NCU-T-77-003 C. 3

Ten Years of Development of Man-Initiated Coastal Barrier Dunes in North Carolina

UNC Sea Grant College
Publication
UNC-SG-77-01

Ten Years of Development of Man-Initiated Coastal Barrier Dunes in North Carolina

W. W. Woodhouse, Jr.
Professor of Soil Science,
N. C. State University at Raleigh

E. D. Seneca
Associate Professor of Soil Science and Botany,
N. C. State University at Raleigh

S. W. Broome
Research Associate in Soil Science,
N. C. State University at Raleigh

ACKNOWLEDGMENTS

This bulletin is the result of research supported by the North Carolina Center for Marine and Coastal Studies; North Carolina Sea Grant Program, NOAA Office of Sea Grant, Department of Commerce; Coastal Engineering Research Center, Corps of Engineers, U. S. Army; and the North Carolina Agricultural Experiment Station. The authors wish to express appreciation to personnel of the Cape Hatteras and Cape Lookout National Seashores for their cooperation in the conduct of those studies, to R. P. Savage, Chief Research Division, CERC, for his advice in the interpretation of these findings, and to Messrs. D. M. Bryan, C. L. Campbell, Jr. and U. O. Highfill for their assistance in all phases of the field work.

Ten Years of Development of Man-Initiated Coastal Barrier Dunes in North Carolina

INTRODUCTION

General

Coastal dunes have long been valued for such purposes as sea defense, water storage and nature preserves in some countries (King, 1974). Dunes form a significant part of the Dutch sea defense (Adriani and Terwindt, 1974). In the United States, until recently, they have been more commonly viewed as places to graze livestock, construct buildings, or race dune buggies. This attitude together with the natural coastal processes has resulted in the loss or deterioration of dune formations along much of the seacoast of this country. However, with the increased attention to the coastal zone, there is a growing interest, particularly along the Atlantic and Gulf coasts, in the preservation, repair, management, restoration, construction and function of coastal dunes.

Dunes are natural features of sandy seashores throughout most of the world except in the tropics where their occurrence is rather erratic (Jennings, 1965). They function as flexible barriers to storm tides and waves, and as sand reservoirs, nourishing the beach during storm attack, but are ineffective against persistent beach recession. They may be constructed mechanically, or where blowing sand is available and rainfall is sufficient, their natural development may be initiated and managed through planting sand-trapping vegetation.

Where it can be done, dune building with vegetation has distinct advantages. It is usually less expensive, the dune is stabilized as it grows, and is aesthetically pleasing and easier to maintain. Also, this method discourages placement of dunes in inappropriate locations. Building dunes with vegetation is using a natural process as a management tool. It does require a supply of blowing sand, plus time. The literature on aeolian sand transport and dune stabilization has been reviewed recently by Dahl et al. (1975) and Phillips (1975). We have cited only references having a bearing on specific points in this report.

During the 1964-1967 period, a series of dune-building experiments involving the use of sand fences and dune grasses was initiated. The initial results of these tests were reported in 1968 (Savage and Woodhouse, 1969). During the 6 years since that report, significant changes have occurred within these developing dunes. Their development has shed some light on factors affecting growth and utility of dunes in this region, and are the subject of this report.

Characteristics and Management of Dune Grasses

The natural ranges of two major dune grasses, American beachgrass (*Ammophila breviligulata* Fern.) and sea oats (*Uniola paniculata* L.), overlap over about the northern half of the North Carolina coast. American beachgrass is the dominant plant of the exposed foredunes from the Virginia Capes into Canada, while sea oats generally fills this role from about Ocracoke Inlet southward into Mexico. Both have excellent sandtrapping capacities, along with the highly specialized adaptations necessary to tolerate stresses, such as sand accumulation, sand blast, salt spray, drought, etc., which enables them to thrive under foredune conditions.

American beachgrass is, by far, the more easily propagated of the two species. It can be multiplied rapidly and is relatively free of pest problems under nursery conditions. American beachgrass is quite tolerant of soil conditions, can be transplanted to dune and beach areas with a high rate of survival, and grows off rapidly following transplanting.

Sea oats, on the other hand, is difficult to produce, is subject to pest problems under nursery conditions, usually exhibits poor survival on transplanting, and is very slow to initiate new growth following transplanting. Until recently, the mode of reproduction and factors affecting the dissemination of this plant were not understood (Wagner, 1964; Woodhouse and Hanes, 1967; Woodhouse, Seneca, and Cooper, 1968; Seneca, 1969).

In view of these differences, it is not surprising that American beachgrass has been relied upon almost exclusively for planting beaches, dunes, and dikes along the North Carolina coast. However, in spite of its obvious and immediate advantages, the planting of pure stands of this species may not represent the long range solution to stabilization of all such areas. Sea oats invaded and largely replaced many American beachgrass plantings in this region within 10 years (Woodhouse, Seneca, and Cooper, 1968). Further, American beachgrass is very susceptible to at least one disease, Marasmius blight (Lucas et al., 1971), and one insect pest, *Eriococcus carolinae* Williams (Fuzy, 1969; Campbell and Fuzy, 1971), which often attain serious proportions in this part of its range. Consequently, some attention to sea oats and other adapted species was desirable. It was for this reason that supplies of sea oats planting stock were developed and incorporated into dune plantings beginning in 1965.

A third dune grass has received attention only since 1962. Prior to the Ash Wednesday storm of that year, running beachgrass or bitter panicum (*Panicum amarum* Ell.) was relatively rare along the North Carolina coast and had exhibited little inclination to spread. This storm served to break up and widely distribute patches of this species. Subsequently it spread rapidly, invading particularly the older American beachgrass stands. Earlier scarcity of this species was apparently due to its relatively high palatability (Dahl et al., 1975) causing it to be largely grazed out of barrier island areas years ago. Since it rarely, if ever, produces viable seeds, it is very slow to reinvade unless transplanted by man or by storm activity.

Selections of this grass were increased, and it was included in tests involving revegetation of Marasmius blight areas in American beachgrass plantings beginning in 1971 and in a dune section experiment in 1973. These results will be reported in separate papers (Seneca, Woodhouse, and Broome, 1976; Woodhouse, Seneca and Broome, in press).

Spartina patens (Ait.) Muhl. (saltmeadow cordgrass) is not, strictly speaking, a dune grass, but it is a very important species on the North Carolina barrier islands. It covers a large acreage on the sand flats and low dunes behind the foredune, growing best in a band along the landward edges of the salt marshes, just above the highest spring tide line where it is sometimes referred to as high marsh. It is more salt tolerant than the native dune grasses (Seneca, 1972), but less tolerant of drought. It seeds profusely, spreads readily into bare, moist flats by seeds, and is easy to transplant into such areas.

This grass does initiate the development of new dunes, but having smaller and more pliant leaves and stems, it does not trap sand as effectively as the primary dune grasses. It is sometimes found on high dunes, probably starting on a flat area and growing upward with the sand as it accumulates. Our findings and those from Texas (Dahl et al., 1975) indicate that saltmeadow cordgrass is not easy to transplant into the drier sites and for this reason is not usually recommended for dune-building purposes.

Location and Description of Sites

This work was done on portions of two low, sandy, barrier islands—Ocracoke and Portsmouth—lying between Cape Hatteras and Cape Lookout (Fig. 1). These islands vary from about one-half to one mile in width in the vicinity of the experimental sites, and generally attain

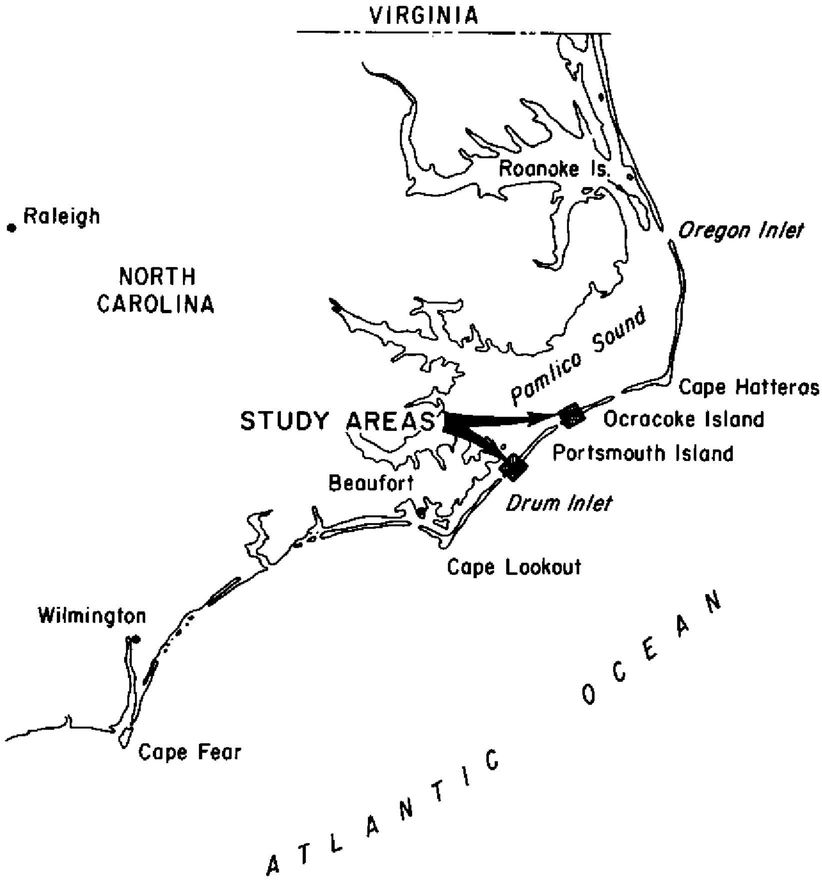

Fig. 1. Location of study areas.

their highest elevations of 4 to 6 ft. mean sea level (msl) along the storm berm, sloping gently back from there toward the sound behind them. The sands are medium to fine (approximately 0.2 mm median diameter) and mixed with varying amounts of shell.

Due to overgrazing followed by a particularly severe series of hurricanes in the 1950's, vegetation was largely absent at the time these experiments were initiated. The Ocracoke Island site was devoid of vegetation, but some revegetation activity had been carried out for several years immediately northward of this site. Vegetation on Portsmouth Island was limited generally to the landward half, or less, of the island and consisted almost entirely of a thin stand of saltmeadow cordgrass, backed by broken stands of *Spartina alterniflora* Loisel. (smooth cordgrass), or *Juncus roemerianus* Scheele (black needlerush) salt marsh along the edge of the sound. Two of the principal dune grasses of this area, running beachgrass and American beachgrass, were absent from the island while the third, sea oats, was in the early stages of reinvasion with an average of less than two clumps per mile present in 1964.

The experiments on Portsmouth Island were located in areas (4 to 6 ft msl) where it is reasonable to assume that a foredune would eventually develop naturally, given another 5 to 10 years of weather comparable with that of the last 10, and provided interference by man could be held at the same level. The evidence for this is the unassisted development of natural dunes on similar parts of the island, mostly during the last 5 to 6 years. This is not the case on Ocracoke Island as the low elevation, 3.5 to 5.0 ft msl, permits frequent overwash and has kept this area bare from sea to sound. There were a few isolated dunes, probably relicts, some distance to the south, and several new dunes have formed since the experiments were initiated, but there has been no general development outside the sphere of influence of the planted areas. Natural revegetation of this area would obviously be extremely slow and would probably not advance very far without a climatic change.

Climate

The climate in this region is humid temperate, with a mean annual rainfall of about 50 inches. The rainfall is normally spread rather evenly throughout the year but the distribution can be quite erratic in any given year. The coast is subject to both tropical cyclones, termed "hurricanes" when wind speeds reach 74 mph, and extra tropical storms, called "northeasters."

Hardy and Carney (1962) list about 60 tropical cyclones as having affected North Carolina during the first 62 years of this century. Although this is an average of about one per year, their occurrence has been quite erratic. For example, three hurricanes per year occurred in 1944, 1954, and again in 1955 when three struck within a 5-week period.

Hurricanes are potentially very damaging with dangerous winds, violent waves, intense rainfall, and high tides. However, the effect of a hurricane upon any given segment of the coast varies widely depending upon the storm's magnitude, path, duration, forward speed, and its time of passage in relation to the occurrence of astronomic tides. Mean tidal range on this coast is around 3.6 ft and the near shore waters are shallow, as are the sounds. Consequently, there is a potential for very substantial storm surges.

The extra-tropical storms are much more frequent in occurrence (Andrews, 1963) but, on the average, much less intense. The more severe of these produce wind speeds approaching hurricane force, and can be just as damaging as hurricanes. Usually the damage is lighter but more widespread than hurricane damage. The so called "Ash Wednesday" storm of March 7, 1962 was of this type and probably caused the most damage along the Middle and South Atlantic Coast of any storm in this century.

This storm activity, together with the low elevation and narrow width of these islands, imposes a harsh environment for plant growth. The experimental sites are subjected to flooding and salt spray from both the sound and the sea. Sand movement by wind is substantial. As much as 16 yds^3/front foot within a period of 15 months have been recorded (Savage and Woodhouse, 1969).

The relative transporting capacity of the sand-moving winds (those with speeds greater than 12 mph) at Cape Hatteras for a 5-year period is shown in Figure 2.

GENERAL METHODOLOGY

Experimental Conditions to be Reported

The combined initial objectives of the three dune-building experiments to be reported on were to evaluate planting width and spacing of vegetation, response of one and two species plantings, and the presence or absence of sand fence. These objectives were achieved after a few years, and since that time other factors have influenced vegetation and dune profile differences now apparent in the plantings. Sand supply, disease, and seed supply are among these factors which appear to have had a major influence. Ten conditions which have resulted from the interaction of initial planting design and the subsequent influence of the above mentioned factors seem of sufficient importance to report (Table 1). Four of these conditions result from the 1965 Ocracoke experiment, four from the 1966 Ocracoke experiment, and the other two from the 1965 Portsmouth experiment.

Grass Establishment

These trials were described in some detail in 1968 (Savage and Woodhouse, 1969). Since, except for species, the effect of the original

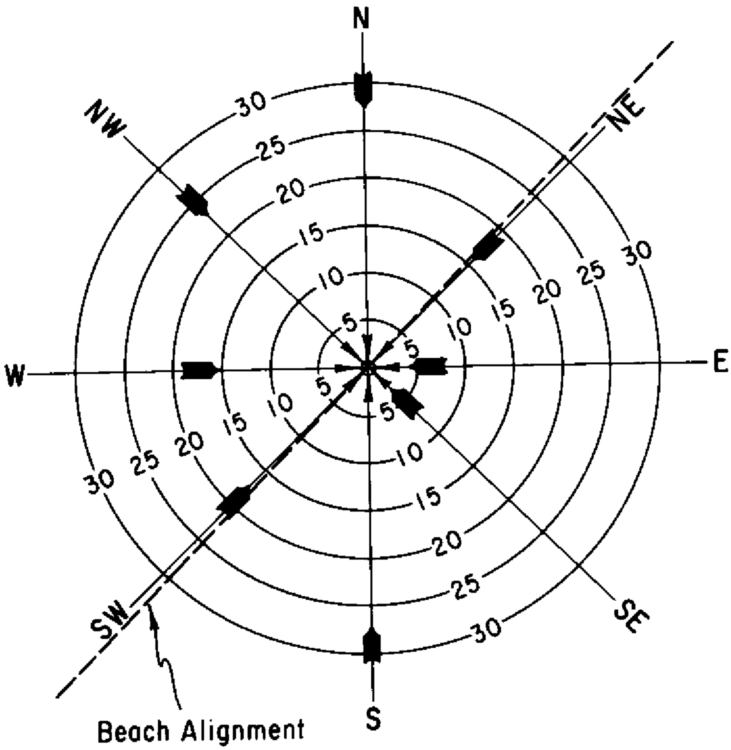

Fig. 2.[1] Relative transporting capacity of sand-moving winds (velocities above 12 mph) in the study area. (Capacity of the wind to transport sand is assumed to be proportional to the wind velocity cubed).

