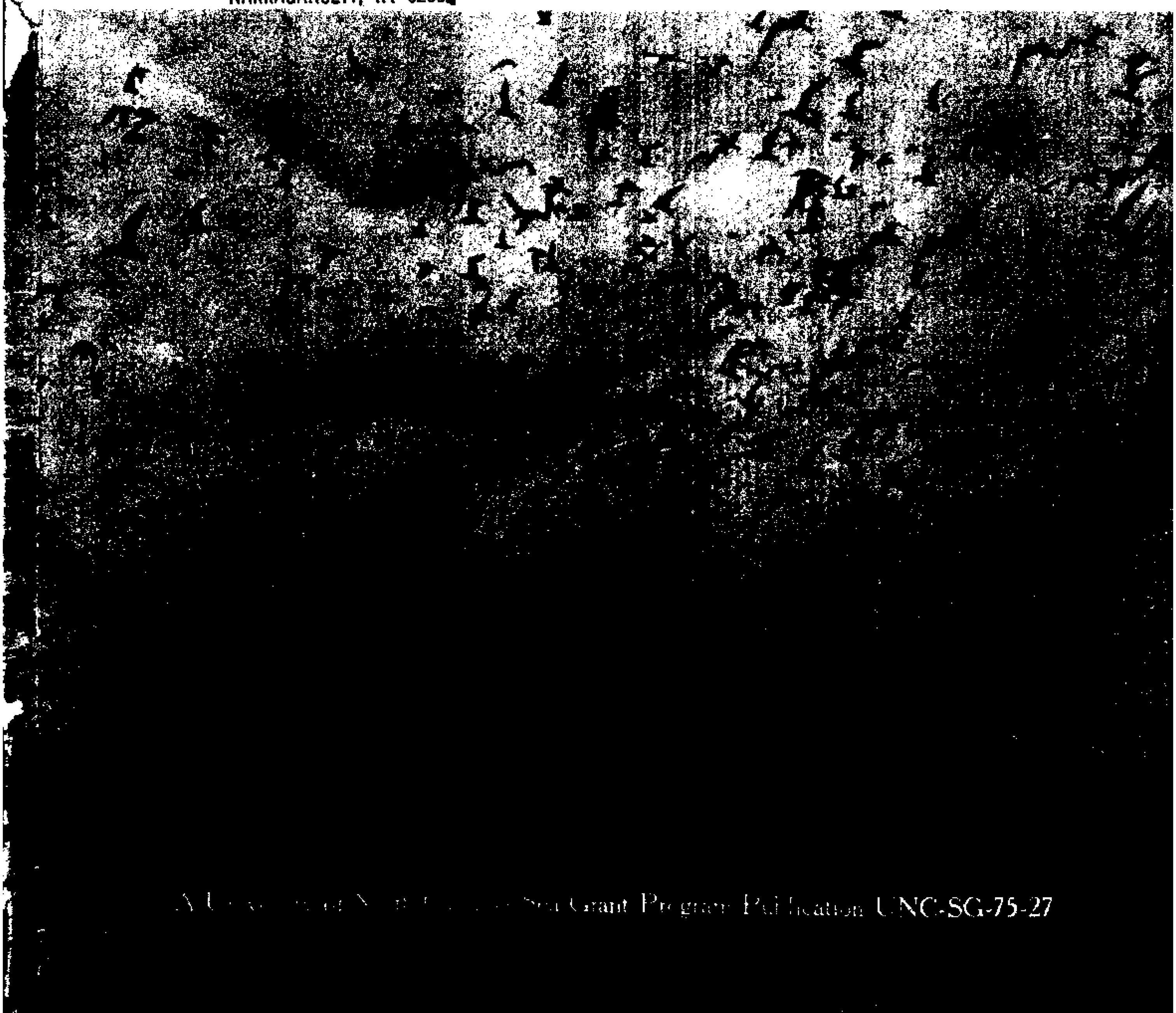
ECOLOGICAL SUCCESSION OF BREEDING BIRDS IN RELATION TO PLANT SUCCESSION ON DREDGE ISLANDS IN NORTH CAROLINA

DECEMBER, 1975



A U[illegible] Sea Grant Program Publication UNC-SG-75-27

ECOLOGICAL SUCCESSION OF BREEDING BIRDS IN RELATION TO PLANT SUCCESSION ON DREDGE ISLANDS IN NORTH CAROLINA ESTUARIES

by

ROBERT F. SOOTS, JR.[1]

and

JAMES F. PARNELL[2]

[1]Biology Department, Campbell College, Buie's Creek, North Carolina 27506. [2]Biology Department, University of North Carolina at Wilmington, Wilmington, North Carolina 28401.

This research was sponsored by: The Office of Sea Grant, NOAA, U. S. Department of Commerce under Grant Number 04-3-158-40; Campbell College; and The University of North Carolina at Wilmington.

UNC-SG-75-27 December 1975

Sea Grant Program. 1235 Burlington Laboratories, N. C. State University, Raleigh, North Carolina 27607

ABSTRACT

Utilization of man-made dredge islands by nesting birds in relation to the seral stages of plant succession was examined in the estuaries of North Carolina. Phytosociological analysis of a series of known-age dredge islands revealed that during the initial growing season plants first invaded two drift ridges located just above the perimeter. During the next 10 years growth of dense perennials gradually moved up the slopes onto the dome, replacing sparse annual and biennial forbs. From about the tenth through the twentieth growing seasons these perennials were replaced by shrubs and by 40 years trees were becoming dominant. The seral stages recognized over a 40-year growth period were: sparse forb, dense forb, forb-shrub, shrub thicket, shrub forest, and young maritime forest.

The plants found to be the major dominants during the early stages of succession were Sea Rocket (Cakile harperi), Salt Meadow Cordgrass (Spartina patens), Salt Grass (Distichlis spicata), Sandspur (Cenchrus tribuloides), Wild Bean (Strophostyles helvola), Seabeach Orach (Atriplex arenaria), Purple Sandgrass (Triplasis purpurea), the sedge (Fimbristylis spadicea), Three-square (Scirpus americanus), Seaside Spurge (Euphorbia polygonifolia), Horseweed (Erigeron canadensis) and Reed (Phragmites communis). The dominant species during the mid-seral stages were S. patens, S. helvola, T. purpurea, Sea Myrtle (Baccharis halimifolia), Camphorweed (Heterotheca subaxillaris), and

Sundrops (Oenothera humifusa). The dominants during the late seral stages were B. halimifolia, Wax Myrtle (Myrica cerifera), Live Oak (Quercus virginiana), Loblolly Pine (Pinus taeda), and Youpon (Ilex vomitoria).

A succession of breeding birds was associated with the vegetative changes. The earliest stages of plant succession, characterized by sparse forbs, were utilized primarily by ground-nesting members of the Charadriiformes. The most common colonial species were Herring Gull (Larus argentatus), Gull-billed Tern (Gelochelidon nilotica), Royal Tern (Thalasseus maximus), Sandwich Tern (T. sandvicensis), Common Tern (Sterna hirundo), Least Tern (S. albifrons), and Black Skimmer (Rynchops niger). Solitary nesting species were American Oyster Catcher (Haematopus palliatus), Wilson's Plover (Charadrius wilsonia), and Willet (Cataptrophorus semipalmatus). Species diversity of nesting birds became reduced in the dense forb stage. Laughing Gull (Larus atricilla) and Forster's Tern (Sterna forsteri) were the only colonial species nesting abundantly in this seral stage. C. semipalmatus was the only common solitary nester.

The most important nesting birds of the shrub thickets, shrub forests and developing maritime forests characteristic of later stages of plant succession were members of the Cinconiiformes. These birds nested in dense, mixed colonies generally located in shrubs and trees but occasionally on or near the ground in dense forbs. The species included White Ibis (*Eudocimus albus*), Glossy Ibis (*Plegadis falcinellus*), Great Egret (*Casmerodius albus*), Snowy Egret (*Egretta thula*), Louisiana Heron (*Hydranassa tricolor*), Little Blue Heron (*Florida caerulea*), Cattle Egret (*Bubulcus ibis*), Green Heron (*Butorides virescens*), and Black-crowned Night Heron (*Nycticorax nycticorax*.)

The pattern of plant succession was influenced on some islands by birds. Large colonies of Royal Terns slowed the invasion of plants into their colony sites by defecation and trampling. Plants tolerant to the substrate enrichment invaded the sites, thus altering the usual species composition found in comparable sites where no colony existed. Birds affected the species composition and rate of succession by dissemination of seeds.

Nesting associations were analyzed and five positive and 19 negative associations were recognized, indicating that factors in addition to vegetative structure and habitat affected the composition of nesting colonies. Positive associations were found between *T. maximus* and *T. sandvicensis* *L. atricilla* and *S. fosteri*, and among *G. nilotica*, *S. hirundo*, and *R. niger*.

Shifting of the substrate in the vicinity of inlets filled the navigation channels and led to frequent dredging to keep them open. The periodic redeposition of dredge spoil on some of the existing islands maintained the early stages of succession necessary for many species. Evidence indicated that the populations of many species were increasing -- perhaps primarily due to the favorable nesting habitat provided by dredge islands.

ACKNOWLEDGEMENTS

Financial support for this project was supplied by The University of North Carolina Sea Grant Program. Research facilities and some equipment were provided by Campbell College and The University of North Carolina at Wilmington.

A number of individuals from North Carolina State University contributed to the success of this study. Special appreciation is expressed to Dr. Thomas L. Quay for assistance throughout the project. We are also grateful for the assistance of Dr. Robert J. Hader, Dr. John F. Roberts, and Dr. Benjamin W. Smith.

Several undergraduate students at both Campbell College and The University of North Carolina at Wilmington assisted with this project. They are Anne Creech, Scott Daugherty, Leon Jernigan, Robert Needham, Frank Sessions, Donna Sykes, and Robert Walton.

We would like to give special thanks to Sharon Soots for her assistance in the field and typing the manuscript.

The North Carolina Soil Testing Division of the North Carolina Department of Agriculture was most helpful with the analysis of soil samples. The U. S. Army Corps of Engineers, Wilmington District, provided maps and other assistance.

TABLE OF CONTENTS

Page

LIST OF TABLES

Page

LIST OF ILLUSTRATIONS

INTRODUCTION

The objectives of this study were to determine the pattern of ecological succession of nesting birds in relation to the succession of vascular plants on dredge islands in North Carolina estuaries and to determine effects of these islands on bird populations of the estuaries. The study was begun in 1971 and continued through 1974.

In 1824 congressional authorization was received by the U. S. Army Corps of Engineers to improve waterways in the United States. Since then, in North Carolina, 558 kilometers of channels have been constructed or modified by the Corps of Engineers (U. S. Army Corps of Engineers District, Wilmington 1972). Most of the channelization has been done along the Atlantic Intracoastal Waterway, which was constructed from 1929 to 1932 (Hall 1975), or around harbors or inlets. Spoil generated in maintenance dredging operations has averaged 4.2 million cubic yards annually in North Carolina and about 80 million cubic yards in the United States (Boyd, et al 1972). Additional channels are maintained by the State of North Carolina. Much controversy has centered around dredging practices in recent years, with governmental agencies, private organizations, and individuals often having conflicting interests (Cronin, et al 1971; Boyd, et al 1972; Tanzberger 1974).

Most of the dredging for navigational purposes in North Carolina takes place in estuaries. The primary purpose of this dredging has been to maintain, improve, and extend navigable waters. It has been shown that the dredging process may cause destruction of benthic organisms in the immediate area of deposition and that the large volume of suspended sediments may harm aquatic systems on a short-term basis (Lunz 1938, Ingle 1952, Mackin 1961, Odum 1963, Chesapeake Biological Laboratory 1966). Long-term effects are much less understood.

When dredge spoil is deposited, it generally forms a wide, inverted, cone-shaped mound. This mound often extends above the water, forming an island. Such islands, usually called dredge-spoil islands, regularly occur adjacent to dredged channels. They have generally been considered to be an undesirable by-product of the dredging process. While such dredge-spoil deposits have been closely associated with the dredging controversy, they have not until recent years been the subject of biological studies.

Relatively few reports on avian succession have been published (Adams 1908, Saunders 1936, Quay 1947, Odum 1950, Johnson and Odum 1956). Still less research has been done on the successional patterns of birds associated with man-made communities. Studies of plant succession on dredge-spoil islands have been done in Florida (Carlson 1972, Beamon 1973), and in Texas studies on the vegetation and nesting of certain colonial birds on dredge islands in Laguna Madre have been accomplished (Barnes 1971, McMurry 1971, Simersky 1971). No detailed studies on the succession of vertebrate communities on dredge islands have been accomplished prior to this study. Quay (1947, 1959) and Funderburg and Quay (1959), however, have recorded dredge islands among the sites utilized by breeding birds in North Carolina and listed species of birds associated with the various habitats found on the island. Furthermore, Funderburg (1956) pointed out the importance of frequent deposition of dredge spoil on islands in maintaining the vegetation in the early stages of succession necessary for ground-nesting birds.

The geographic part of North Carolina which supports vegetation most similar to that found on dredge islands is the Outer Banks region of North Carolina. A number of floristic studies have been made on the vegetation of the North Carolina Outer Banks (Lewis 1917; Wells 1928, 1932; Oosting and Billings 1942; Oosting 1945, 1954; Boyce 1954; Brown 1959; Burk 1962; Godfrey 1970; Hosier 1973; and Au 1975). Prior to this study none have been made on dredge islands in North Carolina other than those dealing with artificial establishment of vegetation (Woodhouse, Seneca, and Broome 1972).

MATERIALS AND METHODS

Methods of selecting dredge islands to be used in the study varied because two separate but related objectives had to be fulfilled. First, a series of islands of varying ages had to be selected for study of plant succession. Second, islands inhabited by nesting birds had to be located in order to study bird succession on them.

Approximately 406 dredge islands were found in the North Carolina estuaries. Islands were located by aerial surveys, U. S. Army Corps of Engineers' dredging maps, and U. S. Coast and Geodetic Survey maps. The size of the islands were estimated by using aerial photographs and a K and E Planimeter. The islands ranged in size from 0. 1 to 18. 0 hectares.

Selection of Islands for Vegetative Study

Location, age, accessibility, stability, size, and elevation were considered when selecting dredge spoil islands to be used for study of plant succession. Islands selected were located as near as possible to the base of operations at The University of North Carolina at Wilmington. All islands between New River Inlet and the South Carolina state line were evaluated. The best distribution of islands in varying stages of succession was found between Masonboro and Carolina Beach inlets and in the lower Cape Fear River (New Hanover and Brunswick counties). Ten islands were selected from these areas and one from the New River Inlet area (Fig. 1).

