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ARTICLE

Characterizing the Erosion of Coastal Archaeological Sites on the Maritime Peninsula Using Survey, Collection Analysis, Excavation, and Modeling

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Abstract

The erosion of coastal archaeological sites is a worldwide heritage crisis. However, regional variability in the archaeological record and the natural environment necessitates localized consideration of the erosion of archaeological sites to facilitate informed research prioritization decisions about coastal cultural resources. In this article, we present and compare the results of recent coastal survey programs from southern Nova Scotia and far northeastern Maine to earlier ones to ascertain the extent of erosion since the mid-twentieth century. We then situate regional erosion in culture-historical terms via a case study from archaeological sites at Sipp Bay, Maine, from which materials were collected and tested in the early to mid-twentieth century. We compare the results of that work to our recent excavations. Finally, we model future sea-level rise scenarios to estimate future site destruction and compare these models between regions. Together, these data illustrate patterns in site preservation for geoarchaeological examination, provide insight into erosion-driven biases in the extant archaeological record, and offer information to guide research prioritization.

Resumen

L'érosion des sites archéologiques côtiers fait peser une menace sur le patrimoine mondial. Cependant, du fait de la variabilité régionale des données archéologiques et de leur articulation avec l'environnement naturel, il est nécessaire de prendre en compte l'érosion des sites archéologiques au niveau local afin de faciliter la prise de décisions éclairées au sujet des priorités en matière de recherche sur les ressources culturelles côtières. Dans cet article, nous présentons et comparons les résultats des programmes d'études côtières du sud de la Nouvelle-Écosse et de l'extrême nord-est du Maine. Nous comparons les résultats de ces enquêtes à ceux d'enquêtes antérieures afin de déterminer l'ampleur de l'érosion depuis le milieu du vingtième siècle. Nous replaçons ensuite l'érosion régionale dans une perspective historico-culturelle en nous appuyant sur une étude de cas concernant les sites de Sipp Bay, dans le Maine, qui ont été collectés et testés entre le début et le milieu du vingtième siècle. Nous comparons les résultats de ces travaux à ceux de nos récentes fouilles. Enfin, nous modélisons les futurs scénarios d'élévation du niveau de la mer afin d'estimer la destruction future des sites et nous comparons ces modèles entre les régions. Ces données rassemblées illustrent des modèles de préservation des sites pour l'examen géoarchéologique, un aperçu des biais dus à l'érosion dans les données archéologiques existantes, et des informations cruciales pour orienter le choix des priorités en matière de recherche.

Keywords: archaeological survey; coastal erosion; legacy collections; sea-level rise

Palabras clave: étude archéologique; érosion côtière; collections d'objets; élévation du niveau de la mer

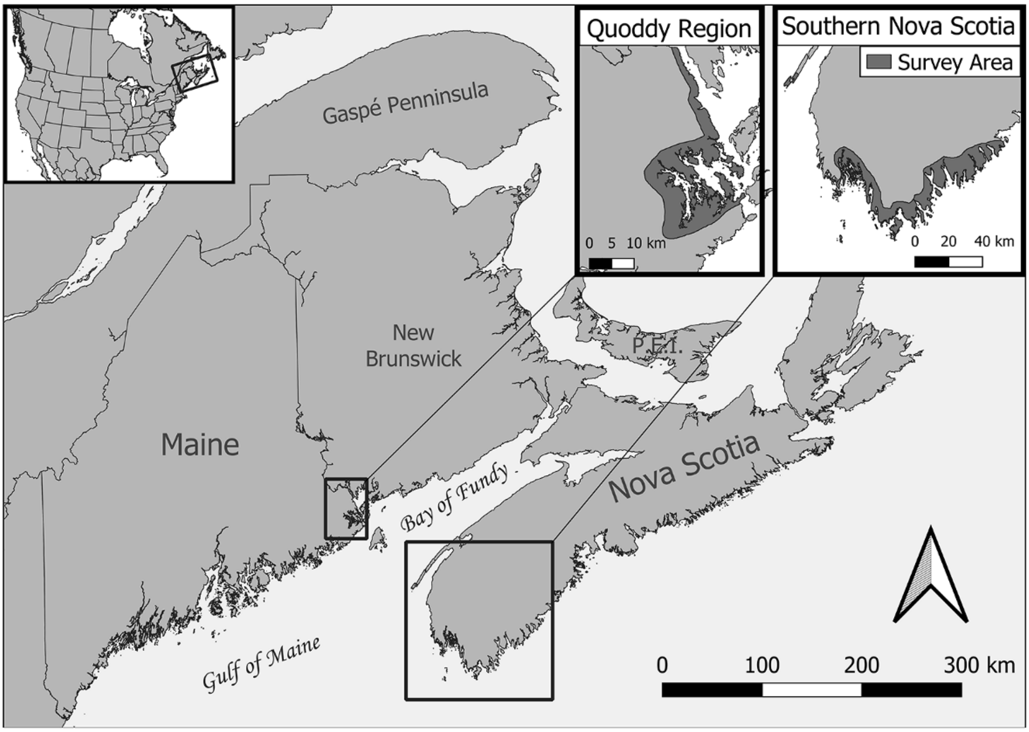

Figure 1. Map of the Maritime Peninsula, with insets showing (in dark gray) our survey areas in the western Quoddy Region and southern Nova Scotia.

