off of freshwater vegetation near Aspinet Pond and increased flooding of Aspinet Road.

Extensive previous research performed on erosion rates are consistent with the present rates. However, present data from this report include more up-to-date photographs, and include specific attention to dune retreat and recent tidal inlet migration and number of inlets. Such decadal updates on the behavior of Nauset Barrier Beach and the adjacent Orleans Town Beach can provide valuable timely information for assessing management practices for this region.

The focus of this study was on three specific management issues associated with recent changes in the barrier beach and dune system:

A) Health effects associated with erosion of the septic system at Orleans Town Beach
B) Flooding of Aspinet Road
C) The fate of New Island, and its contribution to stability and habitat suitability of South Spit of Nauset Barrier Beach

Several management options have been identified for further study and analysis in Phase II of this project. These management options are:

A) Health effects associated with erosion of the septic system at Orleans Town Beach

- relocate the septic field under the parking lot
- relocate the septic field to incorporate it into the field of the adjacent motel
- strengthen the dune system by sand fencing and other structural means, while moving the pedestrian access to the beach, to isolate the septic system from the water more effectively
- use porta-johns for the parking lot, or other pump-out options, to remove the need for a septic field at the site. A package plant should be one option considered.

B) Flooding of Aspinet Road

- raise Aspinet Road so it drains better and is above most flooding levels

- re-route Aspinet Road (investigate alternative routes)
- use sand fencing to encourage repair of the dune line
- truck sand into the site to repair the dunes artificially

C) The fate of New Island, and its contribution to stability and habitat suitability of South Spit of Nauset Barrier Beach

- Signage and/or fencing to restrict vehicle and human access to the island
- Dredging of South Channel to prolong the flow between South Spit and New Island - (restricting access once again)

We recommend that the Town of Orleans examine these options carefully in a Phase II study, providing estimates of feasibility, permittability, town and state acceptance, costs and likelihood of achieving the management objectives.

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BEACH CHANGES AND MANAGEMENT OPTIONS FOR NAUSET BARRIER BEACH AND ORLEANS TOWN BEACH, CAPE COD, MA

David G. Aubrey and William Robertson V
Department of Geology and Geophysics
Woods Hole Oceanographic Institution
Woods Hole, MA 02543

INTRODUCTION

The scope of the present study (Phase I) was defined as follows:

Phase I: Historical perspective and prediction of future beach state

Ia) Document the historical changes in the Nauset beach system (focusing on Orleans), updating the earlier studies of Aubrey et al. which extend from the 17th century to 1985.

Ib) Determine the causes of erosion and deterioration of the Nauset beach system during the past decade. Several hypotheses have been identified to be examined.

Ic) Based on our knowledge of the behavior of the beach system, and our knowledge of barrier beach behavior in general, provide assessment of the likely state of the Nauset beach system for the next decade.

Id) Provide assessment of potential alternatives for effective beach management.

To carry out this study, the authors analyzed aerial photographs from more than 60 years, focusing on barrier beach, marsh and inlet change at Nauset Inlet, as well as Orleans Town Beach. The Town of Orleans has funded projects to evaluate Nauset Inlet and its contiguous coastal systems during the past two years, to provide needed input for more effective management of its coastal resources.

Nauset Estuary is a salt marsh located on outer Cape Cod, Massachusetts (Figure 1), characterized by *Spartina* marshes and unvegetated sand flats separated by shallow channels. Barrier beaches divide the marshes from the ocean, and have been serviced by one or two inlets at different times. The main inlet has migrated north since the 1930's, and there is often a second inlet due to strong storms and overwash processes. Evidence of a second inlet dates back to 1960. The tidal range is about 6 feet, and the sediment source is the cliffs to the north, as described by Speer et al. (1982).

Orleans Town Beach (Figure 2) is about 75 to 100 feet wide, from Mean High Water (MHW) to the duneface. There are three main pedestrian paths through the dunes which provide access to the beach from the parking lot. The parking lot is located to the west, just beyond the dunes. Three buildings border the parking lot.

Woods Hole Oceanographic Institution has produced numerous reports concerning Nauset Estuary in recent years. Past reports include the geologic evolution (Aubrey et al., 1982; Uchupi et al., 1996), evolution of the barrier beach and adjacent beaches (Speer et al., 1982; Aubrey and Speer, 1983; Aubrey and Speer, 1984; Miller and Aubrey, 1985; Geise and Aubrey, 1987), tidal behavior (Aubrey and Speer, 1985; Speer and Aubrey, 1985; Hess and Aubrey, 1985; Aubrey, 1986; Aubrey and Friedrichs, 1988; Friedrichs and Aubrey, 1988; Fry and Aubrey, 1990; Speer et

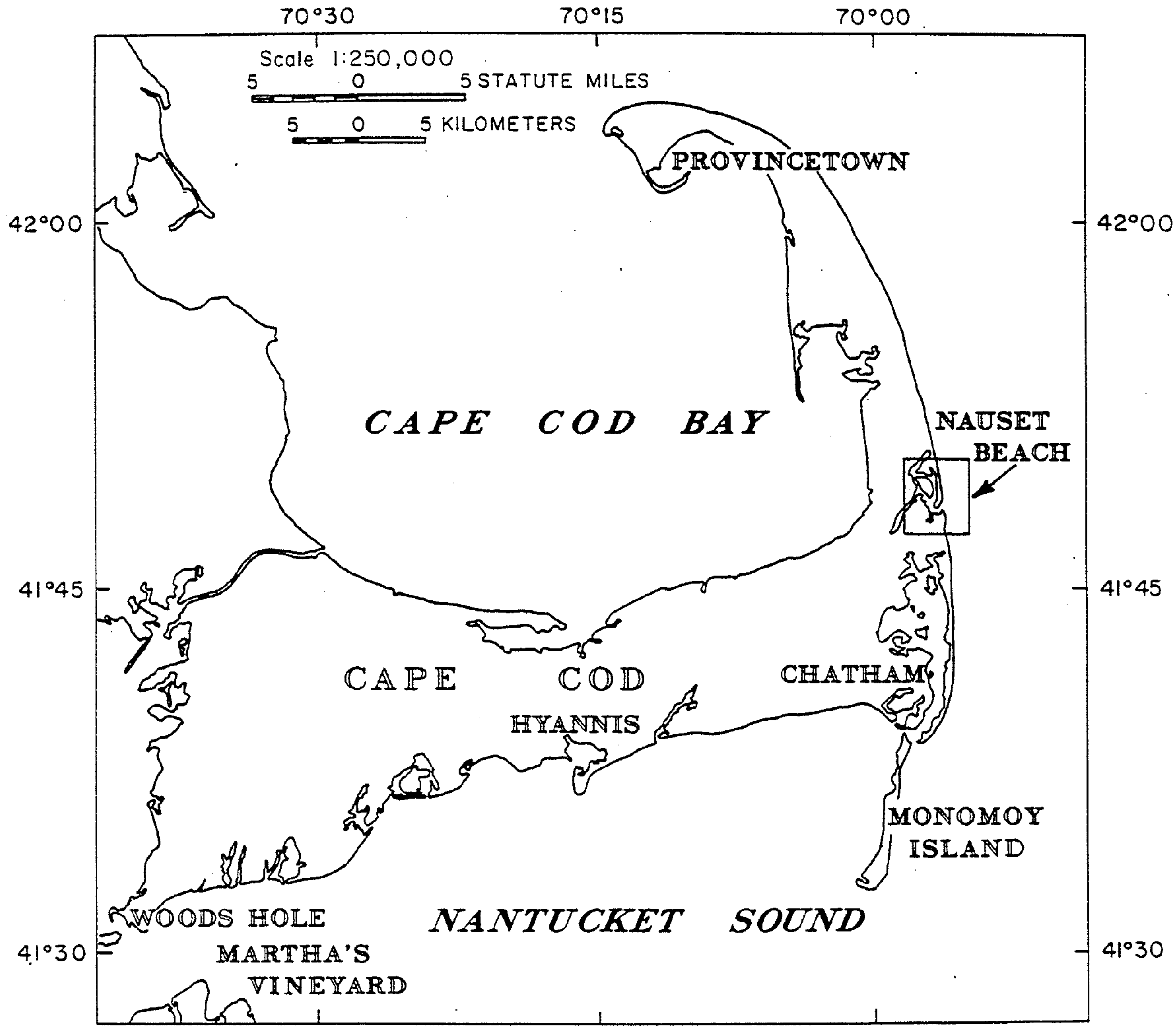

Figure 1: Map showing the location of Nauset Estuary.

al., 1991; Aubrey et al., 1997), sediment transport (Aubrey, 1986; Fry and Aubrey, 1990; Aubrey and Speer., 1983), and tidal inlet migration (Speer et al., 1982; Aubrey and Speer, 1984).

Most recently, Aubrey et al. (1997) examined the flushing characteristics of the embayment, under conditions of a single inlet and dual inlet characteristics during the first half of the 1990's. This 1996 report provides up-to-date information on the water exchange within the embayment, but does not examine the barrier beach evolution. The present report focuses on the barrier beach and dune systems.

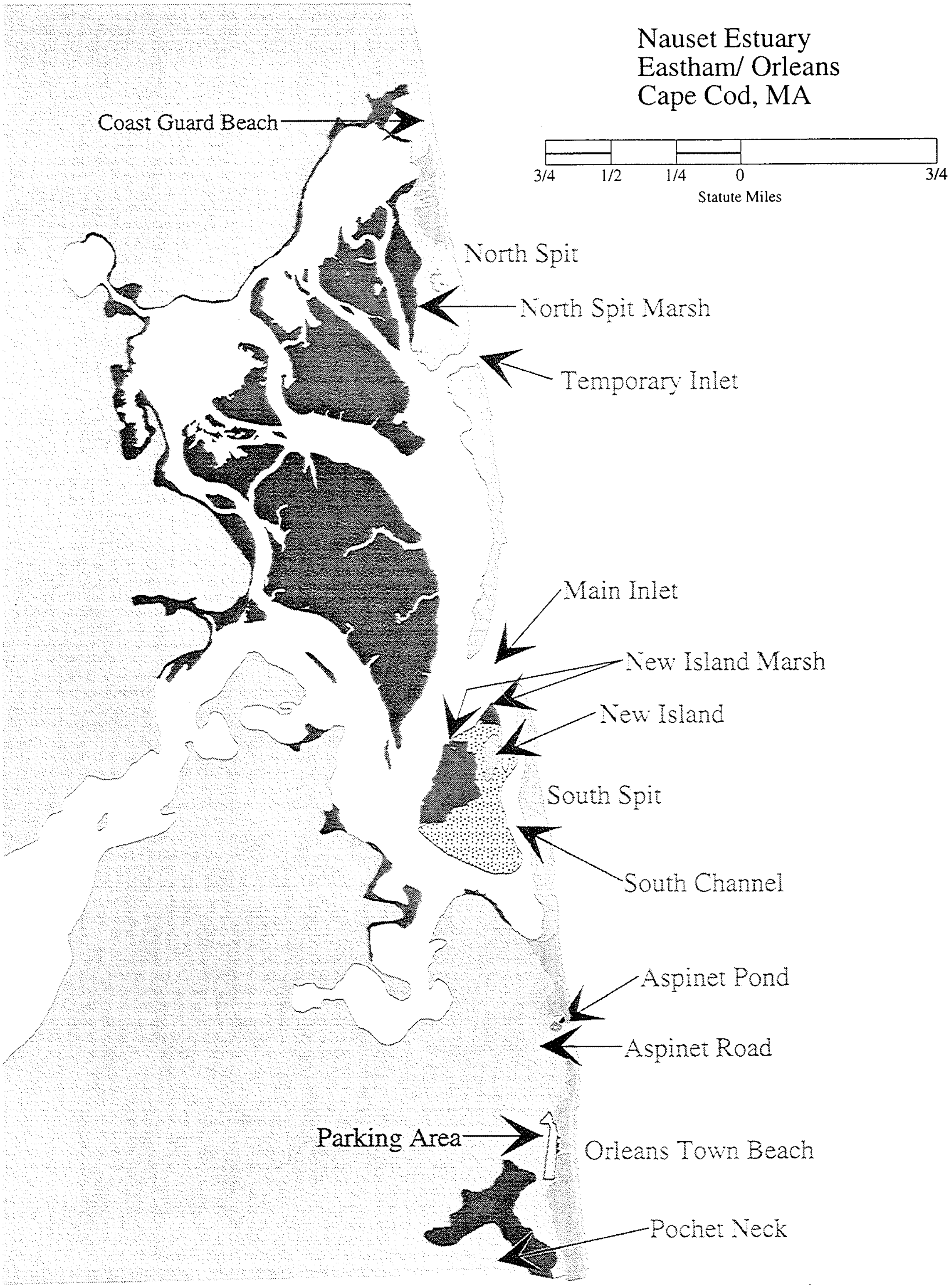

Figure 2. Map of Nauset Estuary and Orleans Town Beach defining locations mentioned in text.

Previous work (e.g., Speer et al., 1982) discussed erosion rates along the outer Cape Cod region, including Nauset Inlet. An erosion rate of 5 ft/year at Coast Guard Beach was determined by Zeigler and Tuttle (1961). Gatto (1979) determined the historical shoreline erosion rates of the mid-Cape, which is south of Provincetown and north of Chatham, at -0.2 to -4.4 ft/year. Leatherman (1979) stated that the erosion rate of the Nauset Inlet area was at least 3 ft/year. Speer et al. (1982) determined the area between Nauset Heights and Coast Guard Beach was eroding at a rate of 5.6 ft/year to 17.4 ft/year. Sea level rise described by Speer et al. (1982) and overwash processes described by Zaremba and Leatherman (1984) are causes of erosion and landward migration of barrier spits.

Orleans Town Beach and Nauset Inlet are of growing concern for Orleans Town Officials for three reasons: emergence and growth of New Island, Orleans Town Beach septic system, and flooding of Aspinet Road. Years of observations has led the Town to believe that the shoreline is eroding, the dune structure is eroding, and the barrier beaches are moving landward. Stemming from these concerns a few questions arose.

1) What is the future evolution of the barrier beach, and how will it serve its recreational, natural resource, and storm damage functions?
2) How should the barrier beach be managed?
3) Will the South Spit connect to New Island? If so, when and how should it be managed?
4) How should Orleans Town Beach be managed?
5) When should plans be made to relocate or replace the septic system?
6) How should Aspinet Road be managed?

New Island has developed due to increasing sand deposits within Nauset Estuary. The island is now surrounded by marshes and sand shoals below Mean High Water (Figure 2). One concern is that South Spit will connect with New Island. Rare birds including the Common Tern, Least Tern, and Piping Plover inhabit the island. If New Island connects to the land, animal and human intervention is inevitable, thus placing the rare bird nesting site in danger.

The Orleans Town Beach septic system (Figure 8) consists of two 5,000 gallon septic tanks connected to 7 leaching pits by a 4 inch diameter tight PVC pipe. Only 234 feet currently separate the septic system from mean high water. Title 5 of the State health regulations requires the system to be at least 100 feet from the ocean and 6 feet above the water table. By documenting the erosion rates of the shoreline and dunes on Orleans Town Beach, we investigated how long the Town of Orleans has before it must relocate its septic system.

Aspinet Road (Figure 2) is an access road servicing four homes. The road is east of Nauset Heights and runs approximately north-south. The road is often flooded from the ocean during northeast storms, and the homeowners lose access to their homes. The homeowners are seeking a plan to assure uninterrupted access to the homes for health and emergency purposes.

The purpose of this report is to address the questions listed above. The report is an update of a previous report completed by Speer et al. (1982). Using several sets of vertical aerial photographs, GIS mapping and previous work completed in the area, we present alternatives and suggestions to the problems facing the Town of Orleans.

METHODS

Several sets of maps were examined to produce the necessary data for evaluation. Speer et al. (1982) presented their analysis using tracings of charts and aerial photographs from 1670 to approximately 1980. Their data set covers an extended period of time, yet does not provide the accuracy which can be accomplished today. We sought a data set that is accurate, durable, easy to use and easy to add to in the future. We considered the best method is to digitize vertical aerial photographs into a Geographic Information System (GIS). The GIS selected for use, in part because the Town of Orleans has access to Macintosh computers, is MapGrafix.

Table 1: List of aerial photographs used for GIS

Date	Photographed By	Obtained From	Scale
11/21/38		National Arcives & Records	1:23,158
10/20/51	National Ocean Survey	NOAA	1:9,498
06/03/52		Virginia Ins. Marine Science	1:20,220
05/10/53	U.S. Coast & Geodetic Survey	NOAA	1:9,950
03/15/55	U.S. Coast & Geodetic Survey	NOAA	1:24,599
04/20/60	Teledyne Geotronics	Cape Cod National Seashore	1:7,200
1962	U.S. Geological Survey	WHOI	1:24,000
09/12/70	U.S. Coast & Geodetic Survey	NOAA	1:19,412
09/24/70	U.S. Geological Survey	U.S. Dept. of Interior	1:25,419
02/21/74	U.S. Geological Survey	U.S. Dept. of Interior	1:23,937
03/18/75	Col East, Inc.	Col East, Inc.	1:9,541
04/23/78		Cape Cod National Seashore	1:24,000
09/21/81	Col East, Inc.	Col East, Inc.	1:18,000
08/22/82	Col East, Inc.	Col East, Inc.	1:18,000
10/20/82	Col East, Inc.	Col East, Inc.	1:18,000
09/16/87		Cape Cod National Seashore	1:7,200
04/04/91		Town of Orleans	1:24,000
Oct-94	Mass. Coastal Zone Managemt.	Cape Cod National Seashore	1:10,000
03/30/96	Col East, Inc.	Col East, Inc.	1:6,000

An exhaustive search for aerial photographs produced 19 sets covering 58 years (Table 1). We only accepted photographs with a scale greater than 1:25,000. This ensured accuracy of the digitized product, as smaller scales make locating main features difficult and the error in positioning becomes unacceptable. Ten control points were established from an Orleans Geologic Quadrangle and mosaics for the respective photograph sets were created (see Appendix II).