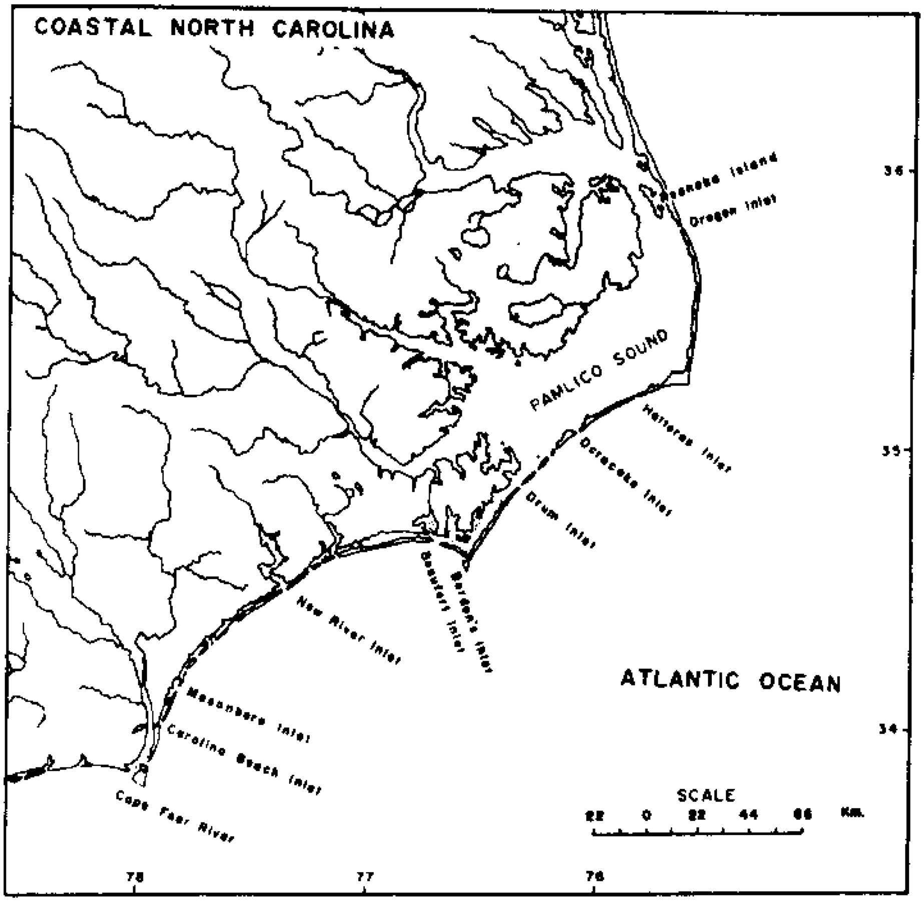


Fig. 1. Coastal North Carolina.

The ages of the islands, based on the time of the last extensive deposit, were determined by examining the dredging records of the U. S. Army Corps of Engineers, Wilmington District. The ages of the older deposits were further checked by ring counts of the oldest trees or shrubs present or from discussions with local people. The ages of the islands studied ranged from fresh deposits to an estimated 35 - 40 years.

An effort was made to select islands that would remain relatively stable during the projected 4-year period of study. Two of the islands were later altered by erosion and spoil deposition, making them no longer usable for vegetative studies. Changes in the other eight islands were due primarily to natural phenomena and were studied all four years.

It was hypothesized that island elevation above high tide level would be the most important factor in zonation of vegetation and that size would be less important. Thus, the smallest islands available with a wide range of elevation gradients were selected. Islands ranged in size from 1.9 to 13.5 hectares. The largest island (13.5 hectares) was made up of multiple domes but the vegetation on only one was studied. Maximum elevations ranged from 1.7 to 3.6 meters and averaged 2.3 meters. One of the islands in the lower Cape Fear River was selected because it was a new deposit occupied by a large nesting colony of Royal Terns, which enabled us to study the effects of a large colony of birds on vegetation.

Selection of Islands Utilized by Nesting Birds

Location of islands utilized by nesting birds was accomplished by aerial surveys and ground inspection. Surveys were conducted between 18 and 25 May in 1972, 1973, and 1974, by aerial searches of the Atlantic Intracoastal Waterway and other channels created by dredging. These dates were chosen because ground observations made in 1971 revealed that, by these dates, most colonies would be established and birds would be incubating, thus making the colonies more visible. Furthermore, sufficient time would be left after locating the colonies to do ground studies before the young left the colony sites. A Cessna 170 aircraft was used to conduct the surveys. Natural islands in the estuary and barrier islands were also examined. Aerial photographs both in black and white and in color were made of most of the islands supporting bird colonies. Photographs were taken with 35 mm single lens reflex cameras, using both normal and telephoto lenses. All islands located by aerial surveys which contained colonies were visited by boat and additional searches by boat were made throughout the study area.

Systematic ground searches for solitary nesting shore birds were made on all dredge islands located between Masonboro and Carolina Beach inlets and in the lower Cape Fear River (Fig. 1). Each island was examined by a line of three to five observers systematically walking through all of the suitable nesting habitat.

Analysis of Vegetation

Permanent transects were established on the islands to be used in the detailed plant studies. These transects were systematically placed perpendicular to the Atlantic Intracoastal Waterway, beginning at the mean high tide level and extending across the highest point on the island to the mean high tide level on the opposite side. If there appeared to be marked variation in the island profile, an additional transect was placed across the center of the island running parallel to the waterway. Many of the islands were longer than wide, with the long axis running parallel to the waterway. Transects were not placed parallel to the waterway on the long islands since all elevations would not be sampled. Treated stakes were placed at 4 m intervals along the length of each transect. On older islands containing shrub or tree vegetation, additional stakes were placed to establish 4 m x 4 m plots. Number 18 nylon line was tied between stakes to establish quadrat boundaries. The herbaceous plots were delineated by the use of a 1 m^2 wooden frame (Fig. 2). Further divisions into quarters helped in estimating coverage and counting plants. These techniques were similar to those employed by Bazzaz (1968).

Vegetative analysis of herbaceous vegetation along transects involved sampling in 1 m^2 units. During the second year the transect width was reduced to one-half meter and sample units were 0.5 x 1.0 m. The shrub and tree vegetation transects were sampled in 16 m^2

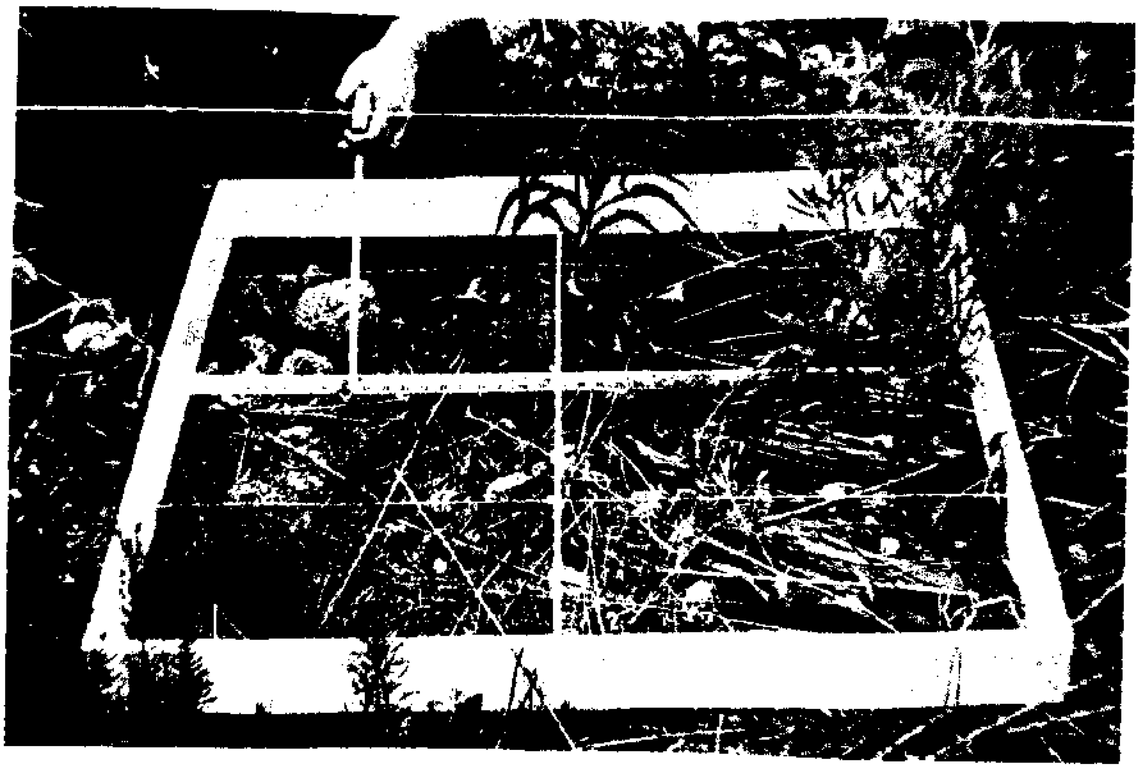


Fig. 2. M^2 frame used in vegetative analysis.

quadrats. Subplots 1 m^2 in size were used to sample the herbaceous vegetation growing under the shrubs and/or trees.

The following data were recorded for herbaceous plants: percent coverage, species, density, and height. The same data plus DBH (diameter at breast height) were recorded for shrub and tree vegetation.

After the transect measurements were completed a general reconnaissance of the vegetation was made over the whole island. A subjective evaluation was made of vegetation which appeared to vary significantly from transect observations. All plant data were recorded on 5" x 8" Unisort Analysis Cards upon which appropriate forms had been printed.

Scientific names of plants follow Radford, et al (1968).

Nesting Site Analysis

When a bird nesting colony was located, the following data were recorded on a cassette tape recorder: species, estimate of number of adult birds present, and an estimate or count of the number of nests, eggs per nest, and young per nest. The size of the colony, the stage of nesting, and weather conditions dictated the extent of the quantitative data taken. An effort was made to examine the colonies as quickly as possible to minimize stress and mortality to developing eggs and/or young. In some large colonies it was necessary to measure the dimensions or map the colony and then make an estimate of the number of nests per m^2, which could then be used to calculate the number of nests and contents. When hot weather prevailed, early morning observations were made to avoid being in the colony during the hottest part of the day.

Many of the problems encountered with colonial birds were not present when working with solitary nesting species. Since it did not take long to examine one nest, data were entered directly on forms printed on Unisort Analysis Cards.

A general description of the substrate was recorded for most of the nesting sites, noting especially the material upon which the nests were placed and the slope.

The species of plants present in 1 m^2 and 16 m^2 quadrats surrounding solitary nests were listed in order of dominance. This was done so that a comparison could be made between the immediate nest site and the surrounding area. In colonies, the species of plants occurring within the colony site were recorded. An estimate was made of the height and percent coverage of vegetation. Techniques used were similar to those employed in the plant succession studies and these measurements were made whether or not the site was used in succeeding nesting seasons.

Effects of nesting birds on vegetation were noted by recording and photographing damage to vegetation which appeared to be caused by fecal deposition and/or trampling. Species of plants involved were also recorded. Soil samples were collected in the nesting area of a few large colonies and from similar nearby islands not supporting colonies, when it appeared that plant damage was caused by fecal depositions. The soil samples were analyzed by the Soil Testing Division of the North Carolina Department of Agriculture.

Finally, the presence of any objects other than vegetation was recorded on the assumption, based on earlier observations, that such objects might influence selection of the site for nesting.

Names of birds follow the 1957 edition of the AOU Checklist.

Description of Study Area

Birds nest in suitable habitats throughout the North Carolina estuaries. There are, however, obvious concentrations which seem to be related to certain environmental conditions. North Carolina estuaries change greatly from south to north (Williams *et al* 1966, Swartz and Chestnut 1973). From the South Carolina line to the Cape Fear River (Fig. 1), the estuaries are very narrow and are dominated by extensive *Spartina alterniflora* marshes (Adams and Quay 1958, Funderburg and Quay 1959, Wilson 1962). Here the salinity is high, substrates contain much silt, there is little open shallow water, and the tidal amplitude is greater than farther north. From the Cape Fear River to Beaufort Inlet the estuaries widen somewhat, but vast marshes still predominate. Substrates become more sandy and salinities remain high. From Beaufort Inlet north to Roanoke Island the estuaries widen to incorporate large, shallow, open-water sounds and contain proportionately less _S. alterniflora_ marsh. Large expanses of _Juncus roemerianus_ marshes are, however, present (Wilson 1962, Cooper 1974). The bottoms remain sandy and salinities decrease. From Roanoke Island northward, the sounds again decrease in size but remain open. Salinities continue to decrease due to a lack of inlets. Lunar tides are insignificant, but wind tides can be as high as 3 meters (Riggs and O'Connor 1974).

Barrier islands lie along the entire North Carolina coast, separating the rich estuaries from the Atlantic Ocean. The narrow sand strands are broken irregularly by inlets which may open and close with storms or which may be maintained by the dredging process (Engels 1942, Dolan 1972, 1973).

Within this framework lie the natural and man-made islands that provided nesting sites for the birds studied in this project.

RESULTS

Analysis of Substrate

When dredging was in process, the pipe carrying the mixture of water and substrate usually ended at the top of the dome of an existing island. Sorting of the spoil occurred as it flowed down the slope (Fig. 3). Thus, initially the dome consisted of coarser material and the lower portions of the islands contained more of the smaller sized particles. As dredged deposits dried they were exposed to wind action. This added further to the sorting and moved the finer materials down the slope (Fig. 4). Usually deposits contained shell fragments as well as inorganic particles. These larger fragments were not readily moved by wind and once exposed tended to accumulate at the surface.

The result of sorting was a series of particle-size compositions following a fresh deposit. Initially there was some sorting by run off during the deposition. Immediately after the cessation of dredging, the surface of the upper slope and dome was composed of relatively coarse material, small amounts of shell, and considerable fine particles. After about a year wind and rain action had removed enough of the surface layer of the dome and upper slopes to expose previously buried shell material. As the amount of shell increased the dome and upper slopes became more stable, with the shell acting as a stabilizing cover. If considerable shell were present the dome may have become

Fig. 3. Spoil being deposited on dome of an island.

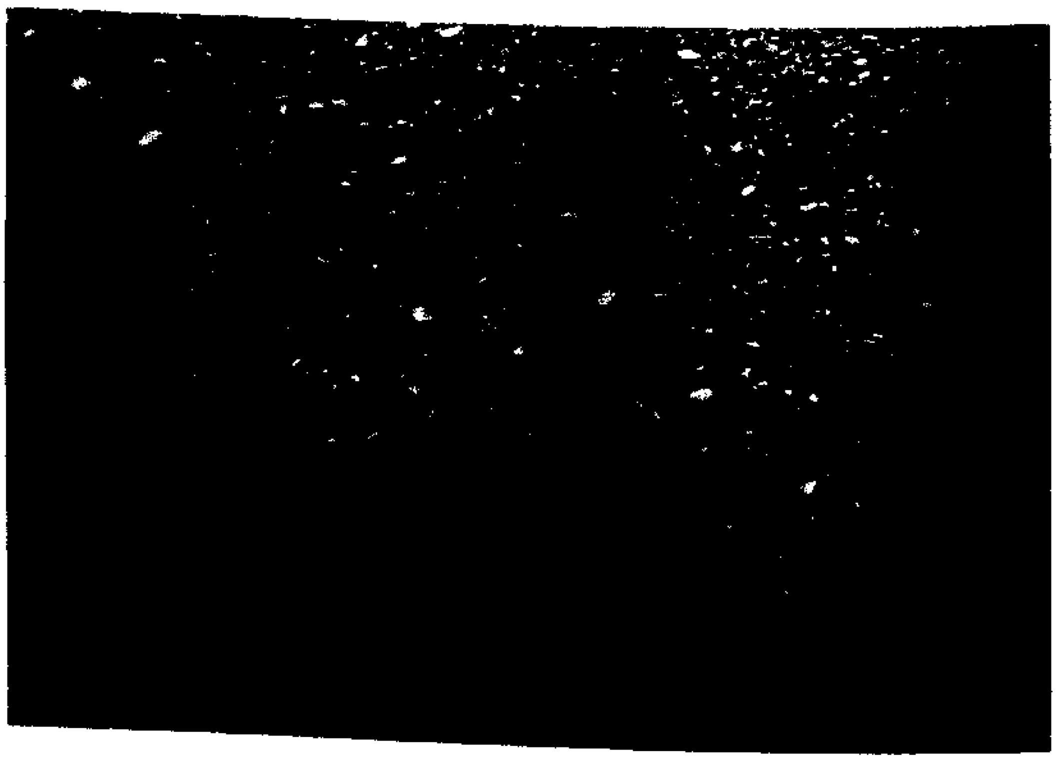


Fig. 4. Wind sorting of shell and sand on dome of dredge island.

nearly stable in one or two years. If, however, little or no shell were present in the dredged material, wind rapidly caused erosion of the dome and shifting dunes resulted.

Analysis of Vegetation

Permanent belt transects were established and phytosociological studies were done on 10 islands. Over a period of four years a total of 2665, 1.0 or 0.5 m^2 quadrats and 129, 16 m^2 quadrats were analyzed.

