Geological and Botanical Features of Sand Beach Systems in Maine

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and
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GEOLOGICAL and BOTANICAL FEATURES of SAND BEACH SYSTEMS in MAINE

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This Sea Grant publication was originally prepared as a report for the Critical Areas Program, Natural Resource Planning Division of the Maine State Planning Office. Further information regarding this or any of the other critical area studies may be obtained by writing the Director, Critical Areas Program, State Planning Office, Augusta, Maine 04330.

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FOREWORD

(from original report)

The following report on the sandy beaches is one of a series of reports being prepared for Maine's Critical Areas Program. This program was established by an act of the Legislature in 1974 which directed the State Planning Office to develop an official Register of Critical Areas and to encourage and coordinate the conservation of such areas as part of its overall responsibility for comprehensive statewide planning and coordination of planning activities. The Act defines Critical Areas as natural features of statewide importance because of their unusual natural, scenic, scientific, or historical significance.

The Act also created the Critical Areas Advisory Board to advise and assist the State Planning Office in the establishment of the Register and the conservation of critical areas. The program established by the Act is not regulatory, with the minor exception that notification of proposed alterations of critical areas is required of the landowners thereof. The program is primarily one of identifying critical areas and providing advice to and coordinating the voluntary activities of landowners, state and local government organizations, conservation groups and others to the end of encouraging the conservation of critical areas. The Critical Areas Program further provides a specific focus for the evaluation and coordination of programs relating to critical areas in Maine. The program also serves as a source of information on critical areas and their management.

The purpose of these reports is to present the results of thorough investigations of subject areas chosen for consideration in the Critical Areas Program. The reports are an intermediate phase in a systematic registration process which starts with the identification of subjects for consideration and concludes with the analysis of each potential critical area individually and, if appropriate, inclusion of areas on the Register.

In addition to the specific task they are intended to fulfill in the registration process, it is my hope that these reports will be useful in a more general sense as a source of information on the various topics they cover. For more information on the sandy beaches contact me or other members of the staff at the State Planning Office.

R. Alec Giffen, Supervisor
Natural Resource Planning Division
State Planning Office

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GEOLOGY, DISTRIBUTION AND GEOMORPHOLOGY OF MAINE'S COASTAL SANDY BEACH AND DUNE SYSTEMS

Introduction

According to King (1972), "A beach is an accumulation of loose material around the limit of wave action." Although succinct, this definition limits the boundaries of a beach to that area between the upper limit of wave action and that depth at which approaching waves first cause appreciable movement of the bottom material. A more comprehensive approach is taken in this report by extending the boundaries to include the supratidal sand bodies and associated vegetational communities as well as the salt marshes, thereby treating the beach area as an ecosystem.

The discussion of physical features and processes for each beach ecosystem will be restricted, primarily, to those of the intertidal beachface and dune areas; although offshore and nearshore bars are considered where they are readily visible as breaker zones. A further constraint is that only sand beaches will be discussed.

Maine's sand beaches form one of the state's most valuable coastal resources since they represent most of the public access, intensive recreational use, open space, and salt marsh boundary portions of the coastline. The lack of use and management policies, an absence of basic data for Maine's unique beach systems, and limited expertise within the state to formulate plans, have led, collectively, to general abuse of beach ecosystems, expensive, and usually futile, erosion prevention measures, and public controversy over causes of beach erosion and shore property loss. Maine's specific and regional beach problems can be attributed to development of a natural resource without an adequate understanding of fundamental geological and botanical processes.

In an effort to increase the general understanding of the natural processes active on beach systems and to document the significant features of many Maine beach and dune ecosystems, this report presents information on twenty-seven beach areas. In part, this compilation is directed toward an identification of the natural dynamic processes active in Maine's beach systems and an understanding of their relative importance and interactions.

Beach Sand
Its Sources and Interaction with Natural Physical Forces

The term *sand* denotes a specific range of sizes within a sediment classification based on particle diameter. According to the Wentworth Scale (Table I) sand beaches consist of material between 1/16 mm and 2 mm. A commonly used alternative scale is based on a transformation of the millimeter scale and is shown in Table I as the Phi Scale where Phi (or Φ) = $-\log_2$ (particle diameter in mm).

Table 1

Wentworth size class	Particle diameter	Φ scale
Boulders	> 256 mm	below -8Φ
Cobbles	64 mm - 256 mm	-6Φ to -8Φ
Pebbles	4 mm - 64 mm	-2Φ to -6Φ
Granules	2 mm - 4 mm	-1Φ to -2Φ
Very coarse sand	1 mm - 2 mm	0Φ to -1Φ
Coarse sand	$\frac{1}{2}$ mm - 1 mm	1Φ to 0Φ
Medium sand	$\frac{1}{4}$ mm - $\frac{1}{2}$ mm	2Φ to 1Φ
Fine sand	$\frac{1}{8}$ mm - $\frac{1}{4}$ mm	3Φ to 2Φ
Very fine sand	$\frac{1}{16}$ mm - $\frac{1}{8}$ mm	4Φ to 3Φ
Silt	$\frac{1}{256}$ mm - $\frac{1}{16}$ mm	8Φ to 4Φ
Clay	$< \frac{1}{256}$ mm	above 8Φ

Accumulation of sand on a beach is due partially to an interesting interaction between sediment size and the velocity of moving water. This phenomenon, first documented by Hjulström (1935, 1955), is illustrated in Figure 1 which shows that the most easily eroded or suspended particles are actually fine-medium sand sizes (0.1 mm - 0.5 mm) rather than silts or clays, because silt and clay size materials form a smooth, compact, cohesive surface which resists erosion. Pebbles and cobbles also require more energy for erosion than sand simply because of their larger size. Once eroded, however, silt and clay size particles will only settle out in a calm, wave-free environment. They do not remain near the breaker zone and thus can not form beaches. For particles of sand size and larger, the current velocity or wave energy at which a given size of particle will settle is not much less than the current velocity or wave energy at which that particle size will be suspended. Sand-sized grains are very easily suspended in the breaker zone but settle out quickly in the slightly lower energy environment of the swash zone immediately landward of the breakers. The result of the Hjulström phenomenon is a preferential selection of sand-sized particles while larger sediments are left behind and finer silts and clays are carried away.

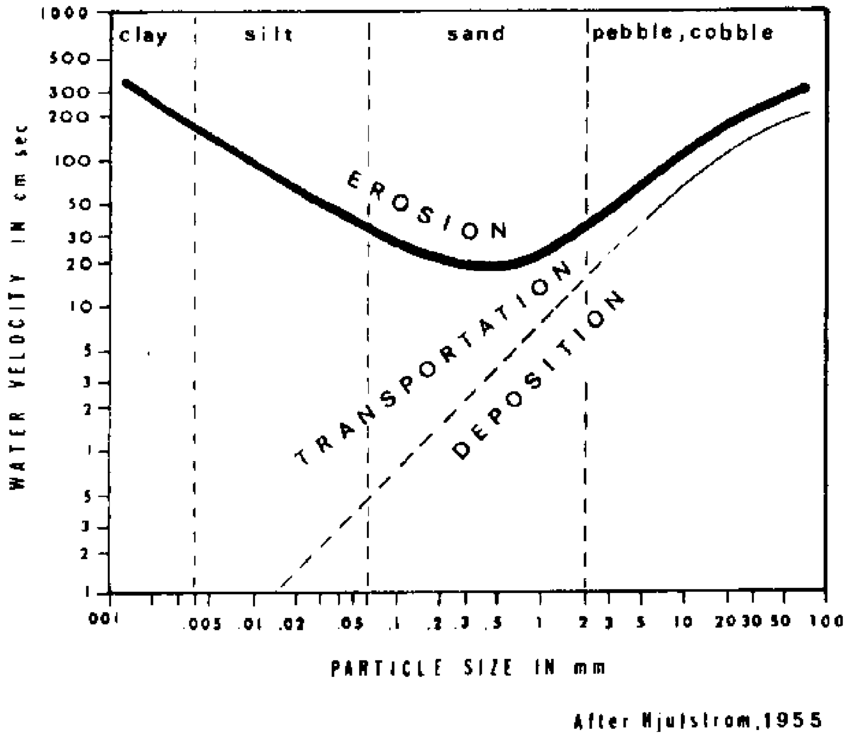


Figure 1   Hjulström Curve showing relationships among particle size, water velocity, erosion, transportation, and deposition.

Accumulation of material on a beach slope is also related to the permeability of the material. Settling is encouraged in the swash zone by percolation of uprushing water down through the accumulating slope. This reduces the volume of backwash relative to uprush and leads to further accumulation. The greater the permeability of an unconsolidated material, the greater the slope of the accumulated surface. Krumbein and Monk (1942, cited in Pettijohn, 1957) have shown permeability to increase as the square of particle diameter and as the log of sorting expressed as standard deviation.

The Hjulström phenomenon acted first in glacial meltwater streams to refine and accumulate sand into its various modern source forms, and acts today in the wave environment to further refine sand from till sources which include clay, silt, gravel, cobbles and boulders. This leads to a sand-sized, well sorted material available to beaches. The good sorting in turn increases permeability in the swash zone so that finally the sand is accumulated as a sandy beach.

Sand beaches are, therefore, depositional forms and, according to the Hjulström phenomenon, are the result of a preferential size selection process. Before sand beaches can develop, a sediment source is required, and for any long-term persistence, a continuing sediment supply is necessary, or at least, efficient recycling mechanisms. For beaches there are four generally recognized sediment sources:

1. Riverborne Sediment Load: This source of sand for beaches is known to be important for only two beach systems in Maine; the Kennebec River has supplied sand to the Popham-Seawall baymouth barrier systems and the Saco River has been the primary source of sand for Maine's longest beach system at Old Orchard Beach and Hills Beach. The source of much of the sand-sized sediment in the Saco and Kennebec Rivers is erosion of glacial drift deposits located along those rivers.

2. Reworking of Glacial Deposits by Waves: Since almost all of the sand on Maine beaches was derived from some kind of glacial deposits, this has been the dominant mechanism by which material was provided and refers to:

   a. wave erosion of upland glacial till and ice-contact stratified drift to form fringing beaches characterized by small sand volumes and rocky low-tide terraces.

   b. wave erosion and landward transport of submerged glacial deposits, such as outwash and recessional delta deposits or till and ice-contact drift units, to form barrier beaches by extensive tidal flooding of low relief back-barrier upland areas through small tidal inlet streams.

   This latter process has occurred in two phases related to sea level rise rates; they are discussed in greater detail in the Glacial History section.

3. Erosion of Local Bedrock: Rock fragments are eroded from headlands and then transported into adjacent embayments to form pocket beaches with a low volume of poorly sorted sand. In Maine this erosion is an ineffecient mechanism and usually can provide only minor amounts of sand-sized material to the beaches. Sand Beach on Mount Desert Island is an exception. It has a large sand volume per meter of beach length, and 60 to 70 percent of this is apparently derived from local bedrock.

4. Onshore Transport of Biogenic Carbonate Sand: Sand can be derived from adjacent shallow-water areas characterized by an abundance of marine organisms having carbonate skeletal parts or shells. This sand source is dominant for beaches in tropical areas where carbonate production is high, but in Maine this is usually a minor source. There are, however, beaches on which the carbonate shell hash constitutes a relatively high percentage of the sand volume, e.g. Mt. Desert Island's Sand Beach, Merchant Island Cuspate Foreland, and Marshall Island's carbonate beach.

As sand is derived from the various sediment sources, it is delivered to the shore as waves move the particles along the seafloor. The limiting depth for this shoreward transport by waves appears to be between 10 m and 18 m, depending on prevailing wave dimensions. As the sand accumulates around the limit of wave action, a dynamic equilibrium between the beach material and natural physical forces acting on the material is established. This equilibrium has been described by Krumbein (1963) and King (1972) in terms of a process-response model. The process agents are the natural physical forces (waves, tides, currents, and winds), the textural characteristics of the beach material, and the periodic changes in sea level.

The process agents act in unison to establish the general morphology and specific characteristics of the beach systems. The morphology and specific characteristics of beaches constitute the response side of the model. Fundamental to understanding the process-response model is recognizing the presence or absence of feedback mechanisms. Feedback mechanisms explain how some response characteristics influence or alter process agents in such a way that the process becomes self-limiting. An example of such a feedback mechanism is the response of a Maine beach to northeast storms which alter the beachface in such a way that wave energies are increasingly dissipated on the lengthening beachface. Implicit in the process-response model and its feedback mechanisms is that time, in varying amounts, is required to establish an equilibrium between the various process agents and the consequent beach form.

Beach ecosystems are among the most dynamic of geologic environments. The form and position of beach and dune features respond to slight changes in the process agents which control their development. It is instructive to view beach and dune formation and change in Maine as the result of an interactive process-response equilibrium.

Beach Processes

There are certain first order features of the earth which ultimately cause the process agents that effect beach process and responses in Maine. These first order features are:

1. Differential Heating of the Earth — causes all oceanographic and weather phenomena.
2. Astronomical Tides — cause daily and longer term variations in the sea surface through interaction with basin geometry.
3. Tectonic Phenomena — cause changes in the coastal freeboard through crustal movements of the earth.

Interaction of these first order features have established the important process agents which are involved in beach ecosystem dynamics in Maine. The process agents are: 1) waves, 2) winds, 3) tides, 4) storms, 5) currents, 6) sediment characteristics, 7) relative sea level change. These agents, the beach processes in which they are involved, and the responses which are visible in the form and behavior of coastal sandy beaches are discussed below.

Waves

Waves as process agents are treated only briefly in this report. A good general discussion of waves and their effect on Maine's beaches can be found in Timson and Kale (1977).

Waves are the most important process agent since they not only initiate shoreward transport of sand but are involved, subsequently, in most of the daily and long-term beach processes. Waves are formed by winds, either locally or at a great distance. Waves generated by local winds are called *seas* and are characterized by discontinuous, confused crests and a wide range of lengths and periods.

If winds create seas at a great distance from a beach, the waves become sorted out by wavelength as they travel toward the coast and combine into long regular swells with parallel crests and a more restricted range of periods, usually 6 to 10 seconds. The three factors which determine the heights and periods of waves are the wind velocity, the duration of the wind, and the fetch or distance over which the winds transfers its energy to the waves.

As waves, either locally derived or long-period swell, approach a shore, they undergo a transformation when the water depth becomes about one-half the wavelength. The wavelength and velocity decrease progressively and the wave height increases. The steepness of the wave increases also since its steepness is the ratio of wave height to wavelength. Eventually the wave attains an unstable steepness and the wave falls forward and breaks. This transformation process for deep water swell is schematically illustrated in Figure 2. After the wave breaks the particle motion of the water changes dramatically from purely oscillatory to translational. The translational water motion characterizes both the surf zone, which extends from the break-point to the swash zone, and the swash zone which is that part of the beachface covered and uncovered by the uprush and backwash of the transformed waves. It is primarily in the area between just seaward of the break-point and the upward swash limit that most of the sediment transport by waves occurs. Sediment transport is enhanced in this zone because of the suspension of sediment by the turbulence of the breaking wave and the Hjulström transport capacity of the translational waves.

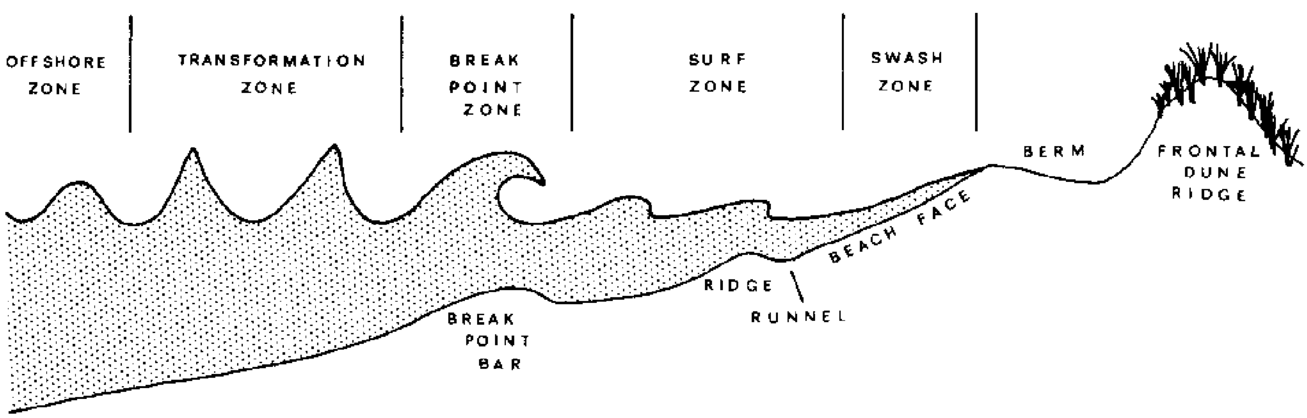


Figure 2 *Illustration of transformation of deep water swell waves as they approach shore. Water particle motion becomes translational after reaching the break-point zone.*

It is because of the sand transport that waves can either erode beaches or build them up. Which they do depends on the relative amounts of onshore-offshore movement of sand. Wave tank experiments by King (1972) indicated that seaward of the break-point sand was almost always moved landward, whereas inside the break-point the direction of net sand transport depended primarily on the wave steepness. Waves with a height to length ratio greater than a given critical steepness value always moved sand seaward but less steep waves swept sand landward. These wave tank experiments tend to verify observations on natural beaches where it is known that steep waves erode beaches and flat waves cause beachface accretion. King suggests that the explanation for this lies in the difference in the relative velocities of the swash and backwash for waves of varying steepness. For low waves the backwash has a lower transport capacity and sand is deposited on the beachface. As steepness increases for a constant wavelength, the volume of water in the wave increases which in turn increases the swash and backwash velocities to maintain sand suspension, and a net seaward movement of sand occurs because of the relatively longer backwash period. Even though sand is transported offshore in the zone inside the break-point by steep, high-energy waves, landward transport still occurs outside the break-point. This means deposition of sand moving from two directions must occur around the break-point; the consequence is the formation of break-point submarine sand bars and shoreline recession during periods of erosion by steep, high-energy waves. Long, low swell conditions result in a net landward sand transport or beachface accretion in a seaward direction.

In Maine, the critical steepness ratio for the change from constructional swell to destructive high-energy waves depends on the grain size of the beach. Larger grains can be accumulated by waves of greater steepness (and greater energy) and still be moved landward. This is because of the higher percolation capacity of large grains, which reduces the erosive capacity of the backwash. Cobbles and boulders (Table I) are moved landward by the highest energy waves encountered on Maine beaches to form high ridges or storm berms. Because Maine's beaches are predominantly fine to medium grain sands (Table I), waves less than 0.75 m in height are constructional; higher waves cause erosion. This is based on a critical steepenss (wave height : wavelength) value of 0.012 and a wave period of 6 seconds.

Most erosion and accretion phases on Maine's small beaches are an onshore-offshore phenomenon rather than the alongshore transport that takes place when waves strike the beach at an angle and cause littoral currents which erode sand from an updrift source and deposit it at a downdrift trap. Waves approaching Maine beaches usually strike the beaches parallel to the strand line, seldom at an angle. This is because the limited sand supply has been reworked into an equilibrium with the wave approach angle such that the strand line and break-point line are parallel.

As waves approach the shallow water of a coast they undergo refraction, the bending of wave crests as the seafloor begins to influence wavelength and velocity in shoaling water. That part of the wave in shallower water begins to slow down while that part in deeper water continues to travel fast. This causes the wave crests to bend around to become parallel to the bottom contours. Since Maine's beach strandlines have adjusted their orientation to the approaching wave crests, it follows that the gross orientation of Maine's beaches is determined by the offshore relief through wave refraction. Refraction also causes wave energy to be concentrated on headlands and dispersed in embayments (Figure 3).

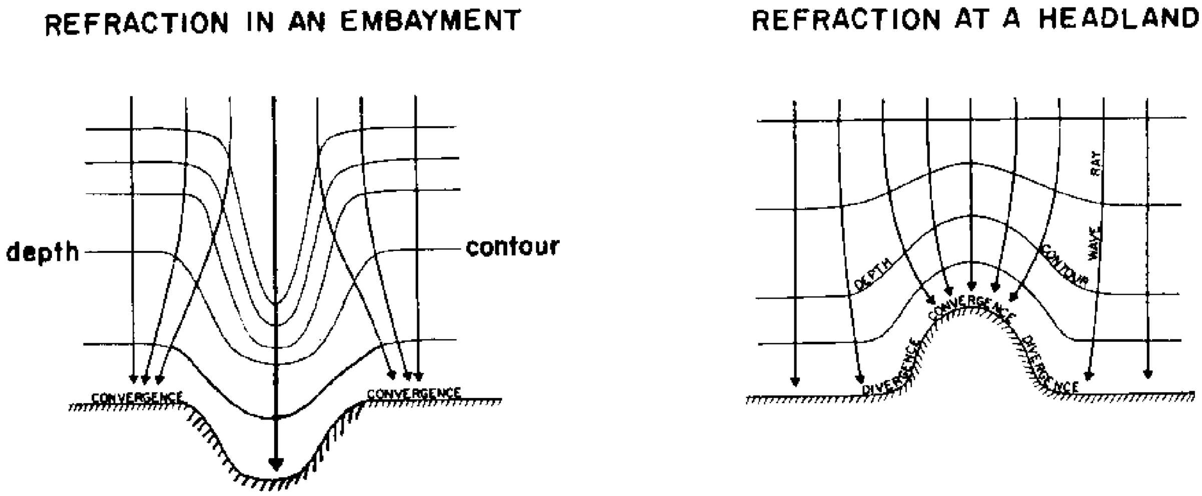


Figure 3 *Refraction of waves at embayments and headlands (modified from Komar, 1976). Wave energy is dissipated in embayments and concentrated on headlands.*

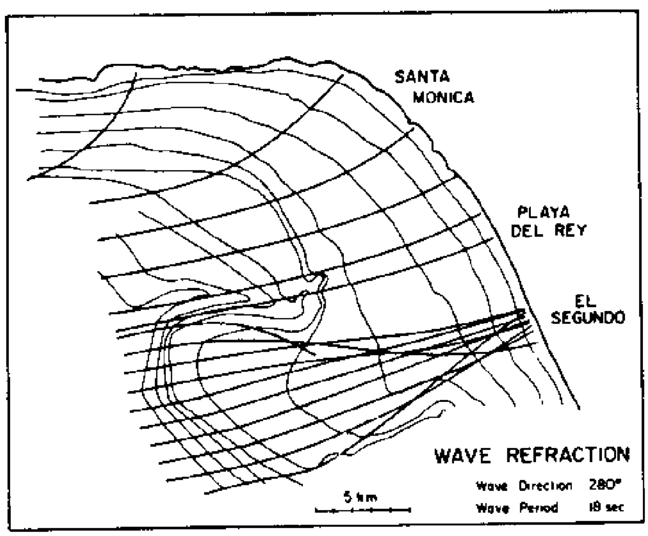


Figure 4 *The "lens effect" (from Komar, 1976). Offshore topography can concentrate wave energy on a particular section of the shoreline. This may occur at portions of Hunnewell Beach, Phippsburg.*

A special variation of wave refraction occurs in the case of a nearshore shoal which, under certain conditions, acts as a wave energy lens, concentrating wave energy on a particular part of the beach (Figure 4). This phenomenon appears to occur at Hunnewell Beach (Figure 28) where a sandy shoal between Wood and Fox Islands may focus wave energy on specific portions of that shoreline during northeast storms.

Tidal and river currents also cause wave refraction. The tidal current effect is constantly changing and may be responsible for the highly dynamic nature of the shoreline and ebb-tidal delta features at tidal reentrants (tidal rivers leading to back-barrier marshes).

A wave rose compiled by the U.S. Army Corps of Engineers for the Gulf of Maine off Penobscot Bay (U.S. Army Corps of Engrs., 1957) is presented in Figure 5. The wave rose shows that waves over 1.22 m (4 feet) come predominantly from the east and northeast. Waves over 3.66 m (12 feet) come only from these directions and reflect the influence of northeast storm winds over a long fetch in generating steep, high-energy waves.

Winds

As a process agent winds are secondary to waves in the intertidal part of beach systems, but they are the dominant agent for the supratidal areas which are primarily aeolian dune forms. Winds cause the development of the frontal dune ridge, alongshore transport of sand, formation of parabolic dunes, and the processes of barrier maintenance in a regime of rising sea level. They also influence the height of waves striking the beach and thereby the erosional or accretionary response of the beach.

Long-term wind data for Maine are available from the Portland and Rockland airports, Brunswick Naval Air Station, Seguin Island Lighthouse, and Maine Yankee Atomic Power Company in Wiscasset. A synoptic summary of meterological observations is available for New England waters from NOAA (U.S. Naval Weather Service Command, 1976). From the wind rose (Figure 7), aerial photographs, and direct observations from a recording anemometer located at Popham Beach, it is clear that the prevailing winds (those which occur more frequently) blow from the western half of the compass. The dominant winds (those which blow less frequently but at higher velocities) come from the northwest, southwest, southeast, and northeast. Because the northwest and southwest winds are both dominant and prevailing, they exert greater influence on those beach responses affected by aeolian processes.

Wind transport of sand occurs by three means:

1. Creep — a simple rolling of sand grains along the dune surface.
2. Saltation — a bouncing of individual sand grains (Figure 6), the distance of each bounce being the same as the wavelength of any aeolian ripple marks that may be visible.
3. Suspension — a carrying of sand grains a long distance through the air in the turbulent boundary layer just above the sand surface. Sheets of blowing sand are visible.

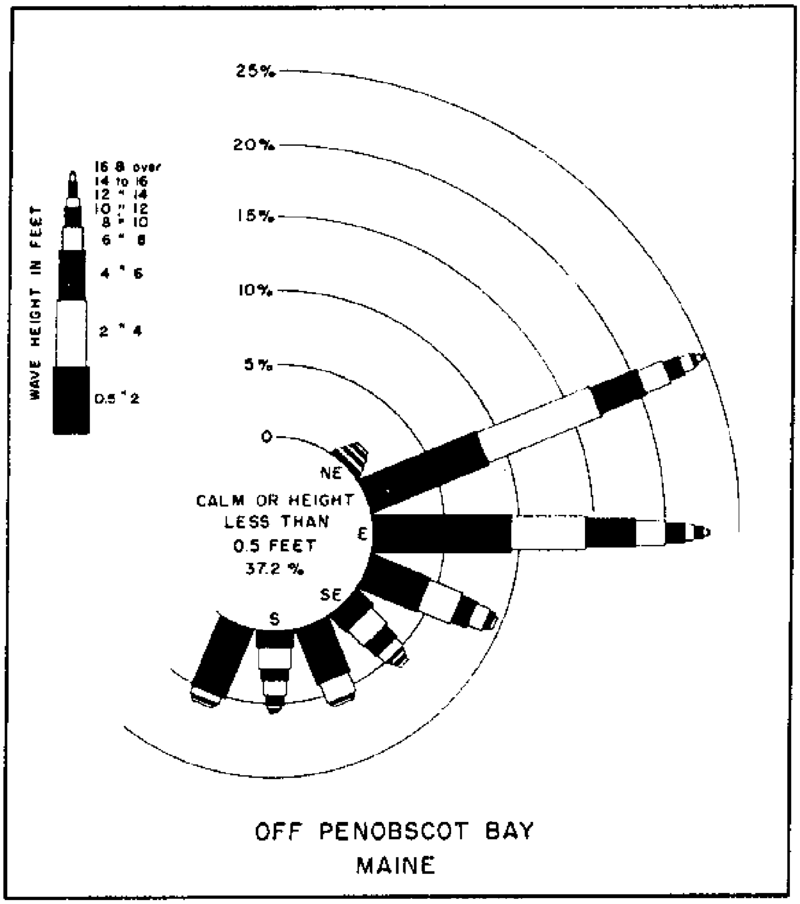


Figure 5 Wave rose composed of data obtained from three years of wind records (1948-1950) showing percent of time that waves of various heights occur from each direction (from U.S. Army Corps of Eng., 1957).

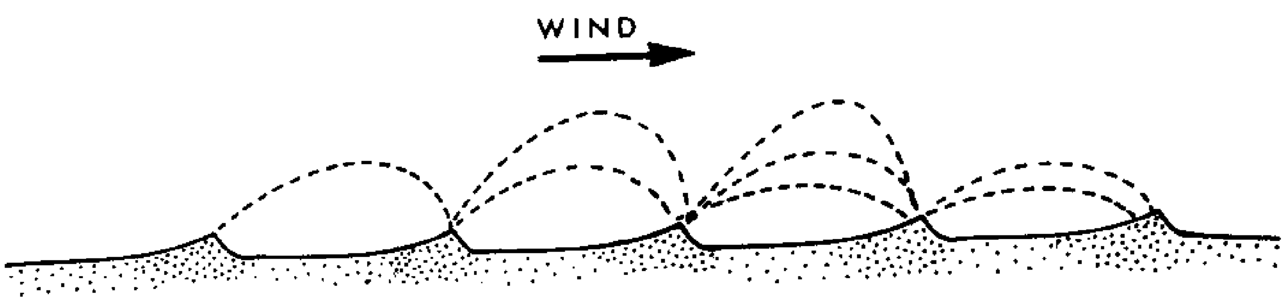


Figure 6 Saltating sand grains

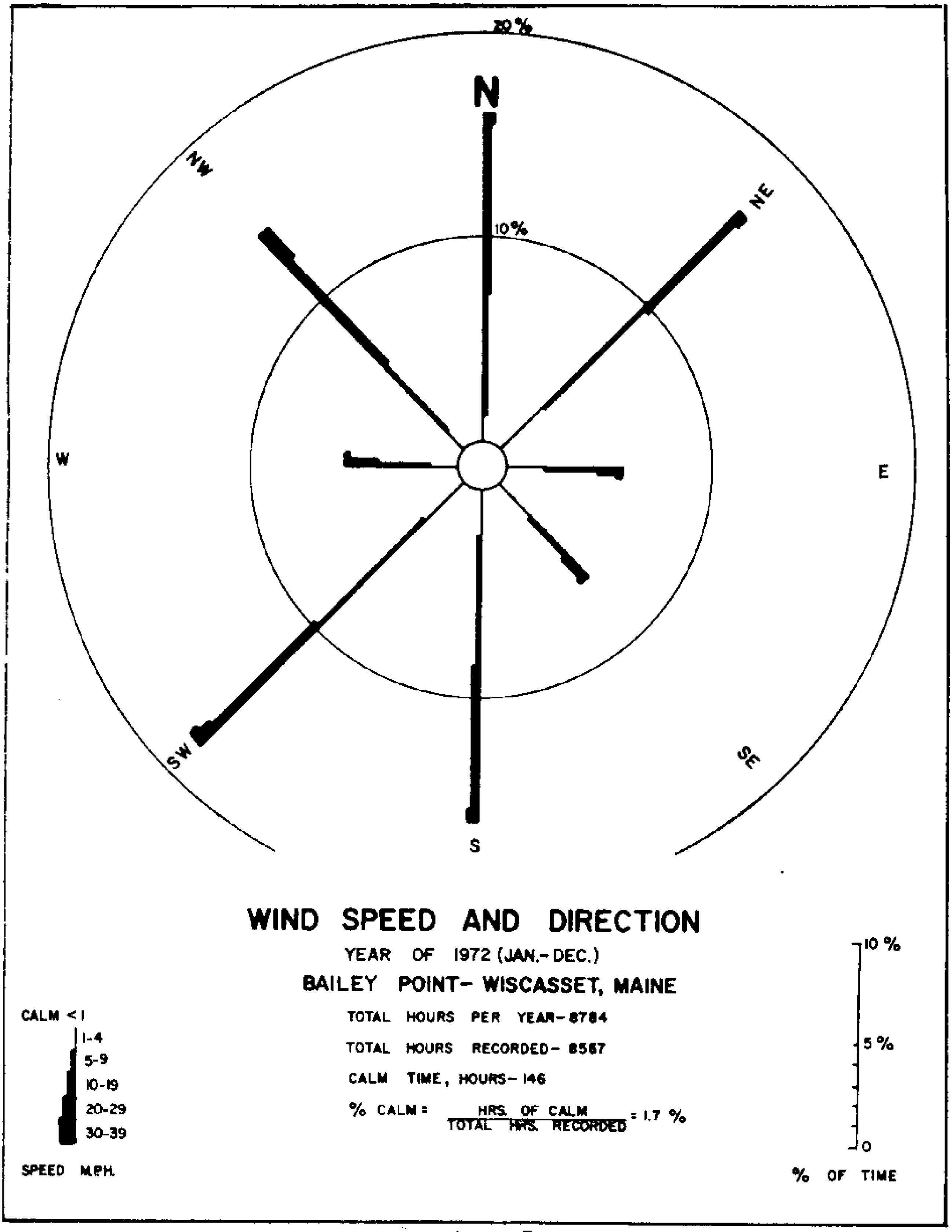

20 %
N
NW
NE
10%
W
E
SW
SE
S
WIND SPEED AND DIRECTION
YEAR OF 1972 (JAN.-DEC.)
BAILEY POINT- WISCASSET, MAINE
TOTAL HOURS PER YEAR- 8784
TOTAL HOURS RECORDED- 8567
CALM TIME, HOURS- 146
% CALM = HRS. OF CALM / TOTAL HRS. RECORDED = 1.7 %
CALM < 1
1-4
5-9
10-19
20-29
30-39
SPEED M.P.H.
10 %
5 %
0
% OF TIME

Figure 7

Although all three mechanisms can operate at the same time, one will dominate at any specific wind velocity. Creep is associated with low wind speeds, saltation with intermediate, and suspension with high velocities; the exact transition from one to another is a function of grain size and density. The volume of sand transported by these aeolian mechanisms increases with the cube of the wind velocity, making high speed winds very important despite their short duration.

Because northwest, south to southwest, and northeast storm winds are most important in their influence on beach and dune behavior and morphology in Maine, the characteristics of each are outlined below.

Northwest Winds Northwest winds are associated with large high pressure systems moving down the St. Lawrence River Valley and are strongest in the fall and winter. Because northwest winds are dry and of high velocity, they are capable of transporting large volumes of sand in a seaward direction. As a result northwest winds are important in development of backdune morphology, barrier maintenance processes, frontal dune ridge post-storm recovery processes, and the redistribution of sand within the system during non-storm conditions.

Northwest winds influence backdune morphology by removing sand as well as by importing it to that area. The winds form parabolic dunes (Figure 8) by scouring sand from devegetated backdune areas. Parabolic dunes are U-shaped, scooped out, high relief dunes which migrate downwind or in a seaward direction. Such morphology typifies backdune areas at Ogunquit, Seawall, Popham, and Reid State Park beaches. Sand is imported into the backdune area by northwest winds from tidal reentrant shores behind the barrier. This occurs during low tide and monthly neap tide cycles by removing sand deposited during high tide and monthly spring tide phases. Such an importation process may be important in allowing the barrier to maintain its sand volume in a regime of rising sea level. It is still not known whether the bulk of sand in Maine's larger dune fields was originally supplied by winds transporting sand from the beach, berm, and tidal river banks or by storm overwash deposits. Export from tidal river shores has a low annual volume, but it constitutes a persistent, frequent contribution.

Because northwest winds blow offshore, they flatten incoming waves and enhance the onshore transport of sand.

Northwest winds blow seaward, usually over frontal dune ridges where the wind flow lines are deflected by the ridge shape. The winds then blow parallel to the long axis of the ridge. Thus the winds transport sand in an easterly direction along the front of the ridge and are important in the constructional growth of the aeolian ramp. This process is particularly active when an erosional scarp exists along the frontal dune ridge, where it serves to heal the scarp quickly.

South to Southwest Winds These onshore winds occur throughout the year and are most important in equilibrium processes related to frontal dune ridge development and post-storm recovery, barrier maintenance proccesses, sand redistribution, and onshore transport of sand. In Maine, the dune fields of beaches are composed of sand originally derived from the beachface or tidal

Figure 8 Parabolic dunes formed by northwest winds blowing offshore at Seawall Beach, Phippsburg. Arrows indicate direction of sand transport and dune migration in two active dunes.

reentrant shores. South to southwest winds are responsible for the formation of local waves (seas) of low height (and low energy) which transport sand onshore and also can cause wind-induced alongshore transport of sand. It is under the prevailing influence of southwest winds that large accretionary ridge and runnel systems migrate onshore during the summer and early fall in Maine, to create wide seasonal berms. The southwest winds then move sand from the dry wave-deposited berm platform to the frontal dune ridge. Again, similar to the northwest wind, the flow lines of the wind are deflected and they become parallel to the frontal dune ridge in the area directly adjacent to it. The deflection of wind flow lines is most active when an erosional scarp exists and the sand transported toward and along the frontal dune ridge very rapidly builds the aeolian ramp.

Because most of Maine's beaches face south or southeast, these winds transport sand to the east or northeast end of the beach, thereby effecting a redistribution of sand within the system. The redistribution takes place through both alongshore wind-induced water currents and supratidal aeolian transport. The height of the frontal dune ridge is influenced to varying degrees by the southwest winds - depending on exposure and the geographic orientation of the beach, which is predetermined by wave refraction patterns.

The onshore winds along the Maine coast can also strongly influence vegetational zonation and successional stages in the dune fields because of the effects of salt spray and wind-borne nutrient supply. White Pines (Pinus strobus) along the coast, and several miles inland as well, often show a flagging effect from the south to southwest winds, indicating how frequently and constantly they blow (Figure 9).

Northeast Winds The high velocity, moist northeast winds are associated with northeast storms and create short wavelength, steep, high-energy waves which erode Maine's beaches and transport sand both offshore and alongshore (by windstress-induced littoral currents). Because of the accompanying moisture, little sand is transported by wind. Therefore northeast storm winds are most important in establishing erosional phases for Maine beaches. The frequency of these winds establishes the rate at which barrier beaches maintain the equilibrium with rising sea level and thereby the rate of shoreline recession in Maine.

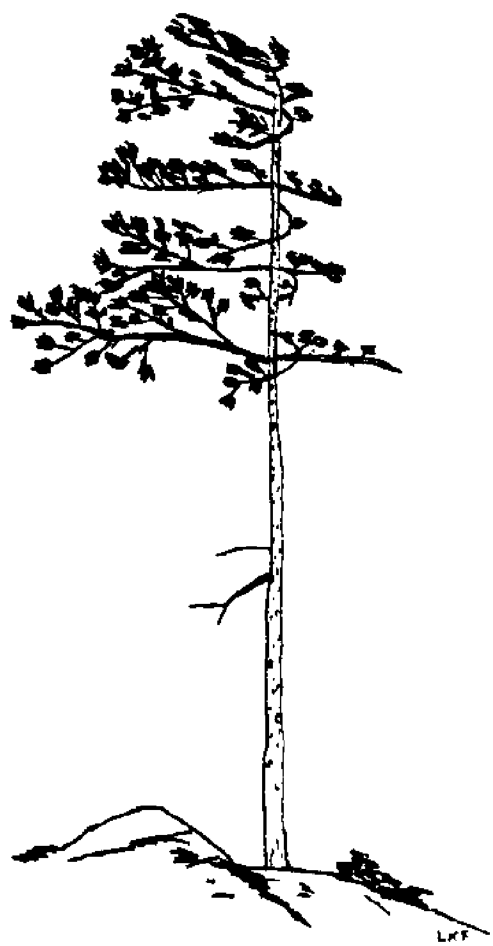


Figure 9 Wind Flagging of Pinus strobus

Tides

Tidal ranges around the world are placed into three categories: microtidal (diurnal or mixed tides with ranges <2 m), mesotidal (2 to 4 m ranges), and macrotidal (semi-diurnal tides with spring ranges >4 m). Maine's beaches occur in the upper range of mesotidal environments. The tidal range determines the vertical distance over which the swash process is active and, consequently, causes a general increase in the beach width and height. It also disperses the accretionary or erosional effects of wave action over a broader zone of the beach. The change from spring to neap range has several effects on Maine beaches; these include an overall smaller beach slope for a given sand grain size (Bagnold, 1940), the formation of multiple berms, and a greater amount of sand available for transport by wind during low stages of the tide and monthly neap cycles.

Storms

Storms are process agents which occur for only brief periods throughout annual cycles of beach processes, but they are clearly the most important control in cycles of erosion and accretion. Storms which pass near the New England coast produce high-energy, steep waves which cause erosional processes, whereas more distant storms provide energy for the formation of construction, low swell which causes accretion.

In Maine, the classical "Nor'easter" is more important than tropical cyclones or hurricanes which, although larger and having higher wind velocities, occur less frequently. The last significant hurricane to hit the Maine coast was in 1954. The characteristics of northeast storms which affect shoreline erosion are listed by Timson and Kale (1977):

1. Northeast storms reach their greatest intensity while passing New England.
2. The storms may affect Maine for twelve to thirteen hours, through more than one high tide. Slow-moving storms accompanied by surges and coincident with spring high tides cause the most erosion.
3. The storms are large and thus influence a single area for a long time even if they travel rapidly.
4. Wind speeds attain 110 km per hour and may blow over a fetch of 500-600 km, so that very large storm waves are generated.
5. Surges of up to 1.56 meters may occur. This is the amount by which the expected high water is elevated. The effect of large storm waves must be further compounded onto the surge.
6. About three to five storms can be expected every year. Most occur in the fall and winter. One or two, on the average, are accompanied by surges of 60 cm or more.

As sea level rises, storms maintain an equilibrium between the shoreline position and sea level. The rate of shoreline recession is largely controlled by the frequency and intensity of northeast storms.

Storms which achieve a new high water level relative to mean sea level of 1929 (called National Geodetic Vertical Datum, or NGVD, 1929) on NOAA tide gauges are assigned the label of *storm of record* which establishes an expected storm flooding level for the area where the tide gauge is located. In south-central Maine there have been four record storm water levels since 1944. On November 30, 1944 and on November 20, 1945, the National Ocean Survey's Portland tide gauge measured 8.7 feet above NGVD, 1929. On January 9, 1978, a level of 9.4 feet above NGVD, 1929, was recorded in Boothbay Harbor by the Maine Department of Marine Resources. On February 7, 1978, a record level of 9.6 feet above NGVD, 1929, was recorded in Portland. Boothbay measured 9.1 feet above NGVD, 1929, on February 7, 1978. These numbers are based on a conversion factor between modern mean low water (February, 1969) and NGVD, 1929. Modern mean low water is 4.28 feet below NGVD, 1929; at both Portland and Boothbay.

Storms of record cause significant frontal dune ridge erosion and wave overwash deposits either by overtopping the ridge or by transport through storm beaches in the dune ridge. The two storms of record in 1978 suggest an answer to the question of whether the bulk of sand in Maine's larger dune fields was originally supplied by aeolian transport from the beach, berm, and tidal river banks or by storm wave overwash deposits. Overwash deposits ranging from several centimeters to one meter thick and extending across the width of the backdune over large areas indicate that one storm of record every fifty to a hundred years will adequately match the volume of aeolian transport over the same period and also can maintain a rate of backdune accretion commensurate with the present rate of sea level rise. The amounts of shoreline retreat measured after each of the 1978 storms verify the importance of storm frequency in affecting erosional cycles since the storms occurred only twenty days apart. It should be kept in mind that such extreme storms do not cause a permanent shoreline and frontal dune ridge retreat. The retreat represents a short-term equilibrium event; during the next few years the frontal dune ridge may be reconstructed by natural processes slightly landward of its pre-storm location.

Most of the area descriptions later in this report are based on field checks prior to the major storms of 1978.

Currents

The types of currents which move sand in the vicinity of Maine's beaches are:

1. Tidal currents
2. River currents
3. Estuarine circulation
4. Gulf of Maine current gyre
5. Longshore currents created by:
   a. Wave approach angle
   b. Longshore differences in wave energy
   c. Wind
   d. Tide

Tidal Currents The most important tidal currents occur at the mouths of long embayments, major rivers and tidal reentrants. Tidal currents in these locations are all fast enough to move sand. Current velocities commonly reach 100 cm/sec. at the mouths of tidal reentrants draining back-barrier marshes. Bottom ebb and flood tidal currents at the mouth of the Kennebec River commonly exceed 100 cm/sec. (Francis et al., 1953). Fine to medium size sand (1/16 mm to 1/2 mm) shows some movement at a current velocity as low as 20 cm/sec. The volume of sand moved by a current increases as the cube of the current velocity, so these fast tidal currents are capable of moving large quantities of sand.

Tidal currents at the mouths of reentrants are stronger on the flood than on the ebb because the ocean has a greater head of pressure than the water-filled marsh or lagoon. This results in a net upstream flow of sand (thus the name *reentrant*). The ebb and flood currents at the mouths of reentrants form large ebb and flood deltas with complex swash bars and channels. The currents, the large volumes of sand in these delta features, and the net drift of sand toward reentrants all have profound effects on shoreline position and beachface features. Shorelines of beach spits near the reentrants are inherently very unstable.

River Currents, Estuarine Circulation, and Gulf of Maine Current Gyre The combination of river currents and estuarine circulation has a significant influence on the forms and sand budgets of beaches at the mouths of major estuaries. Net bottom flow of sand in Maine's large estuaries can be either upstream or downstream depending on season, basin geometry, and volume of fresh water discharge. The spring floods of Maine's major rivers result in a strong net downstream surface flow at their mouths. Because of the Coriolis force this surface flow turns right upon reaching the ocean and drives the Gulf of Maine current gyre counterclockwise (Bumpus and Lauzier, 1965; Graham, 1970). During spring runoff nearshore bottom flow probably behaves similarly in the narrow-mouthed, well mixed estuaries such as the Kennebec River.

Longshore Currents When waves approach a straight coastline at an oblique angle, a longshore current is created which flows parallel to the coastline landward of the breaker zone. This longshore current is responsible for the net transport of sand parallel to the shore in the littoral zone, especially on barrier beaches south of Maine where oblique wave approach is common.

Another wave-induced current system is the cell circulation system of rip currents and associated longshore currents (Figure 10). Rip currents do not result in a net transport of sand in one longshore direction. Transport of sand is convergent upon regularly spaced rip current escape channels. Cell circulation depends upon two phenomena for establishment:

1. Wave setup – the rise in water level above the still water level due to the presence of waves. It provides the head of water necessary to drive the feeder longshore currents of cell circulation. These feeder currents converge at rips.
2. Longshore variations in wave height – this condition allows the rip currents to break through the breaker zone at the positions of lower amplitude waves. The longshore variation in wave height is probably due to standing edge waves which form a regular interference pattern with incoming swell of the same period (Komar, 1976).

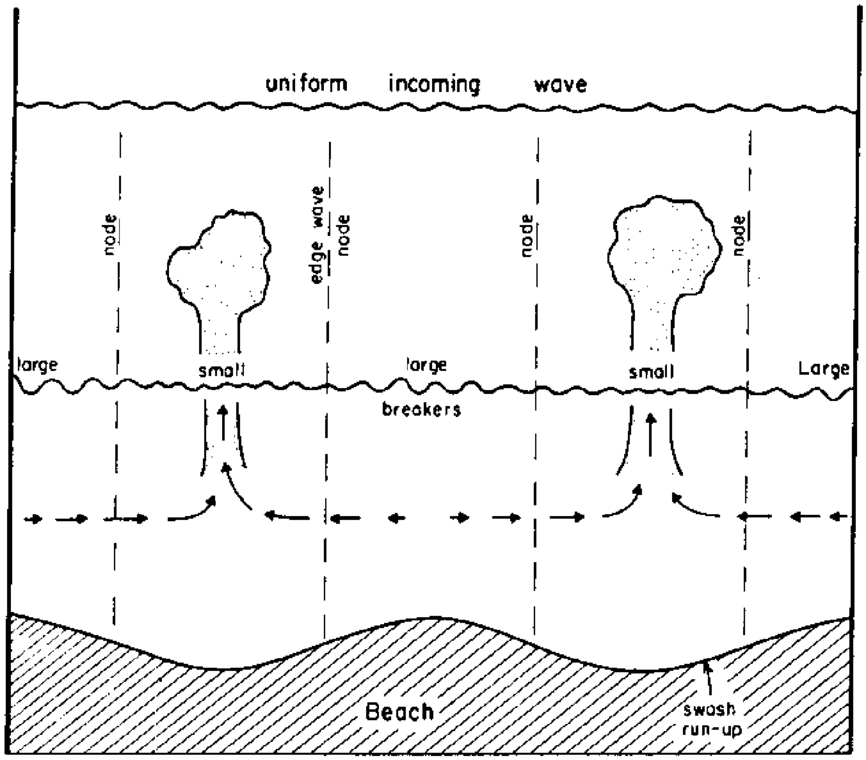


Figure 10 Littoral cell circulation (from Komar, 1976, reprinted with permission Prentice-Hall). Note the relationships between incoming wave crests, standing edge waves, beach cusps and outflowing rip heads.

Cell circulation is usually associated with ridge and runnel beachface topography. This enhances the effect of wave setup since the ridge impounds water trapped in the runnel by swash runup. Escape of water from the runnel is brought about by formation of regularly spaced rip current escape channels through the ridge at the points of lowest breakers in the breaker zone. Ridge and runnel topography with rip current escape channels is common on Maine's beaches in the summer.

Winds blowing in the longshore direction and tides draining from the beach may also contribute to longshore currents. Local winds blowing alongshore create longshore currents both by wind stress and by establishment of short-period, wind-generated local waves which approach the beach at an angle. When the tide ebbs it may enhance rip currents and feeder longshore currents because water is trapped in runnels and can not escape over the associated ridge when the tide is out. The only escape is to flow alongshore until a rip current escape channel is reached. The effect may be enhanced also by waves which break over the ridge and spill their water into the runnel behind (landward of) it. Large swash bars at Popham Beach on either side of Fox Island tombolo have strong longshore currents in the runnels behind them due to tide ebbing from the upper beachface and broad tombolo. This tide-induced longshore current has no rip channels to escape through and seems to be partly responsible for maintenance of the large ridge and runnel systems near Fox Island year-round. There is a noticeable scour of sand on the upstream side of two seawalls which project into the runnel on the east side of Fox Island Tombolo.

Tide-induced longshore currents are also associated with ebb-tidal delta channels of Maine's baymouth barrier reentrants. As these channels meander, the ebb currents move large volumes of sand from intertidal cut banks and deposit these large volumes elsewhere on the ebb-tidal delta. This process was responsible for a major recession of the shoreline at Popham Beach State Park in 1952. In contrast tidal channel meandering was also the agent of major accretion at Popham Beach State Park after 1940 and at Western Beach (Scarborough).

