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Relative Sea-Level Changes Measured by Historic Records and Structures in Coastal Maine

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ABSTRACT

Dykes and other man-made structures, constructed to control the salinity of salt marshes along the Maine coast, were dated through historic methods. Several dykes were then cored to determine the thickness of salt marsh which had accumulated against each dyke since it was constructed. In turn, we interpret this amount of accretion as proxy evidence of relative sea-level rise and any related vertical movements of the earth's crust. Other historic structures were also investigated as corroborative evidence, together with related historic and scientific evidence from other investigators. The amount of relative sea-level rise reported in the area from Milbridge to Eastport, Maine, has averaged about 25 to 35 centimeters per century over the last two hundred years. This result is conservatively estimated in order to minimize apparent relative sea-level changes brought about by other processes such as salt marsh compaction and disturbance of the marsh stratigraphy by the activity of severe storms.

INTRODUCTION

Although it may seem that historians have little to offer to their colleagues in the earth sciences, it is the relative precision of many historical records which makes some contribution possible. Radiocarbon dating of organic materials within the age range of about the last 40,000 years has been the principal means of providing absolute chronologies since this radiometric method was first utilized in the 1950's. Unfortunately, this and other more experimental methods are of little value for precision dating within the historic period of North America (1600 A.D. to present).

In order to obtain historic age dates for evaluating sea-level change in eastern Maine, we conducted site surveys of the Maine coast to locate suitable man-made structures that might provide a record of sea-level change, when used in conjunction with available literature, aerial photographs, maps and marine charts. We concluded, after a number of subsequent reconnaissance trips, that it would be possible to determine a reliable beginning and/or completion date for many man-made coastal structures from the colonial period and the decades immediately thereafter. Where these structures had been allowed to fall into disuse and

disrepair, accreting salt marsh often had partially or completely covered them, apparently in response to relative sea-level rise. Hence, given the age of the structure in association with the measured rise of the juxtaposed and often superimposed salt marsh surface, and the fact that the surface of the marsh ranges from mean tide to mean high tide, the amount of relative sea-level rise could be approximately computed for the elapsed time since the construction of the structure. Earlier researchers (Mitchell, 1875; Davis, 1915, 1916) suggested this method of dating, but experiments in the method either were not published or were treated with a great deal of skepticism.

Among the man-made structures which were located on the Maine coast in sufficient number and proper geographic distribution to render this technique potentially useful, were large numbers of salt marsh dykes. (This spelling is used, rather than "dike", because it remained the contemporary spelling of the word when the structures were built, and is still the preferred spelling in the nearby Maritime Provinces of Canada.)

These dykes were built to maintain the stability of the salt marsh surface for haying purposes, and occasionally to reclaim the salt marsh land into fresh meadow. Other man-made structures of potential use were colonial wharves, piers, shipways, and grist and saw mills powered by tidal movements. During the course of our research many usable structures have been located on the Bay of Fundy, along the coast of Maine and New Hampshire, and as far south as Boston. However, only those on the Maine coast, and in particular the eastern Maine coast, have been adequately investigated.

To ascertain the regional extent of relative sea-level change and possible warping of the earth's crust beyond the Maine coast, further reconnaissance trips were taken along the coast of Massachusetts, including Cape Cod, and along the coasts of Rhode Island and Connecticut, seeking comparable salt marshes and related dykes and other structures similar to those located along the Maine coast. Preliminary analyses in the latter areas indicate that the relative sea-level rise based on salt-marsh accretion appears to have been much less than in Maine. This research was aided by the availability of large numbers of descriptive historic and botanical notes on salt marshes and beach descriptions from Rockland, Maine to Quincy, Massachusetts. These notes, never published, recorded observations from 1910 to 1915 by the well-known worker C. A. Davis. (The notes, both in the original and transcribed form, which uses modern botanical nomenclature, are in the possession of the senior author.)

In addition, other archives in Washington, D.C. and important repositories such as the Registry of Deeds and Probate Records in the shire towns of Maine have been extensively surveyed, and the authors have located and analyzed much valuable material. We have also conducted oral interviews with several elderly persons who instructed us on the history of salt marsh dykes in their locality, as well as showing us how to build and repair a salt marsh dyke. From this work we have been able to provide an adequate record from which to determine the apparent sea-level rise during the historic period for selected sections of the coast, and we have developed and proven a methodology applicable where datable historic structures exist.

HISTORIC BACKGROUND

Early settlers began to modify the New England coast as soon as they arrived. They built wharves and piers, changed the natural drainage, and soon began to dyke and ditch the salt marshes which they found in many locations. The ditching and dyking did promote some desalination of marsh grasses, although reclamation to fresh meadow was not the major purpose of the work. For those persons engaged in logging and lumbering, or in some agricultural pursuits (droving and fattening cattle), the abundant amounts of natural salt grass for hay meant that they could make maximum use of their time on other matters. Salt marsh hay, taken in the autumn from the natural salt marshes near Newburyport, Massachusetts, in the sheltered area landward from the Plum Island barrier beach, became widely known as a ready cash crop by the late 1630's. In other areas more open to the destructive intrusion of the sea than these sheltered sites, settlers soon began to control the sea through the construction of dykes on the marshes, a technology well known from their experiences in the Netherlands, other parts of the Low Countries, northern France, and in East Anglia, England. Some areas of the salt marshes on the Bay of Fundy were probably dyked as early as the beginning of the eighteenth century by the French settlers, and perhaps slightly earlier. In contrast, the English settlers did not build dykes along the Massachusetts coast until the 1770's in the Cohasset area, just south of Boston. North of Boston, in the Plum Island area, some dyking was attempted, but these marshes, protected from the open sea, were generally ditched to control the height of the sea and brackish waters. The ditches improved the movement of fresh water from the land through the marsh and stabilized the water table.