Invasion and Establishment of Pioneer Plants

Two drift ridges formed around the perimeter of islands which had not been diked. Upper and lower drift ridges resulted from the action of storm and spring tides respectively (Hunter and Quay 1953). These ridges were composed of a conglomeration of material brought in by water and left behind as tides receded, and of sand and other particles blown down from the dome. The bulk of the drift material consisted of dead plant remains, primarily *Spartina alterniflora*, when the island was located in the vicinity of low salt marshes, and *Zostera marina* on islands in northern estuaries where *S. alterniflora* is less abundant. Most importantly, seeds were also transported by tidal action. The drift material provided a bed in which the seeds became established. Lower and upper drift ridges averaged 0.47 and 0.59

meters above mean high tide respectively and were the first part of the islands to be colonized by plants.

During the early stages of plant succession, dispersal of seeds by animals appeared less important than by water or wind, but did contribute to the flora of dredge islands. Birds were important transporters of seeds to dredge islands, but seeds may have also been transported to islands near the mainland by mammals. Bluejays, Cyanocitta cristata, were seen carrying acorns to dredge islands. Phytolacca americana occurred abundantly in the understory of shrub forests that were used for roosting sites by Common Grackles, Quiscalus quiscula, and Red-winged Blackbirds, Agelaius phoeniceus. These seeds pass through birds' digestive tracts (Martin, et al 1951) and were observed in birds' feces beneath roosting sites on dredge islands.

Through tidal action, establishment of pioneer plants, and sorting and movement of dredge material, several topographic features were formed on the islands which were very important in the invasion and succession of plants (Fig. 5). Already mentioned are the two drift ridges which occurred around the perimeter of most islands. Two swales formed in conjunction with these ridges. One swale was located between the ridges and the other was located toward the dome just inside the upper ridge (Fig. 6). The swales were wetter than the

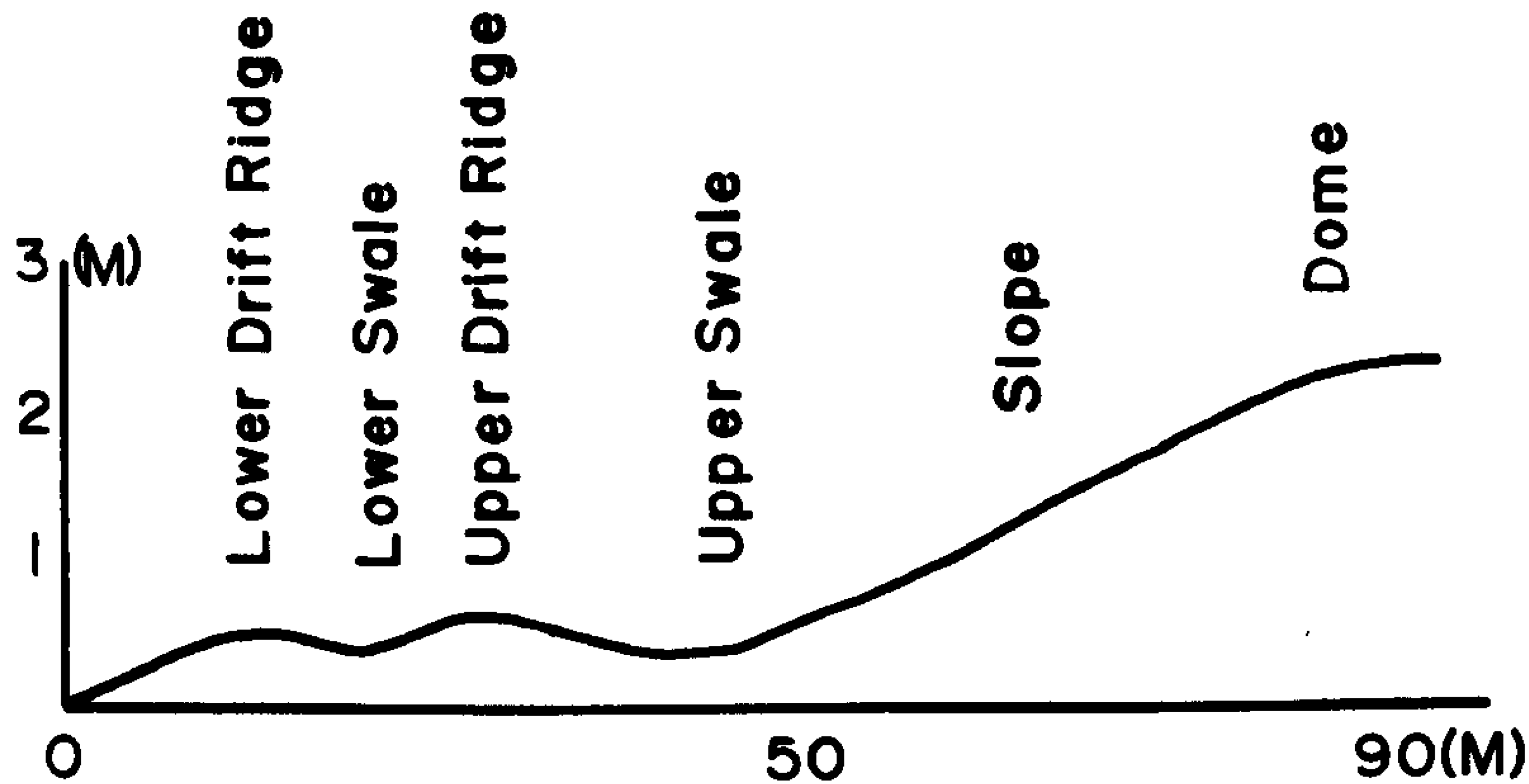


Fig. 5. Topography of a typical dredge island in cross section.

Fig. 6. Aerial view of a new dredge island showing drift ridges, slopes, and dome.

contiguous drift ridges. The third major topographic feature of a dredge island was the dome, which included the central part of the island and was higher than the upper swale (Fig. 7).

The width of the drift ridges and swales on undisturbed dredge islands was fairly uniform regardless of island size, but size of the slopes and dome varied directly with the size of the island. Features were often modified by erosion on those islands located near inlets or in the lower Cape Fear River where ship traffic was heavy. Such changes complicated the analysis of plant succession.

Early Stages of Plant Succession

Vegetation became established over a new island in a definite pattern (Fig. 8). The first plant to become established was usually *Cakile harperi*. The relatively large, light seeds of this plant were deposited on the drift ridges during especially high tides. The early establishment of *C. harperi* on the drift ridges was important as it helped to provide a barrier which trapped the fine materials blown or washed down from higher elevations on the dredge deposit. This resulted in an increase in height of drift ridges and provided a protected area in which other plant species became established.

Other important species that became established on the drift ridges and swales during the first growing season included *Distichlis spicata*, *Atriplex arenaria*, *Cenchrus tribuloides*, and *Spartina patens* (Table 1).

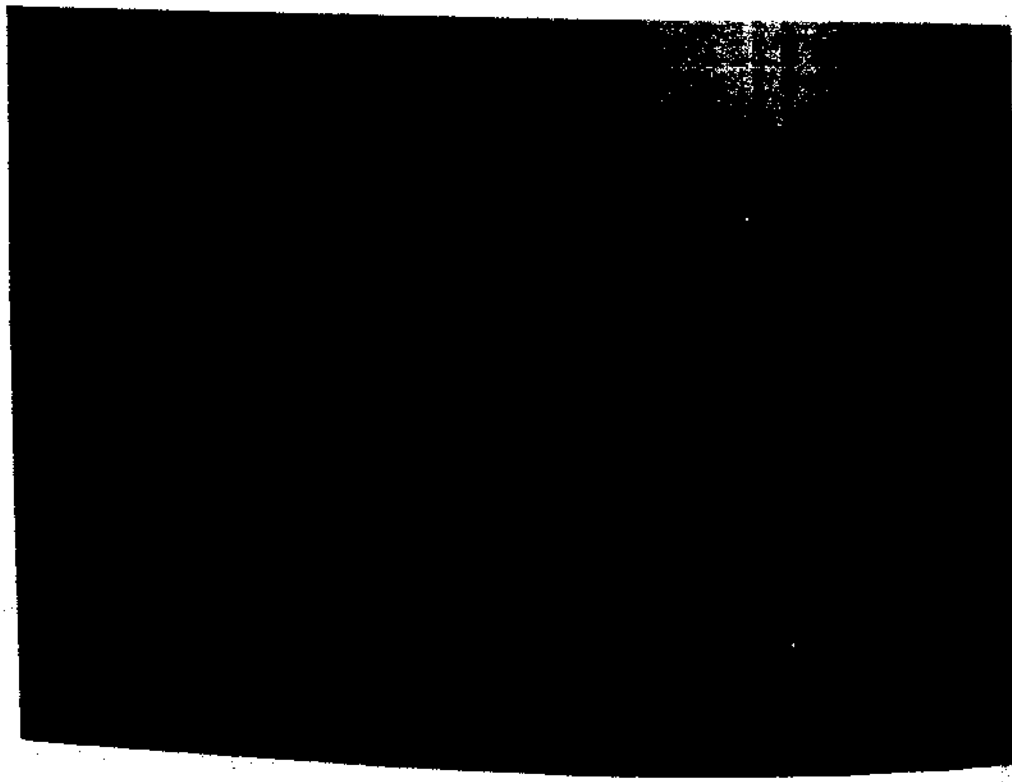


Fig. 7. Ground view of a dredge island showing two vegetated drift ridges in foreground and dome in background.

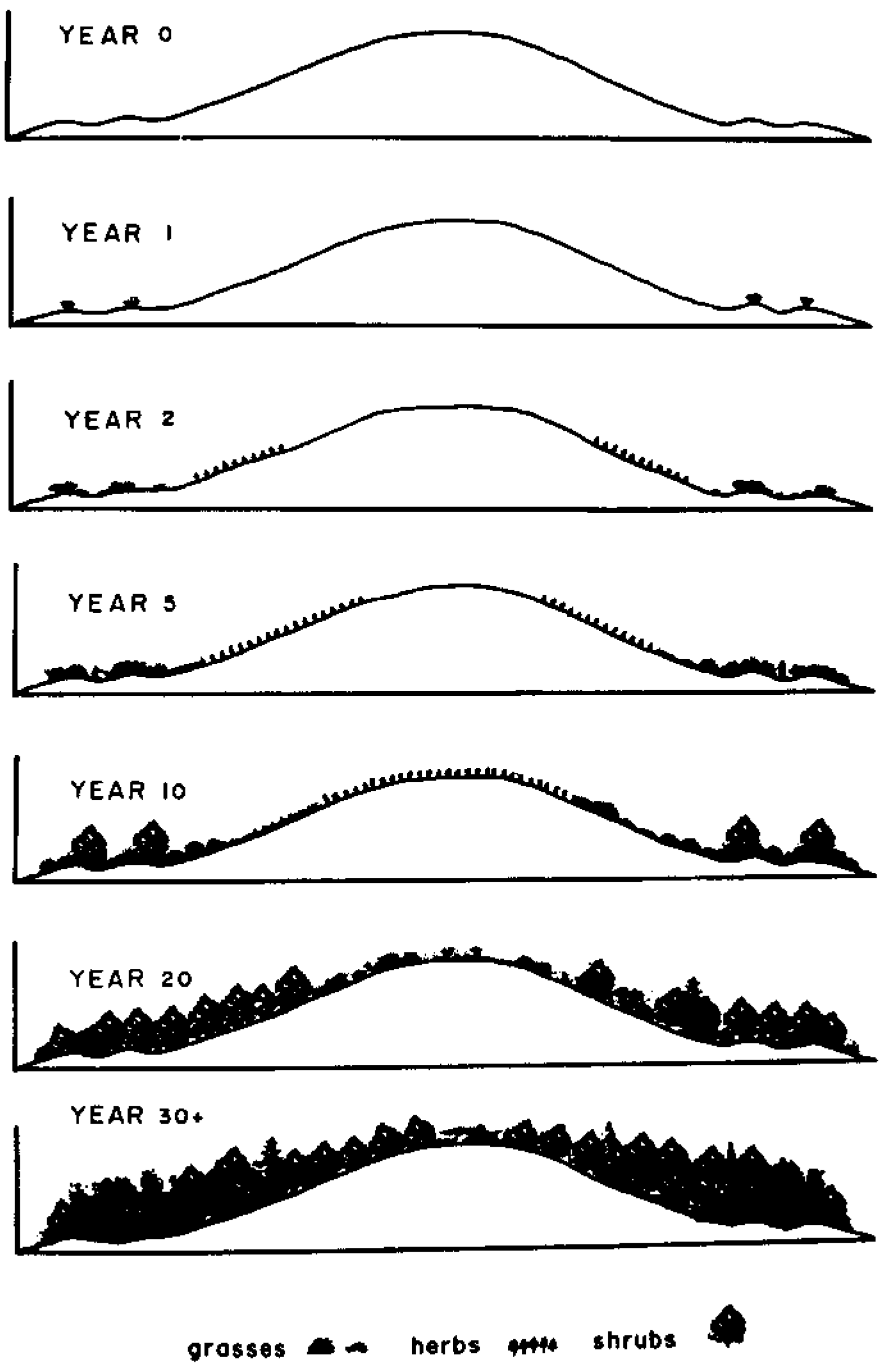


Fig. 8. Plant succession on dredge islands.

Table 1. Importance values of dominant plants found in each topographic feature of a typical dredge island during the first four years of succession. The importance value is the sum of relative frequency, relative coverage, and relative density.

Species	Perimeter	Lower drift ridge	Lower swale	Upper drift ridge	Upper swale	Lower slope	Upper slope and dome
	Year 1						
Spartina alterniflora	231	51	38				
Distichlis spicata		249		88	138		
Cenchrus tribuloides			74		21	64	
Cakile harperi			69	87	105	151	204
Atriplex arenaria			38		28		
Elymus virginicus			36				
Spartina patens				205			
Uniola paniculata				33			
Euphorbia polygonifolia					60		
	Year 2						
Spartina patens	151	105		68	44		
Spartina alterniflora	73						
Distichlis spicata	49	134	144				
Fimbristylis spadicea	47						
Uniola paniculata		179					

Table 1. Continued

Species	Perimeter	Lower drift ridge	Lower swale	Upper drift ridge	Upper swale	Lower slope	Upper slope and dome
Strophostyles helvola		124	117	67			
Cenchrus tribuloides		83		134	143	44	
Atriplex arenaria			89		119	44	
Solidago sempervirens			81				
Baccharis halimifolia			71				
Atriplex patula				106			
Cakile harperi				78	44		
Triplasis purpurea						88	207
Erigeron canadensis						44	
Euphorbia polygonifolia							45
				Year 3			
Spartina patens	185	114	55	178			
Fimbristylis spadicea	145	128	80	68	177	62	
Ammophila breviligulata		128					
Strophostyles helvola		124	145	179			
Distichlis spicata			104				
Solidago sempervirens			96	65	47		
Erigeron canadensis			56	66		97	

Table 1. Continued

Species	Perimeter	Lower drift ridge	Lower swale	Upper drift ridge	Upper swale	Lower slope	Upper slope and dome
<u>Cenchrus tribuloides</u>				83			
<u>Triplasis purpurea</u>				67	43	174	224
<u>Atriplex arenaria</u>					89		
<u>Euphorbia polygonifolia</u>							117
	Year 4						
<u>Spartina patens</u>	192	121		192	82		
<u>Fimbristylis spadicea</u>	170		87	52	146	73	
<u>Solidago sempervirens</u>	54	105	86	140	154	90	
<u>Strophostyles helvola</u>		94	80	112			
<u>Ammophila breviligulata</u>		91					
<u>Scirpus americanus</u>		91	195				
<u>Erigeron canadensis</u>		87	71	112	116	132	56
<u>Heterotheca subaxillaris</u>				84		96	
<u>Triplasis purpurea</u>				53		155	245
<u>Phragmites communis</u>					105	121	49
<u>Euphorbia polygonifolia</u>							66

Invasion of plants onto the upper slopes and dome was a much slower process (Fig. 9). During the first growing season vegetative coverage was less than one percent. The most important species were Cenchrus tribuloides and Cakile harperi.