Each mosaic was digitized into MapGrafix using the 10 control points. MapGrafix, the GIS software, uses Affine Transformation to transfer the control points. The Affine Transformation calculates a best-fit least-squares algorithm, and determines the rotation, offset, and scale adjustments required to produce an accurate map.

Shoreline, marsh, dune, sand shoals, Nauset Heights Pond, and Orleans Town Beach parking lot are the features digitized into the maps (Figure 2). The shoreline is water intersecting land or marshes at MHW. Marshes are determined by heavy vegetation exposed during MHW. Sand dunes are digitized when vegetation and/or distinct changes in elevation occur landward of the shoreface. Sand shoals are determined by large amounts of sand exposed in the photographs below MHW. Sand shoals in the ocean are often characterized by breaking waves. Nauset Heights Pond is a small pond occasionally intruded by salt water during storms. Orleans Town Beach parking lot and buildings are digitized as themselves.

Two reference grids are applied to each map. The grids have a baseline and lines perpendicular to the baseline. The grids were created within MapGrafix and are saved as different layers. The layers are attached to each digitized map, ensuring exact coordinates on each map. Measurements of distance are made from the baseline to the duneface and MHW along the respective perpendicular lines.

The measurements provide distance data from 1938 to 1996. Average Accretion Rate, or AAR, is calculated within Matlab using the distance data and the polyfit function. The polyfit function uses the vectors of year vs. distance and finds a polynomial which fits a line within those vectors in a least squares sense. The slope of that line is AAR, which is in feet per year.

To check the variability of AAR, a t-test described in Aubrey et al. (1984) is applied to the given data with a 95% confidence limit. The t test is a measure of the variability of the slope of the line AAR. By multiplying the t-statistic by the square root of the variance of AAR, an estimate to the accuracy of the data is produced. A large value shows there is a high probability that the data set is more widely scattered from AAR, whereas a small value shows there is a high probability that the data set is grouped close to AAR.

Several factors can increase the inaccuracy of the distances recorded on the maps, especially in areas where there are inlets. The spits on either side of the inlets migrate towards the estuary due to wave activity and overwash processes. Therefore, a station measuring a shoreline which is close to an inlet will return smaller distances due to the spit's local migration toward the estuary. Dune distances are rarely accurate, due to many washouts creating voids in the data and difficulty to digitize when covered with sand after a storm. Dolan et al. (1980) and Smith and Zarillo (1990) describe other errors including a poor base map, incorrect control point, distortion in photographs, and difficulty in locating the mean high water level.

Analysis of analog (film-based) aerial photographs may suffer from a number of error sources:

- Distortion of the camera lens, causing scale mismatches around the outer edge (normally) of photographs.
- Camera at a tilt (not level) on airplane: can be caused by aircraft pitch, yaw or heave, as well as by aircraft acceleration (affecting the gyroscope on the camera)
- Printing errors while making contact prints or enlargements
- Digitizing errors due to poor measurements (generally not a problem with modern accurate board digitizers)
- Inaccurate scaling of reference points
- Sloppy digitizing by operator
- Inaccurate identification of target being digitized (i.e., Mean High Water line, dune crest, vegetation boundary)

These errors are difficult to quantify precisely. Each camera will have its own distortion, which is difficult to correct for analytically. To improve on quality of analysis, and to reduce errors, we have applied modern analytical techniques, including:

- Use of modern digitizing tools (including digitizing table)
- Use of Geographic Information System (GIS) to enable precise overlays
- Error checking through duplicate digitizing of control points
- Estimation of control point errors using statistical capabilities of GIS
- Minimization of camera distortion by using only centers of photo frames

Based on use of these techniques, we estimate our errors to be of the order of several meters, but less than ten meters in most cases. The errors are certainly less than the magnitude of the trends identified in the analysis.

RESULTS

Results from the analysis are presented both as tables and as figures. The data discussion is divided into two segments: one for Nauset Barrier Beach from Coast Guard Beach to Pochet Neck; the second restricted to the vicinity of Orleans Town Beach.

Nauset Barrier Beach

This segment of the outer beach of Cape Cod stretches from Coast Guard Beach south to Pochet Neck (Figure 3). The beach has been divided into 15 separate, equally-spaced transects some 1660 feet apart. Each transect is perpendicular to a baseline which was established in the interior of Nauset embayment, which is overlain digitally onto the aerial photographs using the GIS. The erosion rate of both the dune face and the shoreline have been calculated according to methods discussed in previous sections.

Dune and shoreline advance/recession rates are provided for the 15 transects indicated on Figure 3 (Figures 4 through 6). In all figures, the shoreline erosion is indicated by a line connected by circles, whereas the dune recession is indicated by asterisks. The solid lines show the data points connected by straight line segments, whereas the dashed lines show the best fit linear trends (discussed later). These erosion/accretion trends for both dune and shoreline are summarized in Table 2. The dashed lines represent AAR.

Table 2: Nauset Barrier Beach System Transects 1-15

Transect #	Dune Accretion Rate (ft/yr)	95% Confidence Limits On Dune Accretion Rate (ft/yr)	Beach Accretion Rate (ft/yr)	95% Confidence Limits On Beach Accretion Rate (ft/yr)
1	-2.1	75.8	-1.7	1.3
2	-0.6	3.0	-1.7	1.4
3	-2.7	3.7	-1.9	3.5
4	-4.9	2.0	-3.3	2.5
5	-7.0	2.9	-5.4	2.8
6	-1.4	4.1	-0.4	7.3
7	-0.1	4.0	8.6	15.5
8	-3.4	13.0	-0.3	7.9
9	-6.1	12.6	-8.4	8.5
10	-10.4	5.7	-9.8	8.8
11	-8.5	15.9	-7.7	5.2
12	-5.5	4.7	-7.5	3.4
13	-6.9	3.0	-6.6	3.4
14	-7.7	1.6	-6.5	2.6
15	-5.1	3.4	-5.1	2.2

* Negative numbers indicate erosion (recession), positive numbers indicate advance (progradation)

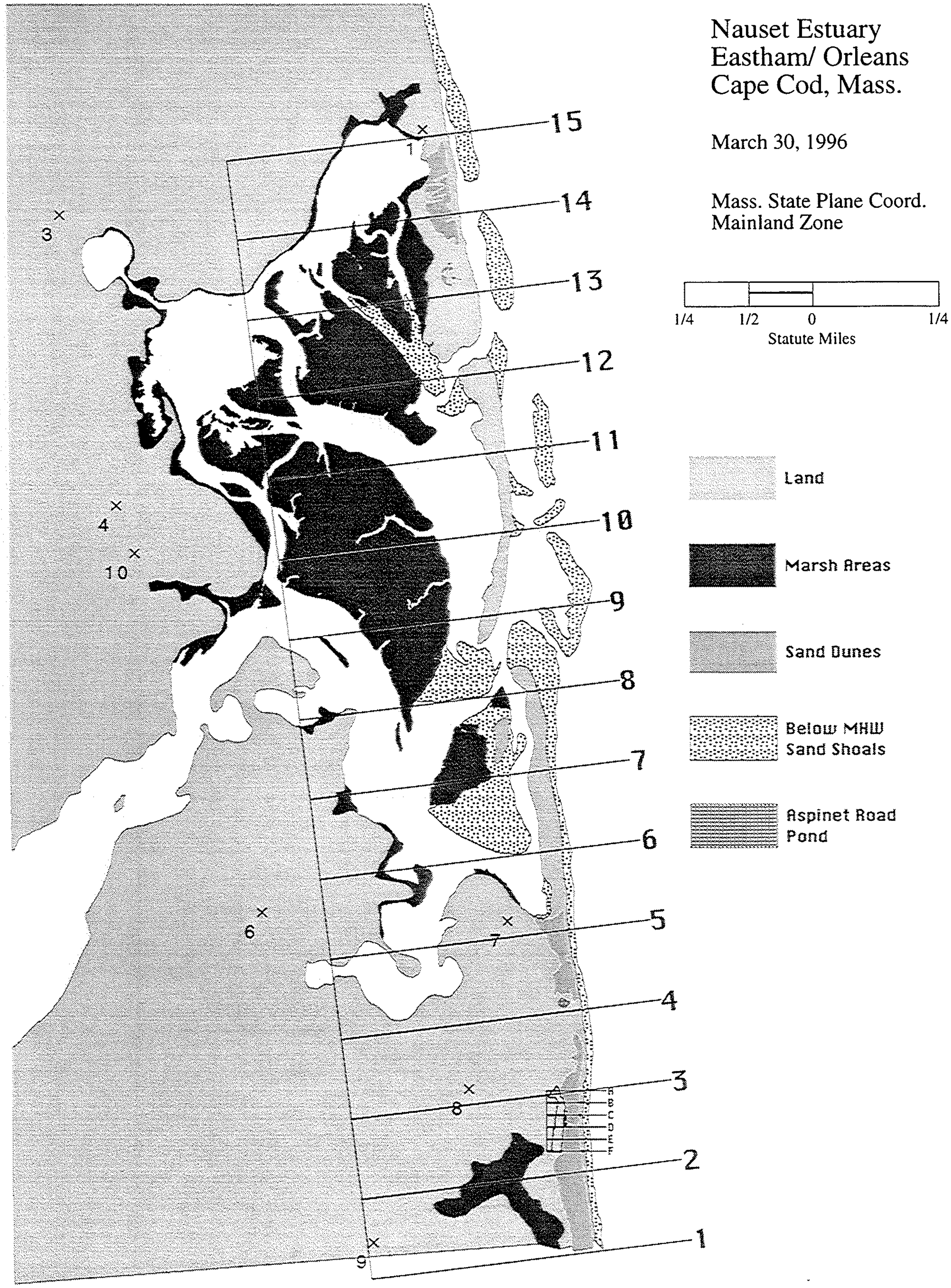

Figure 3. Reference map of Nauset Estuary showing control points and both reference grids.

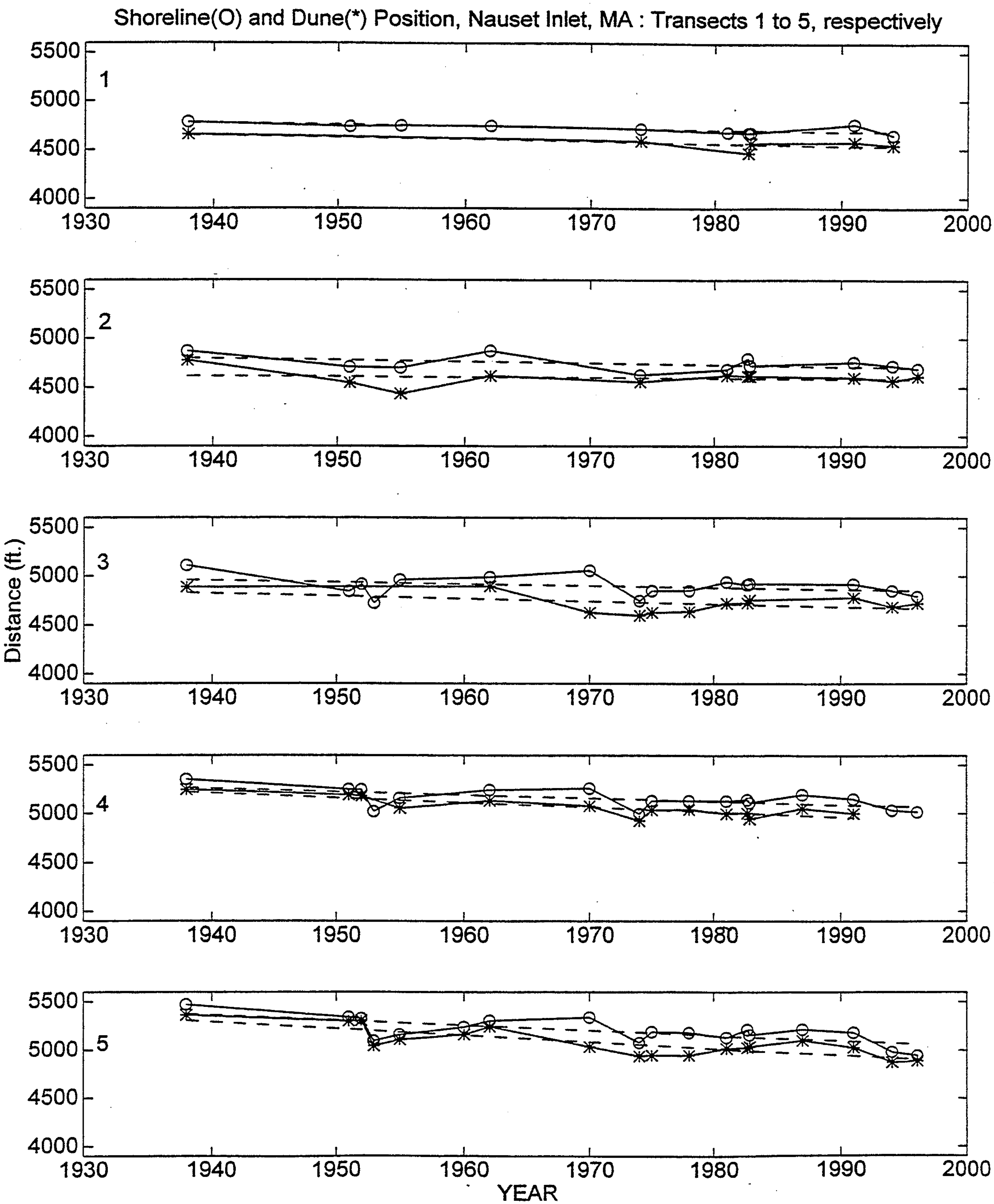

Figure 4. Plot showing shoreline "O" and dune "*" distances for Transects 1-5. Measurements were made from the baseline to duneface and MHW for each transect on the large reference grid (see Figure 3).

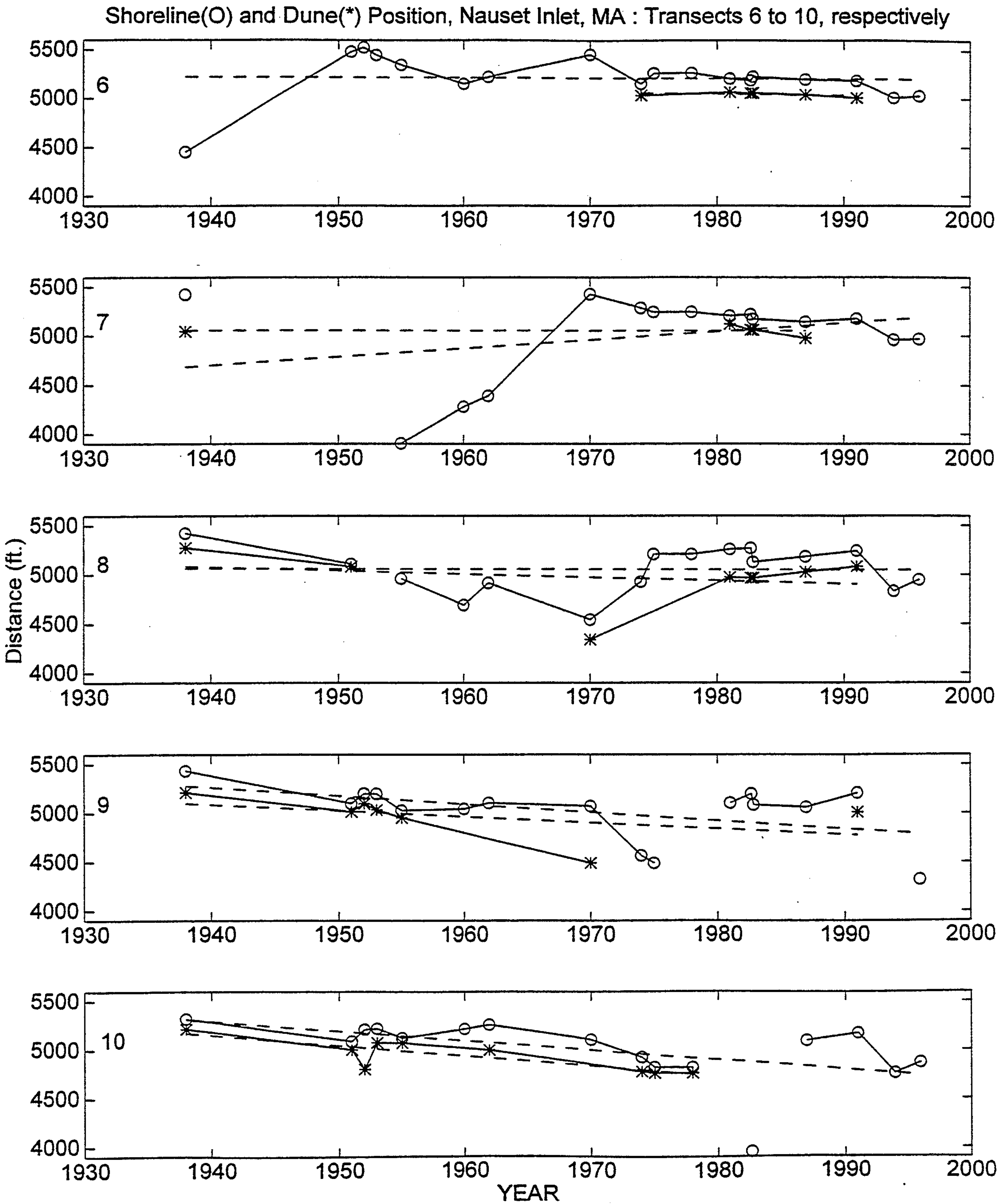

Figure 5. Plot showing shoreline "O" and dune "*" distances for Transects 6-10. Measurements were made from the baseline to duneface and MHW for each transect on the large reference grid (see Figure 3).