In the eighteenth century settlers from Marblehead, Salem, and other towns along the north shore of Massachusetts, familiar with salt marsh manipulation, began to migrate north. At first the migration was seasonal to obtain salt marsh hay grown naturally in the abundant and unaltered marshes in Scarborough (in the District of Maine), and farther "downeast" in Machias. After the great forest fires in southern Maine and New Hampshire in 1761-63, loggers moved north to begin their work anew in the Maine woods near the Machias River (Fox, 1985). These migrants were allotted lands by a company which had been granted rights to the territory by the Massachusetts Bay Colony. Each of the settlers (forty heads of families in all) were granted upland, coastal land, and salt marsh in the same proportions. In fact, in this early period (1780-1790) the salt marsh created a few problems for the new settlers, as it was the most valuable land with its natural hay production, and hay makers occasionally trespassed. At least once, a sheriff's posse had to be called out to control this trespass and theft of the salt marsh hay in Machias. This might even be termed a case of "grass rustling".

By the 1790's, the methods and techniques of dyking salt marshes under North American conditions were well known. The primary purpose of this work was always to control the quality of the hay by regulating the invasion of the sea on the land during storms and high tides. The amount of land reclamation was minimal, especially as one went farther north and east. Land was relatively abundant and cheap, so the produce of the land was more important than providing new or altered land for the farmer. Agricultural dictionaries of the time described the dyking process clearly (Deane, 1790); and widely circulated contemporary farm newspapers published articles on the methods and techniques, along with discussion of expected results. Between 1795 and 1830 many salt marshes along the Maine coast were dyked and thus stabilized against the sea. The dating of the building of these dykes often can be determined with considerable precision and has great potential in determining the extent of relative sea-level change since the time of their construction.

Other structures built during the colonial period also allow the rise of apparent sea-level to be measured, although perhaps with not the same precision afforded by measuring the amount of salt marsh accretion against the dykes. For example, wharves were built for the transport of lumber and other products. Piers were put in place to secure log booms. Ships were built and their ways extended into the sea, providing potentially datable structures against which to measure sea-level rise by various techniques. Tidal mills were widely constructed to control the water level, in order to drive saw and grist mills, and they can be dated if the critical parts (the pond dams, or the dams on which the saws were hung) remain. Roads were constructed on the salt marsh surfaces for a variety of purposes, but mostly for access to the grass, and later the stored hay. Many of these sites, now unusable because of rising sea-level, have been located. If their construction dates are known, the ages of the sites help in determining the extent and rate of sea-level change.

DYKES

We determined that the most useful historic structures for dating sea-level change are the salt marsh dykes because of their commonality of construction methods, their relatively simple relationship to sea-level, their great numbers, their wide distribution, and the abundant written records relating to their ownership and taxation.

In general, the dykes were built by men working in groups of three. The first person, using a specially designed spade, cut out sods and passed them to the second person, who then transferred the sods to the man at the face of the dyke, who in turn built the dyke much like interlocking bricks. Jobs were rotated on a regular basis among the crew, approximately every twenty or thirty minutes. Dykes were wider at the bottom, and sloped gradually to the top which was perhaps a meter wide. A one-way flapper valve was placed at distances of every fifteen meters or more along the dyke. This valve, opening automatically to let water escape at low tides, also closed automatically to limit the amount of salt water which could enter the marsh during high tides. These single dykes, occasionally as long as three hundred meters, enclosed large areas of marsh. Such areas of salt marsh were never granted in their totality to original settlers, so it was nearly always after a period of land acquisition that these long dykes were built. The large numbers of land transactions and the deeds which attest to them allow researchers to date the dykes with precision (Smith and Bridges, 1982).

Researchers visiting the dykes, most of which were abandoned sometime in the middle to late nineteenth century (although some were still in use in Maine until 1945 (Smith and Bridges, 1982), have found substantial salt marsh accretion on the dykes. While the dykes were still operating, the amount of salt water entering the marsh was strictly controlled. Even after the dykes had fallen into disuse, the flapper valves ordinarily continued to operate for a time and controlled the amount of salt water behind the dykes. Salt marsh peat, formed primarily from Spartina grasses (*Spartina patens* and *Spartina alterniflora*) accumulates as a function of the salinity of the marsh and the duration of inundation. These grasses are distributed in salt marshes in a zoned pattern which is easily observed.

Spartina alterniflora dominates the low marsh, which extends from about mid-tide to mean high water. This plant, because of its great vertical range, is of little use in establishing former sea-level positions. *Spartina patens*, the most ubiquitous of the grasses, forms the general broad surface of the high marsh. This high-marsh surface grows upwards in response to rising sea level, and its level at any one time is essentially equivalent to the level of mean high tide. Hence, by measuring the depth of Spartina patens peat that has accreted upon the flanks of a dyke, one has an approximate measure of relative sea-level rise since the dyke was constructed. If the date of dyke construction can be determined, then the amount and rate of relative sea-level rise can be measured (Figure 1).

Although the concept is simple there is a significant problem that must be considered in applying this method. In general, salt marshes undergo autocompaction which varies with time and with the proportion of mud and organic matter, making it very difficult to isolate the sea-level change signal from the variable amounts of autocompaction. Faced with this problem, we selected for examination sections of dykes where the sub-dyke salt marsh thickness generally was only 0 to 30 centimeters over an incompressible substrate. Such situations are commonly present on the landward edge of the marsh and occasionally where dykes cross bedrock highs within the marsh. In these cases the amount of sub-dyke peat compaction is substantially minimized, leaving only the actual sea-level rise recorded by the thickness of the peat resting on the flanks of these dykes (Figure 1).