A total of 21 species of plants was found on dredge island 151-2E (the most heavily studied one-year-old island) during the first growing season. Much of the data on early stages of succession was collected on this island between 1971 and 1974, inclusive. There was a 325 percent increase in vegetative coverage on this island between the first and second growing season. Average coverage for the 301 m^2 quadrats sampled in 1971 was 3.6%. By 1972 coverage had increased to 15.4%, and the number of species of plants had increased to 38. The increase in coverage was most apparent in the swales, but coverage on the dome also increased (Fig. 9). Spartina patens was the most important plant in the island perimeter, with D. spicata, Fimbristylis spadicea, and S. alterniflora also important. Dominant plants on drift ridges were Strophostyles helvola, S. patens, C. tribuloides, and F. spadicea. In some scattered sites Uniola paniculata contributed substantially to the drift-ridge vegetation. Widely scattered clumps of Iva imbricata were also present on the lower ridge. Swales were dominated by Distichlis spicata, S. helvola, and C. tribuloides but diversity had increased.

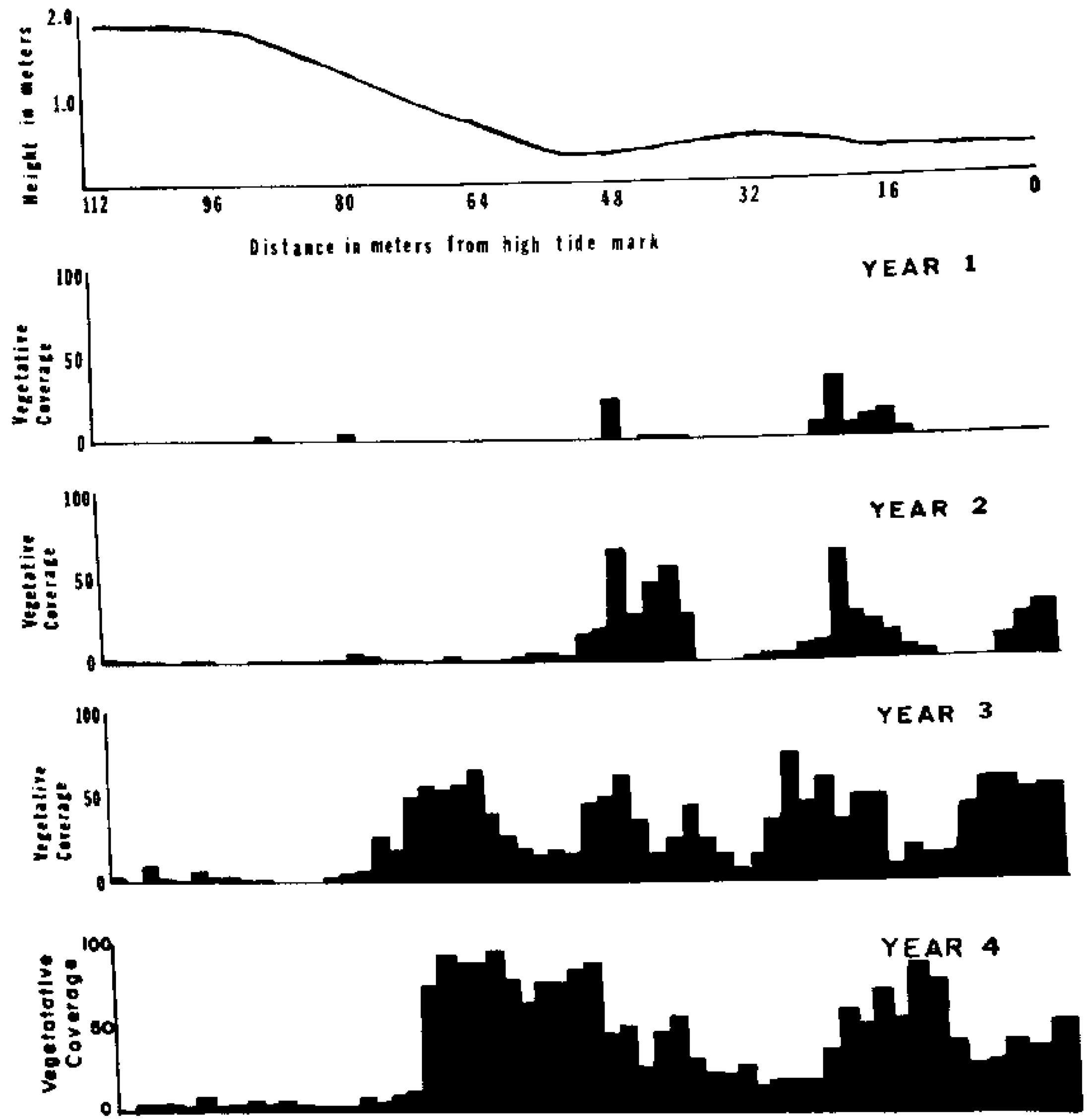


Fig. 9. Coverage of vegetation across a dredge island during the first four growing seasons.

Coverage on slopes and domes remained low in year two, generally less than five percent (Fig. 9). Dominant plants on the upper slopes and dome were *Triplasis purpurea* and *Euphorbia polygonifolia*; most of the contribution to the importance values of these two species came from their presence in a large number of quadrats (relative frequency) across the dome and not from density or coverage. During year two, *Iva frutescens* and *Baccharis halimifolia* seedlings first appeared around the perimeter of the island and in the lower swale; both of these plants were important shrubs in later stages of succession.

The most obvious changes in cover of vegetation during the third growing season were increased densities of vegetation around the perimeter and in the swales (Fig. 9). The vegetative coverage increased to 29.2% in year three, with the bulk of the increase coming from those species already present (Table 1). One new shrub species, *Baccharis angustifolia*, appeared and was one of the characteristic species along island perimeters in later seral stages. An important dome plant, *Heterotheca subaxillaris*, also first appeared in year three.

By year four the perimeter, swale, and drift-ridge vegetation had merged into a solid band (Fig. 10). Coverage in this band had increased to 60.7%. Species diversity had increased somewhat, but perennials such as *Spartina patens*, *Fimbristylis spadicea* and *Solidago sempervirens* were dominant throughout the band. Density on the upper

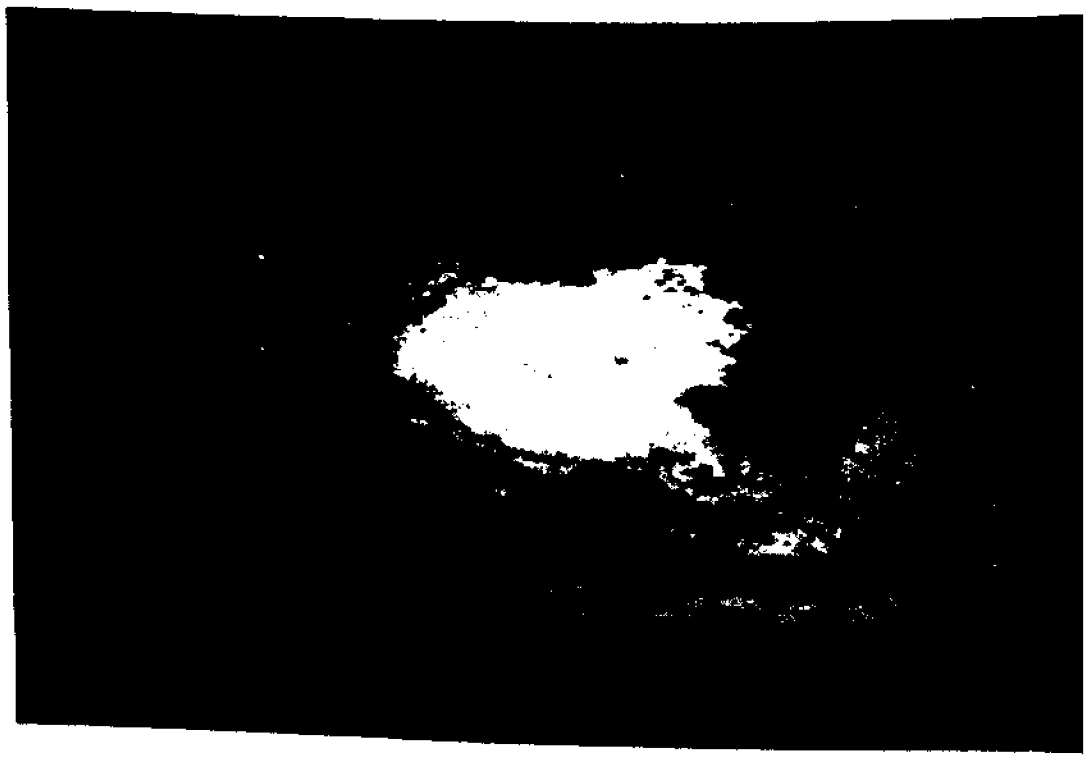


Fig. 10. Solid band of vegetation covering perimeter, swales, and drift ridges during fourth growing season.

slope and dome remained very low (3.4%) with small T. purpurea and H. subaxillaris dominating. Coverage for the whole island had increased to 40.4 percent.

During years 6 to 10 the cover of grasses and other herbaceous perennials continued to increase from the perimeter to the lower slope (Fig. 11). In Figure 11, it appears that a decrease occurred in the cover of vegetation on the lower elevations from year 6 to year 7. Much of the zone of vegetation was covered by dense mats of dead plants (primarily Spartina patens) which remained from the previous season. The dead vegetation retarded new growth. Figure 11 shows live coverage. If dead and live coverage had been combined it would have totaled almost 100% from the perimeter to the lower slope. During this period these perennial plants began to move steadily up the slope, primarily expanding by rhizomes. Thus, each growing season the dense band of perennial vegetation extended farther upslope, replacing the annual or biennial grasses and herbs of the upper slope and dome. Consequently, the swales and drift ridges became indistinct and were no longer recognizable as specific zones of vegetation. The dominant plant species are shown in Table 2.

Shrub species, primarily Myrica cerifera, Baccharis halimifolia, and Baccharis angustifolia, began overtopping the grasses during the 6 - 10 year period. Shrubs generally first appeared in the swale between drift ridges, apparently with the seedlings developing there

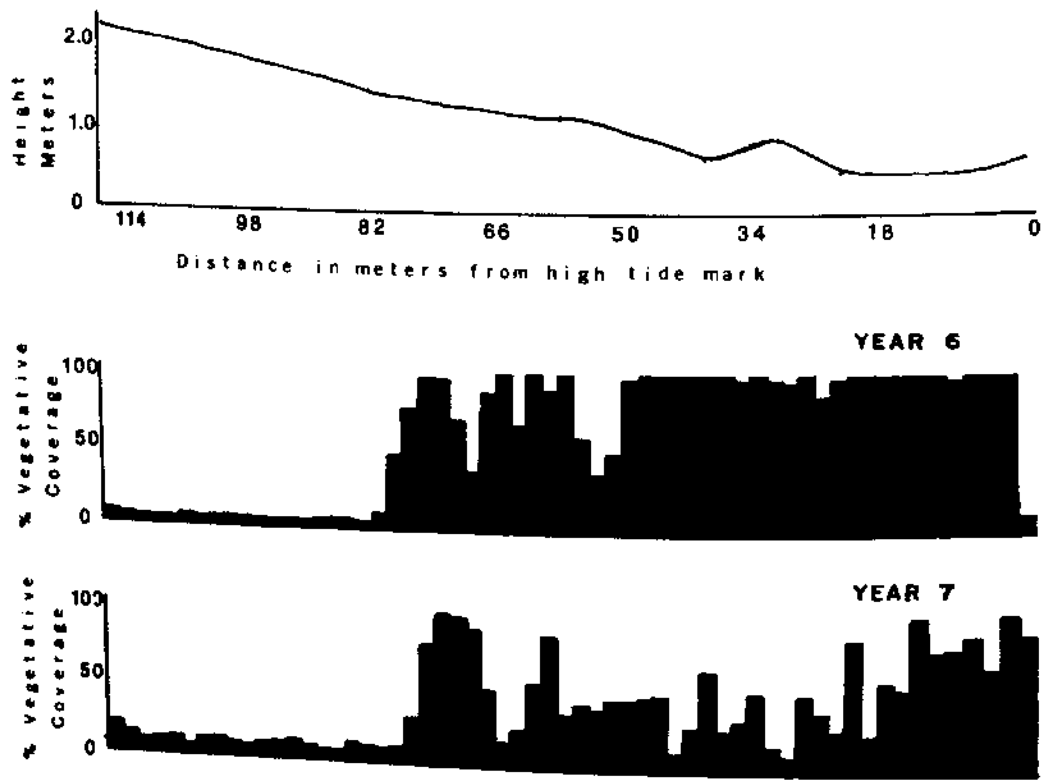


Fig. 11. Vegetative coverage of a typical dredge island during years six and seven.

Table 2. The importance values of the dominant plants found in the vegetative zones of typical dredge islands from the sixth to tenth growing season

Species	Drift ridges and swales	Lower slopes	Upper slopes and dome
Spartina patens	209	245	48
Baccharis halimifolia	106	45	
Borrichia frutescens	72		
Panicum amarulum	68		
Solidago sempervirens	53	65	
Strophostyles helvola		96	
Agalinis purpurea		52	
Erigeron canadensis		49	57
Ambrosia artemisiifolia		49	
Heterotheca subaxillaris		48	121
Festuca octoflora		44	
Triplasis purpurea			187
Oenothera humifusa			96

under the cover of the perennial grasses. Iva frutescens and B. angustifolia also began to appear in the perimeter vegetation just outside of the lower drift ridge. By year 10 there was usually a ragged fringe of low shrubs around the island. At this time the vegetation took on a three-banded aspect including shrub fringe, wide band of grasses, and a sparsely vegetated dome (Fig. 12).

Later Stages of Plant Succession

By years 15 to 20 the fringe of shrubs had expanded to form a relatively solid band from the perimeter of the island to the upper slopes (Fig. 13). B. halimifolia, I. frutescens, and B. angustifolia now predominated along the perimeter with M. cerifera the clear dominant throughout the remainder of the band.

As density of the developing shrub thicket increased, most herbaceous plants were shaded out and lost. Species diversity in this zone decreased during this period. Strophostyles helvola, Panicum amarulum, and Asplenium platyneuron were the most important plants on the upper slope and dome, but diversity was much increased, and dominance was shared by many species. By this time the annual grasses and herbs prevalent in earlier years had been eliminated or very much reduced (Table 3). In column two of this table, slope includes all of the island between the perimeter and the dome. Individual topographic features were no longer recognizable.

Fig. 12. Shrub fringe on ten year old dredge island.

Fig. 13. Shrub forest on 18 to 20 year old dredge island.

Table 3. The importance values of the dominant plants found on the vegetative zones of an 18 to 20 year old dredge island

Species	Slope	Slope understory	Dome
Myrica cerifera	242	23	
Baccharis halimifolia	81		
Pinus taeda	23		
Calystegia sepium		91	
Phytolacca americana		89	
Rubus sp.		78	47
Rhus toxicodendron		38	
Lonicera japonica		30	
Asplenium platyneuron		29	77
Elymus virginicus		24	
Aster pilosus		21	55
Strophostyles helvola		6	127
Panicum amarulum			90
Festuca octoflora			52
Solidago sempervirens			48
Lactuca sp.			48

Generally, between 30 and 40 years were required for an entire island to reach the shrub forest stage. Even at this age there were often indications of openings on the domes of some of the higher islands. Tree species also had invaded the island by this time. The occurrence of tree species was erratic, apparently depending on seed sources and seed transport, *Pinus taeda* coming in as early as year five or six occasionally. Some islands had well developed clumps of *P. taeda* and *Quercus virginiana* present by year 30 while other sites remained as almost pure shrub forest. The dominant plants on the two 30-plus year old islands studied were *Myrica cerifera*, *Q. virginiana*, *P. taeda*, *Baccharis halimifolia*, and *Ilex vomitoria*. Maritime forests had developed on a few islands of about 40 years of age.