Coastal archaeological sites are crucial repositories of cultural and environmental data. Ironically, just as such data are most essential for understanding human adaptation to changing environments, erosion of coastal archaeological sites is accelerating because of the climate change crisis (e.g., Dawson 2013; Erlandson 2008, 2012; O'Rourke 2017; Reeder-Myers 2015; Westley and Andreou 2023). This crisis occurs at a confluence of environmental factors and past settlement patterns and thus is variable from place to place, as are its implications for understanding the archaeological record (Kellogg 1995). The erosion crisis is enormous in scale, and the capacity for archaeological mitigation is limited, requiring prioritization decisions that should consider what has already been lost and what is most at risk of being eroded (e.g., D. Anderson et al. 2024; Dawson 2013; Dawson et al. 2020; Heilen et al. 2018; Westley and McNeary 2014). In this article, we offer an approach to addressing this crisis that considers what has already been lost from the archaeological record and what is most at risk.

Specifically, we report on archaeological survey and site audits from the western Quoddy Region in far northeastern Maine and from southern Nova Scotia (Figure 1). These study areas are part of the Maritime Peninsula (the eastern Wabanaki homeland) comprising the Maritime Provinces of Canada, the Gaspé Peninsula, and northeastern Maine. We compare this survey to earlier—mostly mid-twentieth century—surveys and site audits to evaluate site loss over that time. To put this situation in culture-historical context, we consider in detail material collected from one western Quoddy Region locality in the mid-twentieth century and compare it to what we recently excavated from that location. Finally, we model future sea-level rise to estimate future site loss. These analyses help provide insight into what has been lost from the region's archaeological record, illustrate subregional variability in site erosion, and can help guide research prioritization.

Nineteenth-century natural historians noted that coastal erosion was damaging archaeological sites along the coast of the Maritime Peninsula (Adams 1873:36; see Black 2014). By the closing decades of the twentieth century, salvage archaeology along the region's coastline became a major research emphasis (e.g., Black 1984; Davis 1980, 1982; Ferguson and Turnbull 1980; Kellogg 1994). The second half of the twentieth century also saw the professionalization of archaeology on the Maritime Peninsula (see Connolly 1977; Spiess 1985), resulting in extensive coastal surveys of some parts of the region (e.g., Bower 1973a, 1973b; Pearson 1970). This foundational work made clear that the overwhelming and accelerating extent of coastal erosion—as well as practical concerns—precludes mitigation by armoring all or even many of the region's coastal sites (see Spiess 1981). The situation has been described as "an archaeological apocalypse" (Friesen 2018:30) and is of a scope so severe that difficult prioritization decisions will need to be made about which sites to salvage. Such decisions require attention to the significance of sites for descendant communities, to the potential for sites to contain data for meeting contemporary environmental challenges, and to information gaps in the archaeological record (Dawson 2015; Dawson et al. 2020; Erlandson 2012; Newsom et al. 2023; St. Amand et al. 2020). Fundamentally, each of these challenges requires a localized understanding of the present condition of the coastal archaeological record and models for predicting future damage.

Survey and Site Audits

Site erosion on the Maritime Peninsula has worsened since the 1980s, when Spiess (1981:40) reported that 1,883 sites were known from Maine, more than two-thirds of which were coastal. Of these, "251 sites have been damaged beyond having much value to the archaeologist by coastal erosion. . . . Moreover, there are not more than a handful of coastal sites have gone completely unscathed." In other words, 20% of sites at that time were confirmed to be destroyed, but the status of most sites at the time was unknown.

To better understand the proportion of sites that have been destroyed and the tempo of that destruction, we conducted site audits in southern Nova Scotia (the South, Yarmouth, and Acadian Shores) and the western Quoddy Region (Figure 1) between 2017 and 2022. These areas were particularly useful for our study because, more than a half-century ago, both saw systematic testing by professional archaeologists that produced the bulk of the site inventories to which we compared our surveys. In the Nova Scotia study area, some sites were recorded by Erskine (1962, 1986) and Davis (1980, 1983), but most were identified in a 1973 coastal erosion "salvage" survey by Bower (1973a, 1973b) sponsored by the Archaeological Survey of Canada (now the Canadian Museum of History). In the Maine study area, most of the previously reported sites we considered were recorded in the 1950s by Theodore Stoddard and Robert Dyson under the sponsorship of the Robert S. Peabody Institute in Andover, Massachusetts.