In addition one must be very careful in making observations where the dykes terminate on the landward edge of the marsh, as these points were often considerably modified by activities

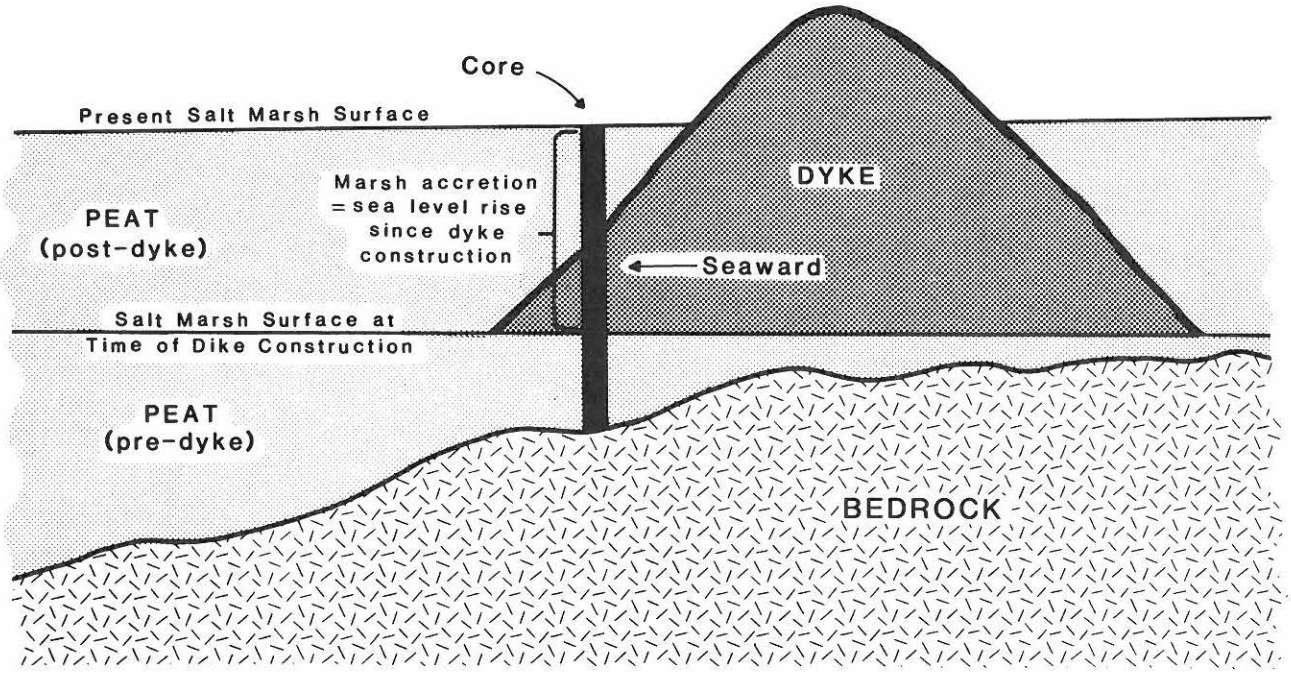

Figure 1. Schematic cross section showing how the amount and rate of sea-level rise can be determined from the accretion of salt marsh on a dyke of known age.

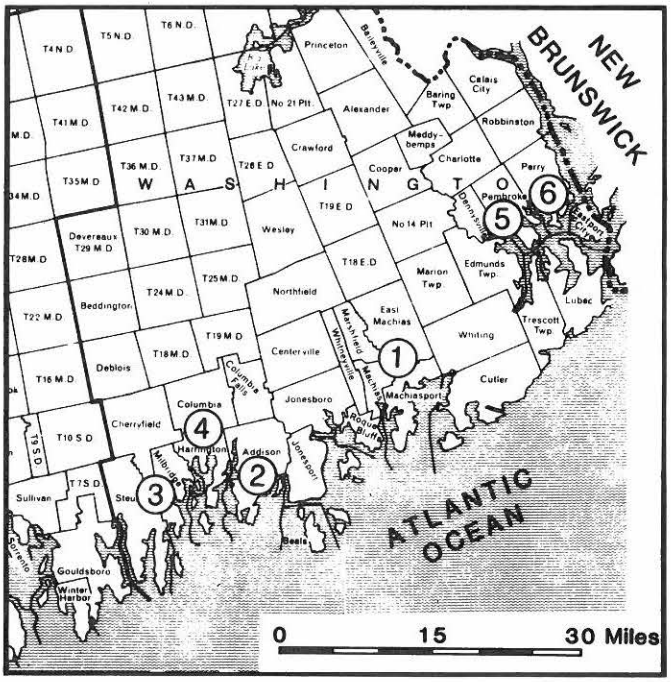

Figure 2. Map of coastal Washington County, showing locations of towns where field work was done for this study: (1) Machias-East Machias-Machiasport area, (2) Addison, (3) Milbridge, (4) Harrington, (5) Pembroke, (6) Perry.

related to dyke and marsh management. For example, these dykes commonly served as pathways and roads onto the marsh.

DISTRIBUTION OF DYKES

In Machias and East Machias (Figure 2) most of the dykes were constructed between 1823 and 1826 under the leadership of a local entrepreneur, Joseph Fenno. Fenno apparently learned the techniques of dyking in Marblehead, Massachusetts, from where he migrated to Machias. These Machias-area dykes were constructed on salt marshes which he systematically purchased from 1813 to 1823. A rather complete record of land transactions on these dykes has been compiled showing close to two hundred real estate purchases. Fenno overshot his mark, however, and apparently was forced to liquidate his holdings prior to his death in the early 1840's.

The largest of these dykes, located between Machias and East Machias, was rebuilt in the 1860's by an incorporated firm, and has since been used to carry the local railroad and the public highway (now U.S. Route 1) between Machias and East Machias. Some of the dykes in this area can easily be noted on the topographic map of the Machias 7.5-minute quadrangle, and are shown as "levees" on this map (Figure 3). In the 1920's the State of Maine introduced large steel one-directional flapper valves to stabilize the many dyked areas.