Avian Analysis

Occurrence and Distribution of Birds Nesting on Dredge Islands

Thirty-five species of birds representing 17 families were found nesting on dredge islands in the estuaries of North Carolina. A species was judged to be: (1) heavily dependent on dredge islands if it placed over 50 percent of its nests on them; (2) moderately dependent if frequently nested on dredge islands but also commonly nested at other sites in the estuary; and (3) not to be dependent on dredge islands if it nested much more abundantly in other habitats than on dredge islands.

The following 19 species were heavily dependent on dredge islands (listed in phylogenetic order):

Little Blue Heron, *Florida caerulea*

Cattle Egret, *Bubulcus ibis*

Great Egret, *Casmerodius albus*

Snowy Egret, *Egretta thula*

Louisiana Heron, *Hydranassa tricolor*

Black-crowned Night Heron, *Nycticorax nycticorax*

Glossy Ibis, *Plegadis falcinellus*

White Ibis, *Eudocimus albus*

Great Black-backed Gull, *Larus marinus*

Herring Gull, *Larus argentatus*

Laughing Gull, *Larus atricilla*

Gull-billed Tern, *Gelochelidon nilotica*

Forster's Tern, *Sterna forsteri*

Common Tern, *Sterna hirundo*

Least Tern, *Sterna albifrons*

Royal Tern, *Thalasseus maximus*

Sandwich Tern, *Thalasseus sandvicensis*

Caspian Tern, *Hydroprogne caspia*

Black Skimmer, *Rynchops niger*

There are only a few records of the Great Black-backed Gull (Parnell and Soots 1975) and Caspian Tern (Quay 1947, Parnell and

Soots in preparation) nesting in North Carolina. The other species were common nesters in the estuaries although the Herring Gull was concentrated along the northern half of the coast and the White Ibis in the southern half. The Forster's Tern also nested only in the northern half of the coast, not having been found south of Cape Lookout (Grant and Fussell 1970, Fussell 1973, Soots and Parnell in press).

The following five species of birds were found to be moderately dependent on dredge islands for nesting sites (listed in phylogenetic order):

American Oystercatcher, Haematopus palliatus

Willet, Catoptrophorus semipalmatus

Wilson's Plover, Charadrius wilsonia

Common Nighthawk, Chordeiles minor

Boat-tailed Grackle, Cassidix major

The following 11 species were nesting on the islands but were not dependent on them for a significent part of their reproductive activities (listed in phylogenetic order):

Green Heron, Butorides virescens

Black Duck, Anas rubripes

Gadwall, Anas strepera

Clapper Rail, Rallus longirostris

Roseate Tern, Sterna dougallii

Mourning Dove, Zenaidura macroura

Fish Crow, *Corvus ossifragus*

Mockingbird, *Mimus polyglottos*

Red-winged Blackbird, *Agelaius phoeniceus*

Painted Bunting, *Passerina ciris*

Seaside Sparrow, *Ammospiza maritima*

A colony of Brown Pelicans, *Pelecanus occidentalis*, was found nesting on North Rock Island which is located in Pamlico Sound near Oregon Inlet. This species was first found nesting in North Carolina in 1929 (Pearson, *et al* 1942). Fourteen pairs were observed nesting on Royal Shoal. Nesting was not reported again until 1947 when 14 active and several inactive nests were observed on Shell Island (Wolff 1947). This island is located about 200 meters from North Rock Island and the pelicans have apparently nested regularly in this vicinity since first discovered in 1947. Quay (1959) reported about 500 adults and at least 100 nests with young in 1958. This was the largest number ever reported as breeding in North Carolina. During this study 30 nests were observed in 1972, 30 in 1973, and 41 in 1974. Although North Rock Island has been heavily altered by man it did not qualify as a dredge island; therefore, the Brown Pelicans will not be considered further in this paper.

In 1973 an effort was made to locate all ground nesting colonies on natural islands and dredge islands in the North Carolina estuaries. A total of 126 colonies were found. Six colonies occurred between the

South Carolina line and the mouth of the Cape Fear River, 35 between the Cape Fear River and Beaufort Inlet, and 85 between Beaufort Inlet and Roanoke Island. None were found north of Roanoke Island even though islands were present. Estimates were also made of the number of nests of the nine most common species of ground nesting, colonial seabirds. Eighty-three percent of all nests found were placed on dredge islands while 17% were on natural sites (Table 4). Buckley and Buckley (1975) have reported on the significance of dredge spoil islands to colonially nesting waterbirds in Fire Island and Cape Hatteras National Seashores and Gateway National Recreation Area.

Association Between Birds and Vegetation

Table 5 gives the percent coverage of vegetation in colonies of the nine common, ground-nesting, colonial species. They are listed in order from the lowest to highest mean coverage of vegetation. Coverage was determined from estimates made in 209 colonies. The coverage of vegetation was determined in a m^2 area surrounding 260 nests of the four common species of solitary, ground nesters. The results are shown in Table 6.

All of the species studied tolerated at least some vegetation within their colony sites. However, the average coverage ranged from 2.5% in the Least Tern colonies to 100% in colonies of the Forster's

Table 4. Estimated number of nests found in 126 colonies of colonial sea birds occurring in North Carolina estuaries during the breeding season of 1973*, listed in descending order of abundance

Species	Nests		Total
	Dredge	Natural	
Royal Tern	32,760	2,574	35,334
Laughing Gull	7,137	6,257	13,394
Common Tern	2,968	353	3,321
Black Skimmer	1,696	184	1,880
Forster's Tern	557	289	846
Least Tern	655	77	732
Gull-billed Tern	399	121	520
Sandwich Tern	251	3	254
Herring Gull	94	5	99
TOTALS	46,517	9,863	56,380
% of Total	82.51	17.49	

*These estimates should be considered minimal since most of them are based on one observation per colony in May or June and do not include subsequent nesting.

Table 5. Coverage of vegetation on the colony sites of the common ground-nesting birds breeding on dredge islands, listed in ascending order of average percent coverage

Species	Number of colonies	Average coverage (%)	Coverage of vegetation (%)						
			0-9	10-19	20-29	30-39	40-49	50-59	60-100
			Percent of colonies						
Least Tern	40	2.5	97	5	2				
Royal Tern	16	6.8	69	25			6		
Sandwich Tern	14	7.8	64	14	14		7		
Black Skimmer	43	8.9	72	12	9		2	5	
Gull-billed Tern	31	14.7	39	32	13	6	10		
Common Tern	30	27.9	7	27	33	3	13	7	10
Herring Gull	10	45.0		10	10	10	20	20	30
Laughing Gull	20	81.0			5			10	85
Forster's Tern	5	100.0							100

Table 6. Coverage of vegetation in a m^2 area surrounding the nest sites of the common ground-nesting, solitary species, listed in order of ascending percent coverage

Species	Number of nests	Average coverage (%)	Coverage of vegetation (%)						
			0-9	10-19	20-29	30-39	40-49	50-59	60-100
			Percent of individual nests						
Oystercatcher	60	2.7	88	10		2			
Wilson's Plover	23	5.7	65	31	4				
Common Nighthawk	21	11.6	33	48	14	5			
Willet	156	48.3	2	8	15	10	12	19	34

Tern. The Herring Gull, Laughing Gull, Forster's Tern, Common Nighthawk, and Willet were never found nesting in sites completely devoid of vegetation. Only one of 30 Common Tern colonies occurred on substrate without vegetation. This bare site consisted of large chunks of consolidated shell material upon which drift material was scattered. Possibly the chunks of shell and drift materials served the same function as the plants occurring in the other sites. Vegetation was absent from 13-50% of the colony sites of the remaining species. The Gull-billed Tern also appeared to readily accept driftwood and other debris as a substitute for vegetation.

Height of vegetative cover for the ground-nesting, colonial species is shown in Figure 14. This graph is based on recordings of the estimated average height of vegetation in each colony studied. It shows the mean, range and standard deviation of the height. The species are listed in ascending order from the lowest to the highest mean height.

The species of plants associated with each nesting colony studied were recorded. Table 7 relates plant species to bird colony sites and gives the frequency of occurrence of plants found within the colony sites of ground nesting species. The species of plants are listed in order of decreasing frequency in all of the bird colonies. Species which occurred in less than 2% of all colonies were not listed. The higher the frequency the greater the proportion of bird colonies containing the

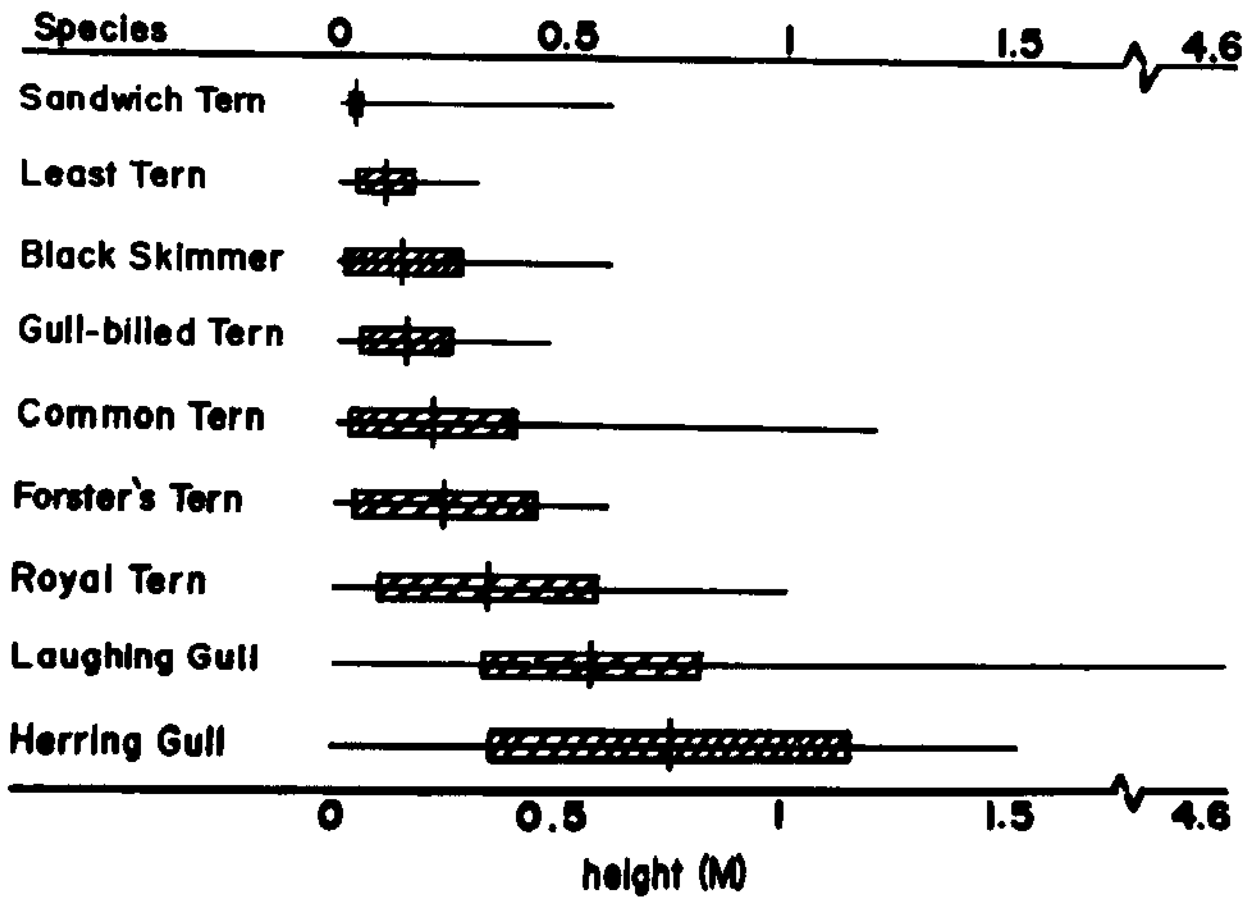


Fig. 14. Height of nesting cover in colony sites of nine ground nesting species. The vertical line represents the average height, the horizontal line the range, and the cross-hatched bar the standard deviation.

Table 7. Frequency of the most common plants found in colony nesting sites on dredge islands in North Carolina estuaries. The number of colonies included in the calculations for each bird species is shown in parentheses, in decreasing order of frequency.

Plant species	Total frequency (254)	Least Tern (38)	Royal Tern (28)	Sandwich Tern (8)	Black Skimmer (38)	Gull-billed Tern (29)	Common Tern (59)	Herring Gull (15)	Laughing Gull (30)	Forster's Tern (9)
Spartina patens	.30	.08	.39	.00	.21	.07	.27	.07	.73	.33
Oenothera humifusa	.26	.63	.07	.13	.29	.31	.19	.13	.13	.11
Erigeron canadensis	.21	.39	.14	.13	.32	.28	.20	.27	.07	.00
Solidago sempervirens	.15	.08	.14	.25	.13	.21	.10	.47	.20	.00
Heterotheca subaxillaris	.15	.50	.00	.00	.11	.21	.08	.07	.07	.00
Cakile harperi	.14	.05	.18	.38	.18	.21	.22	.00	.00	.00
Chenopodium ambrosioides	.12	.03	.21	.38	.16	.10	.10	.00	.20	.00
Panicum amarulum	.10	.08	.04	.00	.05	.03	.07	.47	.17	.00
Ammophila breviligulata	.09	.03	.04	.00	.08	.10	.15	.20	.03	.11

Table 7. Continued

Plant species	Total frequency (254)	Least Tern (38)	Royal Tern (28)	Sandwich Tern (8)	Black Skimmer (38)	Gull-billed Tern (29)	Common Tern (59)	Herring Gull (15)	Laughing Gull (30)	Forster's Tern (9)
Iva imbricata	.07	.05	.04	.00	.08	.10	.12	.07	.03	.00
Triplasis purpurea	.07	.16	.00	.00	.13	.21	.02	.00	.00	.00
Spartina alterniflora	.06	.00	.00	.00	.00	.07	.07	.07	.13	.67
Borrichia frutescens	.06	.00	.00	.00	.00	.00	.02	.13	.30	.22
Cenchrus tribuloides	.05	.13	.04	.00	.00	.07	.08	.00	.00	.00
Lepidium virginicum	.04	.00	.00	.00	.00	.00	.08	.00	.13	.01
Hydrocotyle bonariensis	.03	.00	.07	.13	.00	.00	.03	.00	.13	.00
Iva frutescens	.03	.00	.00	.00	.00	.07	.02	.13	.07	.00
Distichlis spicata	.03	.00	.00	.00	.00	.00	.00	.07	.17	.22
Phytolacca americana	.02	.00	.07	.25	.00	.00	.02	.00	.03	.00

Table 7. Continued

	Total frequency (254)	Least Tern (38)	Royal Tern (28)	Sandwich Tern (8)	Black Skimmer (38)	Gull-billed Tern (29)	Common Tern (59)	Herring Gull (15)	Laughing Gull (30)	Forster's Tern (9)
Panicum amarum	.02	.00	.07	.00	.00	.00	.05	.00	.03	.00
Lactuca canadensis	.02	.00	.00	.00	.00	.07	.03	.00	.07	.00
Paspalum distichum	.02	.00	.04	.00	.03	.03	.02	.00	.00	.11
Croton punctatus	.02	.00	.04	.00	.03	.00	.02	.00	.07	.00
Polygonum glaucum	.02	.00	.04	.00	.03	.03	.02	.00	.00	.11
Uniola paniculata	.02	.05	.00	.00	.05	.00	.02	.00	.00	.00

plant species in question. For example, S. patens occurred in 30% of the colonies of all species and 27% of the Common Tern colonies. It should be noted that for any bird species the number of plants with a high frequency of occurrence is quite small. Some species occurred with a much greater frequency in the colony sites of some birds, however, than was expected considering their contribution to the total vegetative coverage on the islands. Oenothera humifusa was included among the most important plants only on the upper slopes and domes during mid-seral stages (Table 2). Yet, it occurred with a relatively high frequency in colonies of Least Terns (.63), Gull-billed Terns (.31), Black Skimmers (.29) and Common Terns (.19) (Table 7). A possible explanation for the relatively high frequency of occurrence was found in the life history and growth form of O. humifusa and the specific nesting site requirements of the birds. O. humifusa is a perennial plant that has a prostrate growth form and was most frequently found on the slopes and domes with a substrate containing large amounts of shell material. Each of the four species of birds showed a preference for vegetative coverage comprised of short plants in their colony sites (Fig. 14). The Least Tern not only nested in lower vegetation than the other three but also nested in more sparsely vegetated sites (Table 5). It was found that the Least Tern nested earlier in the life history of the perennial plant than did the other species. It also was found to frequently nest higher on the slopes and domes where O. humifusa appeared to be more stunted and occurred in reduced densities. A year or two after O. humifusa germinated it formed lush, prostrate clumps. These clumps were usually scattered, but apparently the coverage was not suitable for the Least Tern since it did not use these sites. It should be noted that the Least Terns probably nested in these sites due to the undulating, shelly substrate and not because O. humifusa (or any other plant) was present. The frequency of occurrence of this plant was high among Least Tern colonies not because a preference was shown for its growth form but because the terns tolerated the plants until large clumps began to form. This assumption is substantiated by the fact that Least Terns were frequently found in bare sites which were later invaded by O. humifusa. Once the clumps formed, the terns no longer utilized the sites. Just the reverse was found in the case of Gull-billed Terns, Black Skimmers and Common Terns. These three species invaded these sites after O. humifusa matured to the clump growth form. Due to the scope of the study, there was not enough time to do quantitative studies of specific nest site selection in mixed colonies of these species (see later section on interspecific associations). It was apparent, however, that the Common Terns placed their nests within the clumps, the Gull-billed Terns contiguous to the clumps, and the Black Skimmers between the clumps. Further studies need to be done on specific nest site selection within mixed species colonies.