[1] Compiled from data furnished by the U. S. Weather Bureau at Hatteras, North Carolina, for the period from January, 1953 to December, 1957.

variables has long since been obscured by other factors, the reader is referred to the earlier report for details. This section will describe only the variables to be considered in this report.

Plantings were made parallel to the beach, starting 300 to 700 ft back of the high tide line, using nursery grown plants. Individual plots or sections were 400 or 500 ft in length the first year, but reduced to 200 or 300 ft in the 1966 Ocracoke plantings to economize on materials. A change was also made from uniform spacing within any one section in the 1965 plantings to a graduated pattern, thick in the center and thin toward the edges, in the 1966 plantings. This spacing permitted sand to penetrate to the center of the planting during the first two growing seasons, resulting initially in a wider, flatter dune than did

Table 1. Four groupings of conditions to be reported by section number, location, and establishment date for three dune building experiments observed from 1965 through 1975.

Location	Date Established	Experimental Section No.[1]	Conditions
Ocracoke	February, 1965	7	American beachgrass—no sea oats seeds
		3	American beachgrass—plus sea oats seeds
		19	American beachgrass—sand starved after 5 years
		8	Sand fence alone—abandoned after 3 years
Ocracoke	November, 1966	36	American beachgrass—full sand supply
		22	American beachgrass—moderate sand supply
		30	Sea oats alone
		28	Sea oats and American beachgrass
Ocracoke	November, 1966	34	Sea oats and American beachgrass—overtopped by storm surge
	March, 1968	37	Sea oats and saltmeadow cordgrass—overtopped by storm surge
		38	Saltmeadow cordgrass—overtopped by storm surge
Portsmouth	November, 1965	26	Sea oats[2]
		25 & 27	American beachgrass alone

[1] Original experimental section numbers as reported by Savage and Woodhouse (1969).
[2] 100-ft wide planting with a 28-ft core of American beachgrass.

the uniform plant spacing used previously. All plantings received N and P fertilizers during the first 3 years, but none thereafter.

At Ocracoke, plantings of American beachgrass and saltmeadow cordgrass were made behind the 1965 experiments starting in 1967. The effect of this can be seen in the elimination of sand coming from that side in later years. Sand supply has also been gradually cut off from the back of the Portsmouth Island plantings and from the 1966 Ocracoke experiment due to natural revegetation of the sand flats behind them.

Measurement of Dune Growth and Species Composition

Elevation

A baseline, tied to a benchmark of known elevation, was established prior to initiation and cross-sections (transects across the dunes) were surveyed at regular intervals. These were spaced 100 ft apart, beginning 50 ft from the end of each section, on the 1965 Ocracoke and Portsmouth plantings (4 per section) and at 50-ft intervals, starting 25 ft from the end, on the 1966-1967 Ocracoke experiment (3 or 4 per section). Surveys were made at intervals of 6 months to a year during the early stages and less frequently thereafter. It was not feasible, with the resources available, to survey at the same time each year.

Initially there was little variation between cross sections within experimental sections. With time, and particularly with stand losses due to disease, variability did develop. For presentation, data for the 2 to 4 cross sections representing each section were averaged, using a running average procedure. This was accomplished using a computer program which interpolated between measured elevation points to estimate an elevation at each 1-ft interval.

Vegetation

The first detailed description of the vegetation on any of these experimental dunes was conducted by van der Valk (1974; 1975). He (van der Valk, 1974) determined that sand burial was a major factor and that salt spray was of lesser importance in seedling establishment of dune forbs. Further, he (van der Valk, 1975) concluded from a study of analysis of vegetative communities which had developed on the series of experimental dunes on Ocracoke Island that the method used to build a dune had a lasting influence on the type of plant community which was subsequently formed. Differences in the amount of cover and distribution of the dominant grasses probably determined the pattern of accumulation and shifting of sand.

Our first vegetation sampling was in June, 1974, when a preliminary survey was conducted to obtain data upon which to base sample size and intensity. For this purpose, each section was divided into two to four zones based on visual differences in sand accumulation, vegetative composition, and plant vigor. A generalized sequence of four zones across the dune was often encountered. The farthest zone from the ocean (Zone 1) often consisted of the sand flat or dune swale dominated by saltmeadow cordgrass and a mixture of other herbaceous plants. The next zone toward the ocean (Zone 2) often occupied the lee slope of the foredune dominated by a mixture of dune grasses and other herbaceous plants. The third zone toward the ocean (Zone 3) usually included the top (crest) and front (ocean) slope of the foredune oceanward to but not including the area of rapid sand accumulation. This third zone was usually dominated by either American beachgrass or sea oats or a mixture of the two. In a typical four-zone sequence, the zone closest to the ocean (Zone 4) occurred in the area of rapid sand accumulation which covered most of the vegetation. This zone was dominated by either American beachgrass or sea oats or a combination of the two. Within transects across the dunes, 10 sample quadrats of each of three sizes per zone were chosen at random (¼ m^2, ½ m^2, and 1 m^2), and the aboveground growth was harvested, separated by species, dried and weighed.

Based upon analysis of this data, the following sampling procedure was selected for the sampling in September, 1974. Ten transects per section were sampled. The transects were placed equal distances apart after the first one was randomly selected. A 1-m^2 sample was randomly selected from each zone on each transect. Aboveground samples were harvested, separated by species, dried, and weighed. Presence of species appearing within zones, but not included in harvested quadrats, was also recorded. Data for American beachgrass and sea oats were summarized, and all other species lumped into an "other" category. A complete list of these "other" species is included (Appendix Table 1) but data on these will be published in a separate report.

This approach was satisfactory in terms of meaningful information obtained for effort expended. However, this method, as well as all others with which we are familiar, underestimates vegetation in the active sand zone. No procedure, short of extensive excavation, seems likely to overcome this limitation. This is unfortunate in that this is the zone of greatest activity, and therefore of considerable interest. Further, there is a tendency toward an inverse relationship between the degree of sand accumulation and the amount of vegetation exposed. It is important to keep this relationship in mind in evaluating data of this kind.

Effects of Disease on Dune Development

Disease was an unanticipated factor which affected the vegetation and the resulting dunes. Marasmius blight was first observed in 1965 on Ocracoke and Hatteras Islands, but was not fully identified until some years later (Lucas et al., 1971). This disease was subsequently found to be quite destructive to American beachgrass in this region and it had profound effects upon the development of these experimental dunes. Dune growth and configuration were materially affected by blowouts as was the spread of other species into what would otherwise have been dense stands of American beachgrass. Blight developed throughout the 1964-1965 plantings on both Ocracoke and Portsmouth in the summer of 1968 and spread extensively through these and the 1966-1967 plantings in 1969 and 1970. Damage varied widely from year to year, but some losses were observed during each growing season thereafter, except that of 1973. For some reason, presumably weather related, no development of Marasmius blight was observed anywhere along the North Carolina coast in 1973.

Damage first occurred in distinct patches, roughly circular or oval in shape and ranging from 2 to 4 ft in diameter in which all plants in the patch appeared to die simultaneously (Fig. 3). Losses were usually limited to the interior of each section behind the zone of active sand accumulation. Thinning in succeeding years proceeded both through

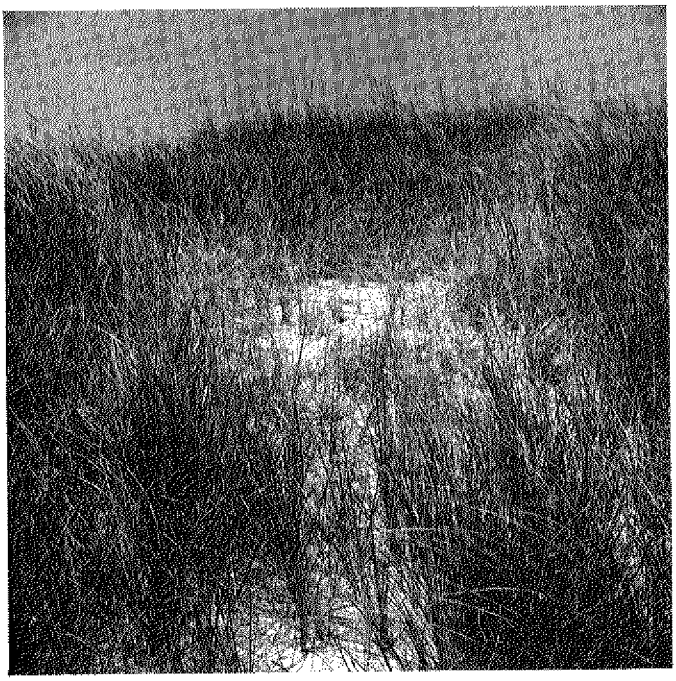

Fig. 3. A patch of American beachgrass killed by Marasmius blight.

the development of new patches and the enlargement of old ones. Some individual culms scattered through otherwise healthy-appearing stands also died. This type of damage was not definitely tied to the Marasmius organism until the 1974 growing season when it was the dominant form observed (Fig. 4).

Losses from this disease appear to be inhibited to a significant degree by rapid sand encroachment. Consequently, the front of a growing American beachgrass dune tends to remain intact even though severe, disease-induced blowouts (Fig. 5) are occurring immediately behind this zone. Also, new grass stands appear to always escape damage through their first, and usually their second growing season, enabling such plantings to establish a continuous front line before losses begin.

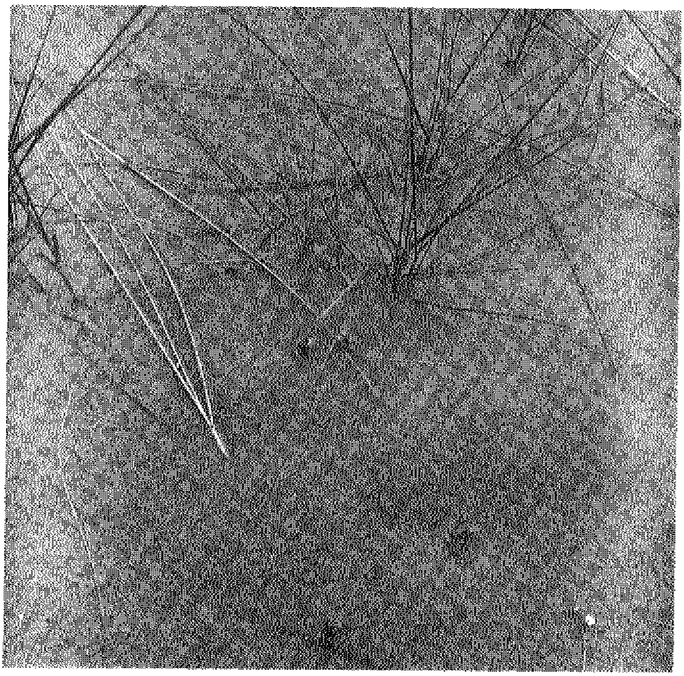

Fig. 4. Closeup of dead American beachgrass culms showing Marasmius blight fruiting bodies.

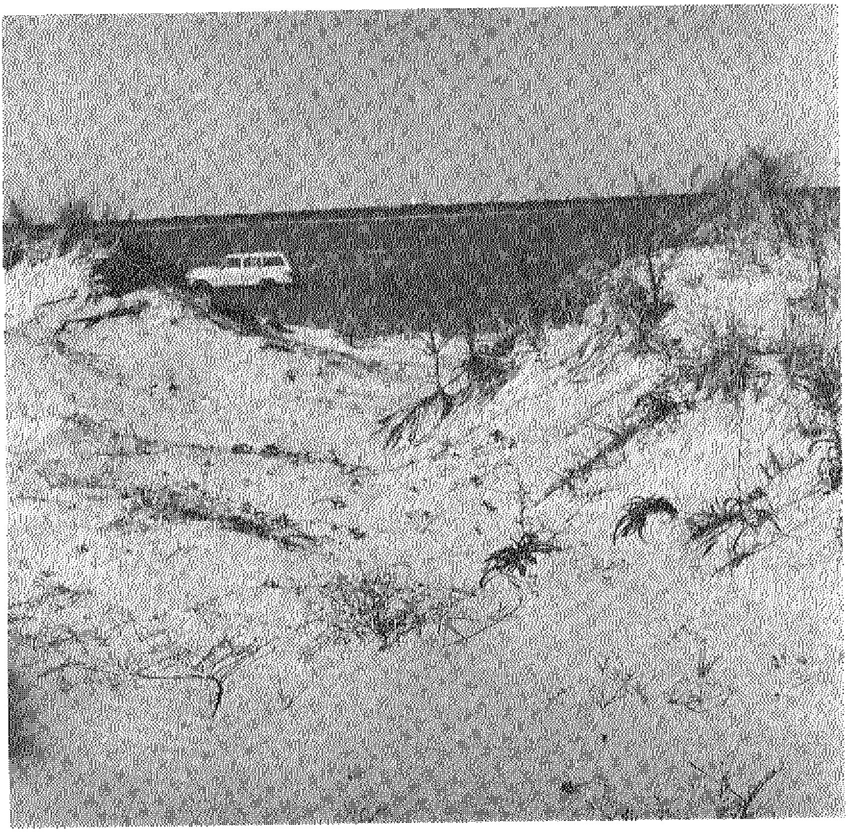

Fig. 5. Blow out caused by Marasmius blight damage.

EXPERIMENTAL METHODS AND RESULTS

Ocracoke, 1965

Methods

The original purposes of the 1965 plantings (to evaluate planting width and spacing of American beachgrass and presence or absence and location of sand fence) were attained in the 1968 season. Even in the spring of that year (Savage and Woodhouse, 1969), the effects of these treatments were being overshadowed by variation in sand supply. Since that time, sand supply, together with disease incidence and seed supply, appear to have been in control. Variations among these factors have established conditions which have caused distinct differences to develop at several points along the distance of over 7000 ft covered by this experiment. Four conditions seem of particular interest in this experiment. These may be described as *Condition I*—American beachgrass isolated from a sea oats seed supply; *Condition II*—American beachgrass adjacent to a sea oats seed supply; *Condition III*—American beachgrass undergoing a sharp reduction in sand supply; and *Condition IV*—sand fence only, abandoned after 3 years.

Condition I—American beachgrass isolated from a sea oats seed supply (Section 7). This condition is rather typical for an American beachgrass planting in this region, receiving a moderate but fairly continuous sand supply. Section 7 was initially planted 50 ft wide with plants spaced 1.5 ft on centers and a 4-ft sand fence in the center. As was the case with all plantings this wide and wider, the sand fence had little or no effect after the first few months, since the vegetation intercepted most of the sand before it could reach the fence. At planting, in February, 1965, the nearest sea oats plants were 1200 to 1500 ft to the northeast with no vegetation of any kind seaward and for about 2000 ft on the sound side (Fig. 6). Consequently, sea oats was much slower to move into this section than was the case with Condition II.