Glacial Events and Sediment Characteristics

Since almost all sediments which make up sandy beaches and dunes in Maine have been derived from some sort of glacial deposit, it is instructive to review the glacial events which gave rise to the present distribution of sediments (Koons, 1976). The last glacial advance reached the edge of the continental shelf southeast of the Gulf of Maine about 28,000 years ago and remained there until at least 18,000 years ago. Maine is more an area of glacial scour than deposition. The advancing ice scoured unconsolidated sediment and bedrock from terrestrial Maine and the Gulf of Maine and carried much of this sediment to the continental shelf. Only bare bedrock or thin till deposits were left beneath the ice mass.

Most deposition which did take place was during glacial recession. There are no large end moraines or drumlins in Maine and few large proglacial deltas. When the ice margin retreated, the ocean which butted against it reached a line about 70 km inland from the present coastline. This occurred about 12,800 years ago. As the ice receded, eskers and other ice-contact stratified drift were deposited by a combination of ablation and meltwater stream transport beneath, within, and alongside ice masses. The combination of depressed land and rising sea level meant that these deposits were left under the ocean where extensive, well sorted sandy glacial outwash plains could not form. The upper Kennebec River Valley was filled with a series of sand deltas which retreated northward along with the ice-ocean boundary. When incursion of the ocean could no longer keep pace with retreat of the ice margin over central and western Maine, large glacial outwash deposits could form. The large meltwater streams followed the same valleys as the glacial ice streams, e.g. the glacial Androscoggin, Kennebec and Penobscot valleys. They carried vast quantities of sand from inland glaciers and spread the sand in thick outwash plains via braided streams.

South of Portland the outwash deposits and receding delta deposits of the early post-glacial Androscoggin were carried to the present coastline. In early post-glacial times the Androscoggin probably drained south through Sebago Lake. Outwash and delta sands reached the present coastline in southern Maine because the western mountains are closer to the present coast there. The large fan of early post-glacial Androscoggin sediments has supplied much of the sand which makes up Maine's southern beaches.

Early post-glacial Kennebec River outwash and receding delta deposits extend only as far downstream as Waterville and are generally confined to the narrower Kennebec glacial valley.

Relative sea level began dropping after the maximum incursion 12,800 years ago, due to crustal rebound and the marginal bulge effect of ice still depressing northern Canada. This increased the erosional capacity of our major rivers and enabled them to transport interior sand deposits (outwash plains, deltas, till and ice-contact stratified drift) downstream to form river-mouth sand flats.

Relative sea level rose again after 8,500 years ago due to subsidence of the marginal bulge and continued worldwide rise in true sea level. As relative sea level rise slowed, river-mouth sand deposits could accumulate in one place rather than retreating upstream with the river mouth. When the rise rate slowed sufficiently, Maine's baymouth barriers (derived from outwash and delta plain sands and from river-borne sands of the Kennebec and Saco rivers) were established. Our preliminary studies suggest that some barriers were established at least 6,800 years ago. Vertical accretion of vegetated dune fields supplied by windblown sand from the berm could keep pace with the slowly rising sea level even as upland areas behind the dune fields were flooded and became marshes. In mid-coastal Maine this process has continued for the last 6,000 to 7,000 years as sea level has risen at a long-term rate of 4 to 6/cm century (Myers, 1964; Snow, 1972; Nelson, unpublished data). The relative rise rate for the present century is considerably higher, 23 cm/century, and will be discussed in the next section.

The sorting of minerals and sand on a beach can be an indication of the distance to sand source or the nature of the sand source. Fine, well sorted, quartz-rich beach sands are further from their source and have been in a beach or river transport environment longer than poorly sorted schist fragment and feldspar-rich sands. Beach sand derived from local bedrock is poorly sorted and associated with boulders, cobbles, pebbles and gravel of the local rock type. Beaches derived from nearby tills or ice-contact stratified drift may be well-sorted on accretionary surfaces but are often associated with boulders, cobbles, pebbles and gravel of many rock types. These are usually visible on the lower beach face as a lag surface. Carbonate sand beaches are easily distinguished since they are found in coves exposed to heavy storm waves and face clean rocky bottoms.

Relative Rise of Sea Level

Changes in sea level, both absolute and relative, are well established in the geologic record. Absolute changes refer to long-term variations of the volume of water contained in the hydrosphere and are controlled, primarily, by climatic changes which cause fluctuations in the polar ice cap volumes. Relative changes in sea level refer to the net effect of absolute sea level change, local changes in the height of the sea surface and vertical movement of coastal land masses. Causes for the relative changes span the spectrum between short- and long-term factors. Relative changes of sea level for specific locations in the United States have been monitored since the 19th century by tide gauges. This effort has produced historical records of relative sea level change and affords the opportunity to discern various factors responsible for the observed changes. The tide gauge record which shows mean sea level for Portland, Maine is reproduced in

Figure 11. The factors which influence sea level as recorded on a tide gauge are: 1) water temperature, 2) salinity variations, 3) local atmospheric pressure variations, 4) prevailing wind directions, 5) tidal variations (spring and neap, perigee-apogee, etc.), 6) tidal range amplification and decrease, 7) river runoff, 8) glacio-tectonic factors*, 9) polar ice cap melting and freezing*, 10) water loading of continental shelf*.

The factors noted with an asterisk are the most important in a consideration of effect on Maine's beach systems since these factors are the only ones which can produce persistent, long-term sea level changes. It is obvious from Figure 11 that such a trend is present; that is, there is a historical relative rise of sea level in Maine at a rate of 23 cm/century (Hicks and Crosby, 1974). The factors primarily responsible for such a change are those marked with an asterisk. The polar ice caps are still melting from the last glaciation (King, 1972), as described in the previous section, and therefore are contributing to the world-wide volume of sea water. From various investigations, the present world-wide, or eustatic, rise of sea level is thought to be approximately 10 to 15 cm/century (Hicks, 1972; Fairbridge and Krebs, 1962). This leaves 8 to 13 cm/century of rise which must be explained by crustal subsidence caused by: 1) relaxation of deformation resulting from glacial retreat factors (or glacio-tectonic), and 2) water loading of the continental shelf due to the eustatic rise of sea level after the most recent retreat of the North American ice sheet. Separation of these factors and assigning values to their effects awaits further investigation. To complicate the issue, the relative rise rate for Eastport, Maine, from tide gauge data is 36 cm/century (Hicks and Crosby, 1972) and releveling data also indicate a current subsidence rate of 60 cm/century (Meade, 1971) near the Maine-Canadian border.

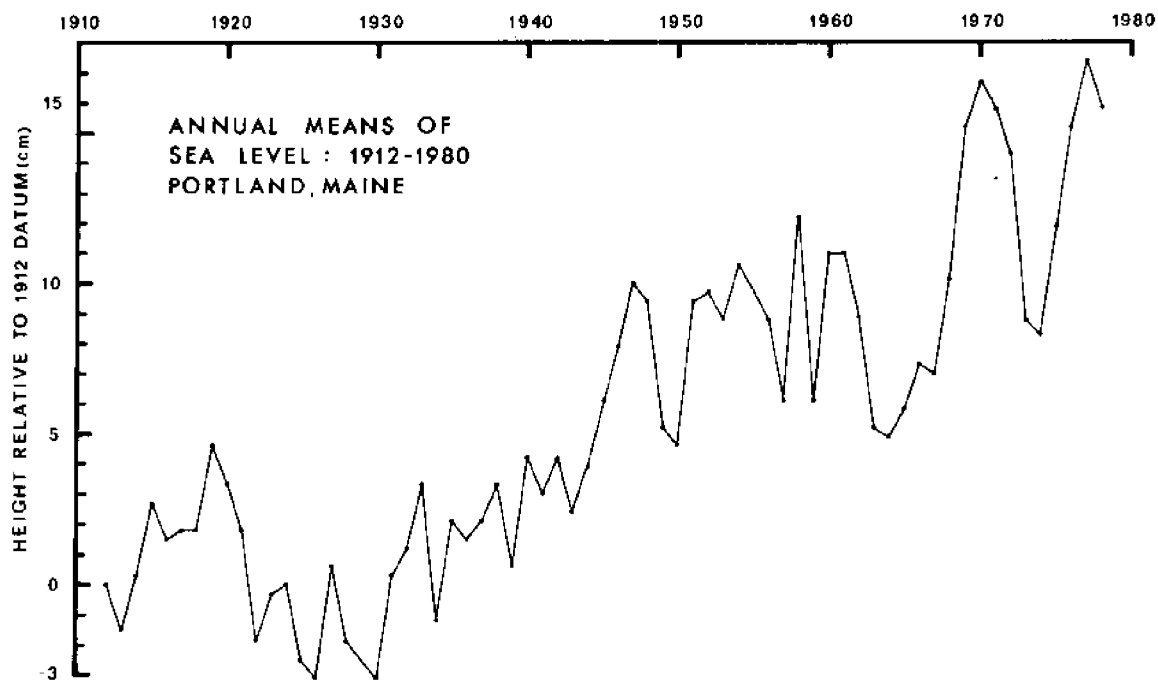


Figure 11 Portland tide gauge record of annual mean sea level (after Hicks and Crosby, 1974).

Another perspective on sea level rise in Maine is provided by the record of the Holocene transgression along the coast. This refers to the rise of sea level in postglacial time. This record is obtained from radiocarbon dating (C^{14}) of barrier beaches. Such dates give us the time of formation of the barrier beaches as well as a record of the rise of sea level between the time of formation and the present. Radiocarbon dating of basal peats from marshes at Popham Beach indicate that barrier beaches probably formed in Maine around 6,000 radiocarbon years ago (Nelson, in preparation) and that since that time relative sea level has risen at the rate of 6 cm/century. It is important to realize that the rate of 6 cm/century is a long-term average and the actual rise rate may have been as high as that indicated by tide gauge records for brief intervals during the last 6,000 years. Alternatively, there is a very real difference between the Holocene and modern rates of sea level rise, and the present rate is four times more rapid than the Holocene rate.

Whatever the ultimate causes or rates of relative sea level rise in Maine are, the mere existence of this process agent has profound implications for the dynamic equilibrium of beach systems in Maine. Long-term transgression of the sea over beach areas has several significant impacts on beaches:

1. Erosion of the beach (and shoreline retreat) is the rule rather than the exception.
2. Rates of process-response cycles become important in determining whether beaches can maintain an equilibrium with the rise of sea level.
3. The beachface, frontal dune ridge, and backdune area must migrate upward and landward over marsh and upland (Figure 12).
4. Unless new sand deposits are being inundated and becoming involved in the sediment selection process of waves and current, the sand supply to beaches from submerged offshore deposits of glacial outwash sediments are diminishing. Most of Maine's beaches are now sediment-starved which implies either a diminishing supply or such relatively rapid retreat that the present supply rate is inadequate.

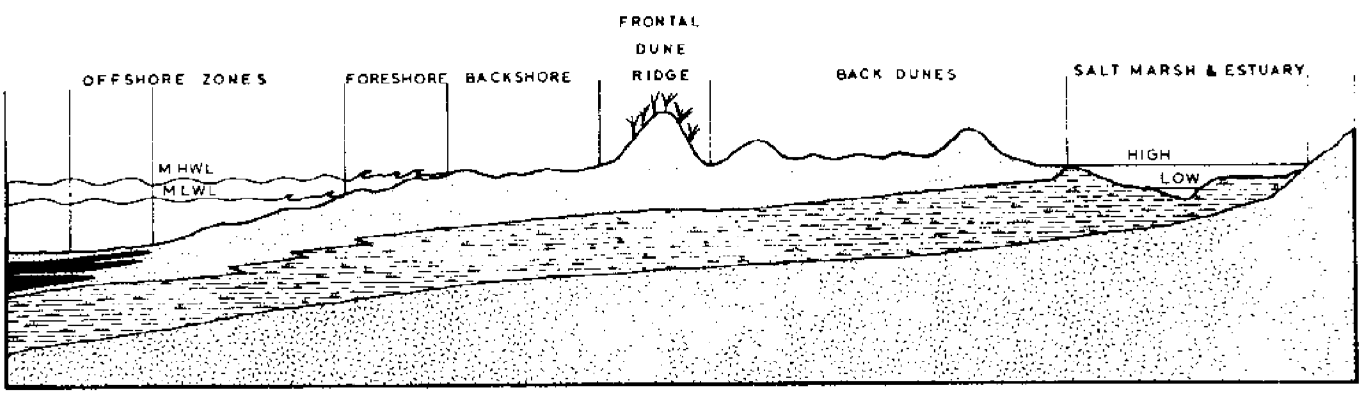


Figure 12 Schematic view of transgressive facies of a barrier beach or barrier spit in a regime of slowly rising sea level.

5. Interferences by man which prevent landward migration of beaches and their associated dune fields could have dire consequences for the future integrity of Maine's beach systems.

6. Instability of beaches is an inherent and necessary characteristic.

The inescapable conclusion is that a thorough understanding of the behavior of beaches and dunes in response to a rising sea level regime is essential to any short- or long-term management plan for Maine's beach systems.

Response Forms and Geomorphic Features of Maine's Beaches

This section discusses the response side of the dynamic equilibrium model for Maine's beach systems. The response forms and features result from various combinations of the process agents. The numerous response forms which occur in Maine can be organized into four main groups: 1) Major Wave Depositional Forms (Beach Types in Plan View), 2) Ephemeral and Minor Wave Depositional-Erosional Forms, 3) Major Wind Depositional Forms, 4) Sedimentary Structures.

Major Wave Depositional Forms (Beach Types in Plan View)

The geologic fabric of bedrock units in Maine exerts a pronounced control on its coast, whose highly irregular and deeply embayed outline contrasts sharply with the rest of the coastline south of New Hampshire. The limited sand supply and coastal geometry make Maine's highly evolved beach forms unique along the East Coast. The following classification treats Maine's diverse, swash-aligned accumulation forms (Figure 13) and has been modified after King's (1972) system.

Fringing Beaches are sandy strandlines, usually without an extensive dune field (Figure 13). Although they usually abut upland bedrock, soil, or unconsolidated sedimentary units with no intermediate lagoon, there may be a swale with a fresh water bog sandwiched between the upland and the beach ridge. Fringing beaches are common on Maine's islands and mainland.

The great irregularity of the embayments and islands results in many *fringing pocket beaches* which are crescent shaped in outline, parallel to the breaking waves, and usually small.

The greater refraction of waves at the heads of bays (Figure 3) causes *bayhead pocket beaches* to be more curved than *midbay pocket beaches*. Most pocket beaches are seaward facing, but a well-formed north-facing pocket beach exists on Seven Hundred Acre Island near Islesboro.

True *fringing delta beaches* do not exist in Maine, though Hunnewell Point at Popham may be a combination of a fringing delta and cuspate foreland.

Large fringing beaches are found only in southern Maine, e.g., parts of Old Orchard, Fortunes Rocks, and Crescent Beaches.

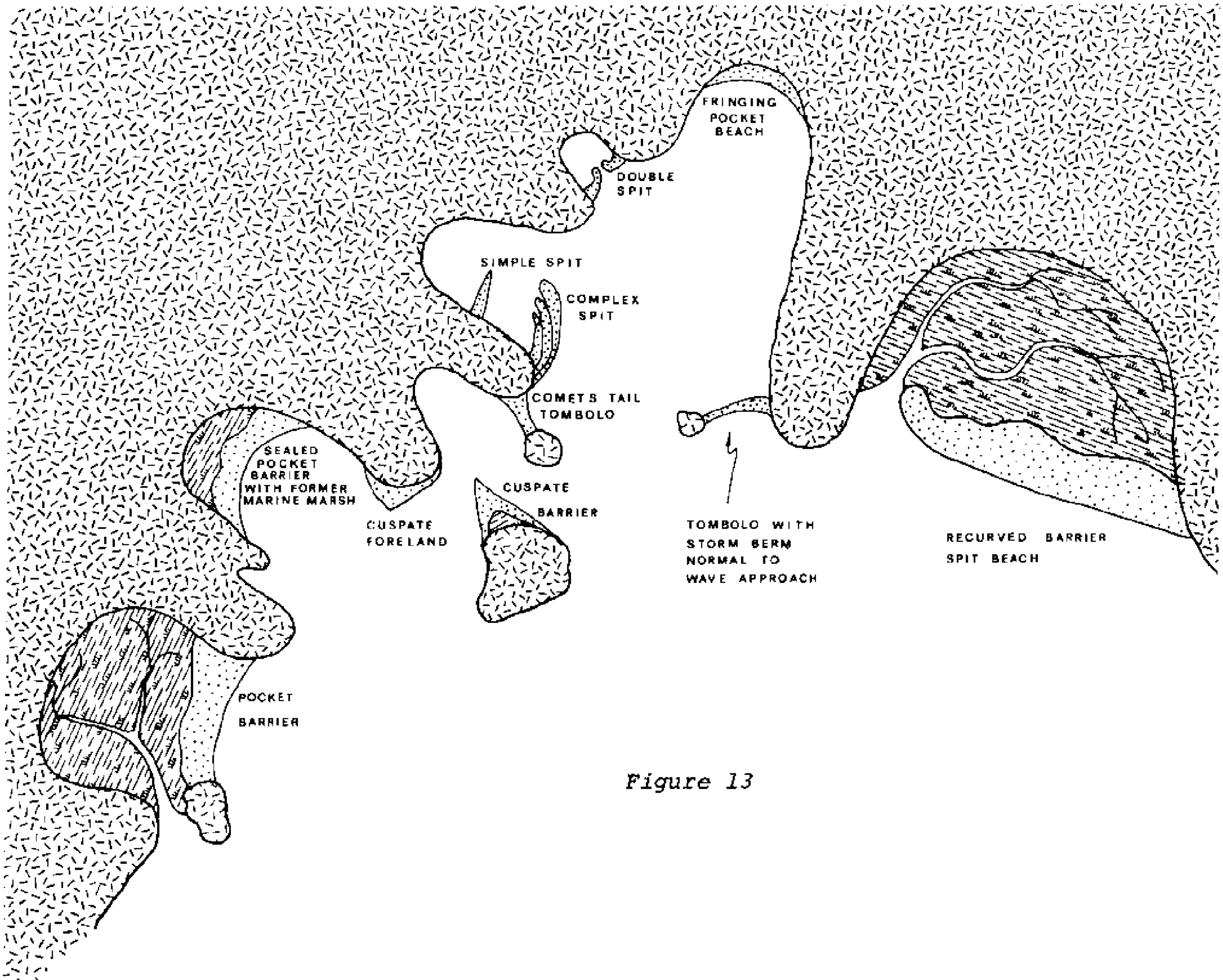


Figure 13

Barrier Beaches in this outline (Figure 13) are defined as being attached to the mainland at both ends, with or without an inlet, but containing a present or former marine lagoon. Reid State Park's mile beach is a barrier of this type. There are many *pocket barriers,* such as Sea Point (Kittery) and Pemaquid. Roque Bluffs is a pocket barrier enclosing a former marine lagoon, now fresh. Such completely sealed marine lagoons are uncommon on sandy beaches and usually require a source of gravel or shingle which is thrown up into a storm berm capable of blocking the tidal exchange inlet.

Cuspate barriers form where refracted wave trains meet in the lee of an island or where two currents come together. Cuspate barriers enclose a present or former marine lagoon.

Tombolos are attached at both ends to islands or at one end to an island and the other end to the mainland (Figure 13). They may be exposed at all tides or only at low tide. They are of two types:

1. Comet's tail – forming in the lee of an island, e.g., Fox Island and Wood Island at Popham.

2. Normal to wave approach – forming on the side of an island. This type requires a shingle or boulder storm berm along its full length to block the flow of sand toward the lee of the island. They are normal to long swell but parallel to storm waves. An excellent example exists near Presley Cove, northwest Deer Isle, but it has little or no sand accumulation.

Cuspate Forelands are formed in the same manner as cuspate barriers but do not enclose a present or former lagoon (Figure 13). They may enclose a fresh water bog as on the northern tip of Louds Island in Muscongus Bay. Cuspate forelands may form at both ends or one end of an intertidal tombolo. The best examples are at Popham Beach in the lee of Fox and Wood Islands.

Spits are attached to the mainland at one end and are free at the other end (Figure 13). Included in this category are the well known *barrier spit beaches* of southwestern Maine. This type of beach occurs at the mouths of bays and is associated with large salt marshes which have pervaded the tidal lagoon, e.g. Ogunquit and Seawall Beaches. These baymouth barrier-spit and salt marsh complexes are long, usually straight, with extensive dune fields and salt marshes which are connected to the open sea through an inlet between the spit end and the headland. The presence of the spit indicates some littoral drift toward the spit end, though this is minimal relative to the barrier islands of the Atlantic coast south of New Hampshire. The alongshore drift may occur primarily during northeast storms when considerable volumes of sand are placed into suspension and carried toward the spit by wind-induced littoral currents. Maine's barrier spit beaches have a considerable sand supply and extensive offshore sand flats with parallel contours which straighten long swells before they hit the beach.

Spits are of various types and sizes. All have potentially unstable tips which are favored nesting sites for the least tern and piping plover. They are further subdivided on the basis of form as follows:

1. Simple spits – are straight from the headland to the end. Aerial photographs show that this type of spit is uncommon, but one formed at Popham in the mouth of the Morse River in the 1940's.

2. Recurved spits – are the most common and are usually associated with the barrier spit beaches. These indicate wave refraction into the inlet, as they are usually curved inward toward the marsh.

3. Complex spits – form as a result of pulsed increases in sand supply or shifts in the course of a tidal inlet. Maine's best example formed in the mouth of the Morse River at Popham between 1950 and 1972. A possible relict complex spit is located in a small salt marsh near Fort Popham.

4. Double spits – face one another and border an inlet. Examples exist at the mouth of the Morse River at Popham, at the mouth of Wells Harbor (before jetty construction), and at Laudholm and Crescent Surf Beaches.

Ephemeral and Minor Wave Depositional and Erosional Forms

Maine's beaches exhibit ephemeral and minor forms and features which are controlled by erosional or depositional cycles. These features are of value for scientific and educational purposes, recreation, bird nesting habitat, and habitat for certain fishes and invertebrates. They are by nature ephemeral, but some features rely on a sand supply which can be influenced by human activities. The features present depend on whether the beach is experiencing erosional or accumulation activity and are best presented in profile view.

Erosion Beach Profile Type and Features These are illustrated in Figure 14 and include:

1. Frontal dune scarp – a cliff cut into the vegetated dunes by winter storm waves; it may persist through the summer.
2. Concave upward beachface – eroded beach profiles are flat to slightly concave upward from the low water mark to the frontal dune scarp. There are no sharp slope breaks. This is the typical winter or post-storm profile.
3. Low-tide terrace with a coarse lag surface – this low tide terrace may be found on accreting profiles as well, where it is a remnant of the surface of maximum erosion. A lag surface is a layer of coarse, heavy material which forms a pavement at the level of maximum erosion when finer material is removed by winter storm waves. The lag surface is usually overlain by *graded bedding*. A graded bed is a layer of increasingly fine grain sizes from bottom to top and indicates deposition during a phase of decreasing wave energy.
4. Offshore bars – sand removed from the intertidal beachface, berm, and frontal dune ridge, is deposited in one or more bars just seaward of the breaker line. This sand is the major source for onshore transport when summer accretion resumes. Winter offshore bars are larger than summer offshore bars because of greater storm frequency.
5. Storm wave breaches of the frontal dune ridge – these cuts occur primarily on those parts of the beaches where the frontal ridge is low because of wave erosion or where pedestrian traffic has created a pathway through the frontal dune ridge. Whether they are natural or man-induced, breaches are one means by which large sand volumes are transported into backdune areas. This is an important process in barrier beach maintenance in a regime of rising sea level.

Constructional Beach Profile Type and Features These are (see figure 14):

1. Broad berm platform – this is the major feature of a constructional profile. The platform accumulates at the level of spring tide high water mark and extends seaward from the toe of the frontal dune ridge for as much as 40 meters (seasonal berm at Ogunquit). Perennially accreting berms may be even wider. The berm is the major recreational area of the beach; it pro-

vides dry sand at high tide for sunbathers. It also supplies enough sand to act as a buffer against erosion of dunes when fall and winter northeast storms strike.

2. Berm crest – this is the edge of the berm. It often has *cusps* which are regularly spaced ridges with scalloped embayments between; relief of cusps depends upon wave energy and grain size. The cause of cusps is not clearly understood, but may be related to standing edge waves and interference patterns (Russell and McIntire, 1965; Williams, 1973).

3. Steep berm slope – the foreset face of the berm forms the steep upper beachface common on accreting profiles. The base of the foreset face joins the low tide terrace, which may have a lag surface covered with a thin veneer of fine sand or may have a ridge and runnel system on it. The steep berm slope is often coarser grained than other accretionary slopes, especially on beaches with a wide range of grain sizes in their total grain size population. Coarse sand can be accumulated on a steeper slope because it is highly porous and allows wave swash to settle down through it rather than sweep seaward as a backwash. This holds true particularly on the seaward face of a berm or ridge where backwash is an important agent. On the non-accumulation surfaces, lag surfaces or low tide terraces, the relationship also does not hold true on the flat or slightly landward dipping top of the berm where backwash is ineffective in removing sand seaward.

4. Ridge and runnel system on low tide terraces – the ridge and runnel system (Figure 14) forms in summer and migrates up the beach until the runnel is filled and the ridge welds onto the berm. This is one of the main mechanisms for transport of sand from the offshore bars to the berm and steep berm slope.

5. Break-point bars – in Maine these are small bars with a trough in front of them which is visible at low tide beneath the breakers of low swell. They may migrate up the beach with each tide to supply, over time, a significant amount of sand to the steep berm slope.

<u>Constructional Features Formed During Storms</u> These are:

1. Coarse grained (cobble or boulder) storm ridge or berm – these are formed when cobbles and boulders are thrown up by storm waves above normal high water. A rocky storm berm underlies the sandy wind-deposited frontal dune ridge at sections of Scarborough Beach, at Laudholm Beach, and at Roque Bluffs Beach. Some sandy beaches have exposed rocky storm berms or ridges year round, e.g. Irish Cove Beach at Swans Island and Sand Cove Beach at Marshall Island.

2. Sandy overwash fans or lobes – sand may be transported through frontal dune ridge breaches, over low-lying frontal dune ridges, or over rocky storm berms into the back dune. This is a mechanism for barrier maintenance, so these are actually accretionary features though they occur during erosive storms. Good examples occur at Reid State Park (relict overwash through a breach) and Irish Cove Beach at Swans Island (overwash over a rocky storm berm). Garnet-rich overwash fans are frequent above the eroding scarp at sections of Popham Beach State Park.

3. Offshore intertidal and subtidal bars – these features are formed during the winter season or storms by offshore directed sand transport between the break-point and the swash limit. Since, seaward of the break-point, sand is transported landward (even during storms), sand accumulates near the break-point to form bars. The best examples are found at Popham where some of the bars are 1 km offshore. Others are in the nearshore breaker zone of Hunnewell.

4. Ebb-tidal delta and flood-tidal delta features – these are found at the inlets of baymouth barrier spits. Some have been dredged and jettied to prevent shoaling of harbor entrances, e.g. Wells Harbor and Saco Bay.

Major Wind Depositional Forms

Aeolian processes are important to Maine's beach systems because these consist predominantly of fine to medium size quartz rich sand. All aeolian accumulation forms are fragile and susceptible to damage by fire, foot traffic, and other human activities which disturb dune vegetation or affect natural sand transport by wind.

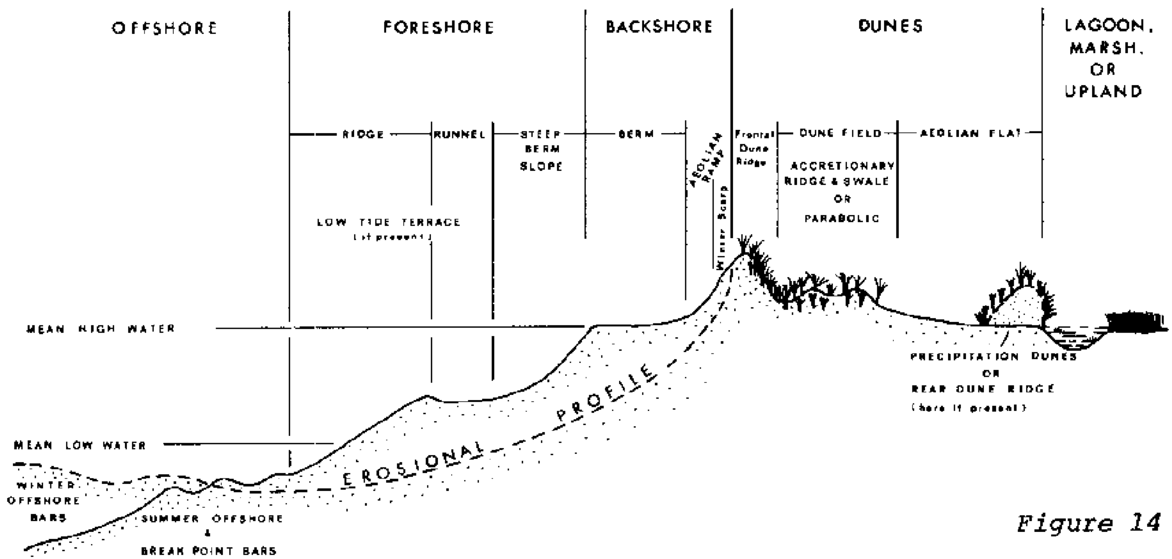


Figure 14

<u>Frontal Dune Ridge</u> On Maine's beach systems, this feature (Figure 14) is pre-eminent, not only in morphology but in function. Frontal dune ridges are the result of a constructional upgrowth process which is the natural interaction between sand blown landward from the berm and beach vegetation, primarily American Beach Grass (<u>Ammophila breviligulata</u>). The windblown sand is trapped by the beach grass, which, when partially covered or even buried up to 1 meter, is stimulated to grow vigorously both horizontally, by rhizome extension, and vertically upward through the sand. The repetition of trapping and subsequent growth combines to build a ridge limited in dimensions only by sand grain size, wind transport velocity, and storm frequency. The functional roles of frontal dune ridges are as: a) buffers against storm erosion of backdune and marsh areas, and b) storage compartments of sand for vital beachface replenishment during storms (Figure 14).

Frontal dune ridges are present on almost all undeveloped beach sections, but may be much reduced in height and width because of recent erosional periods. Frontal dune ridges are conspicuously absent on beaches with seawalls and intense, unrestricted recreational use.

Aeolian Ramp This feature, although widespread in occurrence, was first described by Barry Timson and constitutes a contribution from Maine to the nomenclature of beach geomorphology. The term *aeolian ramp* refers to a feature which is secondary in origin and develops only after erosion has formed a frontal dune scarp (Figure 14). Subsequent to such an erosion event, sand is transported from the berm or backbone field to form a wedge of sand which fills and heals the frontal dune scarp. The initial sand accumulation occurs very quickly since sand is blown both toward the frontal dune ridge and along the ridge by winds from the western half of the compass. Once the scarp is healed, the ramp provides an easier transport route for sand into the vegetated dunes.

Aeolian Flats This term refers to sparsely vegetated sandy flats behind the dune ridge. Aeolian flats are formed by a number of mechanisms:

1. Overwash through blowouts or storm breaches.
2. Sand blown from back-barrier tidal rivers by offshore (northwest) winds.
3. Extension of the back-slope of the frontal dune ridge landward by moderate onshore winds acting over decades or centuries.
4. Smoothing of high flank and lee slopes of parabolic dunes originally formed by strong northwest winds.

Rear Dune Ridges These are found at the border between the dune field and tidal river of some of the barrier spit beaches. They are not extensive features because the sand supply from the tidal river is limited. Examples are found at Seawall Beach, Popham Beach, and Ogunquit Beach.

Accretionary Ridge and Swale Topography Relict berms and relict frontal dune ridges alternate in parallel fashion. They indicate rapid accretion which is not necessarily pulsed. Examples occur at many of Maine's beaches and provide evidence that accretion can occur between major erosional episodes.

Parabolic Dunes and Slacks These are scooped out depressions in vegetated dune sand carved, in Maine, by strong offshore winds. The excavation migrates downwind and sand is deposited on the sides and leading apex. The whole form resembles a parabola when viewed from the air (Figure 8). Most of Maine's parabolic dunes and slacks are now stabilized by vegetation. In earlier decades they formed and migrated due to fires, grazing and foot traffic. The best examples of active and stabilized parabolic dunes and their associated vegetation are found at Seawall Beach (Phippsburg). Examples are also found at Popham, Reid, Ogunquit, and Maine Beach (Cape Elizabeth). Overlapping parabolic dunes are responsible for the ultimate rolling topography of large backdune areas. Vegetated embryo dunes sometimes form in the mouths of parabolic dune slacks, preventing further migration of the apex by stabilizing and cutting off the wind fetch. Good examples exist at

Ogunquit. Maine's parabolic dunes are unusual because they are formed by offshore rather than onshore winds and are only rarely obliterated by washover events during major storms.

Onshore Oriented Blowouts These are parabolic dunes which are formed as breaches in the frontal dune ridge. They are uncommon in Maine and may only form when assisted by foot traffic erosion, fires, storm breaching, or redirection of winds by local bedrock topography. Examples of stabilized, high relief, onshore oriented blowouts exist at Hunnewell Beach (Popham, Phippsburg).

Precipitation Dunes High dunes which form at the upland forest edge on the back of the aeolian flat. They are formed by onshore winds which are weakened and drop their sand when they reach the forest barrier (Figure 14). The best examples are at Main Beach (Cape Elizabeth) and Bailey Beach (Phippsburg).

Sedimentary Structures

There are many ephemeral surface features which are of educational value on beaches. These structures are produced by currents, wave swash and wind. Many of these structures are used by geologists in identifying ancient deposits because they are diagnostic of the beach environment. When these structures are preserved beneath Maine's beaches and dunes, they become valuable management information. Barrier maintenance mechanisms, shoreline change histories, past sea level rise rates and past sand supply changes all leave their record in the strata. Below are listed some sedimentary structures, their mode of formation and geological significance.

Swash marks Wave swash sweeping up the beach carries sand and debris at its leading edge. This is deposited at the swash limit as a thin wavy line of coarser sand with a concentration of black mica flakes, shell hash, seaweed and other debris. The falling tide leaves a series of bifurcating swash marks because the trace from any one wave is truncated by a later swash. Swash marks form only on the upper part of the beachface above the water table runout which obliterates them on the lower beachface. Swash marks are widely spaced on gentle beach slopes and closely spaced on steep beach slopes.

The presence of swash marks in an ancient deposit is a sure sign of wave deposition. Swash marks tend to be convex shoreward, and this is a criterion for determining the orientation of ancient beaches.

Ripple marks There are two basic types of submarine ripple marks, *oscillatory* and *current ripples*. Oscillatory ripples are usually symmetrical and current ripple marks are assymmetrical, with their steep faces downcurrent. Oscillatory ripples are formed by standing waves or oscillations. They are common offshore beyond the breaker zone down to the depth of the wave base which, in some parts of the world, may be as deep as 200 meters during intense winter storms (Komar, 1976).

There are intermediate ripple forms where both oscillations and the current are in the same compass direction. In runnels, oscillation and current ripples form at right angles to one another because the wave oscillatory movement and longshore current act perpendicular to one another. This results in the formation of ladder-back ripples. Ladder-back ripples can also be found on the exposed tidal flats associated with ebb and flood tidal deltas, tombolos and perennially accreting beachfaces.

On the foreshore (upper intertidal beachface) backwash ripples (Tanner, 1965) may develop on fine sand beaches when the backwash of the waves running for a long distance down the gently sloping beach sets up a turbulent motion. These ripples have about a 50 cm wave length, are straight, parallel to the beach, and have a very low amplitude. They are easily recognized as black and white bands because of the separation of quartz and dark colored mica minerals.

Strong currents and large waves may create *current megaripples* of various types. While small ripples are almost always less than 39 cm in length, megaripples vary from 0.6 to 30 meters in length (Komar, 1976). In sand with a grain size greater than 0.6 mm, no small ripples are produced and only megaripples are formed. In Maine megaripples are associated mostly with tidal currents near major rivers and reentrants. They indicate movement of large volumes of sand. *Lunate* or *scour megaripples* (spoon shaped scours with planar crests) are common at the mouth of the Kennebec on the Wood Island tombolo and in tidal reentrants elsewhere. They may have a relief greater than 50 cm.

<u>Groundwater Rill Marks</u> Another beachface surface sedimentary structure is the groundwater rill mark. These are formed by water seeping from the lower beachface at low tide. They are small erosional dendritic gully systems which join to form a small braided stream at their seaward (downslope) end. They are good indicators of orientation of ancient beaches and of lower beachface deposition.

<u>Rhomboid Marks</u> These are diamond shaped (or rhomboid) patterns developed on the beachface by wave backwash. They may be produced by either currents deflected by objects or irregularities in the sand surface, or by the interference of waves which propagate downcurrent from such objects and irregularities.

<u>Current Crescents and V-swash Marks</u> Current crescents and V-swash marks are formed when a shell or pebble deflects a current or backwash. Deflection of the current by the object causes a scour crescent on the upstream side. The V-mark forms downstream in the shadow of the object. When they are preserved in the sediments, these features are indicators of ancient beach orientation.

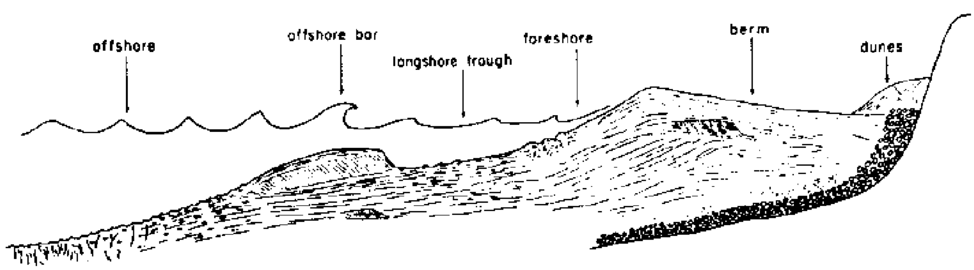
<u>Beach laminations</u> Most useful of all sedimentary structures are beach laminations. Trenches cut perpendicular to the beach show laminations which tell the story of changing beachface profiles, erosional limits, and the amount of perennial and seasonal accretion. Beachface and dune sands can be distinguished in the trenches on the basis of heavy mineral layers, bedding-plane slopes, type and orientation of cross stratification, type and relationships of preserved sedimentary structures, and bioturbation structures. Distinction between wave and wind deposited sand is very valuable for management purposes since it tells the story of long-term shoreline changes.

Wind deposited sedimentary structures Wind deposited sedimentary structures include wind ripple marks in wind deposits. Dune fields dominated by parabolic dunes have a high incidence of steeply dipping beds (dipping away from the dominant wind direction), and wind deposited sand may be distinguished from wave deposited sand on that basis. Aeolian flats behind the frontal dune ridge or on top of relict berms are not so easily distinguished from wave deposited sand because their laminae resemble those of the berm surface. Heavy minerals, such as garnet sands, are left in layers beneath accreted beaches and are relicts of the erosional position of the shoreline before accretion. They may also mark the interface between wave deposited and wind deposited sand in sediment cores through the backdune.

A schematic cross-sectioanl view of a beach with characteristic laminations and cross laminations, heavy mineral layer, and coarse lag surface at the past erosional limit is presented in Figure 15.

The value of sedimentary structures is that all of the above features and their many variants are keys to the nature of present and past depositional environments. The Holocene history of Maine's beaches can be interpreted from preserved sedimentary structures beneath the existing beachface, dunes, and marsh.

Figure 15



METHODS OF LOCATING SANDY BEACHES AND DUNES

Maine's sandy beaches and dunes have been located by an extensive inventory effort:

1. Three years of field studies, coastal overflights and aerial photo studies — these were part of an ongoing investigation of Maine's beaches by L.K. Fink, Jr. and R.J. Foster of the Department of Oceanography, University of Maine. Although this study identified forty-four principal Maine beaches with a cumulative length of 60 km, many small sandy beaches were excluded.
2. A high altitude overflight in June, 1977 — this flight produced a photo atlas for sandy beaches north of Reid State Park.
3. Inspection of the vertical aerial photo collection of the Maine Bureau of Geology and 112 Marine Geology Maps by Barry S. Timson, Bureau of Geology.

From the 112 Marine Geology Maps a complete list (Table II) of all sandy beaches in Maine was made*. From this list twenty-nine beaches were selected for field checking based on certain geological and botanical criteria. Twenty-seven beaches

* It should be noted that many of the beaches identified as sandy on the Marine Geology Maps are likely to be boulder, cobble, gravel or mixed sand and gravel beaches due to resolution limitations of vertical air photos available for Maine.

were visited in June, July and August of 1977 and a total of thirty-seven proposed critical areas were delineated. The two beaches not visited are on coastal islands (Andrews Beach, Long Island, Casco Bay and a north-facing pocket beach on Seven Hundred Acre Island, Penobscot Bay). These two areas are recommended for future field checking. The twenty-seven beaches visited represent approximately 20 km of beach length. This compares with a total of 121 km of sandy beach based on the Marine Geology Maps and 60 km based on the list by Fink and Foster.

Table II

SAND BEACHES OF MAINE
(in alphabetical order of topographic map name)

Beach Location or Name	Length	Topographic Map Name*	Town
Beach along northernmost tip of Bailey Island between N tip and causeway entrance	204 m	Bailey Island	Harpswell
Westward facing beach on northern peninsula of Bailey Island	192 m	Bailey Island	Harpswell
NE beach directly opposite offshore ledges	96 m	Bailey Island	Harpswell
Bean Island southern-side beach	670 m	Bar Harbor NW 1/4	Sorrento
N facing beach on peninsula sandwiched between Bankers & Birch Hbrs. on Schoodic	380 m	Bar Harbor NE 1/4	Gouldsboro
Beach on arrowhead-shaped tip of land between town of Birch Harbor and Prospect Pt.	360 m	Bar Harbor NE 1/4	Gouldsboro
Beach at head landward of Sand Cove	160 m	Bar Harbor NE 1/4	Gouldsboro
Beach facing SW onto Sand Cove	170 m	Bar Harbor NE 1/4	Gouldsboro
Beach facing SE onto Sand Cove	170 m	Bar Harbor NE 1/4	Gouldsboro
Beach surrounding SE tip of Hog Island	340 m	Bar Harbor NE 1/4	Gouldsboro
Thomas Bay beach	290 m	Bath NE 1/4	Brunswick
Fortunes Rocks Beach	2950 m	Biddeford Pool NE 1/4	Biddeford

* All names of topographic maps refer to the 7½ minute series. Where 7½ minute maps do not exist, quadrants of 15 minute maps are identified.

Table II (Continued)

Beach Location or Name	Length	Topographic Map Name	Town
Fortunes Rocks Beach	790 m	Biddeford NW 1/4	Biddeford
Horseshoe Cove Beach SW-facing	290 m	Biddeford NW 1/4	Biddeford
Horseshoe Cove Beach NE-facing	480 m	Biddeford NW 1/4	Biddeford
New Barn Cove Beach	340 m	Biddeford NW 1/4	Biddeford
Goose Rocks Beach	3600 m	Biddeford NW 1/4	Kennebunk- port
Ferry Beach	4500 m	Biddeford NW 1/4	Saco
Beginning of Old Orchard Beach - Camp Ellis	410 m	Biddeford	Old Orchard Beach
Hills Beach	530 m	Biddeford	Old Orchard Beach
Trafton Island Beaches facing NW, just south of northernmost peninsula, eastern	120 m	Boise Bubert	Harrington
Trafton Island Beaches facing NW, just south of northernmost peninsula, western	160 m	Boise Bubert	Harrington
NE side of Dyer Island, head of Watts Cove	180 m	Boise Bubert	Harrington
Reid half mile beach	650 m	Boothbay Harbor	Georgetown
Reid mile beach	1160 m	Boothbay Harbor	Georgetown
Beach midway down E side of Capitol Island	260 m	Boothbay Harbor	Southport
Beach on northern tip of Squirrel Island	190 m	Boothbay Harbor	Southport
Pemaquid Restoration Beach	528 m	Bristol	Bristol
Sandy Pt. beach, Stockton Springs	1370 m	Bucksport SE 1/4	Stockton Springs
Beach on W side of Beauchamp Pt.	220 m	Camden	Rockport
East side beach of Deadman Pt.	530 m	Camden	Rockport
Northernmost beach at mouth of Camden Harbor, slightly SW of Curtin Island	240 m	Camden	Camden
Beach on SW side of Camden Harbor	310 m	Camden	Camden

Table II (Continued)

Beach Location or Name	Length	Topographic Map Name	Town
Beach at head of Camden Harbor, between Eaton Point and Northwest Point	430 m	Camden	Camden
Broad Cove Beach	190 m	Cape Elizabeth	Cape Elizabeth
V-shaped beach, following a point jutting into Richmond Island Harbor	790 m	Cape Elizabeth	Cape Elizabeth
Crescent Beach	1560 m	Cape Elizabeth	Cape Elizabeth
Marshall Cove Beach	110 m	Cape Elizabeth	Cape Elizabeth
John Cove Beach	110 m	Cape Elizabeth	Cape Elizabeth
Beach on NW part of Wilson Point	820 m	Castine NE 1/4	Castine
Morse Cove Beach, western side	310 m	Castine NE 1/4	Castine
Beach on NW side of Cape Jellison	790 m	Castine NE 1/4	Stockton Springs
Beach on NE side of Cape Jellison	770 m	Castine NE 1/4	Stockton Springs
Philbrook Cove Beach	700 m	Castine NE 1/4	Islesboro
Beach on SW bend of Cape Rosier	130 m	Castine SE 1/4	Brooksville
Northwesternmost tip of Pond Island	140 m	Castine SE 1/4	Deer Isle
Beach most westerly of the two between the Cross Island mainland and Northwest Head	160 m	Cross Island	Cutler
More eastern of the two beaches between upper Northwest Head and Cross Island's main body	360 m	Cross Island	Cutler
Westernmost of the two beaches separated by Grassy Pt. (Cross Island)	700 m	Cross Island	Cutler
Easternmost of the two beaches separated by Grassy Pt. (Cross Island)	580 m	Cross Island	Cutler
Beach on the western side of Northeast Harbor's mouth (Cross Island)	170 m	Cross Island	Cutler
Northernmost sandy beach of Island Peninsula containing Coast Guard station	140 m	Cross Island	Cutler

Table II (Continued)

Beach Location or Name	Length	Topographic Map Name	Town
NE-facing beach on Cross Island Coast Guard peninsula	360 m	Cross Island	Cutler
Westerly beach at head of Machias Bay (before Rte. 191 crosses estuaries)	220 m	Cutler	Cutler
Machias Bay head, eastern beach	620 m	Cutler	Cutler
Largest sandy beach midway up southern side of Little River	120 m	Cutler	Cutler
Beach on southern tip of peninsula framing northern side of Southeast Harbor	340 m	Deer Isle NW 1/4	Deer Isle
Beach north of Duck Harbor, Isle Au Haut	160 m	Deer Isle SW 1/4	Isle Au Haut
Beach on NW of Isle Au Haut, facing west to Flake Island	130 m	Deer Isle SW 1/4	Isle Au Haut
SE point of Merchant Island, V-shaped beach	530 m	Deer Isle SW 1/4	Isle Au Haut
Beach on southern half of Merchant Island, facing NE	340 m	Deer Isle SW 1/4	Isle Au Haut
Miller Pt. beaches, South	310 m	Devils Head	Calais
Miller Pt. beaches, North	170 m	Devils Head	Calais
Circumferential beach on Green Island	460 m	Drisko Island	Addison
SE-facing beach on eastern peninsula of Littlejohn Island	310 m	Freeport	Yarmouth
Peter Cove Beach	240 m	Freeport	Harpswell
Stover Point Beach	360 m	Freeport	Harpswell
Sizable beach on southwest quadrant of Cranberry Island	620 m	Friendship	Friendship
Beach S of hook on western side of Cranberry Island	170 m	Friendship	Friendship
Beach just N of southeast point of Friendship Island	140 m	Friendship	Friendship
Beach at head of Southern Cove of Morse Island	160 m	Friendship	Friendship

Table II (Continued)

Beach Location or Name	Length	Topographic Map Name	Town
NE directed beach on northern end of Morse Island	310 m	Friendship	Friendship
Southern tip of Hungry Island beach	310 m	Friendship	Friendship
A series of four beaches along Deep Cove between Hooper and Howard Points	910 m	Friendship	St. George
Martin Point, eastside beach	220 m	Friendship	Friendship
Beach at head of cove between Sproul Point and Fickett Point	460 m	Harrington	Milbridge
Eastward-facing beach at northern end of Pleasant Island	220 m	Hewett Island	Matinicus Island Plantation
One of two connecting beaches, easterly toward Bar Island	140 m	Hewett Island	Matinicus Island Plantation
One of two connecting beaches, westerly toward Graffam Island	180 m	Hewett Island	Matinicus Island Plantation
Beach at head of Hewett Island's mid-section cove	110 m	Hewett Island	Matinicus Island Plantation
Beach along SE point of Hewett Island	100 m	Hewett Island	Matinicus Island Plantation
Eastern beach of spit joining north and south parts of Pleasant Island	120 m	Hewett Island	Matinicus Island Plantation
Popplestone Beach	500 m	Jonesport	Jonesport
Sandy River Beach	790 m	Jonesport	Jonesport
Roque Island's Shorey Cove (NW directed) beach	1130 m	Jonesport	Jonesport
Roque Island Harbor beach	2060 m	Jonesport	Jonesport
Series of three beaches at the head of Roque Island's Pratt Cove	770 m	Jonesport	Jonesport
Squire Point surrounding beaches	2350 m	Jonesport	Jonesport

Table II (Continued)