Erigeron canadensis occurred in relatively high frequencies in the colony sites of five of the nine species of birds (Table 7). These observations can be explained by the fact that this annual plant becomes established in year 2. During at least the following six years of plant succession it was found in all the topographic zones except the perimeter (Tables 1 and 2). It was more important, however, on the lower slopes than the other zones. Black Skimmers and Gull-billed Terns were frequently found nesting on the lower slopes of islands; therefore, it was not surprising to find a high frequency of occurrence of *E. canadensis* in colonies of those species. Additionally, they showed a preference for nesting among plants with open spaces between them. *E. canadensis* fulfilled this requirement.

The relatively high frequency of *Solidago sempervirens* (.47) and *Panicum amarulum* (.47) in Herring Gull colonies was found to be related to the growth form of the plant and the nesting behavior of the bird. Herring Gulls almost invariably nested adjacent to or between large, tall clumps of vegetation. This species generally nested in the highest vegetation of any ground nesting species studied although the vegetation in a few Laughing Gull colonies was higher (Fig. 14). Both of these tall perennials developed into large clumps. A Herring Gull nest was almost invariably placed so that the clump was located between its nest and other nests in the colony. Apparently the presence of the clump acted as a screen which reduced territorial conflicts.

Spartina patens and Cakile harperi were the two species of plants found most frequently in Common Tern colonies. Both were found to be among the dominant species of plants on the drift ridges during the first two growing seasons (Table 1). Common Terns were frequently found nesting on these ridges.

Chenopodium ambrosioides occurred frequently in Royal and Sandwich Tern colonies. This plant frequently invaded their colony sites after they had nested in them several breeding seasons.

Ammophila breviligulata occurred approximately 20 times more frequently in Herring Gull colonies than was its total frequency in all colonies. Most of the colonies were concentrated on islands in the northern third of the North Carolina estuaries (Parnell and Soots 1975). A. breviligulata was much more abundant in this area than farther south.

Spartina alterniflora, Borrichia frutescens, and Distichlis spicata occurred more frequently in Forster's Tern colonies than in other colonies. These results reflected the colony site selection of this species which almost invariably nested on long, narrow drift rows of dead plant material (most frequently Zostera marina) which was located on the lower elevations of the islands. This drift material was usually located in dense vegetation; this is reflected in the high vegetative coverage shown for this species in Table 5. The drift row was often bordered on the lower side by S. alterniflora and the higher side by *B. frutescens*, *D. spicata* and other high marsh species.

Association of Birds with Various Plant Communities

The types of plant communities present on an island was the main factor which determined whether a species nested on it. The general nesting habitats ranged from bare sand and/or shell to young maritime forests. The general habitats were described as bare substrate, sparse forbs (grasses and herbaceous plants) (less than 25% coverage), medium forbs (25-75% coverage), dense forbs (75-100% coverage), forbs and shrubs, shrub thickets (canopy and understory dense), shrub forest (canopy dense, understory open), and maritime forest. The species and plant community associations are shown in Table 8. The range of nesting habitat descriptions given in the table shows the typical result on a dredge island which has not been disturbed by factors that would have changed the pattern of succession.

The column labeled earlier year of invasion refers to the age a dredge deposit reached before suitable nesting habitat developed. Several species which included bare substrate in their site selection usually did not nest on an island during the first year following a deposition, apparently because the substrate was unstable. By the second year the substrate had stabilized due to sorting and shifting of materials by wind and rainfall.

The fourth column refers to the number of years a particular site would provide suitable nesting habitat following the initial

Table 8. Nesting habitats and earliest year of invasion by common nesting birds of dredge islands and span of time included in the range of habitat usage

Earliest year of invasion	Species	Typical nesting habitat	Estimated use of a given site in years
1	American Oystercatcher[1]	Bare sand to sparse forbs	5
1	Black Skimmer	Bare sand to moderate forbs	7
2	Wilson's Plover[1]	Bare shell and sand to sparse forbs	4
2	Least Tern	Bare sand and shell to sparse forbs	4
2	Royal Tern	Bare sand to sparse forbs	4
2	Sandwich Tern	Bare sand to sparse forbs	4
2	Gull-billed Tern	Bare sand (with drift material or heavy shell) to moderate forbs	4
2	Common Tern	Bare shell to moderate forbs	6
3	Forster's Tern	On drift material surrounded by moderate to dense forbs	?[2]
3	Eastern Willet[1]	Moderate to dense forbs	12
5	Herring Gull	Sparse to dense forbs	5

Table 8. Continued

Earliest year of invasion	Species	Typical nesting habitat	Estimated use of a given site in years
5	Laughing Gull	Moderate to dense forbs	10
5	Redwing	Dense forbs to low scattered shrubs	15
8 (4)[3]	Boat-tailed Grackle	Dense tall grasses[3] to maritime forests	35+
10	Herons and Egrets[4]	Dense forbs with scattered shrubs to maritime forests	30+
10	Glossy Ibis	Dense forbs with scattered shrubs to maritime forests	30+
20	White Ibis	Shrub thickets to maritime forests	30+

[1]Solitary nesters, all others colonial.

[2]Often on drift material in marshes adjacent to dredge islands. Such marshes once established may persist indefinitely.

[3]Only when P. communis is present.

[4]Includes Green Heron, Little-Blue Heron, Snowy Egret, Cattle Egret, Great Egret, Louisiana Heron and Black-crowned Night Heron.

invasion of a particular species. Many species depended on the early stages of succession and thus islands soon became unsuitable for nesting sites unless the early stages were maintained.

Some species, especially the Gull-billed Tern, readily accepted cover other than plants in their nesting sites. Pieces of driftwood and other debris were frequently associated with the Oystercatcher, Wilson's Plover, Gull-billed Tern, and Common Tern.

Since Forster's Terns frequently nested on drift rows in *S. alterniflora* marsh, the dense forb habitat in which they were frequently found could potentially last indefinitely while dense forb habitats above the high tide line were transitory.

Ecological Succession of Breeding Birds in Early Seral Stages -- (*Bare Substrate, Sparse Forbs, Dense Forbs*)

As indicated earlier, about one year of sorting was required for the substrate of an island to become stabilized. Thus, year 1 (the first year after deposition) was found to support few birds. The only species to nest regularly on islands during this stage was the American Oystercatcher. One or two nests were usually found on the dome of most of these bare islands. However, the nests were almost invariably placed on small lumps of shell particles protruding above the finer and less stable material. The Black Skimmer occasionally nested on islands prior to substrate stabilization (Table 8). Skimmer nests seldom extended onto the domes of new islands.

Year 2 (Fig. 9) was the seral stage in which five colonial, ground-nesting and one solitary-nesting species began nesting on the islands. This seral stage was characterized by sparse to moderate forbs in the swales and on the drift ridges, and by mostly bare substrate with low, widely scattered annuals and biennials on the slopes and dome. Coverage of vegetation was less than 5%. Thus, two types of nesting habitat were present. Since no shrubs were present in this early seral stage (Table 1), only ground nesters were present.

The five species of colonial nesters that typically chose colony sites from among those islands two years of age were the Least, Royal, Sandwich, Gull-billed, and Common terns.

The Least Tern showed a strong preference for the islands having a large amount of bare shell material in the substrate. It selectively placed its nests on the shell ridges and domes after the finer material had been sorted out and blown or washed to lower elevations.

Royal Terns began nesting in dense colonies on the highest parts of bare domes and as the colonies grew in size they extended down the slopes. When a colony was located on an elongated dome it extended along it rather than down the slope. Sandwich Terns, while fewer in number (Table 4), were invariably found nesting among Royal Terns. Gull-billed and Common Terns nested most frequently in the sparse to moderate forbs found on the drift ridges. The Gull-billed Tern was frequently found in sites lacking vegetation or which were very sparsely vegetated (Table 5). These sites were usually, however, covered with debris such as driftwood (Fig. 15) or other materials. The Common Tern was seldom found on bare substrate, instead it showed a preference for 10 - 30% vegetative coverage (Table 5) which was present on the drift ridges. Spartina patens was one of the most important plants on the drift ridges in year 2 (Table 1), thus accounting for its relatively high frequency of occurrence in Common Tern colonies (Table 7).

The Wilson's Plover and American Oystercatcher were the only solitary nesting species that utilized the early seral stages. Nests of the Wilson's Plover were most frequently placed on one of the drift ridges adjacent to an isolated plant, small clump of vegetation, or an inanimate object.

By years 3 and 4 (Fig. 9) the coverage of vegetation (60.7%) had increased dramatically on the drift ridges and swales. Gull-billed Terns were not found in such dense vegetative cover. Common Terns were rarely found in greater than 50% coverage (Table 5). However, habitat conditions were more suitable for the Willet, a solitary nester which was found to nest first on dredge islands during the third growing season.

As the vegetation on the swales and drift ridges became too dense for those species preferring moderate forbs the vegetation on the lower slope had increased, providing suitable nesting habitat for Black

Fig. 15. Mixed Gull-billed Tern and Common Tern colony site located among debris from a dredging operation.

Skimmers, Gull-billed Terns, and Common Terns. These species were regularly found on the lower slopes of 3 and 4 year old islands. *Oenothera humifusa*, *Erigeron canadensis* and *Heterotheca subaxillaris* were found to be important plants on the lower slope of dredge islands in the third and fourth growing season (Table 1) and had a relatively high frequency of occurrence in colonies of Common Terns, Black Skimmers, and Gull-billed Terns (Table 7). The coverage of vegetation on the upper slopes and dome were still found to be sparse (3.4% on Island 151-2) on most dredge islands through the fourth year of plant succession; American Oystercatchers, Black Skimmers, Wilson's Plovers, Least Terns, Royal Terns, and Sandwich Terns were found in these zones of vegetation.

After the fourth growing season the drift ridges, swales, and much of the lower slopes were found to support only two ground-nesting species — the solitary nesting Willet and the colonial nesting Laughing Gull. Both, especially the latter, often nested in dense forbs (Table 8).

During the fourth growing season vegetative cover on the dome continued to increase while the band of denser vegetation continued to expand up the slopes (Fig. 11). From the fifth to the seventh or eighth growing seasons, Black Skimmers, Gull-billed Terns, Common Terns and Willets were found to occupy the domes, having moved up the slope ahead of the dense vegetation. Willets were found nesting on the domes of higher islands on which vegetative coverage progressed more slowly until about the 15th growing season.

The Herring Gull was also found nesting on domes from about 5 to 8 years of age but occurred predominantly on those supporting large, tall clumps of forbs scattered among low, sparse forbs (Fig. 16). The two species of plants most frequently found adjacent to Herring Gull nests were *Panicum amarulum* and *Solidago sempervirens* (Table 7). Both of these species formed large clumps.

Ecological Succession of Breeding Birds in the Mid-seral Stage of Plant Succession - - (Forb-shrub)

By year 10 the vegetation on the domes had increased substantially and shrubs formed a broken circle among the dense forbs which occupied most of the island (Fig. 12). This forb-shrub stage supported large colonies of Laughing Gulls which were the only abundant ground-nesting species found. *S. patens* was the most frequent dominant plant found among Laughing Gull colonies (Table 7). It was also, by far, the most dominant plant in the mid-seral stage (Table 2). Gadwalls and Black Ducks were also found nesting in the dense *S. patens* in the forb-shrub stage. These ducks were found infrequently on dredge islands in the vicinity of Oregon Inlet (Fig. 1). Most of the duck nests were placed among large colonies of Laughing Gulls.

Fig. 16. Typical nesting habitat utilized by Herring Gulls on dredge islands. The large clumps of vegetation are *P. amarulum* and *S. sempervirens*.

The top of the domes were usually moderately covered by forbs and frequently Willets were found nesting on the dome or in the dense forbs adjacent to it. Birds found nesting among the scattered shrubs were: Boat-tailed Grackles, Red-winged Blackbirds, and all of the species of wading birds except the White Ibis. The White Ibis was found only in shrub thickets, shrub forests, and young maritime forests characteristic of later seral stages. All of the other species of wading birds were also more common in late seral stages. The Boat-tailed Grackle was most frequently found in Myrica cerifera shrubs. The range of nesting habitats utilized by the colonial nesting Boat-tailed Grackle extended from dense, tall grass to young maritime forest (Table 8). Such a wide range is shown because this species was often found nesting in dense stands of Phragmites communis which frequently exceeded 2 m in height and developed by the third growing season on some islands. In some colonies the nests were attached directly to the culms of P. communis but when shrubs were mixed among the culms they were used as nesting sites. Baccharis halimifolia and Iva frutescens were the shrubs usually found in the dense stands. The Red-winged Blackbird nested in lower and more isolated shrubs than the Boat-tailed Grackle; Iva imbricata was the shrub utilized most frequently.

The wading birds were found nesting in all of the common shrubs present during the mid-seral stages. These shrubs included B.

halimifolia, I. imbricata, and M. cerifera. All of the wading birds except the Green Heron were also found occasionally nesting on the ground among dense forbs.

Ecological Succession of Breeding Birds in Late Seral Stages - - (Shrub Thicket, Shrub Forest, Young Maritime Forest)

The shrub thicket was the next seral stage that appeared on undisturbed dredge islands. The species of birds nesting here were similar to those in the late mid-seral stage but the proportion of shrub relative to dense forbs and moderate forbs (on the domes) was much greater, thus providing proportionally more habitat for species nesting in shrubs.

The shrub forest, dominated by M. cerifera (Table 3), replaced the shrub thicket and once this stage was reached very little vegetation other than shrubs remained (Table 3, Fig. 13). The major changes in the breeding bird composition found in this seral stage was the disappearance of Laughing Gulls and increased usage by herons, egrets, and ibises. Twenty heronries were found in the North Carolina estuaries of which thirteen were on dredge islands. Only two of the dredge-island heronries were situated entirely in the forb-shrub stage. Four were in shrub thicket; one in mixed forb, forb-shrub, shrub thicket; and six in mixed shrub thicket, shrub-forest. The progressive encroachment of the shrubs up the slopes and onto the domes also forced the Willet from the interiors of islands. They were, however, found nesting in small numbers among the moderate to dense forbs which formed a transition zone between the shrub forest (and later the maritime forest) and low salt marsh (dominated by *S. alterniflora*) or open water. The same species were found nesting in the shrub forests that were present in shrub thickets. In addition the White Ibis nested in this stage. The Red-winged Blackbird was not found nesting in the interior of the shrub forest, however, but instead chose sites in the shorter, more open, shrub thicket which was always present around the perimeter of the shrub forest. The shrub thicket was dominated by *I. frutescens*, *B. halimifolia*, and *B. angustifolia*.