In each area, our approach was to visit sites along the coast of the study area that had been previously reported and were recorded in the Nova Scotia Museum's archaeological sites database or the Maine Historic Preservation Commission's MPREHIST database. In Nova Scotia, the survey was under the auspices of the Community Observation, Assessment, and Salvage of Threatened Archaeological Legacy (COASTAL) project, conceived of by Betts (2022). This two-year survey project was conducted in collaboration with Mi'kmaw communities and used a shared-governance model to prioritize the mitigation of archaeological sites; it was also the direct impetus for the comparative survey program in Maine.

During each season, we also conducted a prospection survey for previously unidentified sites via the application of locally developed predictive models (i.e., Betts 2019:10–11; Black 2004; Kellogg 1987, 1994). Finally, in each location we conducted a series of public talks and events to share our work and ask knowledgeable locals about eroded artifacts in their collections and sites that had not previously been recorded by professionals.

For the purposes of this article, we confine our discussion to precontact and protohistoric Indigenous archaeological sites (sites older than 350 cal BP). Such sites on the Maritime Peninsula are usually highly visible because of shell eroding from them. However, we supplemented visual inspection of erosional faces with the use of a small-bore soil probe, with which we also evaluated the extent of intact stratigraphy at sites. Our surveys and audits were limited by property access, but over the course of the work we were able to visit many sites reported on private land and to survey high-potential landforms. In Nova Scotia, access to Crown (i.e., public) land was facilitated through a permit from the Department of Natural Resources.

Our categorization of sites emphasized (1) site vulnerability (Betts 2022; Betts and Hrynick 2018; Hrynick et al. 2019; see Dawson 2013), (2) a site's susceptibility to future erosion, and (3) retained intact

Table 1. Summary of the Results of Surveys and Site Audits.

Location	Survey Year(s)	Number of Sites Audited or Newly Identified	Number (%) of Sites Considered That Were Newly Identified or Reported	Number (%) of Sites Destroyed (Lacking Remaining Intact Stratigraphy)
Nova Scotia's South Shore	2017	21	5 (24%)	16 (76%)
Western Quoddy Region	2018–2022	14	1 (7%)	7 (50%)
Nova Scotia's South, Yarmouth, and Acadian Shores	2019	23	5 (22%)	16 (70%)
Combined	2017–2022	58	11 (19%)	39 (67%)

stratigraphy. In total, we considered 58 sites, 47 of which were previously recorded, and the rest of which we identified in survey or were reported to us by locals. The results of this survey, shown in Table 1, indicate the rapidity with which the archaeological record has been eroded since the mid-twentieth century, with 67% of the total site inventory destroyed. All but two of the sites that still retain intact stratigraphy are actively eroding, and those two sites, although technically in the coastal zone, are in unique settings: one is in a low-energy salt marsh, and the other is about 100 m from the shore. There are some subtle differences in the degree of erosion between the Maine and Nova Scotia surveys that may be attributable to local sea-level or geological factors (e.g., bedrock subsidence and the shoreline gradient). These distinctions are beyond the scope of this article but deserve further geoarchaeological attention.

Although our work identified previously unreported sites, professional archaeological survey has not been as effective a way to add to the site inventory as meeting with local residents. In the western Quoddy Region, the only newly identified site was reported by a collector (see Hrynick and Anderson 2021). In Nova Scotia, six of the newly identified sites were reported by collectors, including the most surprising addition to the site inventory: a Palaeoindian point recovered on an eroding shoreline (Betts et al. 2018). The disparity between avocational and professional identification of sites probably occurs because local residents tend to walk along beaches all year, rather than just for a few weeks during each summer. As a result, they have had many opportunities to identify eroding archaeological sites.

Mid-Twentieth-Century Collections from Sipp Bay, Maine, Sites (80.25a, 80.25b, and 80.40)

The results of our surveys show the extent of archaeological site loss on the Maritime Peninsula. For the sites that remain, it may be useful to consider how they are being transformed by erosion and how that effect articulates with past settlement patterns. Specifically, our work indicates the truncation of the region's archaeological record due to the erosion of its oldest portions. On the Maritime Peninsula, this can partly be understood in terms of what Erlandson (2001) calls "Richardson's Rule": around the world, steep bathymetry is associated with more preserved evidence for older marine resource use than shallow bathymetry. The shallow bathymetry in our study area makes it "an extreme example of Richardson's Rule," with poor preservation of older components further perpetuated by large tidal amplitudes (Betts et al. 2019:48). Thus, although use of the region's coast as long ago as the Maritime Archaic period (9500–3500 cal BP) is occasionally attested to by preserved sites from mid-coast Maine (e.g., Bourque 1995), legacy collections (e.g., Cummings 2025), and the fortuitous recovery of temporally diagnostic artifacts in fishing drags (e.g., Black 1997; Crock et al. 1993; Price and Spiess 2007; Spiess and Price 2024), the region's remaining archaeological record is overwhelmingly from the Maritime Woodland period (about 2200–1300 cal BP) or later. The process by which older sites or components of sites erode before younger ones has been termed "chronological shingling" farther south in the Gulf of Maine (Young et al. 1992:242–245). Chronological shingling occurs because people preferred living close to the shoreline on long, gradually sloping coastal areas. As Holocene-era sea levels rose, occupations also progressively shifted slightly inland in response. The result is that the oldest occupations are the lowest and closest to the water and therefore erode before more recent ones.