Nearly opposite to these meadows, across the tidal Machias River, lies a large area in which the dyked meadows were used for haying purposes until well into the twentieth century. These

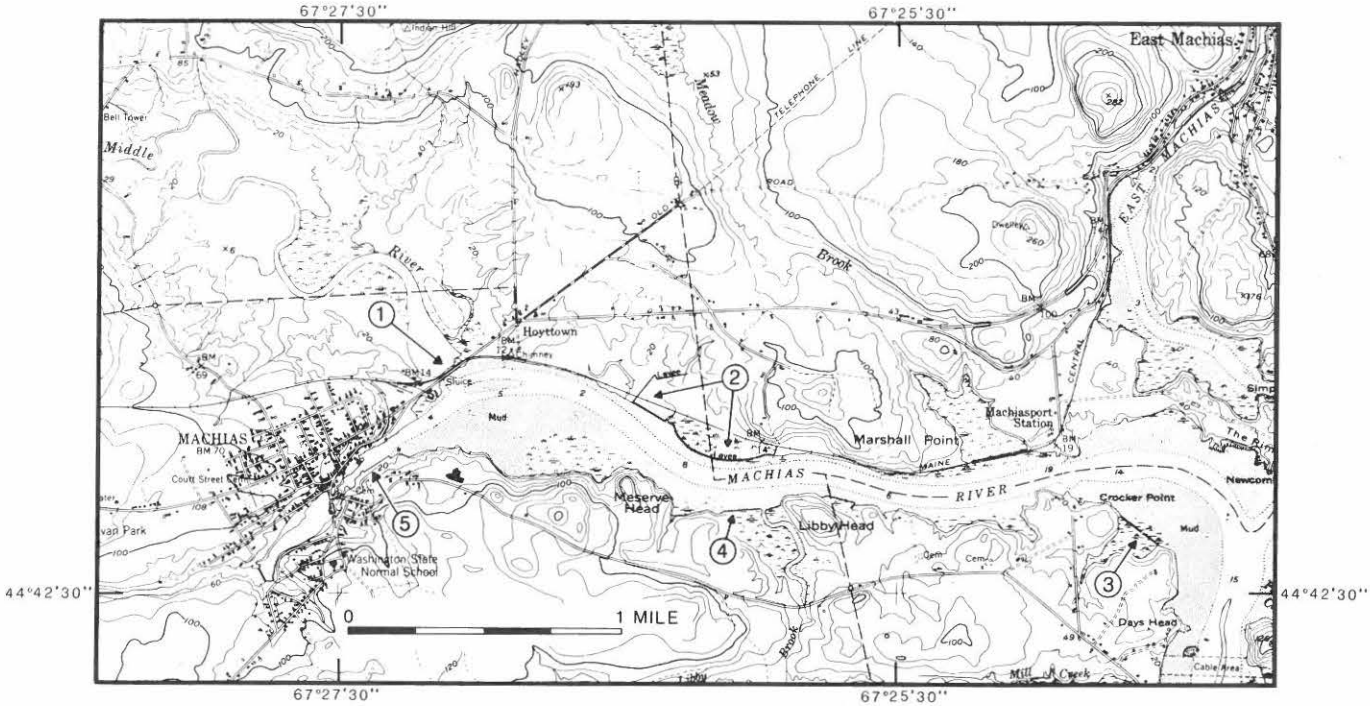

Figure 3. Part of the Machias 7.5-minute quadrangle, showing locations of dykes and wharves near the town of Machias: (1) dyke on U. S. Route 1, (2) dykes ("levees") on north side of Machias River, (3) Crocker Point dyke, (4) Meserve Head dyke, (5) wharves on Machias River.

dykes were investigated as part of our study. They are located adjacent to Crocker Point and Meserve Head on the Machias Quadrangle (Figure 3). A cross-section of the dyke at Crocker Point in Machiasport (Figure 4) shows the internal structure and composition of the dyke, from which its method of construction can be verified, as well as the way in which the salt marsh peat has accreted against this structure.

Many other marshes have been dyked in coastal Maine. For example, the dykes in Addison (Figure 2) were begun in 1795, and others in the system continued to be built until the 1830's. These dykes remained in use until after World War II, although the last repairs on the system were done about 1920. Some dykes in Thomaston, on the central Maine coast, were begun in 1795 by workers employed by General Samuel Waldo. The hay cut on these dykes, primarily designed for reclamation, was substantial, but the effort was abandoned about 1805. Because they were not kept in repair, these dykes were found to be of little use in the dating process described in this chapter.

In Milbridge (Figure 2) an extensive complex of dykes lies along the eastern shore of the Narraguagus River. These dykes, also the result of land acquisition by a local entrepreneur, were constructed between 1815 and 1817, primarily in the spring and summer of 1816. Dykes in the Milbridge-Harrington area were of substantial use in our analysis, as certain sections of them lie directly on or within 10 centimeters of bedrock, consequently eliminating the problem of autocompaction (Figure 5). Some dykes in the Narraguagus system were less useful because an effort had been made to ditch the marsh in this century, thus rendering any measurements of accrued peat of no real significance. Other dykes were cored in Pembroke (Figure 2) near the Perry town line. These dykes were built between 1825 and 1829.

As one travels up and down the coast, it is clear how much of the salt marsh area of Maine, and the New England coast, was controlled at one time by dykes or drainage ditches. The earliest dates for dyking in Maine cluster around 1795, which coincides with a population increase and the publication of detailed instructions on how to construct salt marsh dykes (Deane, 1790). A second flurry of dyking occurred after 1824, when another set of newspaper notices offering advice on dyking was widely circulated (Smith and Bridges, 1982). Among the dykes which appear to hold the most potential for accurate dating are the ones located in Franklin, Frankfurt, Wiscasset, Scarborough, Kittery, and Cape Porpoise.