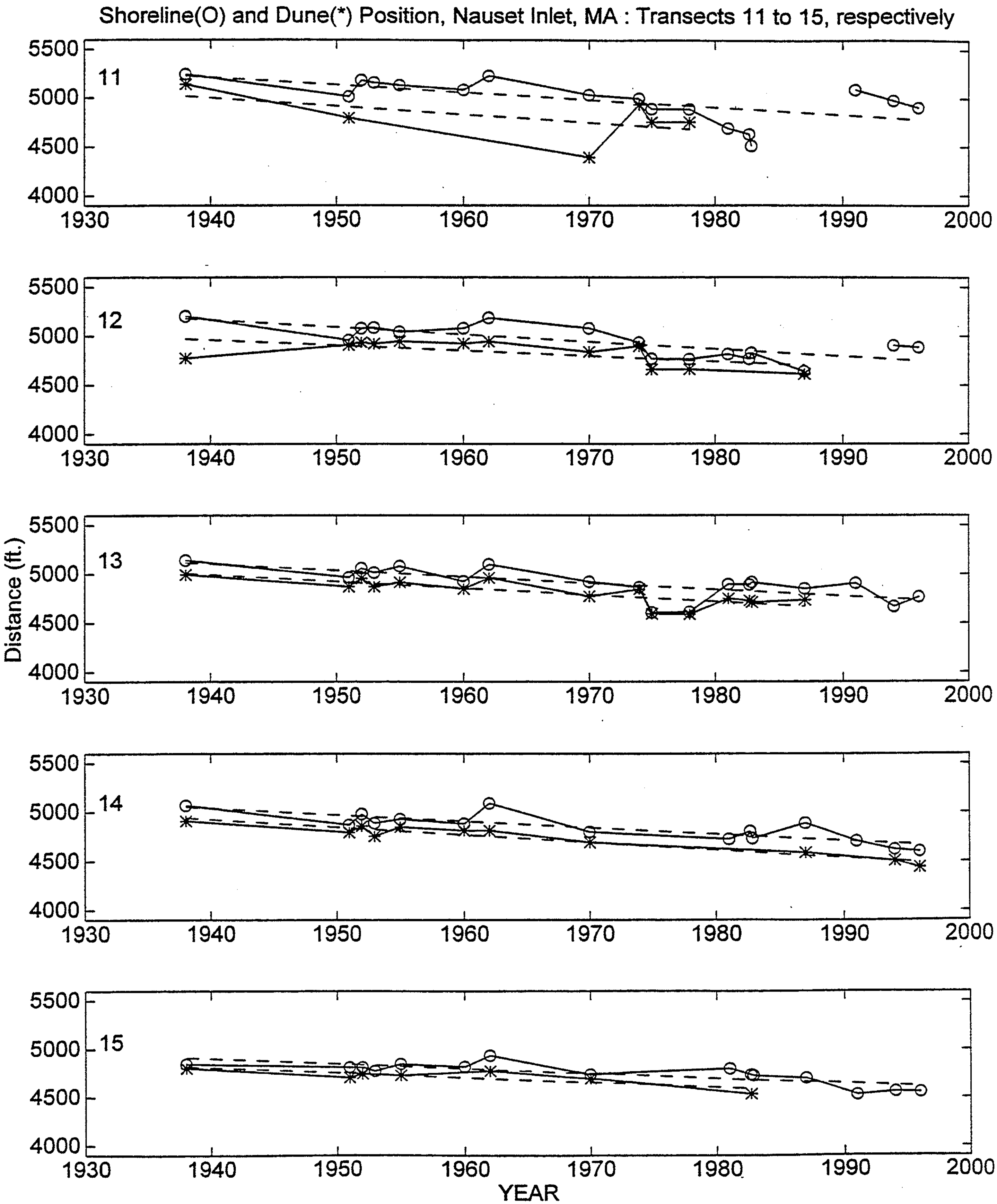

Figure 6. Plot showing shoreline "O" and dune "*" distances for Transects 11-15. Measurements were made from the baseline to duneface and MHW for each transect on the large reference grid (see Figure 3).

Dunes along the entire Nauset region have been eroding steadily during the period of investigation (1938 to 1996). Dune erosion rates have varied from small (fraction of a foot per year) to a rate of 10 feet per year (Transect 10). However, erosion rates for dunes are affected strongly by tidal inlet processes (migration of the inlet) and by human influence (construction of dunes along southern Nauset Barrier Beach in the 1970's). Inlet migration presents complexities in interpretation of the data, since at times dunes and shorelines are absent at that position due to the inlet's presence. In this case, no data was entered for the dune or shoreline position, and the statistics for linear trend were determined based on other data values that are available for that location. Thus, the linear trend does not assure the shoreline or dune change was monotonic, but rather provides an estimate of the mean trend for the sixty year period.

The inlet influence is shown by Transects 8 through 11, where the variability of the dune advance/retreat rate is highest (generally between 10 and 15 feet). This high variability reflects the dunes coming and going as the inlets migrate past. The high erosion rate at Transect 10 reflects the dominance of the inlet at this position during the past twenty years. Accelerated erosion rates and large variability in dune and shoreline position are characteristic features near tidal inlets (within a three to five mile distance, generally, depending on the inlet dynamics).

The human influence on the dunes is reflected in Transects 6 through 8, where dune reconstruction took place in the 1970's. Transect 8, for instance, shows an advance of the dunes of some 125 feet between 1970 and 1980. In spite of this dune reconstruction, however, the average position of the dune has retreated in the sixty year period of the study.

The dunes along Transect 4 are of particular concern now, since this is the location of a significant breach in the entire dune system of Nauset. The extensive wetlands of the Aspinet Road area have been altered due to overwash of the beach following destruction of the dunes. The extensive freshwater wetland pond between the dunes and Aspinet Road now has died due to saltwater incursion, leaving a mass of dead vegetation where healthy freshwater wetlands once thrived. At Transects four and five, dune recession rates have averaged 5 and 7 feet per year respectively, higher than at Transects farther south.

Dune recession generally is not linear, rather occurring on a cyclical basis. For instance, Transects 4 and 5 show several cycles of dune advance and retreat, more or less correlated with the rate of shoreline advance and retreat. North of the inlet, near Transects 12 through 15, dune recession also has been high. Coast Guard Beach (Transect 15) for instance, lost most of its dunes during the March 1978 storm. By 1982, some vestiges of dunes had reformed, but later no significant dunes existed.

Shoreline erosion rates prevail along the entire coast, except at Transect 7, which is located just east of New Island (see Figures 2 and 3 for location). Here, net shoreline accretion is shown because of the rapid oceanward advance following the inlet migration past this Transect in the mid-1950's. This shoreline advance is therefore erroneous, and only a measure of inlet processes, rather than overall beach stability. The large value for 95% confidence limits support this observation (15 feet, or twice the mean value).

Beach erosion tends to be smaller along the southern stretch of the study area, from Transects 1 through 5. This stretch of beach is not a barrier beach, but rather a beach fronting a low-land protecting what were formerly wave-cut coastal bluffs. This low-land may represent the fill of the former Pochet channel connecting Pleasant Bay with Nauset Harbor (see Speer et al., 1982).

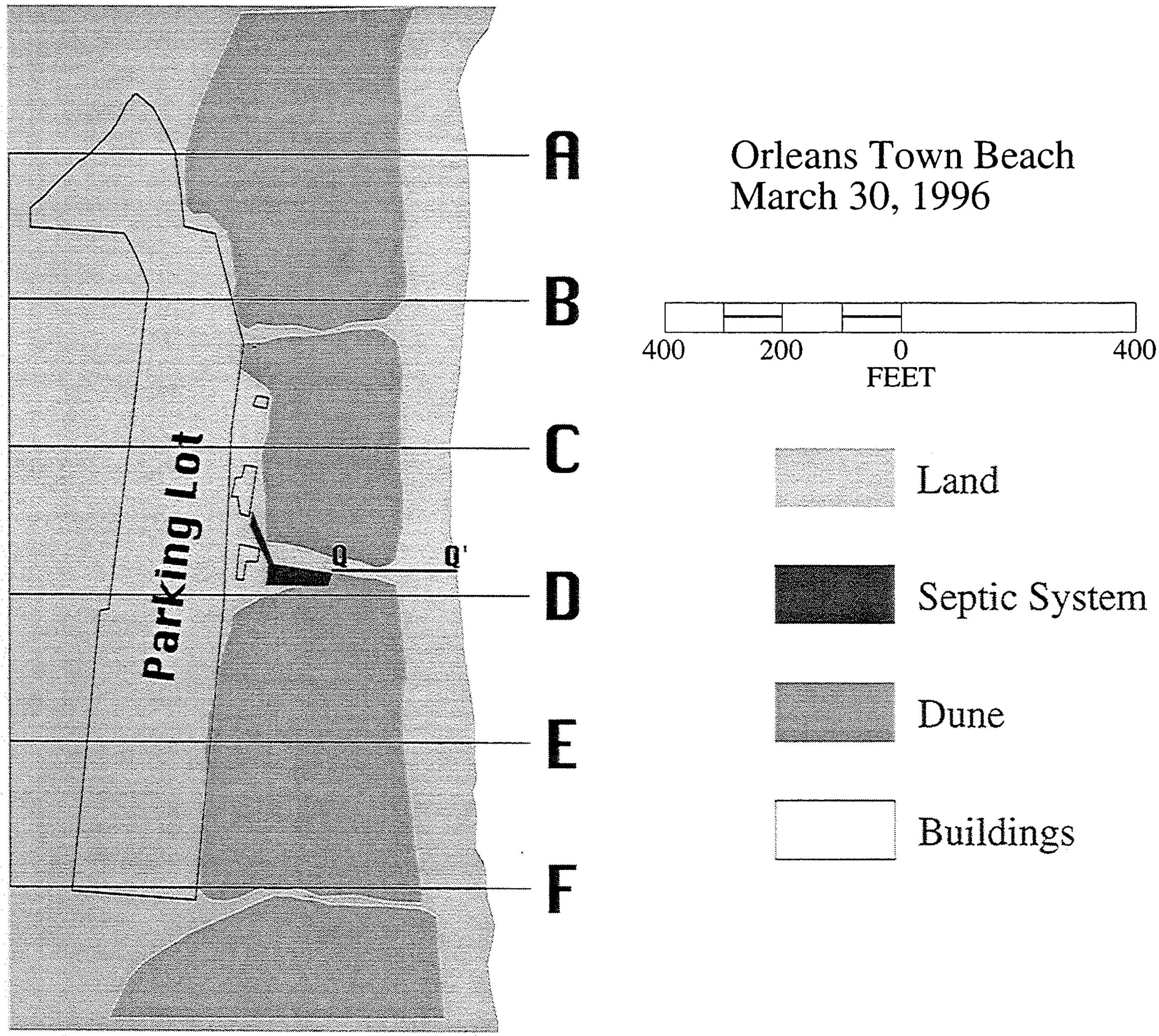

Figure 7 Map of Orleans Town Beach showing reference grid and septic system

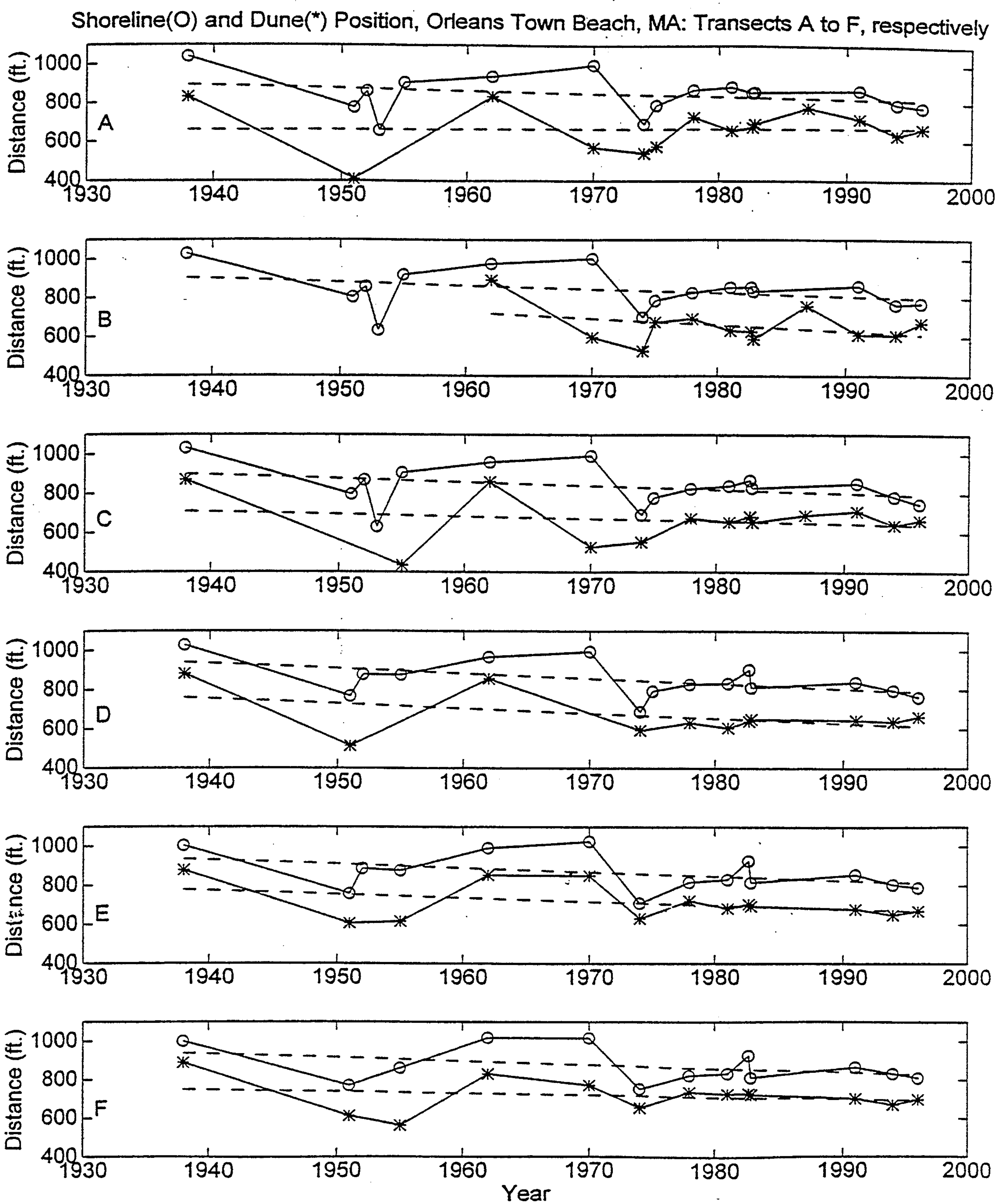

Figure 8. Plot showing shoreline "O" and dune "*" distances for Transects A-F. Measurements were made from the baseline to duneface and MHW for each transect on the small reference grid (see Figures 3 and 7).

As expected, the erosion rates are larger, as are the values for beach variability along the barrier beach itself. Here, erosion rates are generally between 5 and 10 feet per year on average. Along Coast Guard Beach to the north, where inlet processes haven't played a direct role, the erosion rates are about 6 feet per year. Along the inlet-dominated reach, shoreline erosion is generally higher, as is shoreline position variability.

Orleans Town Beach

In order to examine processes closer to Orleans Town Beach, six transects were defined at higher resolution than the transects for the entire study (Figures 7 and 8). These six transects, A through F, spaced some 250 feet apart, span the distance from the south end of the Orleans Town Beach parking lot to the north end of the parking lot. Transect A at the north end, nearly coincides with Transect 3 of the beach-long study. Similar to the regional beach study, the focused study near Orleans Town Beach measured dune and shoreline advance/retreat, as well as the confidence intervals for both (Table 3). The same data sources (Table 1) were used for both studies, so errors due to the photographs themselves (distortions) will be the same.

Table 3: Orleans Town Beach Transects A-F

Transect #	Dune Accretion Rate (ft/yr)	95% Confidence Limits On Dune Accretion Rate (ft/yr)	Beach Accretion Rate (ft/yr)	95% Confidence Limits On Beach Accretion Rate (ft/yr)
A	0.2	3.7	-1.2	7.7
B	-4.4	26.6	-1.7	9.5
C	-1.4	10.1	-1.6	9.6
D	-2.9	15.0	-2.4	11.2
E	-1.9	9.6	-1.9	10.0
F	-1.1	6.2	-1.8	9.7
* Negative numbers indicate erosion (recession), positive numbers indicate advance (progradation)				

Since Transects A and 3 nearly coincide, and since the shoreline positions and dune positions were digitized independently, comparison of results for these two transects can provide some measure of the error associated with digitization and selection of shoreline position and dune location. The comparison shows dune advance of 0.2 feet per year for Transect A, versus retreat of 2.7 feet per year for Transect 3. This comparison is within the 95% confidence intervals for both sets of measurements, so they are consistent. The shoreline erosion is more similar: for Transect A erosion of 1.2 feet per year exists, whereas it is 1.9 feet per year at Transect 3. These values are close, and well within the 95% confidence limits for accretion/retreat rates. Thus, added confidence is provided to the study results due to the close agreement between these independent measurements.

Dune recession rates are generally between one and four feet per year along the entire parking lot area, with significant variability at Transects B and D. The location of the beach access is along Transect D, where the septic system also is located (at a distance of 234 feet shoreward of 1998 mean high water, and 153 feet from the duneface). Dune erosion rates at Transect D are 2.9 feet per year, with a variability of 15 feet per year. Thus, there is a 2.5% probability that the dune erosion rate could be nearly 18 feet per year at this location. If this erosion were to occur for a period of time, within three years the dune line could be within 100 feet of the leaching field.

Shoreline erosion rates are about the same magnitude: they range from about 1.2 to 2.4 feet of erosion per year along the parking lot reach. However, variability in beach erosion rates are often smaller than the dune variability: reaching only about 11.2 ft/year. There is a 2.5% chance of an erosion rate of 14 feet per year at station D, in which case it would take 10 years before the mean high water mark would be within 100 feet of the septic system.

Beach and dune changes along this stretch of Orleans Town Beach is also cyclical. Dune and shoreline tended to accrete during the interval between the mid-1950's and the mid-1970's, which coincides with the interval of the most active migration of Nauset Inlet. Following this period of change, there has been a steady, slow erosion of the beach and dune system during the last 20 years.