Beach Location or Name	Length	Topographic Map Name	Town
Series of beaches on eastern side of Great Head, Roque Island	940 m	Jonesport	Jonesport
Western side of Nepp Point beach	170 m	Jonesport	Roque Bluffs
Cleaves Cove beach	30 m	Kennebunkport SW 1/4	Kennebunkport
Kennebunk Beach, west of Oak's Neck	820 m	Kennebunkport SW 1/4	Kennebunkport
Goochs Beach	1300 m	Kennebunkport SW 1/4	Kennebunkport
Crescent Beach	625 m	Kittery	Kittery
Seapoint Beach	550 m	Kittery	Kittery
Carrying Place Cove beach	620 m	Lubec	Lubec
Series of three beaches on northern side of causeway to West Quoddy Head	720 m	Lubec	Lubec
Beach stretching from West Quoddy Head northward to Woodward Point	1630 m	Lubec	Lubec
NW beach at head of Holmes Bay	410 m	Machias Bay	Whiting
Halls Cove beach	220 m	Matinicus	Matinicus Isle
Southeastern Hadley Cove beach	360 m	Mt. Desert NE 1/4	Bar Harbor
Series of beaches between Salisbury Cove and Sand Point (Mt. Desert)	1080 m	Mt. Desert NE 1/4	Bar Harbor
Lamoine Beach	2740 m	Mt. Desert NE 1/4	Lamoine
Accreted-spit-beach in northern Raccoon Cove	410 m	Mt. Desert NE 1/4	Lamoine
Greening Island SW quad. beach	340 m	Mt. Desert SE 1/4	Lamoine
Part of Old Orchard Beach	1850 m	Old Orchard Beach SW 1/4	Old Orchard Beach
Two beaches (series) at Sebasticodegan Island mouth of cove, NE of East Cundy Point	290 m	Orrs Island	Harpswell
Pemaquid Beach	430 m	Pemaquid Point	Bristol
Fish Point beach	100 m	Pemaquid Point	Bristol

Table II (Continued)

Beach Location or Name	Length	Topographic Map Name	Town
Beach NW around the point from Hunnewell, at mouth of Atkins Bay	310 m	Phippsburg	Phippsburg
Kennebec River shore Popham Beach upper half	430 m	Phippsburg	Phippsburg
Popham Village beach (N-facing)	360 m	Phippsburg	Georgetown
Southern tip of Indian Point beach	100 m	Phippsburg	Georgetown
Eastern side of Indian Point beach	240 m	Phippsburg	Georgetown
Beach on NE side of land neck connecting Indian Point peninsula to Georgetown Island	170 m	Phippsburg	Georgetown
Series of four beaches framing Sagadahoc Bay's western arm	790 m	Phippsburg	Georgetown
Beach at head of Sagadahoc Bay (before branching into estuaries)	140 m	Phippsburg	Georgetown
Ship Cove beach	140 m	Portland East	Cape Elizabeth
South Maiden Cove beach	100 m	Portland East	Cape Elizabeth
Willard Beach, Sononton Cove	650 m	Portland East	South Portland
Southernmost beach of two following the eastern Promenade, extends to Fish Point	360 m	Portland East	Portland
Northerly beach along Eastern Promenade	580 m	Portland East	Portland
Series of beaches curving around SW end of Long Island	1220 m	Portland East	Portland
Andrews Beach	620 m	Portland East	Portland
Beach following SE corner of Little Chebeague Island	910 m	Portland East	Portland
Beach at head of Chandler Cove	290 m	Portland East	Cumberland
Western side of Great Chebeague Island beach (series of beaches)	1990 m	Portland East	Cumberland
Northern Sturdivant Island beach	430 m	Portland East	Cumberland
Continuation of Old Orchard Beach, including Surfside, Grand Beach, Pine Point	4970 m	Prouts Neck	Old Orchard Beach — Scarborough

Table II (Continued)

Beach Location or Name	Length	Topographic Map Name	Town
Western Beach and Back Shore	1700 m	Prouts Neck	Scarborough
Scarborough Beach	2060 m	Prouts Neck	Scarborough
Higgins Beach	910 m	Prouts Neck	Scarborough
Series of beachs on the eastern (lower) shore of the Spurwink River	700 m	Prouts Neck	Cape Elizabeth
Series of three beaches (one to continue) along southeastern-most point of Cape Elizabeth	770 m	Prouts Neck	Cape Elizabeth
Sandy beach between Loring and Frost Coves (closer to Loring)	500 m	Robbinston	Perry
Loring Cove beach	460 m	Robbinston	Perry
Gin Cove beaches (two)	530 m	Robbinston	Perry
Beach north of Lewis Cove's mouth	170 m	Robbinston	Perry
Lucia Beach	220 m	Rockland	Owls Head
Beach east of Lucia Beach	310 m	Rockland	Owls Head
Beach south of Crockett Point	460 m	Rockland	Matinicus Island Plantation
Beach NW of Ginn Pt., head of cove	500 m	Rockland	Matinicus Island Plantation
Crescent Beach	1100 m	Rockland	Owls Head
Holiday Beach (two-part)	650 m	Rockland	Owls Head
Owls Head Harbor/Bay beaches	740 m	Rockland	Owls Head
Beaches between Shag rock and Coast Guard Light	380 m	Rockland	Owls Head
E-facing beach at foot of Ingraham Hill, S-arm of Rockland Harbor	310 m	Rockland	Owls Head
Northeast side of Shoppee Point beach	580 m	Roque Bluffs SW 1/4	Roque Bluffs
Great Cove SE side beach	720 m	Roque Bluffs SW 1/4	Roque Bluffs
Roque Bluffs beach	910 m	Roque Bluffs SW 1/4	Roque Bluffs
Mack Cove beach	260 m	Roque Bluffs SW 1/4	Roque Bluffs

Table II (Continued)

Beach Location or Name	Length	Topographic Map Name	Town
Johnson Cove beach	430 m	Roque Bluffs SW 1/4	Roque Bluffs
Grays Beach	240 m	Roque Bluffs SW 1/4	Roque Bluffs
Small beach N of Grays Beach	170 m	Roque Bluffs SW 1/4	Roque Bluffs
Starboard Cove beach	890 m	Roque Bluffs SW 1/4	Machiasport
Sand Bèach, Tohman Cove	340 m	Small Point	Phippsburg
SW Hermit Island beaches (two)	290 m	Small Point	Phippsburg
Head Beach	360 m	Small Point	Phippsburg
Head Cove beach	100 m	Small Point	Phippsburg
Bald Head Cove beaches (two)	340 m	Small Point	Phippsburg
Seal Cove's upper NE corner beach	100 m	Small Point	Phippsburg
Southernmost of the two beaches	260 m	Small Point	Phippsburg
Northerly of the two beaches on Cape Small's eastern side	650 m	Small Point	Phippsburg
Small Point beach (Seawall)	2450 m	Small Point	Phippsburg
Popham Beach (State Park and Hunnewell incl.)	4030 m	Small Point	Phippsburg
Beach between Coleman Cove and Johnson Cove area, Great Chebeague Island	790 m	South Harpswell	Cumberland
North Waldo Point beach, Great Chebeague Island	500 m	South Harpswell	Cumberland
Upper quadrant of Placentia Island, eastern side beach	410 m	Swans Island NE 1/4	Long Island
NE tip of Placentia Island	360 m	Swans Island NE 1/4	Long Island
Beach on western side of peninsula containing Hockamock Head	170 m	Swans Island NW 1/4	Swans Island
Head of Toothacher Cove beach	30 m	Swans Island NW 1/4	Swans Island
Series of Toothacher Cove beaches	310 m	Swans Island NW 1/4	Swans Island
Beach in cove NW of Irish Point	260 m	Swans Island NW 1/4	Swans Island
Lairey's Island, NE tip beach	190 m	Vinalhaven SW 1/4	Vinalhaven
Western Roberts Harbor beach	120 m	Vinalhaven SE 1/4	Vinalhaven

Table II (Continued)

Beach Location or Name	Length	Topographic Map Name	Town
SE-directed beach (towards Green Island) NE of Arey Cove (two)	190 m	Vinalhaven SE 1/4	Vinalhaven
Beach on southernmost of 700 Acre Island	1130 m	Vinalhaven NW 1/4	Islesboro
Ogunquit and Moody Beaches	4370 m	Wells	Wells
Crescent Surf	1010 m	Wells	Wells.
Crescent Surf, Parsons Beach	1220 m	Wells	Wells
Drakes Island and Laudholm Beach	940 m	Wells	Wells
Wells Beach	4000 m	Wells	Wells
Beach along Bailey's Mistake	960 m	West Lubec	Lubec
Whiting Bay, southwestern shore beach	460 m	Whiting	Trescott
Wildwood Park beach	820 m	Yarmouth	Yarmouth
Lane's Island, Yarmouth	530 m	Yarmouth	Yarmouth
Long Beach and two smaller northern beaches	2180 m	York Beach	York
Short Sands beach	410 m	York Beach	York
N Wadleighs Head beach	530 m	York Beach	York
Beach east of York Harbor, between harbor and E Point	430 m	York Harbor	York
Cow Beach	240 m	York Harbor	York

GENERAL CONSIDERATIONS IN DEVELOPING CRITERIA FOR INCLUSION IN THE LIST OF SIGNIFICANT COASTAL SANDY BEACHES AND DUNES

1. Only geological and botanical criteria are considered.

2. Beach and dune areas must be in a natural state. There must be few or no houses, roads, parking lots, earthworks or planted vegetation. More than fifty percent of Maine's limited coastal dune areas are heavily developed. Often just the presence of an undeveloped sandy beach or dune area is a criterion for significance because natural beach and dune forms and dune vegetation have been obliterated on most of Maine's coastal beaches. Examples of such drastic human impact on the limited dune

and dune plant acreage of Maine are found at Long Sands, Ogunquit, Moody, Wells, Drakes Island, Kennebunk, Goose Rocks, Fortunes Rocks, Hills, Saco, Old Orchard and Higgins Beaches.

Beachfaces backed by extensive seawalls are not included as significant natural areas. Such seawalls alter the shape of the beachface profile by preventing normal responses to storm waves, constructional waves and wind.

3. The geographic distribution of Maine's beaches is a factor in considering their significance. Beaches of different areas owe their existence to various origins. In areas where beaches are rare, the presence of even a small beach or dune area is significant.

4. Scientific and educational values are strong criteria for significance. A beach or dune area may have excellent examples of certain geomorphic features or geological processes. The same is true for botanical features and processes.

GEOLOGICAL CRITERIA FOR SIGNIFICANCE

Two criteria were developed to determine the significance of a beach or dune area. One criterion was whether an area constituted a good example of the various geomorphic types and features. The second criterion was to include those examples which, either through their dune and beachface morphology or actual response behavior, manifest the interaction between the physical elements of beach systems and various process agents. These criteria produced two lists, those geomorphic types and features which occur in Maine and those various process agents which leave their imprint on Maine beaches and dunes. These lists are as follows:

I. Beach and Dune Geomorphic Types and Features

- A. Beach Types According to the Plan View
  - 1. Fringing Beaches
    - a. Fringing pocket
    - b. Fringing delta
    - c. Fringing strandplain
    - d. Large fringing beaches
  - 2. Barrier Beaches
    - a. Pocket barrier
    - b. Former marine lagoon or marsh
    - c. Cuspate barrier
  - 3. Tombolos
    - a. Comet's tail
    - b. Normal to wave approach
  - 4. Cuspate Foreland
  - 5. Spits
    - a. Simple
    - b. Recurved - includes baymouth barrier-spit beaches
    - c. Complex
    - d. Double

B. Beach Features According to Profile Types
   1. Erosional Profile Features
      a. Frontal dune scarp (FDS)
      b. Concave upward beachface
      c. Low-tide terrace
      d. Lag deposit
      e. Heavy mineral fractionation
      f. Graded bedding
      g. Ancient peat and tree stump exposures
      h. Offshore subtidal bar
   2. Accretionary Profile Features
      a. Broad berm
      b. Berm crest (may have cusps)
      c. Steep berm foreslope
      d. Ridge and runnel system
      e. Break-point bar
      f. Graded bedding
      g. Characteristic sorting

C. Storm-Related Beach and Dune Features
   1. Cobble or boulder storm ridge, berm, and cusps
   2. Overwash fans
   3. Frontal dune ridge breaches
   4. Large-scale intertidal bar

D. Wind Related Beach and Dune Depositional Forms
   1. Frontal dune ridge (FDR)
   2. Aeolian ramp
   3. Aeolian flats
   4. Rear dune ridge
   5. Accretionary ridge and swale topography
   6. Parabolic dunes and slacks
   7. Onshore oriented blowouts
   8. Precipitation dunes

E. Sedimentary Structural Features
   1. Swash marks
   2. Ripple marks — many types
   3. Groundwater rill marks
   4. Rhomboid marks
   5. Current crescents and V-swash marks
   6. Beach laminations
   7. Wind formed cross-bedding

F. Ebb Tidal Delta and Flood Tidal Delta Features

II. Process Agents Which Leave an Imprint on Beach and Dune Morphology and Which Influence Beach and Dune Response Behavior.

A. Relative Sea Level Rise
   1. Maine's beaches provide evidence of sea level rise rates, knowledge of which is essential for coastal zone planning.
   2. Transgressive facies (barrier and salt marsh formation), erosion and shoreline recession are results of sea level rise.

B. Prevailing and Dominant Winds
   1. Northeast storm winds – onshore directed
   2. South to southwest winds – onshore directed
   3. Northwest winds – offshore directed

C. Waves
   1. Storm waves
   2. Constructional swell

D. Northeast Storms and Hurricanes

E. Currents
   1. Tidal
   2. River
   3. Estuarine circulation
   4. Gulf of Maine gyre
   5. Longshore

F. Sand Supply
   1. Influence of distribution of glacial outwash sediments on beach type and occurrence
   2. River sand sources
   3. Onshore transport of submerged glacial deposits
   4. Wave erosion of upland glacial deposits
   5. Biogenic carbonate sources
   6. Wave erosion of local bedrock

BOTANICAL CRITERIA FOR SIGNIFICANCE

All undisturbed coastal sand dune and berm plant habitats in Maine are significant simply because of their limited extent. Of the approximately 6,400 km of coastline in Maine, the three beaches with large undisturbed dune fields (Popham, Reid and Seawall Beaches) represent only 8.7 km of coastline length. Almost two-thirds of Maine's original major dune fields are now heavily developed or altered by foot traffic erosion and dike construction. These beaches with major dune fields which are now disturbed represent 18 km of coastline (Ogunquit, Moody, Wells, and Old Orchard Beaches). Smaller scale dune and berm plant habitats which remain undisturbed are also significant because such habitats are rare in Maine. This is particularly true north of Reid State Park where there are no large dune fields or broad accretive berms. The attractiveness of beach and dune areas for potentially damaging recreational and development uses, coupled with the fact that these usage pressures are concentrated on only one or two percent of Maine's coastline, make identification and description of Maine's natural dune and berm plant habitats urgent.

Additional criteria for the determination of significant coastal sandy dune and berm plant habitats are based on the following botanical features.

A. Landward to seaward zonation caused by salt spray effects, soil nutrient changes, and sand burial or deflation rates.

B. Mosaic floristic patterns in stabilized parabolic dune fields. The distribution and abundance of plants in these habitats are functions of depth to water table, successional age, sand burial and deflation rates, and age since last aeolian activity.

C. Dune field successional stages subsequent to accretion, fire, foot traffic, grazing, cutting or aeolian activity.

D. Vegetation development in overwashes and breaches.

E. Vegetation patterns on perennially accreting berms and spits.

F. Good stands of species with limited acreage in the state; e.g. American Beach Grass, Beach Heather, Wormwood, Jointwood.

G. Disjunct populations, especially stands of American Beach Grass north of Reid State Park. These are of value for scientific study of speciation as well as geographic trends in environmentally and genetically controlled traits.

H. Geographic trends in abundance or ecotype which are of scientific value. To discern and study these trends it is necessary to maintain a continuum of natural habitats along the geographic axis in question.

The presence or abundance of many species have been found to decrease from south to north, but these trends are already difficult to study in detail because of excessive development on most of Maine's southern beaches (Figure 16).

The known and possible range limits of coastal sandy dune and berm plants in Maine are:

1. Wormwood — Artemisia caudata The northern coastal range limit for the Atlantic coast of North America is at Crescent Beach State Park (Figure 17).
2. Beach Heather — Hudsonia tomentosa The northern coastal limit within Maine is Reid State Park. The plant reappears on Canadian beaches (Figure 18).
3. Earthstar Puffball — Geaster hygrometricus This dune mushroom reaches its northern coastal range limit at either Seawall or Popham. It may be found in sandy waste areas further north and in Canada (Figure 19).
4. Seaside Spurge — Euphorbia polygonifolia This is a common berm annual on Massachusetts beaches but has been found on only two small Maine beaches. There was one collection in 1880 on Wells Beach. Maine specimens are much smaller than Massachusetts specimens. The plant has also been collected in non-dune habitats in Maine (Figure 20).

GENERAL INFORMATION ON COASTAL SANDY DUNE PLANT SPECIES AND ASSOCIATIONS

Coastal sandy dune plants of New England have peculiar physiologic, morphologic, and life cycle features which enable them to survive and compete in a highly stressed environment. The major stresses which these plants endure are: 1) salt spray,

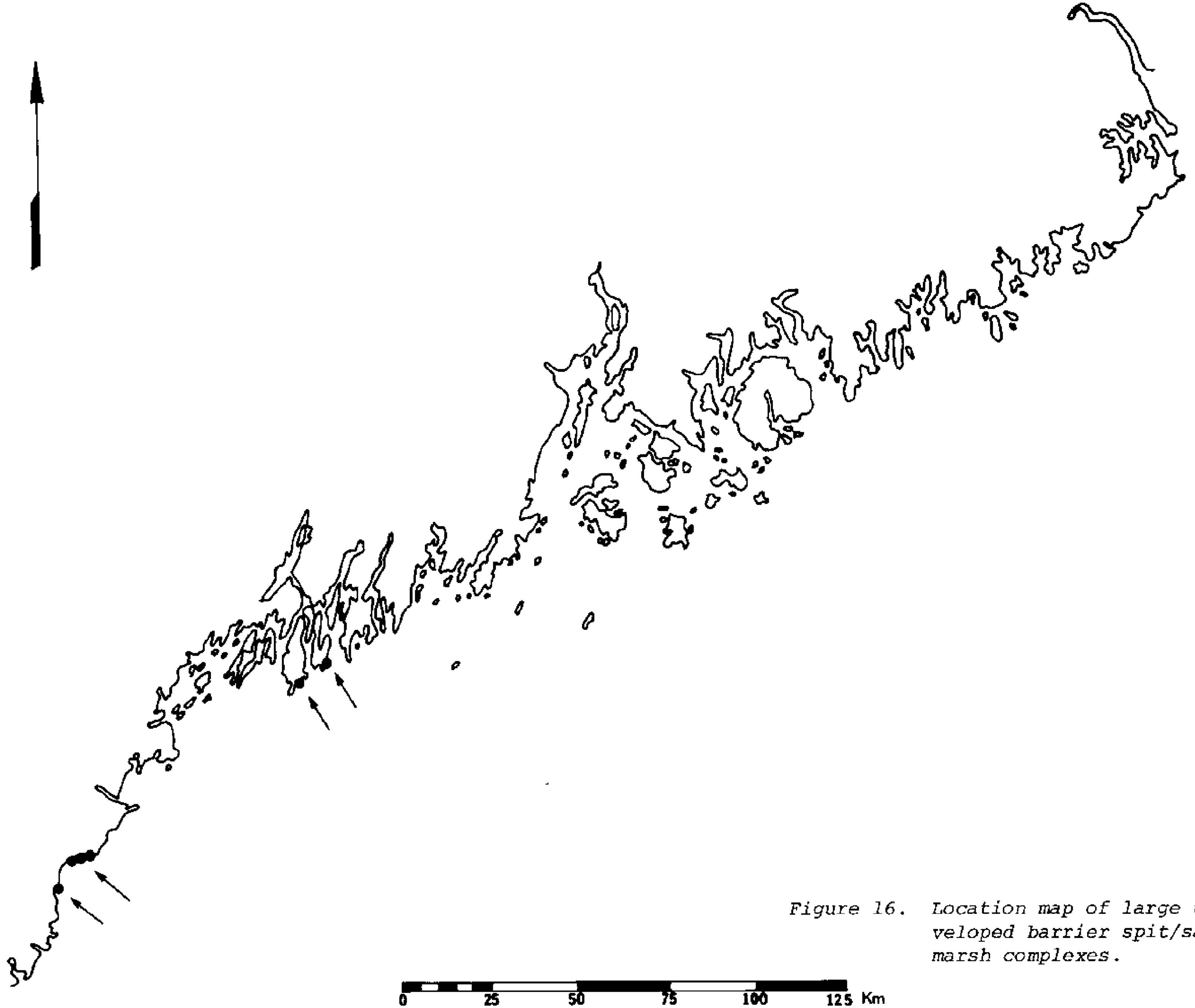


Figure 16. Location map of large undeveloped barrier spit/salt marsh complexes.

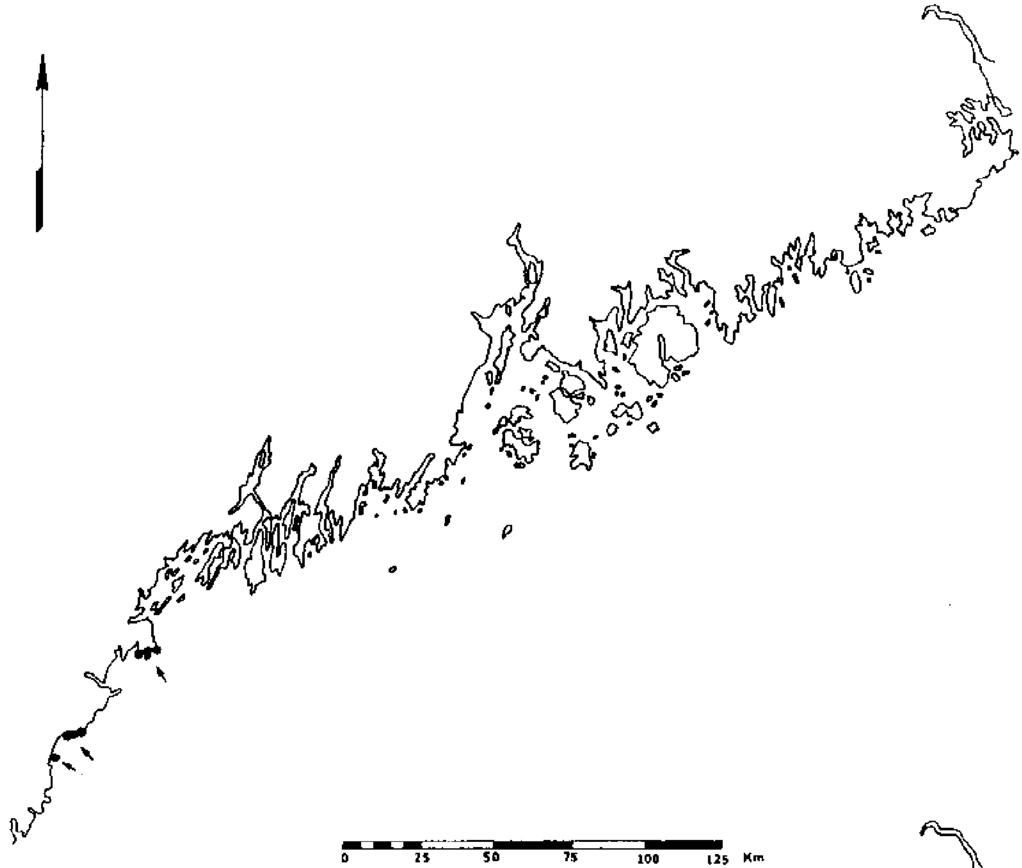


Figure 17 *Location map of significant stands of Wormwood (Artemisia caudata) on coastal dunes*

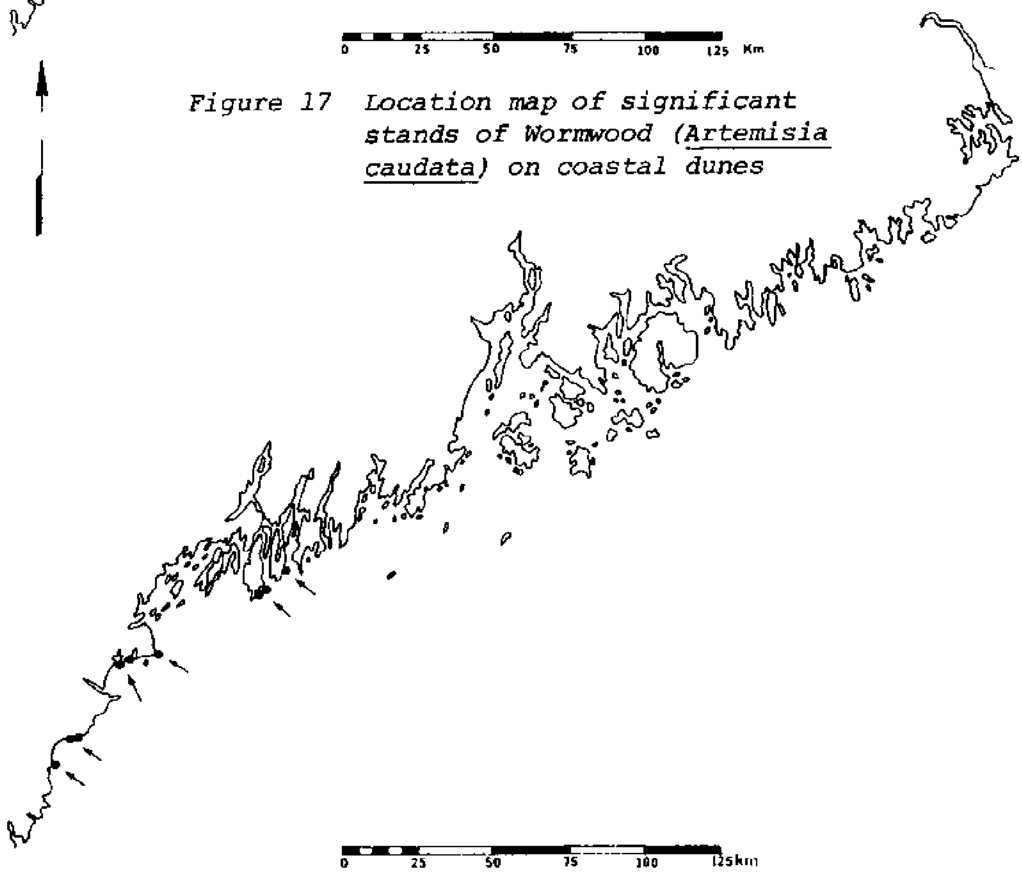


Figure 18 *Location map of significant stands of Beach Heather (Hudsonia tomentosa) on coastal dunes.*

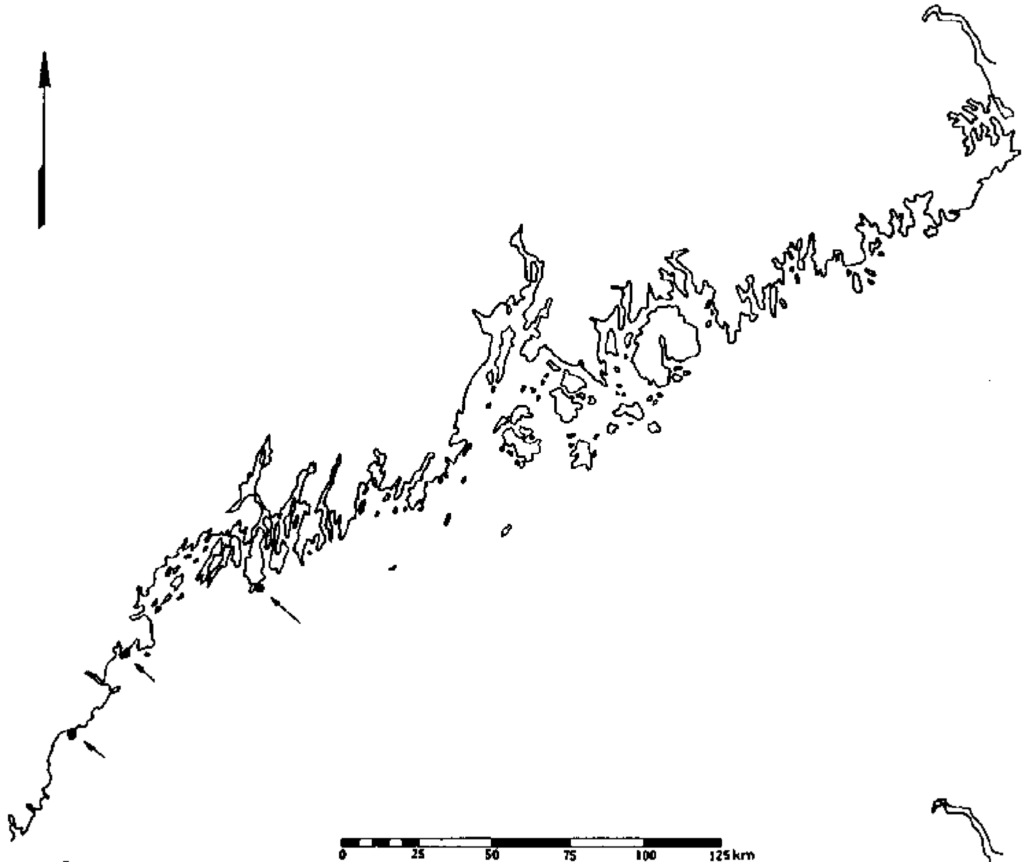


Figure 19 Location map of significant stands of Earthstar Puffball (Geaster hygrometricus) on coastal dunes

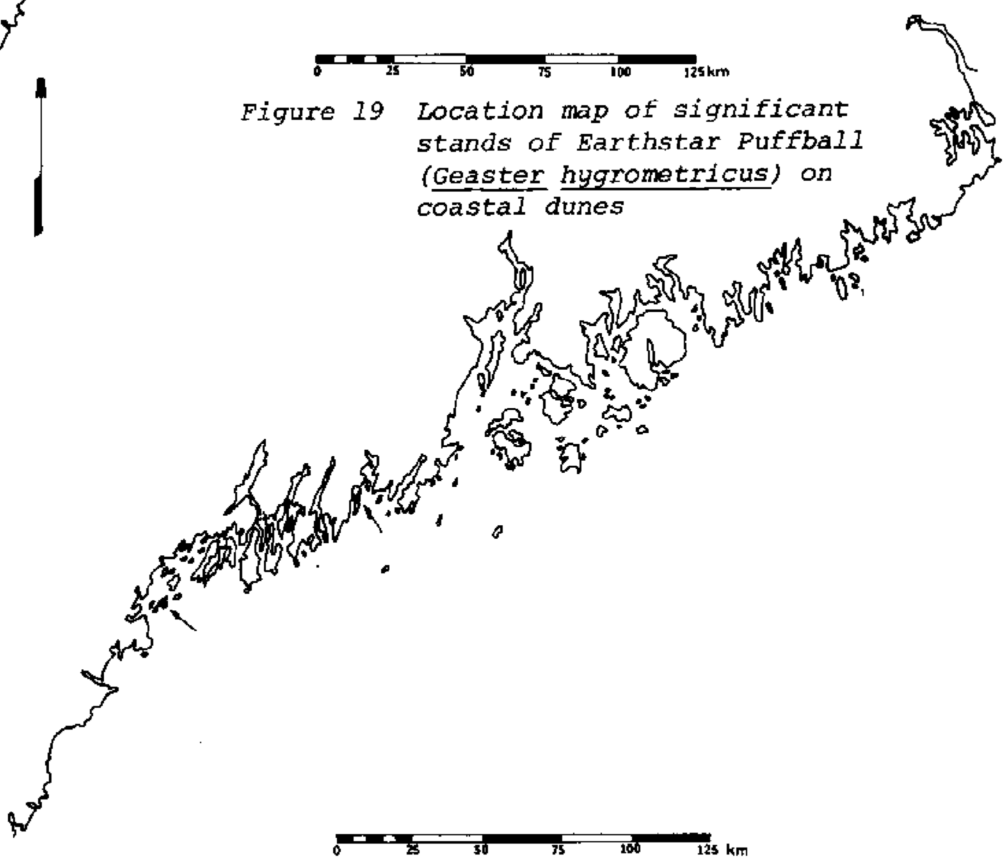


Figure 20 Location map of significant stands of Seaside Spurge (Euphorbia polygonifolia) on coastal dunes.

2) sand burial and sand removal, 3) extreme soil temperature changes, 4) extreme soil moisture changes, 5) extreme soil chemistry changes (including nutrients and salinity), 6) extreme air moisture changes.

Dune plant community structure is a function of changes in these stress factors as well as the processes of overwash, erosion, accretion, frontal dune ridge formation, wind deflation and parabolic dune activity. The floristic patterns of coastal dunes are both zonal (landward to seaward) and mosaic. Mosaic patterns are most evident in recently active parabolic dune fields where the plant cover types reflect mosaicism controlled by depth to water table, sand burial and deflation rates, protection from salt spray, and successional stage since last aeolian activity.

Dune plants have interesting morphologic and physiologic features which enable them to resist dessication and compete under stress. These features are as follows:

1. Rapid growth after burial – American Beach Grass (*Ammophila breviligulata*) can survive up to 1 m of sand burial and, in fact, is healthier when buried by a few cm of sand each year. Beach Heather (*Hudsonia tomentosa*) also can tolerate burial, though only a few cm.
2. Hairy leaves – These prevent evaporation. The best examples are Dusty Miller (*Artemisia Stelleriana*) and Beach Heather (*Hudsonia tomentosa*).
3. Thick cuticle – This reduces evaporation. Virtually all dune plants have this feature. Shrubs on the dune have thicker cuticles than the same species inland.
4. Succulence – This decreases the surface to volume ratio and reduces evaporation loss. Succulence is illustrated by Sea Rocket (*Cakile edentula*), Seabeach Sandwort (*Arenaria peploides*), Saltwort (*Salsola kali*), and Orach (*Atriplex patula*, var. *hastata* or *A. arenaria*). Some plants have reduced leaves for the same reason, e.g. Jointweed (*Polygonella articulata*) and Saltwort (*Salsola kali*). Upland shrubs on the dunes have more succulent leaves than the same species inland.
5. Sunken stomates – These permit gas exchange without loss of water. The best example is American Beach Grass.
6. Curled leaves – These also prevent loss of water from the gas exchange surface. Examples are American Beach Grass and Broom Crowberry (*Corema Conradii*).
7. C_4-photosynthesis – This is a physiologic adaptation common to plants of stressed environments. Sea Beach Orach is an example.

The results of a major study of botanical ecology in Maine's coastal dunes are contained in a report by Philip Trudeau, University of Massachusetts, entitled, "Beach Vegetation and Oceanic Processes Study of Popham State Park Beach, Reid State Park Beach and Small Point Beach." For a detailed discussion of the botany of Maine's three largest remaining natural dune fields, this report is available from the Soil Conservation Service, USDA, in Waldoboro, Maine. The area descriptions of Popham, Reid and Seawall (Small Point) Beaches later in this report also contain a botanical overview of these areas.

Trudeau recognizes five basic plant communities which can be characterized by dominant species and sub-associations:

I. Foredune Community
This is the area seaward of the frontal dune ridge and has two zones:

A. Seasonal Berm – this zone is flooded by spring high tides or winter storms. The plants are annuals which grow rapidly and produce many seeds.
1. Sea Rocket – Cakile edentula
2. Saltwort – Salsola kali

B. Aeolian Ramp or Perennial Berm – these are recently accreted areas with wind deposited sand now above the reach of spring tides and storms.
1. American Beach Grass – Ammophila breviligulata
2. Beach Pea – Lathyrus japonicus
3. Dusty Miller – Artemisia Stelleriana

II. Dune Grass Community
The dune grass community, dominated by American Beach Grass, runs from the frontal dune ridge inland to a heath or shrub community. Species diversity is low. There is no soil, are few nutrients, and salt spray is heavy. Three sub-associations occur in addition to the monotypic beach grass.

Monotypic – pure American Beach Grass
American Beach Grass and Beach Pea (Lathyrus japonicus)
American Beach Grass and Raspberry (Rubus idaeus)
American Beach Grass and Gooseberry (Ribes sp.)

III. Dry Dune Slack Community
This community is found on dry inland dunes when salt spray and sand burial rates are lower than those for the dune grass community. The extreme variability of the dry dune slack community is of interest to plant ecologists. Beach Heather (Hudsonia tomentosa) is the community dominant and its occurrence is significant since there are probably fewer than 40 hectares of this plant in Maine, and the bulk of this is found at Reid and Seawall. Associated plants are:

Pinweed – Lechea maritima
Pinweed Aster – Aster linariifolius
Lichens – Cladonia spp.
Jointweed – Polygonella articulata
Greene's Rush – Juncus Greenei
Sandy Sedge – Carex silicea
Early Sedge – Carex pensylvanica

Some of the above plants will commonly be associated without Beach Heather being present.

The presence of lichens in the back dune is peculiar to Maine and is a result of the high incidence of coastal fog.

IV. Shrub Community
This is a dense tangle of bushes .5 to 1.7 meters high. The dominants are:

Bayberry – _Myrica pensylvanica_
Virginian rose – _Rosa virginiana_
Meadowsweet – _Spiraea latifolia_
Raspberry – _Rubus idaeus_

Stands may be monotypic or in various mixtures. Poison Ivy (_Rhus toxicodendron_) and Gooseberry are common additions. Cherry (_Prunus_ spp.) and Serviceberry (_Amelanchier_ spp.) are found at the edge of this community.

V. Dune Forest Community
In the deficient soil of inactive parabolic dunes and under the stress of salt spray, forests are dominated by Pitch Pine (_Pinus rigida_). Three successional stages toward the edaphic (soil) climax Pitch Pine forest are commonly observed:

A. Semi-open with Beach Heather and Cladonia lichens between trees.

B. Widely spaced Pitch Pines with thick shrubs in between.

C. Mature Dune Forest with Pitch Pine, Red Maple (_Acer rubrum_), Red Oak (_Quercus rubra_), White Birch (_Betula papyrifera_), Poplar (_Populus_ sp.), Serviceberry (_Amelanchier_ sp.). Dominant understory species include many grasses, Canada Mayflower (_Maianthemum canadense_), Star Flower (_Trientalis borealis_), Wild Sarsaparilla (_Aralia nudicaulis_), and Bunchberry (_Cornus Canadensis_).

An additional forest type community occurs in low, moist back dune areas, where a low shrub-thicket forest is found. Dominants are Alder (_Alnus_ sp.), Winterberry (_Ilex verticillata_), Serviceberry, and Poplar.

A partial listing of Maine's berm and dune plants follows. The list was derived from collections and field studies by Nelson and Trudeau.

PARTIAL LIST OF MAINE'S BERM AND DUNE PLANTS

Plants of the Berm or Dune Habitats of Maine's Beaches Which Are Not Characteristic of Other Coastal or Inland Habitats.

Common

American Beach Grass (_Ammophila breviligulata_ Host) – the dominant plant of active and young dunes, especially the frontal dune ridge. It requires sand burial for vigor, resists dessication and salt spray damage and is responsible for entrapment of sand in the frontal dune ridge.

Beach Pea (Lathyrus japonicus L.) - co-dominant with Ammophila in the frontal dune ridge and young nearshore dunes. It is a circumpolar annual which fixes nitrogen and resists salt spray and dessication.

Dusty Miller (Artemisia Stelleriana L.) - a perennial common on accreting berms, on the frontal dune ridge and on young dunes.

Sea Rocket (Cakile edentula Hill) - annual; dominant plant of the berm; found on most beaches, large or small, sandy or rocky. This plant is easily dispersed.

Saltwort (Salsola Kali L.) - annual; minor plant of the berm; widespread occurrence; easily dispersed.

Sea Blite (Suaeda maritima Forskel) - annual; minor plant of the berm; widespread occurrence; easily dispersed; more common on rocky berms.

Occasional or patchy (including geographical gradients in frequency).

Beach Heather (Hudsonia tomentosa L.) - occurs on stable sand surfaces and in stabilized parabolic dune slacks. This plant is locally abundant where foot traffic damage is minimal. Its potential habitat is naturally limited. It is not highly tolerant of sand burial, invades new areas slowly, and is succeeded by other plants on long-stable sand.

Seaside Pinweed (Lechea maritima Leggett) - occasional on stable sand surfaces with Hudsonia tomentosa, Carex silicea and others; absent or uncommon north of Sagadahoc. County.

Seabeach Sandwort (Arenaria peploides L.) - occasional on sandy berms.

Strand Wheat (Elymus arenarius L.) - occasional on stable, low sand volume beaches; more common on rocky beaches.

Sandy Sedge (Carex silicea Olney) - significant because it occasionally dominates stabilized parabolic dune slacks, an uncommon habitat in Maine.

Beach Plum (Prunus maritima Marsh) - associated with dunes though not always restricted to them, absent or very uncommon north of Portland.

Tall Wormwood (Artemisia caudata Mx.) - characteristic of moderately stable back dunes; associated with Ammophila and Lathyrus; also reported from inland but not found on any beach north of Crescent Beach State Park.

Uncommon

Earthstar Puffball (Geaster hygrometricus) - This puffball is specifically adapted to the dune environment but has been found on only a few large baymouth barrier dune systems in Maine. The endemicity and specific habitat of cryptogams of Maine's coastal dunes are not well known.

Seaside Spurge (Euphorbia polygonifolia L.) – common on the berm of Cape Cod but seldom seen on Maine's berms. This annual is locally abundant at Andrews Beach, Casco Bay and is reported from Matinicus, Sagadahoc Co. and Brunswick. A few specimens were found on Louds Island beach (Muscongus Bay).

Plants of the Berm or Dune Habitats of Maine's Beaches Which Are Also Characteristic of Other Coastal or Inland Habitats

Xerophytes

Lichens (Cladonia spp. – rangifera, cristatella, unciabis, alpestris and others) – may form pure lichen carpets in stabilized parabolic dry dune slacks, or in association with Hudsonia tomentosa. Lichen carpets on dunes are peculiar to Maine because of high fog incidence.

Haircap Moss (Polytrichum sp. – and other Bryophyta) – mixed with Lichens and Hudsonia tomentosa.

Broom Crowberry (Corema Conradii T.) – occurs on exposed rocky ledges, especially coastal granite plutons with poor soil development, such as Mount Desert. It is locally abundant as ground cover in the pitch pine forest at Popham Beach.

Bearberry (Arctostaphylos uva-ursi [L.] Sprengel) – This has recently been shown to be a nitrogen fixer. It is a ground cover species in dry sandy forests with poor soil development. It probably occurs on rocky alpine soils as well. It is locally abundant at Popham Beach State Park as pitch pine forest ground cover.

Common Horsetail (Equisetum arvense L.) – common on sandy waste places, not salt tolerant but reported from Popham and Reid.

Golden Heather (Hudsonia ericoides L.) – common on exposed rocky ledges and occasional on dry forested dunes at Popham Beach State Park.

Pitch Pine (Pinus rigida Miller) – dominant forest species of late succession stabilized parabolic dunes, also sandy and rocky inland and coastal sites (e.g. Parker Head, Phippsburg).

Ground Juniper (Juniperus communis var. depressa Pursh) – common on burned or cut coastal and inland sites with poor soil, also frequent in dry stable back dunes (e.g. Bailey Beach).

Umbrella Sedge (Cyperis filaculmis Vahl) – on disturbed sandy areas inland.

Greene's Rush (Juncus Greenei Oaks & Tuck) – on stable, dry, open back dune sands with Hudsonia tomentosa and others, also inland sandy areas.

Bayberry (Myrica pensylvanica Loisel.) – common on the edge of Maine's dune forests and in early forest succession of dunes, also common on sandy or burned or cut inland and coastal sites.

Jointwood (Polygonella articulata [L.] Meisner) – common on open but stable sandy dunes of southern Maine, also sandy waste places inland. The northern coastal range limit for eastern North America may be Reid State Park, though there is one collection from Washington County (inland?).

Sheep Sorrel (Rumex Acetosella L.) – same habitat as Polygonella articulata, also common on coastal islands.

Scarlet Pimpernel (Anagallis arvensis f. arvensis L.) – occasional on dry coastal sites, including rocky berm of Damariscove Island.

Seaside Burdock (Xanthium echinatum Murray) – common annual on the seasonal sandy berms of Maine. It is salt resistant.

Seaside Goldenrod (Solidago sempervirens L.) – common in moderately dry dunes with some soil, in salt marshes and on rocky shores.

Pinweed Aster, Spruce Aster (Aster linariifolius L.) – extensive occurrence with Hudsonia tomentosa in stabilized parabolic dune slacks at Seawall Beach, also in sandy waste places inland and as occasional ground cover in pitch pine dune forest.

Seaside Rose (Rosa rugosa Thurb.) – ubiquitous coastal species, an important dune shrub.

Orach (Atriplex patula var. hastata [L.] G.) – common annual on the seasonal sandy berms of Maine. It is salt resistant.

Sand Orach (Atriplex arenaria Nutt.) – occasional on sandy berms and other shores.

Coast Blite (Chenopodium rubrum L.) – occasional on sandy berms, salt marshes and other ocean shores.

Mesophytes and Hydrophytes (excluding salt marsh plants)

1. Shadbush – Amelanchier laevis
*2. Strawberry – Fragaria sp.
*3. Low Rose – Rosa virginiana L.
4. Pasture Rose – Rosa carolina L.
*5. Raspberry – Rubus idaeus L.
*6. Blackberry – Rubus sp. (subspecies eubatus)
*7. Meadowsweet – Spiraea latifolia DuRoi
8. Black cherry – Prunus serotina Ehrh.
9. Choke Cherry – Prunus virginiana L.
10. Pin Cherry – Prunus pensylvanica L.
11. Black Chokeberry – Pyrus melanocarpa (Michx.) Willd.

12. Hardhack - Spiraea tomentosa L.
*13. Cinquefoil - Potentilla sp.
14. Hawthorn - Crataegus sp.
*15. Wrinkled Goldenrod - Solidago rugosa Aiton
*16. Goldenrod - Solidago spp.
*17. Ragweed - Ambrosia artemisifolia L.
*18. Pearly Everlasting - Anaphalus margaritacea (L.) B. & H.
*19. Pineapple weed - Matricaria matricarioides (Less.) Porter
*20. Fall Rattlesnake Root - Prenanthes trifoliata (Cass.) F.
*21. Toothed Hawkweed - Hieracium canadense Mx.
*22. Spiney-leaved Sow Thistle - Sonchus asper (L.) Hill
*23. Field Sow Thistle - Sonchus arvensis L.
*24. Flat-topped White Aster - Aster umbellatus Miller
*25. Common Yarrow - Achillea millefolium L.
*26. Low Sweet Blueberry - Vaccinium angustifolium Aiton
27. Black Huckleberry - Gaylussacia baccata (Wang.) K. Koch
28. Sheep Laurel - Kalmia angustifolia L.
29. Bog Cranberry - Oxycoccus macrocarpus (Aiton) Purs.
30. Maleberry - Lyonia ligustrina (L.) DC.
*31. Gooseberry - Ribes sp.
*32. Poison Ivy - Rhus toxicodendron L.
33. Staghorn Sumac - Rhus typhina L.
34. Winterberry - Ilex verticillata (L.) G.
*35. Common St. Johns-wort - Hypericum perfoliatum L.
*36. Tufted Vetch - Vicia cracca L.
*37. Yellow Clover - Trifolium agrarium L.
38. Red Maple - Acer rubrum L.
39. Striped Maple - Acer pensylvanicum L.
40. Fireweed - Epilobium angustifolium L.
*41. Evening Primrose - Oenothera sp.
*42. Wild Radish - Raphanus raphanistrum L.
43. Wild Sarsaparilla - Aralia nudicaulis L.
44. Bristly Sarsaparilla - Aralia hispida Vent.
45. Canada Mayflower - Maianthemum canadense Desf.
46. Starry False Solomon's Seal - Smilacina racemosa (L.) Desf.
*47. Great Angelica, Alexanders - Angelica atropurpurea L.
*48. Scotch Lovage - Ligusticum scothicum L.
49. Star Flower - Trientalis borealis Raf.
*50. Deadly Nightshade - Solanum dulcamara L.
51. Bush Honeysuckle - Diervilla lonicera Miller
52. Swamp-Fly-Honeysuckle - Lonicera oblongifolia (Goldie) Hooker
53. Wild Raisin - Viburnum cassinoides L.
*54. Morning Glory - Convolvulus sepium L.
55. Dodder - Cuscuta Gronovii Willd.
56. Red Ash - Fraxinus pensylvanica Marsh
57. Bedstraw - Galium sp.
58. Hemp-Nettle - Galeopsis tetrahit L.
59. Common Plantain - Plantago major L.
60. Common Milkwort - Polygala sanguinea L.
61. Bastard-Toadflax - Comandra umbellata L. (Nutt.)

62. Gray Birch – *Betula populifolia* Marsh.
63. Alder – *Alnus* sp.
64. Quaking Aspen – *Populus tremuloides* Mx.
65. Meadow Rue – *Thalictrum* sp.
*66. Chickweed – *Cerastium* sp.
*67. Campion – *Lychnis* sp. or *Silene* sp.
68. Red Oak – *Quercus rubrum* L.
69. Bunchberry – *Cornus canadensis* L.
*70. Yellow Dock – *Rumex crispus* L.
71. Shore Knotweed – *Polygonum prolificum* (Small) Robinson
72. White Spruce – *Picea glauca* (Moench) Voss
73. Red Spruce – *Picea rubens* Sarg.
74. Balsam Fir – *Abies balsamia* (L.) Miller
75. Blue Flag – *Iris versicolor* L.
76. Toad Rush – *Juncus (bufonius?)* L.
*77. Terrell Grass, Wild Rye – *Elymus virginicus* L.
*78. Quack Grass – *Agropyron repens* (L.) Beaur.
*79. Blue-joint Grass – *Calamagrostis canadensis* (Mx.) Nutt
*80. Redtop Grass – *Agrostis alba* L.
*81. Kentucky Bluegrass – *Poa pratensis* L.
*82. Love Hairgrass – *Deschampsia flexuosa* Beauv.
*83. Spike Grass – *Distichlis spicata* (L.) Greene
*84. Sheep's Fescue – *Festuca ovina* L.
*85. Red Fescue – *Festuca rubra* L.
*86. Timothy – *Phleum pratense* L.

* indicates importance in open dunes or early dune succession.