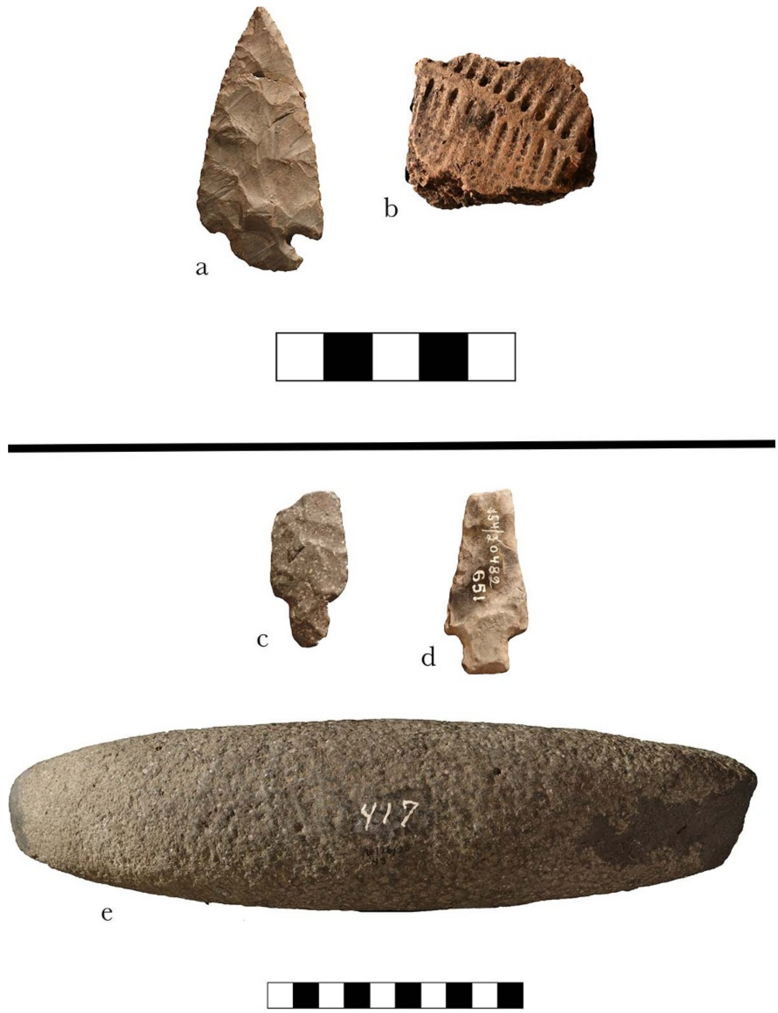

Figure 2. *Top*: Maritime Woodland period objects from the Sipp Bay 1 site in the RSPI collections ([a] 154/20512; [b]154/20465) *Bottom*: Transitional Archaic period objects from Sipp Bay 1 site in the RSPI collections ([c] 1544/20481; [d] 154/20482; [e] 90.172.13). The artifacts are curated at the Robert S. Peabody Institute of Archaeology, Andover, Massachusetts.

To explore this model and its effects locally, we considered Sipp Bay in Perry, Maine, on Cobscook Bay in the western Quoddy Region. Sites Sipp IA (80.25A), Sipp IB (80.25B), and Sipp II (80.40) are all on a small peninsula that extends roughly southwest into Sipp Bay. The southernmost site, Sipp IA, is about 150 m southwest from Sipp IB along a low, roughly southeast-facing beach. Sipp II is about 400 m northwest from Sipp IA and is on a bluff. It faces south, and Sipp IA and IB face south and southeast, respectively. Each site is visibly eroding, with shell and artifacts spilling onto the beach. After excavation, the remaining visible evidence of Sipp IB was destroyed in a series of storms in January 2024.