All of these dyked areas were examined on a reconnaissance basis to locate areas where detailed work would potentially yield data for this study. It is clear that the distribution of dyked marshes would allow further study of historic sea-level changes along the entire coast of Maine as well as adjacent coastal areas in New England and the Maritime Provinces.

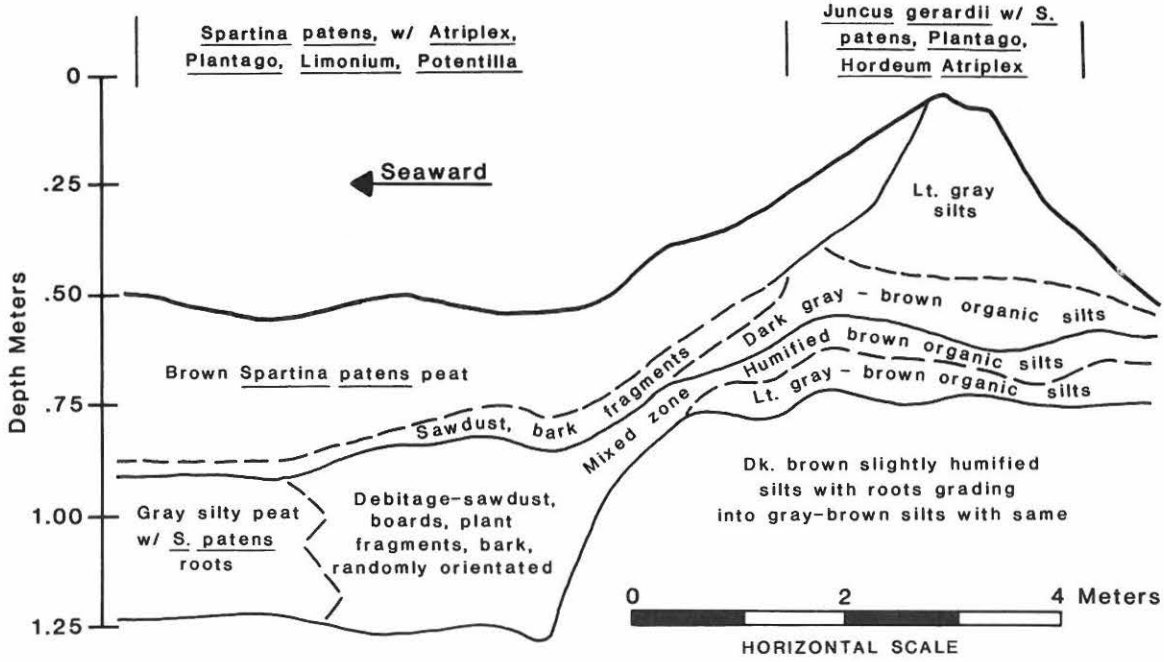

Figure 4. (a) Excavation showing cross section of the salt marsh dyke at Crocker Point, Machiasport. Dyke was built in 1823. See Figure 3 for location. (b) Schematic cross section of the Crocker Point dyke (from Anderson and Borns, 1983) showing how it was constructed and subsequently modified, in part, by relative sea-level rise.

Figure 5. Salt marsh dyke (center) terminating against bedrock, adjacent to the Mill River in Harrington. Dyke was built in 1815-16.

Figure 6. Man-made fill and salt marsh overlying remains of working platform at Shipyard Cove, East Machias.

OTHER EVIDENCE OF SEA-LEVEL CHANGE

Physical evidence perhaps related to sea-level rise, but without the precision of other data, occurs at Shipyard Cove in East Machias (Figure 2), a site of active shipbuilding from the late 1820's to 1890. Over forty vessels were built at this location. During this period, however, the cove partially filled with sediment. The last vessel built became mired in the channel at launch, and after extraction of the ship, the site was abandoned. During natural infilling of the cove, a small salt marsh developed adjacent to, and partially overtopping, the working platform of the shipyard (Figure 6). This is shown by our stratigraphic analysis of the exposed marsh face (Anderson and others, in prep.), during which we identified boards and sawdust from shipbuilding and milling activities within the Machias River drainage. At least 1.36 meters of *Spartina alterniflora* peat have accumulated since the nineteenth century.

Although consistent with other evidence for sea-level rise along the Maine coast, the rapid accumulation of the salt marsh peat at Shipyard Cove is not a precise proxy record of the sea-level change. Unlike *S. patens, S. alterniflora* grows primarily below mean high tide, and can colonize and maintain populations in areas of rapid sediment deposition. It is clear that the growth of this marsh was stimulated by a substantial influx of sediment. This influx of sediment might have resulted from erosion and redeposition of fine-grained coastal deposits, caused by relative sea-level rise, or from erosion of terrigenous materials associated with land clearance. What is clear is that the salt marsh did accrete, filling in the channel of the shipyard and covering the remains of the site once it was abandoned.

Wharves were constructed along the banks of the Machias River in Machias at the head of tide (Figure 3) beginning about 1780 (and in larger and more complex form until about 1845) and were more or less active until the twentieth century. All of these have fallen into disrepair and are completely unusable. The remains, including remnants of the working surface, are completely submerged at high tide but are visible well out of the water at low tide (Figure 7).

Upon close examination we found an original working surface still intact, and about 70 centimeters of *Spartina patens* marsh has accreted on this surface (Anderson and others, 1984). Clearly the working surface was constructed at least slightly above the high-tide level, and yet the present high tide covers it completely. Barring settlement of the wharf, in this area sea level apparently has risen at least 70 centimeters, and possibly as much as 1.5 meters, since the first wharves were constructed. Unfortunately the date of construction cannot be determined exactly, but the use of this working surface as recently as 1875 is indicated by the age of a photograph of the area. In conclusion, this analysis suggests a minimum sea-level rise of 70 centimeters since 1875.