Table III

SIGNIFICANT UNDISTURBED COASTAL SANDY BEACHES

No.	Beach Name	Town	County	Length, Line Along High Water (meters)	Area (hectares)
1.	Ogunquit	Wells	York	1620	40.56
2.	Laudholm	Wells	York	1000	18.00
3.	Crescent Surf	Kennebunk	York	800	17.00
4.	Parsons	Kennebunk	York	900	13.00
5.	Goose Rocks	Kennebunkport	York	300	8.50
6.	Western	Scarborough	Cumberland	1206	20.00
7.	Scarborough	Scarborough	Cumberland	1350	55.00
8.	Main Beach, Ram Island Farm	Cape Elizabeth	Cumberland	457	9.70
9.	Strawberry Hill, Ram Island Farm	Cape Elizabeth	Cumberland	975	12.10

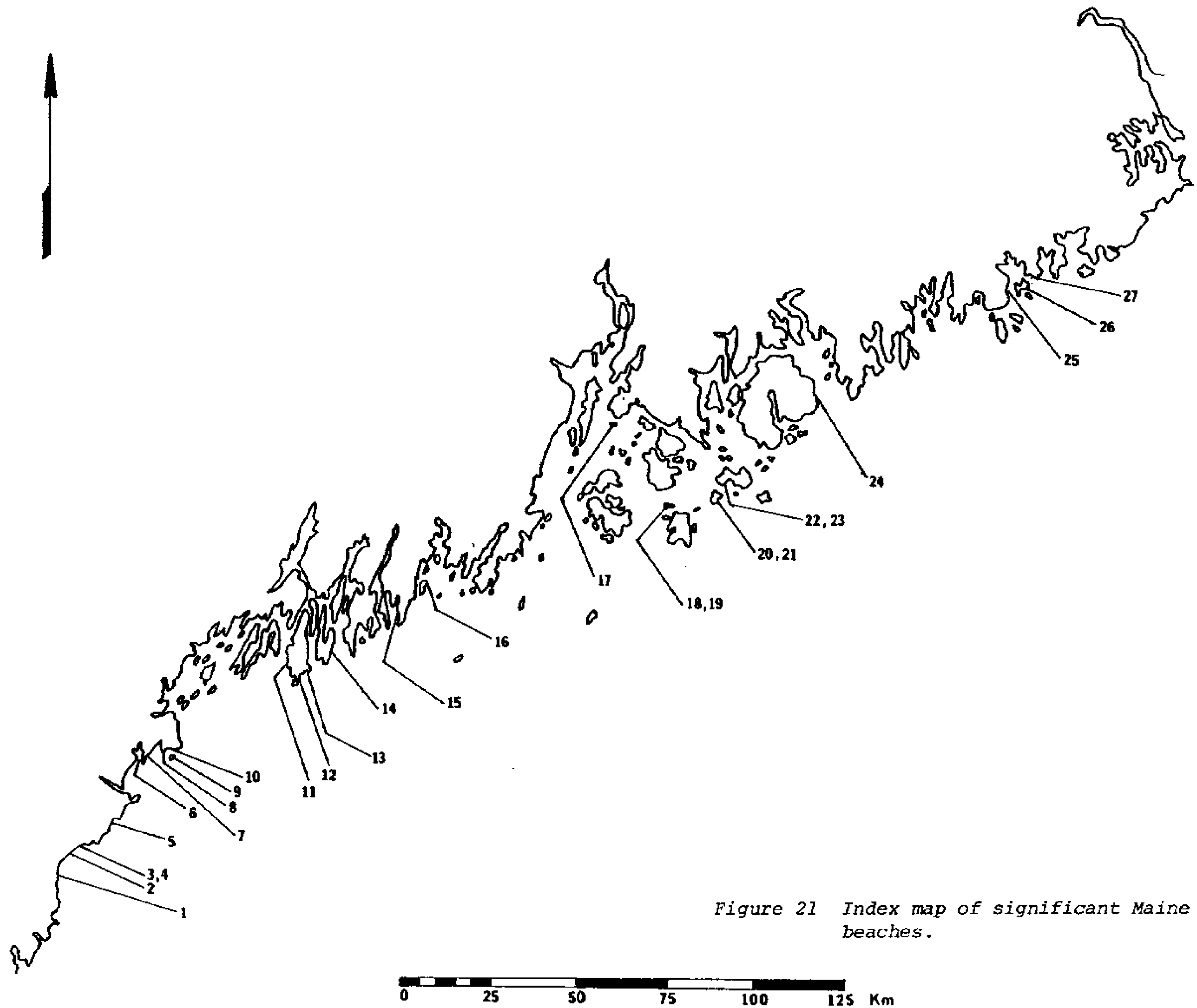


Figure 21 Index map of significant Maine beaches.

Table III (Continued)

No.	Beach Name	Town	County	Length, Line Along High Water (meters)	Area (hectares)
10.	Crescent	Cape Elizabeth	Cumberland	1524	19.20
11.	Bailey	Phippsburg	Sagadahoc	260	3.20
12.	Seawall	Phippsburg	Sagadahoc	2200	52.00
13.	Popham (7 sites)	Phippsburg	Sagadahoc	3640	137.80
14.	Reid (2 sites)	Georgetown	Sagadahoc	1460	25.00
15.	Pemaquid	Bristol	Lincoln	575	4.55
16.	Louds Island	- -	Lincoln	335	3.20
17.	Pond Island	- -	Hancock	1270	6.00
18.	Merchant Island – Pocket Beach	Isle Au Haut	Knox	340	3.40
19.	Merchant Island – Cuspate Foreland	Isle Au Haut	Knox	530	5.30
20.	Marshall Island – Sand Cove	Swans Island	Hancock	170	1.70
21.	Marshall Island – Carbonate sand	Swans Island	Hancock	66	0.70
22.	Swans Island – Irish Cove	Swans Island	Hancock	275	2.80
23.	Swans Island – Fine Sand Beach	Swans Island	Hancock	150	1.00
24.	Sand Beach	Bar Harbor	Hancock	290	2.00
25.	Sandy River	Jonesport	Hancock	500	5.00
26.	Roque Island	Jonesport	Washington	1930	20.00
27.	Roque Bluffs	Roque Bluffs	Washington	780	8.00

DESCRIPTIONS OF SIGNIFICANT MAINE SANDY BEACHES

Ogunquit Beach – York County

Description of Geological Features

Ogunquit and Moody beaches together compose the longest barrier spit in Maine (Figure 22); the total area of the beach-marsh ecosystem is 285 hectares. The only undeveloped barrier spit of comparable size is Seawall Beach in Phippsburg.

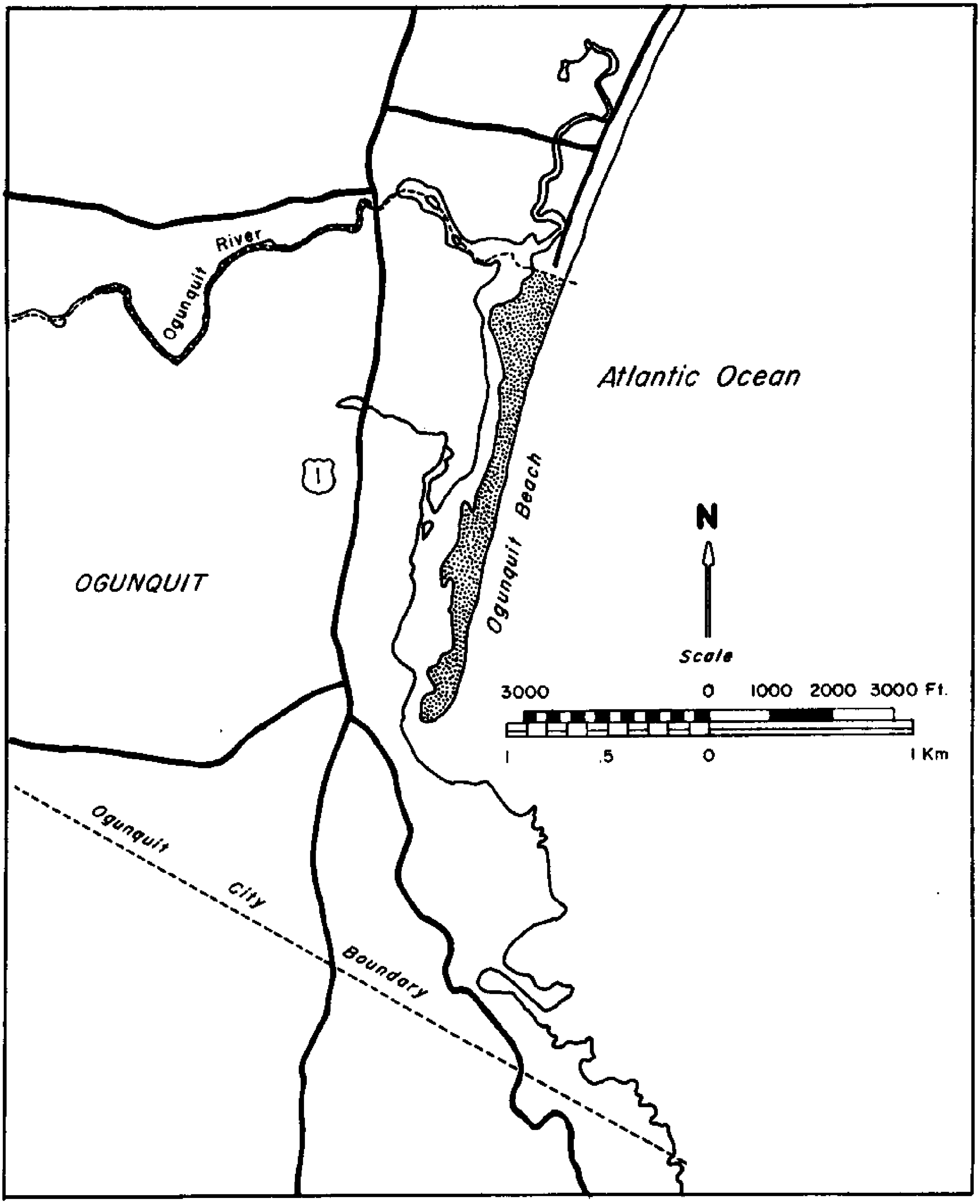


Figure 22 Ogunquit Beach

The surface features (dunes and vegetation) of Moody have been obliterated, Ogunquit's have been drastically altered, while Seawall's dunes and vegetation remain in a largely natural state.

The Ogunquit-Moody barrier spit has formed by transgression of the sea over a low-lying coastal plain glacial outwash sheet. Some of the barrier sand is derived from alongshore and onshore transport of submerged glacial outwash.

The portion of Ogunquit between the sewage treatment plant to the north and the Norseman Motel to the south, retains significant natural features in the beachface, dunes and dune vegetation. The large spit end has been drastically altered by being stabilized with pavement.

Recently a 42 m wide dike (∿4 m high with 5:1 side slopes) was constructed for about an 1800 meter length behind the normal winter high water line. The dike was constructed in two sections using different borrow material for each. The southern section, 490 meters long was built with sand from a flood tidal delta in the Ogunquit River directly behind the beach. The second section, 1310 meters long, utilized glacial outwash sediments from an inland borrow pit. The dike has been stablized with planted and fertilized American Beach Grass (Ammophila breviligulata).

For many decades, the Ogunquit dunes suffered an exaggerated impact from NW winds which created the largest parabolic dunes in Maine. This situation arose and persisted because of heavy foot traffic damage to the dune vegetation. Percent cover of vegetation was 50% or less and succession beyond the Beach Grass and Beach Pea stage was generally prevented. Only a few small areas supported healthy Beach Heather (Hudsonia tomentosa), and there remains only one small stand of Pitch Pine (Pinus rigida).

The most active zone of Ogunquit's dunes has been stabilized by the dike construction, planting, fertilizing, and fencing. But because the vegetation, geomorphology and grain size of the dike are artificial, the dike has been excluded from the proposed area's boundaries. Three areas have been selected as significant areas at Ogunquit:

I. Small Pitch Pine Stand on Low Relief Parabolic Dunes North of Sewage Treatment Plant.

   This small area behind the north end of the Ogunquit dike is significant because it has the only edaphic climax Pitch Pine (Pinus rigida) stand at Ogunquit. The ground cover is depauperate American Beach Grass (Ammophila breviligulata). There are also a few small patches of Beach Heather. A few open sand dune slacks are carpeted with lichens (Cladonia spp.). There is severe foot traffic on most of the open dunes and this prevents growth of Beach Heather and lichens. The pitch pines exhibit a creeping growth form on their lower branches. There are no actively blowing dunes here despite the foot traffic damage.

   Despite its small size and disturbed nature this area has a fairly good spectrum of post-disturbance back dune successional changes from open dry dune slacks to tall pitch pines with soil. Three progressive stages with dominant plants are listed:

1. Open dry dunes: Beach Heather, Lichens, Jointweed, American Beach Grass.
2. Semi-open dunes: Pitch Pines, Wormwood, American Beach Grass, Pasture Grasses, Sandy Sedge, Beach Heather, Lichens and Bayberry.
3. Tall forest with soil and shade: Pitch Pines, Star Flower, Bayberry, Pasture Grasses, and American Beach Grass.

There is a very striking difference in speciation and diversity between this area and the nearby dike. The area should be fenced off and foot traffic prevented. This will encourage growth of Beach Heather and Lichens.

A partial species list follows:

1. Jointweed – _Polygonella articulata_
2. Wormwood – _Artemisia caudata_
3. Bayberry – _Myrica pensylvanica_
4. ? Sedge
5. Pinweed – _Lechea maritima_
6. Hawthorn – _Crataegus_ sp.
7. Shadbush – _Amelanchier_ sp.
8. Seaside Goldenrod – _Solidago sempervirens_
9. Beach Heather – Hudsonia _tomentosa_
10. American Beach Grass – _Ammophila breviligulata_
11. Lichens – _Cladonia_ spp.
12. Star Flower – _Trientalis borealis_
13. Sandy Sedge – _Carex silicea_
14. Pasture grasses

There are several species on the disturbed edge of the area (paved roadside) which are not listed above.

II. Active High Relief Parabolic Dunes Between Sewage Treatment Plant and Norseman Motel and Behind Dike.

This second area can be divided into two sections. North of the footbridge the parabolic dunes are of lower relief and are better stabilized with vegetation. These lower dunes receive less foot traffic because they are not part of the thoroughfare between the footbridge and the beach and because two snow fences run across the area in an east-west direction. There are more plant species here than in the more active dunes to the south of the footbridge. Particularly notable are the Wormwood (_Artemisia caudata_) and Beach Heather (_Hudsonia tomentosa_). The area between the footbridge and the sewage treatment plant (especially roadsides and disturbed gravelly areas) has the best stands of Wormwood (_Artemisia caudata_) yet seen in the state of Maine.

South of the footbridge is a zone of high relief, active and badly eroded parabolic dunes formed by strong nortwest winds. This area between the dike and the Ogunquit River indicates what most of Ogunquit's dune area looked like before dike construction. The area behind the dike is still the largest, active high relief parabolic dune area in Maine (thus a significant geological feature). Some of the active parabolic dunes are encroaching on the backside of the dike.

Before construction of the dike, Ogunquit's barrier spit was occasionally breached by winter storms which flowed through blowouts created by offshore winds (i.e. northwest-wind-oriented parabolic dunes). These breaches accumulated seaweed and other flotsam which permitted colonization by ruderals such as Hawkweeds, Seaside Burdock and Mustards. Some of these weeds are still found behind the dike at the site of former breaches.

In general, species diversity is very low in the high, active parabolic dunes. There are no good stands of Beach Heather. Dominants are American Beach Grass, Beach Pea and Wormwood.

The western boundary of the second proposed critical area follows the dune/marsh or dune/river shore boundary. In some places there is a rear berm-like habitat of sand flooded only during spring tide. There is a zonation here mirroring that usually found on the front of the beach. Near the high water line are Seaside Burdock (Xanthium echinatum), Saltwort (Salsola kali), Sea Blite (Suaeda maritima), and Seabeach Orach (Atriplex patula var. hastata or A. arenaria) all of which depend on flotsam for nutrients. In windblown sand above spring high water, but also dependent on flotsam from storm flood and surges, grow Dusty Miller (Artemisia Stelleriana) and Seaside Goldenrod (Solidago sempervirens). Along snow fence edges and in the high flotsam of the back dune edge is Strand Wheat (Elymus arenarius). This mirror image occurrence of plant zonation can be attributed to the strong role played by the northwest winds at Ogunquit.

III. Beachface Between Sewage Treatment Plant and Norseman Motel.

When field checked, Ogunquit's beachface provided one of the best examples in Maine of a summer constructional profile, which consisted of a 40 m wide berm between the toe of the dike and high water, and, below the steep berm foreslope, a ridge and runnel system of exaggerated relief with rip current exit channels through the ridge at regular intervals.

The Ogunquit beachface is recognized as a significant area because it provides excellent examples of certain geomorphic features and expressions of beachface processes. Field studies over the last two years have shown that the distance from spring high water to spring low water has averaged about 250 m. This makes the beach width of Ogunquit larger than most of Maine's beaches. The unusual width may be due to a large available sand supply and the texture of the sand, which is fine grained, well sorted, and mineralogically pure (i.e. quartz rich).

In late summer of 1977 Ogunquit's beachface showed far more exaggerated constructional features than in two previous summers. There was a 30 to 40 m wide berm and high relief ridge and runnel system. However, monthly profiles taken since 1975 show that the average beachface elevation has lowered slightly. This may be either a natural oscillation or the result of loss of sand formerly contributed to the beachface by offshore-directed wind transport of sand through the northwest-wind-oriented parabolic dunes.

Since 1952 air photos indicate little or no historical perennial accretion or erosion of Ogunquit, but the storms of January 9 and February 7, 1978 caused major retreat of the erosional scarp into the artifical dike and recently, unprecedented lowering of the upper beachface surface. Mid and lower beachface lowering was no greater than in the previous winter.

Tree stumps, probably embedded in peat, were exposed on the beachface after the storms of 1978. This is the only large barrier in Maine where stump exposures have been observed.

When field checked in the summer of 1977, the dike itself was responding to natural processes as follows:

1. There is an actively accreting embryonic frontal dune ridge behind the snow fence on the front of the dike, especially at the north end.
2. There was a winter scarp, partially healed, visible behind the snow fence at the front of the dike; it is particularly visible along the southern half of the dike where less windborne sand accretion has taken place. This scarp was greatly enlarged and the dike badly eroded by the storms of January 9 and February 7, 1978.
3. There was a coarse wind-lag surface on the top and top rear of the dike with depauperate Ammophila and a deposited surface on the mid-front of the dike with healthy Ammophila. This sand shift has been caused by strong northwest winds and gives the dike a slight airfoil cross section.

Another notable feature outside the significant areas is the stand of Beach Plum (Prunus maritima) near Beach Plum Lane and the footbridge parking lot.

Summary of Significant Features

A. Geological

1. Largest barrier spit - tidal river and marsh complex in Maine.
2. Low relief parabolic dunes stabilized with Pitch Pines.
3. Largest and most active parabolic dunes in Maine. Dunes are more severely influenced by winter nortwest winds than any other Maine dunes.
4. Classical illustration of summer vs. winter beachface profile types due to onshore/offshore accretion and erosion.

   Winter Beach Profile - long, flat or concave-upward beach face; dune scarp.

   Summer Beach Profile - wide (40 m) berm with steep foreslope, exaggerated-relief ridge and runnel system, and large accumulation of sand in berm and ridge.
5. Absence of strong correlation between slope and mean grain size of sand (coarse sand sizes are absent).

6. Uniformly fine, nearly pure quartz sand, probably long removed from original source which suggests long distance onshore transport by winnowing from a larger submerged glacial outwash deposit or long-term response to a dominant low energy wave regime which selects fine sand sizes.

7. No lag surface, but tree stumps were exposed on the beachface in March, 1978.

B. Botanical

1. Small example of edaphic climax Pitch Pine community.

2. Best stands of Wormwood in Maine.

3. Some Hudsonia tomentosa.

4. Presence of Beach Plum (Prunus maritima).

5. Three progressive stages of post-disturbance back dune successional changes.

6. Seaside Spurge (Euphorbia polygonifolia) was collected at Moody Beach in 1888. It possibly may be found at Ogunquit today but was not observed. This plant has only been found on two small Maine beaches but is a common berm plant of southern New England beaches.

C. Size

The total area of just the Ogunquit part of the ecosystem is 138 hectares, which includes 104 hectares of marsh and above high water sand, and 34 hectares of low water to high water beachface.

Laudholm Beach — Wells, York County

Description of Geologic Features

Laudholm Beach is the northeast end of the Drakes Island-Laudholm barrier spit. Laudholm and Crescent Surf beaches, together, form double spits which face one another in an overlapping fashion. The Little River, a tidal reentrant with extensive back-barrier salt marsh acreage, drains out between the double spits. Long-term drift of sand should be toward the reentrant. The two spit ends are historically unstable since relict frontal dune ridges are visible behind the present shorelines.

Laudholm, Crescent Surf, the Little River reentrant and the associated back-barrier marshes form a single depositional sedimentary system which is the best example in Maine of a sandy double barrier spit-tidal river and marsh system remaining in a natural state. The Wells Harbor entrance probably resembled this area before development, dredging and jetty construction (Figure 23).

Laudholm Beach demonstrates, as does Scarborough Beach, a most interesting geological feature: the sundry ways in which diverse grain size classes are separated into characteristically defined layers and features, such as aeolian ramp, berm foreslope, and low tide terrace. Laudholm Beach consists of poorly sorted, coarse sand, pebbles, cobbles, and boulders which suggests recent transport from a local till source. The size separation occurs in response to the energy levels and

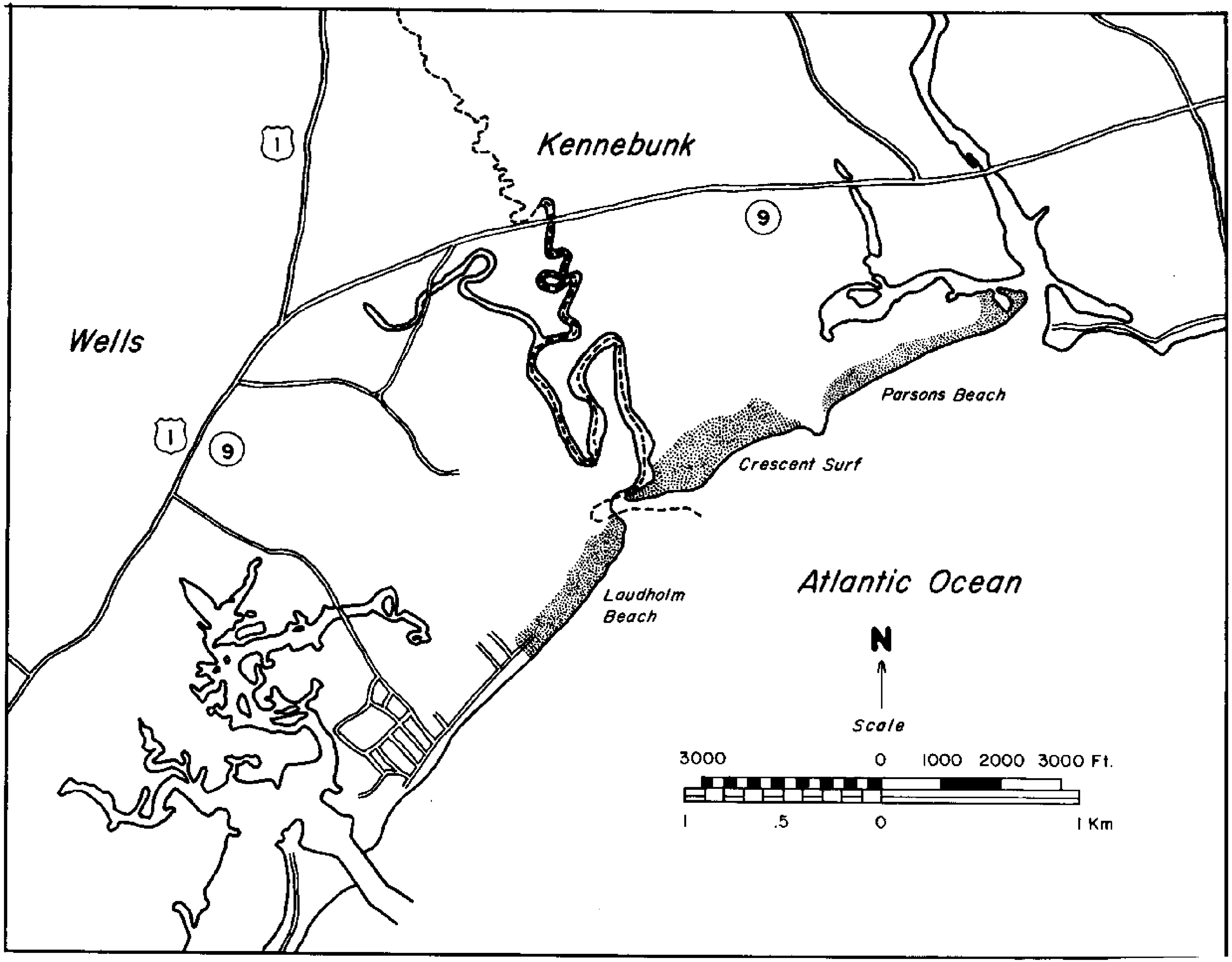


Figure 23 Laudholm Beach, Crescent Surf, Parsons Beach

directions of the transport agents. Most of the size contrasts and associations with specific geomorphic features result from the relative ease with which a particular size grade is mobilized by waves or winds and transported to a specific location along the beach.

At Laudholm this transport has occurred in two directions, onshore and alongshore, to produce two contrasting parts of the beach according to whether erosional or accretionary processes dominate. The southern half of the beach is erosional and shows the results of onshore directed size fractionation and removal of finer sizes toward the spit end by alongshore transport. On the low-tide terrace and in runnels, is exposed a cobble-boulder lag deposit which extends underneath a short steep beachface and narrow berm of coarse sand. Cobbles have been further separated from the lag deposit in an onshore direction to form a rocky storm berm. Little or no frontal dune ridge occurs at all along this southern half, instead an abrupt eroding scarp, less than 1 m high, of overwash-deposited sand and rocks with little backslope is found.

Alongshore transport processes have displaced most of the medium and fine sand sizes toward the northern half of the beach and the actively accreting spit end which is being extended into the Little River. Near the end of the spit, an old frontal dune ridge (FDR) is visble behind a newly colonized aeolian ramp. In contrast to the southern half, where the sandy berm and beachface is only 30 m wide, the northern half of Laudholm has a berm at least 40 m wide consisting of finer sand and exhibiting beach cusps with 15 m wave lengths along the berm edge. The availability of finer sand from the berm and beachface has produced a well-developed, wind-deposited frontal dune ridge, 1 to 2 m high, and accompanying aeolian ramp along the northern half.

At this beach, overwash, as evidenced by wood flotsam and other debris atop and behind the dunes, dominates over aeolian transport in supplying sand to the backdune area. A cobbly overwash extends as far back as 15 meters into the coarse dunes of low relief, particularly on the southern part of Laudholm Beach.

Parabolic dunes of low relief, less than 2 m high, are well stabilized in the SW third of the backdune, but in central and northern sections of the backdune, they become moderately high with active interiors accompanied by much foot traffic erosion.

Description of Botanical Features

The low relief parabolic dunes at the southwest end of the proposed area, and behind the Laudholm Beach Road, are well vegetated with a diverse dry dune slack vegetation, including: Earthstar Puffball (Geaster hygrometricus), Pinweed (Lechea maritima), Pinweed Aster (Aster linariifolius), Beach Heather (Hudsonia tomentosa), American Beach Grass (Ammophila breviligulata). There are also undisturbed, low relief dunes with thick lichen (Cladonia spp.), Beach Heather cover again, Beach Pea (Lathyrus japonicus), Dusty Miller (Artemisia Stelleriana), and Toad Flax (Comandra umbellata). Interspersed among the dune and slack communities are scattered Beach Heather, Lichen, and Sparse Beach Grass plants.

The back dune area in the southern half of the beach, where little onshore aeolian transport of sand is taking place, has floristic patterns which are more mosaic than zonal. Wormwood (Artemisia caudata) is distributed generally throughout the back-dune area in addition to Sandy Sedge (Carex silicea) which extends to the erosional scarp in most places. At areas of overwash deposits, Dusty Miller (Artemisia Stelleriana) grows thickly to create yet another type of mosaic. There are also shrub-covered low relief parabolic dunes, dominated by Bayberry (Myrica pensylvanica) and restricted to the southern third of the back dune area.

Unlike the poor zonation of the southern half of the back dune, there is visible zonation at the accreting northern half of the beach where aeolian sand supply is the greatest. The zonation is best expressed just south of the spit end where more time for successional development has occurred. There are five distinct zones which are arranged, proceeding landward, as follows:

1. Frontal Dune Ridge with Beach Pea (Lathyrus japonicus) and American Beach Grass (Ammophila breviligulata).
2. Sparse back dune grasses with Beach Heather (Hudsonia tomentosa) and Lichens (Cladonia spp.) associations.
3. Sparse back dune grasses with Beach Heather and Lichen associations with abundant Greene's Rush (Juncus Greenei). This occurs in a narrow band at the edge of the Bayberries of the next zone.
4. A back dune community with Bayberry (Myrica pensylvanica), Meadowsweet (Spiraea latifolia), Cherry (Prunus sp.), Shadbush (Amelanchier sp.), and isolated Pitch Pine (Pinus rigida).
5. A back dune forest community of Pitch Pine (Pinus rigida) and tall hardwoods.

An interesting botanical feature occurs in the northern two-thirds of the back dune area where a few Pitch Pines (Pinus rigida) located behind the moderate relief parabolic dunes of this area have attempted to colonize the open dunes seaward of their present stand. These colonizing Pitch Pines have an unusual growth habit which makes them resemble small clumps of Wormwood (Artemisia caudata).

Along the entire back dune area, salt spray damage and southwest-wind pruning is strongly evident at the shrub-tree line.

The absence of berm colonization by plants suggests that the broad berm of the northern half of the beach may be a seasonal feature and not a perennial accretionary event. This would preclude this area as a least tern nesting habitat.

A partial list of species follows:

1. American Beach Grass — Ammophila breviligulata
2. Poison Ivy — Rhus toxicodendron
3. Beach Pea — Lathyrus japonicus
4. Pasture Grasses
5. Yarrow — Achillea millefolium
6. Evening Primrose — Oenothera sp.
7. Seaside Rose — Rosa rugosa

8. Wormwood — _Artemisia caudata_
9. Dusty Miller — _Artemisia Stelleriana_
10. Beach Heather — _Hudsonia tomentosa_
11. Sandy Sedge — _Carex silicea_
12. Pinweed — _Lecha maritima_
13. Pinweed Aster — _Aster linariifolius_
14. Toad Flax — _Comandra umbellata_
15. Pitch Pine — _Pinus rigida_
16. Earthstar Puffball — _Geaster hygrometricus_
17. Meadowsweet — _Spiraea latifolia_
18. Bayberry — _Myrica pensylvanica_
19. Greene's Rush — _Juncus Greenei_
20. Star Flower — _Trientalis borealis_
21. Shad Bush — _Amelanchier_ sp.
22. Cherry — _Prunus_ sp.
23. Hard Hack (hairy) — _Spiraea tomentosa_
24. Goldenrod — _Solidago rugosa_
25. Great Angelica — _Angelica atropurpurea_

Summary of Significant Features

A. Geological

1. Comprises, with Crescent Surf and the Little River, the best remaining natural example of double barrier spits.
2. Parabolic dunes of low relief, well stabilized in southwest third, but on the northeast two-thirds of back dune area they have active interiors and are of moderate relief.
3. Accreting spit at northern end spreading into the Little River with old frontal dune ridge visible behind a broad aeolian ramp.
4. Coarse sand in both beachface and dune.
5. Example of relative importance of overwash and unimportance of aeolian transport in supplying sand to back dune.
6. Wide range of grain size classes, segregated into various features on different parts of beach profile (e.g. cusps, low tide terrace, back dune, beachface).
7. A wind-deposited frontal dune ridge at mid-beach, 1 to 2 m high with aeolian ramp.
8. Amost no frontal dune ridge on most of beach.
9. Eroding at southwest half, accreting at northeast half, and finer at spit (NE) end.
10. Exceptionally wide berm at mid-beach, 40 m and wider as compared to 30 m and less in south half.
11. Cusps with 15 m wavelengths.

B. Botanical

1. Zonation not clearly visible in low relief areas of southern back dune, but visible at accreting center beach where supply of sand is greatest (aeolian).

2. Presence of Wormwood (Artemisia caudata), an uncommon species in Maine which reaches its northern coastal range limit at Cape Elizabeth.

3. Good stands of semi-open Pitch Pine forest, illustrating creeping growth from foot traffic and salt spray damage which accentuate this unusual growth habit to the point where the young pines resemble small clumps of wormwood. There is also a late succession pitch pine and hardwood forest growing between the open dunes and back-barrier marsh.

4. Good stands of Beach Heather (Hudsonia tomentosa) and associated species. There are probably less than 40 hectares of Beach Heather in the state of Maine. It is more sensitive to foot traffic damage than American Beach Grass because it is slow growing. It takes decades to naturally invade a parabolic dune slack or old back dune flat.

5. Presence of Earthstar Puffball (Geaster hygrometricus), an uncommon species in Maine.

C. Size

The size of this area is 18 hectares.

Crescent Surf Beach - Kennebunk, York County

Description of Geological Features

Crescent Surf Beach is a small barrier spit with back-barrier tidal river and salt marsh. Between the open dunes and marsh, there is a large, late succession pitch pine and hardwood forest which grows on wind deposited sand (Figure 23).

Crescent Surf, Laudholm Beach, the Little River tidal reentrant and the associated back-barrier marshes form a single depositional system, which is the best remaining natural example in Maine of sandy double barrier spits (see previous discussion of Laudholm Beach).

Crescent Surf is also unusual among Maine's beaches since the entire beach is accretionary with a broad aeolian ramp, broad berm, steep berm foreslope and broad convex-upward lower beachface. The berm was at least 15 m wide at all points when field checked (June 29, 1977).

The entire beach and dune field is medium to fine grained sand. There are no cobbles or boulders visible, though a lag surface may exist at depth. Relative contrasts in sand grain size exist among the various compartments of the foreshore and backshore zone. The berm sand is coarser than that of the beachface but the steep berm foreslope is finer, and the low tide terrace's accretionary veneer is finer still.

The spit end of Crescent Surf Beach has been accreting for several years so that there is a large sparsely vegetated berm at the spit end which supports at least sixteen nesting least terns and numerous nesting piping plovers. Behind the actively growing frontal dune ridge of the spit end is a thickly vegetated portion which has accreted seaward in past years. This is indicated by a relict double frontal dune ridge several meters behind the active ridge.

There are no high relief or active parabolic dunes and only a few very low relief parabolic dunes formed by northwest winds at Crescent Surf.

Description of Botanical Features

Because of the long accretionary history of Crescent, specific plant associations occur which are related to the variety of accretionary features. The two extremes are the recently accreted spit end and the stable far back dune. In the far back dune there is a pitch pine and hardwood forest which contains many common upland forest species.

The last 1500 meters of the back dune edge at the spit end, however, is not forested. This suggests shoreline instability at the spit end but may also be due to salt spray from the Little River or insufficient depth of dune sand above the salt water table. There are a few patches of Beach Heather (Hudsonia tomentosa) at the southwest end of the forest, as well as a few patches of Cladonia lichens on the open dunes with depauperate American Beach Grass (Ammophila breviligulata). Along the southern edge of the forest, among a semi-open pitch pine canopy, are patches of Cladonia lichens, Greene's Rush (Juncus Greenei), Sandy Sedge (Carex silicea) and Earthstar Puffball (Geaster hygrometricus), along with creeping pitch pine branches and mats. There are numerous specimens of Wormwood (Artemisia caudata) in the healthy Ammophila zone between the frontal dune ridge and the forest edge, open dune associations.

There is an abundance of Seabeach Sandwort (Arenaria peploides) on the berm especially along the low seawall at the northeast end.

A partial species list follows:

1. Seabeach Sandwort - Arenaria peploides
2. American Beach Grass - Ammophila breviligulata
3. Dusty Miller - Artemisia Stelleriana
4. Seaside Rose - Rosa rugosa
5. Beach Pea - Lathyrus japonicus
6. Raspberry - Rubus idaeus
7. Bayberry - Myrica pensylvanica
8. Barberry - Berberis sp.
9. Yarrow - Achillea millefolium
10. Wormwood - Artemisia caudata
11. Evening Primrose - Oenothera sp.
12. Beach Heather - Hudsonia tomentosa
13. Morning Glory - Convolvulus sepium
14. Juniper - Juniperus communis var. depressa

15. Pitch Pine – Pinus rigida
16. Sandy Sedge – Carex silicea
17. Pinweed Aster – Aster linariifolius
18. Lichens – Cladonia spp.
19. Earthstar Puffball – Geaster hygrometricus
20. Greene's Rush – Juncus Greenei
21. Pinweed – Lechea maritima

Summary of Significant Features

A. Geological

1. Comprises, with Laudholm Beach, the best remaining natural example of a double barrier spit (reentrant) salt marsh system.
2. The entire proposed critical area is accretionary; the aeolian ramp, berm, and beachface are all wide and well-developed.
3. The entire beachface and dune ridge area is sandy, no rocky storm berm or visible rocky lag surface.
4. The spit end has accreted historically and is presently accreting very rapidly. There is a relict dune ridge behind the spit end.
5. A few very low relief parabolic dunes behind the spit end.

B. Botanical

1. Presence of Beach Heather – a fragile back dune cover species which dominates a specialized habitat (intermediate succession on coastal back dunes between Ammophila stage and shrub stage, a pre-soil community species). Probably less than 40 hectares of Hudsonia cover exist in the state.
2. Presence of Wormwood – an occasional biennial plant on southern Maine beaches in among healthy Ammophila and in disturbed or gravelly areas of the back dune. This is not an important cover species but it reaches its northern coastal range limit at Cape Elizabeth. All specimens on southern Maine beaches are important because they are near the northern range limit of the plant and provide an important geographic link.
3. Presence of Seabeach Sandwort – the largest stand of this berm plant yet observed on a sandy Maine beach is found at the north end of Crescent Surf.
4. Good examples of undisturbed open and semi-open dry dune association – Cladonia lichens, Beach Heather, Earthstar Puffball, Pinweed, and a Pitch Pine mat growth.
5. Presence of Earthstar Puffball – found on only a few coastal dune areas of Maine.

C. Size

The size of this area is 17 hectares.

Parsons Beach - Kennebunk, York County

Description of Geological Features

Parsons Beach is a small barrier spit and salt marsh complex (Figure 23). Such beaches are significant because of their role in protecting the salt marsh behind them. Despite the relatively small size of the Parsons Beach system (151 hectares) more than 100 hectares of salt marsh are associated with Back Creek and the Mousam River.

The spit end of Parsons Beach is to the northeast, where the Mousam River drains out. The spit orientation suggests that the net downdrift end of the beach is to the northeast, but there are three features which make this conclusion difficult.

1. Presence of a stratified glacial drift source, actively eroding, on the opposite side of the Mousam River mouth.
2. Increasing fineness of beachface material from distal to proximal end of spit, that is, away from the spit end.
3. Opposite orientation of Crescent Surf barrier spit (spit end is to the southwest).

Redistribution of the eroded sediments from Great Hill, the bluff composed of drift deposit, has occurred in a southwesterly direction, since sand on the beachface becomes increasingly coarse and the amount of cobbles and boulders increases from southwest to northeast. The apparent contradiction between downdrift direction and the location and orientation of the spit ends of small barrier spit beaches may be evidence that the presence of a flowing river is the determinant for the spit end location. In all instances of beaches associated with rivers along the coast of Maine, the spit end is oriented toward the river outlet, even when it is located directly adjacent to a headland. This situation contrasts with that of tidal reentrants, whose location is more ephemeral.

Because an eroding source of sand is directly adjacent and a low seawall has been built to protect summer cottages, Parsons Beach has variable beach profiles and grain size along its length. Also, the summer home construction behind the seawall has obliterated any frontal dune and back dune features at that site.

In front of the seawall, toward the southwestern and downdrift end of the beach, the beach profile is 150 m wide, low angle, mature and of the constructional type. Although accretion has occurred on the beachface, the berm is narrow and there is no aeolian ramp. This is because the seawall and house sit where these features would form. The sand at this end of the beach is white, quartz-rich and fine-grained with no rocks. The beachface profile 50 m to the northeast of the seawall is less mature; it has a double ridge and ramp, frontal dune scarp, and frontal dune ridge as high as 2 m. Behind the aeolian ramp and frontal dune ridge, in this section, are stabilized parabolic dunes up to 2.6 m high. Because sand transport by wind and sand supply are low, there are only a few stabilized parabolic dunes in the Parsons beach back dune area. Periodic erosion of the frontal dune ridge has exposed a cobble-boulder storm berm which underlies the wind-derived accumulation. Here and generally along the unaltered portion, garnet layers are preserved beneath the aeolian ramp. Being further updrift, the beachface is characterized by medium-coarse sand and dark minerals.

The general features described for the area north of the seawall persist along the length of the beach toward the northeast. In addition, there are gradational changes in some features in the northeast direction. Pebbles occupy the lower parts of the berm and steep berm foreslope, but are replaced by heavier cobble in the more northeastern end where erosion exposes cobbles on the low-tide terrace. The low-tide terrace is convex up and sandy at central regions, but becomes more cobbled, still remaining convex up, toward the spit end. The beachface width increases from 150 to 500 m between the end of the seawall and close to the spit end. Where the spit end of Parsons Beach extends into the Mousam River the low tide terrace is 500 m wide. The sand becomes increasingly coarser from southwest to northeast and the amount of cobbles and boulders increases toward the source of eroding glacial drift.

Botanical Features

Parsons Beach has a large edaphic climax pitch pine forest at the south end with many of the species listed for this forest type in the Popham Beach description. The low relief, stabilized, open parabolic dunes provide for characteristic associations of Beach Heather (*Hudsonia tomentosa*), Lichens (*Cladonia* sp.), Low Sweet Blueberry (*Vaccinium angustifolium*), Wormwood (*Artemisia caudata*), Sandy Sedge (*Carex silicea*), Beach Pea (*Lathyrus japonicus*), American Beach Grass (*Ammophila breviligulata*), and Seaside Rose (*Rosa rugosa*). The presence of Wormwood is noteworthy for it is an uncommon species in Maine which reaches its northern coast limit at Cape Elizabeth.

The presence of Starry False Solomon's Seal (*Smilacina stellata*) in the open parabolic dune association is unusual.

A partial list of species follows:

1. Nightshade – *Solanum dulcamara*
2. American Beach Grass – *Ammophila breviligulata*
3. Dusty Miller – *Artemisia Stelleriana*
4. Seabeach Orach – *Atriplex* sp.
5. Sea Rocket – *Cakile edentula*
6. Saltwort – *Salsola kali*
7. Beach Pea – *Lathyrus japonicus*
8. Seaside Rose – *Rosa rugosa*
9. Quack Grass – *Agropyron repens*
10. Seabeach Sandwort – *Arenaria peploides*
11. Pitch Pine – *Pinus rigida*
12. Swamp Fly Honeysuckle – *Lonicera oblongifolia*
13. Poplar – *Populus tremuloides*
14. Juniper – *Juniperus communus* var. *depressa*
15. Great Angelica – *Angelica atropurpurea*

16. Evening Primrose – *Oenothera* sp.
17. Campion – *Lychnis* sp. or *Silene* sp.
18. Lichens – *Cladonia* spp.
19. Beach Heather – *Hudsonia tomentosa*
20. Low Sweet Blueberry – *Vaccinium angustifolium*
21. Sandy Sedge – *Carex silicea*
22. Wormwood – *Artemisia caudata*
23. Yarrow – *Achillea millefolium*
24. British Soldiers – *Cladonia cristatella*
25. Chickweed – *Cerastium arvense*
26. Pinweed Aster – *Aster linariifolius*
27. Pinweed – *Lechea maritima*
28. Sheep Sorrell – *Rumex Acetosella*
29. Brown Foliose Lichen – *Cetraria islandica*
30. Goldenrod – *Solidago rugosa*
31. Starry False Solomon's Seal – *Smilacina stellata*
32. Bayberry – *Myrica pensylvanica*

Summary of Significant Features

A. Geological

1. The low-tide terrace width is accentuated from 150 m to 500 m moving northeast closer to the sandy spit end.
2. The presence of the seawalls, the frontal dune scarp along the entire beach, the garnet layers beneath the frontal dune scarp and the lag surface exposures all indicate a history of shoreline recession and beachface erosion. This contrasts with the accretionary state of Crescent Surf Beach nearby.
3. Garnet layers are preserved beneath the aeolian ramp.
4. Beach profiles and grain size are variable, including:
   a. Double ridge and runnel.
   b. Flat convex upward beachface (with both seasonal berm and steep upper beachface).
5. Northwest-oriented, stabilized parabolic dunes up to 2.5 m high at the west end of the unaltered portion of beach.
6. Rocky storm berm beneath sandy frontal dune ridge at northeast end.
7. Rocky lag surface beneath berm and beachface is exposed on the low tide terrace.
8. Beach as a whole is a small barrier spit and marsh complex, which protects a salt marsh behind it.
9. Spit end is to the northeast, where the Mousam River drains out. This would suggest that the downdrift end of the beach is to the northeast, but other evidence suggests the downdrift direction is to the southwest.

B. Botanical

1. Good examples of stabilized, parabolic dune associations.

2. Presence of Wormwood (Artemisia caudata) which is an uncommon species in Maine and reaches its northern coastal range limit at Cape Elizabeth.

3. Presence of Starry False Solomon's Seal (Smilacina stellata) in the parabolic dune association where it is not usually found.

C. Size

The entire beach system is 151 hectares, including 100 hectares of salt marsh. The beach area consists of 13 hectares.

Goose Rocks Spit End – Kennebunkport, York County

Description of Geological Features

Goose Rocks Beach (Figure 24), with an area of 202 hectares is one of the largest beach systems in Maine. The only undeveloped portion of the 3.14 km long frontal dune/back dune area is the spit end.

The Goose Rocks Spit is one of the best examples in Maine of a broadly and perennially accreting spit end. Long-term accretion is indicated by a relict erosional scarp and buried seawall line near the King's Highway. Recent accretion is evidenced by the sparsely vegetated berm (Dusty Miller [Artemisia Stelleriana], American Beach Grass [Ammophila breviligulata], Sea Rocket [Cakile edentula], Saltwort [Salsola kali], and others) which is a new nesting area for least terns and piping plovers.

Some ebb-tidal delta features of the Batson River (a tidal reentrant) are of significance and constitute good examples of the interaction between tidal currents and the distribution of sand at the spit end of a beach. The spit end is part of a barrier spit which includes a back-barrier tidal river and salt marsh. Meandering of the ebb-tidal channels of the Batson River is responsible for the instability of the spit end.

Summary of Significant Features

A. Geological

1. One of best examples in Maine of a perennially accreting spit end.

2. Both long-term and recent accretion have occurred.

3. Perennial accretionary features form ideal nesting habitat for least terns and piping plovers.

B. Botanical

1. Good example of plant associations occurring on perennial accretionary area and plant succession in areas characterized by long-term sand accumulation.

C. Size

The entire beach system is 202 hectares, which includes the 8.5 hectares of the spit end adjacent to the Batson River.

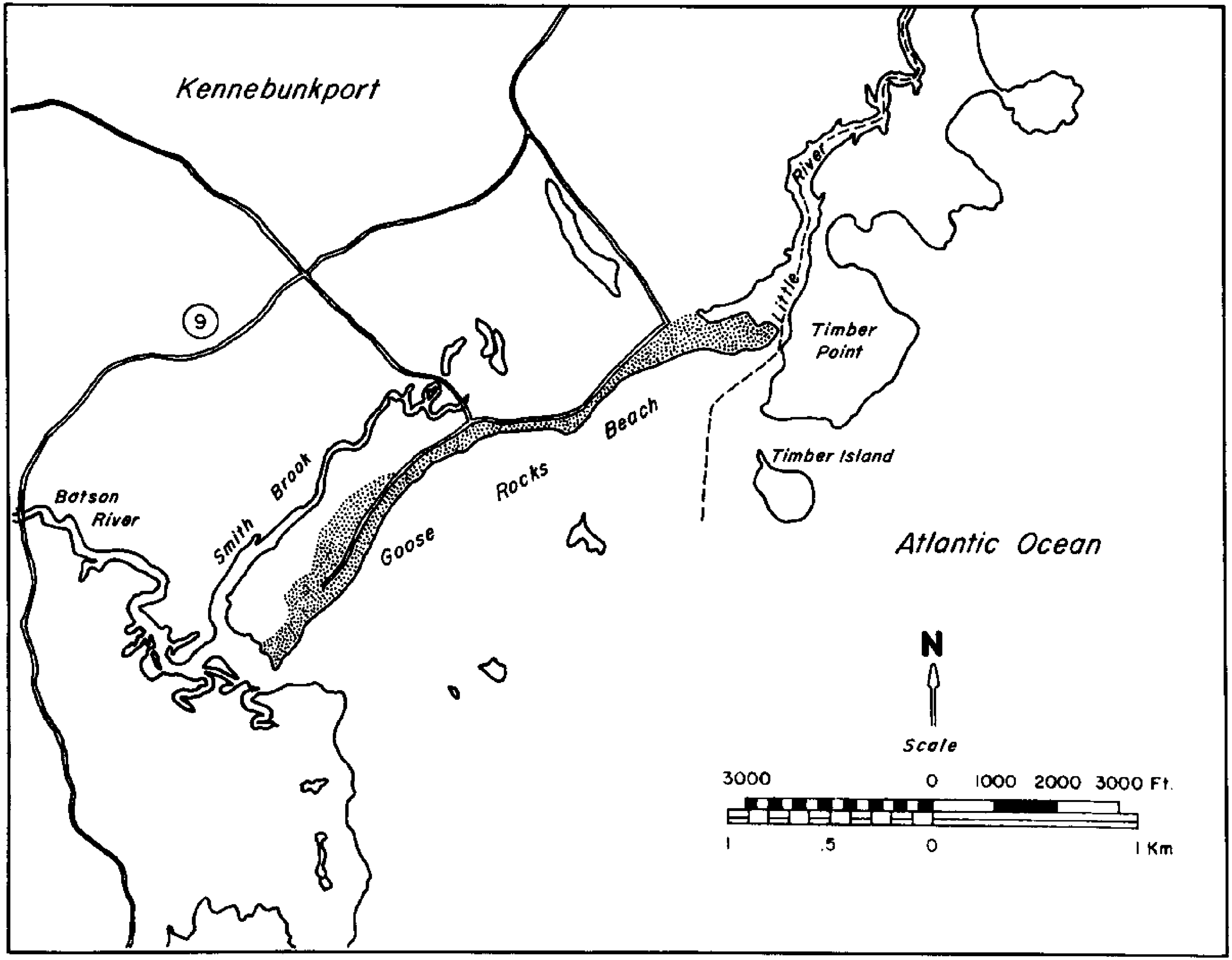


Figure 24 Goose Rocks Beach

Western Beach — Scarborough, Cumberland County

Description of Geological Features

Western Beach, located at the mouth of the Scarborough River (Figure 25), is of the fringing pocket type. The most striking geological feature of Western Beach is its accretionary state. Local residents can recall the time, a few decades ago, when the shoreline was about 70 m landward of its present position. The former location is indicated by the presence of a relict erosional scarp which runs along the forest and lawn, just seaward (southwest) of a golf course clubhouse, for about 300 m. Immediately seaward or southwest of the frontal dune scarp are a succession of three frontal dune ridges which include two relict frontal dune ridges and the present, active ridge. The successional ridges are separated by a few to tens of meters. Seaward of the active ridge is a large perennially accreting berm and aeolian ramp actively being invaded by American Beach Grass (Ammophila breviligulata).