We selected the Sipp Bay sites for this case study because work there by Stoddard in 1951 included both test excavation and collaboration with local collectors—John Knapton, Douglas Knapton, and Carleton Hayward—who had been collecting in the region since the 1930s. They gave their substantial collections to Isaac Kingsbury, a published avocational archaeologist who had summered in and then retired to Perry, Maine. The collection comprises material from all the Sipp sites, but primarily from Sipp IA and IB, which did not appear to be differentiated at the time. Kingsbury provided this collection to the Robert S. Peabody Institute (RSPI), where it is still curated along with written information collected by Stoddard. The entirety of the legacy collection we consider here can be linked to the MPREHIST database of sites because Stoddard assigned distinct numbers to sites he studied that are recorded in his notes and reports and as annotations on a map. As a result, the sites provide a good opportunity to compare in situ archaeological deposits with those that had eroded or been excavated more than 70 years ago.

Fifty-five flaked lithic artifacts from Sipp Bay are recorded in the RSPI collections. Some were excavated by Stoddard in 1951, but the vast majority were collected from the beach and erosional face by Kingsbury, Hayward, and the Knapton brothers. The collection reflects an opportunistic, visual collecting strategy: 20 of the 55 artifacts are bifaces, 21 are flakes, 12 are utilized flakes or unifaces, and two are cores. The catalog numbers used here refer to the RSPI's system from the time of Stoddard's research and are usually written on the artifacts.

Because of a lack of radiocarbon-datable material or intra-site contextual information in the collection, we used artifact typologies to ascribe date ranges to the artifacts. Later in the article, we discuss the detailed temporal assignations that are enabled by regional typologies, especially for lithics (e.g., Boudreau 2016; Burke 2022) and ceramics (e.g., Petersen and Sanger 1991), and are based on well-dated stratigraphic contexts (for more information, see Hrynick et al. 2022).

Together, the temporally diagnostic material we describe in detail and in Figure 2 and Tables 2 and 3 is mostly from the Early (3000–2200 cal BP) and Middle Maritime Woodland periods, with some material from the Late Maritime Woodland period (1300–550 cal BP) and likely from the Transitional Archaic (4000–3000 cal BP) and Late Maritime Archaic periods (5500–3500 cal BP) as well. Overall, the mid-twentieth-century collection at the RSPI confirms that earlier collected material trends older, supporting the idea of chronological shingling from erosion caused primarily by relative sea-level rise. It represents a strikingly different assemblage from that excavated in the twenty-first century, which we describe later in this article.

Bifaces

Eight of the 20 bifaces in the collection are nondiagnostic. The potentially temporally diagnostic bifaces can be divided into the categories of stemmed ($n = 2$), side-notched ($n = 1$), and corner-notched ($n = 9$). Five of the corner-notched bifaces are narrow-notched, and four are wide-notched or expanding stemmed. Information about the 12 diagnostic examples is presented in Table 2 (see Burke 2022).

Groundstone

Eight examples of groundstone artifacts are present in the collections, but there is little temporally diagnostic material. Most are less than 20 cm in length and opportunistic in nature. Many examples are beach cobbles that were flaked, pecked, and ground as needed into serviceable tools. The exception is 90.172.13 (Figure 2e; see Table 2). It is strikingly similar to preform 137/13379, the only object recovered from Sipp II by Stoddard. These two tools are the best candidates for Maritime Archaic period (9500–3500 cal BP) groundstone from the Sipp Bay sites. These objects differ from anything we have excavated in situ and are consistent with the pattern in the flaked stone assemblage of early material eroding out during the mid-twentieth century.

Ceramics

The Sipp Bay collection at the RSPI contains 17 ceramic sherds (Table 3). Of these, eight—137/13372, 154/20465 (Figure 2b), 154/20468, 148/20061 (two sherds), 148/20051, 148/20056, 148/20058, and 154/20467—exhibit dentate or incised motifs, corresponding with the Middle Maritime Woodland period (2200–1300 cal BP). The remainder of the ceramics are undecorated body sherds and are not diagnostic (Petersen and Sanger 1991).

Results of the 2018–2023 Excavations at Sipp Bay

The collections analysis at Sipp provided a mid-twentieth-century baseline against which to compare the contemporary condition of Sipp Bay's archaeological sites. Between 2018 and 2023, we conducted excavations at the Sipp Bay sites to evaluate the effects of erosion on the archaeological record there

Table 2. Summary of Potentially Temporally Diagnostic Lithic Objects from 80.25 (Sipp Bay I) in the Robert S. Peabody Institute Collections.