DISCUSSION AND RECOMMENDATIONS

The entire barrier beach system from Coast Guard Beach in the north to Pochet Neck in the south has been experiencing significant dune and beach erosion during the interval from 1938 to present. Previous studies have examined beach and dune erosion rates up to the early 1980's, and this is the first study to update our understanding of Nauset Barrier Beach system coastal processes.

Beach erosion rates are greatest on the barrier beach in the vicinity of Nauset Inlet, than along the Town Beach farther south. This finding is consistent with the scientific observation that shoreline change is more rapid near tidal inlets. Dune recession rates also are highly variable, and strongly dependent on the proximity to the tidal inlet.

The erosion of the dunes and beaches has not been dominated by a single or several storms. Instead, the process has been somewhat cyclical, with periods of a couple of decades. The cause for this periodicity has not been identified in this study. It may be related to storminess and hence sediment supply from erosion of updrift coastal bluffs. However, there are no indications of sudden jumps in beach behavior: periodic variation superimposed on a gradual erosion trend is the dominant mode.

Erosion of the beach is due to a number of causes, some of which are influenced by human activities, but many of which are natural. Erosion of much of the world coastlines is a natural accompaniment to relative sea-level rise. Relative sea-level rise is the combined result of the global increase in ocean levels that has accompanied the melting of the glaciers during the past 20,000 years or so, with the local tectonic movement of the land. Emery and Aubrey (1991) provide a comprehensive review of relative sea-level rise around the globe, including Cape Cod. Similarly, Uchupi et al. (1996) provide a thorough review of factors causing erosion on Cape Cod, including Nauset region.

In short, relative sea levels along Nauset are rising. This rise is a combination of sinking of the land mass (due to glacial isostasy: offloading of the ice mass causes both rebound where the ice used to be, and sinking of the land surrounding the glacial margin) and global rise in water levels. Although the precise partitioning of these two contributions is still debated by scientists, it is not important as the net result of relative rise of approximately one foot per century is generally accepted. Rise of relative sea-level, in the absence of massive influx of river sands, generally is accompanied by erosion as waves are able to attack the shoreline at progressively higher and higher levels.

Thus, shoreline retreat is a natural, though not universal, result of relative sea-level rise. Numerous authors have documented the retreat of Nauset Barrier Beach through the ages, resulting from this rise. The present study provides a more quantitative measure of this retreat.

Adding to the natural retreat of shorelines are the effects of human interference. Withdrawal of groundwaters from coastal regions, oil and gas extraction, shoreline structures which affect longshore sediment delivery, and dams and barrages as river modifiers, all can have negative effects on shorelines by altering their natural retreat processes. Fortunately, along the Nauset coast, there are few human influences such as this, and retreat is dominantly a natural process.

Beach erosion can also be accelerated near tidal inlets, as inlets widen and narrow, form and disappear, and migrate along the coast. Generally, observations indicate that any beach within two miles of a tidal inlet will experience heightened erosion, and will have more year-to-year variability in erosion rate. The present study and its data support this observation.

Offshore bar conditions also can be correlated with shoreline erosion. Offshore bars are an integral part of the shoreline processes in most coastal areas. Offshore bars are formed and retreat in concert with shoreline processes, so the two mechanisms cannot be separated. Thus, examination of beach and dune stability must address offshore bar conditions, though these are difficult to document from historical data (such as aerial photographs). Offshore bars along the east Cape Cod shoreline are formed from a number of processes. Along the shoreline north of Nauset beach, the bars are formed as sediment accumulations on a much harder erosional surface where sediments are less mobile and less available for transport (see, for example, Aubrey et al., 1982; Uchupi et al., 1996). South of Nauset, however, the sediments are more mobile, as they represent geologically recent active sediments, and not eroding glacial sediments. Here, bars are formed more directly as a result of shoreline processes. Bars also are related to the tidal inlet positions. Tidal inlets are characterized by large sand deposits, including offshore bars such as flood and ebb-tidal deltas.

We hypothesized that the erosion along the Town Beach may be related to fluctuations in bar formation, which in itself may be related to changes in offshore bar morphology. A possible cause of the degradation of offshore bars that may have accelerated erosion along the Nauset shoreline is the migration of Nauset Inlet. Prior to the 1950's, the location of Nauset Inlet was relatively fixed opposite Nauset Heights. However, in the forty years since, the inlet has migrated to the north at a rapid rate, removing the sand source (ebb tidal delta) from the proximity of the Town Beach. Lacking this large feeder delta, it is possible that the longshore bars off the Town Beach have gradually disappeared.

Unfortunately, the aerial photography was inadequate to disprove or prove this hypothesis. We could not identify the bars with sufficient accuracy in all aerial photographs. Thus, this hypothesis is still untested, and this process of inlet migration may have contributed to the instability of the Town Beach (including the Aspinet region).

Dune erosion is also a common feature accompanying relative sea-level rise. Dunes will come and go as the shoreline retreats, generally forming a line of defense during a certain shoreline position, then eroding as the shoreline progressively retreats. Dune erosion is due to wind processes, as well as wave and storm processes. Dunes may come and go even when the beach itself is relatively stable on average. Dune lines may breach during storms, only to repair themselves during inter-storm events.

In summary, then, shoreline and dune erosion and retreat are expected features along the Nauset shoreline, and must be incorporated into any management plan. Management must take into account not only average erosion rates, which may be characteristic over some period of time, but also extreme erosion rates. These concepts are discussed in this report.

Three major management issues are of particular concern to the Town of Orleans:

A) Health effects associated with erosion of the septic system at Orleans Town Beach
B) Flooding of Aspinet Road
C) The fate of New Island, and its contribution to stability and habitat suitability of South Spit of Nauset Barrier Beach

We address these management issues in light of the findings of the present study.

A) Health effects associated with erosion of the septic system at Orleans Town Beach

Orleans Town Beach parking lot and its associated buildings and support infrastructure have been located at their present site for decades. The septic system, according to Town maps provided to us by P. Fulcher, is located seaward (east) of the snack bar at the beach, in a low spot behind the primary dune. Adjacent to the septic system is a main pedestrian access way to the beach.

The distance from the septic field to the duneface was surveyed on 30 January, 1998, by Woods Hole employees. The separation is now 153 feet. Title 5 requirements coupled with Town requirements mandate a separation of at least 100 feet between a septic system and a wetland resource (such as primary dune face or mean water level). The results from this study show the retreat rate for the duneface is up to 18 feet per year (at a probability of one chance in twenty each year), so there is a small but finite probability that the dune will erode to within 100 feet of the septic system within three years or so.

The separation between Mean High Water and the septic field is 234 feet. At an erosion rate of 3 feet per year, it will take 40 years before mean high water is within 100 feet of the edge of the septic field. However, if the 95% probability value is used for sake of conservatism, the septic field will be within 100' of mean high water within 10 years.

Recommendation: We recommend that the Town immediately study options for relocating the septic field from its present position. Within a few years, there is a probability not only that the septic field will be within 100' of a coastal resource area, but also that storm waters will flood the field and alter its effective functioning. Several alternatives should be examined in Phase II in the next few months:

- relocate the septic field under the parking lot
- relocate the septic field to incorporate it into the field of the adjacent motel
- strengthen the dune system by sand fencing and other structural means, while moving the pedestrian access to the beach, to isolate the septic system from the water more effectively
- use porta-johns for the parking lot, or other pump-out options, to remove the need for a septic field at the site. A package plant should be one option considered.

B) Flooding of Aspinet Road

Aspinet Road historically has been flooded several times a year during storms. Some of this flooding is due to freshwater accumulation, but much lately has been due to saltwater accumulation. With the destruction of the dune system which formerly protected the low-land between the primary dunes and the coastal banks behind it, flooding during storm high waters is becoming more frequent and more intense (more water deposits in the lowland, and takes longer to empty).

The temporary loss of Aspinet Road provides a health and safety issue. Some houses use this road as their primary access. Others have this as a secondary access/egress for emergency purposes. Loss of access increases the vulnerability of the houses to loss of emergency vehicle access (fire, ambulance).

This flooding will continue until the dunes have repaired themselves naturally (which may take a decade or more), or until some more active management plan is implemented (such as rebuilding the dunes artificially, using sand fencing or sand trucking).

If the loss of access to Aspinet Road is untenable, several options should be examined during Phase II:

- raise Aspinet Road so it drains better and is above most flooding levels
- re-route Aspinet Road (investigate alternative routes)
- use sand fencing to encourage repair of the dune line
- truck sand into the site to repair the dunes artificially

C) The fate of New Island, and its contribution to stability and habitat suitability of South Spit of Nauset Barrier Beach

The evolution of New Island promises to make it play a larger role in the evolution of South Spit of Nauset Barrier Beach. Several prominent trends have occurred on New Island:

- New Island has been growing steadily larger, as sand flats have been expanding
- New Island has accumulated salt marsh, stabilizing and enlarging it
- New Island has a larger subaerial region, formed from sand dunes
- As South Spit has migrated landward, and Middle Channel has become the dominant conveyance to Town Cove, the South Channel has narrowed so South Spit is now nearly attached to New Island

Consequences of these evolutionary trends include:

- There is a strong likelihood that New Island will continue to grow in the future, unless the inlet re-establishes itself farther south to erode the island
- South channel will likely continue to narrow and shoal
- South Spit will likely attach itself to New Island, on a time scale of a decade or less

The implications of these trends include:

- As South Spit attaches to New Island, the migration of South Spit will likely slow, and the inlet likely will remain north of the juncture formed from the Spit and the Island.
- South channel will close off, so flushing in Nauset Harbor will be less efficient (possibly causing some water quality degradation in Nauset Harbor).
- Attachment of South Spit to New Island will make it easier for humans, vehicles, dogs, and feral animals to intrude onto New Island, affecting subtidal and supratidal habitat for clams, birds, and other animals.
- Attachment of South Spit to New island will provide a measure of stability to Nauset Heights, unless the South Spit is breached exposing Nauset Heights to direct wave erosion once again. By stabilizing the position of South Spit, dune formation may be accelerated, thus enhancing protection of Nauset Heights behind it.

Management options that should be investigated closely during Phase II of this study:

- Signage and/or fencing to restrict vehicle and human access to the island, if island is connected to South Spit
- Dredging of South Channel to prolong the flow between South Spit and New Island (restricting access once again).

FUTURE WORK

The proposal to the Town of Orleans called for a three-phased project. The first phase has been completed and is reported upon in the present report. The next two phases should be considered by the Town for future funding, to enable it to manage the important Atlantic Ocean beach facilities in the most effective manner.

Based on the present study, we have updated the specific actions to be addressed during Phase II:

Phase II: Management, policy, and engineering alternatives

IIa) Research options for relocating the Orleans Town Beach septic field, and determine rough costs for such relocation
IIb) Research options for relocating or enhancing Aspinet Road, and determine rough costs for such management
IIc) Research options for managing the habitat and wildlife associated with New Island, and determine likely viability and rough costs for such management
IId) Identify possible alternatives for enhancing the entire barrier beach system (dune reconstruction, off-road vehicle restrictions, etc.)
IIe) Identify funding and timeline for implementation of such management and policy options

Phase III: Implementation

Following completion of Phase II, we will clarify the specific tasks within Phase III, which is the implementation Phase. Specific tasks for Phase III might include:

- application for funding (either Town or external)
- conceptual design
- engineering design
- consensus building within the Town
- permitting
- construction/implementation

ACKNOWLEDGMENTS

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APPENDIX I: Definitions

Confidence levels

The 95% confidence limits represent the t test measuring the variability of the slope of the dune/beach accretion rate. The confidence limit value represents a +/- limit which we are 95% confident that the value of the accretion rate is within the limits. A large confidence limit value shows there is high variability with the predicted accretion rate. For example, if the accretion rate is -5 and the 95% confidence limit is 2, then we are 95% confident that the predicted value is -5 +/-2. Thus, we are 95% confident that the value can be as high as -3, and as low as -7.

Dune accretion rate

AAR is plotted by Matlab using the vectors year vs. distance and finds a polynomial which fits a line within those vectors in a least squares sense. AAR is the Average Accretion Rate for a given period of time.

In other words, the dune accretion rate is a positive or negative number which describes the average accretion or erosion rate over the given time period.

Beach accretion rate

The beach accretion rate is found with the same method as the dune accretion. The answer describes the average erosion or accretion over a given period of time.

Dune advance/ recession

Dune advance or recession only describes whether the dune is eroding or accreting. Dune recession means erosion, as dune advance means accretion.

Beach advance

Beach advance or recession only describes whether the beach is eroding or accreting. Beach recession means erosion, as beach advance means accretion.

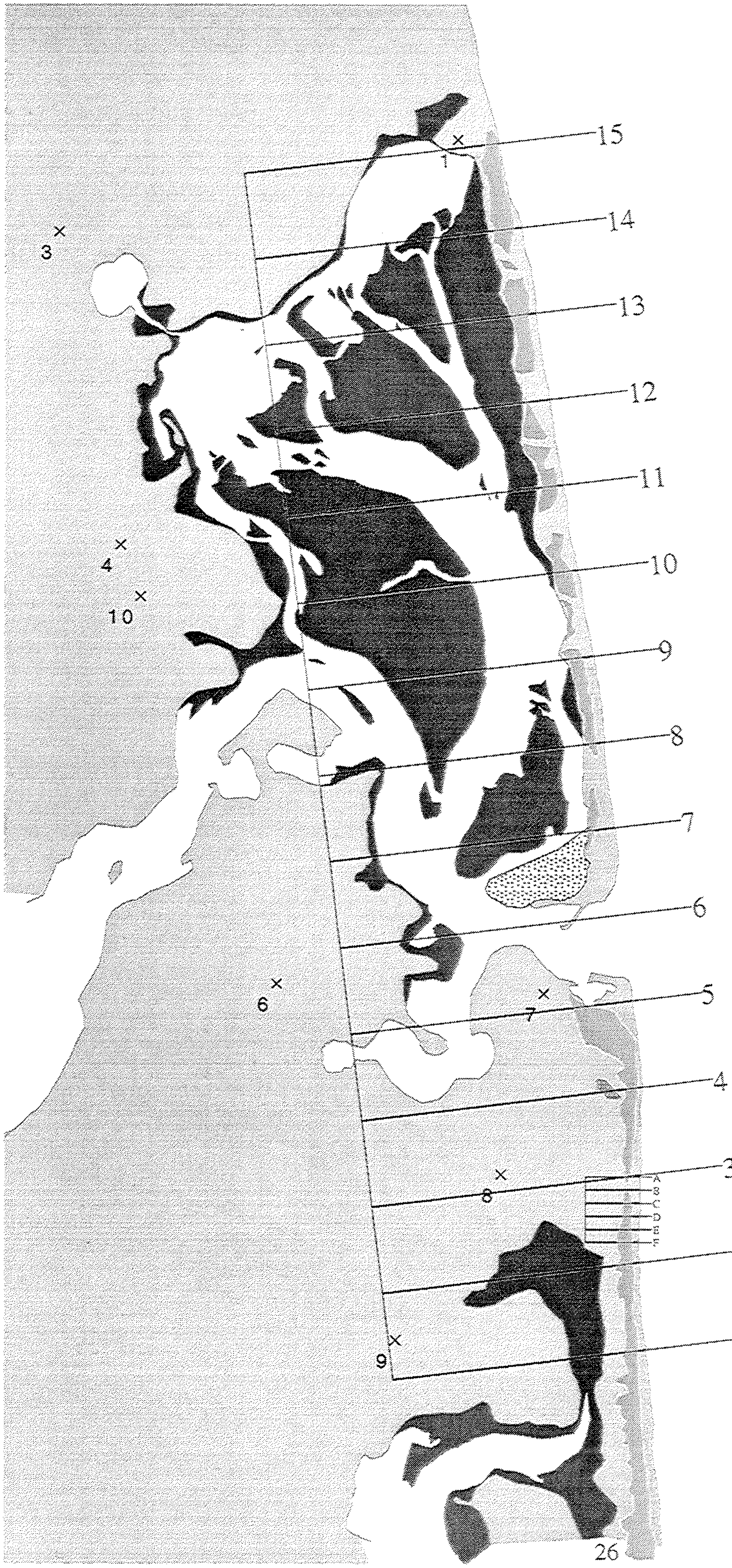
Transect

A transect is a section of the study area which we record data.

Mean High Water	The shoreline is water intersecting land or marshes at MHW. Marshes are determined by heavy vegetation exposed during MHW. MHW along the shoreface is located by a change in color of the sane, and often a buildup of seaweed and other washed-up vegetation. Sand shoals are determined by large amounts of sand exposed in the photographs below MHW.
Average Accretion Rate	The Average Accretion Rate describes the beach or dune erosion or accretion over a period of time. The answers from the dune and beach rates are the Average Accretion Rate.

APPENDIX II:

DIGITIZED AERIAL PHOTOGRAPHS (FROM TABLE 1)



Nauset Estuary
Eastham/Orleans,
Cape Cod, Mass.