The final seral stage studied was the young maritime forest. No differences were observed in the species composition of the breeding bird population of this stage and the shrub forest.

Interspecific Associations

Chi-square values were determined for two-species associations of the nine common species of colonial nesting birds. A 2 x 2 contingency table was used to test the hypothesis that two species were not associated (Simpson, *et al* 1960). The calculations were based on 248 observations over a four-year period. An association was considered to be positive if nests of two or more species were intermingled within the same colony site. Coefficients of association were also determined for the 36 possible associations utilizing the following formula (Krebs 1972): $V = ad - bc / \left[(a + b)(c + d)(a + c)(b + d)\right]^{1/2}$ where: a = species x and y present in a nesting colony; b = species x absent, species y present; c = species x present, species y absent; d = both species absent. This coefficient is useful because it varies from - 1 to +1 and is zero when there is no association, thus enabling one to show graphically the type of association involved for each pair of species (Fig. 17). The symbols shown in the chi-square matrix should be interpreted as follows: 0 = no association, + = a significant positive association, ++ = a highly significant positive association, - = a significant negative association, -- = a highly significant negative association. Of the 36 possible associations 12 were neutral, 5 were positive, and 19 were negative.

Highly significant negative associations were determined for the following: Least Terns and all other species, Royal Terns and Gull-billed Terns, Royal Terns and Common Terns, Royal Terns and Black Skimmers, Sandwich Terns and Common Terns, Sandwich Terns and Black Skimmers, Laughing Gulls and Black Skimmers, and Forster's Terns and Black Skimmers. Calculations showed significant negative associations between Sandwich Terns and Gull-billed Terns, Herring Gulls and Gull-billed Terns, Herring Gulls and Black Skimmers. Highly significant two-species positive associations were found between Royal Terns and Sandwich Terns and Laughing Gulls and

	Least Tern	Royal Tern	Sandwich Tern	Herring Gull	Laughing Gull	Forster's Tern	Gull-billed Tern	Common Tern
Royal Tern	- -							
Sandwich Tern	- -	+ +						
Herring Gull	- -	0	0					
Laughing Gull	- -	0	0	0				
Forster's Tern	- -	0	0	0	+ +			
Gull-billed Tern	- -	- -	-	-	0	0		
Common Tern	- -	- -	- -	-	0	0	+ +	
Black Skimmer	- -	- -	- -	-	- -	- -	+ +	+ +

Fig. 17. Chi-square matrix showing associations between pairs of colonial, ground nesting species.

Forster's Terns. One highly significant three-species association was found among the Gull-billed Terns, Common Terns, and Black Skimmers.

The Great Black-backed Gull, Roseate Tern, and Caspian Tern were found nesting on dredge islands, but observations were insufficient to determine species associations. Great Black-backed Gulls were found nesting on two dredge islands near Oregon Inlet in Dare County (Parnell and Soots 1975). Only three pairs appeared to be nesting and all of these were closely associated with nesting Herring Gulls. One Roseate Tern nest was found. This nest was on a dredge island near Cape Lookout and was situated among a large colony of Common Terns (Soots and Parnell 1975). Ten Caspian Tern nests were found and the following associations observed: four with Royal Terns, two with Common Terns, two with Common Terns and Black Skimmers, and two alone.

DISCUSSION

There are approximately 406 dredge-built or dredge modified islands and 260 natural or unmodified islands in the North Carolina estuaries. Dredge islands continue to be built, although the rate of construction has slowed dramatically and only in unusual cases is dredge spoil now placed in open water. Existing dredge islands and natural islands will, however, continue to be modified by the deposition of spoil. Thus community succession will continue to be returned to year zero.

The pattern of invasion of plants onto these new deposits was consistent. The predictable pattern included the initial establishment of pioneer plants on two drift ridges and the subsequent invasion of the lower parts of the island by perennial forbs. Equally constant was the early establishment of annual, biennial, and perennial forbs on the upper slopes and domes and in about 20 years the replacement of all early seral stages by shrub thickets. The establishment of maritime forest was less well documented, as most dredge islands were yet too young or had been disturbed too often to have reached this stage of development. However, tree species were established on 35 - 40 year old islands and were replacing the shrubs as dominants.

The pattern of succession on dredge islands is similar in terms of vegetational structure and patterns to old field succession as described in the Piedmont of North Carolina (Crafton and Wells 1934, Oosting 1942). Few old fields have the compacted environmental gradients found on the coarse sand and shell of the dome-shaped dredge islands. The more complete details and data analysis of plant successional patterns on dredge islands will be discussed more fully in a future paper devoted entirely to that topic (Soots and Parnell in preparation).

There were several factors that regularly altered the typical successional pattern. If Phragmites communis became established it altered the successional pattern dramatically by completely dominating the early stages, although the normal pattern eventually was re-established at the shrub thicket stage. For example, P. communis invaded the lower slope of one vegetation transect on an island in its second growing season but did not invade a second nearby transect. By the fourth growing season coverage of vegetation on the lower slope of the transect invaded by P. communis was 72.4%, being only 6.3% on the other transect which was dominated by the more usual Triplasis purpurea, Erigeron canadensis, and Heterotheca subaxillaris. Islands subjected to heavy wind erosion usually failed to establish herbaceous cover on the upper slopes and dome. Here shifting dunes developed with Uniola paniculata gradually becoming established and providing some stability. Along boat channels, constant wave action from passing vessels eroded island perimeters, preventing the establishment of vegetation on the lower part of the island. In most locations, however, the development of vegetation was predictable in both pattern and time, exhibiting only the normal variation expected in natural phenomena.

Closely associated with the succession of plant communities on dredge islands was an orderly and well-marked succession of nesting birds, especially among the Charadriiformes and Ciconiiformes. As most of the birds nesting on the islands fed elsewhere, they used the islands primarily during the summer months as nesting sites.

Nesting birds were grouped generally: (1) as those preferring bare or nearly bare substrate, (2) preferring a sparse to moderate cover of relatively low forbs, (3) preferring dense forbs, and (4) requiring the presence of shrubs or shrub thickets.

Fifteen species of gulls, terns, and shorebirds nested on the ground, and it was this group of birds that dominated the use of dredge islands during the early years of succession. Within this group a regular progression of use was found as the density of grasses and herbs increased.

As the vegetation developed to the shrub-thicket stage, the ground nesters disappeared from the nesting population and were replaced by Red-winged Blackbirds, Boat-tailed Grackles, herons, egrets and ibises. All of the wading birds known to breed in North Carolina except the Great Blue Heron, *Ardea herodias*, and Yellow-crowned Night Heron, *Nyctanassa violacea*, were found on dredge islands.

It is important to realize that during the early years of plant succession, vegetative density increased rapidly on the lower parts of islands and much more slowly on the upper slopes and domes. Thus, bird use related to specific sites and density and structure of vegetation rather than to islands. Common Terns often nested, for example, on the drift ridges during the first two growing seasons and then moved up the slopes to the domes for several subsequent years. Thus, the use of any island by a particular species of nesting birds extended over the period of availability of its preferred habitat, generally considerably longer than the use of the original site.

Certain nesting species were capable of making important modifications in the rate of succession in their colony sites. Royal Terns generally arrived on the nesting sites in early April, before the annual or biennial forbs characteristic of the upper slopes and domes showed much growth. As a result of trampling and overfertilization, most vegetation present was killed and the colony site remained nearly bare throughout the nesting season. Nutrient analyses were made of soil samples taken in July 1973 from two adjacent islands of similar substrate in the lower Cape Fear River, one with a large colony of Royal Terns (several thousand nests) and the other without a large colony of nesting birds. The nutrient analysis yielded the following average values in Kg/Ha: Phosphorus 1476 on the island with a colony, 307 on the island without a colony; Potassium 122 to 29; and Nitrogen 139 to 0.

Occasional clumps of plants which were too large to trample when the terns arrived, and which were not killed by the heavy fertilization, grew rapidly and provided much of the cover indicated in Table 6. Occasionally a colony site was invaded by *Chenopodium ambrosioides*. This plant appeared to be able to tolerate both the trampling and the heavy fertilization, and in two instances sites that were bare or nearly bare at the time of colonization had lush clumps of these tall weeds interspersed by the time the young hatched. Situations such as this gave rise to cover values for Royal Terns that were probably not representative of what the birds preferred or selected earlier in the breeding season. Further support for this hypothesis is the fact that the birds did not return to a site once the plants had invaded it.

Trampling and overfertilization may have effectively extended the usability of nesting sites of Royal Terns for at least a year or two in several instances. When the plants did become established, however, growth was much more rapid than normal. During the year after abandonment, a Royal Tern colony site showed considerably more plant growth than was the case on similarly aged islands not so occupied.

Most other species of ground-nesting, colonial birds did not nest in the very dense colonies characteristic of Royal Terns and their effect on sites was less dramatic. It was also apparent that adults of ground-nesting species which tended to nest in smaller colonies, spaced their nests farther apart, and laid cryptically colored eggs, did not defecate in their colony site. This would decrease the amount of fertilization contributed by the nesting birds. Young birds which tended to remain in the area of the nesting site did appear to defecate there and thus would add some enrichment to the soil. The Gull-billed Tern, Common Tern, and Black Skimmer all fall in this category. By late summer Black Skimmer colony sites could often be delineated by lush green plant growth compared to the browning vegetation on adjacent areas.

It was frequently observed that wading birds affected their colony sites significantly by fertilization. Characteristically, there was little herbaceous vegetation beneath old heronries, and in some cases the woody shrubs or trees used for the placement of nests were killed or stunted by overfertilization and mechanical damage. Detailed studies of the effects of colonial birds on their nesting sites would be rewarded and should be pursued.

Myrica cerifera, a dominant shrub, was probably brought to the islands by passerine birds through their fecal depositions. Some birds, such as the Yellow-rumped Warbler, Dendroica coronata, and the Tree Swallow, Iridoprocne bicolor, may, in fact, cause an increase in the rate of succession to their own benefit, but to the detriment of those species that do not use the islands once the shrub stage develops. Both Yellow-rumped Warblers and Tree Swallows feed on fruit of *M. cerifera* in large numbers during the winter months and undoubtedly spread seeds from one island to another. Dependence on bird transportation for its distribution may in fact account for the later establishment of *M. cerifera* than other dominant shrubs on dredge islands. Perennial forbs must become established on the islands before they become attractive to birds which feed on *M. cerifera.* By this time the other important shrub species are well established. *Baccharis halimifolia, Baccharis augustifolia*, and *Iva imbricata* made up this group and all of them have light seeds which are transported by the wind.

Individual islands or closely spaced groups of islands were regularly occupied by nesting colonies of several species. In fact, more often than not specific islands contained more than one colony or mixed colonies. After year 3 or 4 in the succession of plants, bare substrate, sparsely vegetated areas, and more densely vegetated areas were usually present. By about year 6 to 8 suitable nesting habitat for all of the ground-nesting species was often present on the same island. Seven species were recorded on a single dredge island during 1973. This island was larger than average (about 15 hectares) and contained nesting habitats ranging from bare substrate to shrub thickets. Such mixtures of species were not found on small islands, probably because the diversity of habitats found on the larger islands was not present and the small area increased interspecific competition.

When such assemblages occurred, each species usually selected suitable units of habitat and generally nested as a discrete unit. At times, however, nesting colonies intermingled. Such close associations were analyzed through the use of a 2 x 2 contingency table, seeking indications of preference by a species for nesting intermingled with a second species. The results shown in Figure 17 indicate that in several cases such preferences did occur. Sandwich Terns were never found nesting except in close association with Royal Terns and apparently preferred the company of the larger terns. Sandwich Terns regularly nest in association with other ground-nesting birds, usually Royal Terns, in eastern North America (Bent 1921, Buckley 1971) and Black-headed Gulls, Larus atricilla, Common Terns and Artic Terns, Sterna paradisaea, in Europe (Cullen 1960, Langham 1974).

A possible explanation for this association can be found in the mating behavior of the Sandwich Tern. It forms pairs before arriving on the breeding grounds and lays eggs within a couple of days after its arrival (Lack 1968). The other colonial species observed in this study appeared to perform mating rituals at colony sites several weeks prior to actually laying eggs. This in effect allowed the birds to scout the site and enabled them to move to another location if the chosen island did not meet their requirements. Since the Sandwich Terns laid eggs soon after arrival there may be an adaptive advantage to laying their eggs in a site already established by another species. Buckley and Buckley (1972) hypothesized the main adaptive value may be that the survival rate of chicks is increased by joining creches of young Royal Terns.

The relationship between Common Terns, Gull-billed Terns, and Black Skimmers was also strong. All three species were regularly found nesting in loose, intermingled colonies.

Negative associations were also found. Least Terns showed a highly significant negative association with all other colonial species (Fig. 17). Some of the negative associations may be explained by differences in habitat preferences, but apparently there were also antagonistic behavioral actions that prevented some associations. Common Terns were observed in the act of chasing Least Terns on a number of occasions. These chases often lasted several minutes. Invariably, the Least Tern being pursued carried a fish in its beak. It appeared in each case that the Common Tern was trying to take the fish from the Least Tern. Bent (1921) states that Least Terns are not as sociable as some other species, but they live in perfect harmony with their neighbors on their breeding grounds.

Nonsignificant departures from the expected values indicated that some species were neither strongly attracted nor strongly repelled by associations with other species.

Associations between the various herons, egrets, and ibises were not tested as it is well established that they regularly nest in dense multispecied colonies (Bent 1926, Quay 1947, Giles and Marshall 1954, Jenni 1969), although there may be divisions of the available space (Simersky 1971, McCrimmon 1975).

Solitary nesters were so widely dispersed that associations between species were not evaluated, but it did appear that Wilson's Plovers showed a preference for nesting in, or adjacent to, Least Tern colonies. Bent (1921) points out that Least Terns prefer the same localities as, and became intimately associated with Piping Plovers, Snowy Plovers, and Wilson's Plovers in their respective breeding ranges. Funderburg and Quay (1959) observed 75 Wilson's Plover nests during the summer of 1955 and reported that one or more pairs nested near the edge of every Least Tern colony observed in a study of the maritime birdlife of southeastern North Carolina.

The positive association shown above probably occur as a result of social factors in addition to preferences for similar nesting habitats. Additional unused habitat of apparently suitable nature was almost always present and it appeared that sufficient space was generally available for interspecific colony separation.

Associated colonies of Black Skimmers, Gull-billed Terns, and Common Terns were usually small, often not more than 50 to 150 combined pairs and association may have been advantageous in colony defense. Upon disturbance by a person walking near or into the colony, all species reacted in concert to the intruder. Similarly, Sandwich Terns were usually only a small percentage of the total nesting birds in Royal Tern colonies and may have reaped the same advantage. Properly oriented studies of these multispecied colonies should yield information of considerable interest and value.