Accession Lot	Technology	Brief Description	Typological Dating	Date Range	Detail on Typological Dating	Figure
90.172.13	Pecked and Ground	Ca. 30 cm long ground stone adze, tapered at each end from a bulbous middle and with a flat bottom. It is entirely pecked, with grinding at each end, with one end clearly fashioned into the bit.	Maritime Archaic?	5500–3500 cal BP	Size and form incompatible with Maritime Woodland examples	2e
154/20482	Flaked	Narrow, square-stemmed point missing tip.	Transitional Archaic	4000–3000 cal BP	Consistent with examples of Atlantic phase Transitional Archaic points from the region (see A. Anderson et al. 2024; Black 2018)	2d
154/20481	Flaked	Proximal section of straight stemmed, lobate based biface.	Early Maritime Woodland	3000–2200 cal BP	Burke (2022) suggests as comparable to Adena in this region	2c
90.172.470	Flaked	Small expanding stem point with a slightly broken tip and sloping shoulders.	Early Maritime Woodland	3000–2200 cal BP	Comparable example from CfDl−1 (Oxbow site) dating to 2980 ± 80 (uncal.) BP (Allen 1980:Figure 57; see also Burke 2022)	—
90.172.510	Flaked	Complete expanding stem point with an excurvate blade and sloped shoulders.	Early Maritime Woodland	3000–2200 cal BP	Comparable with examples from CfDl−1 (Oxbow site) around 2500 BP (Allen 1980; see also Burke 2022)	—
137/13370	Flaked	Small (ca. 3 cm in length) side-notched biface.	Middle Maritime Woodland	2200–1300 cal BP	Burke 2022; many examples from Goddard (Cox 2021)	—
90.172.511	Flaked	Narrow corner-notched point with excurvate blade edges. Broken tip, break possibly retouched.	Middle/Late Maritime Woodland	2200–550 cal BP	Burke 2022	—
137/13367	Flaked	Proximal end of snapped, lightly excurvate, weakly barbed corner notched point.	Middle/Late Maritime Woodland	2200–550 cal BP	Burke 2022	—

(*Continued*)

Table 2. Summary of Potentially Temporally Diagnostic Lithic Objects from 80.25 (Sipp Bay I) in the Robert S. Peabody Institute Collections. (*Continued.*)

Accession Lot	Technology	Brief Description	Typological Dating	Date Range	Detail on Typological Dating	Figure
154/20479	Flaked	Complete, rough, and somewhat asymmetrical weakly barbed corner notched point.	Middle/Late Maritime Woodland	2200–550 cal BP	Burke 2022	—
154/20480	Flaked	Corner-notched point, missing tip.	Middle/Late Maritime Woodland	2200–550 cal BP	Burke 2022	—
154/20512	Flaked	Two glued fragments forming a nearly complete, very lightly excurvate corner notched point. Missing an ear. Finely retouched and symmetrical.	Middle/Late Maritime Woodland	2200–550 cal BP	Burke 2022	2a
37/13365	Flaked	Nearly complete, excurvate point with a rounded tip. Missing an ear.	Indeterminate	—	Missing ear complicates determination of damaged or rough corner notch vs. expanding stem	—
148/20044	Flaked	Medial section of a heavily resharpened biface.	Indeterminate	—	Shoulders and partial stem present, but notching indeterminate	—

Table 3. Ceramics from 80.25 (Sipp Bay I) in the Robert S. Peabody Institute Collections.

Accession Lot	Decoration	Typological Dating	Date Range
137/13372	Dentate	Middle Maritime Woodland	2200–1300 cal BP
154/20465	Dentate	Middle Maritime Woodland	2200–1300 cal BP
154/20466	Undecorated	Maritime Woodland	3000–550 cal BP
154/20467	Incised	Middle Maritime Woodland	2200–1300 cal BP
154/20468	Dentate	Middle Maritime Woodland	2200–1300 cal BP
154/20469	Undecorated	Maritime Woodland	3000–550 cal BP
148/20061 (1)	Dentate	Middle Maritime Woodland	2200–1300 cal BP
148/20061 (2)	Dentate	Middle Maritime Woodland	2200–1300 cal BP
148/20051	Dentate	Middle Maritime Woodland	2200–1300 cal BP
148/20052	Undecorated	Maritime Woodland	3000–550 cal BP
148/20053	Undecorated	Maritime Woodland	3000–550 cal BP
148/20054	Undecorated	Maritime Woodland	3000–550 cal BP
148/20055	Undecorated	Maritime Woodland	3000–550 cal BP
148/20056	Dentate	Middle Maritime Woodland	2200–1300 cal BP
148/20057	Undecorated	Maritime Woodland	3000–550 cal BP
148/20058	Dentate	Middle Maritime Woodland	2200–1300 cal BP
148/20059	Dentate	Middle Maritime Woodland	2200–1300 cal BP
148/20060	Dentate	Middle Maritime Woodland	2200–1300 cal BP

since Stoddard's work. Alarmingly, the results of our excavations indicate that, in coarse terms, more than 2,000 years of occupation at Sipp Bay have been lost to erosion between the time of Stoddard's work and of ours.