Condition II—American beachgrass adjacent to a sea oats seed supply (Section 3). This section is near the northern end of the 1965 planting on Ocracoke Island beginning about 1000 ft south of a relict dune covered largely by sea oats and known locally as Billy Goat Hills. Billy Goat Hills anchored the southern end of the foredune constructed by the National Park Service in the early 1960's. During the 1963 and 1964 growing seasons, a few (less than 25) small haycock shaped dunelets developed around sea oats seedlings on the sand flat south of the relict dune and behind approximately the northern 1000 ft of the 1965 plantings (Fig. 7). These dunelets together with Billy Goat Hills, provided an initial source of sea oats seeds which gradually expanded under the protection of the 1965 planting.

By 1969, sea oats seedlings were invading the 1965 American beachgrass plantings where openings had been created by disease. Section 3, being close to the seed supply, was one of the first to be invaded. Unfortunately, after January, 1967, some reduction in survey scope was required for reasons of economy and surveys were discontinued on several sections, including Section 3, not to be resumed until 1974. One reason for choosing this part of the experiment for de-emphasis in 1967 was an apparent decline in sand supply in that area. However, by the time surveys were resumed, Section 3 and others near it were accumulating almost as much sand as the best section in the experiment, but

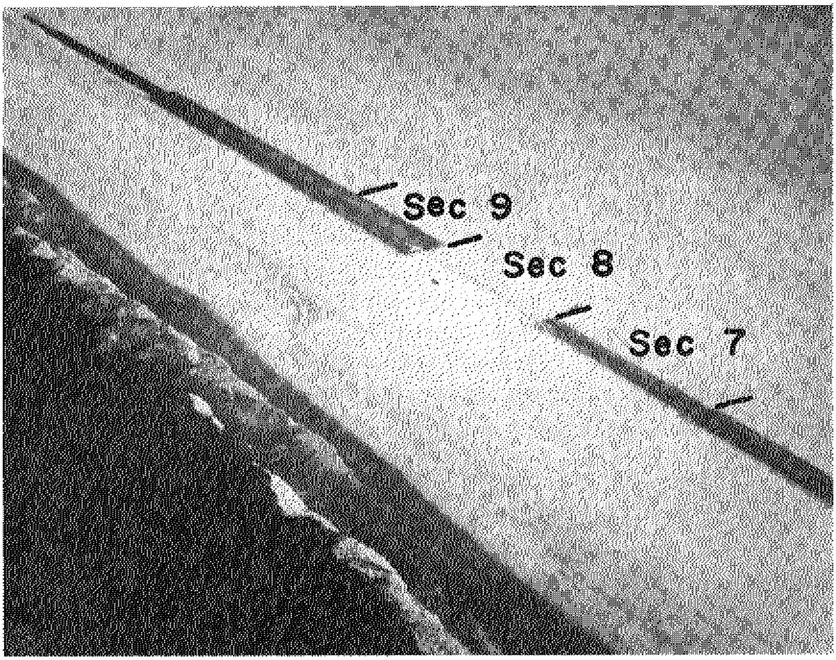

Fig. 6. Aerial view of Sections 7, 8, and 9, showing absence of natural vegetation in the vicinity, December, 1967.

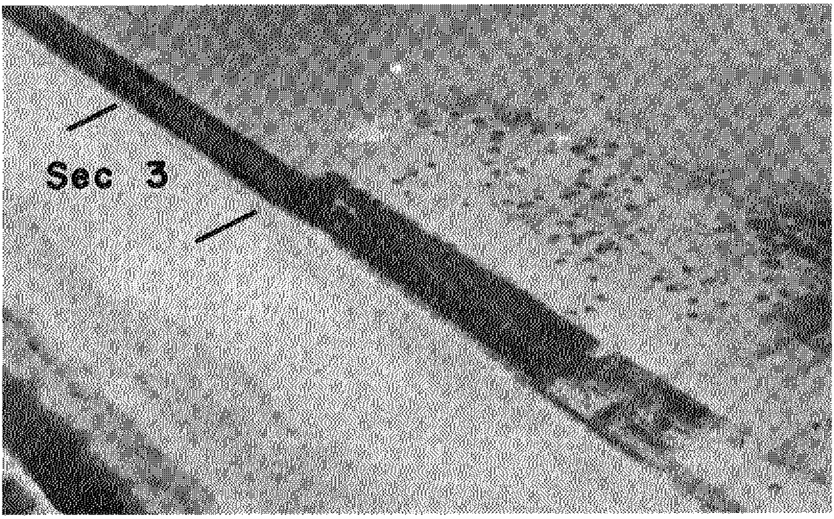

Fig. 7. Aerial view showing sea oats dunelets in vicinity of Section 3, back of Sections 1, 2, and 4, December, 1967.

due to early invasion by sea oats these dune cross sections became distinctly different.

Condition III—American beachgrass undergoing a sharp reduction in sand supply (Section 19). When this section was installed in February, 1965, it consisted of a planting of American beachgrass 25 ft wide reinforced by a 4- ft sand fence along the landward edge. This section was at the southern end of the 1965 experiment in an area of plentiful sand supply. The sand fence was buried during the first year, the dune widened rapidly the following year, and by January 1967, there was very little difference in the size of this dune and that of Sections 3 and 7 which were similar beachgrass plantings.

Changes in Section 19 began to occur when during 1967 a volunteer dune, resulting from American beachgrass material which drifted into place, began to develop about 100 ft in front of this section (Fig. 8). After two unsuccessful attempts to control it, the dune was allowed to grow unimpeded. Since 1970, it has been intercepting increasing amounts of sand from Sections 18, 19, and 22. This sequence of events has enabled us to follow the development of a dune that grew rapidly for about the first 5 years and then became increasingly sand-starved over the next 5-year period. This situation is of considerable interest since it represents a rather common occurrence.

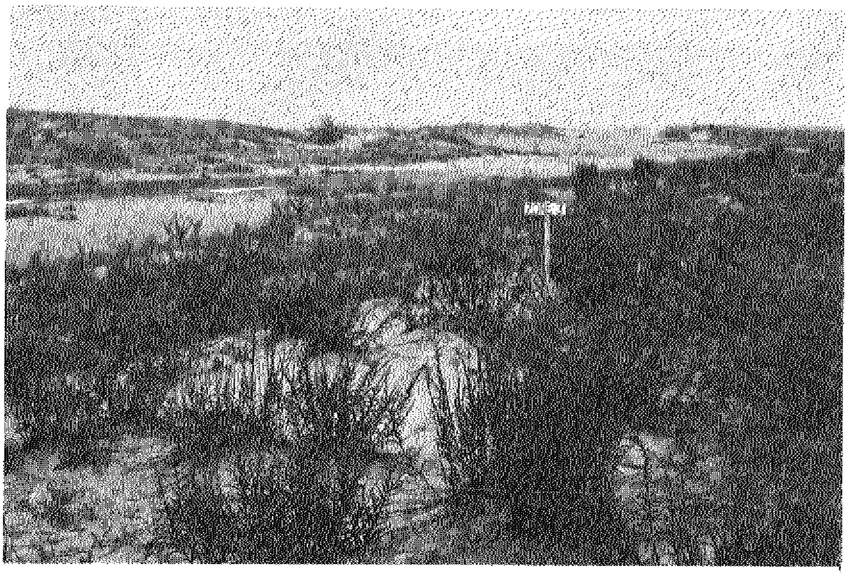

Fig. 8. Front of Sections 18 and 19, foreground, and natural dune developing in front, background, September 1974.

Condition IV—Sand fence only, abandoned after three years (Section 8). The sand fence section began as a single 4-ft slat-type sand fence installed at the time the experiment was established in February, 1965. As one fence filled a second was installed following, generally, Method B described by Savage and Woodhouse (1969); however, a tendency soon developed for vegetation to encroach from the planted sections on each end of the fence section. Also, as the vegetated dunes began to outgrow the fence section, there was more and more sand intercepted by the vegetation rather than the fences. Consequently, after 3 years and 5 to 7 fences, maintenance was discontinued. Since then, the sand fence section has gradually become partially vegetated and it seems worthwhile to include data on its present condition in this report.

During the period covered by this report, a total of 12 topographic surveys were made on this experiment. However, for the sake of clarity of presentation, data from only four are shown for the treatments or conditions to be considered here. These are: February, 1965 immediately prior to establishment; January, 1967 near the end of the second year; May, 1969 after the onset of Marasmius blight and just before disease damage began to materially effect dune shape; and April, 1975 in the 10th year of dune growth.

Results

Condition I—American beachgrass isolated from a sea oats seed supply (Section 7). At the end of 2 years (January, 1967), this 50-ft wide planting had developed a dune about 80 ft wide which consisted of a steep ridge about 5.5 ft high centered over approximately the front edge of the original planting with a much smaller ridge near the rear edge of the planting (Fig. 9a). In the succeeding 27 months (January, 1967—May, 1969) there was a substantial expansion of the dune, both upward and seaward, with little change in profile shape. The dune also had attained very nearly maximum height at this time (around 12 ft msl compared with 13 ft 5 years later) and had advanced seaward about 20 ft. It was still essentially pure American beachgrass, but with numerous areas of dead but not fully disintegrated plants.

During the next 5-year period, 1969-1974, the dune doubled in size, advanced seaward another 60 ft and developed a more gradual seaward slope. Early in this period, the flat behind the dune became stabilized, diminishing the sand supply from that side and causing the ridge on the back to blend into the backslope.

During this same 5-year (1969-1974) period, dramatic changes in vegetative composition took place on the older part of the dune (Zones 1 and 2), roughly from the back of the early frontal ridge through the

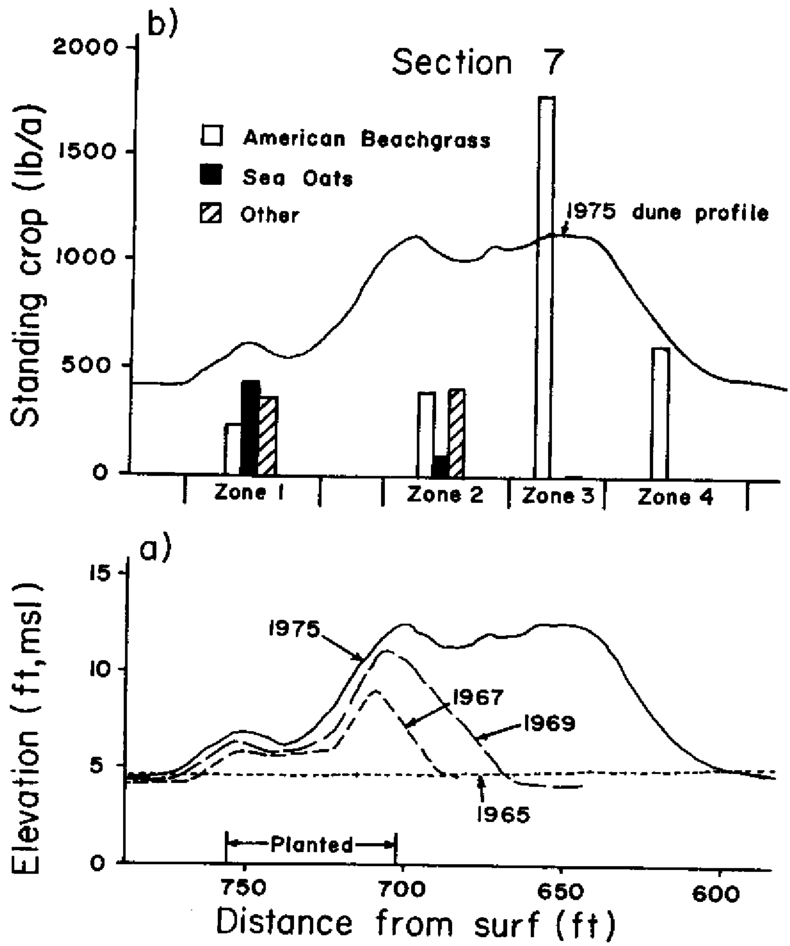

Fig. 9. American beachgrass isolated from a sea oats seed supply.
a. dune contours, 1965-1975.
b. standing crop of vegetation by zones, September, 1974.

toe of the present backslope (Fig. 9b). American beachgrass was still present throughout Zone 1 but greatly reduced in vigor. It was exceeded in weight of standing crop by sea oats, although the latter occurs in only half of the quadrats sampled. In addition to sea oats, 10 other species had become established in Zone 1 in significant quantities, the most prominent of these being *Erigeron canadensis* L. (horseweed), *Gaillardia pulchella* Foug. (gaillardia), *Hydrocotyle bonariensus* Lam. (pennywort), and *Solidago sempervirens* L. (goldenrod).

American beachgrass was still dominant in Zone 2, with most species present in Zone 1 also invading this zone. Sea oats was considerably less prominent, occurring in only 10 percent of the quadrats.

Zone 3, an area still accumulating sand, formed a sharp contrast. It remained essentially a pure stand of American beachgrass with a marked increase in vigor over that in Zones 1 and 2. Zone 4 represents a continuation of this condition down the seaward slope, the zone of most rapid sand accumulation. Growth was vigorous but the amount showing above the fresh sand at any one time was less than in Zone 3, with only about half of the quadrats containing vegetation aboveground.

Condition II—American beachgrass adjacent to a sea oats seed supply (Section 3). This planting, originally 75 ft wide without sand fence, had by January 1967 developed a slope similar to Section 7, and had trapped about the same amount of sand (Fig. 10a). The hump in the rear was about 25 ft further back, a reflection of the 25 ft wider planting.

By June, 1974, when surveys were resumed, this dune had accumulated almost as much sand as Section 7 but had developed a distinctly different shape—steep on the back, long gentle slope to the front, with another low hump in front of that. The latter represents new sea oats dunelets which are robust but only partially connected, developed from seedlings that became established beyond the toe of the advancing beachgrass dune. The true nature of this frontal ridge is better seen in Figure 11.

The continuous portion of the dune front, represented by the toe of the gentle slope, had advanced seaward essentially the same distance as in Section 7. However, the discontinuous sea oats dunelets (Fig. 11) had intercepted sand from the primary dune and produced an additional 50 ft of growth towards the sea.

The vegetation in Zones 1 and 2 was similar to that on Section 7, except for less sea oats in Zone 1, (Fig. 10b). In Zone 3, sea oats was more prominent, appearing on 20 percent of the quadrats. The main contrast occurred, however, in Zone 4. This zone was substantially wider than in Section 7, extending 55 ft farther seaward, and was covered almost exclusively by sea oats, in contrast to nearly 100 percent American beachgrass in this zone of Section 7.