November 21, 1938

Mass. State Plane Coord.
Mainland Zone

Land

Marsh Areas

Sand Dunes

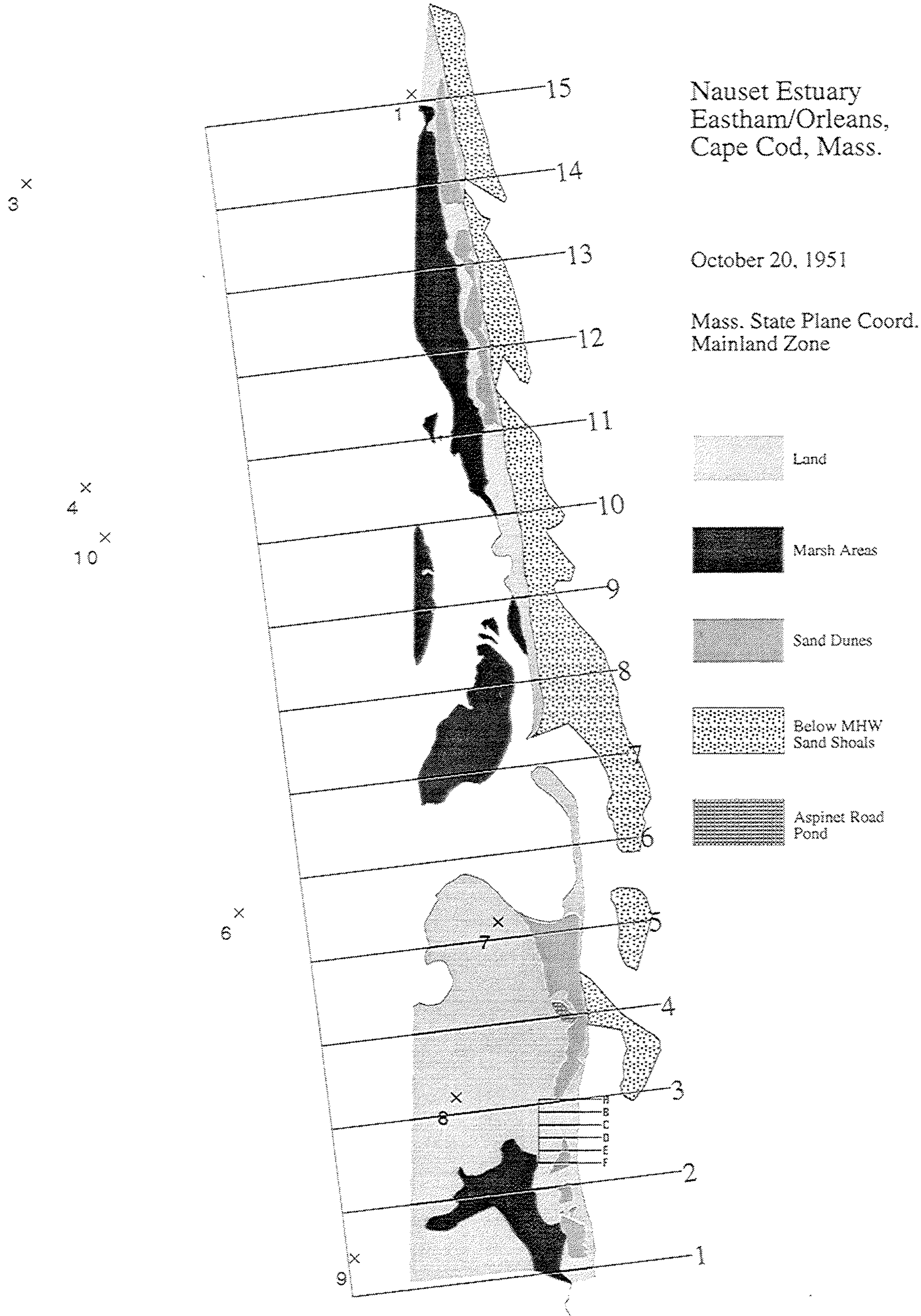
Below MHW
Sand Shoals

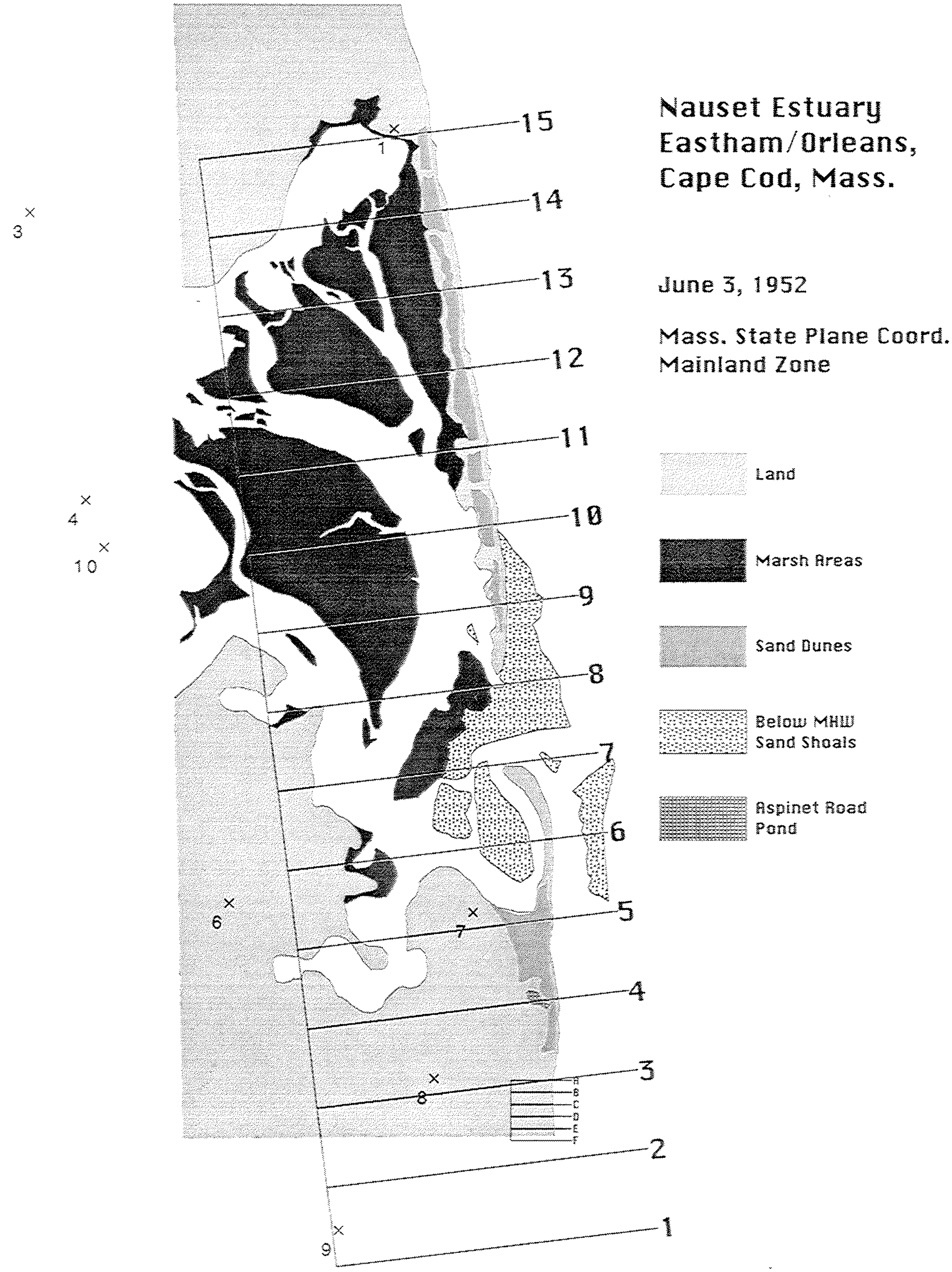
Aspinet Road
Pond

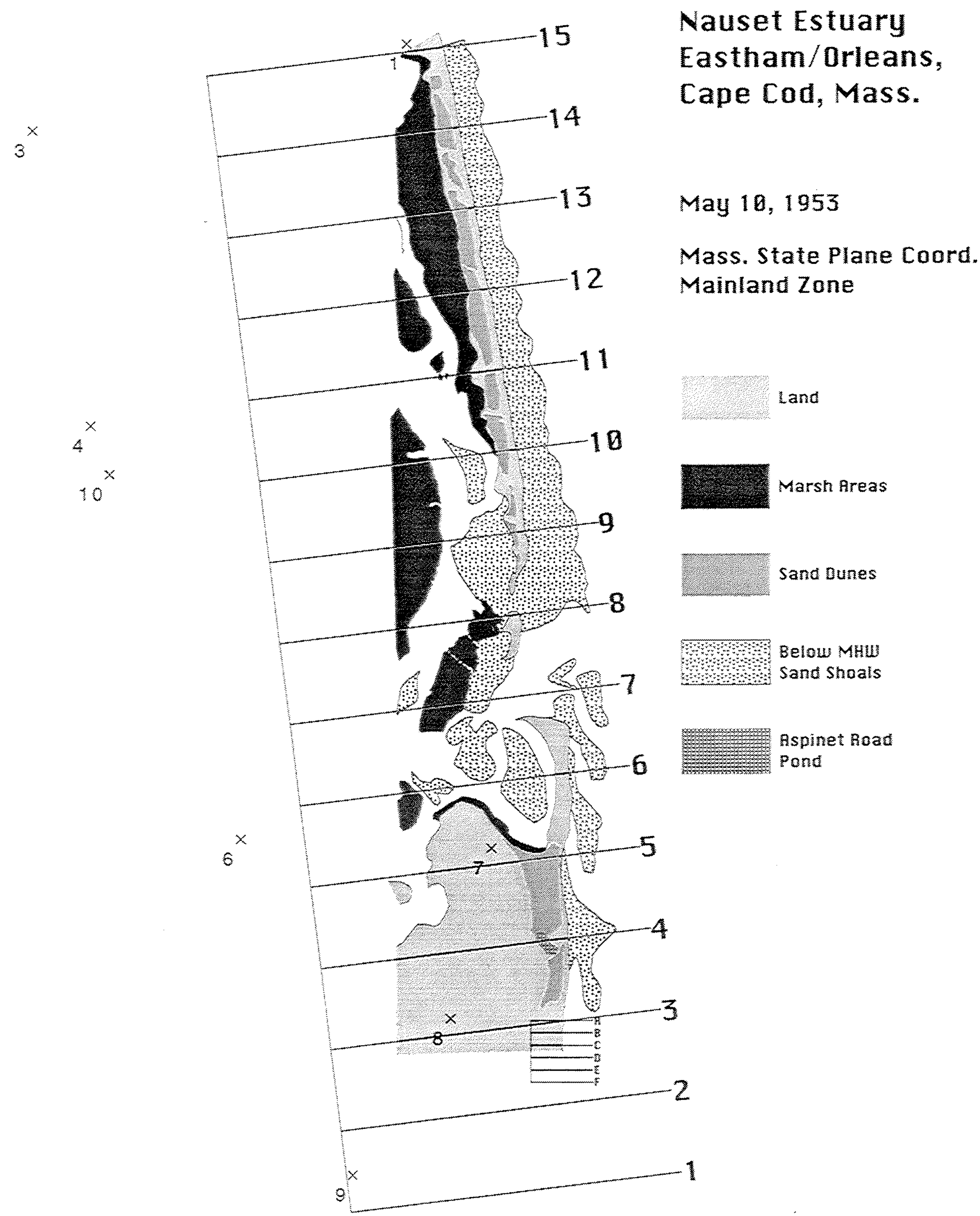
Nauset Estuary
Eastham/Orleans,
Cape Cod, Mass.

October 20, 1951

Mass. State Plane Coord.
Mainland Zone




Nauset Estuary
Eastham/Orleans,
Cape Cod, Mass.
June 3, 1952
Mass. State Plane Coord.
Mainland Zone
Land
Marsh Areas
Sand Dunes
Below MHW
Sand Shoals
Aspinet Road
Pond
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1


Nauset Estuary
Eastham/Orleans,
Cape Cod, Mass.
May 10, 1953
Mass. State Plane Coord.
Mainland Zone
Land
Marsh Areas
Sand Dunes
Below MHW
Sand Shoals
Aspinet Road
Pond
15
14
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6
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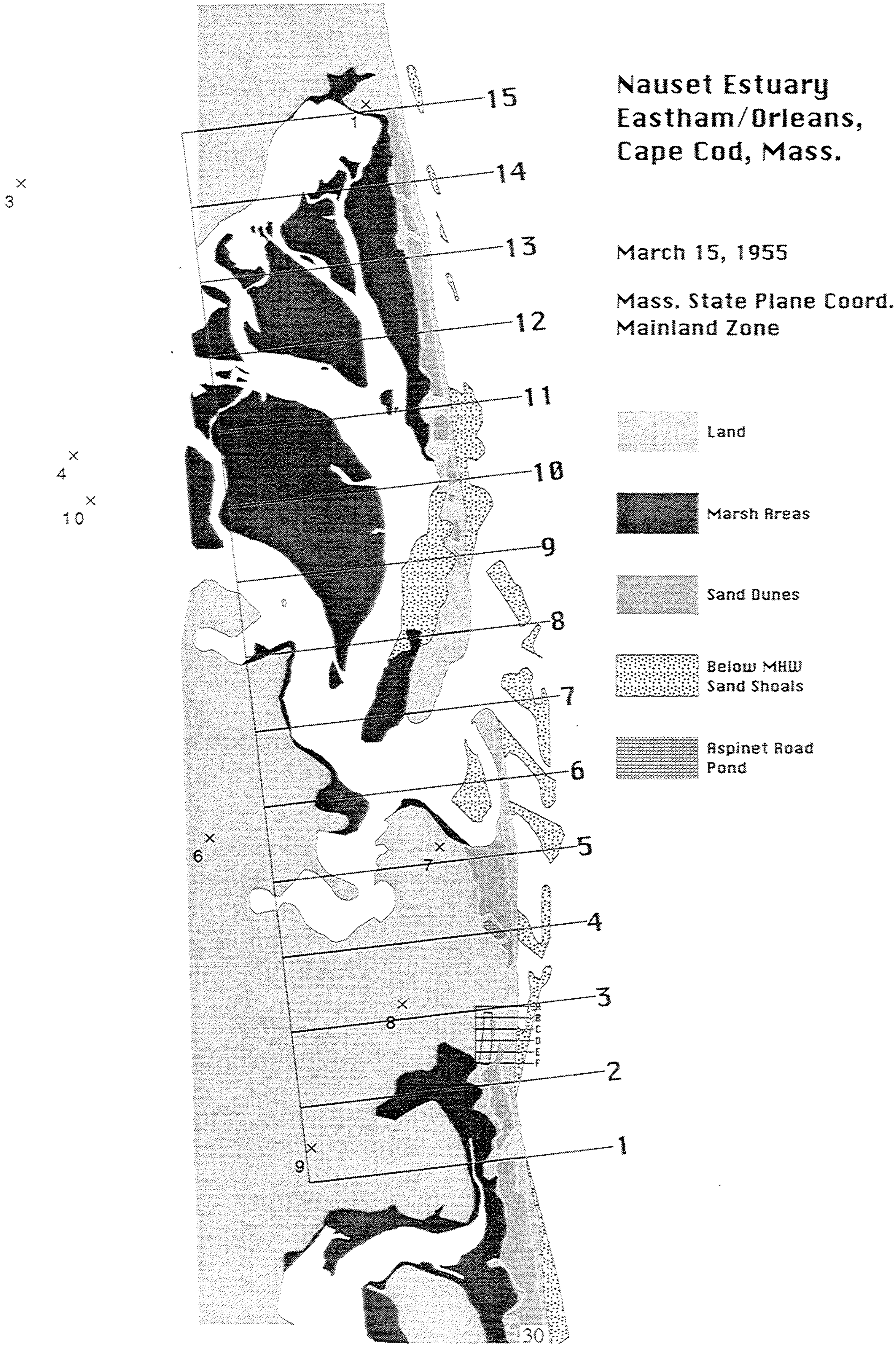
1
A
B
C
D
E
F