Sipp IA

In 2022, we excavated 14 m^2 at Sipp IA, which was a shallow, shell-bearing deposit with a dwelling floor or work surface feature made of beach gravel on its landward side. In the Quoddy Region, people often made floors and work surfaces from nearby gravel beaches (see Hrynick 2018; Hrynick and Robinson 2012). Sipp IA was devoid of lithic artifacts, except for a single water-rolled flake. We think it is likely that the water-worn flake had already eroded onto or been left on the beach before preparation or during maintenance of the gravel feature (see Hrynick 2018; Hrynick and Robinson 2012) and been incorporated into it in that way. Preserved archaeofauna at the site, especially *Microgadus tomcod* ("frostfish"), which spawn and are easily captured during cold weather, and evidence for grease and marrow extraction on mammal bone suggest a cold-season occupation. The site contained an abundance of Middle Maritime Woodland period ceramic forms (dentate and pseudo-scallop shell and grit-tempered ceramics; see Petersen and Sanger 1991). The age is confirmed by radiocarbon dates from the bottom of the cultural deposit, within it, and at the top of the cultural deposit, which indicate a Middle Maritime Woodland period occupation between 1525 and 1301 cal BP (Table 4).

Sipp IB

Sipp IB is separated from Sipp IA by about 150 m of eroding low-gradient beach. In 2024, we excavated 4 m^2 of Sipp IB, recovering the only remaining archaeological deposits at the site. This area contained nondiagnostic lithics and highly fragmented bone. The remaining shell deposit at the site was taken in bulk from the erosion face. The site's radiocarbon date was run on terrestrial mammal bone contained in that sample, yielding a date of 1695–1527 cal BP (Table 4). In a previous beach survey, we had recovered the base of a broken corner-notched projectile point, which is consistent typologically with Late Maritime Woodland period forms.

Table 4. Radiocarbon Dates from Work between 2018 and 2023 at Sipp Bay Sites, Middle Maritime Woodland Period and Protohistoric Period Occupation.

Site	Sample No.	Radiocarbon Date (^{14}C Years BP)	2σ Age Range (cal Years BP)	Material
80.40	Beta−545628	380 (± 30)	504–319	Terrestrial mammal (Medium cervid, likely *Odocoileus virginianus*) bone
80.40	Beta−675334	510 (± 30)	623–501	Terrestrial mammal (Medium cervid, likely *Odocoileus virginianus*) bone
80.25A	Beta−654551	1460 (± 30)	1386–1301	Terrestrial mammal bone
80.25A	Beta−654550	1530 (± 30)	1516–1347	Terrestrial mammal bone
80.25A	Beta−654549	1560 (± 30)	1525–1376	Terrestrial mammal bone
80.25B	Beta−675335	1690 (± 30)	1695–1527	Terrestrial mammal bone

Note: Dates were calibrated using OxCal 4.4 (Bronk Ramsey 2009) and the IntCal20 curve (Reimer et al. 2020).

Mid-Twentieth-Century Collections from Sipp Bay, Maine, Sites (80.25a, 80.25b, and 80.40)

In 2022 and 2023, we excavated 9.5 m^2 of Sipp II, a patchy, shallow, and diffuse shell-bearing site in a wooded area on a steep eroding bluff that is between 1 and 2 m high. One broken Kidd type Ia19 glass bead (Kidd and Kidd 1970) was recovered during a systematic survey of the intertidal area in front of the site. Such beads date to the sixteenth and early seventeenth centuries AD on the Maritime Peninsula (Bradley 2012; Whitehead 1993). The site is strikingly similar in structure to shallow Protohistoric period (ca. 550–350 cal BP) living surfaces at other Maritime Peninsula sites (e.g., Betts 2019:358; Hrynick et al. 2017) and contained a variety of lithic materials and forms consistent with—but not necessarily diagnostic of—Late Maritime Woodland or Protohistoric period habitation. The site also included spirally fractured mammal long bone. Our impression of the site as a Protohistoric surface consistent with others on the Maritime Peninsula was confirmed by two Protohistoric period radiocarbon dates on terrestrial mammal bone indicating occupation between 623 and 319 cal BP (see Table 4).

Summary

In sum, our excavations indicate that the RSPI collection, largely gathered from erosional contexts between the 1930s and the 1950s and from Stoddard's tests in 1951, indicate an Early to Middle Maritime Woodland period occupation at Sipp Bay. The collections also provide strong evidence that from the 1930s to the 1950s there were still uneroded or recently eroded Transitional Archaic period or earlier artifacts at Sipp Bay. In dramatic contrast, our recent excavations identified only evidence of Middle Maritime Woodland period or more recent occupation (Table 4).

Models of Future Erosion in the Western Quoddy Region of Maine

So far, we have summarized the extent of loss at a regional scale and reviewed the implications to date on one landform. However, informed heritage management decisions also require estimates of future erosion. To accomplish this, we returned to site inventories and modeled scenarios for future erosion. We first examined each coastal site on a section of the Quoddy Region from the international border west to Machias Bay (Figure 1). We used aerial photographs and satellite imagery to remove sites from the database that were not precisely recorded or that had coordinates inconsistent with site location descriptions. This data triage produced a dataset consistent with the Nova Scotia survey and audit data, where we had better site access, permitting us to develop a relative model of erosion that considers a range of landforms.