Accretion has been and continues to be greatest along the southeast half of Western Beach. The uneven nature of historical accretion can be seen in the non-parallel configuration of the relict frontal dune ridges. The truncation of the older relict frontal dune ridge by the younger frontal dune ridge suggests an erosional interlude within the general accretive history.

A possible source of sand for the exceptional accretion may be Pine Point (Figure 25) which is directly across from Western Beach on the other side of the Scarborough River. Pine Point accreted northeastward as a result of the natural closing of the Little River's flood tidal delta, bypassed this area and moved northeast by littoral drift. Inlet closure took place between 1871 and 1875. By 1923 Pine Point had grown 550 m closer to Fury Rock, constricting the Scarborough River inlet. By 1953 significant accretion was taking place at Western Beach on the opposite shore.

The northwest half of the rear boundary of Western Beach's dune field is lined with parabolic dunes which were formed by northwest winds. The parabolic dunes seem to have obliterated the erosional scarp which is so evident on the southeast end of the landward boundary of the accretionary area.

The sand of Western Beach is fine, well sorted, white (quartz-rich), and appears to be finer at the southeast end. The gradational change suggests that the net drift is southeast toward Prout's Neck. The large low-tide terrace with its bars and ripple bedforms is part of the complex ebb-tidal delta of the Scarborough River.

The moderate steepness of the beachface may be due to the longshore movement of the tidal currents through the Scarborough River Inlet.

Description of Botanical Features

The effects of sand burial, accretion, dune age and blowout history are all visible in the floristic patterns of Western Beach. Five areas are distinguishable on the basis of botanical-geological interaction:

1. The seasonal berm is sparsely vegetated with annuals, e.g. Saltwort (Salsola kali) and Sea Rocket (Cakile edentula).
2. The perennially accreting berm and broad aeolian ramp are rapidly being invaded by rhizomes and new shoots of American Beach Grass (Ammophila breviligulata) and by Dusty Miller (Artemisia Stelleriana).
3. The actively building frontal dune ridge is a good site for observing how American Beach Grass thrives when buried by windblown sand. The frontal dune ridge builds quickly because prevailing winds are from the western half of the compass.
4. Relict ridges and swales are vegetated by depauperate American Beach Grass, the result of lack of sand burial. In a few more decades Beach Heather (Hudsonia tomentosa) may move into this environment. Some of the plants usually associated with Beach Heather are already here — Greene's Rush (Juncus Greenei) and Haircap Moss (Polytrichum sp.), for example. A Bird's Nest Fungus (Nidularia sp.) was found growing here on dead American Beach Grass culms and leaves.
5. Stabilized parabolic dunes and deflation slacks are vegetated by a healthy cover of Beach Heather (Hudsonia tomentosa). Healthy carpets of lichens (Cladonia spp.) and Cetraria islandica grow here, as well as isolated Pitch Pines (Pinus rigida) and Bayberry (Myrica pensylvanica). Pinweed (Lechea maritima), Wormwood (Artemisia caudata) and Sandy Sedge (Carex silicea) complete the assemblage in this floristic pattern.

A partial list of plant species follows:

1. American Beach Grass — Ammophila breviligulata
2. Dusty Miller — Artemisia stelleriana
3. Beach Pea — Lathyrus japonicus
4. Sea Rocket — Cakile edentula
5. Saltwort — Salsola kali
6. Greene's Rush — Juncus Greenei
7. Beach Heather — Hudsonia tomentosa
8. Bayberry — Myrica pensylvanica
9. Pitch Pine — Pinus rigida
10. Sandy Sedge — Carex silicea
11. Wormwood — Artemisia caudata
12. Lichens — Cladonia sp.
13. Iceland Moss — Cetraria islandica
14. Bird's Nest Fungus — Nidularia sp.

Summary of Significant Features

A. Geological

1. Accretion of beach seaward from historical erosional scarp.
2. Accretionary ridge and swale topography.
3. Good northwest-wind-oriented, stabilized parabolic dunes behind the historical erosional limit.

4. Presently accreting berm over most of the length.
5. Process of frontal dune ridge formation is evident; ridge faces the prevailing wind.
6. Beachface variable in slope width and shape.
7. Finer grained white, quartz-rich sand at southeast end (suggesting downdrift direction).
8. Good illustration of various bedforms, ripples, and ebb-tidal delta features.
9. Example of association between historical instability (accretion) and proximity to a tidal inlet.
10. A fringing beach, not associated with a salt marsh.

B. Botanical

1. Sharp delineation between historically stable and unstable areas (wave erosion). No Beach Heather (*Hudsonia tomentosa*) plants occur seaward of the oldest historical erosional limit.
2. Good Beach Heather (*Hudsonia tomentosa*) patches stabilizing old parabolic dunes and deflation slacks. Also good lichen cover (*Cladonia* spp.) and *Cetraria islandica*.
3. Presence of Wormwood (*Artemisia caudata*), an uncommon plant in Maine which reaches its northern coastal range limit at Cape Elizabeth.

C. Size

The entire beach area is 11 hectares. The area vegetated by dune plants is 9 hectares.

Scarborough Beach - Scarborough, Cumberland County

Description of Geological Features

While Scarborough Beach (Figure 25) appears to be of the closed barrier type now, it may formerly have been an open barrier type, protecting a back-barrier lagoon and salt marsh. The extensive narrow-leaved cattail stands in freshwater Massacre Pond suggest that this area was once a salt marsh and mud flat. Coring a few meters below the cattails should reveal marine clay and silt or salt marsh peat if this interpretation is correct. Whether the former inlet was located at the southwest or the northeast end of Massacre Pond is problematical. Old topographic maps indicate a man-made channel between the pond and the sea at the southwest end where the separation is least. However, the indicated downdrift direction would place the inlet at the northeast end.

An interesting geological feature of the beach is its illustration of the various ways in which grossly different grain size classes are separated into distinct layers, zones, and morphological features by wave, current, and wind transport

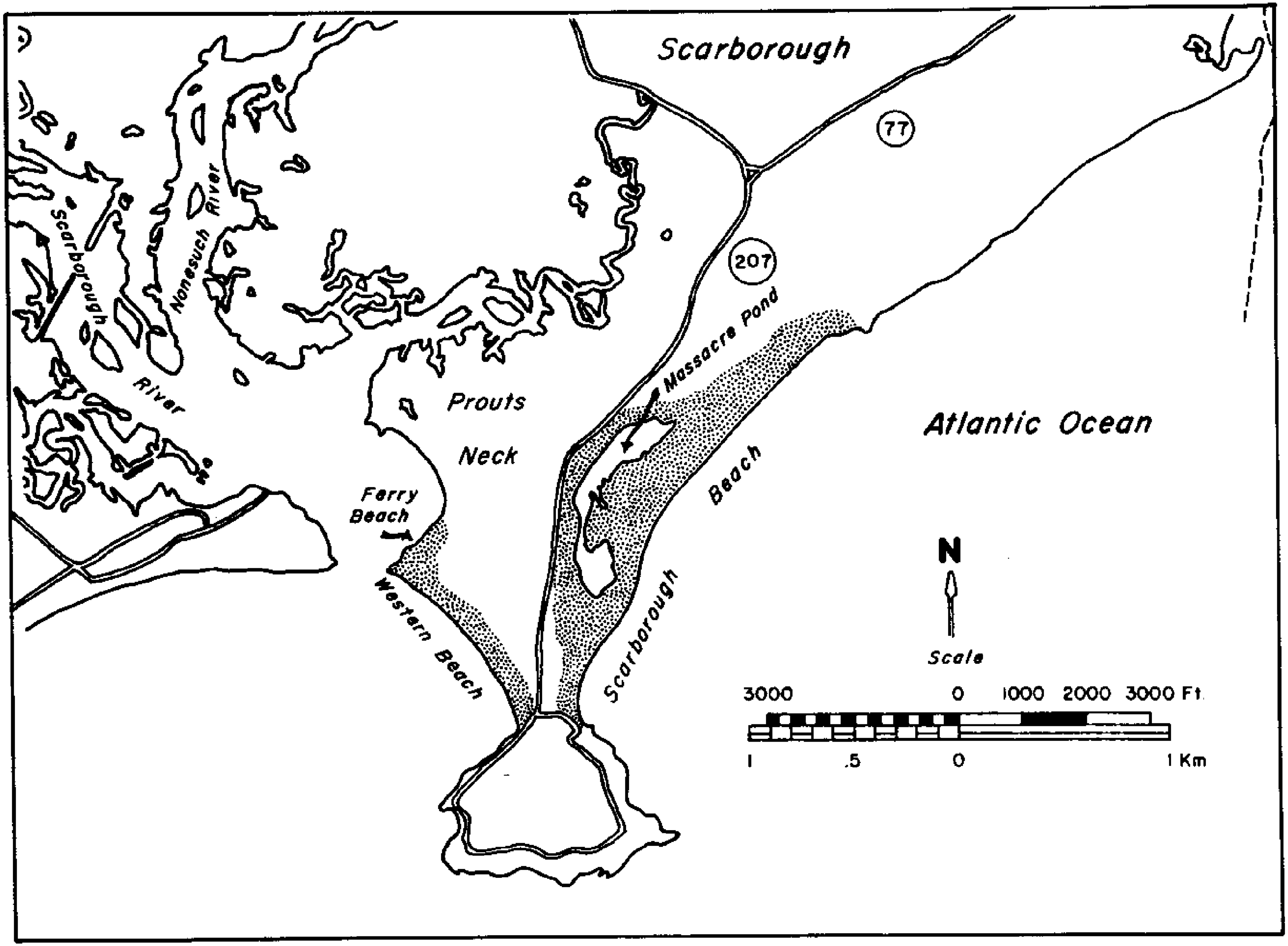


Figure 25 Western and Scarborough Beaches

processes. Both erosion and accretion are occurring and serve to expose the size separations and emphasize the seasonal effects of the transport mechanisms. Although the southwest end is generally erosional and the northeast end, beginning at the Pierce House, lot #38, is accretionary, seasonal differences in wave energy and processes are apparent.

The seasonal nature of erosion along most of the length of the beach is indicated by the association of an erosional scarp and a sandy berm. This association suggests that where the scarp occurs, it is a minor, seasonal recession. The erosion was drastic enough in 1977, however, to fractionate out garnet sand which remains visible in a layer below the eroded scarp along the central portion of the beach. Further evidence of periodic higher energy conditions, probably during the storm season, is seen where erosion has revealed a rocky storm berm beneath the sandy erosional scarp, a boulder ramp underlying the sandy berm topset beds, and relict rocky cusps partially buried by the seasonal sandy berm. In many places, the low-tide terrace is eroded down to a lag pavement of boulders, cobbles, and pebbles. This pavement represents the limit of past erosion and is the level to which many large, heavy stones have settled when erosion has removed sand around and beneath them.

While the central and southwest parts of the beach are erosional and more large grains occur here, including cobbles and boulders, the northeast end is accretionary and is enriched in medium and fine-grained sand. The contrast in grain size also indicates the short- or long-term net drift of sediment toward the northeast due to uneven wave energy, wave approach angle, or longshore currents established by onshore southwest-wind stresses. Where the perennial accretion has occurred, one can observe active frontal dune ridge formation, invasion of a broad, aeolian ramp by American Beach Grass (Ammophila breviligulata), and the perennially accreting berm.

Protruding from the low tide terrace near the base of the berm foreslope about 480 m northeast of the state-owned access road, is an exposure of salt marsh peat. Leaves of Salt Marsh Cord Grass (Spartina alterniflora) are identifiable in this peat exposure. The occurrence of peat indicates that:

1. Scarborough Beach was once an open barrier with a back-barrier lagoon and salt marsh.
2. Sea level has risen since that time, which may be as long ago as 4,000 years.
3. The dunes have retreated up and over the old salt marsh and the beachface has retreated as well.

The back dune and backside of the foredune at Scarborough show little relief and no accretionary ridge and swale topography (relict frontal dune ridges and berms). Between the state-owned access road and the Devens house (lot #3) are a few low relief parabolic dunes, formed by northwest winds and located close to the shore where they receive enough salt spray and windblown sand from the berm to be vegetated by healthy, thick American Beach Grass (Ammophila breviligulata).

Dry, semi-open dune flats are found in a narrow band between the tree line and the start of the broad backside of the foredune. A few indistinct, low relief short-flanked parabolic dunes and slacks, with good Beach Heather (Hudsonia tomentosa) cover, occur in this zone.

Wave overwash may be a significant form of intermittent supply of sand to the back dune area. Evidence for overwash is the presence of some large logs which appear to have been thrown up over the backside of the foredune in the center of the beach. The presence of a storm berm beneath the sandy frontal dune ridge at the southwest end of the beach means that waves have washed over the berm here in the past, before the frontal dune ridge last formed. An old dune breach channel now full of logs is located about 50 m northeast of the Kasdy house near the central part of the beach.

Description of Botanical Features

Scarborough Beach is remarkable for its high vegetational cover even in sensitive back dune environments. The prolific lichen cover here indicates little trampling. The zone of dry, semi-open dunes between the backside of the foredune and the shrub-tree line is vegetated by sparse American Beach Grass (Ammophila breviligulata) and frequent patches of Beach Heather (Hudsonia tomentosa). Also in this transition zone between healthy Beach Grass and shrubs are: Lichens (Cladonia spp.), Pinweed (Lechea maritima), Wormwood (Artemisia caudata), Sandy Sedge (Carex silicea), Sheep Sorrel (Rumex acetosella), Earthstar Puffball (Geaster hygrometricus), and Greene's Rush (Juncus Greenei).

The Earthstar Puffball (Geaster hygrometricus) is most abundant in two patches of semi-open Pitch Pine (Pinus rigida) forest edge with bare sand, due to foot traffic. One patch is northwest of the Devens house (lot #3), the other more extensive patch is southwest of the state-owned access road. The consistent association of Earthstar and Pitch Pines may be the result of a mycorrhizol relationship. The latter Earthstar site is noteworthy for its Pitch Pine on low relief hummocky (probably parabolic) dunes. The Pitch Pines here show good examples of salt-spray-induced growth form of creeping lower branches.

All along the shrub-tree line salt spray dieback is evident on the southwest side of hardwoods. Isolated Prunus, Amelanchier and Pinus rigida are flagged by prevailing southwest winds which carry salt spray into the back dune area.

Seaward to landward zonation is dominant over mosaic floristic patterns at Scarborough Beach; this is due to the lack of high-relief parabolic dunes. The zones in evidence, with their dominant plant species, are:

1. Berm and aeolian ramp: annual berm colonizers, American Beach Grass (Ammophila breviligulata) and Dusty Miller (Artemisia Stelleriana).
2. Eroded foredune and its backslope: American Beach Grass (Ammophila breviligulata), Beach Pea (Lathyrus japonicus), Wormwood (Artemisia caudata).
3. Semi-open aeolian flats: American Beach Grass (Ammophila breviligulata), Beach Heather (Hudsonia tomentosa), Licens (Cladonia spp.), Pinweed (Lechea maritima), Wormwood (Artemisia caudata), Sandy Sedge (Carex silicea), Sheep sorrel (Rumex acetosella), Earthstar Puffball (Geaster hygrometricus), and Greene's Rush (Juncus Greenei).
4. Shurb-tree line: Bayberry (Myrica pensylvanica), Pitch Pine (Pinus rigida) and upland hardwoods.

A partial list of species follows:

1. American Beach Grass – _Ammophila breviligulata_
2. Beach Pea – _Lathyrus japonicus_
3. Dusty Miller – _Artemisia Stelleriana_
4. Wormwood – _Artemisia caudata_
5. Sheep Sorrel – _Rumex Acetosella_
6. Joint Weed – _Polygonella articulata_
7. Pinweed Aster – _Aster linariifolius_
8. Pinweed – _Lechea maritima_
9. Beach Heather – _Hudsonia tomentosa_
10. Goldenrod – _Solidago rugosa_
11. Seaside Rose – _Rosa rugosa_
12. Yarrow – _Achillea millefolium_
13. Saltwort – _Salsola kali_
14. Sea Rocket – _Cakile edentula_
15. Orach – _Atriplex patula_ var. _hastata_ or _A. arenaria_ or _Chenopodium rubrum_
16. Sea Blight – _Suaeda maritima_
17. Lichens – _Cladonia_ spp.
18. Earthstar Puffball – _Geaster hygrometricus_
19. Bayberry – _Myrica pensylvanica_
20. Pitch Pine – _Pinus rigida_
21. Shadbush – _Amelanchier_ sp.
22. Cherry – _Prunus_ sp. (not _maritima_)
23. Greene's Rush – _Juncus Greenei_

Summary of Significant Features

A. Geological

1. Stable or only slowly eroding, historically.
2. Ridge and runnel beach profile.
3. Rocky storm berm overlain by sandy frontal dune ridge at southwest end.
4. Rocky cusps.
5. Wide range of grain size classes segregated into various features on different parts of beach profiles (e.g. lag surface, cusps, coarse berm foreslope).
6. Garnet fractionation by wave erosion.
7. Accreting berm and aeolian ramp at northeast end.
8. Finer grained at northeast end, probable downdrift direction due to uneven wave energy along beach, wave approach angle or alongshore currents caused by onshore southwest-wind stress.
9. Rocky lag surface along most of low tide terrace.
10. Salt marsh peat exposure.
11. Probable former marine lagoon or salt marsh (Massacre Pond).

12. Low-relief parabolic dunes.
13. Washover accretion and breach.

B. Botanical

1. Presence of Earthstar Puffball (Geaster hygrometricus), an uncommon species in Maine.
2. Presence of Wormwood (Artemisia caudata), an uncommon species in Maine which reaches its northern coastal range limit at Cape Elizabeth.
3. Good stands of Beach Heather (Hudsonia tomentosa) and associated species. There are probably less than 40 hectares of Beach Heather in the state. It is more sensitive to foot traffic damage than American Beach Grass because it is slow growing. It takes decades to naturally invade a parabolic dune slack or old back dune flat.
4. Exceptionally good percentage of cover of vegetation — little foot or vehicular damage.
5. Good stands of semi-open Pitch Pine forest on hummocky dunes, illustrates creeping lower branches growth habit.

C. Size of Area

The entire beach system includes 55 hectares.

Main Beach - Cape Elizabeth, Cumberland County

Description of Geological Features

Main beach is of the fringing pocket type with a relatively stable shoreline position and large back dune area disproportionate to its length. The shoreline is fairly straight with minor irregularities due to wave refraction around nearshore bedrock outcrops. Both the seasonal and perennial beach profiles are very variable (Figure 26).

The single frontal dune ridge, of moderate height (1 to 2 m above high water), has a winter storm erosional scarp which heals annually during the summer sand buildup. Although the summer profile is definitely constructional, no flat berm develops. The steep aeolian ramp below the foredune is being colonized by American Beach Grass (Ammophila breviligulata). Despite the fine grain size of the sand, the beachface is continuous with the aeolian ramp and is variably steep throughout.

A band of level back dune, about 110 m wide, extends the length of the beach and includes a large freshwater marsh area which is periodically filled with seawater during winter storms by dune washover and exchange through an artificial channel cut in the frontal dune ridge. Two other low areas, in the drainage from Japanese Pond, support a large stand of Blue Flag (Iris versicolor) and a mixed hardwood-softwood forest.

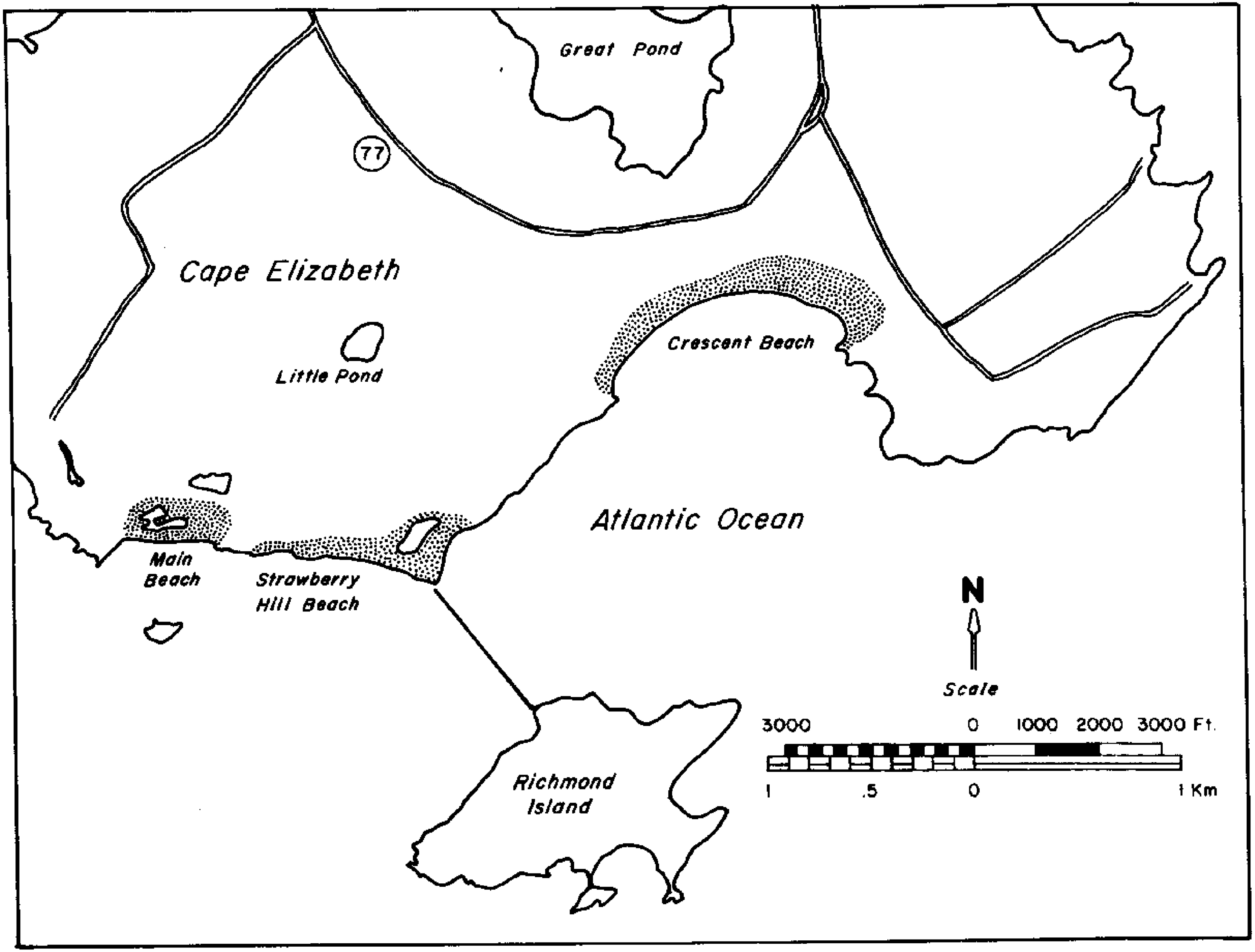


Figure 26 Main Beach, Strawberry Hill Beach, Crescent Beach

The entire perimeter of the back dune acreage is ringed by precipitation dunes and parabolic dunes, many of which are not stabilized, as well as upland trees, shrubs and vines. The parabolic and precipitation dunes may represent a period of denudation of the source aeolian flats by grazing or fire. The highest parabolic dunes (up to 8 m high) are found along the eastern boundary of the proposed critical area. Their location and size are the result of the open wind fetch across the back dune area and the dominance of winds out of the west, especially winter northwest winds of high velocity.

The small precipitation dunes occur only along the northern perimeter of the back dune area and were formed by onshore or alongshore winds (south, southwest and west). The precipitation dunes owe their presence in the back of the dune field to protection from strong offshore winds (northeast, north, and northwest) by the adjacent upland area and forest.

The large parabolic dunes at the southwestern corner of the critical area are badly damaged by foot traffic erosion which enhances subsequent wind excavation. Active deposition of the excavated sand is visible on the leeward (eastern) apex ramps of these dunes.

Description of Botanical Features

Main Beach has good examples of undisturbed back dune plant associations on both the back dune flat and the stable parabolic dunes. Large patches of Beach Heather (*Hudsonia tomentosa*), Greene's Rush (*Juncus Greenei*) and Sandy Sedge (*Carex silicea*) are found here. Circular patches of Meadowsweet (*Spiraea latifolia*) and Bayberry (*Myrica pensylvanica*) appear to be expanding and some of these shrub patches have exclusion rings around them. A few Pitch Pines (*Pinus rigida*) and White Spruce (*Picea glauca*) grow singly on the open back dune flats and open parabolic dunes. Some White Spruces at the northeast corner of the proposed critical area have creeping lower branches, a result of wind and salt spray damage.

This beach has three species which are uncommon on coastal dunes north of Cape Elizabeth. They are Beach Plum (*Prunus maritima*), Wormwood (*Artemisia caudata*) and Climbing Bittersweet (*Celastrus scandens*).

Successional zonation, proceeding landward, is well illustrated in the back dune area. Five zones, which can be recognized, and their dominants are listed below:

1. Foredune and back side of foredune are dominated by American Beach Grass (*Ammophila breviligulata*) and Beach Pea (*Lathyrus japonicus*).
2. Dry back dune flats and stable open parabolic dunes dominated by Beach Heather (*Hudsonia tomentosa*), Sandy Sedge (*Carex silicea*) and Greene's Rush (*Juncus Greenei*).
3. Low shrubs in patches and fringing forest are dominated by Meadowsweet (*Spiraea latifolia*), Bayberry (*Myrica pensylvanica*) and Raspberry (*Rubus* sp.).
4. Low trees of fringing forest are dominated by Cherry (*Prunus* sp.) and Shadbush (*Amelanchier* sp.), also some isolated Pitch Pine (*Pinus rigida*) and White Spruce (*Picea glauca*).

5. Mixed hardwood-softwood in low area of northern portion of proposed critical area.

Summary of Significant Features

A. Geological

1. Good examples of precipitation dunes, found rarely on Maine beaches.
2. High parabolic dunes, both active and stabilized.
3. Good example of influence of local upland topography on the effect of wind on dune behavior.
4. Good laboratory for study of natural response of a pocket beach after an attempt to create a channel and harbor behind the frontal dune ridge.
5. Large back dune area for the length of the beach – suggests long-term shoreline stability and abundant sediment supply.
6. Beachface disproportionately steep for the sand grain size.

B. Botanical

1. Possible northernmost stand of Beach Plum (*Prunus maritima*) in coastal Maine.
2. Good examples of undisturbed back dune plant associations.
3. Large patches of Beach Heather (*Hudsonia tomentosa*).
4. Presence of Wormwood (*Artemisia caudata*).
5. Presence of Climbing Bittersweet (*Celastrus scandens*).
6. Good example of seaward to landward zonation.
7. Exceptional stand of Blue Flag (*Iris versicolor*).

C. Size

The size of this area is 9.7 hectares.

Strawberry Hill Beach – Cape Elizabeth, Cumberland County

Description of Geological Features

This beach is a natural cuspate foreland artificially enlarged by construction of a breakwater (ca. 1870) along a natural tombolo between Richmond Island and the beach (Figure 26).

The importance of summer southwest winds in determining the height of frontal dune ridges is well illustrated here. The southwest facing leg of this beach (cuspate foreland) has a frontal dune ridge about 4 m high, but the east facing side has a frontal dune ridge only 1 to 2 m high. The southwest facing side displays ridge and swale topography with relict frontal dune ridges and storm scarps which indicate a phase of accretion in the past. It is currently undergoing erosion as evidenced by wave erosion, density fractionation layers of heavy garnet sand on the upper beachface below the presently eroding scarp.

The east facing leg of the cuspate foreland is undergoing accretion. It has a broad berm and sparsely vegetated aeolian ramp which, together, extend 30 to 40 m seaward from the low, and only, frontal dune ridge. Winter wave runup onto the low frontal dune ridge, however, is indicated by the presence of seaweed and flotsam.

Strawberry Hill Beach is a good example of how erosion and accretion may take place at different times at the same location and how, at two adjacent locations, erosion and accretion occur simultaneously. These perennial changes occur despite a general rise in relative sea level in Maine and are a reminder of the cyclical nature of short-term beach processes even within a long-term transgressive regime.

There are no parabolic dunes on Strawberry Hill Beach and only one incipient deflation area (500 m^2) on the back side of the foredune of the southwest leg. The dependence of American Beach Grass (Ammophila breviligulata) on sand burial is well illustrated at this incipient deflation area where all the grass has died.

A 1-hectare freshwater pond (Dune Pond) is included in the critical area.

Description of Botanical Features

Strawberry Hill Beach provides an excellent example of six seaward to landward vegetational zones. The zones and their dominants are listed below.

1. Berm Annuals - Sea Rocket (Cakile edentula), Saltwort (Salsola kali).
2. Foredune and backside of foredune — American Beach Grass (Ammophila breviligulata), Beach Pea (Lathyrus japonicus), Poison Ivy (Rhus toxicodendron).
3. Dry back dune heath - Beach Heather (Hudsonia tomentosa), Sandy Sedge (Carex silicea), American Beach Grass (Ammophila breviligulata).
4. Shrub zone — Bayberry (Myrica pensylvanica), Meadowsweet (Spiraea latifolia), Raspberry (Rubus sp.).
5. Small trees - Cherry (Prunus spp.), Shadbush (Amelanchier sp.).
6. Mixed Hardwood-Softwood.

Some of the species found at the beach are listed below. Few shrub or tree species are listed.

1. Greene's Rush — Juncus Greenei
2. Sandy Sedge — Carex silicea
3. American Beach Grass — Ammophila breviligulata
4. Gooseberry — Ribes sp.
5. Beach Pea — Lathyrus japonicus
6. Poison Ivy — Rhus toxicodendron
7. Chickweed — Cerastium arvense

8. Bayberry – Myrica pensylvanica
9. Yarrow – Achillea millefolium
10. Seaside Rose – Rosa rugosa
11. Low or Pasture Rose – Rosa virginiana or carolina
12. Goldenrod – Solidago rugosa
13. Beach Heather – Hudsonia tomentosa
14. Wormwood – Artemisia caudata
15. Dusty Miller – Artemisia Stelleriana
16. Wild Ginseng – Aralia nudicaulis
17. Saltwort – Salsola kali
18. Sea Rocket – Cakile edentula
19. Blue Flag – Iris versicolor

Of the species noted, the most significant are Beach Heather (Hudsonia tomentosa) and Wormwood (Artemisia caudata); many examples of Artemisia caudata are located in the back dune and backside of the foredune. There is only one location further north on the coast where Wormwood is found. In addition, there are several large patches of Hudsonia, Carex, Juncus association relatively undisturbed by traffic.

A good stand of Blue Flag (Iris versicolor) is growing on the south shore of Dune Pond.

Summary of Significant Features

A. Geological

1. A natural cuspate foreland – uncommon beach type, but has been enlarged by the construction of a breakwater.
2. The importance of southwest vs. northeast winds in influencing the height of the frontal dune ridge is well illustrated.
3. One side of cuspate foreland is presently eroding; other side is accreting.
4. Accretionary ridge and swale topography.
5. Incipient wind deflation area in back dune.

B. Botanical

1. Presence of Wormwood (Artemisia caudata), only found at one other coastal site farther north.
2. Good stands of Beach Heather (Hudsonia tomentosa) and associated dry dune slack species.
3. Good stand of Blue Flag (Iris versicolor).
4. Good example of landward to seaward vegetational zonation.

C. Size

The size of this area is 12 hectares.

Crescent Beach - Cape Elizabeth, Cumberland County

Description of Geological Features

Crescent Beach (Figure 26) is a fringing pocket beach type. Two streams drain from small freshwater ponds through the dunes to the beachface. They are not tidal streams and are sometimes sealed off by summer berm accretion.

The frontal dune ridge at Crescent Beach State Park exhibits significant variations in height and cross-sectional area along its length. There is no frontal dune ridge at the eastern end. The western end has a moderately high ridge, and the central portion has the highest ridge. A broad seasonal berm forms only along the western three-quarters of the beach, whereas at the eastern end, the beachface is sediment starved and no berm accumulates.

The western half of Crescent Beach has the widest back dune and so appears to be the downdrift end of the system. Winter waves from the east and northeast are probably responsible for the net transport direction on this and many other Maine beaches (see wave rose, Figure 5).

Summer sea breezes blowing from the south to southwest set up small waves which winnow finer grain sand from the western end and transport it to the center of the beach. The winnowing effect which accompanies this short-term transport is visible as a change in sand grain size in the berm from medium-coarse at the western end to fine near the center of the beach. Though the eastern end is sediment starved in the long-term, it also accumulates on the summer beachface a veneer of fine sand derived from the western end. Short-term drift of sand from the western toward the central portion of the beach is also indicated by the presence there of a broad, fine-sand double berm. An open fetch to the sea permits waves to form a broader berm here and also permits strong south to southwest winds to pick up sand from the berm and create the highest portion of the frontal dune ridge here.

Crescent Beach illustrates very well the relative importance of two mechanisms of alongshore sand transport. The two mechanisms are: 1) strictly aeolian transport, and 2) wind, storm and fetch induced wave transport. Most of Maine's dry wind blows from the western half of the compass rose. Waves must approach from the eastern half of the compass and the southwest. The strongest waves approach from the east and northeast. If dry aeolian transport were the principal mechanism of alongshore sand movement, the eastern end of Crescent Beach would be sediment rich with a broad back dune field. The sediment starved state of the eastern end of the beach with no berm or dunes suggests that wave approach direction is far more important than alongshore dry wind transport in determining net drift direction on Maine beaches (Note: here, as on all Maine beaches, "drift direction" is used in an historical sense. The plan view of Crescent Beach has long since adjusted itself to the alongshore drift forces acting on it by accumulating sand at the western end. There is no "river of sand" running from east to west. If seasonal changes are ignored, Crescent Beach can be considered swash aligned).

The sand of Crescent Beach is derived from: 1) onshore transport of poorly sorted ice contact stratified drift deposits, 2) local bedrock headland erosion and alongshore transport into the embayment.

These sources are suggested by the low sand volume of the beach, the pebbles on the lower half of the beachface, the pebble cusp ridges exposed at the berm crest of the western end, the medium to coarse moderately-sorted sand, and the presence of soft minerals in the sand.

Overwash appears to be a relatively important form of sand transport into the area immediately behind the frontal dune ridge. This is indicated by the presence, behind the dune ridge, of Dusty Miller (Artemisia Stelleriana).

Description of Botanical Features

There are open dry dune plant associations (Hudsonia tomentosa, Cladonia sp., Juncus Greenei, Artemisia caudata, Lechea, Aster linariifolius, etc.) behind the main footpath of the western end of the beach.

The northern coastal range limit for Wormwood (Artemisia caudata) is at this beach. This plant is found on every undeveloped sandy beach with dunes south of Crescent Beach, though it always represents a small percentage of the biomass. This is the only range limit which has been precisely located and is so abrupt. This feature alone makes Crescent Beach one of the most significant dune plant habitats in the state.

The only other notable features are two small Hudsonia tomentosa patches east of the concession stand area, Dusty Miller in old overwashes, and Freshwater Cord Grass (Spartina pectinata) along the stream southwest of the parking lot.

A partial vegetational species list follows:

1. Freshwater Cord Grass – Spartina pectinata
*2. American Beach Grass – Ammophila breviligulata
*3. Wormwood – Artemisia caudata
*4. Beach Heather – Hudsonia tomentosa
5. Dusty Miller – Artemisia Stelleriana
6. Greene's Rush – Juncus Greenei
7. Sandy Sedge – Carex silicea
8. Pasture Grasses
9. Beach Pea – Lathyrus japonicus
10. Lichen – Cladonia spp.
11. Bayberry – Myrica pensylvanica
12. Pitch Pine – Pinus rigida
13. Pinweed Aster – Aster linariifolius
14. Evening Primrose – Oenothera sp.
15. Pinweed – Lechea maritima
16. Yarrow – Achillea millefolium

* indicates dominance in the area

Summary of Significant Features

A. Geological

1. Fringing pocket beach with two central beach stream outlets (non-tidal).
2. Low sand budget with dramatic summer buildup resulting in a wide berm.
3. Stable shoreline position.
4. The southwestern end is the long-term downdrift end. This is indicated by the width of the back dune, but the beach has finer sand toward the northeast, suggesting short-term downdrift toward the northeast.
5. Good illustration of seasonal accretionary profile.
6. Height of the frontal dune ridge is a function of width of the berm more than a function of the direction it faces.
7. There are no parabolic dunes, but there are good dry dune flats with associated dune plant species in the back dune.

B. Botanical

1. The northern coastal range limit of Wormwood (Artemisia caudata).
2. Good Beach Heather (Hudsonia tomentosa) patches and associated plants.
3. The presence of Freshwater Cord Grass (Spartina pectinata).
4. No pitch pines or semi-open community. (Not a positive feature.)
5. Good vegetation cover, no foot traffic damage, well managed.

C. Size

Crescent Beach State Park covers an area of 31 hectares and has a length of 1524 m.

Bailey Beach — Phippsburg, Sagadahoc County

Description of Geological Features

Bailey Beach (Figure 27) is a small fringing pocket beach (2.4 hectares) with a relatively wide back dune area for such a short beach. A large volume of sand has been blown onshore to cover low-lying bedrock upland. Exposure of a coarse cobble/boulder lag surface at the western end of the beach and the rapid grading to coarse sand beneath the lower beachface suggests that the shoreline has probably never been much further back than today. The sand appears to be locally derived and is not spillover from the Popham-Seawall system. This is indicated by the presence of a lag surface and the rapid grading, i.e. poor sorting, and high (feldspar + mica)/quartz ratio of the coarse grains. The source is probably:

1. Onshore transport from a small till or ice-contact stratified drift deposit, which was submerged by the Holocene rise of sea level.
2. Erosion of local bedrock headlands and their covering of glacial sand.

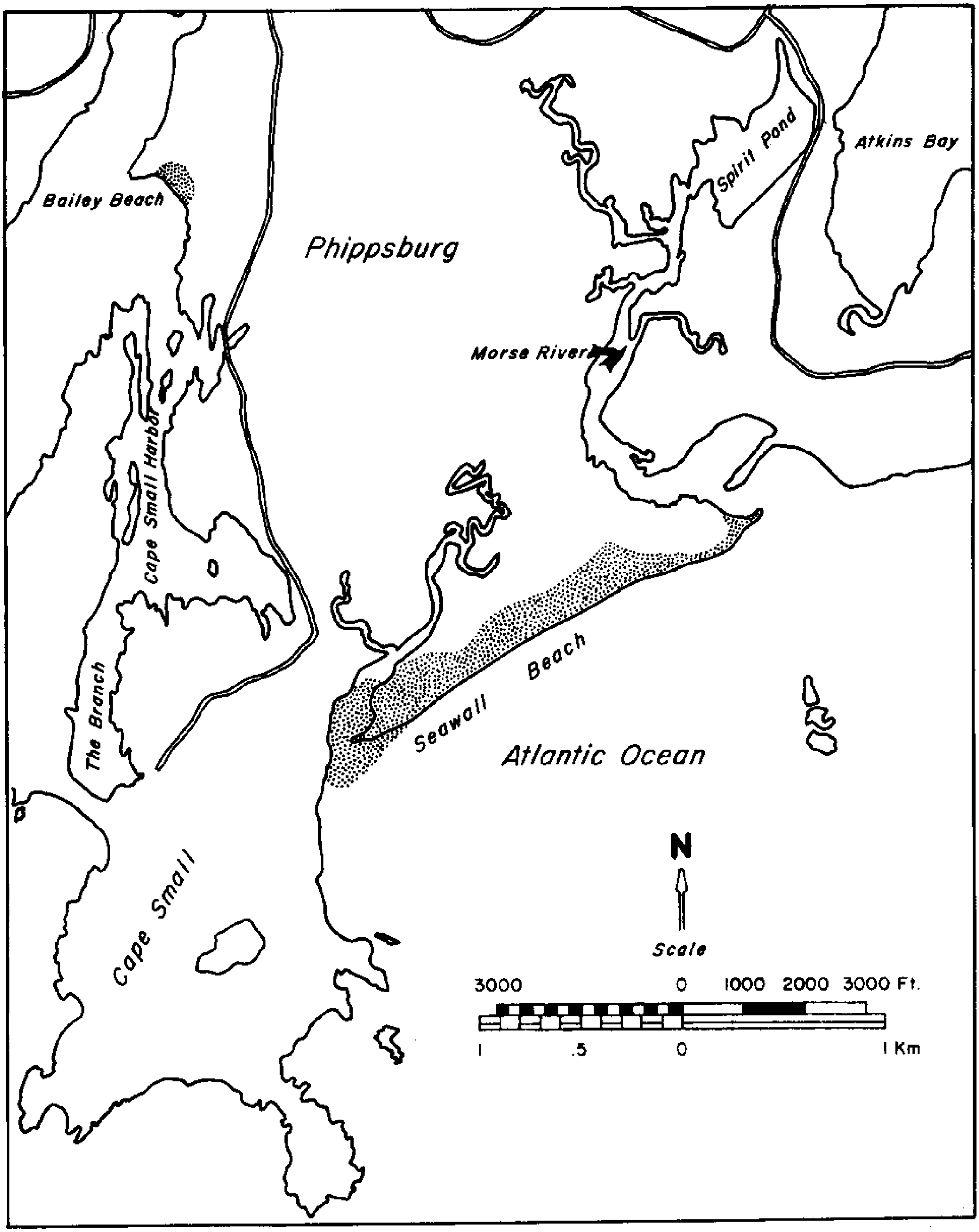


Figure 27 Seawall Beach, Bailey Beach

A marked variation in grain size is a significant feature of the beach. The following grain size gradations are recognizable:

1. Vertically, from an underlying lag unit to beachface surface.
2. Laterally, from west to east, a change from coarse to fine, suggesting some short-term drift of sand to the east.
3. Along the profile: coarse sand on lower beachface → less coarse sand on upper beachface → medium sand berm → medium and fine grain frontal dune ridge and seaward half of back dune → coarse grain wind-lag surface on landward half of back dune flat → medium and fine sand precipitation dunes at forest edge.

The most significant geological feature of Bailey Beach is the presence of large precipitation dunes at the forest edge. These are up to 4 m high and rim the shrub-tree line along the northern edge of the back dune area. Precipitation dunes are a rare geomorphic form in Maine and only this beach and Main Beach at Cape Elizabeth have precipitation dunes of any size. A lag surface has formed in the back dune area after many years of removal of finer sand to the precipitation dunes behind. The coarse grain wind-lag surface is unusual for a back dune area, especially on such a small beach well up in an embayment away from strong winds. The highest precipitation dunes are at the east end of the shrub-tree line where SW winds would deposit them after blowing across Casco Bay, north of Hermit Island and diagonally across the back dune.

The frontal dune ridge at Bailey Beach also has some unusual features which include relatively high relief (∿2 m), a stable position, and a very long back slope. These features indicate both a current sand source and the importance of wind transport in supplying the frontal dune ridge and back dune area with sand. An unhealed winter scarp remained along the length of the frontal dune ridge at the time of field checking, though recent, active building of the frontal dune ridge is evident at one point where the aeolian ramp reaches the crest. The berm is narrow (∿8 m) and the beachface is very steep. The reason for such a steep beachface is unknown and worthy of study.

Botanical Features

Seaward → Landward zonation is well illustrated at Bailey Beach. There is extremely good vegetational cover and a high number of species. The seaweed row is thick and abundant and is almost immediately followed by the beginning of the vegetational line. The berm and aeolian ramp are populated by Sea Rocket (Cakile edentula), Saltwort (Salsola kali), and Seabeach Orach (Chenopodium rubrum). On the frontal dune ridge are found Beach Pea (Lathyrus japonicus), American Beach Grass (Ammophila breviligulata), and Quack Grass (Agropyron repens). The succeeding area contains mainly Beach Grass (Ammophila breviligulata) and Meadowsweet (Spirea latifolia); however, Yarrow (Achillea millefolium), Blueberry (Vaccinium angustifolium), Goldenrod (Solidago spp.), Chickweed (Cerastium arvense), Strawberry (Fragaria sp.), Gooseberry (Ribes hirtellum), Beach Pea (Lathyrus japonicus), Raspberry (Rubus idaeus), Rush (Juncus Greenei), and several lichen species including British Soldiers (Cladonia cristatella) and a Birds Nest Fungus, grow there. In the depauperate former deflation zone is scattered sparse Beach Grass (Ammophila breviligulata) interspersed with Sandy Sedge (Carex silicea) and Pinweed (Lechea maritima). The ground there is well covered with small hummocks of folious lichens and Cladonia spp. including British Soldiers (Cladonia cristatella). There are also two small circular patches of healthy Beach Heather (Hudsonia tomentosa). The last zone is that of the forest fringe which is populated by the following: Meadowsweet (Spirea latifolia), Sweet Gale (Myrica Gale), Northern Wild Raisin (Viburnum cassinoides), Prunus spp.), Staghorn Sumac (Rhus typhina), Wild Sarsaparilla (Aralia nudicaulis), Bayberry (Myrica pensylvanica), Red Maple (Acer rubrum, Populus sp., Betula sp.), Fireweed (Epilobium angustifolium), Yarrow (Achilles millefolium, Juncus sp.), and Raspberry (Rubus idaeus).

Summary of Significant Features

A. Geological

1. Presence of precipitation dunes — relationship with southwest winds and fetch.
2. Coarse sand wind-lag surface.
3. Stable shoreline position with one frontal dune ridge, long frontal dune ridge back slope, seasonal accretion and erosion, and steep beachface.
4. Clear example of aeolian dominated mechanism of sand supply to back dune (no recent overwashes).

B. Botanical

1. High percentage of plant cover, even in fragile areas; little foot traffic damage.
2. Good site for the study of dune plant survival on a deflating surface.
3. Undisturbed fragile association: depauperate American Beach Grass, Lichen species, Mosses, Fungi, Pinweed, and Beach Heather.

C. Size

The total beach and back dune area is 2.4 hectares, which include 0.8 hectares of intertidal area.

Seawall Beach — Phippsburg, Sagadahoc County

Description of Geological Features

Seawall Beach (Figure 27) assumes particular importance among Maine's sandy beach systems since it is the largest undeveloped barrier spit in Maine. The other large barrier spits (Ogunquit-Moody, Wells, Camp Ellis and Old Orchard) have been heavily altered and developed. Characteristic of barrier spit systems, Seawall Beach is connected to a rocky headland, in this case, at the northeast end. The beach and back dune areas extend over 2200 m to the southwest and protect an extensive salt marsh and tidal river complex behind. The beach, back dune, and marsh areas cover 158 hectares.

The interaction between strong northwest winds and a broad (up to 400 m) back dune area is very well illustrated at Seawall Beach, which has the largest acreage of stabilized parabolic dunes in Maine. The entire back dune area consists of northwest-oriented, stabilized, parabolic dunes with a few still active dunes toward the spit end at the Sprague River. One of these has the largest dimensions of any active parabolic dune in Maine and, on the basis of measurements of aerial photographs, has migrated 17 m between 1940 and 1972.

The frontal dune ridge at Seawall provides an excellent example of not only annual cycles of response processes but the interaction between longer term changes and active back dune processes as well. The single frontal dune ridge undergoes erosion during the winter and spring followed by a late spring through fall rebuilding through aeolian sand transport which fills in the frontal dune ridge erosional scarp by establishing an aeolian ramp. The aeolian ramp is then invaded and stabilized by successional vegetational colonization. Measurements from vertical aerial photographs indicate frontal dune ridge retreat rates of 33 to 44 cm/year, averaged over the period 1940 to 1972. During this same period, average sea level in Casco Bay, according to tide gauge data, rose a vertical distance of 15 cm. On an average beach slope of 1° this would correspond to an annual landward encroachment rate of approximately 27 cm/year. This correlation suggests that the gradual frontal dune ridge retreat, despite significant annual regrowth, may be the result of a response to the secular rise of sea level along the Maine coast. Along some sections of the beach, a consequence of this frontal dune ridge retreat through high relief parabolic dunes, formerly behind the ridge in the back dune area, is that the frontal dune ridge attains heights of 4 to 5 meters. Wherever parabolic dunes are not being transgressed by the retreating perennial winter scarp, the frontal dune ridge relief diminishes to an average of 1.5 meters. The lower sections are subjected, annually, to storm overwashes and breaches.

The marsh-dune boundary follows broad curves which suggest the shaping of the present boundary by, and the former presence of, tidal river channel meanders. As these ancient meanders moved landward, sand on their seaward banks was colonized by dune vegetation. The rear edge of the barrier could thereby migrate landward in a manner similar to the growth of a point bar in a large meandering river. When stable, tidal river channels along the rear boundary of the barrier dune field provided a supply of sand for the formation of rear dune ridges by seaward transport by northwest winds. Such rear dune ridges are present today as relicts. The relict ridges are now bounded by salt marsh rather than tidal river channels. Other geomorphic features, such as curvilinear sand ridges suggest substantial late Holocene modifications of Seawall Beach.

Coring transects (Trudeau, 1977) indicate that in some places the back dune sand has transgressed over the marsh at least 18 meters. In many places, however, the marsh appears to be transgressing seaward over the rear dunes in response to sea level rise. The failure of the dunes to retreat over the marsh appears to be due to: 1) the stability and inactivity of the dunes, and 2) washover fans fail to transgress the entire dune field. The result is that the barrier dune field is being narrowed by a marsh encroachment from the rear and slow frontal dune scarp recession in front, both due to rising sea level. This narrowing process is very slow.

The sand at Seawall is probably derived originally from the Kennebec River since, on a larger scale, Seawall is part of the Popham-Seawall strand plain and barrier system which covers a total of 408 hectares, including 158 hectares at Seawall and 250 hectares at Popham. The net long-term drift is from the northeast to the southwest, away from the Kennebec River, probably due to northeast storm waves and the counter-clockwise Gulf of Maine current gyre which is driven by the Kennebec and other coastal rivers. Finer-grained sand on Seawall than Popham supports the Kennebec River as a source.