Nauset Estuary
Eastham/Orleans,
Cape Cod, Mass.
March 15, 1955
Mass. State Plane Coord.
Mainland Zone
Land
Marsh Areas
Sand Dunes
Below MHW
Sand Shoals
Aspinet Road
Pond
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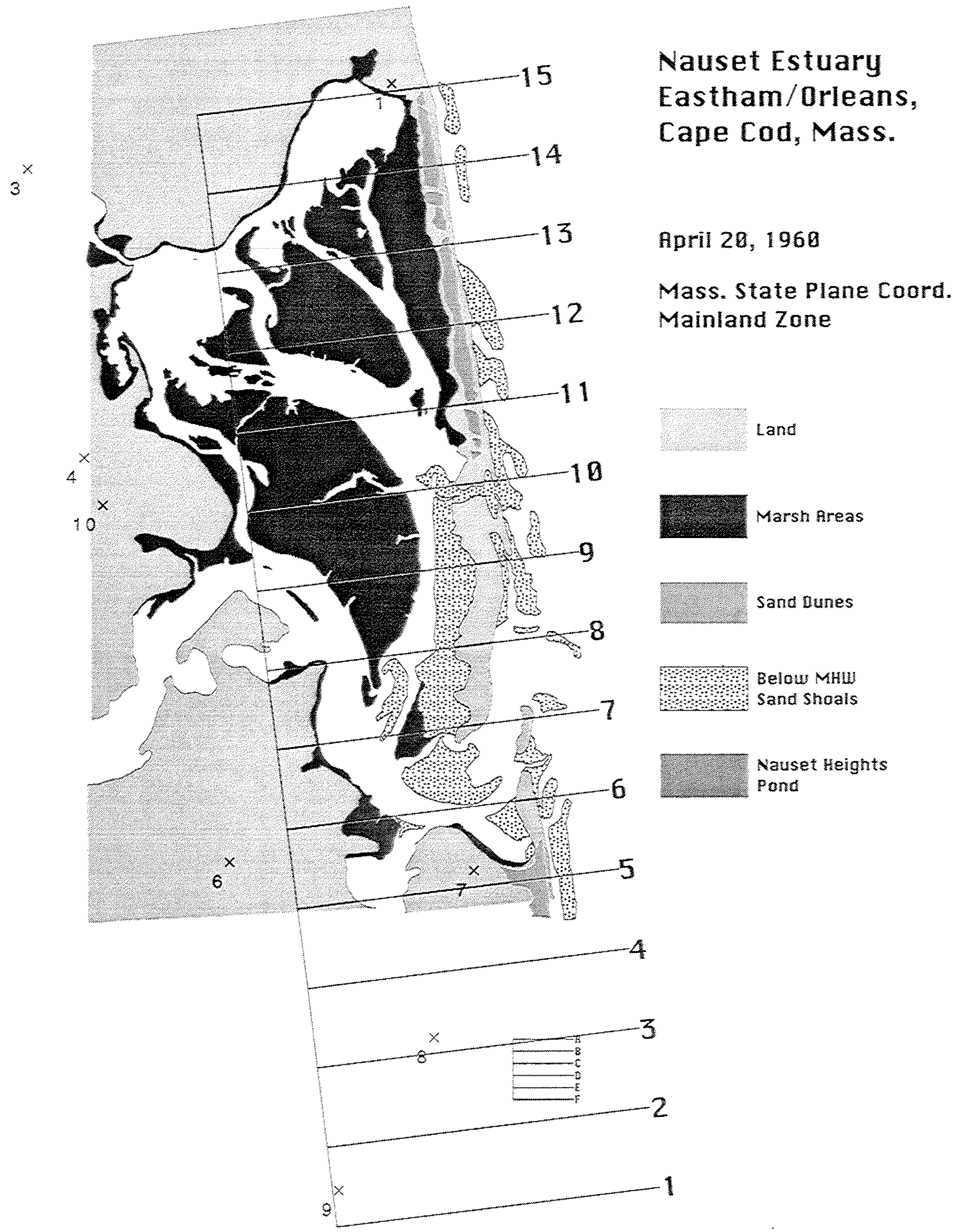
Nauset Estuary
Eastham/Orleans,
Cape Cod, Mass.
April 20, 1960
Mass. State Plane Coord.
Mainland Zone
Land
Marsh Areas
Sand Dunes
Below MHW
Sand Shoals
Nauset Heights
Pond
15
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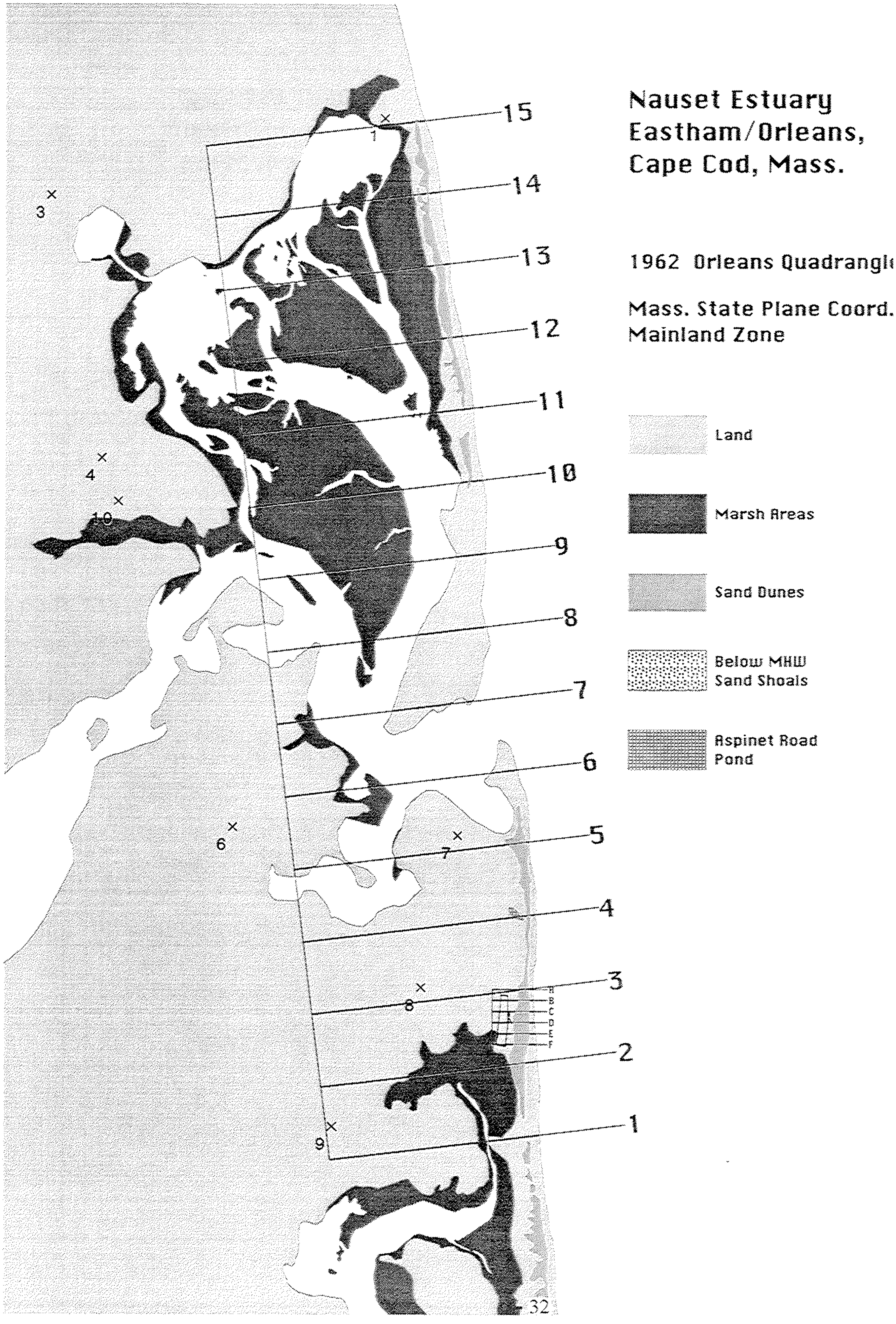
Nauset Estuary
Eastham/Orleans,
Cape Cod, Mass.
1962 Orleans Quadrangl
Mass. State Plane Coord.
Mainland Zone
Land
Marsh Areas
Sand Dunes
Below MHW
Sand Shoals
Aspinet Road
Pond
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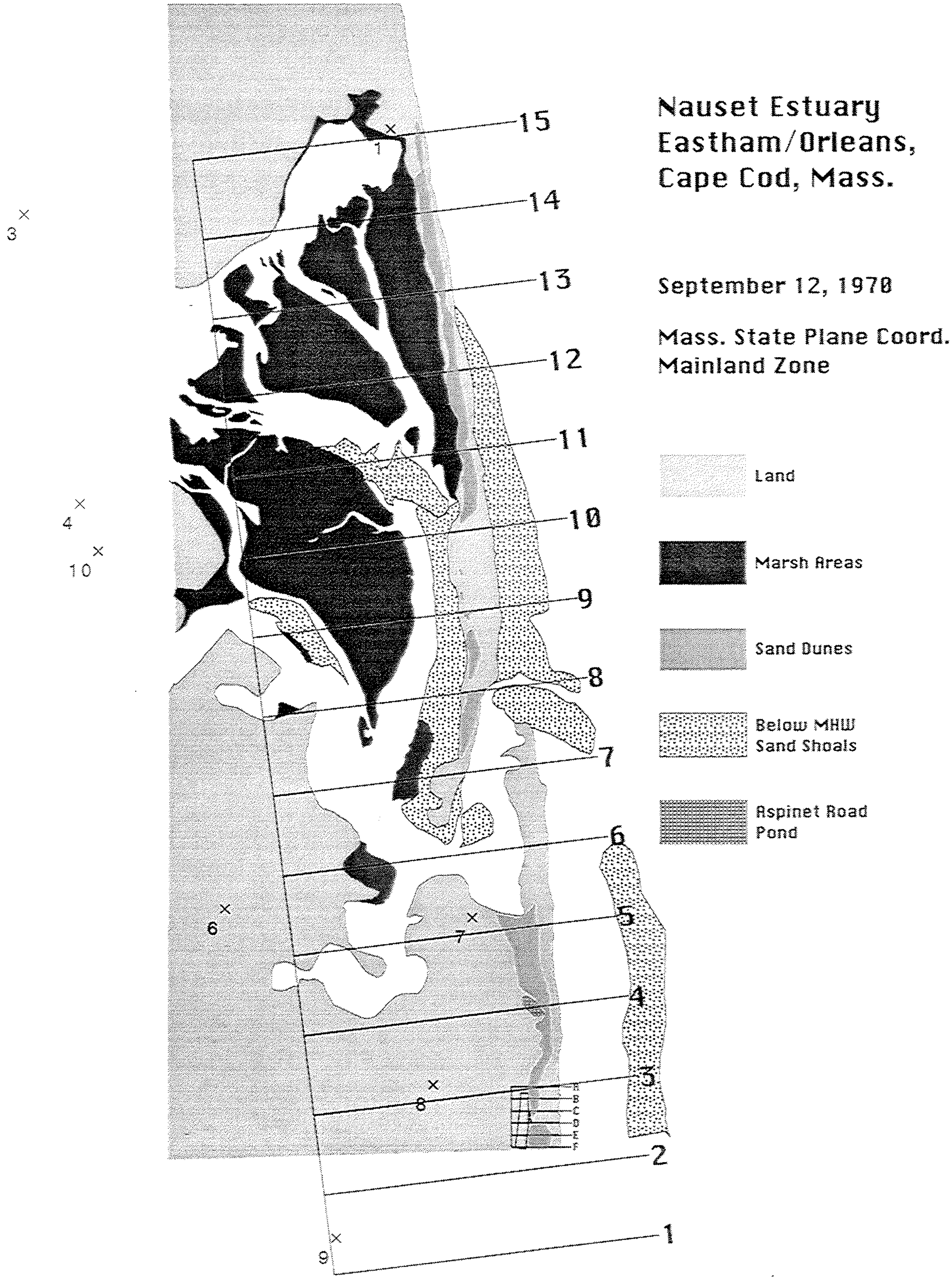

Nauset Estuary
Eastham/Orleans,
Cape Cod, Mass.
September 12, 1970
Mass. State Plane Coord.
Mainland Zone
Land
Marsh Areas
Sand Dunes
Below MHW
Sand Shoals
Aspinet Road
Pond
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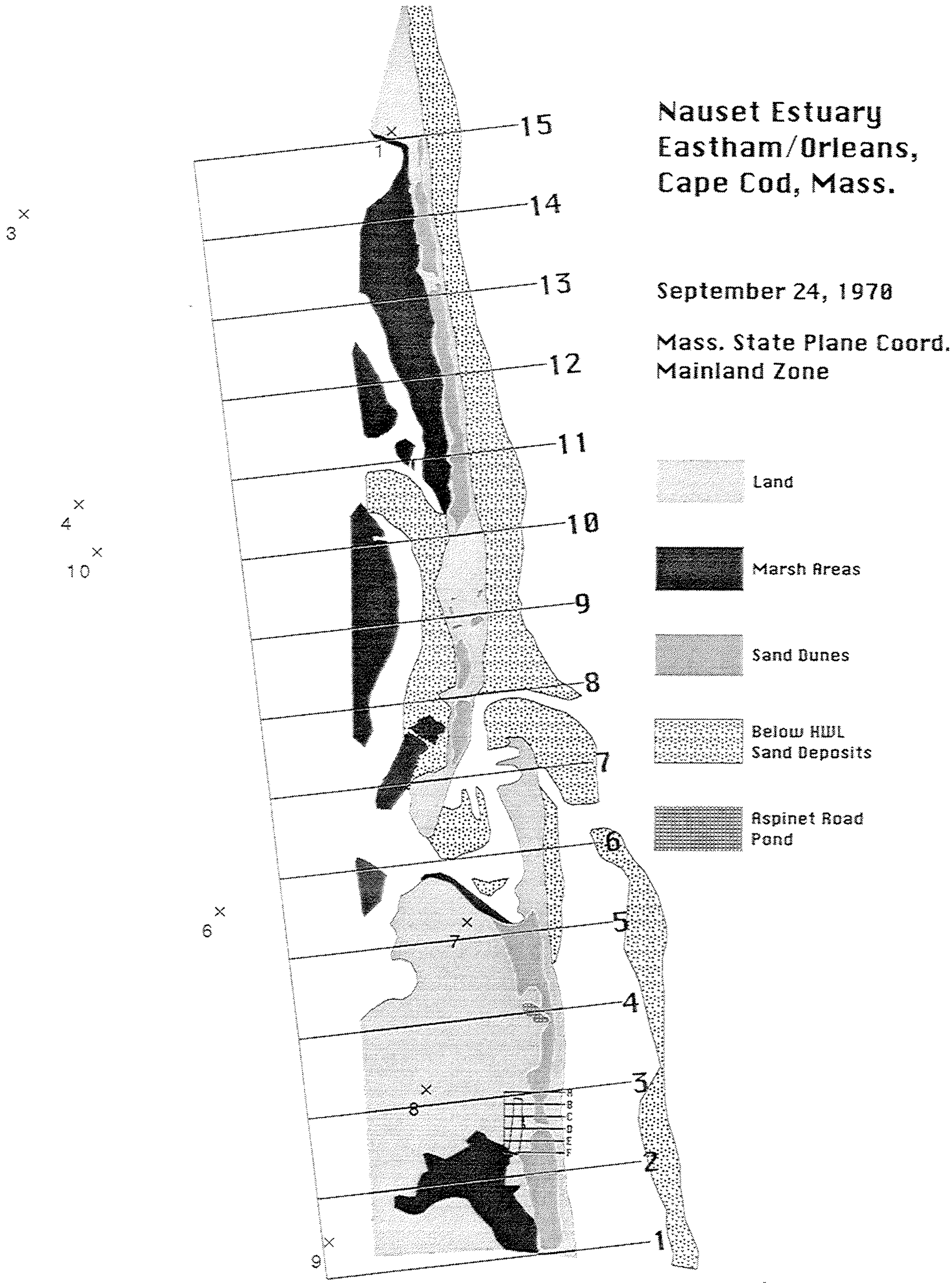
Nauset Estuary
Eastham/Orleans,
Cape Cod, Mass.
September 24, 1970
Mass. State Plane Coord.
Mainland Zone
Land
Marsh Areas
Sand Dunes
Below HWL
Sand Deposits
Aspinet Road
Pond
15
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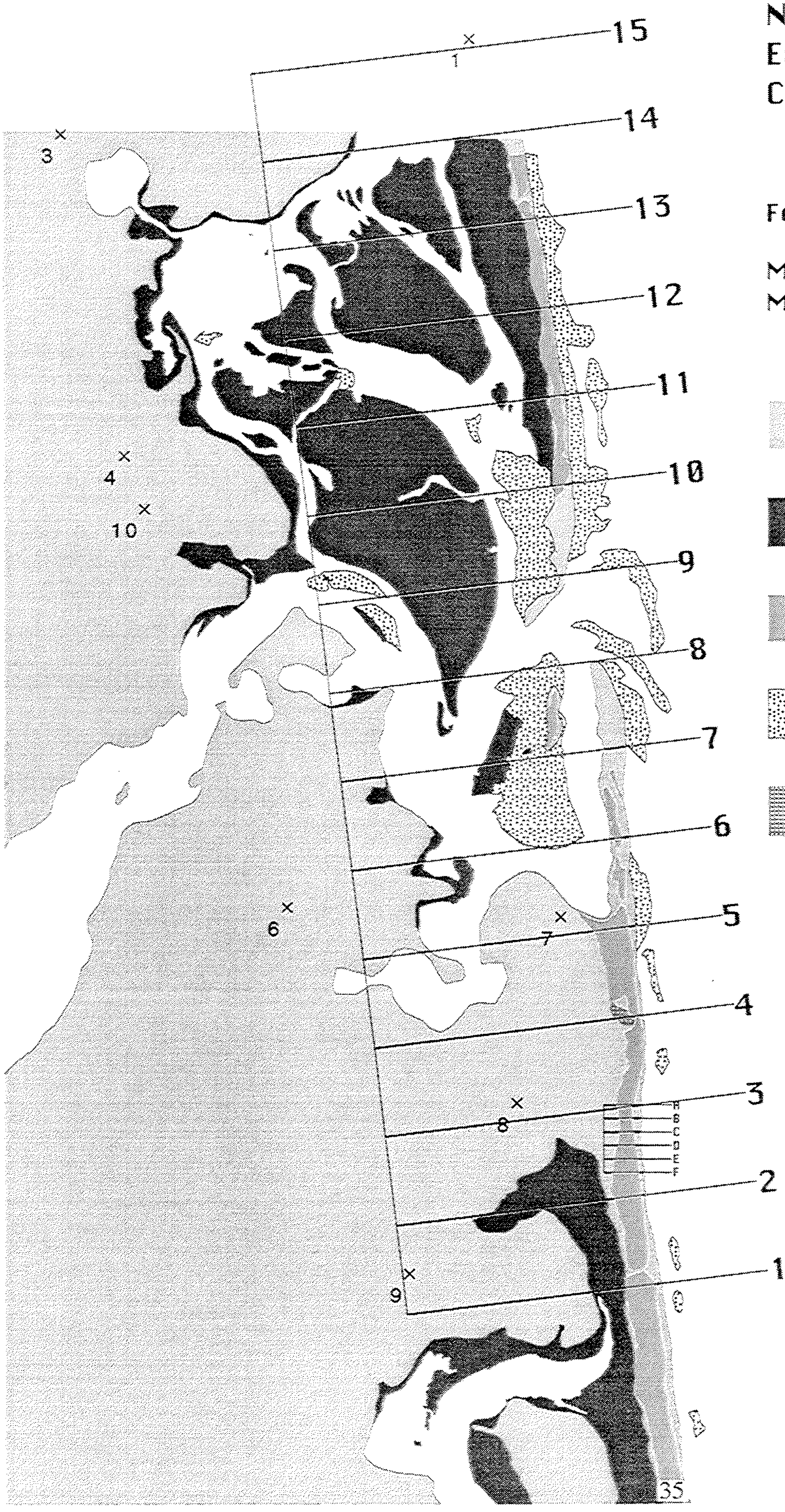
Nauset Estuary
Eastham/Orleans,
Cape Cod, Mass.