This section is of interest primarily as an illustration of one mode by which sea oats moves seaward in front of a dune. This species is not capable of as rapid lateral expansion through rhizomes as is American beachgrass, but given ample seed supplies, a favorable weather sequence, and the protection of a dune on the landward side, it will advance toward the sand source by means of seedlings. However, it

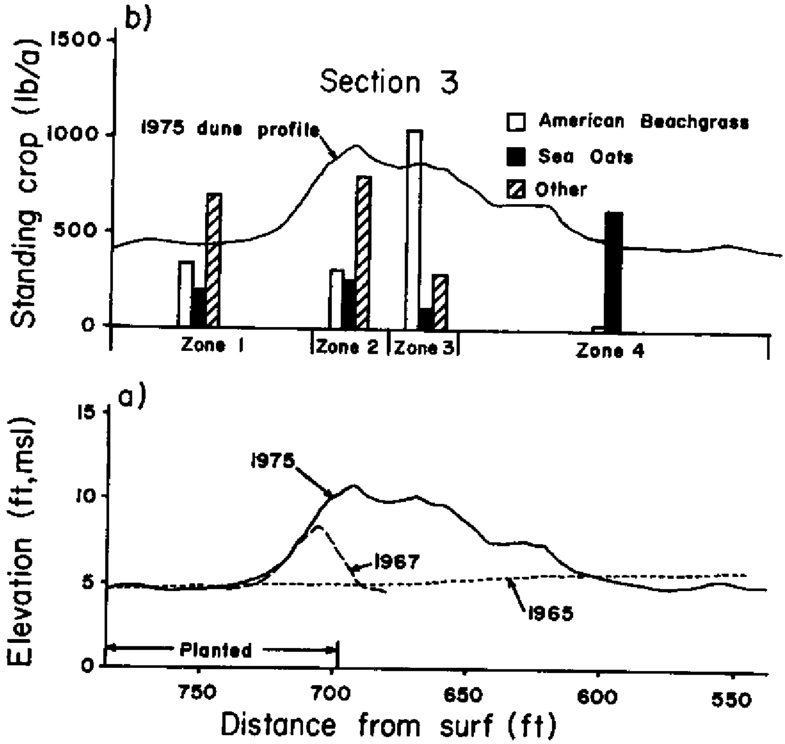

Fig. 10. American beachgrass adjacent to a sea oats seed supply.
a. dune contours, 1965-1975.
b. standing crop of vegetation by zones, September, 1974.

tends to expand in surges or jumps rather than in the continuous growth seen in Section 7, since the seedlings usually require two favorable years in sequence to become established. In the absence of interference in the form of traffic or grazing, this process can be expected to continue, erratically, until cut back by storm action. If intervals between severe storms and sand supply permit, the discontinuous dunes will gradually merge, forming a new frontal dune and causing the older dune behind to enter a period of sand-starvation. The next storm reaching the new dune will leave a scarp along the front, if it does not destroy it altogether, thereby making a straight dune line along what was a jumble of irregular dunes grown together. Many of the continuous lines of natural sea oats dunes found along the South Atlantic and Gulf Coasts are believed to have formed in this manner. Others

Fig. 11. View of sea oats dunes developing along front of Section 3 (American beachgrass). Note stubble of American beachgrass in a Marasmius blight patch in foreground.

have been observed forming through the germination of seeds along continuous spring or storm tide drift lines.

Condition III—American beachgrass undergoing a sharp reduction in sand supply (Section 19). As indicated earlier, this was a narrow planting that grew and trapped sand quite rapidly the first few years. By January, 1967, the amount of sand which had been trapped was about the same as Section 7. However, after the fourth year (1969), dune growth on Section 19 essentially ceased and dune shape began to change (Fig. 12a). Cessation of dune growth was the result of a sand shortage, created by the development of a natural dune seaward of Section 19. The change in dune shape resulted from this lack of sand plus the loss of American beachgrass through Marasmius blight. Between 1969 and 1974, the sharp ridge reaching to nearly 13 ft msl on the front of this dune, disappeared and was replaced by a gently rounded ridge with an elevation of 10.5 ft. The toe of the dune advanced seaward only about 20 to 25 ft during the 1969-1974 period as compared with 60 ft for Section 7.

The contrast in vegetative cover between Section 19 and Section 7

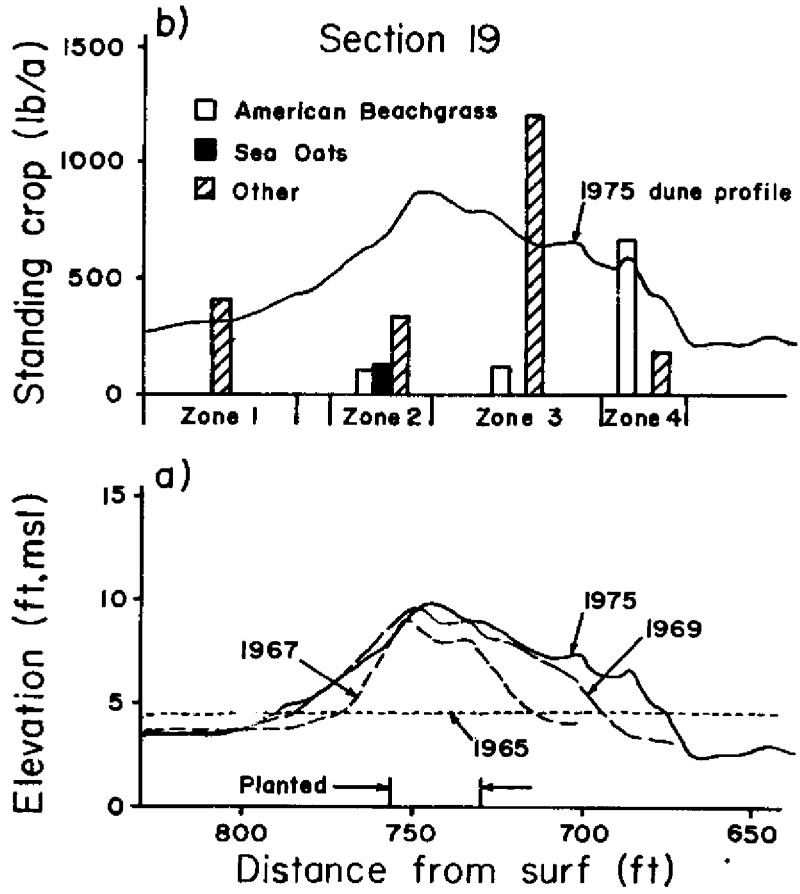

Fig. 12. American beachgrass undergoing a sharp reduction in sand supply.
a. dune contours, 1965-1975.
b. standing crop of vegetation by zones, September, 1974.

in 1974 is equally striking (Fig. 12b). In the almost total absence of fresh sand, American beachgrass has completely disappeared from Zone 1 and for all practical purposes, from Zones 2 and 3. There was little invasion by sea oats due, in part, to the distance (about 6000 ft) from the original seed supply for this area, as well as the lack of sand movement required to bury the seeds after sources developed nearer at hand. Zone 4, the active sand zone, was very narrow, but continued to carry a healthy cover of American beachgrass. Due to the slower growth, and perhaps to protection by the natural dune in front, several species invaded this zone that have not yet reached comparable areas of Sections 3 or 7.

The development of this dune (Section 19) over the past 10 years is worthy of study since somewhat similar circumstances occur quite frequently. Sand supply to growing foredunes, both artifical and natural, is often interrupted by the formation of new dunes in front, as in this case, or by the development of an armor of coarse shell over the beach, or by beach recession. In either case, the effect on dune development and especially upon growth and composition of the vegetative cover, can be substantial.

Condition IV—Sand fence only, abandoned after 3 years (Section 8). Abandoning this treatment in late 1968 resulted in a sharp decline in the rate of dune growth. At the January, 1967 survey, the mean cross section on this treatment (Fig. 13a) was almost identical to that of Section 7 (Fig. 9a). A little over 2 years later, the dune was noticeably smaller than Section 7 and had migrated landward in contrast to the seaward growth of the latter. During the next 5 years, the sand fence dune grew very little, but did become wider at the base. The expansion to the rear was the result of volunteer vegetation, while the frontal growth was due to the same cause plus some protection afforded this section by the more rapidly growing planted sections on either end.

Although there was a moderate amount of vegetation on this dune (Fig. 13b) in 1974, it was still confined largely to the back-slope, Zone 2, where it initially became established. The species composition was similar to the comparable zone on Section 7 and the dry weight was only slightly less. Zone 1 was entirely on the sand flat and although protected by it, it was not part of the dune. Zone 3, in front of the ridge, was much more sparsely vegetated. The cover was limited largely to the dune grasses, sea oats and American beachgrass, while vegetation in Zone 4 (not shown in Fig. 13b) was confined to a few dunelets of these grasses.

This treatment is of interest primarily as an example of the gradual encroachment by vegetation onto a dune accumulated by an inert obstruction. It shows a much slower, but otherwise similar pattern to that seen in the planted sections, the major difference being the difficulty the dune grasses have with invading the exposed dune front. It serves as a good illustration of the necessity for planting in the stabilization of mechanically built dunes.

This treatment should still be considered a more favorable than normal situation for natural establishment of vegetative cover, due to the protection and seed supply afforded by the planted sections on each end. We have observed the gradual, but almost complete disappear-

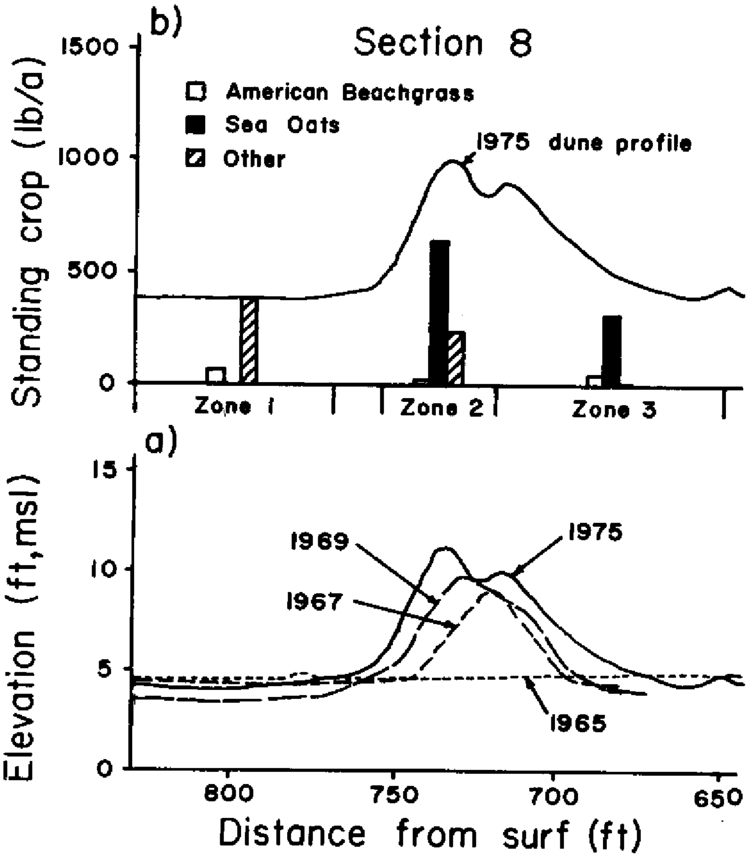

Fig. 13. Sand fence only; abandoned after three years.
a. dune contours, 1965-1975.
b. standing crop of vegetation by zones, September, 1974.

ance of many of the fence-built dunes described by Savage and Woodhouse (1969) on Portsmouth Island since the termination of sand-fence maintenance there. Lacking seed sources nearby, vegetation was frequently unable to invade and stabilize such dunes before the fences disintegrated and released their sand. However, in some locations near a seed supply, new dunes are developing along old fence lines where accumulated debris has enabled seeds to germinate and become established around the few remaining fence posts. This is a process that may proceed anywhere debris traps sand and seed. The fence posts simply encourage the new dunelets to form along a line.

Lateral Movement of Sand Along Foredunes

The beach and the sand fences erected parallel to it are aligned almost NE-SW at this site. Since strong winds from either of these quarters occur frequently in this area (Fig. 2), substantial lateral movement of sand might be expected along dunes constructed in this orientation. Evidence of this is quite marked in the case of Section 8. The first sand fence on this section was aligned with the centers of Sections 7 (50 ft wide) and 9 (100 ft wide), and succeeding installations during the next 3 years alternated front and back of this line. Consequently, there was sufficient vegetation jutting out well beyond this dune (Fig. 6), at each end, to trap any sand leaving the ends of the sandfence dune. This did not occur with Section 17, where the original fence was aligned with the front row of the adjoining planted sections (Fig. 14). Consequently, sand sliding past the end of the fence tended to be dispersed along the front of the other sections. Sand supply in this area decreased in later years when the planted sections might have otherwise grown seaward enough to enable them to intercept such sand.

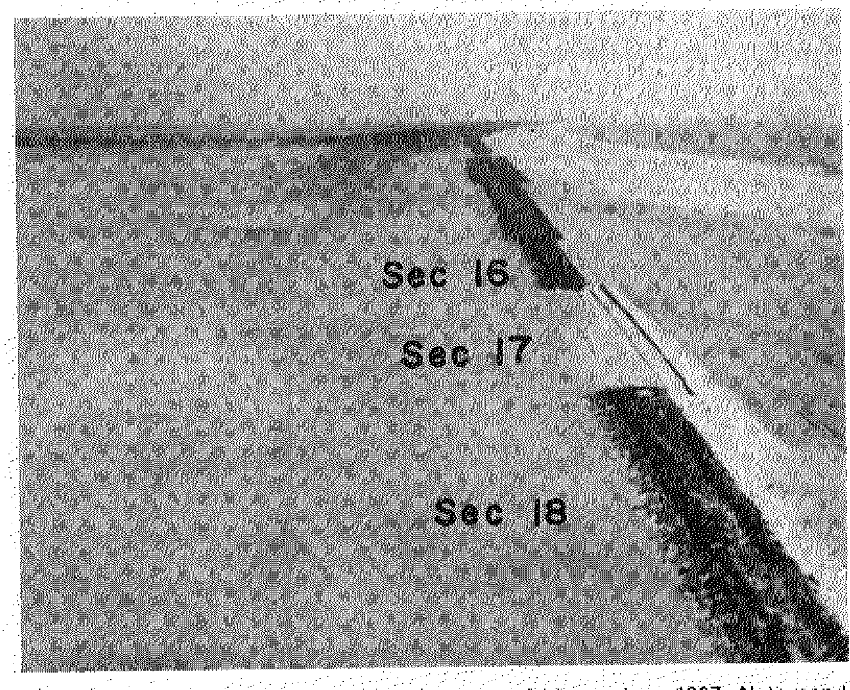

Fig. 14. Aerial view of Sections 16, 17, and 18, December, 1967. Note sand from Section 17 spreading in front of planted sections.

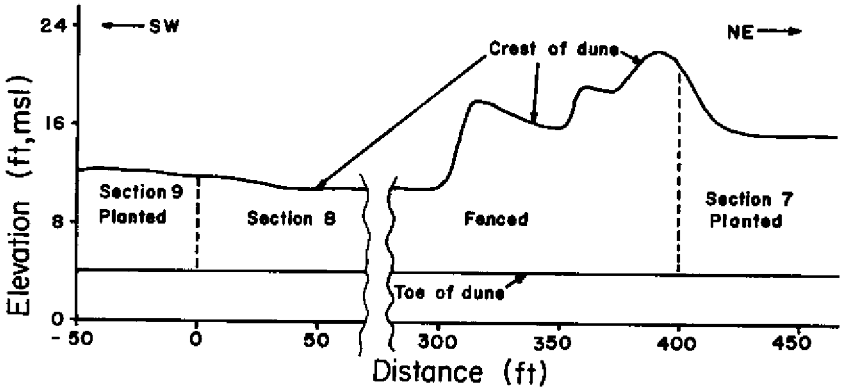

Fig. 15. Diagram of dune crest viewed from the front showing a sand fence section and portions of adjacent transplanted sections (June, 1975).