The beachface has several interesting features, as follows:

1. A beachface which is always broad (~150 m), even in winter, and never steep. Summer profiles show a moderately constructional aspect with berms around 25 m wide.
2. In summer the lower beachface has a ridge and runnel system with a broad, convex upward, accretionary ridge.
3. The sand of both the beachface and the dune at Seawall is significantly finer than at Popham, but no significant difference in textural characteristics, including mean grain size, exists between dune sands and the beachface.

Description of Botanical Features

There are high, northwest-wind oriented, parabolic dunes with very interesting relationships between vegetation and the dune morphology and behavior. The depositing leeward slopes of the active parabolic dunes at Seawall Beach are good sites to study the response of American Beach Grass (*Ammophila breviligulata*) and Beach Heather (*Hudsonia tomentosa*) to sand deposition in the back dune area, away from salt spray and seaweed. Both plants show increased growth rates and more robust forms under these depositing conditions.

The vegetation pattern at Seawall is mosaic rather than zonational because of hummocky parabolic dunes which dominate the back dune field. This causes vegetation patterns which are related to the depth to the water table, and accretion and deflation rates, successional age, and sand stability rather than distance from the frontal dune ridge.

Most important is the area covered by Beach Heather (*Hudsonia tomentosa*) at Seawall. There is probably more acreage of Beach Heather at Seawall and Reid State Park than in all other stands in Maine combined.

Seawall appears to be the northernmost coastal dune habitat for the Earthstar Puffball (*Geaster hygrometricus*) in Maine.

There are a few relict overwash sites through the high frontal dune ridge which are indicated by the presence of patches of Dusty Miller (*Artemisia Stelleriana*) and flotsam debris.

There is a young pitch pine forest with many upland forest species in the back dune of Seawall. This forest is not as mature as the one at Popham. Its youth and the generally mosaic floristic patterns of the rest of the dune field suggest that fire or timber cutting may have taken place here in the last century.

A complete species list for Popham, Reid and Seawall beaches has been compiled by Trudeau (1977), thus only the dominant cover species of the back dune are noted here. The dominant vegetation species in their approximate order of importance are:

1. American Beach Grass – Ammophila breviligulata
2. Beach Heather – Hudsonia tomentosa
3. Bayberry – Myrica pensylvanica
4. Pitch Pine – Pinus rigida
5. Meadowsweet – Spiraea latifolia
6. Beach Pea – Lathyrus japonicus
7. Raspberry – Rubus idaeus

Summary of Significant Features

A. Geological Features

1. The only large, undeveloped or unaltered, barrier spit in Maine.
2. The largest parabolic dune field in Maine.
3. A few high relief, active, northwest-wind oriented, parabolic dunes.
4. A measured shoreline retreat of 11 to 14 m during the period 1940 to 1972.
5. Because of its unaltered state, a good laboratory for the study of natural barrier maintenance, sedimentary events of the Kennebec River, and sea level rise effects.
6. Relict dune ridges exist because of northwest wind transport of sand from ancient channel banks of the Sprague River during neap tide periods.

B. Botanical

1. The highest percentage of cover of non-forest dune vegetation in Maine's large back dune areas.
2. Extremely high diversity and large numbers of dune species.
3. Full range of successional stages.
4. The most mosaic floristic patterns in Maine's back dune areas, due to sand accretion and deflation processes, depth to water table, and successional age of sites, i.e. controlled by the preponderance of parabolic dunes rather than back dune aeolian flats.
5. Most important, a large share of Maine's Beach Heather (Hudsonia tomentosa) is located here.
6. Northernmost stand of Earthstar Puffball (Geaster hygrometricus) on coastal sand dunes within the state.

7. Immature or near edaphic climax pitch pine forest in the center of the back dune area.

C. Peripheral Significant Features

1. Habitat for specially adapted spiders, insects and small mammals.
2. Least tern and piping plover nesting site at spit end.
3. Feeding habitat for other shore birds.
4. Solitude/Isolation. Seawall is cut off from shoreline access by two tidal rivers. This improves management and preservation potential.
5. Surfboard riding is a popular summer recreation because of broad beachface and isolation.

Popham Beach Areas – Phippsburg, Sagadahoc County

Popham Beach (Figure 28) is one of the largest (250 hectares of supratidal sand) and most complex systems in Maine. Because of the complexity, Popham Beach has been divided into seven separate areas. However, it is instructive to list all the significant features of Popham in one list. Some of the features listed below are general or more important to the Holocene history of Maine than to sandy beach and dune processes.

Significant Geological Features of Popham Beach System (Morse River to Fort Popham)

1. Complex spit in mouth of Morse River.
2. Two large cuspate forelands.
3. The only two large, sandy tombolos in Maine – the only large tombolos which connect a public beach to an island.
4. Presence of accretionary ridge and swale topography from a past accretionary period. Another area of accretionary ridge and swale topography may form in the next few years at the eastern end of Popham Beach State Park.
5. Relict erosional scarps – especially at the seaward edge of the pitch pine forest west of the State Park parking lot.
6. Relict shorelines, possibly 2900 years old, behind Popham village in a small salt marsh.
7. Possible former marine lagoon which is now a freshwater lake – Silver Lake.
8. Configuration and bathymetry illustrating river-derived sand and influence of Coriolis force, one of the few beaches in Maine with predominantly river derived sand.
9. Evidence that overwash is important in supplying sand to some of the back dune areas.

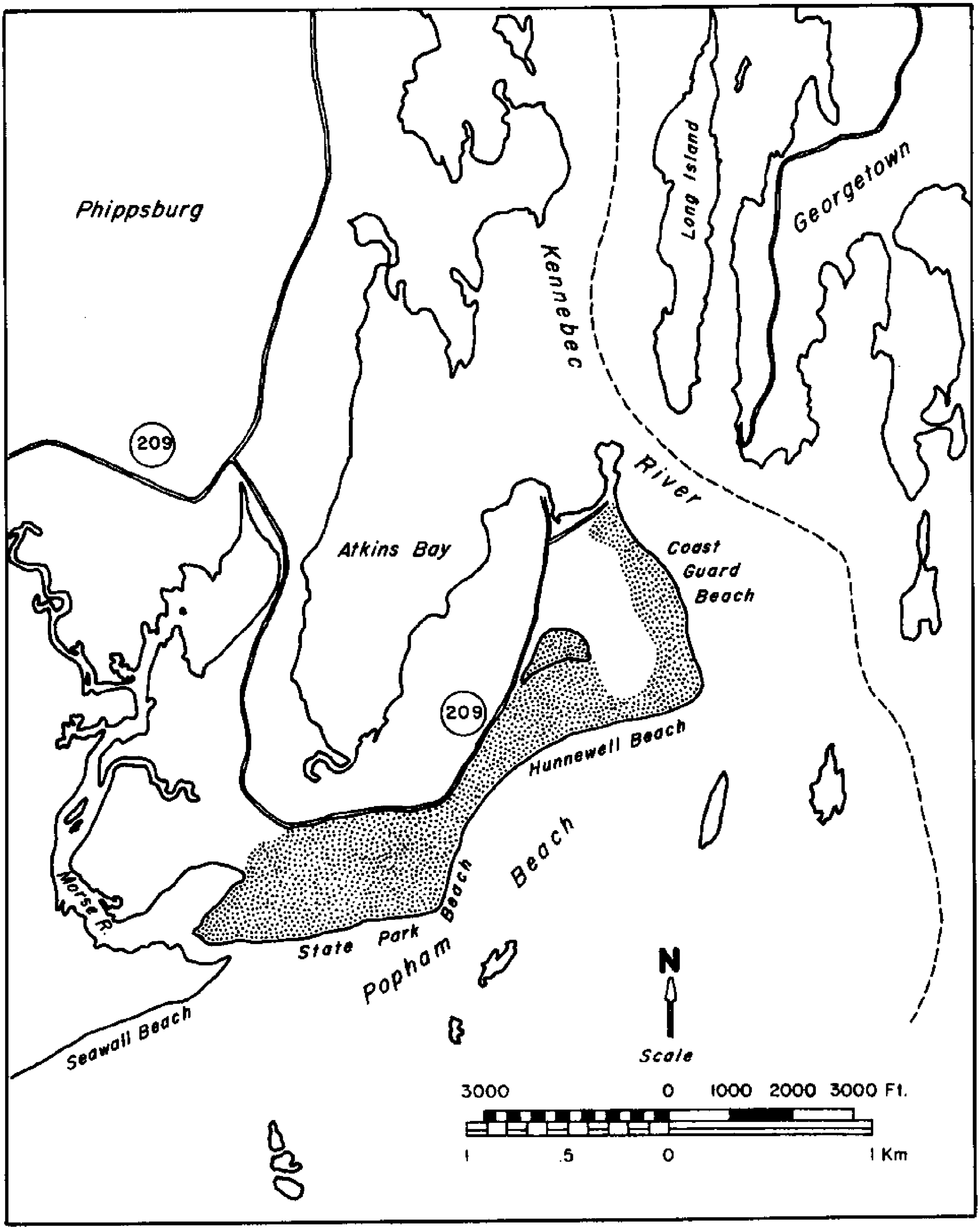


Figure 28 Popham Beach

10. Large stabilized parabolic dunes, created by northwest winds, in Popham Beach State Park pitch pine forest and some on Hunnewell Beach.

11. Presence of a dated relict intertidal sand flat beneath Atkins Bay salt marsh may indicate catastrophic barrier formation about 6,800 years ago.

12. Potential key to catastrophic Holocene sedimentary events in the Kennebec and Androscoggin Rivers.

13. Best illustration of very unstable natural geological processes; major shoreline changes have occurred which are due to: Kennebec River tidal current effects on sand bodies, Kennebec River tidal current effects on wave refraction, and migration of Morse River tidal channel.

14. Relict garnet layer (former erosional shoreline) preserved beneath dunes near Rockledge, active garnet fractionation occurring where beach is being eroded during storms.

15. Extremely varible beach profile types, both spatially and temporally.

16. Accreting berm at Popham Beach State Park (on both sides of Fox Island cuspate foreland) which has value for recreation, as least tern nesting sites, and as an illustration of a short-term accretionary process in a time of rising sea level.

17. Extensive variety of sandy bedforms, especially ripple mark patterns of many types.

18. Eroding profiles — until recently Hunnewell Beach was eroding at the fastest rate in Maine.

19. Obvious examples of wave refraction/wave energy/erosion-accretion relationships (especially obvious when selecting a spot from which to launch a boat at Hunnewell Beach).

20. Natural laboratory for the study of the relative magnitude of man-induced versus natural changes in beach profiles and sand supply.

21. A good example of the influence of southwest wind on the height of the frontal dune ridge (large southwest facing frontal dune ridge south of State Park parking lot).

22. Two very large nearshore sand bars, persistent and migrating onshore, the only ones of this size in Maine.

23. Large sandy ebb-tidal delta features up to two miles offshore formed by the Kennebec River, includes Pond Island Shoal with its surficial bars. Largest ebb-tidal delta in Maine.

24. Example of poor relationship between grain size, distance from sand source, and beachface slope (unless Seawall Beach is included in system).

25. High relief parabolic dunes behind Hunnewell Point formed by onshore southwest winds.

26. High rear dune ridge (along access road to Morse River from Route 209).

Significant Botanical Features of Popham Beach System (Morse River to Kennebec River to Fort Popham)

Trudeau (1977) has mapped the complex floristic patterns of this beach and dune area and has compiled an extensive species list for Popham as well as Seawall and Reid beaches. Consequently extensive species lists have not been compiled for the Popham areas in this report.

General dune plant habitat types which are of statewide significance are listed below:

1. Parabolic dunes of various ages since last activity have many successional stages from Beach Heather (Hudsonia tomentosa) association through edaphic climax Pitch Pine (Pinus rigida) forest.
2. Relict berm-and-ridge dune areas, as in the complex spit at the mouth of the Morse River.
3. Sandy marsh flats, newly formed.
4. Overwash deposits in back dune and on perennially accreting berms.
5. Perennially accreting berms.

Specific botanical features which are of statewide significance are listed below:

1. Absence of Wormwood (Artemisia caudata), which is present on all major beaches south of Casco Bay, but none north of the bay.
2. Presence of : Poverty Grass (Corema Conradii), Bearberry (Arctostaphylos uva-ursi), Golden Heather (Hudsonia ericoides).
3. Associations of Beach Heather (Hudsonia tomentosa), Sandy Sedge (Carex silicea), Pinweed Aster (Aster linariifolius), Pinweed (Lechea maritima), Jointweed (Polygonella articulata), Greene's Rush (Juncus Greenei), and Lichens (Cladonia spp.) in stabilized parabolic dunes of the State Park and behind portions of Hunnewell Beach.
4. The northernmost coastal dune stands in Maine of Earthstar Puffball (Geaster hygrometricus) are located either here at Popham or at Seawall (never observed personally at Popham, but have been seen at Seawall).

The seven divisions of the Popham Beach System are arranged in geographic order from Fort Popham to the Morse River and are as follows:

1. Village Marsh Ancient Shoreline at Popham Village
2. West Bank of the Kennebec River, from Coast Guard Station to Hunnewell Point
3. Wood Island Tombolo and Intertidal Cuspate Foreland at Hunnewell Point
4. Pond Island Shoal's Offshore Bars
5. Hunnewell Point Back Dune Area
6. Hunnewell Beach Back Dune Area
7. Popham Beach State Park

Village Marsh Ancient Shoreline — Popham Village

Description of Geological Features

A single type of geological feature makes this a critical area of statewide significance, i.e. the presence of two probable former shorelines far back from the present shoreline in an historically stable area. The shorelines occur as two curved sandy ridges in the Village Marsh and are wind deposited features which outline underlying wave shaped sandy shorelines. The wave deposited sand is now buried by the encroaching salt marsh peat — a result of sea level rise since the shorelines formed.

These former shorelines may be either a complex spit or accretionary ridges of a swash aligned beach section. If they are part of a complex spit, the waves which formed them approached from the north and the relict shorelines have been followed by only 100 to 200 m of beach accretion. If they are swash aligned ridges, the waves which formed them approached from the east and 450 m of accretion has since taken place.

The Village Salt Marsh north of the ancient shorelines is underlain by a coarse-sand flat at 1.5 m below the present marsh surface. This is strong evidence for ancient wave approach from the north. Deposition of salt marsh peat first occurred when the sand flat was sealed off either by the ancient ridges or by the present harbor shoreline to the north or by both. C^{14} dating of the first marsh peat over the coarse sand flat puts this event at about 2900 years ago. The ancient shorelines are part of the longest lasting accretionary regime known for any Maine beach in the late Holocene. They may represent a catastrophic accretionary event at the mouth of the Kennebec River; otherwise, normal beach processes in a regime of rising sea level would have long since obliterated them as geomorphic features.

Description of Botanical Features

The two sandy ridges are vegetated by Bayberry (*Myrica pensylvanica*), Gooseberry (*Ribes* sp.), Raspberry (*Rubus idaeus*), Great Angelica (*Angelica atropurpurea*), Pasture Grasses, Seaside Rose (*Rosa rugosa*) and a few isolated trees. Proximity of the salt water table beneath these low ridges prevents later succession despite the age of the ridges. Wind whipped salt spray from the flooded salt marsh during spring high tides probably has the same inhibiting effect on succession.

Summary of Significant Features

A. Geological

1. Two relict shorelines — oldest late Holocene sandy beach shorelines with surficial expression known in Maine — potential key to catastrophic sedimentary events at Popham and in the Kennebec River.
2. Coarse grain wave deposited sand flat and basal salt marsh peat contact — further key to sedimentary events of the area and source of C^{14} date of

shorelines. This is also a regressive sedimentary sequence (peat over sand) in a rising sea level regime where transgressive sequences (sand over peat) are expected.

B. Botanical

Illustrates stagnated plant community succession on a relict frontal dune ridge of great age – due to effects of salt spray and proximity of salt water table.

C. Size

The size of the area is 2.4 hectares.

West Bank of the Kennebec River at Popham

Description of Geological Features

This area is significant because it has a perennially accreting berm of at least five years age. The age is based on the presence near the southern end of a relict erosional scarp, formed in 1972, behind the vegetated overwash berm. The berm continues to accumulate sand by wave overwash despite the fairly abundant vegetational cover.

The Kennebec River shore is one of the few beach areas in Maine where wave overwash is the dominant means of sand transport into the vegetated dunes normally above high water. Overwash is significant here largely because the beach faces east, a direction from which wind seldom blows. Thus, onshore aeolian transport is minimal and there is no frontal dune ridge to block the flow of overwash sand. There is no aeolian ramp. The dominance of overwash deposition has favored Dusty Miller (Artemisia Stelleriana) and berm colonizers over American Beach Grass. It has also left abundant flotsam exposed, especially large logs and driftwood.

The perennially accreting overwash berm is about 50 m wide. It might be a good piping plover and/or least tern nesting site if the area were not so heavily used by beach strollers and sunbathers.

The overwash sands of the river shore are rich in garnet. This is an important key to the mechanism of sand transport at Hunnewell Beach. Only the extensive wave erosion of eastern Hunnewell (over the last few years) could fractionate out the large volumes of garnet seen today on the river shore. The garnet has acted as a tracer which indicates that the initial path of sand eroded from eastern Hunnewell is eastward and northward upriver around Hunnewell Point.

The beachface of the river shore area is fairly steep due to the velocity of the longshore river tidal current. A swale of variable dimension is located on the beachface today and can be seen in most old photos of the area. Study of this swale and its history may indicate the rates and directions of sand movement on the Kennebec and Hunnewell Beach shores of Popham.

Description of Botanical Features

The species composition of an overwash-dominated, vegetated, relict berm is of interest because of the rarity of overwash dominated areas in Maine. The most striking feature of the flora here is the abundance of Dusty Miller (*Artemisia Stelleriana*). Berm colonizers extend well into the relict berm because of overwash transport of their seeds and the presence of a suitable nutrient-rich substrate such as seaweed. American Beach Grass (*Ammophila breviligulata*) is fairly healthy in this environment, though it grows in isolated clumps rather than a thick carpet.

The common species are:

American Beach Grass — *Ammophila breviligulata*
Dusty Miller — *Artemisia Stelleriana*
Saltwort — *Salsola kali*
Sea Rocket — *Cakile edentula*
Beach Pea — *Lathyrus japonicus*

Summary of Significant Features

A. Geological

1. An accretionary area, accreting while Hunnewell's south shore was eroding.
2. Extensive garnet in overwash indicates path of sand eroded from Hunnewell.
3. Illustrates importance of overwash in supplying sand to vegetated area. Relative importance of overwash at this site may be greater than almost any other sand beach in Maine (cf. Pemaquid Beach).
4. Presence of relict erosional scarp — educational warning of instability of shoreline position.
5. Examples of beachface features related to Kennebec River — steep beachface slope (caused by river's tidal current); persistent swale, perhaps related to the path and rate of longshore sediment movement.

B. Botanical

Illustrates floral composition of an overwash site, characterized by dominance of Dusty Miller.

C. Size

The size of the area is 5 hectares.

Wood Island Tombolo and Hunnewell Point Intertidal Cuspate Foreland - Popham Beach

Description of Geological Features

All significant features of the tombolo and cuspate foreland area between Wood Island and Hunnewell Point are geological since the area is entirely intertidal with no vascular plants.

Wood Island Tombolo is one of only two large, sandy tombolos in Maine and provides public access to a wooded island of significant geological, botanical, and wildlife value. The tombolo demonstrates extreme seasonal and longer term variability in size and shape. The variability is attributed to a response to changing wave refraction patterns, changes in channel characteristics of the Kennebec River, and man-induced removal of sand from the adjacent Kennebec River channel. Because of the strong tidal potential across the tombolo created by the Kennebec River flow, a transverse channel is cut across the tombolo occasionally. Such breaching of the tombolo and subsequent current velocity increases may trigger major changes in the erosional-accretionary status of Hunnewell Beach and Hunnewell Point by increasing current scour along Hunnewell Beach and altering current influence on wave refraction patterns. The effects of Kennebec River ebb-current and onshore wave transport of sand can be seen in the occasional formation of oppositely oriented spits on opposite ends of the tombolo breach channel. Where transverse tidal currents are strongest in the low portion of the Wood Island Tombolo, excellent examples of small and large ripple bed forms are found.

The Hunnewell Point portion of the area is an excellent example of a cuspate foreland formed by two processes: confluence of currents and wave refraction in the lee of an island. Hunnewell Point cuspate foreland is significant for its history of extremely rapid perennial accretion with an associated formation of a band of ridge and swale dune topography between 1910 and 1930. The accretionary phase was eventually followed by a period of equally rapid erosion beginning in 1965. Some features observed during 1977-78 may presage a new perennial accretion of Hunnewell Point. The features which suggest this are the present filling of the breach channel of the Wood Island Tombolo, the higher and broader relief of the tombolo throughout its length, the accretionary summer berm on the south shore of the Hunnewell Point cuspate foreland, and the confluence of wave sets from the east and the west just to the west of Hunnewell Point.

Hunnewell Point and the Pond Island Shoal may be the nearest approximation to a river delta in Maine. The sands comprising these features are almost certainly derived from the Kennebec River. On a larger scale, the entire Popham-Seawall-Pond Island Shoal system is an example of river-derived beach and nearshore sand. The influence on river-derived sand distribution by the counterclockwise Gulf of Maine current gyre and the Coriolis force is well illustrated in the large-scale features of this system.

Size

The size of the area is 20 hectares.

Pond Island Shoal's Offshore Bars

Description of Geological Features

These two offshore bars are surficial features of the large cusp shaped Pond Island Shoal. Pond Island Shoal is a subtidal extension of the Hunnewell Point cuspate foreland. The Shoal is a constructional, delta-like feature formed at the equilibrium trap point of net onshore and net downstream sediment movement. The surficial bars are variable features which can be likened to the ebb-tidal delta bars of a barrier beach inlet. They are significant as features of the largest sandy ebb-tidal delta in Maine. They may, in fact, be features of a true river delta. Their significance to the beach proper lies in their influence on: 1) wave refraction patterns and wave energy striking the beach, 2) sand supply to the beach from the bars. Changes in these bars may be the key to explaining drastic erosion and accretion at Hunnewell Beach.

Hunnewell Point Back Dune Area – Popham Beach

Description of Geological Features

The most significant geological features of this area are its stabilized high relief parabolic dunes formed by winds blowing out of the south or southwest. These are the only high relief parabolic dunes with this orientation yet encountered in Maine. Most of Maine's parabolic dunes are formed by strong northwest winds. Here the orientation is different because of: 1) fetch restriction – Rockledge Ridge blocks northwest winds, 2) wind direction changed by local topography – west and southwest winds take on a southerly wind direction as they blow around the tip of Rockledge Ridge.

Description of Botanical Features

The stabilized parabolic dunes here are notable for their thick healthy cover of Beach Heather (Hudsonia tomentosa). There are probably less than 40 hectares of Beach Heather in the State of Maine. This is a fragile sand dune cover, more susceptible to foot and vehicle traffic than American Beach Grass because it is slow growing, takes decades to colonize new areas and grows in historically stable dunes where development pressure is highest.

Summary of Significant Features

A. Geological

1. South wind oriented, stabilized, high relief parabolic dunes – a rare or unique orientation in Maine.
2. Part of a cuspate foreland – one of the largest in Maine.

B. Botanical

Good Beach Heather (Hudsonia tomentosa) cover.

C. Size

The size of the Hunnewell Point Back dune area is restricted to 1.2 hectares.

Hunnewell Beach Back Dune Area – Popham Beach

Description of Geological Features

This area has well vegetated, stabilized parabolic dunes with both semi-open dry dune slacks and thick Pitch Pine (*Pinus rigida*) cover. The orientation of these parabolic dunes is no longer obvious but they probably formed under the influence of south and southwest winds, thus making them unusual in Maine. The wind fetch is restricted on the northwest side by Sabino Hill.

Just south of this area a boundary exists between an edaphic climax community of Pitch Pines and a younger successional stage relict frontal dune ridge. This boundary represents the approximate historical limit of former beach erosion at Hunnewell Beach. The age of this erosion limit is 1900 or earlier.

Description of Botanical Features

The area has a variety of cover types and species mixes. The floristic pattern is mosaic due to the presence of parabolic dunes. Cover type ranges from open Lichen carpets through thick Pitch Pine cover. Species present include:

1. Pitch Pine – *Pinus rigida*
2. Beach Heather – *Hudsonia tomentosa*
3. Lichens – *Cladonia* spp.
4. Jointweed – *Polygonella articulata*
5. Early Sedge – *Carex pensylvanica*

The area includes part of a Cranberry-Sweet Gale bog which is seasonally flooded. In the bog area are Cranberry (*Vaccinium macrocarpon*), Sweet Gale (*Myrica gale*), Swamp Winterberry (*Ilex verticillata*) and numerous Rush, Sedge and Grass species.

Summary of Significant Features

A. Geological

Examples of parabolic dunes created by south to southwest winds, now stabilized by various mixtures of Pitch Pines (*Pinus rigida*) and dry dune slack vegetation.

B. Botanical

1. Good example of vegetational variety of open dry dune slack plants mixed with Pitch Pines.
2. Example of a seasonally flooded temporary bog dominated by Cranberry and Sweet Gale.

C. Size

The Hunnewell Beach back dune area is 1.9 hectares.

Popham Beach State Park - Phippsburg

Description of Geological Features

The dune vegetation and oceanic processes of Popham Beach State Park have been described in detail by Trudeau (1977). The emphasis of his work has been on vegetation. He has compiled floristic maps and a species list for the park. Because of his work a species list and detailed floral description were not attempted during field checking of the Popham Beach System.

A detailed shoreline change map of Popham Beach has been compiled by Nelson, 1977. It includes information from cores, old ground level photos, a vertical air photo collection and three years of sequential oblique and near vertical air photos. Trudeau's report and Nelson's shoreline change map are available for reference from the Bureau of Geology, Dept. of Conservation, Augusta, Maine.

The Popham Beach State Park area includes a barrier dune field, associated salt marsh, and a complex spit and tidal inlet. The shoreline and intertidal features throughout the area are among the most unstable in Maine. Drastic accretion and erosion have characterized this area historically. This instability is the single most significant geological feature of the area. The degree of instability is responsible for the formation of a variety of geological and botanical features. For ease of discussion, these various features are categorized into thirteen subunits.

1. Fox Island Tombolo

This is one of only two large sandy tombolos in Maine, the other being the Wood Island Tombolo. It is a complex feature, flanked by two large nearshore sand bars when field checked and sometimes traversed by a distributary channel of the Morse River. Migration of these bars and sealing of the distributary has sometimes left relict longitudinal and transverse swales on the tombolo. Fox Island Tombolo (including the proximal ends of the associated nearshore bars) is larger than Wood Island Tombolo. Since the tombolo is uncovered throughout most of the tidal cycle, it provides public access to Fox Island from Popham Beach State Park. The Tombolo area is about 14 hectares (excluding the nearshore bars or flanks).

2. Western Hunnewell Beach Large Nearshore Sand Bar

This feature has grown in size and moved shoreward over the last three years. Before reaching the beachface it had a hook-shaped downdrift on spit end in front of the seawalls of central Hunnewell Beach. The bar has grown in a northeast direction toward the eroding section of Hunnewell. It protects and supplies sand to all the beachface behind it - causing appreciable perennial accretion. Remnants of a beachface runnel were visible on the landward edge of the large nearshore bar in August of 1977. The bar and runnel once formed a ridge and runnel beachface profile type of exaggerated proportions. The size of the nearshore bar in December 1976 was about 16 hectares.

Though the direction of transport of sand in this bar is onshore and toward the Kennebec River, the bar's formation and growth have been contemporaneous with sand loss from central and eastern Hunnewell, suggesting a paradox, i.e. the beach at the downdrift end of the bar was the source area for the bar. What is even more confusing is that in the late 1940's a similar nearshore bar formed off western Hunnewell when no portion of Hunnewell was eroding.

This nearshore bar may be one reservoir in a cyclical path of sand which includes the Wood Island Tombolo, the Kennebec channel and Pond Island Shoal. Rates of sediment flow from one reservoir to another may be triggered by breaching of the Wood Island Tombolo, changing Kennebec sand supply, dredging, spring runoff rates, evolution of the Kennebec ebb-tidal delta bar configurations and other factors. The cycle itself may exist since there are natural and artifical tracers to document the cycle path. Behavior of the cycle may be the major cause of drastic erosion and accretion at Hunnewell Beach.

An alternative explanation for the development of the nearshore bar would not require major and large-scale transfers of sand but only a short-term reversal, during a northeast storm, of the usual alongshore current direction toward the Kennebec River. Such a reversal is possible because of the properly oriented wind stresses during the passage of a northeast storm, which also produces the sand volume which can be rapidly transported to an equilibrium trap position where the nearshore bar then forms.

3. Large Perennially Accreting Berm of Western Hunnewell.

The berm here is 90 to 120 m wide, the widest berm in Maine. There is a broad aeolian ramp being invaded by American Beach Grass. The berm itself is being invaded by American Beach Grass and Dusty Miller. This is a good area for viewing frontal dune ridge formation; however, the mature ridge will not be very high since the beach faces southeast. The perennial accretion of this area is noteworthy because only three years ago it was eroding perennially. The accretion is also noteworthy because it is contemporary with drastic erosion of eastern Hunnewell. Thus, general statements about the erosional status of Popham Beach, the effect of Kennebec dredging on Popham Beach or the effect of sea level rise on Popham Beach can not safely be made. The area of the berm is 4 hectares.

4. Relict Ridge and Berm Province of Western Hunnewell (Accretionary Ridge and Swale Topography).

Prior to 1940 all of Hunnewell Beach was accreting. Some of the relict frontal dune ridges and berms left by this accretion are still visible at the western end of

Popham Beach State Park between utility poles #825-164S and #169-87. The area is dominated by American Beach Grass which is now depauperate because of the age of these dunes and lack of sand burial. The landward-most ridge may be more than 100 years old. Formerly disturbed areas have been invaded by Beach Heather (Hudsonia tomentosa), Lichens (Cladonia spp.), Pinweed (Lechea maritima) and Early Sedge (Carex pensylvanica). There are no parabolic dunes in the area, which covers 2.8 hectares.

5. Morse River Ebb-Tidal Delta.

The complex bars, channels, and small bedforms of the Morse River ebb-tidal delta are valuable features for the study of the formation and preservation of barrier inlet sedimentary structures. The characters of these features are very variable. The meanders of the intertidal Morse River ebb channel are significant for their effect on erosional/accretional status of the dunes between Morse Mountain Headland and Fox Island Tombolo. The area of the ebb-tidal delta is about 32 hectares (including the large nearshore bar west of Fox Island Tombolo).

6. Large Nearshore Sand Bar West of Fox Island Tombolo.

This bar is similar to the one off western Hunnewell in that it formed in the last three years and is migrating onshore, protecting and supplying sand to the berm and dunes landward of it. It does not have an apparent downdrift or spit end, but this may be because the western end is truncated by a distributary of the Morse River ebb channel. The runnel landward of this nearshore bar is also a former ebb channel distributary which once traversed Fox Island Tombolo, but now is sealed off. The large nearshore bar may, therefore, be part of the Morse River ebb-tidal delta. Its eastern end is welded to, and part of, the Fox Island Tombolo. A bar similar to this one existed in the same area in 1964. Onshore migration of such large bars leads to shoreline accretion. Subsequent meandering of Morse River ebb channel distributaries removes sand seaward and leads to shoreline erosion. This cycle does not have a regular periodicity. Boundaries are indistinct, but the area of this bar is approximately 15 hectares.

7. Incipient, Perennially Accreting Berm Landward of Western Large Nearshore Sand Bar.

This is an indistinct area of accretion which has formed only since the channel, or runnel, landward of the western large nearshore bar became sealed and began filling. Prior to sealing of the channel, which used to breach the Fox Island Tombolo and connected with the runnel landward of Hunnewell's large nearshore bar, tidal currents maintained a steep upper beachface below the berm edge.

8. Overwashed, Perennially Accreting Berm West of Fox Island Cuspate Foreland

This large area accreted subsequent to a channel shift in the early 1970's. Frequent winter washover and ice damage inhibited vegetation in most of the area until 1975. In the last 2½ years washover accretion has replaced washover damage. The area is now sparsely vegetated by American Beach Grass and Dusty Miller as well as berm colonizers. There is a very broad, actively growing, incipient frontal dune ridge on the seaward edge of the area and another actively growing frontal dune ridge near the rear of the area (just seaward of the 1972 river channel bank position). The second frontal dune ridge derives its sand from a deflation zone seaward of it, but landward of the first frontal dune ridge.

The area is unique in Maine in that it has two actively growing frontal dune ridges, one behind the other. Overwash accretion has played an important role in the supply of sand to this area, but the role of aeolian transport should become greater as the seaward frontal dune ridge builds vertically.

The area is a significant nesting habitat for least terns and piping plovers.

The western margin of the area is being eroded by a cut bank of one of the Morse River ebb-tidal channels. The area size is 5.3 hectares.

9. Thick Healthy Beach Grass Zone

This zone has the shape of an acute triangle, bounded on the north by the approximate 1953 scarp line (caused by meander of the Morse River at that time), on the southwest by the 1972 scarp line, and on the south by the 1976 scarp line (from a now sealed off minor distributary of the Morse River). The area has been vegetated for about twenty years and now has some of the healthiest American Beach Grass in Maine, certainly one of the largest stands of healthy beach grass on young dunes in the State. Sand is supplied to the back dune here by wind transport more than by overwash. Not much vertical sand accretion (sand burial) is taking place, however. Dead culms and blades of Beach Grass form a dry straw carpet over the sand. This is a good site for studying natural senescence rates of Beach Grass on young dune flats without sand burial. This area also has the highest frontal dune ridge at Popham — 3 m. This is because the ridge faces the prevailing, onshore-directed southwest wind and because there has been an abundant sand supply from the overwashed perennially accreting berm described above. The area is 2.8 hectares.

10. Semi-open Parabolic Dunes and Old Overwash Area

This small dune area surrounds the north, east, and south sides of the state park parking lot. The parabolic dunes are of high relief and were formed by winter northwest winds. The dunes were active in the 1930's and 1940's. These are the highest relief parabolic dunes at Popham. They are also significant for providing most of the habitat for Beach Heather (Hudsonia tomentosa) within the park boundaries (recall that there are less than 40 hectares of Hudsonia tomentosa in Maine and that this plant is highly susceptible to foot traffic damage).

About thirty per cent of these high relief parabolic dunes with semi-open Pitch Pine (*Pinus rigida*) cover and Beach Heather (*Hudsonia tomentosa*) were leveled when the parking lot was constructed at Popham Beach State Park. Further construction of parking lots or large user facilities should be discouraged in this area.

The area also includes what appear to be old overwashes with thick beach grass cover just south of the parking lot. These overwashes would be about twenty-five years old, having formed subsequent to an erosional event around 1953. Construction of a parking lot or large user facilities in this area would be unwise since its proximity to an historical erosional shoreline indicates a potential for repeated erosion here. The area is 3.6 hectares.

11. Stabilized Parabolic Dunes with Climax Pitch Pine Forest.

This is the largest mature pitch pine forest on sandy dunes in the state. It forms the bulk of the Popham Beach barrier. The area is highly valuable for studying the edaphic climax of Maine's coastal dunes. For this purpose it is more valuable than the immature pitch pine forest of Seawall Beach (Phippsburg). There are many upland forest species in the ground cover and understory. Species diversity is higher than that for most dune communities.

The area is the least fragile of any of Popham's dune communities, especially since a soil layer has developed. It is, therefore, the best choice within the dune system for placement of picnic tables, parking lot expansion or large user facilities. Nonetheless, encroachment of such facilities should be discouraged because of the area's unique scientific value, particularly when there is the option of placing such facilities on upland bedrock.

There is a rear dune ridge to the northwest of the forested area at the marsh/sand border. The size of the area is 20 hectares.

12. Complex Spit with Relict Frontal Dune Ridges.

This is the best example of a complex spit in Maine. Its orientation is a key to the net westward drift of sand at Popham (away from the Kennebec River). The spit formed as a result of a major channel shift in the Morse River in the 1940's. An unusual bar island, originally formed by waves and currents, remains preserved in the complex spit with a vegetated wind-deposited veneer. The spit reached an accretionary maximum in 1972 and has since eroded dramatically as a result of the meanders of a distributary channel of the Morse River. The eroding scarp has left behind heavy garnet sand as a result of density fractionation. The eroding shoreline is also notable for its considerable overwash deposits which take place because there is no berm or frontal dune ridge to stop them.

During the storms of January 9 and February 7, 1978, almost all the grassy dune surface of the complex spit was overwashed. Observations after the January 9 storm do not indicate any significant vertical accretion or landward migration of the dunes via overwash sand deposition. The impact of the overwash on the vigor of the next season's Beach Grass remains to be seen.

Because the dunes here are less than thirty years old they still have a thick, healthy American Beach Grass cover. In the southeast corner are some parabolic dunes formed prior to 1940. They are stabilized with Early Sedge (Carex pensylvanica), Sandy Sedge (Carex silicea), and Pasture Grasses. The eastern margin is of greater age and provides an example of late succession on moist back dune. Raspberry (Rubus idaeus) and Fireweed (Epilobium angustifolium) are common here.

The complex spit is also significant in that it provides protection for a newly formed salt marsh on a former sand flat behind the spit. A geological cross section through the new marsh and spit would indicate a regressive (lowering sea level) or accretionary regime. This is unsual since sea level is rising in Maine. The anomaly can be explained as the result of a locally abundant sand supply caused by a shift in the Morse River channel. The area is 7.7 hectares.

13. Former Sand Flat with New Salt Marsh Behind Complex Spit, Old Shoreline Behind

This area is significant primarily for its geological indications of a regressive regime as explained above. It is interesting to note that more than a meter of pure salt marsh peat has accumulated vertically over portions of the sand flat in just a few decades. This verifies the need for using basal salt marsh peat for C^{14} dating of sea level rise or sedimentary events. The area is thus very instructive in a geological sense.

The area is of statewide significance because it is a large, newly created salt marsh of great ecological value.

There is an old shoreline and sand dune at the rear edge of the marsh. There has been no sand activity here since the salt marsh formed, yet the vegetational composition (American Beach Grass, Dusty Miller and Beach Pea) resembles that of a young frontal dune ridge or aeolian ramp. The vegetational assemblage is due to salt spray and the proximity of the water table. The influence of either salt spray or sand blasting damage to back dune trees on the Maine coast is dramatically illustrated on the utility poles of this rear sand dune. Pitting of the poles is greatest on the southwest side. The metallic letters on the poles are raised in relief on wooden pedestals as all the wood around them has been removed by windborne abrasive agents (sand or salt).

The rear dune and shoreline are valuable as: 1) indicator of extreme variability of shoreline position, 2) example of stagnant succesion due to salt spray and salt water table.

The area of the former sand flat with new salt marsh, including the narrow dune at the rear, is 12.1 hectares.

Reid Beach — Sagadahoc County

Description of the Geological Features

There are two significant areas at Reid State Park (Figure 29). They are 1040 m long Mile Beach and adjacent 420 m long Half Mile Beach. Mile beach connects Todd's

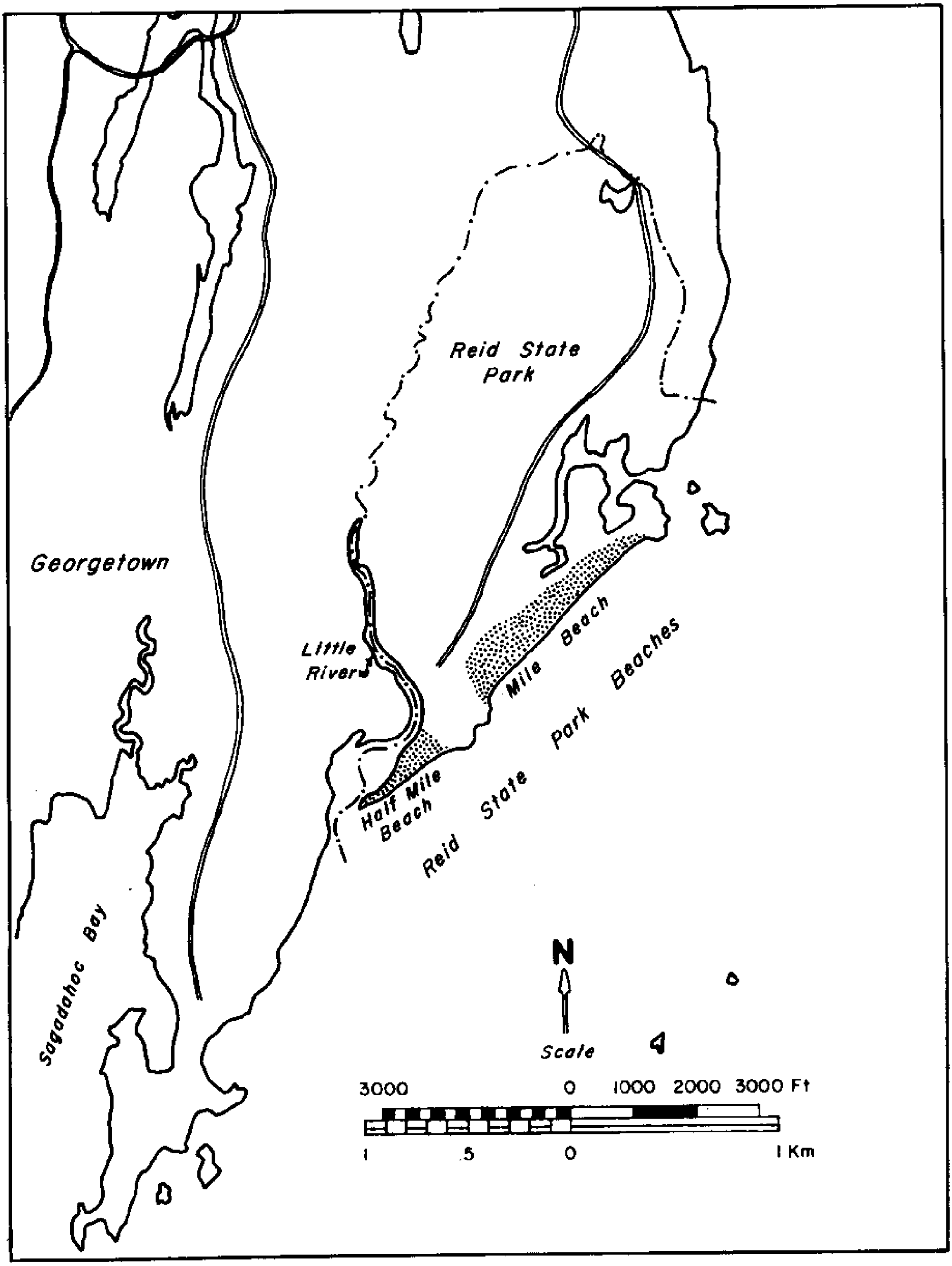


Figure 29 Reid State Park Beaches: Mile and Half Mile Beaches

and Griffith's Heads and is a long, straight closed barrier. It protects a salt marsh which drains to the sea north of Griffith's Head. The straightness is due to the position of the beach at the mouth of the underlying bedrock embayment and at the mouth of Sheepscot Bay. Incoming waves are not refracted into a curve before striking the beach. (Recall that baymouth beaches are straight whereas bayhead beaches are curved).

Half Mile Beach is an open barrier spit with a tidal reentrant (Little River) draining out of the southwestern end. Half Mile Beach also protects a substantial salt marsh. The diversity of habitats and thus the diversity of species in the back dune is lower at Reid than in the Popham-Seawall system, but Reid is the northernmost, large, back dune habitat in Maine and thus may be the northern range limit in the state for several species. It has the northernmost stands of Beach Heather (Hudsonia tomentosa) in Maine.

Mile and Half Mile beaches have interesting features relevant to the study of barrier formation, barrier maintenance, sea level rise, drift versus swash alignments, sand source, and inlet migration.

The salt marsh behind Mile Beach is connected via a sill to the ocean. This sill is about 1 m below present mean high water. Thus when sea level was about 1 m lower than today (about 2000 years ago) the present inlet was too high to permit passage of salt water into the marsh behind the barrier. Perhaps an inlet once existed through the closed barrier of Mile Beach. Sealing of this former inlet may have taken place when sea level became high enough to open the existing inlet over the rocky sill north of Griffith's Head. Sealing of such an inlet may be responsible for: 1) the historical shoreline stability of Reid due to both an increased sand supply when sand was no longer lost upstream into the tidal reentrant and the removal of the complicated effect of an ebb-tidal delta on wave refraction, sand supply and drift direction, 2) an end to breaching caused by cut banks of the meandering tidal river channel, 3) an end to sand supply from the rear for barrier maintenance and parabolic dune field broadening. (The shore of the tidal Little River provides abundant sand to the backside of Half Mile Beach's dune field. The same process is active at Ogunquit, where parabolic dunes are supplied by sand brought in by the Ogunquit River.)

It is also possible that the marsh behind Mile Beach is only as old as the present inlet over the sill north of Griffith's Head. Coring of the marsh to determine thickness of marsh peats would indicate the age of Reid as a barrier.

Because of contrasting characteristics, the two sections of beach at Reid are discussed separately.

Mile Beach — Geological Features

The sand is coarse or medium in the entire beachface and berm. It is young (i.e. not far from its source of eroded rock or glacial sand deposit). Youth is indicated by the high percentage of feldspar and schist fragments. Because of the relative coarseness of grain size there is a steep upper beachface (coarse sand has higher permeability to water and thus can be accumulated into a steeper slope by waves). The sand of Half Mile Beach is finer in comparison, but also young. The beachface slopes are moderate there.

In recent years, all of Mile Beach has experienced erosion. When field checked, this trend had reversed along the northeast half of the beach, where the relict frontal dune scarp was healed by a perennially accreting talus slope and aeolian ramp. This sand wedge was vegetated predominantly by American Beach Grass (Ammophila breviligulata) and Beach Pea (Lathyrus japonicus).

The southwest half of Mile Beach has an unhealed frontal dune scarp caused by winter erosion into the frontal dune ridge. The frontal dune ridge of all of Mile Beach is, historically, fairly stable. There is no accretionary ridge and swale topography and the single frontal dune ridge is straight and uniformly high (3 to 5 m). This suggests that the dune ridge is stable or retreating very slowly in response to sea level rise. The ridge has a long back slope extending through half or more of the back dune. The height and extensive back slope are due to: 1) shoreline stability, and 2) exposure near the tip of a peninsula where south and southeast winds are stronger than might be otherwise. South to southwest winds (the predominant onshore winds in Maine) have a net onshore component, thus making them important in frontal dune ridge accretion at Reid despite the southeast exposure of the beach.

There is a rocky lag surface on the beachface at the southwest end of Mile Beach indicating that the beachface is eroded to its past limit at this point. In 1976, metal from Navy World War II landing operations was exposed at this same spot indicating a precedent for beachface erosion to the depth of 1976 within the last thirty-five years.

The contrasting erosional versus accretionary status of the southwest half versus the northeast half of Mile Beach has a parallel contrast of beachface features. From southwest to northeast the seasonal berm broadens and the low-tide terrace narrows. The southwest end of Mile Beach has only a moderately constructional profile in summer with a narrow berm and wide low-tide terrace.

There was a double berm at the northeast end when field checked in 1977. Both berm crests had high relief sandy cusps with approximately 20 m wavelengths. High relief is due to the high permeability of coarse sand. The coarsest sand is usually concentrated at the limit of the last swash, that is, at the berm crest.

There is a large, high relief, parabolic dune on the back slope of the frontal dune ridge about one-third of the way up from the southwest end of Mile Beach. This dune, formed by northwest winds, is stabilized by Bayberry (Myrica pensylvanica) and other shrubs. The flank and leeward slopes of the high parabolic dune are now truncated by the frontal dune ridge, making the ridge appear higher at this point.

The dune field at Reid is narrow since transport of sand into the back dune and onto the marsh has not kept pace, apparently, with gradual recession of the frontal dune ridge and migration of salt marsh peat onto the back dune field in response to sea level rise. The back slope of the high frontal dune ridge extends halfway across the barrier. The rear half of the back dune field is dominated by moderate relief parabolic dunes, formed by northwest winds and stabilized with Beach Heather (Hudsonia tomentosa), sparse American Beach Grass (Ammophila breviligulata) and xerophytic back dune plants.

A significant feature at Reid is the marked difference in grain size of the aeolian ramp versus berm and beachface sand. At finer grained beaches this difference would not be noticeable, but here the medium and fine grained ramp sand is obviously different in grain size from the predominantly medium and coarse sand of the berm and beachface from which it was blown. The frontal dune ridge and back dune sands are not markedly finer than beachface and berm sands, however. Perhaps strong northwest winds remove finer sizes from the dune field, leaving a coarse grained lag deposit.

Half Mile Beach – Geological Features

The most striking difference between this and Mile Beach is the medium to fine grain size of the sand. This may be partially due to lower wave energy, but is also due, probably, to this being the downdrift end for the entire system in the longer term. Finer sand is carried further from the source than coarse sand, since storm waves from the northeast are probably responsible for the net long-term drift direction alongshore at the Reid Beach system.

The beachface slope is moderate at Half Mile Beach due to the fine grain size and lower wave energy. When field checked in 1977 there was a double berm, a moderately steep, short, upper beachface and a broad, fine grained low-tide terrace. There were no sharp slope breaks. The berm and low-tide terrace actually dipped seaward forming a smoother profile without particularly steep sections.

There was a relict, erosional scarp along the entire length of Half Mile Beach, which was being healed by perennial accretion. The perennial accretion took the form of an aeolian ramp or wedge, which was vegetated with American Beach Grass and Beach Pea.

There are a few stabilized, moderate relief, parabolic dunes in the back dune area of Half Mile Beach. The frontal dune ridge is lower here than at Mile Beach, because of the recent erosion through the highest part of the ridge. In 1977 it was about 2.5 to 3 meters high, but still had a broad back slope like the frontal dune ridge at Mile Beach. The sand is also mineralogically young with high concentrations of feldspar and schist fragments.