Dredge islands are very important to the nesting birdlife of the North Carolina estuaries (Table 4). It was found during this study that many of the colonial, ground-nesting seabirds nested extensively on dredge islands. Eighty-three percent of the nests of the nine most common species were placed on dredge islands in 1973 compared to 17 percent on natural sites and all nine species nested mainly on dredge islands. Usage of the dredge island sites varied among the species from 53.3% in Laughing Gulls to 98.6% in Sandwich Terns. Laughing Gulls accounted for 63.4% of the nests found on natural sites. Excluding Laughing Gulls from the calculations, shows that 91.6% of the nests of the other eight species were placed on dredge islands. Many ground nesting species that now nest primarily on dredge islands formerly nested on natural beaches recently usurped by man. Along many parts of the North Carolina coastline, high-density, summer-resort areas, such as Nags Head, Atlantic Beach, Wrightsville Beach, and Carolina Beach, now occupy sites formerly utilized by nesting birds. Some species still attempt to nest on more remote sections of barrier islands. Disturbance by humans and their pets as well as beach vehicular traffic prevents successful reproduction among those species attempting to nest on the barrier islands. Artificial dune maintenance is another factor which has reduced the amount of natural nesting habitat on barrier islands by the reduction of oceanic overwash. The few seabirds and shorebirds which nest on barrier islands of North Carolina preferentially select overwash sites. Furthermore, artificial planting of dune grasses result in dense vegetative cover which is not tolerated by most of the ground nesting species. Herons and egrets are in some cases refugees from inland heronries, also disturbed by man. The presence of new nesting habitat in the form of dredge islands has been of tremendous importance to the continued existence of nesting populations of many of these birds in North Carolina.

Dredge islands appear actually to be superior in many ways to the natural islands and barrier beaches used prior to the occurrence of this new estuarine feature. Natural islands and beaches are generally lower in elevation and subject to overwash during strong northeast winds that often come during the early part of the nesting season in conjunction with high tides. Human exploitation and the ephemeral environment of barrier islands has been well documented (Pilkey, et al 1975). Dredge islands, on the other hand, are usually higher in elevation and are seldom covered by storm waters. Many examples of colonies on natural sites in North Carolina being destroyed by high water have been reported (Page 1937, Craighill 1938, Murray 1938, Davis 1953, Hailman 1960), and were observed during this study. Nest destruction by overwash on dredge islands was rarely observed. Barrier islands generally are inhabited by mammalian predators, such as: Raccoons, Procyon lotor, Gray Foxes, Urocyon cinereoargenteus, and feral House Cats, Felis domesticus (Engels 1942, Quay 1959). Dredge islands which lack dense vegetative cover and which are not adjacent to large marshes are less likely to be able to support populations of these predators. In addition, the isolation of many islands makes them inaccessible to such predators and less likely to be visited by people. Predators are sometimes present on dredge islands, however, and in one case colonies of Common Terns and Laughing Gulls abandoned an island during successive years apparently due to the activities of Norway Rats, Rattus norvegicus. The periodic but regular redeposition of dredge spoil on islands also maintains the early stages of succession necessary for many species (Soots and Parnell 1975). The irregular occurrence of storm tides on natural islands and barrier beaches produces the same results. Thus, nesting habitats are more plentiful and consistent on dredge islands.

Evidence obtained during the four years of this study indicates that the populations of several species are increasing -- at least partially and perhaps primarily due to the presence of dredge islands.

This gives support to the concept that dredge islands provide nesting conditions superior to those found on most natural sites. Unfortunately, baseline population data for the period prior to the beginning of dredging are not available, and definite information may not be obtainable. New and useful data on current breeding bird populations in North Carolina estuaries will come from a current Sea Grant research project addressed to this problem. It is well documented by the present study, however, that the substitute sites provided by the dredging process are being used very successfully by many species of coastal birds. The main nesting populations found on the dredge islands were comprised of 9 species of ground nesting members of the Charadriiformes and 9 species of the Ciconiiformes. Eighty-three percent of the nests of species of Charadriiformes in North Carolina were placed on dredge islands and 13 of 20 heronries found in the estuaries were on dredge islands.

LITERATURE CITED

Adams, C. C. 1908. The ecological succession of birds. Auk 25: 109-153.

Adams, D. A. and T. L. Quay. 1958. Ecology of the Clapper Rail in southeastern North Carolina. J. of Wildl. Mgt. 22:149-156.

American Ornithologists' Union. 1957. Checklist of North American Birds. 5th ed. American Ornithologists' Union, Baltimore, Maryland.

Au, Shu-fun. 1975. Vegetation and ecological processes on Shackleford Banks, North Carolina. National Park Service. Scientific monograph series, No. 6. Washington, D. C.

Barnes, D. 1971. Anatomy of a spoil island. Master of Science thesis. Texas A & I Univ., Kingsville, Texas.

Bazzaz, F. A. 1968. Succession on abandoned fields in the Shawnee Hills, Southern Illinois. Ecology 49:924-936.

Beaman, B. 1973. Plant community structure and vegetational zones on spoil islands. Bachelor of Arts thesis. New College, Sarasota, Fla.

Bent, A. C. 1921. Life histories of North American gulls and terns. Bull. U. S. Natl. Mus. 113, Washington, D. C.

Bent, A. C. 1926. Life histories of North American marsh birds. U. S. Nat. Mus. Bull. 135, Washington, D. C.

Boyd, M. B., R. T. Saucier, J. W. Keely, R. L. Montgomery, R. D. Brown, D. B. Mathis, and E. J. Gruice. 1972. Disposal of dredge spoil. U. S. Army Waterways Exp. Sta. Tech. Rpt. H-72-8., Vicksburg, Miss.

Boyce, S. S. 1954. The salt spray community. Ecol. Monographs. 24:29-67.

Brown, C. A. 1959. Vegetation of the Outer Banks of North Carolina. La. State Univ. Stud. Coastal Stud. Sec. 4, Baton Rouge.

Buckley, F. G. and P. A. Buckley. 1971. The breeding ecology of Royal Terns, Sterna (Thalasseus) maxima maxima. Ibis 114: 344-359.

Buckley, P. A. and F. G. Buckley. 1975. The significance of dredge spoil islands to colonially nesting waterbirds in certain national parks. Proc. of a Conference on Management of Dredge Islands in North Carolina Estuaries, May 1974. N. C. Sea Grant Publ. UNC-SG-75-01, Raleigh, N. C.

Burk, C. J. 1962. The North Carolina Outer Banks: A floristic interpretation. J. Elisha Mitchell Sci. Soc. 78:21-28.

Carlson, P. R. 1972. Patterns of succession on spoil islands - A summary report. New College, Sarasota, Fla.

Chesapeake Biological Laboratory. 1966. Biological and geological research on the effects of dredging and spoil deposition in the upper Chesapeake Bay. Ref. No. 6673A. Second Prog. Rpt. 47 pp.

Cooper, A. W. 1974. Salt marshes. pp 55-98 in Vol. II. H. T. Odum, B. J. Copeland, and E. A. McMahan eds. Coastal Ecosystems of the United States. The Conservation Foundation, Washington, D. C.

Crafton, W. M. and B. W. Wells. 1934. The old field prisere: an ecological study. J. of the Elisha Mitchell Sci. Soc. 49:225-246.

Craighill, F. H. 1938. Gull-billed Terns breeding on Pea Island. Chat 2:43-46.

Cronin, L. E., G. Gunter and S. H. Hopkins. 1971. Effects of engineering activities on coastal ecology. Report to Office Chief of Engineers, U. S. Army, Washington, D. C.

Cullen, J. M. 1960. Some adaptations in the nesting behavior of terns. Proc. Int. Orn. Cong. 12:153-7.

Davis, H. T. 1953. Bird nesting colonies in North Carolina. Chat 17:43-44.

Dolan, R. 1972. Man's impact on the outer banks of North Carolina. Natural Res. Rpt. No. 3, U. S. Dept. of Interior, National Park Service, Washington, D. C.

Dolan, R. 1973. Barrier islands: natural and controlled. pp 265-278 in Coastal Geomorphology edited by D. R. Coates, State Univ. of New York, Albany, N. Y.

Engels, W. L. 1942. Vertebrate fauna of North Carolina Coastal Islands I. Ocracoke Island. Am. Midl. Nat. 28:273-304.

Funderburg, J. B. 1956. An ecological study of the summer maritime birds of southeastern North Carolina. Master of Science Thesis, N. C. State Univ., Raleigh, N. C.

Funderburg, J. B., Jr. and T. L. Quay. 1959. Summer maritime birds of southeastern North Carolina. J. of the Elisha Mitchell Sci. Soc. 75:13-18.

Fussell, J. 1973. Forster's Tern nest found near Cape Lookout, N. C. Chat 38:24.

Giles, L. W. and D. B. Marshall. 1954. A large heron and egret colony on the Stillwater Wildlife Management Area, Nevada. Auk 71:322-325.

Godfrey, P. J. 1970. Oceanic overwash and its ecological implications on the Outer Banks of North Carolina. National Park Service, Washington, D. C.

Grant, S. G. and J. Fussell, III. 1970. Forster's Terns summering in coastal North Carolina. Chat 34:37-38.

Hailman, J. P. 1960. Destruction of Pea Island Laughing Gull colony in 1960. Chat 24:24.

Hall, P. H. 1975. Land of the Golden River: Historical events and stories of southeastern North Carolina and the lower Cape Fear River. Wilmington Printing Co., Wilmington, N. C.

Hosier, P. E. 1973. The effects of oceanic overwash on the vegetation of Core and Shackleford Banks, North Carolina. Doctor of Philosophy Dissertation, Duke University, Durham.

Hunter, W. S. and T. L. Quay. 1953. An ecological study of the helminth fauna of McGillivrays seaside sparrow, Ammospiza maritima macgillivraii (Audubon). Amer. Midl. Nat. 50:407-413.

Ingle, R. M. 1952. Studies on the effects of dredging operations upon shell and shellfish. Gulf Carib. Fish. Inst. Proc. 5:106-112.

Johnson, D. W. and E. P. Odum. 1956. Breeding bird populations in relation to plant succession on the Piedmont of Georgia. Ecology 37:50-62.

Jenni, D. A. 1969. A study of the ecology of four species of herons during the breeding season at Lake Alice Alachus County, Florida. Ecol. Monog. 39:245-270.

Krebs, Charles J. 1972. Ecology: The experimental analysis of distribution and abundance. Harper and Row, New York.

Lack, D. 1968. Ecological Adaptations for Breeding in Birds. Methuen, London.

Langham, N. P. E. 1974. Comparative breeding biology of the Sandwich Tern. Auk 91:255-277.

Lunz, G. R., Jr. 1938. Oyster culture with references to dredging operations in South Carolina. U. S. Eng. Off., Charleston, S. C.

Lewis, I. F. 1917. The vegetation of Shackleford Bank, Carteret Co., N. C. Geol. and Econ. Surv. Paper 46:1-32.

Mackin, J. G. 1961. Canal dredging and silting in Louisiana bays. Univ. Texas, Inst. Mar. Sci. Publ. 7:262-314.

Martin, A. C., H. S. Zim and A. L. Nelson. 1951. American Wildlife and Plants. McGraw-Hill Book Co., Inc., New York.

McCrimmon, D. A., Jr. 1975. Nest-site selection among five species of herons on the North Carolina coast. Doctor of Philosophy Dissertation, N. C. State Univ. at Raleigh, Raleigh, N. C.

McMurry, S. L. 1971. Nesting and development of the Reddish Egret (Dichromanassa rufescens) on a spoil bank chain in the Laguna Madre. Master of Science Thesis. Texas A & I Univ., Kingsville, Texas.

Murray, J. J. 1938. Late nesting date for the Least Tern. Chat 2: 51, 64.

Odum, H. T. 1963. Productivity measurements in Texas turtle grass and the effects of dredging on intracoastal channel. Univ. Texas Inst. Mar. Sci. Publ. 9:48-58.

Odum, E. P. 1950. Bird populations of the Highlands (North Carolina) Plateau in relation to plant succession and avian invasion. Ecology 31:587-605.

Oosting, H. J. 1942. An ecological analysis of the plant communities of Piedmont, North Carolina. Amer. Midl. Nat. 28:1-126.

Oosting, H. J. 1945. Tolerance to salt spray of plants of coastal dunes. Ecology 26:85-89.

Oosting, H. J. 1954. Ecological processes and vegetation of the maritime strand in the southeastern United States. Bot. Rev. 20:226-262.

Oosting, H. J. and W. D. Billings. 1942. Factors effecting vegetational zonation on coastal dunes. Ecology 23:131-142.

Page, G. W. 1937. Breeding habits of the Least Tern. Chat 1:1.

Parnell, J. F. and R. F. Soots. 1975. Herring and Great Black-backed Gulls nesting in North Carolina. Auk 92:154-157.

Pearson, T. G., C. S. Brimley, and H. H. Brimley. 1942. Birds of North Carolina. Bynum Printing Co., Raleigh, N. C.

Pilkey, O. H., Jr., O. H. Pilkey, Sr. and R. Turner. 1975. How to Live with an Island: A handbook to Bogue Banks, North Carolina. N. C. Dept. of Natural and Economic Resources, Raleigh, N. C.

Quay, T. L. 1947. Bird islands of Beaufort, N. C. Chat 11:55-57.

Quay, T. L. 1947. Winter birds of upland plant communities. Auk 64:382-388.

Quay, T. L. 1959. The birds, mammals, reptiles, and amphibians of Cape Hatteras National Seashore Recreation Area. Project Completion Report, Cape Hatteras National Seashore Recreational Area, Manteo, North Carolina.

Radford, A. E., H. E. Ahles and C. R. Bell. 1968. Manual of the Vascular Flora of the Carolinas. Univ. of North Carolina, Chapel Hill, North Carolina.

Riggs, S. R. and M. P. O'Connor. 1974. Relict sediment deposits in a major transgressive coastal system. N. C. Sea Grant Publ. UNC-SG-74-04, Raleigh, N. C.

Saunders, A. A. 1936. Ecology of the birds of Quaker Run Valley, Allegheny State Park, New York. State Mus., Albany, N. Y. Handbook No. 16.

Schwartz, F. J. and A. F. Chestnut. 1973. Hydrographis atlas of North Carolina estuarine and sound waters, 1972. N. C. Sea Grant Publ. UNC-SG-73-12. Raleigh, N. C.

Simersky, B. L. 1971. Competition and nesting success of four species of herons on four spoil islands in the Laguna Madre, Master of Science Thesis. Texas A & I Univ., Kingsville, Texas.

Simpson, G. G., A. Roe, and R. C. Lewotin. 1960. Quantitative Zoology. Harcourt, Brace, Jovanovich, New York.

Soots, R. F. and J. F. Parnell. 1975. First record of the Roseate Tern nesting in North Carolina. Chat 39:20-21.

Soots, R. F. and J. F. Parnell. 1975. Introduction to the nature of dredge islands and their wildlife in North Carolina and recommendations for management. Proc. of a Conference on Management of Dredge Islands in North Carolina Estuaries, May 1974. N. C. Sea Grant Publ. UNC-SG-75-01, Raleigh, N. C.

Soots, R. F. and J. F. Parnell. In press. Forster's Tern nesting in North Carolina. Wilson Bull.

Tanzberger, E. P. 1974. A newcomers look at the industry. Proc. of the Sixth Dredging Seminar. Texas A & M Univ. Sea Grant Publ. SG-74-104. College Station, Texas.

Wells, B. W. 1928. Plant communities of the coastal plains of North Carolina and their successional relations. Ecology 9:230-242.

Wells, B. W. 1932. Natural gardens of North Carolina. The Univ. of N. C. Press, Chapel Hill, North Carolina.

Williams, A. B., G. S. Posner, W. J. Woods, and E. E. Deubler, Jr. 1966. Hydrographic atlas of larger North Carolina Sounds. U. S. Fish and Wildl. Serv. Data Rept. 20. (also N. C. Sea Grant Pub. UNC-SG-73-02). Raleigh, N. C.

Wilmington District, U. S. Army Corps of Engineers. 1972. Atlantic Intracoastal Waterway between Norfolk, Va., and the St. Johns River, Fla. Project Maps Fiscal Year 1972: la. Wilmington, N. C.

Wilson, K. A. 1962. North Carolina wetlands: their distribution and management. N. C. Wildl. Res. Comm., Raleigh, N. C.

Wolff, Bob. 1947. Brown Pelicans nesting in Pamlico Sound. Chat 11:72.

Woodhouse, W. W., E. D. Seneca and S. W. Broome. 1972. March building with dredge spoil in North Carolina. Bull. 445. Ag. Expt. Sta., N. C. State Univ., Raleigh, N. C.