Other sites where relevant dates have been determined for the construction of associated artifacts include wharves at Robbinston (1840's); wharves and ways in Perry (1840's); and tidal dams at the following locations: Roque Island (c. 1835), Starboard (1830's), Arrowsic (at least as early as 1800, and perhaps as early as 1750; active until 1923), Bath (c. 1840 and active until 1885-88), and Kittery (perhaps as early as 1780, certainly in operation by 1825). Oral testimony from elderly citizens along the Maine coast also gives an indication of the extent of coastal change within the last century. They routinely describe sea-level changes of about a meter in the past hundred years, pointing out where mooring irons for small boats, the location of fish houses, and other aspects of every day life have had to be relocated as the waters at high tide rise higher and higher. A visit to the Pembroke Iron Works also gave corroborative evidence, as the current high-tide marks are substantially above the location of erected dams and wharves of a century and a half ago. No salt

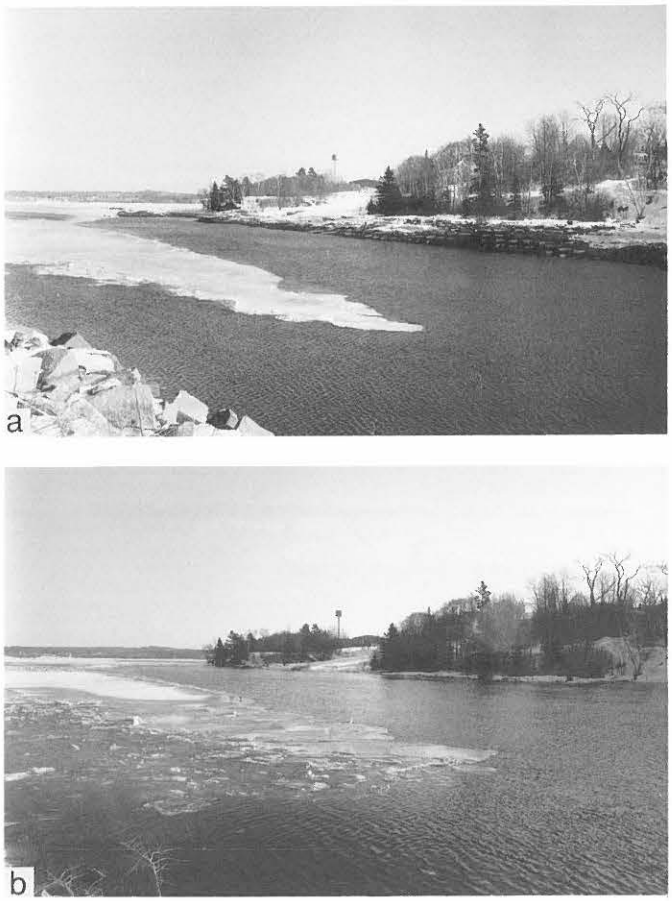

Figure 7. Remains of wharves on the Machias River in the town of Machias. These wharves were used through the late 1800's, when lumber was shipped from local sawmills. (a) View at low tide. (b) The same view at high tide.

TABLE 1. SEA-LEVEL RISE INDICATED BY SALT MARSH DYKES

Coring Date	Location of Dyke	Date of Dyke Construction	Salt Marsh Accretion Since Initial Construction	Inferred Average Sea-Level Rise (cm/century)
1986	Milbridge (next to U.S. Route 1-A, behind Davey house, on Narraguagus River)	1819	45 cm	27 cm (min)
1985	Harrington (Mill River, next to U.S. Route 1-A)	1815*-6	51 cm	30 cm (min.)
1987	Machias (east of Meserve Head, on Machias River)	1823	60 cm	36 cm
1986	Pembroke (Sipp Brook, U.S. Route 1)	1825*-9	45 cm	28 cm (min.)

*indicates date used for determination of sea-level rise

marsh grows on the river, thus precluding accurate measurement of sea-level rise, as the river runs through a rock channel.

RESEARCH TECHNIQUE AND RESULTS

The researchers carried out their tasks in two ways. First, a prospective dyke was located. Visits to the Registry of Deeds, using deductive reasoning from the present ownership, determined the history of the site. By following the land descriptions closely it was then possible to provide a date when there was no dyke, and a later date when a dyke existed on the property. Occasionally, as in the case of the major dyking at Machias, it was possible to refine the dates even further because we found newspaper accounts giving the time of actual construction. In all cases providing the basis for conclusions in this chapter, the dating window is less than three years, and usually it is within a year of the actual construction of the dyke.

Once the potentially useful dyke was dated historically, a detailed field study was initiated, in which cores were taken from the adjacent marsh. Several cores were taken in each case, to determine the amount of accretion of salt marsh on the dyke. Table 1 shows the sampling sites chosen, and the results obtained in the field. As it seems probable that the work of building the dykes disturbed the ecology of the salt marsh, the initial build-up of the salt marsh peat in areas behind the dykes was delayed somewhat. The dykes analyzed here were all kept in repair for some time (on the average about 25 years) and then fell into disrepair, although some of them continued to be used. Even when hay was still harvested, little or no repair occurred. Therefore, the relative sea-level change measured by salt-marsh accretion behind the dykes must date from about 25 years after the dyke was actually constructed. However, this problem is relevant only in the case of the Mill River site (Table 1), since the other cored sites are located on the seaward sides of the dykes.