An important barrier dune field maintenance mechanism is well illustrated at Half Mile Beach. The rear edge of the back dune field has shifted landward as the Little River channel has shifted landward. Sand blown from the south bank of the Little River by northwest winds formed two relict rear dune ridges (former shorelines) now in the interior of the dune field. This is an important mechanism for barrier maintenance and retreat in a regime of rising sea level and frontal dune erosion. The mechanism is active here, possibly at Ogunquit, and on the spit ends of many barriers. The mechanism may have been active several thousand years ago at Seawall Beach and at Reid's Mile Beach.

Description of Botanical Features

The flora of Reid State Park have been studied by Trudeau (1977). He has compiled a fairly complete species list for this dune area as well as Popham and Seawall. A partial species list of the two areas was made during field checking in August 1977:

A. Berm and Aeolian Ramp

1. Sea Rocket — Cakile edentula
2. American Beach Grass — Ammophila breviligulata
3. Beach Pea — Lathyrus japonicus
4. Saltwort — Salsola kali
5. Sea Blite — Suaeda maritima

B. Broad Frontal Dune Ridge

1. American Beach Grass — Ammophila breviligulata
2. Beach Pea — Lathyrus japonicus
3. Poison Ivy — Rhus toxicodendron
4. Bayberry — Myrica pensylvanica (where the frontal dune ridge is receding into the high stabilized parabolic dunes)
5. Numerous composites (no identification)
6. Chickweed — Cerastium arvense
7. Gooseberry — Ribes sp.
8. Raspberry — Rubus idaeus
9. Seaside Goldenrod — Solidago sempervirens

C. Stabilized Parabolic Dunes and Open, Dry Parabolic Dune Slacks

1. Beach Heather — Hudsonia tomentosa
2. Bayberry — Myrica pensylvanica
3. Large Composite (no identification)
4. Jointweed — Polygonella articulata
5. Yarrow — Achilles millefolium
6. Sandy Sedge — Carex silicea
7. British Soldiers Lichen — Cladonia cristatella
8. Other Cladonia species including C. Rangifera
9. Virginian Rose — Rosa virginiana
10. Purple Stemmed Angelica — Angelica atropurpurea
11. Blackberry — Rubus sp.
12. Raspberry — Rubus idaeus
13. Poison Ivy — Rhus toxicodendron
14. Two Cherries — Prunus or Amelanchier sp.
15. Low Sweet Blueberry — Vaccinium angustifolium
16. Goldenrod — Solidago rugosa
17. Dodder — Cuscuta sp.

Notable general characteristics of the flora area:

1. Three general zones with increasing diversity:

   a. Berm and aeolian ramp with lowest diversity - only annual and perennial colonizers occur.

   b. Back slope of the frontal dune ridge where diversity is low - dominated by American Beach Grass, Raspberry, Gooseberry, and Beach Pea.

   c. Stabilized, moderate-relief, parabolic dunes with good stands of Beach Heather (*Hudsonia tomentosa*) and associated plants. The dominance of parabolic dunes in this area causes a mosaic floristic pattern and higher diversity than on the broad frontal dune ridge. This is due to variable depth to the water table, variable accretion and deflation rates, and variable successional age since the last aeolian activity. Such variable habitat parameters are always associated with parabolic dunes.

2. No Pitch Pine forest, only one large stand of Bayberry and Cherries in a large, stabilized, parabolic dune. Salt spray and narrowness of the dune field are the probable reasons. Reid is a high energy beach so salt spray is probably greater here than at Seawall Beach where Pitch Pines grow close to the frontal dune ridge.

3. Northernmost, large dune field in Maine - thus, the potential for being the northern range limit within the state of several of Maine's dune plant species exists. The northernmost Jointweed (*Polygonella articulata*) stands on coastal dunes within the state probably occur here. Non-dune stands do occur further north. Canadian distribution was not researched. The northernmost stands of Beach Heather (*Hudsonia tomentosa*) and the complete *Hudsonia* association occur at Reid's Mile Beach, though Beach Heather reappears on Canadian dunes. *Hudsonia* association includes Jointweed (*Polygonella articulata*), Sandy Sedge (*Carex silicea*), Pinweed (*Lechea maritima*), Pinweed Aster (*Aster linariifolius*), Greene's Rush (*Juncus Greenei*), British Soldiers Lichen (*Cladonia cristatella*), Alpine Reindeer Lichen (*Cladonia alpestris*) and Haircap Moss (*Polytrichum* sp.).

Summary of Significant Features

A. Geological

   1. Strong contrast between aeolian ramp sand grain size and beach sand grain size, but the coarsest of back dune sand in Maine, suggesting very strong northwest winds.

   2. Coarseness, poor sorting, and mineralogical youth of Mile Beach's sand indicate source of sand is nearby and is not the Kennebec River.

   3. High, broad frontal dune ridge, historically stable, at Mile Beach. It may transgress the entire dune field in some places.

   4. Numerous, moderate relief, stabilized parabolic dunes.

5. Narrow back dune field at Mile Beach - due to absence of an important barrier maintenace mechanism. This maintenance mechanism is active at Half Mile Beach.
6. Northernmost, large dune area in Maine.
7. Both erosion and accretion taking place simultaneously at Mile Beach. The northeast end is accreting and the southwest end is eroding.
8. Perennial accretion along the entire length of Half Mile Beach after several years of dramatic perennial erosion.
9. Good site for study of barrier beach maintenance in response to sea level rise.
10. A very large beach considering that the sand is all locally derived. There is very little sand offshore. The bottom becomes rocky very quickly.
11. Unique among Maine's large, barrier-marsh systems in that there is no tidal exit through the strandline. The baymouth shoreline is straight and continuous from one rocky headland to another rocky headland.

B. Botanical

1. There are three basic vegetational-geomorphological zones:
   a. Berm and aeolian ramp.
   b. High, broad frontal dune ridge
   c. Stabilized parabolic dunes
2. Illustration of importance of salt spray effects on vegetation, in this case it maintains succession at the pre-pitch pine stage.
3. Northernmost parabolic dune field in Maine. May be the northern limit for several species. Northernmost stand of Beach Heather (<u>Hudsonia tomentosa</u>) within Maine. Northernmost dune stands of Jointweed (<u>Polygonella articulata</u>) in Maine.

C. Miscellaneous

1. The unstable spit end of Half Mile Beach is probably the northernmost potential nesting habitat for least terns and piping plovers on Maine beaches. There are none there now because of the non-accretive state and heavy visitation.
2. Large, burrowing spiders with web-lined burrows and burrow mouths were noted in the open dry dune slacks of the back dune among sparse Beach Heather, Beach Grass, and Jointweed.

D. Size

1. Reid One Mile Beach has a length of 1040 m, a dune area of 7.7 hectares and a beach area of 7 hectares.
2. Half Mile Beach has a length of 640 m, a dune area of 3.1 hectares, and a beach area of 7.2 hectares.

Pemaquid Beach - Bristol, Lincoln County

Description of Geological Features

Pemaquid (Figure 30) consists of a large main beach, 450 m long, and a smaller western beach, 125 m long. The two are separated by a bedrock outcrop. The beaches are of the pocket barrier type, but the inlet to the back barrier salt marsh does not breach the strandline; the inlet is situated at a rocky intertidal sill as at Reid. The two beaches are only moderately curved in plan view because they are located near the mouths of their underlying bedrock embayments. On a larger scale some curvature of wave trains is caused by passage of the crests several km from the sea up Johns Bay before reaching Pemaquid. This situation contrasts with Reid Beach which receives straight wave trains. The greatest curvature is found at the eastern end of the main beach. Here the beach approaches the classical log-spiral shape of waves refracted into the lee of a jutting headland.

The smaller western beach section of Pemaquid Beach had three distinct sets of pebbly cusps when field checked in July of 1977; the first set located on the upper beachface was formed by spring high water; the second, located further down the beachface, was a result of neap high water and the third marked the boundary between the eroded, pebbly lower beachface and the accreted, more sandy, upper beachface.

The western beach was generally accretive but poorly sorted with medium and coarse sand, granules, and pebbles. A lot of dark mineral grains such as biotite are present. Seaweed is found on the entire berm and beachface.

A sand-rich aeolian ramp guarded a very low relief frontal dune ridge. The lower half of the beachface consisted of pebbles, granules, and coarse sand.

The western end of the main beach at Pemaquid had a constructional profile throughout and evidence of seasonal accretion. Profiling from the back dune in a seaward direction, there was a flat back dune followed by a low frontal dune ridge (approximately 1 m high), a still-visible winter scarp protruding from the aeolian ramp, a 2 m wide aeolian ramp, a 3 m wide berm, a convex-upwards beachface, a second slope break at the upper beachface resembling a second berm (probably formed by neap high water) and scattered pebbles on the lower beachface with an abundance of biotite, which was visible on the beachface in swash layers. The sand, generally fine grained on accretionary surfaces, was finer than the smaller western beach section. The accretionary upper berm and aeolian ramp were white, quartz rich, well sorted, fine sand.

In the winter there is a lag surface of cobbles and pebbles. Pemaquid is probably derived from landward transport of submerged glacial till or ice contact stratified drift. A small glacial unit of fine-grained sand is exposed at the extreme eastern end of the beach.

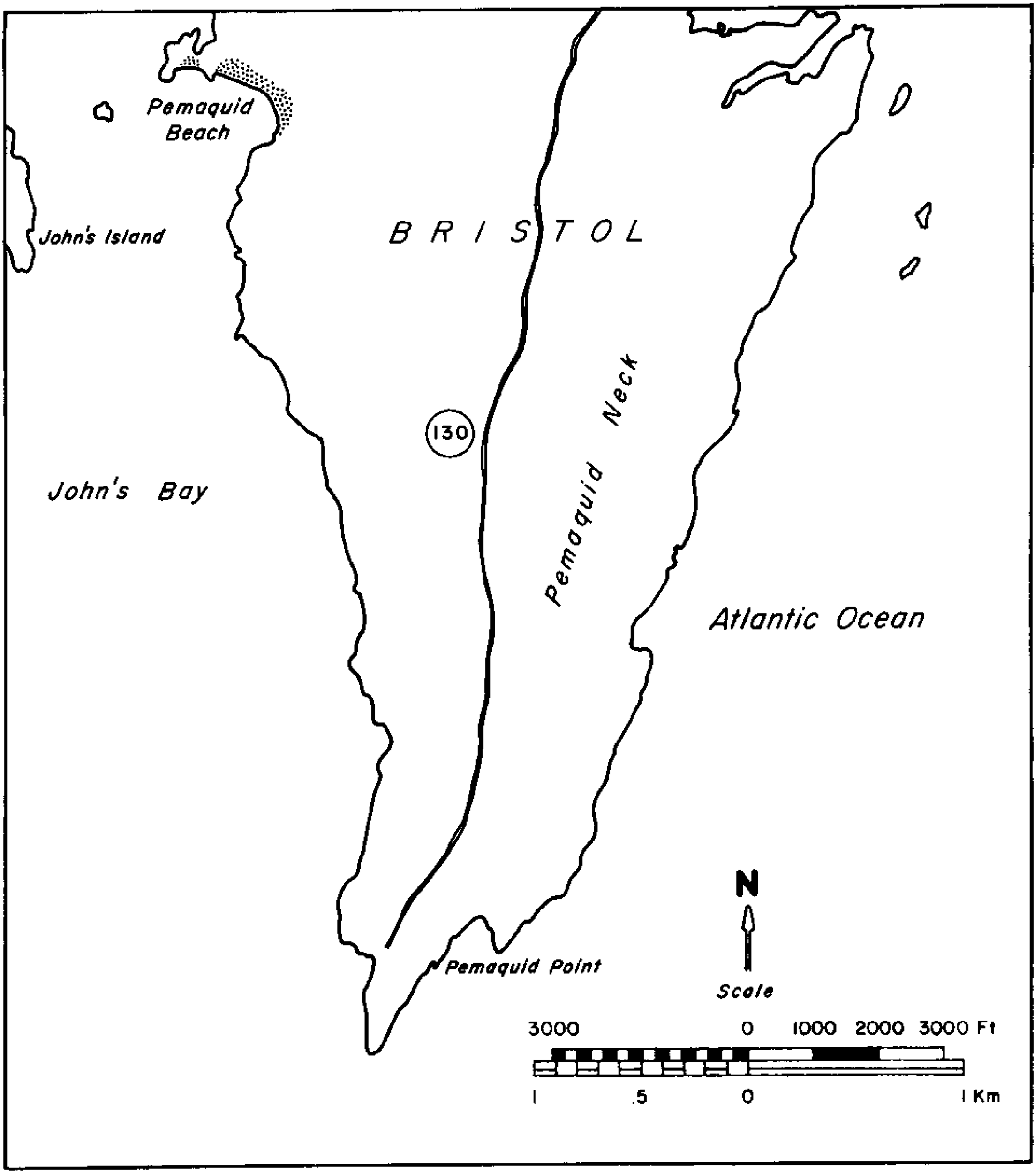


Figure 30 Pemaquid Beach

Other significant features include: 1) Pemaquid, as a whole, is a closed barrier with a salt marsh in the rear, 2) it has a low sand budget with the lag surface exposed each winter, 3) salt marsh peat and tree stumps are exposed on the beachface in the winter.

Over the very long term the small western beach and the western end of the main beach are probably at the downdrift end of the whole system, because the western back dune is broader with no trees, whereas it is narrow with trees at the edge of the scarp on the eastern end of the main beach. This suggests that the eastern end has eroded and the western sections have accreted slightly. However, the beach is predominantly swash aligned rather than drift aligned.

On January 9, 1978 a storm surge of 2.7 feet (Boothbay Harbor tide gauge) associated with high waves, a spring tide and strong southeast winds led to the following dramatic effects on Pemaquid:

1. About 4 m of landward recession of the frontal dune scarp, resulting in a lengthening of the beachface profile.
2. Toppling of spruce trees at the edge of the former scarp position.
3. Lowering of the upper beachface by about 1 m. This sand was removed to offshore but returned within a month.
4. Most important – waves overwashed the entire dune field, depositing several cm of poorly sorted medium and coarse sand on the surface of the back dune. Small deltas or overwash fans formed near the marsh/dune boundary depositing sand up to 15 cm thick. Thus the storm provided a mechanism for barrier retreat and vertical buildup (barrier maintenance) even as it caused erosion of the frontal dune. These few cm of vertical accretion throughout the dune field are enough to compensate for many decades of sea level rise.

A second storm, a northeaster, coincided with the spring high tide of February 7, 1978. The storm surge of 3.4 feet (Portland tide gauge), high waves and spring tide of this date also led to complete overwash of the back dune field at Pemaquid. This storm deposited an even larger volume of sand in the dune field. Sandy overwash fans transgressed the entire dune field, extending the dune field landward over the marsh. The height of still water on February 7, 1978 was measured 9.6 feet above NGVD, 1929 the Portland tide gauge. This is 0.9 feet higher than the previous record of 8.7 feet above NGVD, 1929 reached on November 30, 1944 and November 20, 1945.

Description of Botanical Features

Seaweed affects the speciation of the frontal dune ridge and back dune by increasing the fertility of the sand, allowing Coast Blite (*Chenopodium rubrum*) to inhabit the frontal dune ridge along with three other dominant grasses, Strand-Wheat (*Elymus areniarius*), Quack Grass (*Agropyron repens*) and American Beach Grass (*Ammophila breviligulata*), two of which (Strand-Wheat and Quack Grass) were more common than American Beach Grass in the first few feet of the dune and back dune when field checked. Their dominance was due to the seaweed that had been raked from the beaches to the back dune by the summer maintenance staff. Sea Rocket (Cakile edentula) also expands its borders into the dunes because of the seaweed's presence. The vigor of vegetation on the berm is also dependent upon where the seaweed lies. This seaweed allows many non-beach plants to grow, e.g. Mustard (Brassica sp.), Nightshade (Solanum dulcamara) and Quack Grass (Agropyron repens). Abundant seaweed, coupled with the minimal wind transport of sand, make American Beach Grass less important in the flora.

Areas of sandy, barren back dune of the main beach which were once foot-traffic damaged are now covered with pasture grasses, Sandy Sedge (Carex silica), Greene's Rush (Juncus Greenei), Beach Pea (Lathyrus japonicus), Yarrow (Achillea millefolium) and depauperate American Beach Grass. Bayberry (Myrica pensylvanica) is among the spruce trees. A partial list of species follows:

1. American Beach Grass – Ammophila breviligulata
2. Saltwort – Salsola kali
3. Sea Rocket – Cakile edentula
4. Mustard – Brassica sp.
5. Coast Blite – Chenopodium rubrum
6. Great Angelica – Angelica atropurpurea
7. Nightshade – Solanum dulcamara
8. Bayberry – Myrica pensylvanica
9. Quack Grass – Agropyron repens
10. Evening Primrose – Oenothera sp.
11. Morning Glory – Convolvulus sepium
12. Raspberry – Rubus idaeus
13. Yellow Dock – Rumex crispus
14. Seaside Rose – Rosa rugosa
15. Rose – Rosa sp. (carolina or virginiana)
16. Yarrow – Achillea millefolium
17. Strand-Wheat – Elymus arenarius
18. Beach Pea – Lathyrus japonicus
19. Timothy Grass – Phleum pratense
20. Seaside Goldenrod – Solidago sempervirens
21. Sandy Sedge – Carex silicea
22. Shadbush – Amelanchier sp.
23. Toadflax – Comandra umbellata
24. Pinweed – Lechea maritima
25. Love Hairgrass – Deschampsia flexuosa
26. Greene's Rush – Juncus Greenei
27. Bristly Sarsaparilla – Aralia hispida

Summary of Significant Features

A. Geological

1. Pemaquid, like Reid Beach, is a closed pocket barrier with a salt marsh in the rear, the best example of this beach type.

2. There is a low sand budget and consequently the lag surface is exposed each winter. Salt marsh peat and tree stumps are also exposed on the beachface each winter.

3. The main beach had a double berm (spring and neap) with a pebbly, eroded lower beachface at the eastern and middle sections. Its sand was finer and better sorted than the western beach.

4. The western beach was accretive but poorly sorted with medium and coarse sand, granules, and pebbles.

5. Many dark mineral grains, including biotite were present on the eroded lower beachface. Sand of the accretionary berm and aeolian ramp is fine, white, quartz rich. The main beach is thus a good example of mineralogic sorting as a function of erosion and deposition.

6. Three distinct sets of pebbly cusps were located on the smaller western beach section of Pemaquid.

7. Over the very long term the western section is probably the downdrift end of the whole system.

8. The beach is predominantly swash aligned rather than drift aligned.

9. Foot-traffic eroded areas of the back dune of the main beach have been revegetated, however not without the effects of such a pre-existing condition (i.e. incipient dry dune slack species exist here, such as Sandy Sedge and Greene's Rush). The American Beach Grass which has moved into these areas is depauperate (yellow and spindly). Where seaweed has overwashed into these areas and into the spruce trees near the pavilion, Strand-Wheat (*Elymus arenarius*) has moved in.

10. The only documented case in Maine of barrier dune maintenace by complete washover of the dune field associated with vertical buildup and landward retreat.

B. Botanical

1. Seaweed affects the speciation of the frontal dune ridge and berm by increasing the fertility of the sand, allowing Coast Blite, Strand-Wheat and Quack Grass to inhabit the ridge in greater numbers than should be expected, thereby reducing the numbers of the usually predominant American Beach Grass.

2. The minimal wind transport of sand also makes American Beach Grass less important in the flora.

3. The vigor of vegetation on the berm is dependent upon where the seaweed lies. Seaweed also allows non-beach plants to grow on the berm.

4. There are no dry dune slacks of parabolic dunes to provide an encouraging habitat for Beach Heather (*Hudsonia tomentosa*). There is no Beach Heather. (Pemaquid and Sand Beach at Acadia are the only beaches north of Reid which are ever likely to evolve suitable habitat for Beach Heather in Maine.

C. Size

1. The main beach at Pemaquid has a length of 450 m, a dune area of 2.3 hectares, and a beach area of 1.4 hectares.

2. The western beach has a length of 125 m, a dune area of 0.5 hectares and a beach area of 0.35 hectares.

NOTE: There are no highly noteworthy botanical features on any beaches north of Reid Beach. There are no more range limits and the only plant found on these northern beaches which is strictly a plant of the coastal sand dune habitat is American Beach Grass (*Ammophila breviligulata*).

Many beaches north of Reid have been selected as significant areas for the single reason that they provide stepping stones in this portion of the range of American Beach Grass. They may be of scientific value for studies of geographic variation in the growth form and genetic composition of Beach Grass and for studies of disjunct populations.

The rarity of sand dune habitats north of Reid makes each habitat disproportionately significant. Many of these areas would not have been selected if they were located in southern Maine where extensive dune fields are found nearby.

Louds Island Cuspate Foreland - Bristol, Lincoln County

Significant Geological Features

Louds Island's (Figure 31) northern tip is a comet's tail type of cuspate foreland. Cuspate forelands are a common beach type north of Reid but this is one of the larger ones and therefore significant. The area is also significant because there are few sandy beaches with dunes north of Reid. The width of the cuspate foreland from the tip southward to the forest edge is about 120 m.

There is a possible former shoreline ridge, 1 m high, about 50 m seaward of the forest and 20 to 75 m behind the western shore. The ridge runs obliquely to the western shore.

There are two freshwater marshy areas in the back dune, both dominated by Cattail (*Typha latifolia*).

There are no active wind-blown dunes in the back dune area though a slight, rolling topography suggests former activity.

Washover accretion is more significant than wind-blown accretion in the foredune and back dune. Only a short stretch of the western shore has an actively accreting frontal dune ridge. Because of the predominance of washover accretion, the frontal dune ridge might more properly be called a sandy storm berm. The frequent washovers have left a large amount of seaweed in this sandy berm.

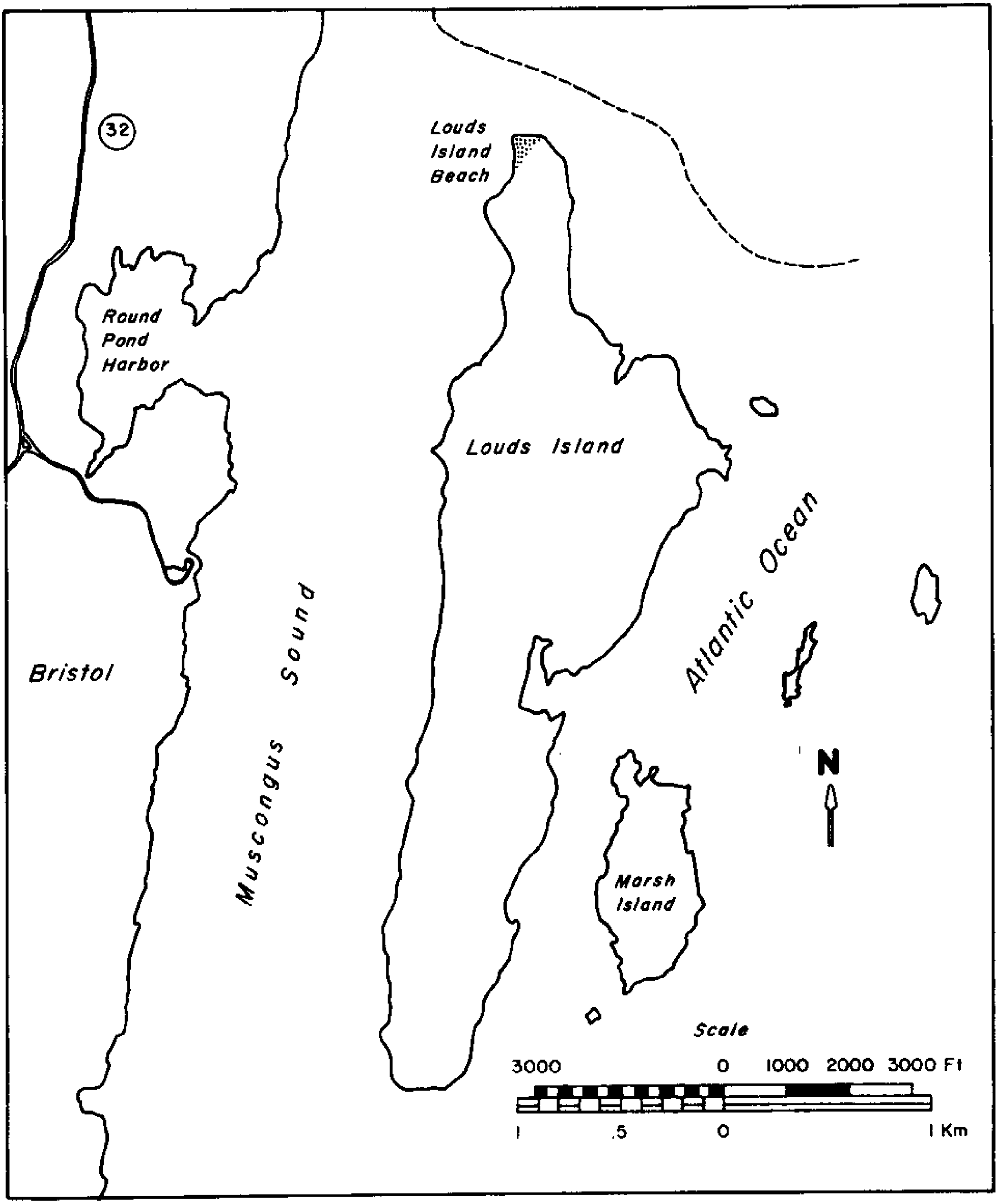


Figure 31 Louds Island Beach

The beachface has a low sand volume and is poorly sorted. There was a minor, constructional, medium-grained sandy berm when field checked in 1977. Below the berm was a straight steeply sloping, coarse-grained sandy beachface with pebbles and cobbles. Below this is a silty clay low-tide terrace, which is vegetated below low water by Eel Grass (Zostera marina).

The western leg of the cuspate foreland has a greater sand supply than the northeastern leg. Aeolian activity is greater on the western leg because of greater sand supply and because it faces the prevailing wind. Vegetational zonation also is more marked on the western leg probably because of stronger aeolian sand activity, washover, and salt spray.

The presence of the cuspate foreland on the northern tip of Loud's Island suggests a net up-estuary flow of bed-load sediment in Muscongus Bay. This contrasts with net downstream bed-load transport in the Kennebec River as evidenced by a sandy sediment tail below Perkins Island. This is partly conjecture, however, because the relative effects of waves and currents at Louds Island are unknown.

Significant Botanical Features

Quack Grass (Agropyron repens) replaces American Beach Grass (Ammophila breviligulata) on the frontal dune ridge because of low aeolian activity and high nutrient input from seaweed by washover and storm berm accretion. As a consequence, there is no American Beach Grass at Louds Island. A narrow zone of annual berm colonizers grows immediately seaward of a winter scarp in the frontal dune ridge on seasonally accreted sand of the berm. These include Sea Rocket (Cakile edentula), Sea Beach Orach (Atriplex patula var. hastata or A. arenaria) and Coast Blite (Chenopodium rubrum). The foredune ridge is dominated by Quack Grass and sparse patches of Strand-Wheat (Elymus arenarius) and Beach Pea (Lathyrus japonicus). The grassy back dune area is dominated by Greene's Rush (Juncus Greenei). A large patch of Seaside Rose (Rosa rugosa), grows near the tip of the cusp with a small stand of Staghorn Sumac (Rhus typhina). In trampled, open sandy areas grow Sandy Sedge (Carex silicea), and Seaside Spurge (Euphorbia polygonifolia). This latter species has only been encountered on one other beach in Maine, Andrew's Beach, Long Island, Casco Bay. Though it is not strictly a beach plant it grows in hot, open sand and is a xerophyte. It is a common berm plant on Massachusetts beaches where it attains a much larger size than the specimens collected in Maine.

A general species list follows:

1. Quack Grass – Agropyron repens
2. Sea Rocket – Cakile edentula
3. Sea Beach Orach – Atriplex arenaria or A. patula var. hastata
4. Sandy Sedge – Carex silicea
5. Seaside Rose – Rosa rugosa
6. Milkweed – Asclepias sp.
7. Seaside Spurge – Euphorbia polygonifolia
8. Greene's Rush and another rush species – Juncus Greenei and Juncus sp.
9. Raspberry – Rubus idaeus

10. Pasture Grasses
11. Bayberry – _Myrica pensylvanica_
12. Lichens – _Cladonia_ spp.
13. Haircap Mosses – _Polytrichum_ spp.
14. Gooseberry – _Ribes_ sp.
15. Wooly Steeplebush (pink) – _Spiraea tomentosa_
16. Meadowsweet – _Spiraea latifolia_
17. Staghorn Sumac – _Rhus typhina_
18. Cattail – _Typha latifolia_
19. Strawberry – _Fragaria_ sp.
20. Cranberry – _Vaccinium macrocarpon_
21. Yellow Hawkweed – _Compositae_

Summary of Significant Features

A. Geological Features

1. Beach type – large comet's tail type cuspate foreland.
2. Possible former shoreline in back dune.
3. Example of relative importance of overwash versus aeolian transport.
4. Fairly extensive back dune area, periodically wet, indicated by presence of Rush.

B. Significant Botanical Features

1. Quack Grass replaces _Ammophila breviligulata_ on frontal dune ridge.
2. Presence of _Euphorbia polygonifolia_ – most significant of all features.
3. Good example of vegetational zonation on western shore (berm colonizers → Quack Grass → Greene's Rush).

C. Size

The beach on Louds Island has a combined length of 335 m, a dune area of 1.8 hectares and beach area of 1.4 hectares.

Pond Island – Unorganized Area, Hancock County

Description of Geological Features

The beaches of Pond Island (Figure 32) are predominantly gravel and cobble, but there are two sandy dune ridges along the legs of a large open cuspate barrier, which has an interior salt marsh, at the southeast end of the island. The open cuspate barrier is the best example of this geomorphic type in Maine. The position and orientation of the cuspate barrier is of interest because it is not in the wave shadow of the island. The ebb current of the Penobscot and the proximity of Hog Island are as important as waves in determining the distribution of sediment around Pond Island.

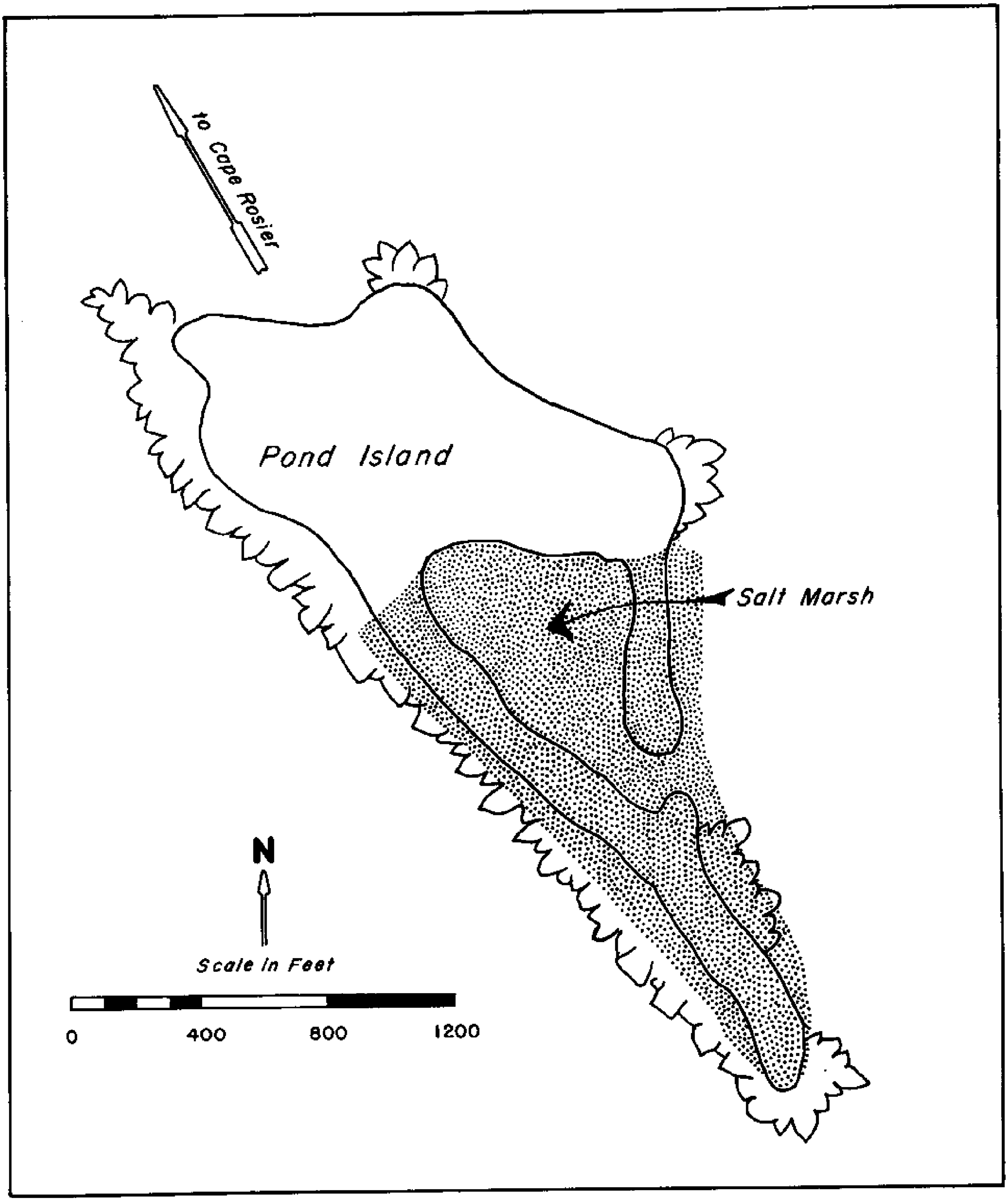


Figure 32 Pond Island Beaches, Northern Penobscot Bay

There is one small sandy beach on the northwest end of the island. A high eroding bluff of glacial till is located on the north side of the island and is one of its most striking features. The gravel, pebble and cobble dominated beach which forms the northeast leg of the cuspate barrier has derived some of its sediment from wave erosion and mass wasting of this high till bluff.

The northeast leg of the cuspate barrier had a remarkably straight beachface profile with almost no berm when field checked in July of 1977. Cusps and swash ridges were of extremely low relief and the lower beachface was cobbly. Above the beachface and narrow berm is a low relief wind-deposited frontal dune of medium grained and coarse grained, poorly sorted sand. The frontal dune is only a few meters wide and backed by salt marsh. It supports a healthy stand of American Beach Grass (*Ammophila breviligulata*). A narrow, wind-deposited sand dune of low relief also backs the cobble, boulder and shell hash dominated beach on the southeast leg of the cuspate foreland.

The presence of American Beach Grass on the two dune ridges of the open cuspate barrier is a significant feature. Healthy stands of *Ammophila breviligulata* are small and infrequent north of Reid State Park. Northern stands are of value to phytogeography; they provide stepping stones in the study of genotype and phenotype variation along a geographic gradient. These northern stands are also interesting sites for the study of disjunct populations and speciation. Healthy stands of Beach Grass on Pond Island, Eagle Island and perhaps a few other Penobscot Bay islands are, thus, of significant scientific value.

Other species include Raspberry (*Rubus idaeus*), Sea Rocket (*Cakile edentula*), Pasture Grasses, Mullein (*Verbascum thapsus*), Purple Thistle (*Cirsium* sp.) and Mustard (*Brassica* sp.).

Summary of Significant Features

A. Geological

1. Best example of an open cuspate barrier in Maine.
2. Low relief windblown dune ridges.

B. Botanical

Presence of American Beach Grass.

C. Size

The northeast leg of the cuspate barrier is 600 m long. The southeast leg is 670 m long.

D. Other Features of Note on Pond Island

1. Large glacial till bluff on north side of island — wave eroded at base.
2. At least two Indian shell heaps.
3. Salt marsh with Sea Lavender, Salt Hay and Cord Grass.

Merchant Island Pocket Beach — Isle Au Haut
Hancock County

Description of Geological Features

Merchant Island's beach type (Figure 33) is a fringing, pocket beach. Behind the beach is an alder lowland which was probably never marine. There is a drainage stream through the dunes at the center of the beach, but this stream was blocked by berm accretion when field checked in late July, 1977.

A relict frontal dune ridge with an erosional scarp lies 2 to 5 m behind the limit of American Beach Grass (*Ammophila breviligulata*). This indicates perennial accretion over the last few years along the entire beach length, especially the central and western portions. A frontal dune ridge had not yet formed in front of the old erosional scarp.

The upper half of the beachface was sandy with scattered pebbles and cobbles. When field checked it also had three pebble and cobble berms, all between spring and neap high water marks. All three berms had low relief cusps along their crests. The lower half of the beacface consisted of small boulders with gravel matrix.

The back dune and aeolian ramp are moderately sorted medium-grained sand.

There is no downdrift end to the beach system. Sand accumulates at the center more than at either end. The back dune is also widest in the center.

Description of Botanical Features

The following plants are strictly sandy or rocky beach and dune plants: Strand-Wheat (*Elymus arenarius*), American Beach Grass (*Ammophila breviligulata*), Beach Pea (*Lathyrus japonicus*) and Sea Rocket (*Cakile edentula*).

Non-beach plants in a boggy area beneath spruce trees on the back edge of the dune area at the eastern end of the beach are: Bog Cranberry (*Vaccinium macrocarpon*), Sun Dew (*Drosera comosa*), Sphagnum Moss, Hardhack (*Spiraea tomentosa*).

A partial list follows:

1. Strand-Wheat — *Elymus arenarius*
2. American Beach Grass — *Ammophila breviligulata*
3. Beach Pea — *Lathyrus japonicus*
4. Sea Rocket — *Cakile edentula*
5. Rough Cinquefoil — *Potentilla norvegica*
6. Common Skullcap — *Scutellaria epilobiifolia*
7. Bog Cranberry — *Vaccinium macrocarpon*
8. Sun Dew — *Drosera comosa*
9. Sphagnum Moss — *Sphagnum* sp.
10. Hardhack — *Spiraea tomentosa*
11. Alder — *Alnus* sp.

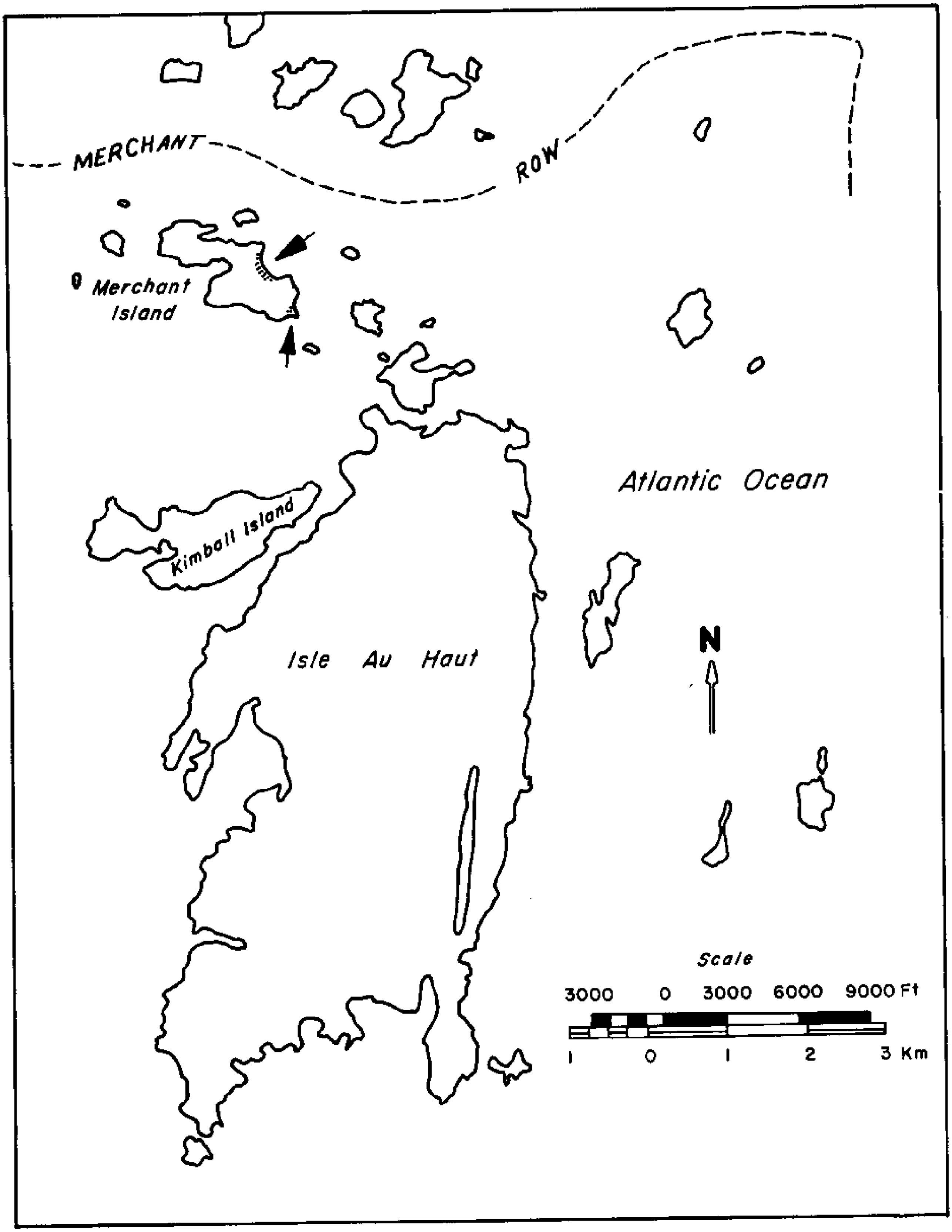


Figure 33 Merchant Island Beaches

12. White Spruce – _Picea glauca_
13. Blue Flag Iris – _Iris versicolor_
14. Quack Grass – _Agropyron repens_
15. Saltwort – _Salsola kali_
16. Purple Thistle – not identified

Summary of Significant Features

A. Geological

1. The dune area is dominated by healthy American Beach Grass suggesting abundant sand supply despite the gravelly and pebbly nature of the beachface.
2. Moderate perennial accretion has occurred over the last few years as evidenced by the relict frontal dune ridge.
3. The beach faces northeast, an unusual orientation for a pocket beach in Maine, and is protected from heavy surf by the islands of Merchant's Row.
4. A classical pocket beach with the finest sand and broadest back dune located at the apex of the pocket.

B. Botanical

1. Thick, healthy American Beach Grass stands (uncommon in this part of Maine, therefore an important population in this portion of its range).
2. Healthy American Beach Grass despite apparent low beachface sand supply. One would expect Beach Pea and Strand-Wheat to be more dominant than they are.
3. American Beach Grass of the accreting aeolian ramp is a darker green (healthier) than that of the back dune. Sand deposition has stimulated some individuals to flower on the aeolian ramp.

Merchant Island Cuspate Foreland – Isle Au Haut, Hancock County

Description of Geological Features

The beach type is a comet's tail cuspate foreland formed in the wave shadow of Merchant's Island. Its form and genesis is similar to that of Louds Island Cuspate Foreland in Muscongus Bay. The sand source is submerged till or ice contact stratified drift with some biogenic carbonate input. The bottom in this area is clean and rocky with large numbers of sea urchins and periwinkles (similar to Sand Beach at Acadia). The upper beachface, aeolian ramp and frontal dune ridge of the northeast leg are medium sand, moderately to well sorted, with a very high carbonate content of shell hash and sea urchin spines. The northeast leg of the foreland is accretionary and the southeastern leg is eroded. The northeastern leg has a broad sand and gravel beachface, while the southeastern leg has only a narrow, sand and shell, upper beachface with boulders below.

When field checked, the beachface of the northeast leg had a straight slope with three very small berm crests in the high tide zone composed of pebbles and cobbles and periwinkle shells. There were also gravel and pebble swash lines on the upper beachface below the high tide mark. The lower beachface had shingle-shaped pebbles and cobbles with a gravel matrix and very little sand.

There is a relict erosional scarp behind a 2 to 5 m wide, perennially accreting aeolian ramp on the northeastern leg. What appears to be a former shoreline runs parallel to, and as much as 15 m behind, the present shoreline.

Shell hash and periwinkle shells have accumulated into interesting forms on the two beaches of the cuspate foreland. On the northeast beach, periwinkle shells have been segregated into low relief cusps evenly spaced on the fine gravel, upper beachface. Shell hash and periwinkle shells have been segregated into thick ridges on the lower beachface of the southeast beach.

Description of Botanical Features

A large, healthy stand of American Beach Grass is present (despite the apparent lack of sand burial).

A partial list of species follows:

1. American Beach Grass – *Ammophila breviligulata*
2. Beach Pea – *Lathyrus japonicus*
3. Quack Grass – *Agropyron repens*
4. Sea Rocket – *Cakile edentula*
5. White Spruce – *Picea glauca*
6. Mullein – *Verbascum Thapsus*
7. Strand-Wheat – *Elymus arenarius*
8. Purple Thistle – not identified
9. Evening Primrose – *Oenothera* sp.
10. Yarrow – *Achillea millefolium*
11. Common Skullcap – *Scutellaria epilobiifolia*
12. St. John's Wort – *Hypericum perforatum*

Summary of Significant Features

A. Geological

1. Unusual beach type – comet's tail cuspate foreland.
2. High carbonate content in sand of the upper beachface and the dune.
3. A very old, relict shoreline.
4. Recent relict scarp with perennial accretion in front of it.

B. Botanical

A large, healthy stand of American Beach Grass, despite the apparent lack of aeolian transport. The two beaches of Merchant Island have most of the American Beach Grass in the region between Deer Isle and Swans Island.

C. Other Features of Note

There is a large Indian shell heap with chipped artifacts behind the northwest corner of the cuspate foreland.

Marshall Island Sand Cove Beach - Swans Island, Hancock County

Description of the Geological Features

Marshall Island Sand Cove Beach (Figure 34) is a pocket beach with a sandy, intertidal beachface and a cobble and boulder storm berm above high water. The storm berm creates a barrier for a freshwater marsh behind. There is no sand above high water, therefore there are no dunes or dune vegetation. All significant features are geological, though vegetation of the rocky storm berm is listed below.

The length of the beach increases as the tide goes out. At the high water line the beach is about 120 m long. At the mid-tide line the beach is about 170 m long. The distance from the crest of the rocky storm berm to the low water mark measures approximately 100 m, a very wide beachface which faces southeast.

When field checked in late July, 1977 a steep upper beachface covered the foreslope of the rocky storm berm, followed by a runnel with ripple marks and then a convex upward beachface or ridge.

The fine surface sand and coarse subsurface sand has a high carbonate content.

Botanical Features

Partial species list of plants on the rocky storm berm.

1. Beach Pea - *Lathyrus japonicus*
2. White Spruce - *Picea glauca*
3. Quack Grass - *Agropyron repens*

Summary of Significant Geological Features

A. Sand Cove beach is the only fine sand beach on Marshall Island. The unusual grain size with a large volume of fine sand contrasts with all the other rocky beaches on Marshall Island. The sand source may be more from local bedrock erosion and biogenic carbonate than from submerged glacial deposits. This is suggested by the numerous clean rocky beaches derived from local bedrock.

B. High carbonate content of fine surface sand and coarse subsurface sand.

C. A very broad beachface occurs, despite the periodic high energy environment which is indicated by the large rocky storm berm. The grain size is bi-modal

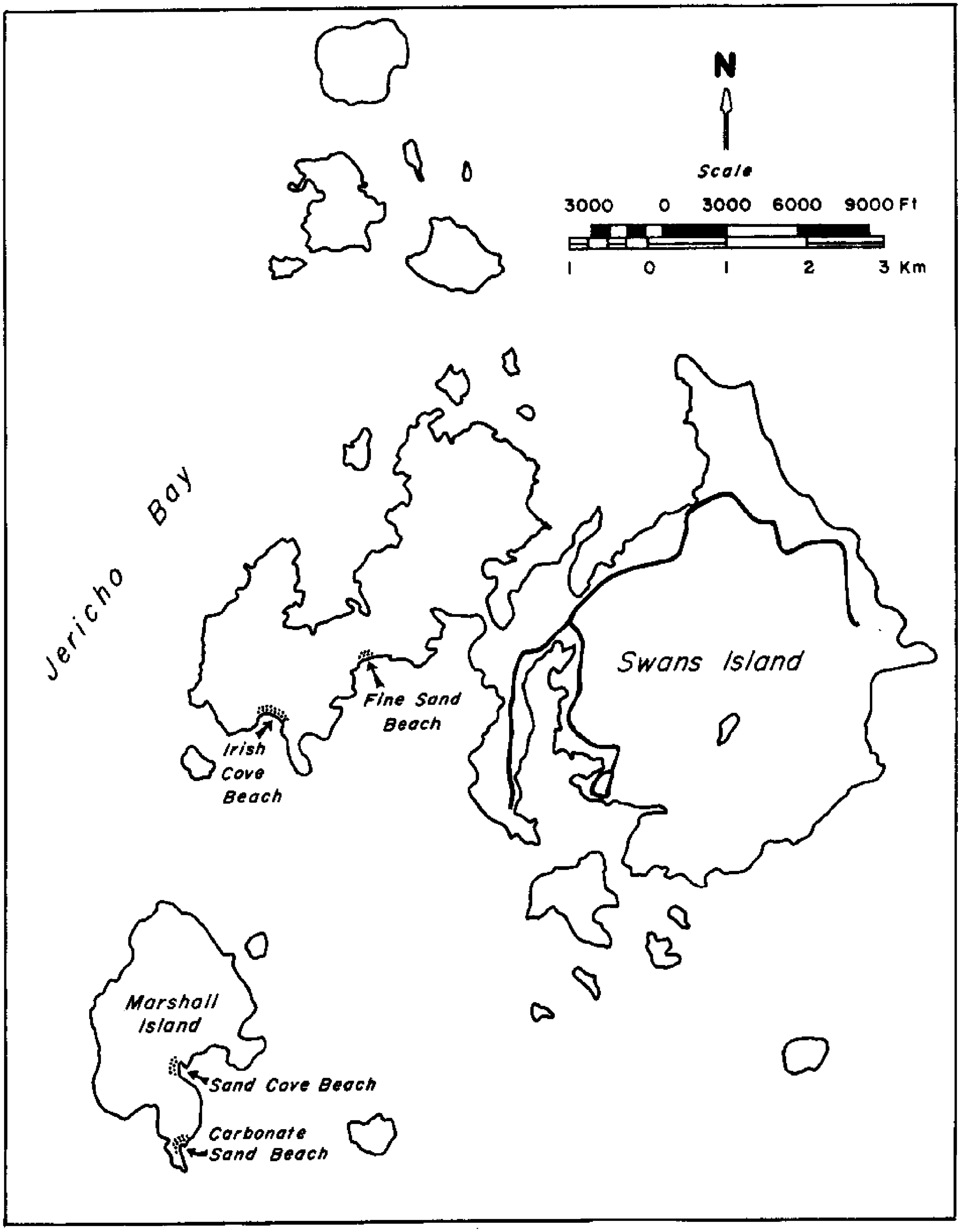


Figure 34 Marshall Island and Swans Island Beaches

with extreme contrast, i.e. boulder storm berm and fine sand beachface. This suggests that the beach experiences construction by weak refracted swell most of the time to bring in sand, but occasionally experiences short, steep storm waves of high energy, probably northeast storm waves coming out of the east to build the rocky storm berm.