The wind data (Fig. 2) suggest that the amount of lateral sand movement would be about evenly balanced in the two directions since the sand-moving capacity of winds from the SW and NE are essentially equal as are those from the north and south. However, a profile taken in April, 1975, along the dune ridge of Section 8 and extending into Sections 7 and 9 showed a large hump near the NE end of Section 8, extending over into Section 7, without a similar accumulation on the SW end at the junction with Section 9 (Fig. 15). Cross sections taken at the same time show a slight accumulation near the junction of Sections 8 and 9 of 161 yds^3 compared with 3066 yds^3 at the NE end (Fig. 16). This amounts to a net movement to the NE of 7.5 yds^3/ft of dune and only 0.4 yds/ft to the SW!

The explanation of this difference is apparently due, in large part, to the tendency for southerly winds to predominate in the warmer weather when the sand surface is much more likely to be dry and more susceptible to movement, while northerly winds predominate during the winter when the sand surface is often wet (Dept. of Commerce, 1968). This does not imply that wet sand does not become windblown. This movement occurs in this region but only in winds approaching gale force. It is also likely that strong N and NW winds moved sand from the fenced section back toward the beach and the wind transport capabilities toward the southeast are only about ¼ of those to the northeast.

This "sliding" of sand along the face of a fence-built dune is of little consequence where very long, continuous sand fences are installed. Only a small proportion of the total sand collected is likely to be lost from the ends. Consequently, the addition of lateral spurs to the line fence for the prevention of this movement has generally been con-

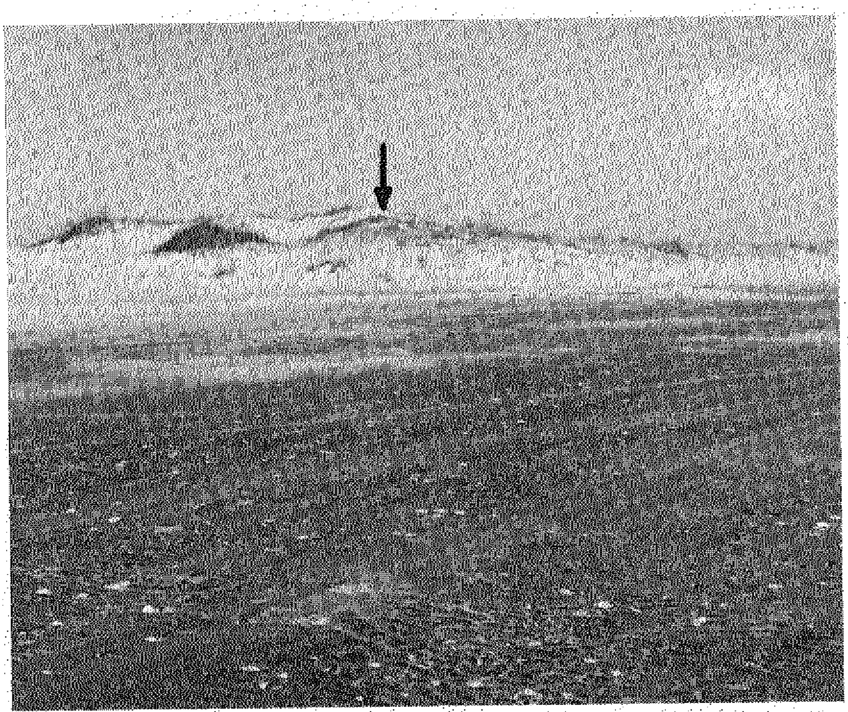

Fig. 16. Front view of area of maximum sand accumulation on northern 100 ft of Section 8 and southern 50 ft of Section 7. Arrow indicates junction between Sections 8 (sand fence) and 7 (American beachgrass).

sidered unwarranted (Savage, 1963). However, it is quite apparent from this example, as well as from similar observations elsewhere along this coast, that short installations (in the order of 100's of ft) are an entirely different matter. Sand loss from the ends may become a significant part of the total sand trapped by the installation.

Ocracoke, 1966

Methods

These plantings were made in November, 1966, but, due to severe salt damage (Savage and Woodhouse, 1969) required substantial replanting during the winter of 1967-1968. This trial included a comparison between American beachgrass, sea oats, and a mixture of these two species. These three treatments from this experiment are discussed in this report. From 1966-1975, eleven topographic surveys were made but in the interest of clarity only four are presented. These were November, 1968, prior to planting; May, 1969, soon after distinct dunes started to form; October, 1970, after the major outbreak of blight, but before serious blowouts developed; and June, 1975.

American beachgrass in a pure stand (Sections 22 and 36). The two sections of this treatment have developed under substantially different conditions. Section 22 has been gradually coming into the shadow of the volunteer dune developing in front of Section 19 about 1000 ft to the northeast. More important, the sand flat just behind this section has become largely stabilized during the past 2 or 3 years by invasion of vegetation from the north, effectively cutting off sand supply from the sound side. Section 36, on the other hand, is still fully exposed and receiving sand from both sides.

The treatments to be compared with these are on sections lying in between these two extremes and the conditions surrounding them would be approximated by the mean of these extremes. However, averaging the topographical and vegetation data for Sections 22 and 36 would conceal information of interest. Consequently, the data on each of these two beachgrass dune sections is presented separately.

Sea oats in a pure stand (Section 30). Due to the typical slow start of this species, plants were poorly established in the spring of 1967, resulting in substantial stand losses at that time. Around 30 percent survival was recorded for sea oats in October, 1967, compared with about 75 percent for American beachgrass (Savage and Woodhouse, 1969). This in turn delayed sand accumulation and dune growth. In March, 1968, American beachgrass sections had accumulated around 5 yds^3/front foot while the sea oats had recorded only a trace. Consequently, the initiation of growth of the dune on Section 30 was delayed about 2 years in comparison with the other two treatments.

American beachgrass plus sea oats (Section 28). This treatment consisted of a planting of these two species in alternate rows, a 50-50 mixture. Survival in the sea oats rows in October, 1967 was similar to that of pure sea oats plantings (about 30 percent) in Section 30. However, American beachgrass survival on this section was just slightly below that on the pure beachgrass plantings. There was little indication at this point that either species had affected the survival of the other. The mixture was able to trap around 3 yds^3/front foot by March, 1968, due almost exclusively to the survival and early growth of the American beachgrass component.

Results

American beachgrass in a pure stand (Sections 22 and 36). These two sections were compared to illustrate the effect of difference in sand supply. Section 36 received a sand supply from the front (ocean side) and rear (sound side) while Section 22 received sand only from the front. Section 36 represents somewhat of an extreme for this coast in that sand supply from both sides, front and rear, has remained plentiful throughout the 8-year period. Consequently, in spite of the very wide plant spacing (4 ft x 4 ft) along the edges, a small ridge appeared along the sound side very early and growth of the dune has maintained a fairly rapid pace on the back as well as on the front (Fig. 17a). Seaward growth, since planting, has been about 75 ft or 9.3 ft/yr, very close to

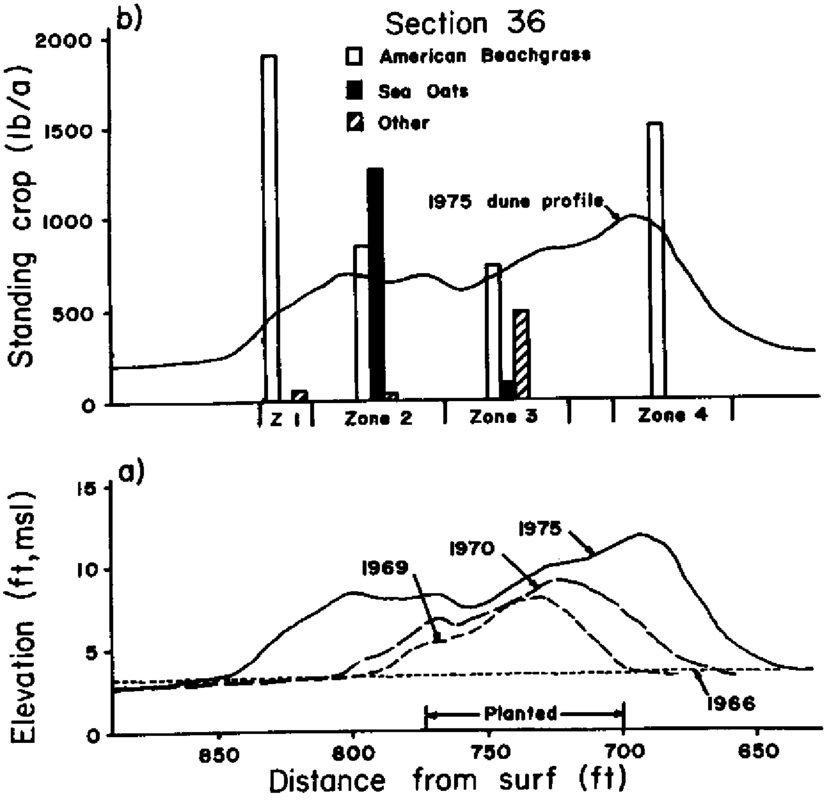

Fig. 17. American beachgrass with sand still available from the back (sound side).

a. dune contours, 1966-1975.

b. standing crop of vegetation by zones, September, 1974.

the 10 ft/yr rate for Section 7. However, this dune has also expanded landward about 55 ft during this period. With continuous growth, both front and back, a pronounced trough has developed through the center of the dune (Fig. 17a).

Sand supply has also affected both the vigor and composition of the vegetation cover (Fig. 17b). The stand and growth of American beachgrass in Zone 1 is equal to that in Zone 4, an excellent example of the effect of supply of blowing sand upon the vigor of American beachgrass. Very little invasion by other species has taken place in Zone 1. American beachgrass is still present over Zones 2 and 3 but with greatly reduced vigor and a corresponding increase in invaders. However, the number and vigor of the invading plants are generally less than for the corresponding zones in Section 22. Zone 4 is an essentially pure stand of vigorous American beachgrass, normal for these conditions.

Section 22, originally identical to Section 36, has been undergoing a gradual reduction in sand supply (primarily from the sound side) since shortly after establishment. Consequently, it differs markedly from Section 36 in both profile and vegetation. The wide plant spacing along the edge prevented the development of the usual hump along the back until 1970 and the initial dune ridge formed over the close-spaced central portion of the planting (Fig. 18a). By 1974, this dune consisted of a seaward ridge with a slight back ridge forming in the zone of natural revegetation about 60 ft behind the original planting. Seaward advance since establishment is about 60 ft, somewhat less than Section 36.

Since sand supply from the back was cut off, the vegetative pattern and composition on this treatment (Fig. 18b) resembles that on Section 7, rather than 36, which was planted as a duplicate plot. The large number of invading species, together with the very sparse stand of American beachgrass in Zone 1, is largely explained by the fact that this zone was completely behind the planted area. All of these plants are volunteer. Zone 2, which includes most of the original planting, carries a very weak stand of American beachgrass plus about a dozen invading species. American beachgrass in Zone 3 lacks vigor and there is significant invasion by other species, in contrast to a pure stand of very vigorous beachgrass on the corresponding zone of Sections 7 or 36. This difference is doubtless due to the slower growth of Section 22. In other words, in spite of the close proximity of Zone 3 of Section 22 to the active sand zone, enough time has elapsed since it received fresh sand to permit it to mature significantly. Zone 4 is also unlike its counterpart in Section 36. It still has a vigorous growth of American beachgrass, but due presumably to slower growth plus a nearby seed supply, it is being invaded by sea oats.

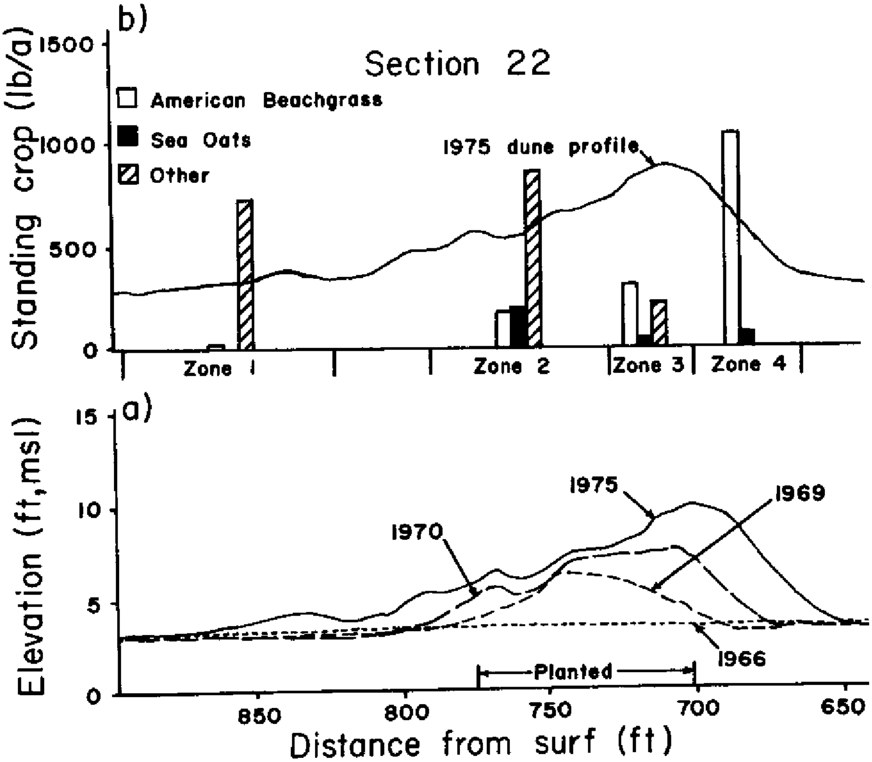

Fig. 18. American beachgrass with sand cut off from the back (sound side).
a. dune contours, 1966-1975.
b. standing crop of vegetation by zones, September, 1974.

Sea oats in a pure stand (Section 30). Dune growth on this treatment was effectively delayed for nearly 2 years in comparison with the other treatments. The first semblance of a dune ridge was recorded in the May, 1969 survey (Fig 19a). At that time, the dune was located over the close-spaced center of the original planting and was only about 6.5 ft above msl at the crest. During the next 5 years, this dune grew to a height of 10.5 ft msl and advanced seaward about 25 ft. Vertical growth of the sea oats dune during this period was somewhat more rapid than for the American beachgrass dunes (Sections 22 and 36) but lateral expansion was slower.