February 21, 1974

Mass. State Plane Coord.
Mainland Zone



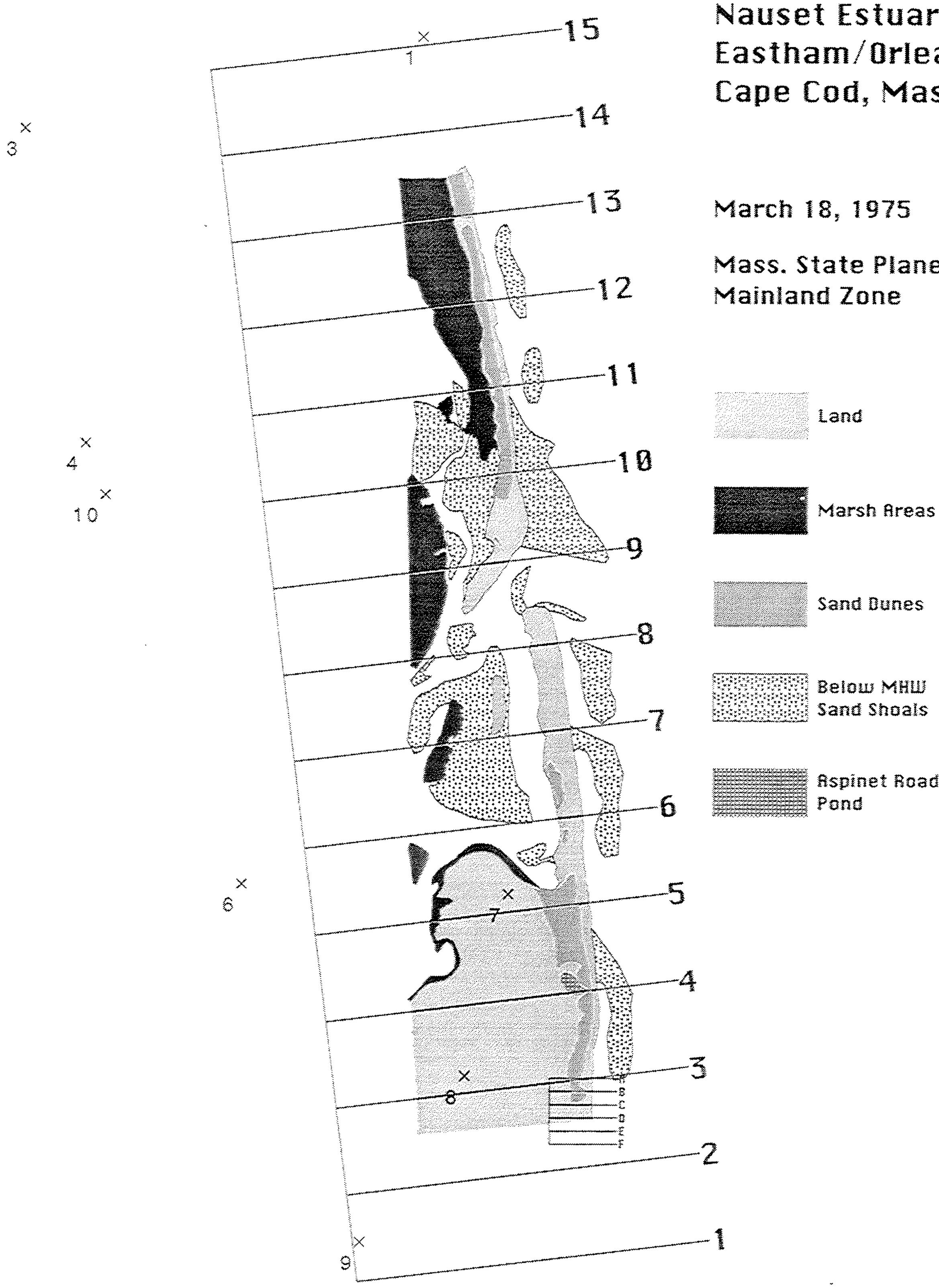
Land

Marsh Areas

Sand Dunes

Below MHW Sand Deposits

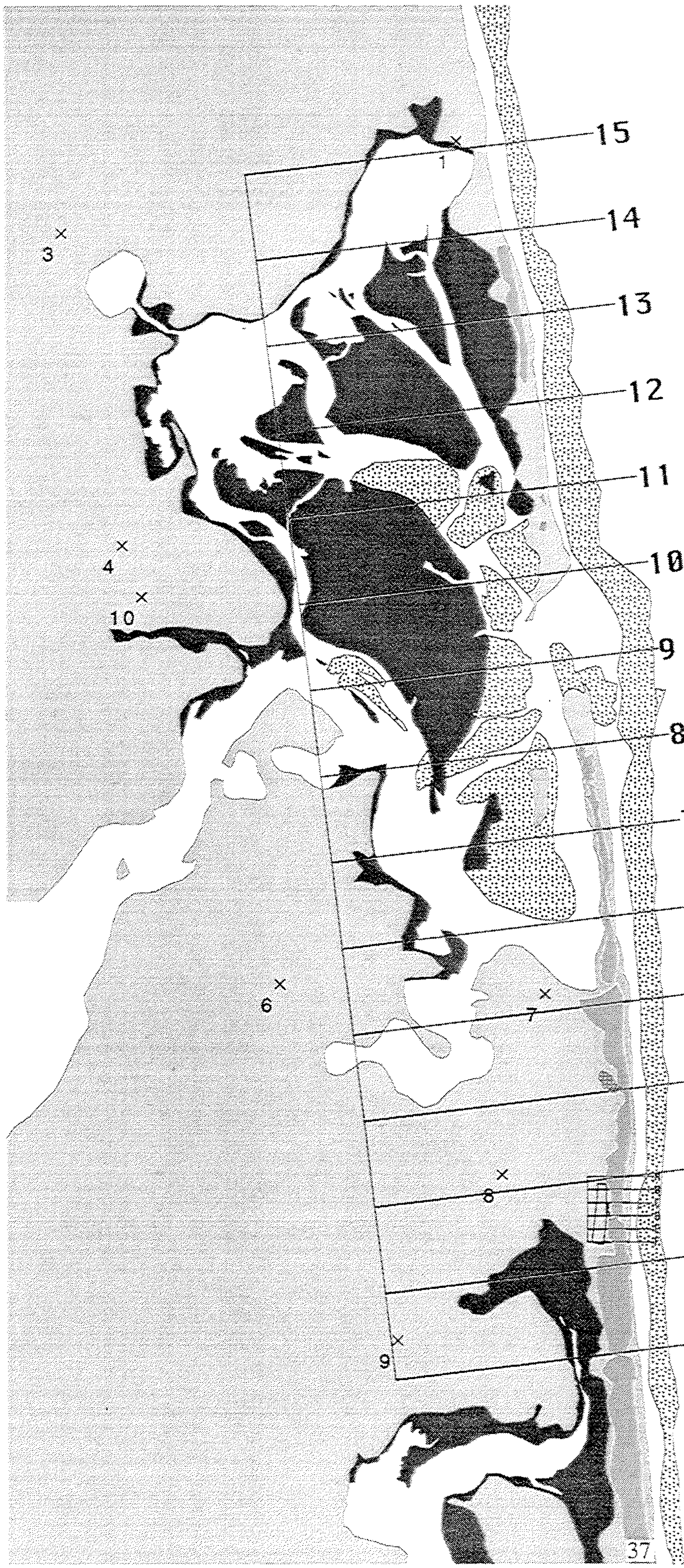
Aspinet Road Pond



Nauset Estuary
Eastham/Orleans,
Cape Cod, Mass.

March 18, 1975

Mass. State Plane Coord.
Mainland Zone



Nauset Estuary
Eastham/Orleans,
Cape Cod, Mass.

April 23, 1978

Mass. State Plane Coord.
Mainland Zone

Land

Marsh Areas

Sand Dunes

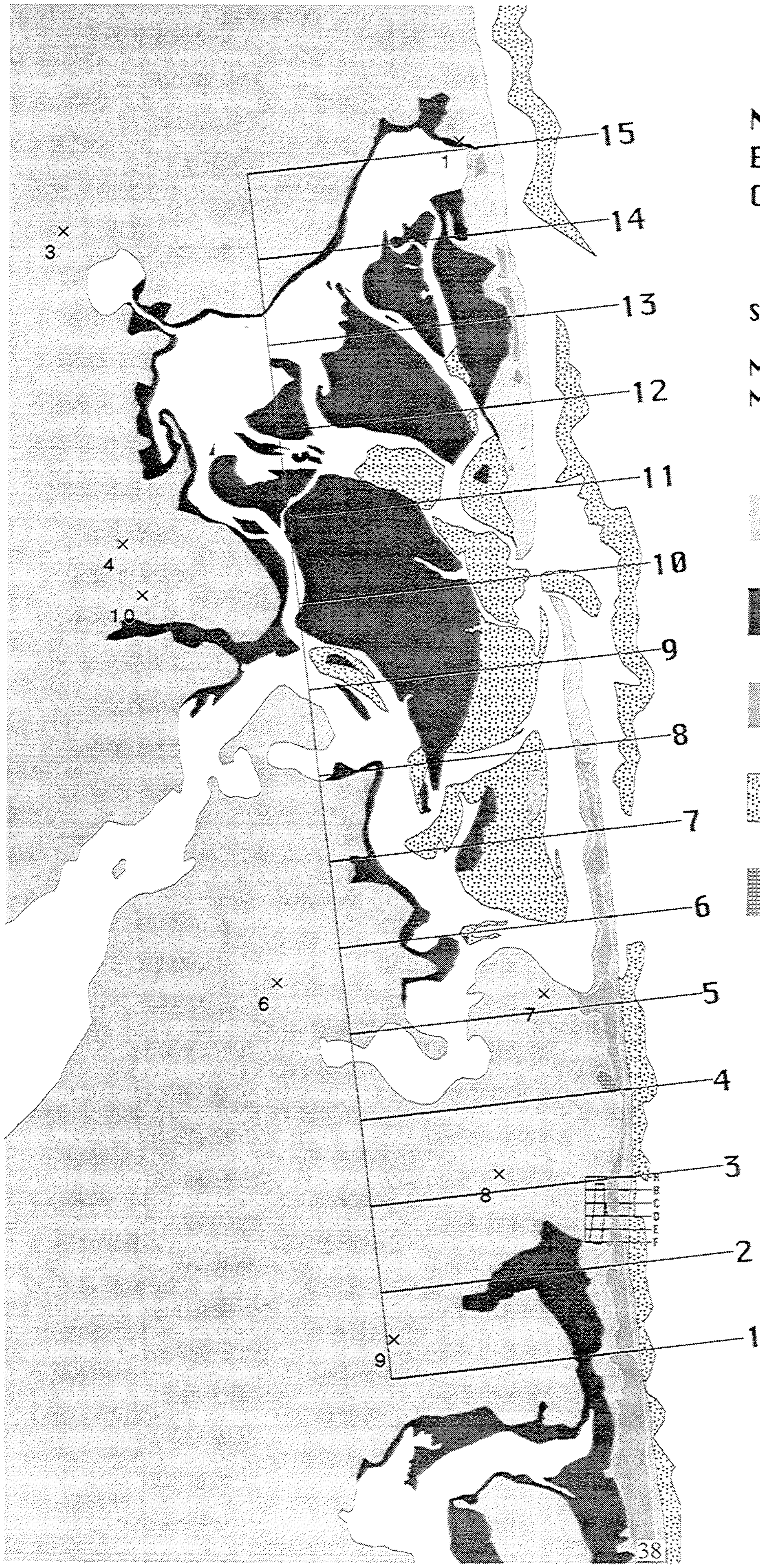
Below MHW
Sand Shoals

Aspinet Road
Pond

Nauset Estuary Eastham/Orleans, Cape Cod, Mass.

September 21, 1981

Mass. State Plane Coord.
Mainland Zone



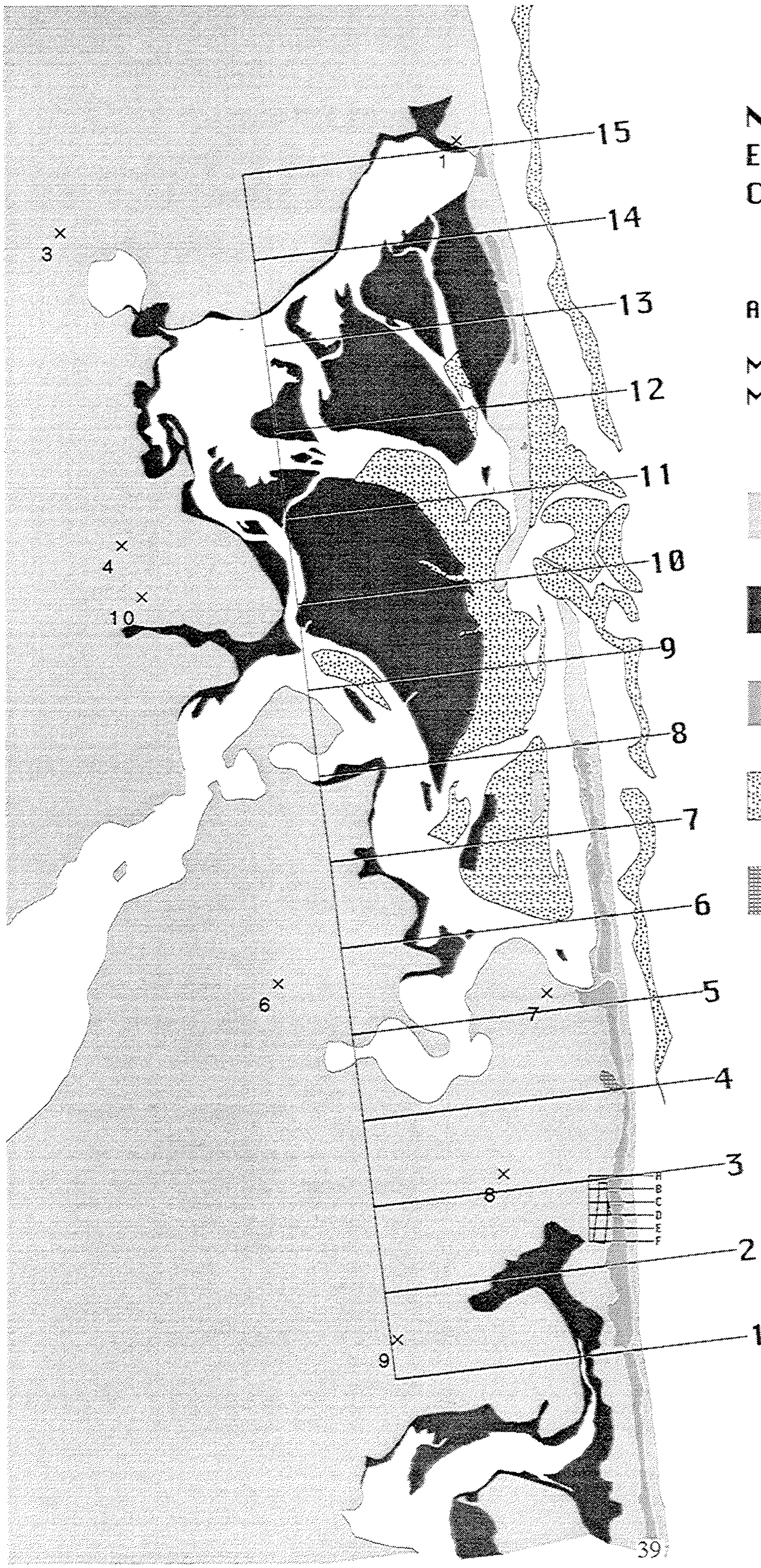
Land

Marsh Areas

Sand Dunes

Below MHW Sand Shoals

Aspinet Road Pond



Nauset Estuary Eastham/Orleans, Cape Cod, Mass.