D. A constructional beachface profile with the following features:

1. Steep, sandy upper beachface.
2. Broad ridge and runnel at northern end.
3. Smaller ridge and runnel with rip current escape channels at southern end.

E. The fine sand surface layer is probably suspended or removed to offshore bars during winter northeast storms. This is suggested by graded bedding observed on the mid-tide beachface. Fine sand and shell hash on the surface grades to coarse sand and shell hash within 20 cm depth.

Marshall Island Carbonate Beach – Swans Island, Hancock County

Description of Geological Features

The carbonate sand beach of Marshall Island (Figure 34) is the only pure carbonate sand beach yet encountered in Maine by the authors. There is almost no non-carbonate sand. The sand is a shell hash of medium to coarse size. There is a shell hash and soil berm with an eroded scarp in it. The beach extends down only to the mid-tide level. There is Salt Marsh Cord Grass (*Spartina alterniflora*) and Sea Milkwort (*Glaux maritima*) below the beach at the northern end. Cobbles and boulders occupy the mid- to low-tide zone below the rest of the beach on the southern and central portions. There is a small vegetated berm below the eroded scarp.

Description of Botanical Features

Partial species list

1. Strand-Wheat – *Elymus arenarius*
2. Lungwort – *Mertensia maritima*
3. Beach Pea – *Lathyrus japonicus*
4. Sea Rocket – *Cakile edentula*
5. Sea Milkwort – *Glaux maritima*
6. Cord Grass – *Spartina alterniflora*

Summary of Significant Features

The single feature which makes this a significant natural area is the mineralogy of the sand. Such carbonate beaches may exist on other exposed offshore islands but discernment of these small areas is not possible using the high altitude photos available.

Irish Cove Beach – Swans Island, Hancock County

Description of Geological Features

Irish Cove Beach (Figure 34) is an open pocket barrier beach type. In plan view the beach is fairly straight because it is located near the mouth of a rocky embayment where incoming waves are only slightly refracted. The beach is about 275 m long.

This beach protects a large back-barrier salt marsh which exchanges water with the sea through a tidal inlet at the downdrift or spit end of the barrier. The supratidal barrier is a rocky storm berm with an aeolian and washover sand veneer and matrix. It is a combination storm berm/frontal dune ridge. The barrier was about 25 m wide from the rear marsh edge to the frontal dune scarp when field checked in July of 1977. The aeolian ramp and narrow summer berm, composed of medium and medium to fine sand respectively, extended 7 m further seaward. The steep beachface was straight with no accretionary ridges or convex upward surfaces. The upper beachface did, however, have a fine sand veneer overlying a pebble, cobble, and boulder lag surface. This lag surface was exposed on the lower beachface. Exposure of the lag surface even in summer indicates that the beach has a low sand budget. The beachface was 38 m wide from the berm crest to the low water line.

Because of the orientation of the beach, the western end is downdrift and receives more sand and finer sand than the eastern end.

Some of the sand on the beachface is transported over the storm berm by storm overwash as indicated by sandy overwash fans on the backside of the rocky storm berm. These fans extend over the marsh and are thick enough to permit growth of healthy American Beach Grass (*Ammophila breviligulata*).

Description of Botanical Features

There is a large stand of American Beach Grass. This is significant because suitable habitats are rare in this portion of its range. The large, sandy washover fans are vegetated with American Beach Grass and the upper half of the backside of the high storm berm/frontal dune ridge is vegetated almost exclusively with Beach Pea (*Lathyrus japonicus*) and Strand-Wheat (*Elymus arenarius*).

A partial species list with habitat for each species follows:

1. Sea Rocket – *Cakile edentula*, berm
2. Beach Pea – *Lathyrus japonicus*, berm, aeolian ramp and frontal dune ridge/storm berm.
3. Seabeach Sandwort – *Arenaria peploides*, berm and aeolian ramp.
4. American Beach Grass – *Ammophila breviligulata*, aeolian ramp, some on frontal dune ridge/berm and much more on lower backside of ridge (sandy washover fans).
5. Freshwater Cord Grass – *Spartina pectinata*, frontal dune ridge/storm berm.

6. Strand-Wheat – *Elymus arenarius*, aeolian ramp and frontal dune ridge/storm berm.
7. Ruderal composites – frontal dune ridge where rocks or seaweed show through sand.
8. Terrell Grass – *Elymus virginicus*, one plant at spit end.
9. Squirrel Tail Grass – *Hordeum jubatum*, one plant at spit end.

Summary of Significant Features

A. Geological

1. Sandy washover fans on the backside of the storm berm/ridge vegetated with healthy American Beach Grass.
2. High, boulder storm berm with sandy matrix and veneer and sandy aeolian ramp. Vegetated with Beach Pea, Strand-Wheat, Freshwater Cord Grass and Quack Grass.
3. Open barrier – protects a substantial salt marsh behind it.
4. The beachface sand blocks the flow of the tidal inlet, especially on the neap tides. Thus, the vegetation of the salt marsh is affected. Particularly notable is the presence of Squirrel Tail Grass (*Hordeum jubatum*) in and among the Salt Marsh Hay (*Spartina patens*) and Black Rush (*Juncus gerardii*) of the salt marsh.
5. The downdrift (spit) end has more sand and finer sand on the beachface. This is the west end of the beach.
6. There is a low sand budget, and a pebble, cobble, and boulder lag surface is visible on the beachface even in the summer, but there is a large stand of American Beach Grass on the backside of the combination sandy frontal dune ridge and rocky storm berm due to washover deposition. There is not much berm accretion in the summer (less than at Fine Sand Beach which is also located on Swans Island).

B. Botanical

1. Presence of Freshwater Cord Grass (*Spartina pectinata*) in large quantities on the rocky and sandy storm berm/ridge.
2. A few American Beach Grass plants with seed heads indicate significant aeolian sand burial in some places. This occurs despite the low sand budget, because of the southern exposure.
3. Presence of a large stand of American Beach Grass in this portion of its range where suitable habitats are rare. Lush American Beach Grass on the lower half of the back of the combination frontal dune ridge/rocky storm berm probably is due to washover of sand. This is unusual since American Beach Grass is usually healthiest on the upper portion and top of the ridge.
4. Beach Pea dominates the ridge/storm berm top, top foreside, and bottom foreside.

5. Presence of Squirrel Tail Grass in the salt marsh (not a beach feature, though one plant was growing on open sand of the spit end).

C. Size

The beach is about 275 m long.

Fine Sand Beach – Swans Island, Hancock County

Description of Geological Features

Fine Sand Beach of Swans Island (Figure 34) is a very small fringing pocket beach with no former or present marine lagoon or salt marsh behind. It was formed by onshore transport of submerged till or ice contact stratified drift. In summer the surface is composed of fine sand which is well sorted and quartz-rich with some feldspar. There are no boulders, cobbles, pebbles, gravel or coarse sand on the beachface surface in summer, though there is a cobble lag surface located one foot below the surface of the beachface near the low water mark. This is probably exposed in winter. There is a remarkably simple example of graded bedding from the beachface down to the lag surface grading from fine sand to medium sand to coarse sand to gravel to pebbles and cobbles.

There was a summer, accretionary profile when field checked in July of 1977, although a lag surface was exposed on the lower beachface. The flat berm was 10 m wide. There was a moderately steep beachface, 30 m wide from the berm crest to low water. Sandy cusps, with 4 m wavelengths, were located on the berm crest.

The lower beachface length is approximately 150 m. The upper beachface length, along the edge of vegetation, is approixmately 80 m, so the beachface area forms a trapezoid of sand within two rocky headlands.

A small freshwater stream drains out of the upland through the beachface, dune, and berm near the southwest end of the beach. There is no apparent drift alignment for the beach system.

The dune ridge is formed largely by washover accretion. Seaweed and logs are found throughout the back dune area. Seaweed nutrient content of the berm, aeolian ramp and frontal dune ridge is high and affects speciation. Aeolian accretion was minimal, with only a small aeolian ramp in front of the healing winter scarp, when field checked.

Description of Botanical Features

The vegetation is zonational. The following zones make up the vegetational species pattern: 1) berm and aeolian ramp plants, 2) frontal dune ridge plants, 3) back dune plants, 4) shrub/tree edge. The berm and aeolian ramp plants include the following, in order of importance:

1. Strand-Wheat – *Elymus arenarius*
2. American Beach Grass – *Ammophila breviligulata*
3. Sea Rocket – *Cakile edentula*
4. Beach Pea – *Lathyrus japonicus*
5. Seabeach Sandwort – *Arenaria peploides*
6. Yellow Hawkweed – *Hieracium vulgatum*
7. Seabach Orach – *Atriplex patula* var. *hastata* or *A. arenaria*

The frontal dune ridge plants include the following (again, in order of importance):

1. American Beach Grass – *Ammophila breviligulata*
2. Strand-Wheat – *Elymus arenarius*
3. Beach Pea – *Lathyrus japonicus*
4. Quack Grass – *Agropyron repens*
5. Yellow Duck – *Rumex crispus*

The area between the frontal dune ridge and the shrub/tree edge is approximately 10 m by 80 m, which makes the back dune area approximately 800 m square. Its plants include the following in order of importance:

1. Blackberry – *Rubus* sp.
2. Raspberry – *Rubus idaeus*
3. Bayberry – *Myrica pensylvanica*
4. Seaside Rose – *Rosa rugosa*: very large, healthy stand at southwest end of dune area
5. Blue Flag Iris – *Iris versicolor*
6. Pasture Grasses

The shrub/tree edge plants include the following in order of importance.

1. Bayberry – *Myrica pensylvanica*
2. Pasture Grasses

Summary of Significant Features

A. Geological

1. The only fine-sand beach encountered on Swans Island. No others known within many miles.
2. Perennially stable with good seasonal accretionary profile and a single berm; simple behavior because of low sand budget.
3. Fringing pocket beach type with predictable seasonal profiles – a good educational example of seasonal beachface changes.
4. Good example of graded bedding to the lag surface. No reverse grading and therefore a simple educational example of change in grain size with change in wave energy.

B. Botanical

1. Habitat for one strictly sandy beach plant — American Beach Grass (Ammophila breviligulata).
2. Simple zonation from the frontal dune ridge to the shrub tree line.
3. Though there are no rocky accumulations, the vegetation is a mixture of rocky beach and sandy beach plants. This is due to low aeolian activity and high seaweed content.

C. Size

Fine Sand Beach has an area of 1 hectare.

Sand Beach – Mt. Desert, Hancock County

Description of Geological Features

Sand Beach (Figure 35) is a sandy pocket barrier with a partially closed inlet in summer, due to summer berm accretion and abundant sand supply. There is probably a net upstream movement of sand into the fresh/brackish back barrier marsh when spring tides or winter storms open the inlet. The inlet is never open at mid to low tide because of a boulder beach underlying the sandy berm/spit which seals the inlet.

There is a moderately large frontal dune ridge but a small back dune aeolian flat. The aeolian flat is very stable and supports many non-beach plants. There are no parabolic dunes or suitable Beach Heather (Hudsonia tomentosa) habitat at present.

The beach profile had the following features when field checked in August, 1977:

1. Frontal dune ridge with winter scarp 1 to 2 m high
2. 13 m wide aeolian ramp
3. Wide berm (22 m)
4. Moderately steep berm foreslope with cusp ridges (∿25 m wide foreslope or upper beachface).
5. ∿18 m wide low-tide terrace with rapidly grading bedding; a coarse shell hash lag surface is located only a few cm down.

Sand beach has a larger volume of sand per meter of beach length than any other beach north of Pemaquid (except Roque Island Beach). It is sand rich throughout the year and is in a healthy accretive state. The sand is medium sized and moderately well sorted. There are no boulders, cobbles, pebbles or gravel exposed on the beachface. Their absence and the anomalously high sand volume are partially due to the fact that the origin of almost half of the sand is biogenic rather than glacial. There is, however, a cobble/boulder beach or lag surface beneath the sand of the seasonal berm at each end of the beach. These rocks are derived from wave erosion of local bedrock.

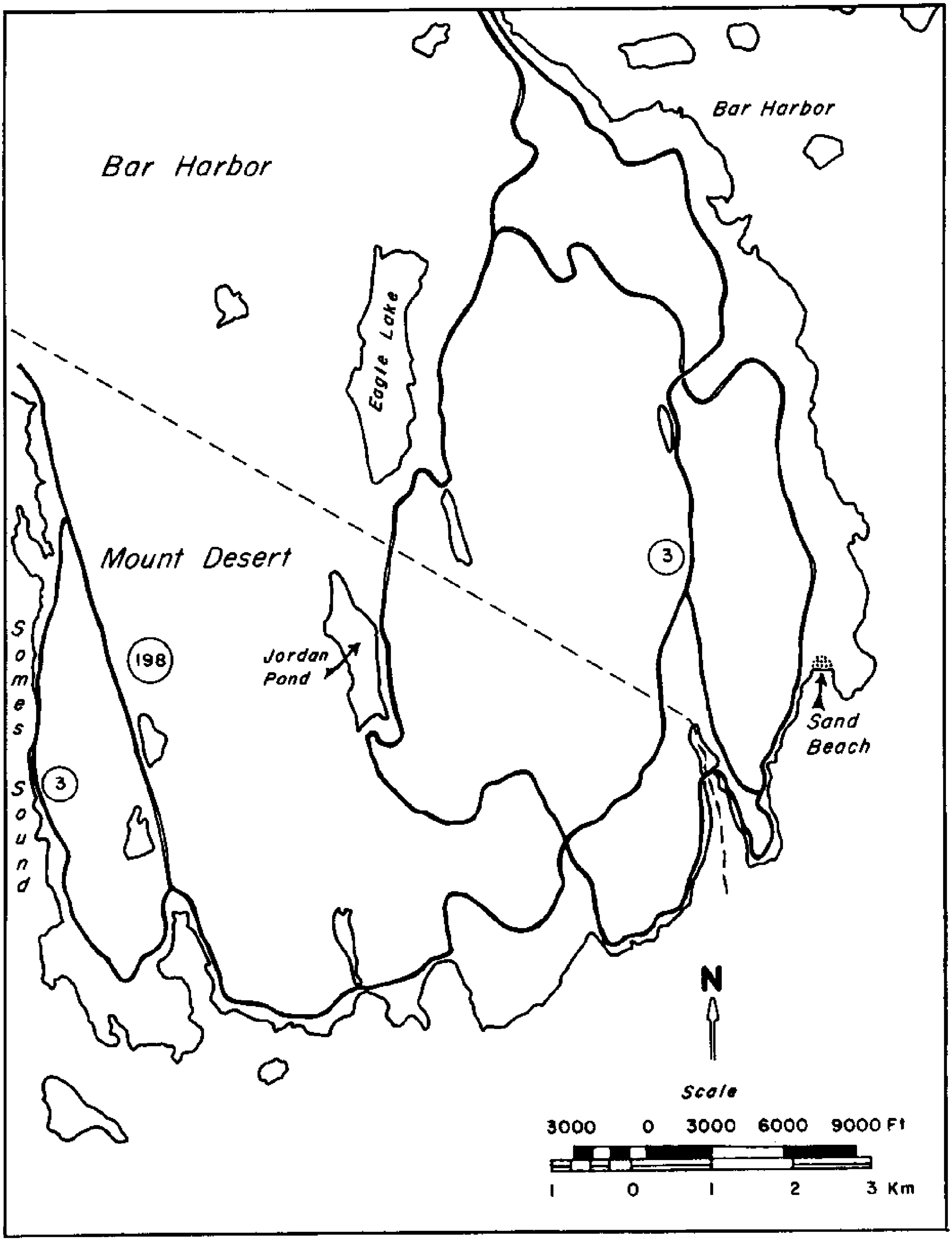


Figure 35 Sand Beach — Acadia National Park

The beach has a measured carbonate (shell hash) content of 30-40% by weight. This is the only purely sandy beach yet encountered in Maine which has such a high carbonate fraction. This is the single most significant feature of the beach. The beach sand also has a high potassium feldspar content. Grains of this mineral give the sand a pink color.

Sand Beach was visited on February 11, 1978 after the severe storms of January 9 and February 7. The berm and aeolian ramp of the previous summer were completely removed, leaving a straight profile from low water to the toe of the new erosional scarp. Lowering of the upper beachface gave the impression of raising the frontal dune ridge by 1 to 1.5 m. The total erosional recession of the dune line caused by these storms was 3 to 5 m along the entire beach. There was no significant washover of sand behind the crest of the new frontal dune scarp.

Description of Botanical Features

Sand Beach at Acadia has a very large and healthy stand of American Beach Grass (_Ammophila breviligulata_), large for this part of Maine where sandy coastal dunes are rare. This is the only plant here which is found only on coastal sandy dunes. There is no Beach Heather (_Hudsonia tomentosa_) here.

Other plants present on the back dune are:

1. Beach Pea - _Lathyrus japonicus_
2. Yarrow - _Achillea millefolium_
3. Evening Primrose - _Oenothera_ sp.
4. Pasture grasses
5. Mullein - _Verbascum thapsus_
6. Quack Grass - _Agropyron repens_
7. Freshwater Cord Grass - _Spartina pectinata_ (on margin of fresh/brackish water).
8. White spruce - _Picea glauca_
9. Bayberry - _Myrica pensylvanica_
10. Ground Juniper - _Juniperus communis_ var. _depressa_
11. Seaside Rose - _Rosa rugosa_

There are no berm colonizers despite the seasonally accretive state of the berm and aeolian ramp. This is probably due to heavy recreational use of this area. A snow fence designed to keep pedestrian traffic off the dunes runs along the frontal dune ridge crest.

Summary of Significant Features

A. Geological

1. 30-40% (by weight) carbonate, by far the best example of a sandy carbonate beach in the state.

2. Sand-rich, high sand volume per meter of beach length. This is due to the carbonate sand source. Glacial sand sources north of Pemaquid are usually too small or coarse to permit formation of a healthy, sand-rich beach profile.
3. Moderately well sorted, an unusual feature for beaches north of Pemaquid, also due to the carbonate sand source.
4. Marked difference in winter and summer profiles, excellent site for educational illustration of this feature of beaches.
5. Moderately steep berm foreslope – due to medium grain size and moderately good sorting – increases permeability of the sand.
6. Simple illustration of graded bedding beneath low-tide terrace surface.
7. Seasonally closed pocket barrier, a rare geomorphic form.

B. Botanical

1. Large healthy stand of American Beach Grass – the best stand within many miles, valuable for the study of disjunct populations and geographic gradient variations of genotype and phenotype.
2. Potential site for Hudsonia tomentosa and associated plants. This is the only beach north of Pemaquid with a back dune aeolian flat. It is, however, too stable at present to support Hudsonia tomentosa and associated plants.

C. Size

The vegetated dune line is 140 m long. The length of the beach at the seaward edge of the berm, including the spit, is 275 m. The length at the low water line is 290 m.

Sandy River Beach – Jonesport, Washington County

Description of Geological Features

Most of Sandy River Beach (Figure 36) is of the fringing pocket beach type, but there is a barrier spit at the north end where a tidal river drains out. The tidal river is small and drains a salt marsh of about 15 hectares. This is the northernmost sandy barrier-spit in the eastern United States, though a long gravel/cobble barrier is located in Lubec.

There is an open fetch to the south so that the north end is the downdrift end. When field checked in July of 1977, the north end had more sand, a constructional ridge and runnel profile on the lower beachface, and a broad berm on the upper beachface. The beachface sand was fine, the berm sand was medium and a pebble and cobble lag surface was on the lower half of the beachface along the entire length of the beach.

There was an eroded winter scarp, about 1 m high, along most of the dune line with a zone of annual colonizers (dominated by Sea Rocket (Cakile edentula) 1 to 5 m wide

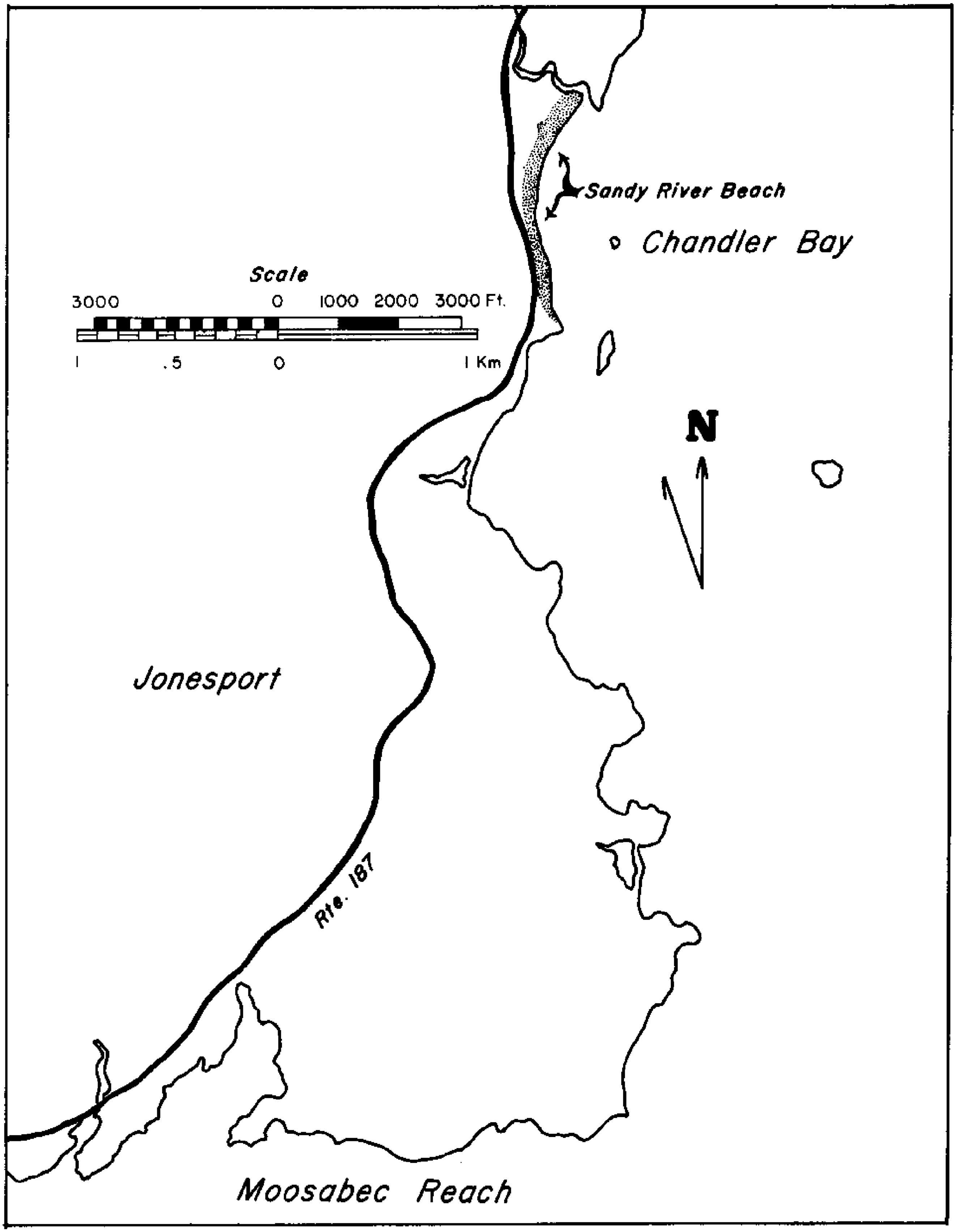


Figure 36 Sandy River Beach

in front of the scarp. The scarp was of low relief since it faces east and therefore does not receive prevailing winds of Maine. At the south end, the annual colonizer zone included Strand-Wheat (*Elymus arenarius*) and American Beach Grass (*Ammophila breviligulata*), indicating short-term perennial accretion of the south end.

A possible relict frontal dune ridge is located about 35 m behind the frontal dune scarp near a stand of White Spruce (*Picea glauca*) at the northern end, but this possible relict ridge is not associated with a change in vegetation and runs straight to the forest, where it is truncated suggesting that it is man-made. There is a definite relict frontal dune scarp in front of the parking lot at the northern end. This relict scarp is 4 m behind the winter scarp of 1977.

Beachface sand volume is low with a possible rocky lag surface beneath the sandy beachface and berm. The sand source is submerged till or ice contact stratified drift. The sand resembles that of Roque Island in that accretionary surfaces are white, quartz rich, well sorted, and not so mineralogically young as Reid Beach. There are seventeen houses all within 30 m of the frontal dune scarp.

Description of Botanical Features

There are large stands of Seabeach Sandwort (*Arenaria peploides*) on the aeolian ramp where seaweed is mixed in the sand.

The following is a partial list of the vegetation:

1. Sea Rocket – *Cakile edentula*
2. Beach Pea – *Lathyrus japonicus*
3. Strand-Wheat – *Elymus arenarius*
4. American Beach Grass – *Ammophila breviligulata*
5. White Spruce – *Picea glauca*
6. Seabeach Sandwort – *Arenaria peploides*
7. Quack Grass – *Agropyron repens*
8. Yarrow – *Achillea millefolium*
9. Evening Primrose – *Oenothera* sp.
10. Fireweed – *Epilobium angustifolium*
11. Bayberry – *Myrica pensylvanica*
12. Seaside Rose – *Rosa rugosa*
13. Orach – *Atriplex patula* var. *hastata*

Summary of Significant Features

A. Geological

1. Fine sandy beach, uncommon in this area of Maine. It provides a steppingstone habitat for dune plants and beach macrofauna.

2. Possible accretionary ridge and swale topography (visible on stereoscopic view of vertical air photo).

3. Definite relict frontal dune scarp 4 m behind the present scarp.

B. Botanical

Healthy stand of American Beach Grass. This stand and nearby Roque Island and Roque Bluffs beaches contain most of the American Beach Grass between Mt. Desert and Lubec.

C. Size

The significant portion of the beach, from a seawall at the southern end to the north tip, is 500 m long.

Great South Beach — Jonesport, Washington County

Description of Geological Features

Roque Island' Great South Beach (Figure 37) is of the fringing pocket type. Unlike the sand and gravel beach on the north side of the island, there is no wave-eroded bluff behind the south beach. There is a high sand volume per meter of beach length considering the paucity of sand sources in this part of Maine. Accretionary portions of the beach profile and the aeolian frontal dune ridge are white, quartz rich and well sorted.

Presence of cobbles, boulders, gravel and rapidly graded bedding to these coarser sizes below the fine lower beachface suggests a glacial till or stratified drift source for the beach sand of Roque Island's Great South Beach. This glacial source is now completely eroded or submerged and there are no wave-eroded bluffs visible. The sand has probably been reworked by wind, waves and currents of the harbor for thousands of years because its finer beds are well sorted by both grain size and mineralogy. There are fewer feldspar grains and schist fragments in the medium and fine layers than at a mineralogically younger beach such as Reid State Park.

The southwest end of Great South Beach approaches the classical log-spiral plan view of wave fronts refracted around a headland. The southwest end of the beach is the spiral or downdrift end. The sand here is fine and well sorted and the beachface slope is very gradual (approximately 70 m wide).

Because of the configuration of nearby islands, there is no open fetch to the sea. Swell which passes between these islands is substantially weakened by both refraction and diffraction. Local wind waves can form along a 4 km fetch to the southeast.

The log spiral end of the beach (towards the southwest) receives only constructional, low energy, long swell (short wavelength, steep waves which are of high energy are not capable of major refraction). This accounts for the finer grained sand and gradual slope at the southwest end. Also, refraction causes a stretch of the wave front and thus a reduction of wave energy leading to fine grain size, accumulation, and gradual slope.

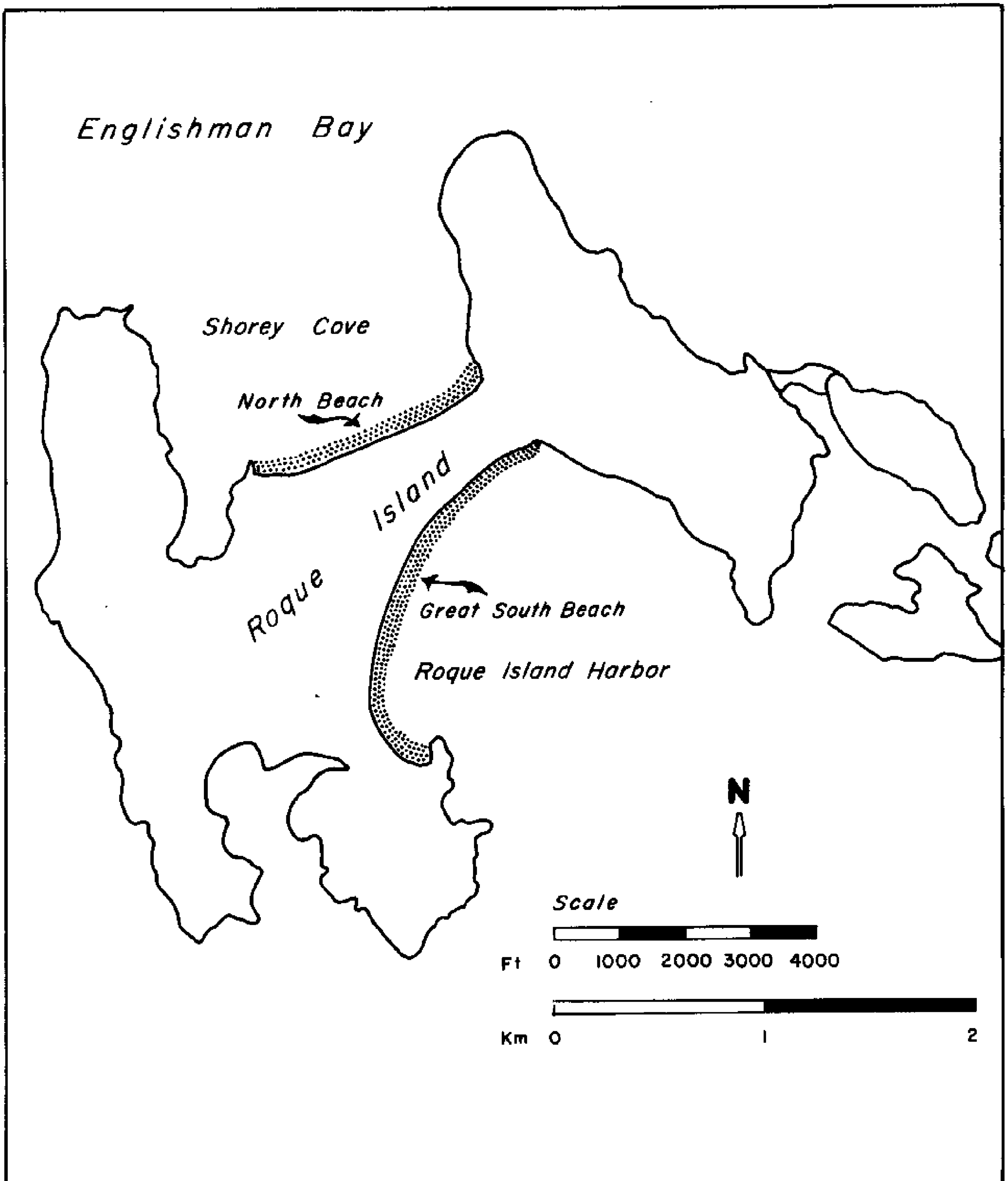


Figure 37 Great South Beach, Roque Island

Th[illegible] are no dry dune slacks or parabolic dunes present. There is no frontal dune ri[illegible] behind the southern third of the beach, only a narrow sandy overwash area. The forest comes close to the winter scarp in this narrow overwash area.

The aeolian frontal dune ridge begins south of mid-beach and a well-established steep frontal dune ridge of approximately 2 m height runs behind the mid-third of the beach. In this area the ridge is composed of medium sand with an aeolian ramp, including multicrystal grains. There is apparent seaward accretion here because the frontal dune ridge has a deep swale behind it. There is, however, no former wave cut shoreline visible behind the swale, only upland forest. There is a Sweet Gale bog and pond behind the mid-beach frontal dune ridge in the swale.

A cobble lag surface covers the beachface on the northernmost third of the beach.

There is a strong correlation between grain size, slope and wave energy at Great South Beach. The southwest end has fine sand, gradual slope and receives only long refracted swells. The center and northeast end are of medium grain size (with fine sand on lower beachface), more poorly sorted, and can receive short, steep, storm waves.

Description of Botanical Features

There is more acreage of American Beach Grass here than at Roque Bluffs. Roque Island, Sandy River Beach and Roque Bluffs have the only large stands of American Beach Grass between Mt. Desert and Lubec. There is much Strand-Wheat (*Elymus arenarius*) along the frontal dune scarp where aeolian activity is low, especially along the southwestern third of the beach.

Quack Grass (*Agropyron repens*) is common behind the scarp of the southwest end of the beach, also in low aeolian activity areas. It is healthy due to seaweed overwash input.

Blueberry (*Vaccinium angustifolium*) and Cranberry (*Vaccinium macrocarpon*) are present, especially in eroding glacial and Indian shell heap areas (Beach Field).

There is poor zonation and no salt spray pruning. There is no distinct dry back dune area. The beach grass of the frontal dune ridge east of the Sweet Gale bog simply blends into pasture grasses and upland forest or field species.

The following is a partial species list for Roque Island - Great South Beach:

1. Strand-Wheat - *Elymus arenarius*
2. Quack Grass - *Agropyron repens*
3. Beach Pea - *Lathyrus japoncius*
4. Yarrow - *Achillea millefolium*
5. Pasture Grasses
6. Saltwort - *Salsola kali*
7. Sea Rocket - *Cakile edentula*
8. Sea Chickweed - *Arenaria peploides* (one plant)
9. Orach - *Atriplex patula* var. *hastata*

10. Raspberry – <u>Rubus idaeus</u>
11. Alder – <u>Alnus</u> sp.
12. Sweet Gale – <u>Myrica gale</u>
13. Cranberry – <u>Vaccinium macrocarpon</u>
14. Blueberry – <u>Vaccinium angustifolium</u>
15. American Beach Grass – <u>Ammophila breviligulata</u>
16. Mustard – <u>Brassica</u> sp.

Summary of Significant Features

A. Geological

1. The shape of the southwest end of the beach approaches the classical log spiral shape of wave fronts refracted around a headland.

2. There is a strong correlation between grain size, slope and wave energy. The southwest end is fine and well sorted with a gradually sloping beachface (70 m wide). It receives only long refracted swell. The central part and northeast end of the beach have medium grain size (though fine on the lower beachface), are more poorly sorted and can receive short, steep, storm waves.

3. The sand source is a reworked submerged glacial till or ice contact stratified drift.

4. Multiple ridge and runnel system and ground water (rip channel?) escape channels at western end. The system is of very low relief.

5. Neap high water berm edge at southwest beach end at time of field checking. There was no marked spring high water berm.

6. No aeolian ramp or frontal dune ridge at southwestern end of beach (no onshore wind). There was a short, sometimes double, scarp. There is very little sand in the vegetated portion of the southwest beach back dune. The ridge here is probably formed by overwash.

B. Botanical

1. There are no dry dune slacks or parabolic dunes to provide habitat for Beach Heather (<u>Hudsonia tomentosa</u>) and associated plants.

2. The beach grass of the frontal dune simply blends into the pasture grasses and upland forest or field species. There is poor zonation and no salt spray pruning.

3. Quack Grass is located behind the scarp at the southwest end of the beach where there is low aeolian activity. It is healthy due to seaweed overwash input. Good correspondence between dune grass speciation and exposure to aeolian sand activity.

4. Strand-Wheat (<u>Elymus arenarius</u>) is present along the front of the scarp wherever aeolian activity is low, especially southwest of the beach field.

5. The most important botanical feature: along with Roque Bluffs and Sandy River Beach in Jonesport these are the largest stands of American Beach Grass between Mt. Desert and Lubec.

C. Size

The length of the beach is 1930 m.

Roque Bluffs Beach – Roque Bluffs, Washington County

Description of Geological Features

Roque Bluffs Beach (Figure 38) is a pocket barrier with a probable former marine lagoon behind the beach and dunes. This former lagoon is now a shallow freshwater lake.

The barrier was formed by a combination of overwash and aeolian transport. The long flat back slope of the barrier between the road and pond is sandy but probably underlain by rocky overwash fans. Perennial accretion has left a veneer of sand over most of the barrier.

When field checked (August, 1977) the beachface was largely cobbles, with double rocky berms on the beachface and a combination of a rocky storm berm and a sandy frontal dune ridge above the limit of normal winter high water. The two beachface rocky berms corresponded approximately to spring high water and neap high water. Each berm had rocky cusps.

There was an erosional scarp in the sandy dune in front of which there had been perennial rocky berm accretion with vegetation on the accreted area. The edge of vegetation in 1977 generally varied from 1 to 6 m from the relict erosional scarp in the sandy dune, but in some places the scarp was actively eroding because of overwash of the perennially accreted area. Most of the beach was experiencing accretion in front of the sandy scarp in the form of wave deposition of cobbles with a sandy matrix. This sandy matrix allows American Beach Grass to invade the accreting area.

A terrace-like profile in the central portion of the barrier suggests another relict erosional scarp up to 15 m from the 1977 vegetational edge, which indicates a significant amount of perennial accretion on such a small beach.

Description of Botanical Features

The plant species are more like those of a rocky beach than a sandy beach, but there is abundant American Beach Grass (*Ammophila breviligulata*). The edge of vegetation generally varies from 1 to 6 m from the relict erosional scarp in the sandy dune.

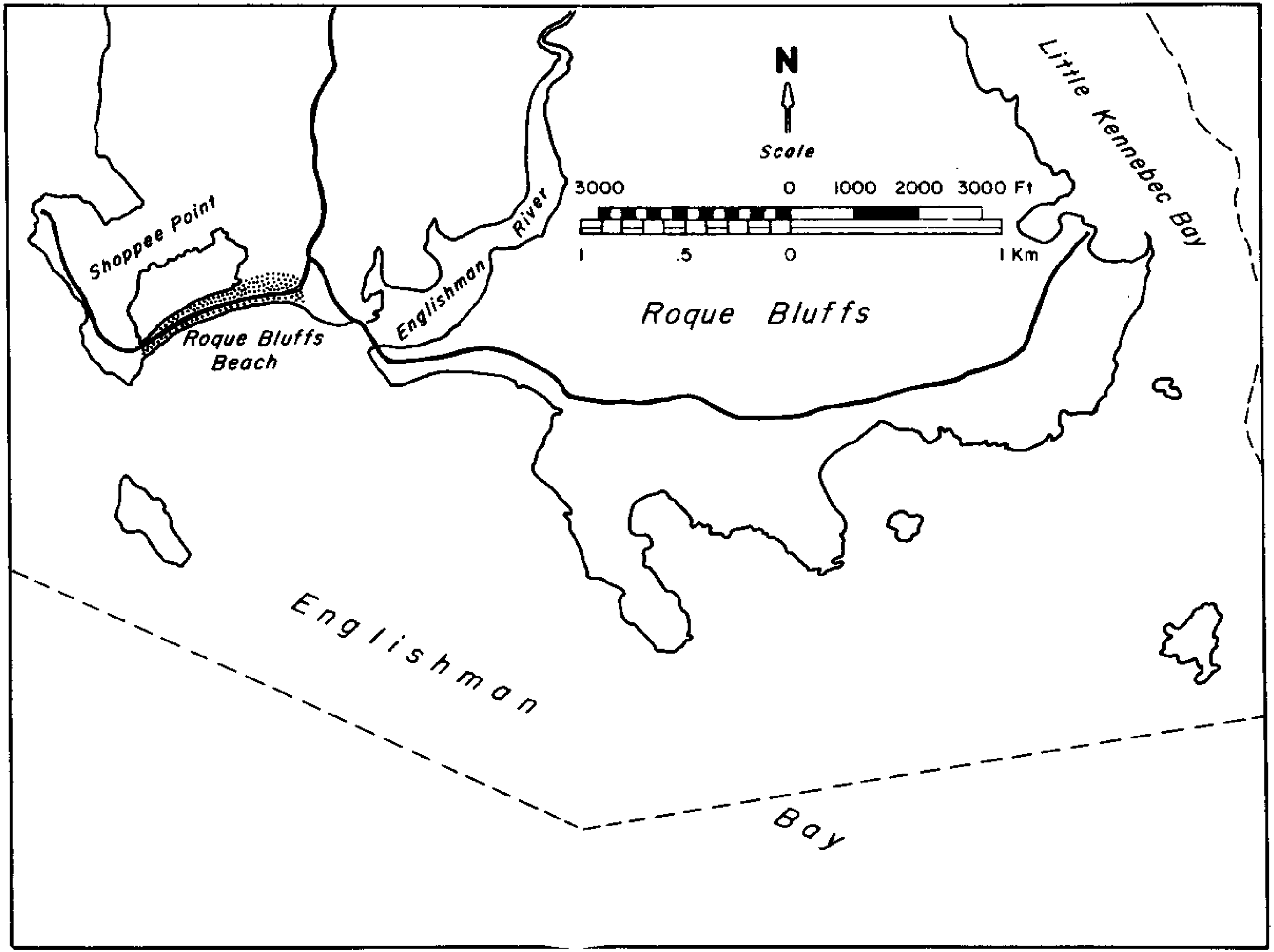


Figure 38 Roque Bluffs Beach

The most marked characteristics of the vegetation of Roque Bluffs is the abundance of Seabeach Sandwort (Arenaria peploides) and Beach Pea (Lathyrus japonicus).

Species seaward of the sandy erosional scarp include:

1. Seabeach Sandwort – Arenaria peploides
2. Sea Rocket – Cakile edentula
3. Coast Blite – Chenopodium rubrum
4. Orach – Atriplex patula var. hastata or A. arenaria
5. Lungwort – Mertensia maritima
6. Beach Pea – Lathyrus japonicus
7. American Beach Grass – Ammophila breviligulata
8. Quack Grass – Agropyron repens

Additional species which are in the back dune include Seaside Rose (Rosa rugosa) and Evening Primrose (Oenothera sp.).

Summary of Significant Features

A. Geological

1. The most significant feature is the presence of a probable former marine lagoon behind the beach. C^{14} dating of the freshwater/salt water sediment interface would provide interesting data related to sea level rise and sediment supply.
2. A terrace-like profile in the central portion of the barrier suggests a relict erosional scarp.
3. Two beachface rocky berms occurred, which corresponded to spring high water and neap high water respectively. Each berm had rocky cusps.
4. There was a recent erosional scarp in the sandy dune in front of which there had been perennial rocky berm accretion with vegetation on the accreted area. The beach was experiencing perennial accretion in front of the sandy scarp by wave deposition of cobbles with a sandy matrix.

B. Botanical

1. The sandy matrix being deposited in front of the sandy scarp allows American Beach Grass to invade the accreting area in front of the sandy scarp. This may be the northernmost large stand of American Beach Grass in Maine.
2. The most marked characteristic of the vegetation of Roque Bluffs is the abundance of Seabeach Sandwort (Arenaria peploides) and Beach Pea (Lathyrus japonicus).

C. Size

The length of the beach is 780 m.

GENERAL EVALUATION OF SAND BEACHES FOR INCLUSION ON THE REGISTER OF CRITICAL AREAS

Description Sand Beaches

Sand beaches occur along the coast of Maine and are concentrated in the southern part of the state, in York and Cumberland Counties. A variety of geomorphic forms and botanical associations are found along the coast. The features are the result of the interaction of several processes of the beach system and as a result are in a constant state of change.

Considerations in Registration

A. Values and qualities represented by feature (specifically including any unique or exemplary qualities of the feature).

Maine's sand beaches form one of the state's most valuable coastal resources since they represent most of the public access, intensive recreational use, open space and salt marsh portions of the coastline. Diverse scientific and educational values are numerous on the sand beaches in Maine and are strong criteria for significance. Many beaches display excellent examples of certain geomorphic features or geological processes. The same is true for botanical features and processes.

Beach systems are among the most dynamic of geologic environments. The form and position of beach and dune features respond to slight changes in the process agents which control their development. The geologic fabric of the bedrock units in Maine exerts a pronounced control on its coast, whose highly irregular and deeply embayed outline contrasts sharply with the rest of the coastline south of New Hampshire. The limited sand supply and coastal geometry make Maine's beach forms unique along the East Coast.

Maine's beaches provide evidence of sea level rise rate, knowledge of which is essential for coastal zone planning.

All undisturbed coastal sand dune and berm plant habitats in Maine are significant simply because of their limited extent. Almost two-thirds of Maine's original dune fields are now heavily developed or altered. Of approximately 6400 km of coastline in Maine, the beaches with large undeveloped dune fields, Popham, Reid, and Seawall, represent only 8.7 km of coastline length. In contrast beaches with major dune fields which are now disturbed represent 18 km of coastline. Smaller scale undisturbed dune and berm plant habitats are significant because such habitats are rare in Maine. Good stands of species with limited area in the state, e.g. American Beach Grass, Beach Heather, Wormwood, Jointweed, are found on a few of the remaining undisturbed dune habitats. Also, a few coastal dune plants reach their coastal range limit in Maine. The presence or abundance of many species have been found to decrease from south to north but these trends are already difficult to study in detail because of extensive development on most of Maine's sand beaches.

B. Probable effects of Uncontrolled Use (specifically in relation to its intrinsic fragility).

The attractiveness of beach and dune areas for potentially damaging recreational and development uses, coupled with the fact that these usage pressures are concentrated on only one to two percent of Maine's coastline, could result in the destruction of these unusual beach systesm. The lack of use and management policies, and absence of basic data for Maine's unique beach systems have led to expensive and usually futile erosion prevention measures. This inevitably results in public controversy over causes of beach erosion and shore property loss. Continued development of Maine's beaches without a full understanding of fundamental beach system and dune ecosystem dynamics could result in the eventual disturbance of the remaining sand beaches in the state. The maintenance and conservation of these areas is especially significant since they display a variety of values including: scenic, zoological, geological, botanical, educational, and scientific. Proper management of the remaining sand beaches is necessary in order that they be preserved for future use.

C. Presence and Probable Future Use (specifically present and future threat of destruction).

Sand beaches on the coast of Maine have a variety of present uses. These range from state parks and conservation easements to private ownership and highly developed areas. Beaches along the coast of Maine are subject to the increasing pressures of development and alteration. A large percentage of the coastline is in private ownership making probable future use uncertain.

D. Level of Significance.

Sand beaches in Maine are of regional significance because they represent a unique habitat on the Atlantic Coast of North America.

E. Probable Effects of Registration - positive and negative (specifically including the economic implications of inclusion of the feature on the Register).

The expected positive effect of registration will be to give official recognition of the importance of sand beaches by the State. Also, landowners will be informed of the importance of sand beaches in Maine. Registration will also aid in the monitoring of sand beach systems in the State and, perhaps, aid in their conservation.

The expected negative effect of registration would be any publicity generated by the registration process. Publicity would attract visitors, which might result in the destruction of the fragile dune areas and their related plants. No substantial economic implications should result from the registration process.

F. Programs Which Affect or Are Relevant to the Feature.

1. Zoning by Land Use Regulation Commission
2. Shoreland Zoning
3. Wetlands Laws

Conclusion

A. Conformance with Definition Contained in the Act

The Act defines critical areas as being: "areas containing or potentially containing plant and animal life or geological features worthy of preservation in their natural condition, or other natural features of significant scenic, scientific, or historical value."

Significant sand beach systems support rare and unusual geological, botanical and zoological features that are worthy of preservation in their natural condition. Thus, significant sand beach systems meet the legislated definition of critical areas.

B. Conformance with the Guidelines for the Registration of Critical Areas, Adopted by the Critical Areas Advisory Board on September 11, 1975.

Section 1. Knowledge of the Feature

The report Geological and Botanical Features of Sand Beach Systems in Maine and Their Relevance to the Critical Areas Program of the State Planning Office, was prepared for the Critical Areas Program in order to provide detailed information on Sand Beach Systems in Maine.

Section 2. Representation on the Register

Three sand beaches, Popham, Reid and Seawall, have been included on the Register of Critical Areas as significant bird nesting sites.

Section 3. Variety of Values

Sand beaches generally have a variety of values including: scenic, recreational, botanical, zoological, geological, scientific, and educational.

Section 4. Scarcity

Sand beaches are rare in Maine. Out of 6400 km of coastline sand beaches represent only 121 km of this length.

Section 5. Quality

Twenty-seven sand beaches, out of a total 200 have met the criteria outlined in the "Methods" section of this report.

Section 6.

Sand beaches are dynamic systems. They are subject to the influences of wind, waves, sand source areas, storms and human activity. Their persistence is related to the interaction of all these processes; and as a result beach systems are constantly changing.

Section 7. Geographic Distribution

The majority of the sand beaches are found south of Reid State Park on the Coast of Maine in York and Cumberland counties. These beach systems are unique along the Atlantic Coast of the United States.

Section 8. Use

Sand beaches have potential scientific, educational and recreational uses.

Section 9. Manageability

Due to the many processes that influence sand beach development, management of the areas requires thorough investigation of the implication of any alteration to the system.

Section 10. Potential Economic Effects

Registration of sand beaches should have few economic implications for the land owners.

Section 11. Potential Effect on Conservation of Feature

Registration is expected to have a positive effect on the conservation of sand beaches in Maine.

AUTHORS' RECOMMENDATIONS

The authors make the following recommendations to the Critical Areas Program for the beach systems discussed in this report:

1. Because Maine's beach systems have unique value as a coastal resource and because development pressures are increasing, it is urgent that the twenty-seven described beach systems be evaluated for inclusion on the Critical Areas Registry.

2. Andrews Beach on Long Island in Casco Bay and Lubec Spit in Lubec met the criteria for recommendation as critical areas but were not field checked. These should be visited and included in the final list.

3. Because of the fragile nature of the vegetational compartments of beach systems, it is important that these areas be monitored and management plans developed.

4. As additional information on other beach systems becomes available, if the information indicates that a beach meets the geological and botanical significance criteria developed in this report, that beach should be added to the Critical Areas Registry.

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