This is a reflection of differences between the species. Sea oats has much shorter rhizomes than American beachgrass and is not capable of the rapid spread toward the sand supply commonly observed with

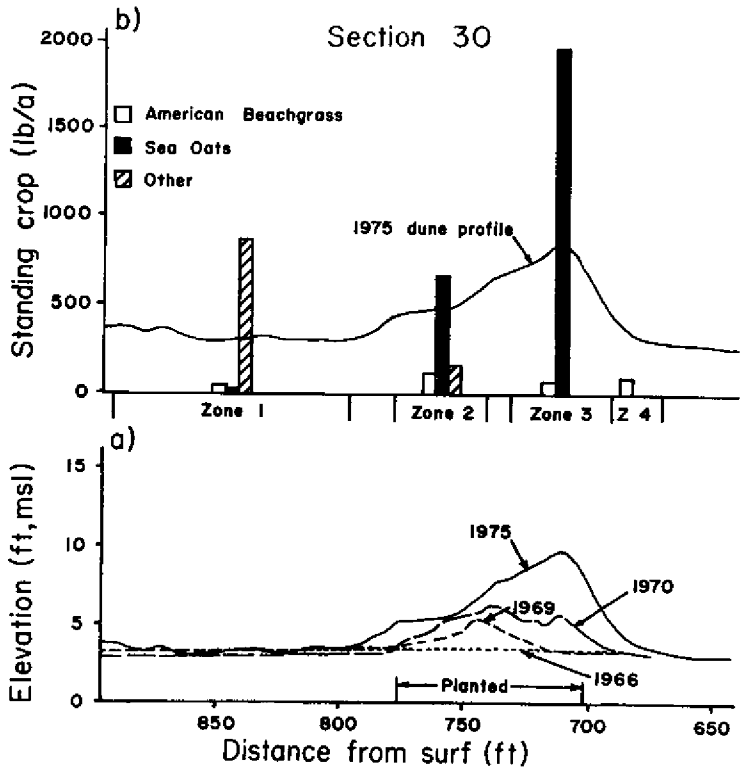

Fig. 19. Sea oats transplanted in a pure stand.
a. dune contours, 1966-1975.
b. standing crop of vegetation by zones, September, 1974.

beachgrass. On the other hand, the sand-trapping capacity of established plants of sea oats is exceptional, as is the ability of this plant to elongate upward as sand accumulates around it.

The pattern of vegetation on this dune (Fig. 19b) is somewhat similar to that on the American beachgrass dunes. Zone 1 is behind the planted area and is being populated by a mixture of saltmeadow cordgrass, American beachgrass and sea oats. Zone 2, on the back half of the original planting, still carries a complete stand of sea oats that has lost vigor due to the absence of fresh sand. The thin, but quite uniform, sprinkling of American beachgrass throughout this zone is of interest since this represents invasion of a pure stand of sea oats by this species. The invasion appears to have taken place largely as seedlings and is somewhat surprising in view of the scarcity of surviving beachgrass seedlings on this coast. The reverse, sea oats invading and replacing American beachgrass, has been widely observed; however, since sea oats has seldom been planted, and then almost never in a pure stand, instances of beachgrass invasion have not been confirmed, although sometimes suspected.

Zone 3 includes the front half of the planted area on this section plus a seaward expansion of about 25 ft. It is in the active sand zone and carries an almost pure stand of quite vigorous sea oats, maintained in this condition by the fresh sand supply. Zone 4 is on the toe of the dune and carries a few young American beachgrass plants that have moved in from the beachgrass sections on each end of Section 30. There are also a few sea oats seedlings, too scattered to show up in the survey.

Sand is being intercepted from this section by beachgrass sections abutting it on each end. These sections started developing ahead of it and are growing seaward at a more rapid rate. Also, American beachgrass is encroaching from each end along the active sand zone of this dune (Fig. 20). Consequently, in a few more years, this section seems likely to become very similar to Section 28 (sea oats and American beachgrass), pure beachgrass in front with sea oats and secondary invaders behind.

American beachgrass plus sea oats (Section 28). Initial dune formation on this section occurred over, and to the front of, the close-spaced center of the planting. Although early growth was slowed somewhat by the sparse stand and slow development of the sea oats component of this mixture, the planting has produced a substantial dune, as large as Section 22 (Fig. 21a). In fact, seaward expansion from May, 1969 to June, 1975, has been about 45 ft, very close to the annual rate of the better beachgrass sections. This section also developed a small ridge astride the landward edge of the planted area during 1969-1970, leaving a distinct trough in front of it. This continued to develop after 1969, although sand supply from that side has been largely cut off during the last year or two.

The vegetative pattern that presently occupies this dune is quite revealing (Fig. 21b). Zone 1 is all behind the planted area and has a vegetative cover fairly typical of the sand flat. Zone 2 is almost all within the planted area and still carries a mixture of American beachgrass and sea oats, plus a scattering of about 10 other species. However, the ratio of beachgrass to sea oats has changed from about 7 to 3 in 1968 to about 1 to 35 in 1974. American beachgrass has been almost completely replaced by sea oats in this older part of the dune. The situation in Zone 3, the frontal portion of the original planted area, is very similar except that the sea oats component is considerably more vigorous and other invading species have not yet become established. Zone 4 constitutes a

Fig. 20. View along front of Section 30 (sea oats) with end of Section 31 (American beachgrass) in background showing Section 31 advancing further seaward.

sudden and complete reversal to pure American beachgrass. This zone was not planted but represents most of the seaward expansion of this dune beyond the planted area (since about summer of 1969).

This dune provides examples of several important aspects of the interaction of these two grasses with sand supply and with each other. In brief, these are as follows:

1. Sea oats is capable of crowding out American beachgrass along this part of the coast, and tends to remain more vigorous in the face of declining sand supply, but is much slower and less competitive than American beachgrass in lateral expansion in response to sand supply.
2. Through rapid growth and lateral spread, American beachgrass

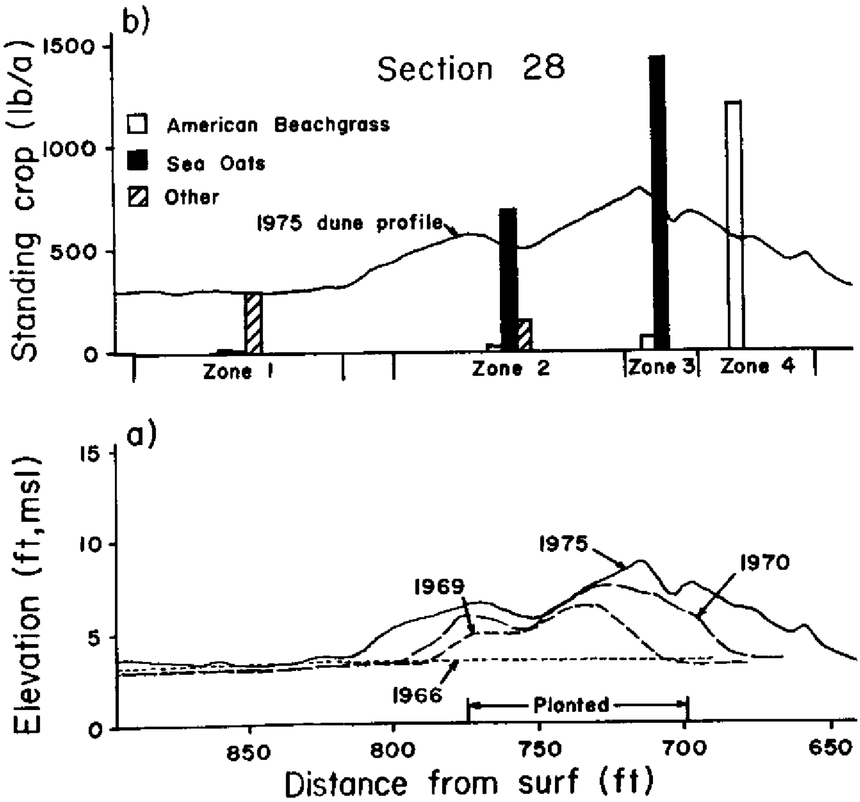

Fig. 21. American beachgrass plus sea oats.
a. dune contours, 1966-1975.
b. standing crop of vegetation by zones, September, 1974.

can overcome or grow away from Marasmius blight in response to a plentiful sand supply. Behind the zone of rapid sand accumulation, sea oats eventually becomes dominant.

Portsmouth, 1965-1966

Methods

Two treatments, sea oats and American beachgrass, are compared in this trial. Three 400-ft dune sections were involved, including one section with sea oats located between two American beachgrass sections. These plantings were part of an 11-section trial involving plant spacing and sand fence variables established in November, 1965. The plantings were 100 ft wide with a 28-ft "core" of American beachgrass, spaced 15" x 21" through the center of all plantings. All spacing and species variables were then imposed in front and behind this 28-ft strip.

American beachgrass (Sections 25 and 27). Plants were spaced 15" x 21 " on the front 36 ft of Section 25 and 48" x 48" on Section 27. Differences between these sections disappeared toward the end of the second growing season, and for the purpose of this comparison the two sections are averaged to represent this treatment.

Sea oats (Section 26). Sea oats plants for this section were grown from seeds planted in the nursery at Clayton, North Carolina, in April, 1965. This is, to our knowledge, the first dune built in this manner with this species. Survival of these transplants was satisfactory except in a small area near one end which was replanted during the following winter. Unfortunately, this left a low spot in the dune near the end of the section which later developed into a gap through the action of storm tides and beach buggy traffic. Due to the greater section length in this trial, the effect of adjacent beachgrass plantings on this treatment was reduced and the result from this sea oats planting provides a meaningful comparison with American beachgrass.

Results

Sand movement at this site has been substantially less and more erratic since 1965 than occurred at the Ocracoke location although beach alignment is almost identical. This has been due primarily to the higher proportion of shell on the beach and deflation plain at the Portsmouth site, resulting in the development of an armor of shells (Fig. 22) over the bare sand during intervals between severe storms. We feel that the shell armor was the major factor in restricting sand movement rather than island orientation as suggested by Godfrey and Godfrey (1972). Following the 1962 storm, but prior to the extensive sorting and concentration of the shell-sand mixture, sand accumulation as high as 16 yds^3/front ft was recorded on a planting in this vicinity only 15 months of age (Savage and Woodhouse, 1969). Sand supply is far more critical to dune growth than is prevailing wind direction. It appears from observations along the North Carolina, Florida, and Texas coasts that sand deposition around a sand fence is affected by the angle of sand-transporting winds, with winds perpendicular to a fence depositing sand beyond the fence and winds at a sharp angle depositing astride the fence. Wind tunnel tests by Manohar and Brun (1970) appear to confirm this. Vegetated dunes are much less sensitive to wind angle.

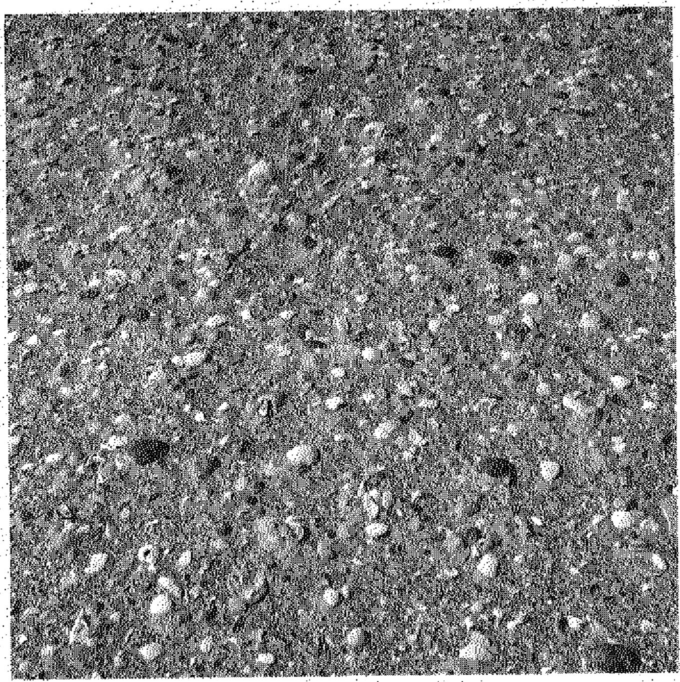

Fig. 22. Closeup of sand surface becoming armoured by shells between storms at Portsmouth.

This comparison is of interest as an example of dune development with both sea oats and American beachgrass under conditions of a lower and more erratic sand supply than at the Ocracoke Island site. It is also a case in which the length of these sections (400 ft here vs. 200 ft for the sea oats section on Ocracoke Island) resulted in less interference from adjoining sections, and may therefore have allowed a truer expression of the sea oats dune pattern.

American beachgrass (Sections 25 and 27). This treatment should be roughly comparable with Section 3 on Ocracoke Island, being established just a year later. Development of this dune was much slower than on Ocracoke Island, particularly during the first five growing seasons to June, 1971 (Fig. 23a). Growth has accelerated somewhat since then due largely to sand deposition and remixing of sand and shell by Hurricane Ginger. The seaward slope has become very similar to that on Section 3 on Ocracoke Island, but about 2 ft lower. Seaward advance has also been similar between the sections. The natural revegetation of the sand flat to the rear has cut off sand supply from that side since about 1970.

The vegetation pattern (Fig. 23b) is similar to that on comparable sections in the Ocracoke Island experiments. The American beachgrass stand on Zone 1 is still intact but has lost vigor for lack of fresh sand, and contains substantial amounts of several invading species. Zone 2, the back-slope of the frontal ridge, retains a very weak stand of American beachgrass, which is being replaced by sea oats, plus a thin sprinkling of about the same invading species as Zone 1. Zone 3, the seaward slope, still has some fairly active American beachgrass plus an equal amount of quite vigorous sea oats. The latter has formed some dunelets beyond the toe of this slope similar to those described on Section 3, Ocracoke.

Sea oats (Section 26). The normal delay in development of a new planting of this species is reflected in the 1969 cross section of this dune

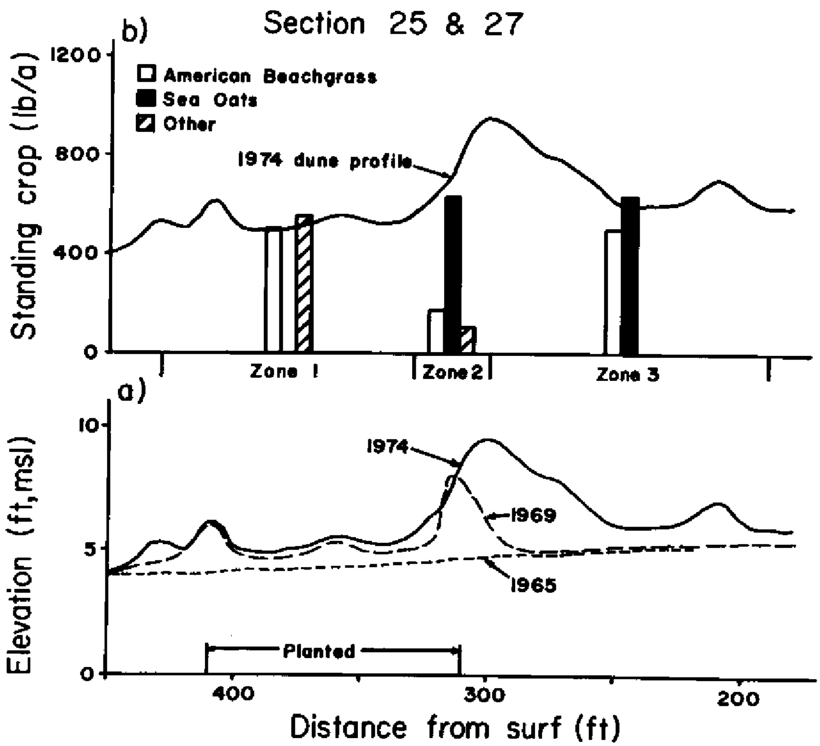

Fig. 23. American beachgrass on Portsmouth Island.
a. dune contours, 1965-1974.
b. standing crop of vegetation by zones, September, 1974.