It is occasionally possible to refine the sea-level rise evidence as shown in Figure 8. The cores taken from the dyke east of Meserve Head in Machias show, in addition to the overall sea-level rise measured by peat accretion, further evidence within that time period. The dyke was constructed in 1823. Large scale saw-milling in the Machias River area began between 1830 and 1840. This event is indicated in the core by sawdust particles imbedded in the peat. Saw-milling activity continued at a high level into the 1880's (Wood, 1935; Smith, 1971). It then diminished quickly, ending by 1930. The core through the toe of the Meserve Head dyke shows this sawmill activity as occurring from at least 54.5 centimeters depth to 10 centimeters in depth (Figure 8). The dyke, constructed in 1823, clearly predates the sawmill operation, since no sawdust exists on the landward side or under the dyke, while it is ubiquitous in the marsh seaward of the dyke. Thus we infer that the relative sea-level rise in this area averaged at least 44.5 cm/century from 1830 to 1930, and slowed to about 17.5 cm/century from 1930

to the present. The changing rates of historic sea-level rise in the Machias River estuary need to be studied in more detail, since we presently have only these limited data.

CORROBORATIVE EVIDENCE

Two other methods were used to obtain further evidence of the amount of relative sea-level rise. Following the methods used on the Lynn, Massachusetts marshes by C. A. Davis, we located a salt marsh in Perry, Maine (Figure 2), that was crossed by a railroad trestle of the Washington County Railroad constructed in 1899. We assumed, as Davis did, that trains crossing the trestle would have showered cinders on the marsh surface. These cinders would show up in cores taken in the marsh, and the total marsh thickness within and above the cinder-bearing lens should indicate the extent of marsh accretion since construction of the railroad. This thickness would then provide a proxy indication for the amount and rate of relative sea-level rise for the time interval following initial railroad operations. X-ray photographs of cores taken at Perry did show the cinder distribution. The marsh, and presumably also the relative sea-level, have risen 18 centimeters in the 88 years (a rate of 20.5 cm/century) since the railroad was constructed and the trestle built. This evidence is clear corroboration of the findings in the salt marsh dyke cores.

In addition, the authors have located a very large number of field notebooks from nineteenth century sea-level research, which are now part of the National Archives in Washington, D.C.

TABLE 2. NATIONAL ARCHIVES TIDAL DATA FOR MAINE

Location	Years of Observation
Calais to Eastport	1841, 1860, 1861, 1887
Eastport to Cobscook Bay	1887, 1888, 1889
Cobscook to Lubec	1861, 1866, 1888
Quoddy Roads to Cutler	1886
Cutler to Machiasport	1885, 1886, 1887
Machiasport to Mudhole Channel	1859, 1883, 1885, 1887
Jonesport	1870
Jonesport to Pleasant River	1871, 1872, 1883, 1885, 1886, 1888
Addison/Milbridge	1857, 1882, 1883
Narraguagus Bay	1884
Narraguagus to Pigeon Hill	1882, 1883, 1884

This research was undertaken to determine mean sea-level at a number of places on the coast of the United States. Those field notebooks which concern Maine are located in Boxes 38-50, Record Group 23, National Archives. They include 46 manuscript volumes of data. The data range in location from Eastport to Kittery, and in time from 1841 to 1890. Further data is available for the twentieth century from the same and similar sites.

The observation periods of National Archives data in these volumes are unfortunately too short to be of much importance; however, perusal of the data indicates that the sea level of today is substantially higher than the sea levels noted by observers in the 1800's. Table 2 indicates the places where the sea-level data were obtained, as well as the times of the observations.

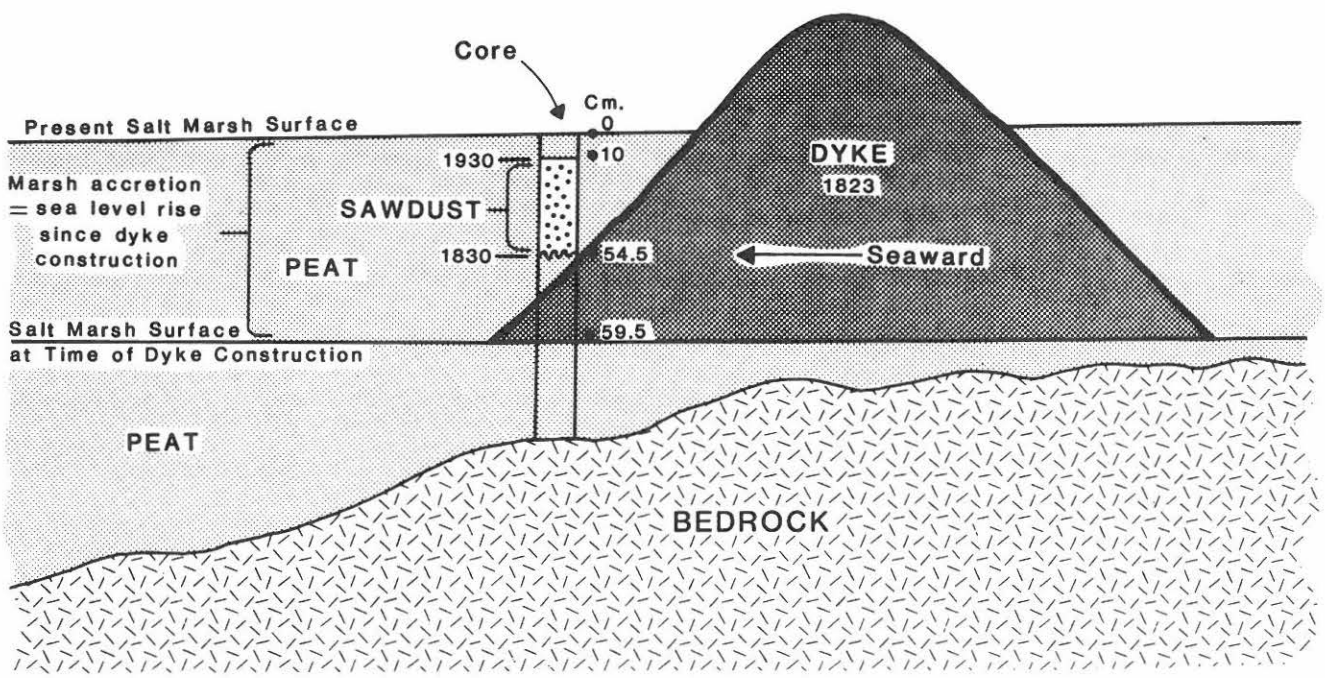

Figure 8. Schematic cross section of the dyke east of Meserve Head in Machias, showing the stratigraphy of a core taken on the seaward flank of the dyke. See Figure 3 for location.