August 22, 1982

Mass. State Plane Coord. Mainland Zone

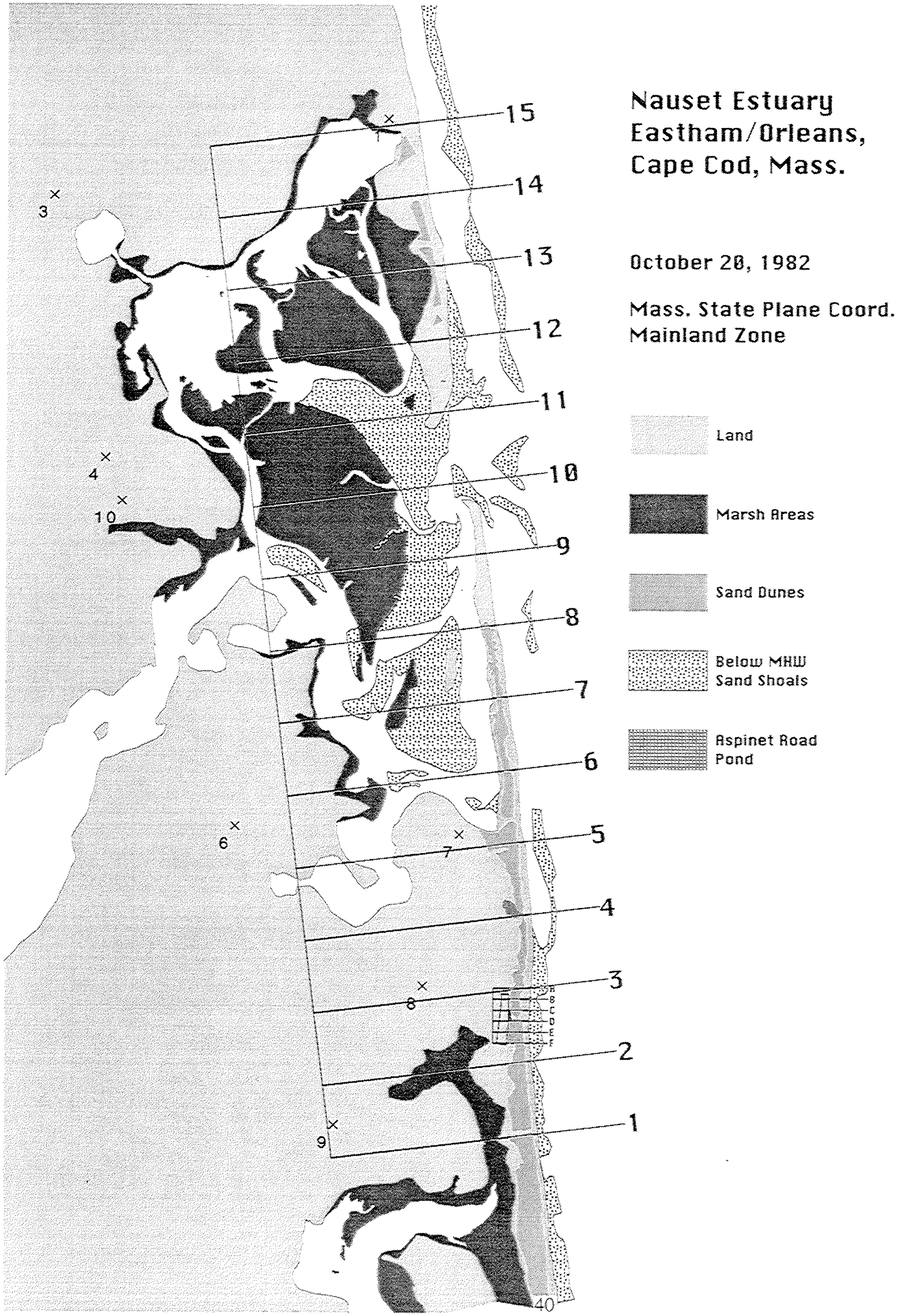
Land

Marsh Areas

Sand Dunes

Below MHW Sand Shoals

Aspinet Road Pond


Nauset Estuary
Eastham/Orleans,
Cape Cod, Mass.
October 20, 1982
Mass. State Plane Coord.
Mainland Zone
Land
Marsh Areas
Sand Dunes
Below MHW
Sand Shoals
Aspinet Road
Pond
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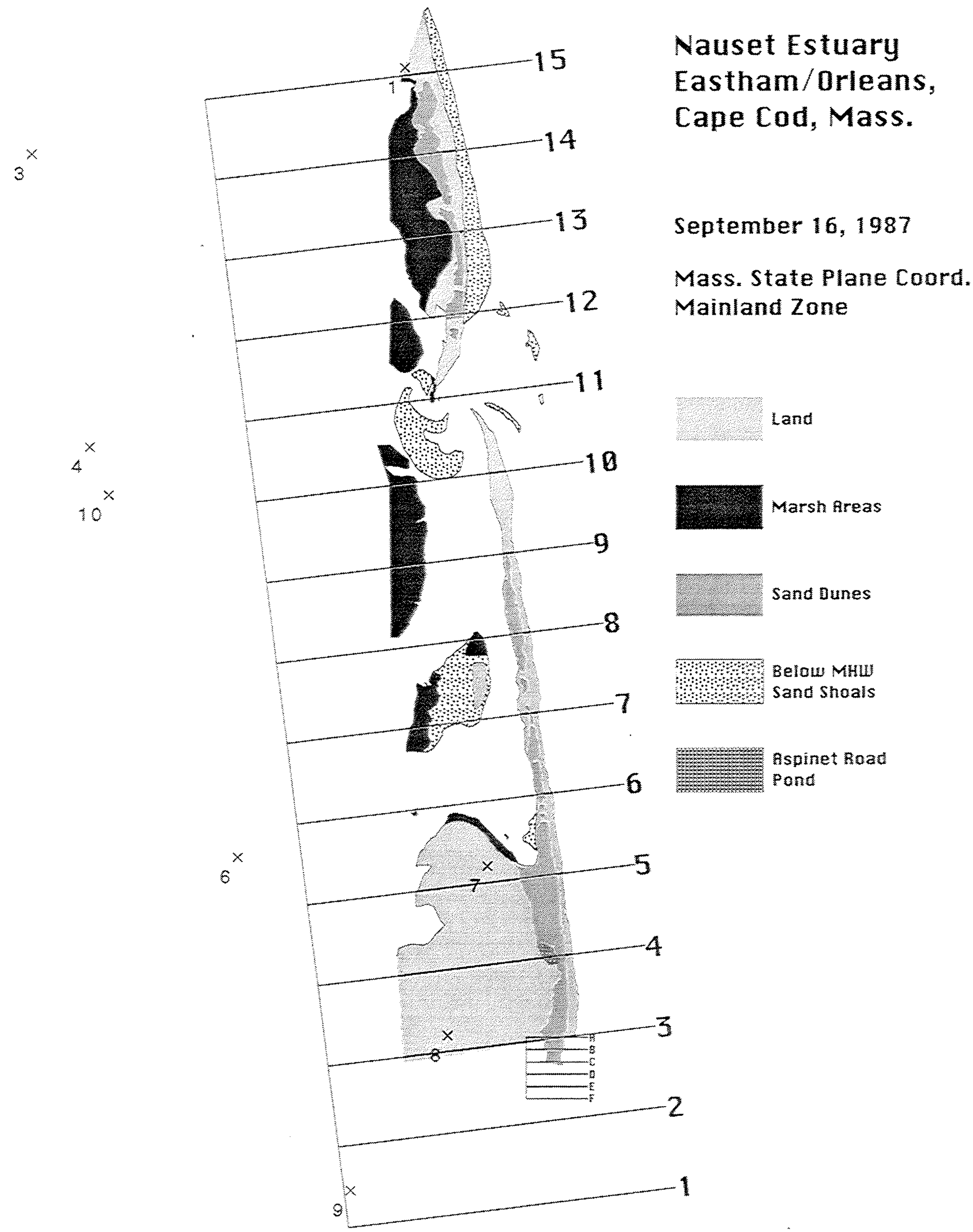
Nauset Estuary
Eastham/Orleans,
Cape Cod, Mass.
September 16, 1987
Mass. State Plane Coord.
Mainland Zone
Land
Marsh Areas
Sand Dunes
Below MHW
Sand Shoals
Aspinet Road
Pond
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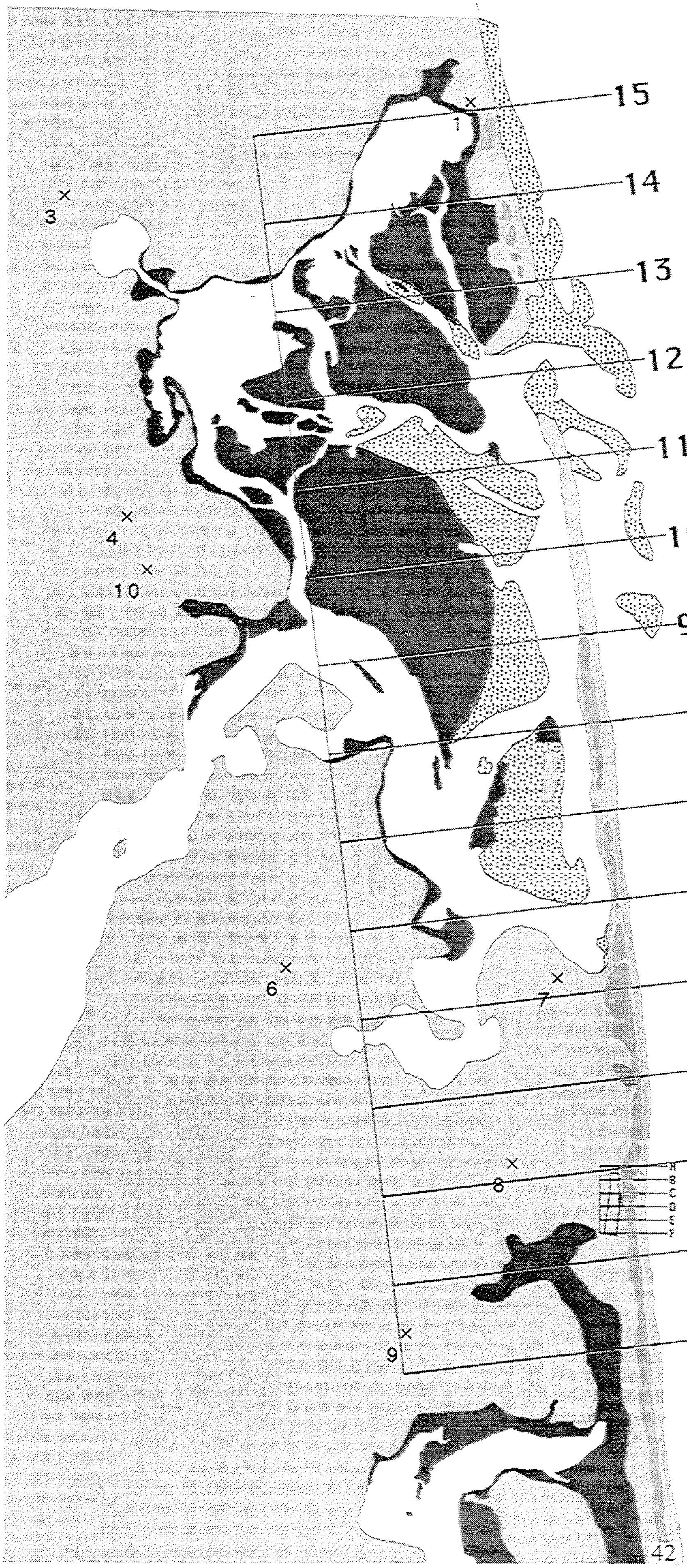


Nauset Estuary
Eastham/Orleans,
Cape Cod, Mass.

April 4, 1991

Mass. State Plane Coord.
Mainland Zone

Land

Marsh Areas

Sand Dunes

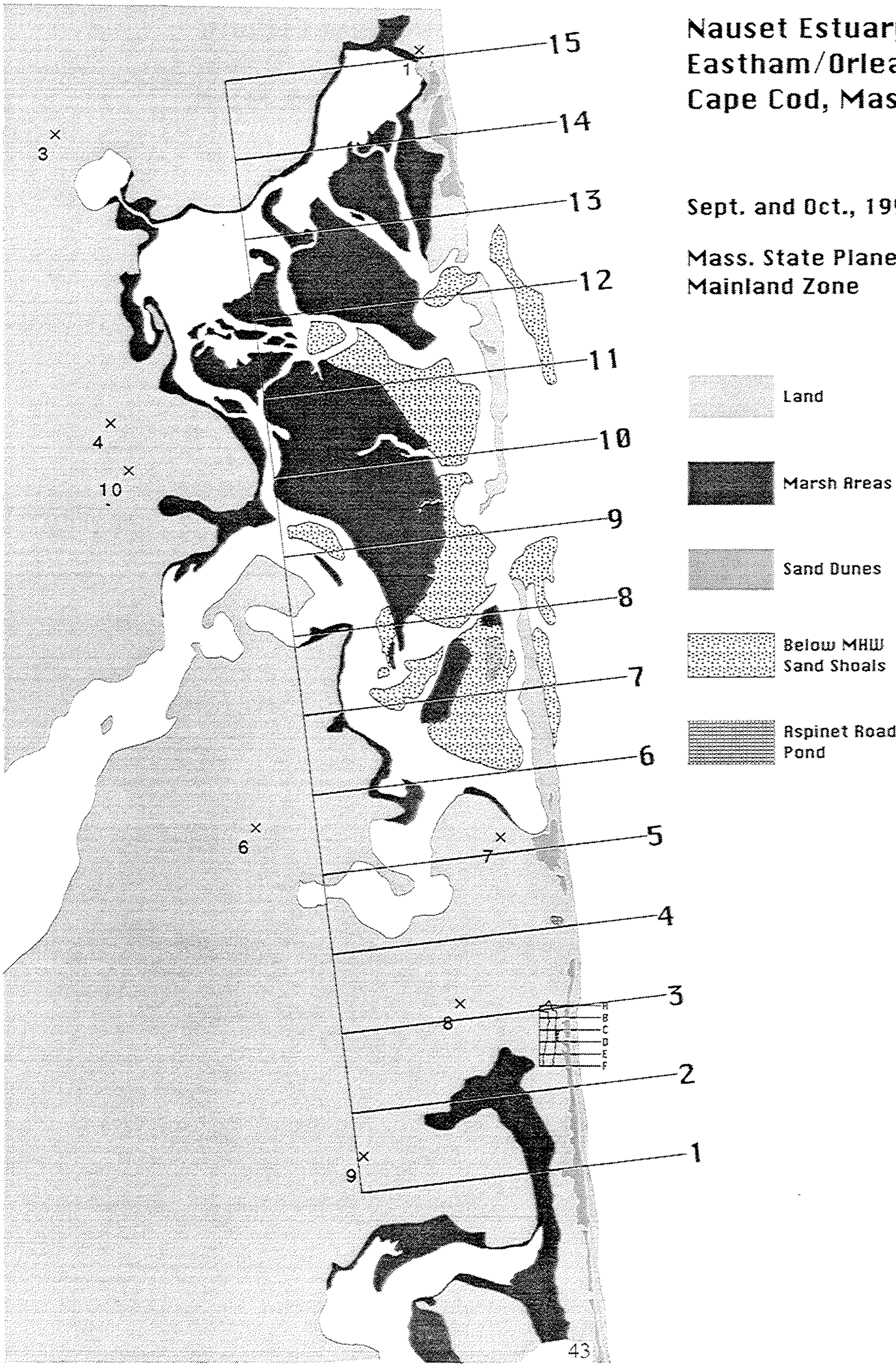
Below HWL
Sand Shoals

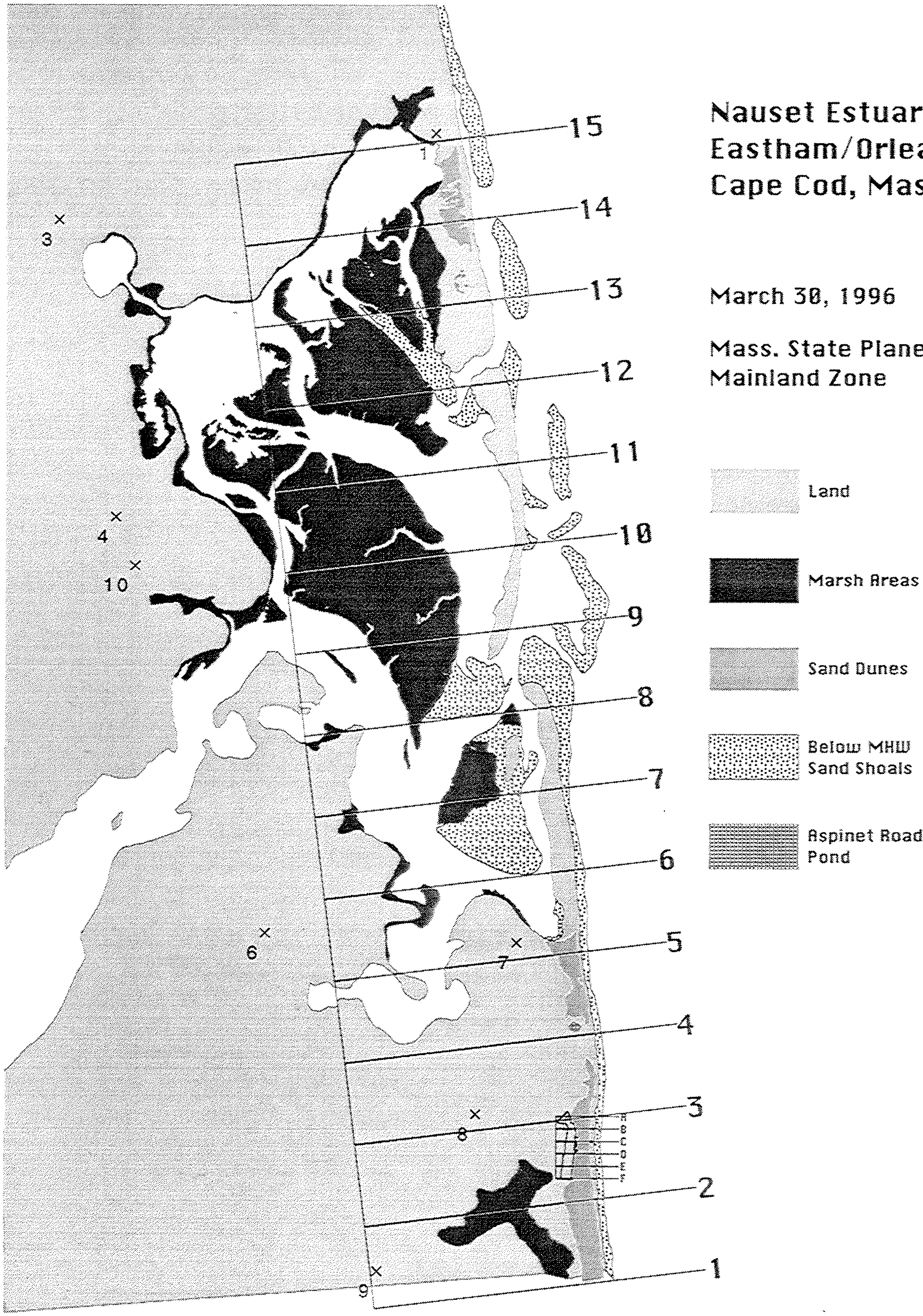
Aspinet Road
Pond

Nauset Estuary
Eastham/Orleans, Cape Cod, Mass.

Sept. and Oct., 1994

Mass. State Plane Coord.
Mainland Zone





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			6.
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16. Abstract (Limit: 200 words)

The present study investigated the shoreline and dune changes occurring along Nauset Barrier Beach system during the past sixty years, based on examination of aerial photographs, charts, and other data sources.

Significant changes have occurred to the barrier beach and dune systems of Nauset during the fifteeen intervening years since the last major study of the system. The barrier and shoreline in general has continued to retreat, and nearly all the dunes along South Spit have eroded away during storms, so the new profile of the South Spit is extremely low lying and storm waves overtop it frequently. Overwash has resulted in closing off South Channel which separates the Spit from New Island. Dunes near Aspinet Road have been eroded away, causing increased flooding of Aspinet Road.

Extensive previous research performed on erosion rates are consistent with the present rates. However, present data from this report include more up-to-date photographs, and include specific attention to dune retreat and recent tidal inlet migration and number of inlets. Such decadal updates on the behavior of Nauset Barrier Beach and the adjacent Orleans Town Beach can provide valuable timely information for assessing management practices for this region.

17. Document Analysis a. Descriptors

barrier beach

inlet

coastal management

b. Identifiers/Open-Ended Terms

c. COSATI Field/Group

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