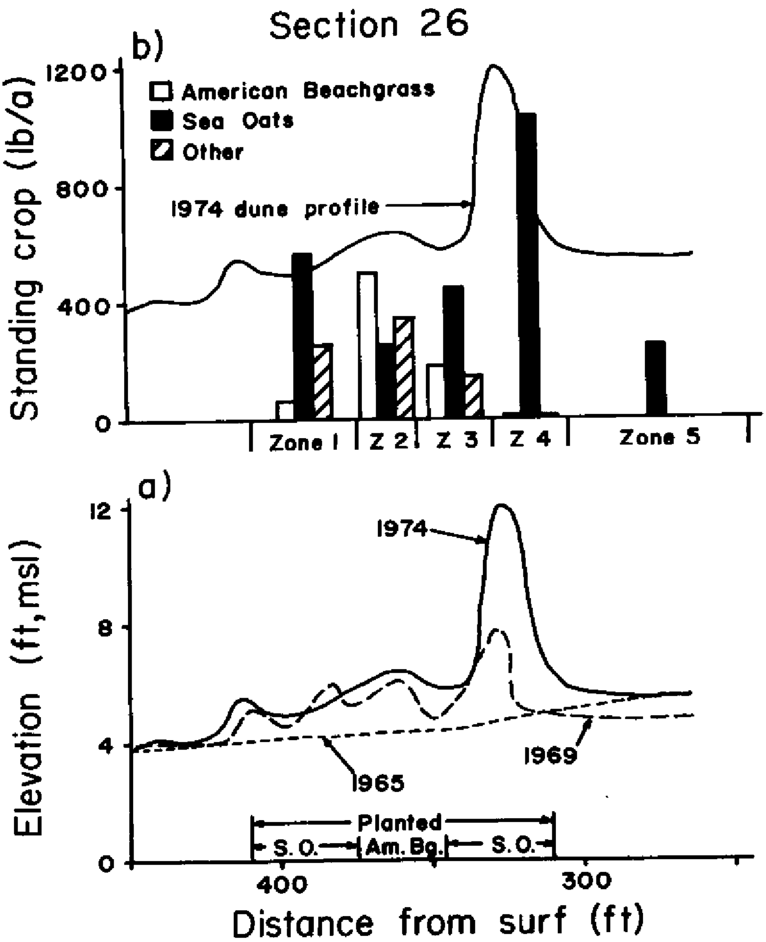

Fig. 24. Sea oats on Portsmouth Island.
a. dune contours, 1965-1974.
b. standing crop of vegetation by zones, September, 1974.

(Fig. 24a). Note that the frontal ridge developed just inside the original planting rather than astride the front edge, as was the case in the adjoining beachgrass. Since 1969, dune growth has been almost straight up. With a reduced sand supply, very little of it has penetrated beyond the 1969 ridge and due to the sea oats short rhizomes, this species has advanced seaward only a few feet. This situation has resulted in a very steep dune, which is common for this species.

The vegetative composition of this dune (Fig. 24b) is similar to that of the sea oats treatment (Section 30) on Ocracoke Island. Sea oats still dominates in Zone 1 but has been invaded by some American beachgrass plus a half dozen other species. Zone 2, planted to American beachgrass, is still dominated by that plant but has been invaded by sea oats and about the same group of plants as Zone 1. Zone 3, the backslope of the frontal ridge, is still dominated by sea oats but has been invaded by American beachgrass, and, to a lesser degree, by a few other plants. Zone 4, the top and steep front slope (the area of sand accumulation) is almost pure, and quite vigorous, sea oats. This dune is a good example of the ability of this species to stop sand movement within a short distance and to elongate upward in response to this stimulus.

The profile of this dune in the later stages is strikingly different from the sea oats section on Ocracoke Island (Section 30). The latter is not and has never been as steep, although it is approaching it on the front. The difference is believed to be due to at least three factors. First, the Ocracoke dune grew on a graduated planting pattern. As the thin spacings filled in toward the front, the frontal ridge moved seaward but the crest has not yet advanced to the leading edge of the original planting. In this respect, it is no farther seaward than the Portsmouth dune. Second, the Ocracoke planting of sea oats was only 200 ft in length and received some shelter from the more rapidly advancing American beachgrass at either end. Some of the accumulation on the toe seems to be due to this rather than an extension of the vegetation. Third, the gap in the Portsmouth dune caused some lateral flow of storm tides along the toe, and may have in this way increased the steepness at the toe to some degree.

Overtopping by Storm Tides

Continuous foredunes obviously present barriers to storm tides, so long as they remain unbroken and are not extensively overtopped. In this role, they are often valuable in the protection of roads, buildings, etc., of the developed beaches and in maintaining the integrity of barrier islands. Also, it can be readily observed that, where such dunes are bare or only sparsely vegetated, they disintegrate quickly when overtopped by storm tides or waves. It appears reasonable to assume that the provision of a complete vegetative cover should improve the ability of a dune to withstand overtopping. However, this is a very difficult point to test, and as a practical matter, susceptible to testing only in the field. Further, field observations of this kind are difficult to quantify and worse yet, must await the coming of the right storm at the suitable time and place. In view of these difficulties, the scarcity of information on this point is understandable.

In this project, meaningful observations of the effects of overtopping have been confined to a few spots in the Ocracoke site, following Hurricane Ginger, October 1-2, 1971. This is the only hurricane passing directly over this area during the period of our study. Forward speed of this storm slowed as it approached the North Carolina coast, causing wind direction to remain constant over any given location for a period of some hours. While damage was, in general, relatively light, rather high water was produced, particularly in the vicinity of Ocracoke Island and parts of several experimental dune sections on Ocracoke were overtopped. Observations were taken on those areas shortly thereafter.

Section 34 was planted to an American beachgrass-sea oats mixture in 1966 and was intended to be a duplicate of Section 28, discussed earlier. However, this section suffered somewhat more severe salt damage in 1967 than Section 28, and was slower to develop. It wound up being lower than the adjacent sections with a gap near one end, which required repair several times by planting and sand fences before healing over completely. This left a low place in the dune profile that was overtopped during Hurricane Ginger. Data on elevations in and around this area are shown in Figure 25.

After the storm, the dune crest on adjacent sections was around 8.0 ft msl, approximately the same as at the last survey, October, 1970. The lower part of the gap was at 5.7 ft, the mean elevation of the storm drift line was 6.9, and the bare toe of the dune on the front was at 3.5 ft on October 12. The toe was probably a good bit lower than this during and immediately after the storm as there was evidence of a 2- to 3-ft scarp along the front of all sections on October 3.

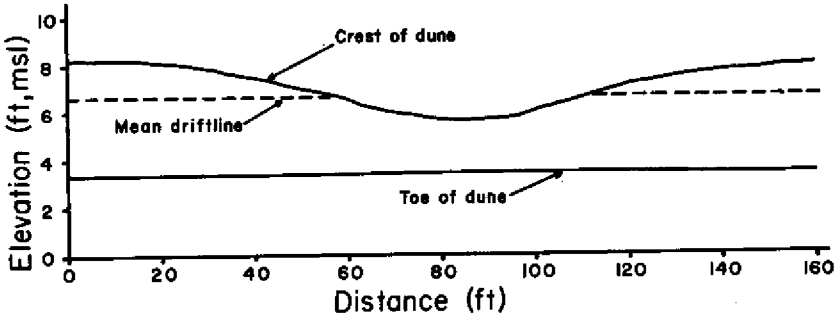

Fig. 25. Front view of the dune crest of Section 34 on October 7, 1971, following overtopping by Hurricane Ginger, October 1 and 2, 1971.

It is quite evident from Figure 26 that substantial amounts of water passed over the dune at this point without causing a break. This is further reinforced by Figure 27 showing a water-filled depression scoured out of the rear edge of the dune by water flowing down the back slope. Note particularly in Figure 26 that instead of erosion on the front, the grass cover encouraged the deposition of a protective layer of sand. Note also in Figure 26, the immediate response of the grass, in the form of new shoots, to the fresh sand deposit. This stimulation of regrowth can be a very effective self-healing mechanism following moderate storm damage.

Two new sections added to the southern end of the Ocracoke experiment in 1968 were almost completely overtopped. One of these, Section 37, was 200 ft in length, planted to a mixture of sea oats and salt-

Fig. 26. Section 34 after overtopping, view along front, sea at right, October 3, 1971. Note sand deposition over vegetated crest of dune.

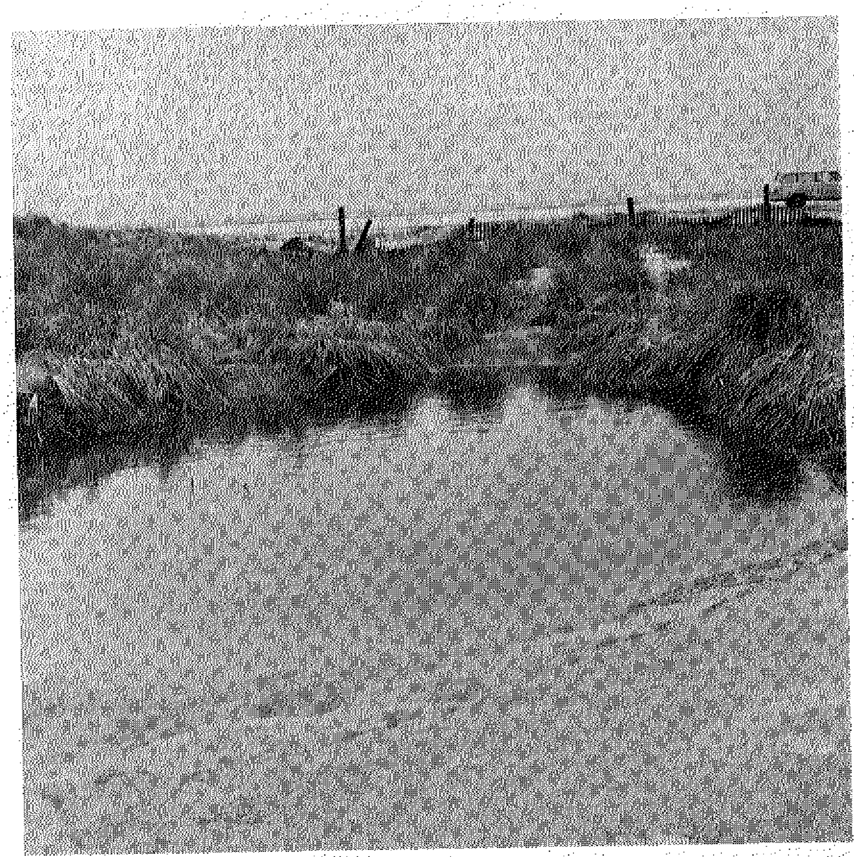

Fig. 27. Section 34 after overtopping, viewed from rear, showing pond scoured out by water flowing down dune back slope, October 3, 1971.

meadow cordgrass. The second, Section 38, was 300 ft long, planted to saltmeadow cordgrass only. Following Ginger, the crest of the ridge on these sections, over the 400 ft overtopped, ranged from 4.8 to 6.9 ft msl (5.3 to 6.0 ft, in October, 1970). In this case there was some evidence of erosion (Fig. 28) where, due to the lower elevation the amount and duration of water movement across the dune must have been far in excess of that across the gap in Section 34. However, there were no breaks and the vegetation recovered rapidly. A little over 50 ft was cut from the exposed end of Section 38 by the tide flowing around it. This loss appeared to be a result of undermining, a process to which dunes are particularly vulnerable.

While these observations leave something to be desired, particularly in the lack of estimates of the volume and duration of water flowing

Fig. 28. View of front of Section 38 saltmeadow cordgrass, foreground and Section 37 saltmeadow cordgrass and sea oats background, following overtopping. Note some evidence of erosion along crest of foredune.

over the dune, they do offer evidence of the ability of well vegetated dunes to withstand moderate amounts of overtopping. We are quite confident that bare or sparsely vegetated dunes of similar dimensions would have been incapable of surviving this storm at this location. On the other hand, it is true that this tolerance to overtopping on the part of well vegetated dunes is a matter of degree. Obviously, continued long enough, the undermining from the rear, seen in Figure 27, would cut a gap through the dune on Section 34. This indicates a breakthrough mechanism unlike that normally envisioned, i.e., from the rear, rather than the front.

IMPLICATIONS

The data reported here are from selected sections of a series of vegetative dune building experiments covering about 2.3 miles of beach frontage on Ocracoke Island and about 2.2 miles on Portsmouth Island. Absence of natural vegetation on these locations is attributed to overgrazing followed by severe storms. Most of these plantings are in their eleventh year and have grown substantial "artificial" dunes. These dunes are artificial in the sense that they have formed around vegetation initially planted for this purpose, as opposed to awaiting the reinvasion of these areas by plants, through natural processes. Following establishment of the plantings, the growth of these dunes has been in response to precisely the same forces that produce natural dunes in this region.

Even the unplanted sand-fence sections have an indirect or unplanned parallel. Obstructions of many kinds cause sand to accumulate and initiate dune formation. For example, the only dune within several miles of Portsmouth Village for some years following the removal of livestock from the island was known locally as the "shipwreck dune." It was a large, vegetated dune, oval in shape, near the beach about opposite the village, and is said to have originated around a wreck deposited on that site by a storm.

Experience in establishing and monitoring these experiments has provided observations on the phenomenon of dune development, both artificial and natural, that are apparently not always understood or appreciated. Some of these appear to warrant further consideration and discussion.

Factors of Dune Growth

The growth of dunes is affected by a number of factors but primarily by rate and timing of sand movement and by plant species, once vegetative cover has reached normal density. Wind transport of sand occurs in only three ways (Bagnold, 1941): as bed load, by saltation, or in suspension. The latter can be largely ignored except for extremely fine sand. The nature of the other two types of movement dictate that essentially all of the particles will come to rest shortly after entering an adequately vegetated strip, until the sand-trapping capacity of that portion of the vegetation is satisfied. As this occurs, sand grains spill over into the unfilled vegetation beyond.

Thus, liberal sand movement during the dormant season will produce a broad band of sand-filled vegetation which may extend well across the dune. On the other hand, limited sand transport will fill only a narrow band along the edge which tends to produce a very steep, narrow ridge along this edge with little increase in elevation occurring behind it.

A high rate of sand transport during the growing season will cause a much higher proportion of the sand to be trapped near the edge than would occur during the dormant season. This is due to the fact that as fresh sand accumulates around the grass the culms are stimulated to elongate upward and outward, thereby regenerating the trapping capacity of the affected zone. This also results in a narrow steep ridge near the edge, similar to, but much larger than that formed by limited sand movements during dormant season. American beachgrass is capable of growing laterally at a rapid rate in response to fresh sand. Consequently, rapidly growing dunes dominated by this species will normally expand in the direction of the sand supply at rates of 8 to 10 ft/year. At the same time, if sand supply is sufficient, upward growth may be as high as 3 to 4 ft/year initially (Woodhouse and Hanes, 1967). However, with increased height, the force required to move sand to the crest increases. Also, as the dune expands horizontally, the zone of vertical growth tends to move with it. For these, and perhaps other reasons, after a few years the rate of increase in height levels off.