These data collections were begun by the U.S. Coast and Geodetic Survey, but were interrupted by the Civil War. From the indications in the field books, they were primarily used as a way of spending a few weeks in Maine in the summer after the Civil War period. The data collectors spent most of the year in Mobile Bay, coming to Maine only for the summer months. As a consequence the data is of little use at the moment, except as corroboration of other results. There is, in addition, a continuous twenty-year record from tide gauges at North Haven, Maine, but the actual data are currently missing at the National Archives. Only the correspondence, unfortunately without any data other than to indicate a rising sea level in general terms, is still available. It is interesting, however, that the researcher who undertook this work (begun soon after the Civil War) felt that sea level was changing and he wished to test his hypothesis. Additional correspondence in these files indicates that other observers were aware of changes in apparent sea level at this time. We did not pursue this avenue of research because of projected time requirements as weighted against the predicted value of results.

CONCLUSIONS

Historical dating of dykes and other coastal structures, and their use in determining sea-level changes, is interesting and productive work, especially as it utilizes research from several disciplines. The researcher must be prepared to spend substantial time in surveying maps from the past, scrutinizing them minutely, and then following that work with examination of modern maps. Differences shown in mean water height through time may well be the consequences of sea-level change, and research on man-made structures may allow determination of the actual changes which have occurred. County officials often have detailed maps from the times of earliest settlements in their files and archives, and these often show details of valuable property such as salt marshes, dykes, levees, and other structures.

Problems are raised by our methods, of course. Dyke and marsh substrates may compact under the weight of the marsh to some degree, and they are subject to damage from heavy storms and higher than normal tides. The dykes we chose to study in detail, however, usually did not suffer much from these forces. Those persons who built the dykes constructed them for their own purposes, not for modern research, so the value of the sea-level analysis depends on careful selection of dykes followed by cautious stratigraphic study. Many dykes that were dated and cored were eventually found to be unsuitable for our purposes. They were too problematical for a variety of reasons, although the salt-marsh accretion of their flanks qualitatively supported our findings. Those dykes which met our standards have substantial amounts of accreted salt marsh peat, averaging about 25 to 35 centimeters per century. Since the time when the later dykes were constructed along the coast of eastern Maine, the apparent sea-level rise may indicate that crustal downwarping in that area has been as much as 60 centimeters.

This research, when used in conjunction with other work reported in this publication, and with the annual reports produced in the past for this project, helps extend our perceptions of changes in the land and adjacent sea level in coastal Maine. Over the past two hundred years a substantial change has occurred, locally as much as 1.5 meters of sea-level rise that may have resulted in part from crustal downwarping. The amount of relative sea-level change in the southern coastal zone, near Thomaston and farther south, is not as great as near Eastport and in the Bay of Fundy. A greater rate of change apparently occurs east of Machias, to the Maine-New Brunswick boundary, and perhaps beyond that point. Researchers in adjacent Canada have reported similar changes in sea level (Boardman, 1885; Ganong, 1903; Johnson, 1925; Ogden and Harvey, 1975). Our results are consistent in direction and magnitude with those derived by other workers and from tide-gauge records. Moreover, they contribute precise data for definite periods of historic time generally unobtainable by other methods.

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APPENDIX A

Henry Mitchell to Superintendent, Coast and Geodetic Survey, June 2, 1875, headed - Our Coast Pilot (A Few More Jealous Remarks Concerning It.)

Dear Sir:

Perhaps you will recollect that some years ago, when on the subject of reclamation of tide lands, I reported -- what I regarded as an important general rule -- that *the salt marshes lie at the plane of mean high water*, almost exactly. I had examined localities where different heights of tides obtained, as, for instance, Buzzards Bay, Cape Cod Bay and San Francisco Bay, and I had overhauled the levellings made by the Royal Engineers, for a proposed ship canal from the Bay of Fundy, to the Gulf of St. Lawrence. In the last named case, I found marshes on the two sides of the isthmus -- not many miles apart -- differed in elevation some 30 feet (:) being the difference in the elevations of mean high water with which each corresponded locally.

(:) I don't remember just the figures. I was so impressed with this matter that I remember suggesting that the elevation of marshes (from mean of line of levels) should be slated as a bench of reference for soundings.

Now: - Has Prof. Shaler based his interesting statement relative to the emergence of the coast (1 to 3 feet per century) upon the discovery of great plains of *upland* once covered by *deed* or *patent* as *salt marshes*? or on a special observation of tides? or on old chart?

If we go back to the charts of Champlain of 1605 and 1606, i.e., *270 years*, we find upon his harbor map of *Le Beauport* (Gloucester) *marshes where they now exist* - the same may be said of his map of *Chouacoit* (Saco). I have already called your attention to the correspondence between Champlain's soundings at Gloucester and our own. They are stated in fathoms, and out of 36 only *one* is deeper than ours. They are reduced to L. W. like our own. No change of *practical importance* seems to have occurred in the firm bed of the Gloucester channel and it is only in this *"practical"* sense that I offer any criticism.

This question of *rise and fall* of the coast is an old one in the Coast Survey, and the watch has been kept for a quarter of a century or more so that we ought to know the fact nearer than 1 to 3 feet.

I very respectfully submit,
H. Mitchell
to Superintendent C. P. Patterson, U.S. Coast Survey.