In this region, the capacity of American beachgrass to grow and respond to sand accumulation during the early spring and late fall months, when much of the sand movement normally occurs, gives it a distinct advantage over the warm-season species (running beachgrass and sea oats) as a dune builder. The ability to grow toward the sand supply and thereby produce a more gentle seaward slope, may also be related to season of growth. At any rate, American beachgrass is a superior dune builder in this area so long as it remains healthy. However, in view of its susceptibility to very serious pest damage in this region, it probably should never be planted alone.

The sea oats plant is an exceptionally efficient sand trapper, having heavy stiff leaves and culms and a pronounced ability to elongate upward in response to sand accumulation. It is common to find individual hummock dunes developed around sea oats seedlings originating from a single panicle, growing to heights of 4 to 5 ft within a 2- or 3-year period. On reaching their maximum heights, these dunes often become undercut and may disappear altogether, due evidently to their very steep slopes. This is in contrast to isolated American beachgrass and running beachgrass dunelets which are generally lower and more rounded in shape. The steep slopes of foredunes developed by sea oats alone might be expected from the above. The fact that, in this region at least, major movement of wind-borne sand is likely to occur during the dormant period for this plant may contribute to the steepness of continuous dunes as well as to isolated dunelets occupied by it. If it is a major factor, this characteristic might be expected to be magnified by the relatively short growing season of this species in North Carolina. However, Dahl et al. (1975) report the seaward expansion of a rapidly growing sea oats dune to be only 2 ft/year over a 5-year period on Padre Island where this species exhibits no obvious period of dormancy and tillering may occur in any month. Slow lateral spread seems to be characteristic of this species throughout its range.

Importance of Dune Location

The placement of dunes too close to the surf is a common problem, one encountered to a considerable degree in the past on parts of the North Carolina barrier islands. Stratton and Hollowell (1940), working on adjacent Hatteras and Bodie Islands, stated that the most efficient place to build dunes in this region is "40-60 yds west of mean high water." This may be correct, viewed purely from the standpoint of trapping sand, but it makes little allowance for the meandering in and out of MHW common to sandy beaches, for beach recession associated with the recent rise of the sea, or for the normal seaward growth of the dune. This type of dune location probably accounts for some of the losses of foredunes experienced in recent years on these islands. Shoreline fluctuations are inevitable on most beaches and in most cases need not be disastrous to constructed foredunes provided allowance is made for them. Dutch workers (Blomethal, 1964) consider the minimum distance between the MHW line and the first sand fence to be 200 m, preferably more.

Location of the dune closer than several hundred ft to the MHW on other than accreting beaches, unnecessarily exposes the foreslope of the dune to storm wave attack and undermining. The most serious of these often is undermining by periodic, but temporary beach recession. While well-vegetated dunes are effective barriers to storm tides and are capable of withstanding moderate degrees of overtopping, they are highly vulnerable to undermining through beach recession or persistent wave attack, and vegetative cover cannot be maintained on dune foreslopes under these conditions.

Recognition of the mode of dune growth is of equal importance in determining the proper location of a dune, i.e., vegetated dunes grow only toward the sand source and a narrow strip of vegetation will, in most cases, stop all wind transported sand. This means that the successful establishment of a vegetated duneline effectively forecloses the opportunity to build a second line of defense behind it. The second line must come first! In light of this, it appears that for wide, bare undeveloped areas, such as the Ocracoke and Portsmouth experimental sites, dune restoration should begin as far toward the landward side of the bare deflation plain as feasible. However, on low lying areas initial dune location too far back from the crest of the storm berm often places it at a lower elevation and may make it more susceptible to overtopping during the early stages. It may also encourage ponding of water coming over the storm berm resulting in continued water pressure, salt buildup, and destruction of vegetation along the dune toe. Where this problem exists, dune location must always be a compromise. Where it is feasible, the provision of room for the formation over time of two or more dune lines as opposed to a single massive dune close to the sea seems desirable. In this arrangement, the eventual development of a frontal dune line close to the storm berm, which may form during long periods of favorable weather, would not be objectionable. This type of dune might be totally consumed in nourishing the beach during storm attack without seriously weakening the barrier effect of the total dune system. And, as is often the case, the sand involved may return to the berm in good weather, thereby remaining in the beach-dune system.

Choice of Species

It appears that there will be a strong temptation on most coasts to use a single species for dune building and stabilization. Species diversity is extremely limited in the dune strand environment due to the high degree of specialization required of plants growing in this habitat. This is particularly true of the pioneer species that must provide the initial stabilization of foredunes. This situation makes it all the more likely that for any given coast there will be one particular species that seems preferable to all others for dune planting. American beachgrass in New England and North Carolina, running beachgrass in Texas and European beachgrass in the Pacific northwest are examples where superiority in ease of propagation and speed of coverage would suggest that these species be used exclusively in their respective regions.

Experience along the North Carolina coast indicates that although monospecific plantings may be the most economical short cut solution to a dune and beach stabilization problem, mixtures of two or more species will usually provide much more reliable long-term protection. It seems likely that this may turn out to be the case elsewhere. A major reason for this in North Carolina has been the buildup of two pests on American beachgrass, Marasmius blight and a scale insect, that were unknown 10 years ago.

Similar threats to other major foredune species are not, to our knowledge, in evidence at present. However, pests of dune plants have received little attention to date, and extensive plantings of single species in pure stands will surely increase the pest hazards to such plantings. For this reason, planting mixtures containing two or preferably three species (American beachgrass and sea oats and running beachgrass) are being advocated on the North Carolina coast, and it is believed that efforts to develop viable alternatives to monospecific dune plantings in other regions may be highly desirable.

SUMMARY

Development of experimental dunes, initiated by planting and sand fences, has been followed over a period of 10 years. The dune grasses, American beachgrass and sea oats, were compared. American beachgrass was found to be nearly ideal for early stabilization and dune development, being easy to propagate and quick to establish. However, this species is susceptible to several pests, is short-lived in the region, is eventually replaced by sea oats on most foredunes and probably should not be planted alone. Sea oats is difficult to propagate and slow to establish and is not very satisfactory for initial stabilization. Consequently, mixed plantings are suggested for most such situations on the North Carolina coast.

Mixed species dune plantings are also advocated to reduce pest and other hazards.

American beachgrass spreads toward the sand supply at rates up to 10 ft/yr or more, producing moderately sloping foredunes. Sea oats dunes, on the other hand, grow laterally by vegetative means, at rates of no more than 2 ft/yr, thereby, producing steep dune fronts.

Three experimental foredune sections built by dunegrass planting—a) an American beachgrass—sea oats mixture, b) a sea oats—saltmeadow cordgrass mixture, and c) saltmeadow cordgrass alone—survived overtopping by storm tides generated by Hurricane Ginger, October, 1971. Observations following this event suggest a different breakthrough mechanism.

Results and observations suggest that, in choosing foredune location, careful consideration should be given to rate and direction of dune growth and to the normal fluctuations of shorelines along sandy seashores.

Experience indicates that where sand supplies and climate permit, the "growing" of foredunes through the use of suitable plantings, supplemented by sand fences, is feasible and practical.

REFERENCES

Adriani, M. J. and J. H. J. Terwindt. 1974. Sand Stabilization and Dune Building. Rijkwaterstaat Communications No. 19, Directie Waterhuishouding en Waterbewegung, The Hague, Netherlands.

Andrews, J. F. 1963. Cyclogenesis Along the Atlantic Coast of the U. S. Mariners Weather Log. 7(2).

Bagnold, R. D. 1941. The Physics of Blown Sand and Desert Dunes. London, Methuen.

Blomethal, K. P. 1964. Some Aspects of Land Reclamation in the Netherlands. Proceedings of 10th Coastal Eng. Conf. p. 1331-1359.

Campbell, W. V. and E. A. Fuzy. 1971. Survey of the scale insect *Eriococcus carolinae* Williams. Shore and Beach 40(1):18-19.

Dahl, B. F., B. A. Fall, A. Lohse, and S. G. Appan. 1975. Construction and Stabilization of Coastal Foredunes with Vegetation. Padre Island, Texas. Misc. Paper 9-75, U. S. Army Corps of Engineers Coastal Engineering Research Center, Ft. Belvoir, Va.

Department of Commerce, "Climatic Atlas of the U.S." June, 1968.

Fuzy, E. A. 1969. The biology, seasonal history and distribution of *Eriococcus carolinae* Williams in North Carolina. Unpubl. M.S. Thesis, N. C. State University, 109 p.

Godfrey, P. J. and M. Godfrey. 1972. A Comparison of Ecological and Geomorphological interactions between an altered and unaltered barrier island system in North Carolina. p. 239-258. In D. R. Coates (ed.) Coastal Geomorphology. St. Univ. of N. Y., Binghamton.

Hardy, A. V. and C. B. Carney. 1962. North Carolina Hurricanes. Dept. of Commerce Weather Bureau, November.

King, C. A. M. 1974. Beaches and Coasts. 2nd ed., St. Martin's press, New York, New York.

Lucas, L. T., T. R. Warren, W. W. Woodhouse, Jr., and E. D. Seneca. 1971. Marasmius blight, a new disease of American beachgrass. Plant Disease Reporter, 55:582-585.

Jennings, J. N. 1965. Further Discussion of factors affecting coastal dune formation in the tropics. Australian J. Sci., 28(4):166-169.

Manohar, M. and P. Brun. 1970. Mechanics of dune growth by sand fences. Dock and Harbour Authority 51:243-252.

Phillips, C. J. 1975. Reviews of Selected Literature on Sand Stabilization. Dept. of Engineering, Univ. of Aberdeen, June.

Savage, R. P. 1963. Experimental Study of Dune Building with Sand Fences. Proc. 8th Conf. on Coastal Eng., Mexico City, pp. 380-396.

Savage, R. P. and W. W. Woodhouse, Jr. 1969. Creation and Stabilization of Coastal Barrier Dunes. Proceedings of the 11th Cong. on Coastal Engineering, London, Sept., 1968, pp. 672-700.

Seneca, E. D. 1969. Germination response to temperature and salinity of four dune grasses from the Outer Banks of North Carolina. Ecology 50:45-53.

Seneca, E. D. 1972. Seedling response to salinity in four dune grasses from the Outer Banks of North Carolina. Ecology 53:465-471.

Seneca, E. D., W. W. Woodhouse, Jr., and S. W. Broome, 1976. Dune Stabilization with *Panicum amarum* along the North Carolina coast. Misc. Report, No. 76-3, U. S. Army Corps of Engineers, Coastal Engineering Research Center, Ft. Belvoir, Va.

Stratton, A. C. and J. R. Hollowell. 1940. Methods of Sand Fixation and Beach Erosion Control. National Park Service, 102 p.

Wagner, R. H. 1964. The ecology of *Uniola paniculata* L. in the dune strand habitat of North Carolina. Ecol. Monogr. 34:79-96.

van der Valk, A. G. 1974. Environmental factors controlling the distribution of forbs on coastal foredunes in Cape Hatteras National Seashore. Can. J. Bot. 52:1057-1073.

van der Valk, A. G. 1975. The floristic composition and structure of foredune plant communities of Cape Hatteras National Seashore. Chesapeake Sci. 16:115-126.

Woodhouse, W. W., Jr. and R. E. Hanes. 1967. Dune Stabilization with Vegetation on the Outer Banks of North Carolina, TM22 U. S. Army Corps of Engineers. Coastal Eng. Res. Center, Washington, D. C.

Woodhouse, W. W., Jr., E. D. Seneca, and A. W. Cooper. 1968. Use of sea oats for dune stabilization in the southeast. Shore and Beach, 36(2):15-21.

Woodhouse, W. W., Jr., E. D. Seneca, and S. W. Broome. 1975. Effect of Species on Dune Growth. Proceedings of 7th Int. Biogmet. Congress. Univ. of Md., August, 1975 In press.

APPENDIX TABLE 1. ANGIOSPERM SPECIES FOR THREE DUNE EXPERIMENTS BY ZONE AVERAGED OVER SECTIONS.

Scientific name	Common name	Ocracoke 1965 Zones				Ocracoke 1966-1968 Zones				Portsmouth 1965 Zones				
		1	2	3	4	1	2	3	4	1	2	3	4	5
Ambrosia artemisiifolia L.	Ragweed						X							
Ammophila breviligulata Fern.	American beachgrass	X	X	X	X	X	X	X	X	X	X	X	X	X
Andropogon scoparius Michaux	Little bluestem	X				X								
Atriplex arenaria Nuttall	Seabeach orach		X											
Baccharis halimifolia L.	Silverling	X	X	X		X	X			X				
Cakile edentula (Bigelow) Hooker	Sea rocket		X	X	X	X		X						
Carduus sp.	Thistle		X				X							
Cenchrus tribuloides L.	Sandspur		X				X	X						
Chloris petracea Swartz	Finger grass	X					X							
Commelina sp.	Dayflower	X												
Croton punctatus Jacquin	Seaside croton					X								
Cyperus filicinus Vahl.	Sedge	X	X											
Eragrostis spectabilis (Pursh) Steudel	Purple lovegrass	X	X	X		X	X	X		X			X	
Erigeron canadensis L.	Horseweed	X	X	X	X	X	X	X		X	X	X	X	
Eupatorium capillifolium (Lam.) Small	Dog-fennel		X											
Euphorbia polygonifolia L.	Seaside spurge	X		X	X	X	X	X		X	X	X	X	X
Fimbristylis spadicea (L.) Vahl.	Sedge	X	X			X					X			
Gaillardia pulchella Foug.	Gaillardia	X				X								
Gnaphalium obtusifolium L.	Rabbit tobacco	X	X	X		X	X	X			X			
Hydrocotyle bonariensis Lam.	Pennywort	X	X	X		X	X	X		X	X	X		
Juncus sp.	Rush	X					X							
Lactuca canadensis L.	Wild lettuce	X	X								X			
Lepidium virginicum L.	Peppergrass	X												
Lippia nodiflora (L.) Michaux	Lippia	X					X							
Oenothera humifusa Nuttall	Evening primrose	X	X	X		X	X							
Panicum amarulum Hitchcock & Chase	Silver bunchgrass			X				X						
Panicum amarum Ell.	Bitter pancium			X	X	X								
Physalis viscosa spp. *maritima*											X			
(M. A. Curtis) Waterfall	Ground cherry													
Sabatia stellaris Pursh	Marsh-pink	X												
Solanum gracile Link	Nightshade						X							
Solidago sempervirens L.	Seaside goldenrod	X	X	X	X	X	X	X		X	X	X	X	
Spartina patens (Aiton) Muhl.	Saltmeadow cordgrass	X	X	X	X	X	X	X		X	X	X	X	
Strophostyles helvola (L.) Ell.	Beach pea	X	X			X	X	X						
Triplasis purpurea (Walt.) Chapm.	Purple sandgrass	X	X	X	X	X	X	X		X				
Uniola paniculata L.	Sea oats	X		X	X	X	X	X	X	X	X	X	X	X
Spiranthes vernalis Engelm. & Gray	Spring ladies' tresses	X												
Polypogon monspeliensis (L.) Desf.	Rabbitfoot grass	X												

Bulletin 453 December, 1976

AGRICULTURAL EXPERIMENT STATION

North Carolina University at Raleigh

K. R. Keller, Director of Research