For modeling Maine sites, we used a digital elevation model (DEM) from the US Geological Survey, downloaded from the National Oceanic and Atmospheric Administration (NOAA) Data Access Viewer (https://coast.noaa.gov/dataviewer/). The DEM was collected in 2011 as part of a larger northeast lidar dataset collected from New York to Maine. The DEM has a reported vertical accuracy of 0.071 m and a horizontal accuracy of 1 m, with 1 m point spacing. For modeling Nova Scotia sites, we used the high-resolution digital elevation model (HRDEM) from National Resources Canada

Table 5. Number and Percentage (%) of Sites Predicted to Be Threatened by Each Sea-Level Scenario.

Location	Site Elevation	Currently Threatened	Threatened by 2050	Threatened by 2100	Unlikely Threatened by 2100
Maine	Minimum	14 (61%)	15 (65%)	15 (65%)	8 (35%)
	Mean	9 (39%)	11 (48%)	15 (65%)	8 (35%)
	Maximum	5 (22%)	7 (30%)	8 (35%)	15 (65%)
Nova Scotia	Minimum	26 (63%)	29 (71%)	32 (78%)	9 (22%)
	Mean	22 (54%)	23 (56%)	28 (68%)	13 (32%)
	Maximum	15 (37%)	21 (23%)	25 (61%)	16 (39%)

Notes: We modeled 23 sites in Maine and 41 sites in Nova Scotia where elevation data were available. Site elevation indicates the minimum, mean, and maximum elevations within a 5 m radius of each site, which were compared to current and predicted sea levels to determine the extent to which sites are or could be exposed to sea levels.

(https://open.canada.ca/en). The HRDEM was collected in 2017 as part of a larger lidar dataset of southern Canada, and it has a reported vertical and horizontal accuracy of less than 1 m, with 1 m point spacing. To understand the impact of storm surge and future sea-level rise, we created 5 m circular buffer polygons around each site point. Within these buffers, we calculated the minimum, mean, and maximum site elevations using the zonal statistics tool. Seven sites in the Maine dataset did not have data in the DEM, so we either classified them as "currently threatened" if they are confirmed "currently fully eroded" (four sites) or "not threatened by 2100" if they were inland (three sites). One Maine site was omitted from our study because it fell in a no-data gap in the DEM. Three sites (AlDe-01, AlDe-02, and AlDe-03) in the Nova Scotia dataset were not in a location with available elevation data, so we removed them from the dataset for modeling. Models of elevation with 5 m were completed for 23 sites in Maine and 41 sites in Nova Scotia.

We used three sea-level—or effective erosional water level—scenarios to quantify the extent to which each site is threatened by sea-level rise and storm surge: current sea level, predicted sea level in 2050, and predicted sea level in 2100. All sea levels reported here use the highest astronomical tide as the datum and do not consider waves that would occur in addition to the higher water level. For Maine sites, we determined current sea level by combining the highest astronomical tide with the highest storm surge recorded at the Eastport, Maine, tide gauge (station ID: 8410140; https://tidesandcurrents.noaa.gov/stationhome.html?id=8410140) from the NOAA. In Maine, a record-high storm surge of 1.112 m occurred on January 10, 2024; therefore, the highest erosional water level is 1.112 m above the highest astronomical tide at the mouth of Cobscook Bay for our current scenario. For Nova Scotia sites, we determined current maximum sea level as directly reported at the Yarmouth, Nova Scotia, tide gauge (station ID: 00365; https://tides.gc.ca/en/stations/00365) from Fisheries and Oceans Canada, which is 0.54 m. The state of Maine is planning to manage 0.457 m of sea-level rise by 2050 and 1.189 m of sea-level rise by 2100, so we used these scenarios in our modeling for both Maine and Nova Scotia sites, even though future sea-level rise could be higher. Using these predictions, we added the maximum current water level to the projected sea level to determine the highest possible water levels in 2050 and 2100. We report all water levels in the highest astronomical tide datum. In Maine for 2050, the maximum predicted water level is 1.569 m, and in 2100 is 2.301 m. In Nova Scotia for 2050, the maximum predicted water level is 0.997 m and in 2100 is 1.729 m.

We calculated minimum, mean, and maximum site elevations within 5 m of our site points and compared these elevations to the three water levels (current, 2050, and 2100) to determine the extent to which sites are threatened or are exposed to tides and storm surges and to predict when or if the sites will be threatened in the future. Sites were then designated "currently threatened," "threatened by 2050," "threatened by 2100," or "unlikely threatened by 2100" based on their minimum elevations in comparison to the water levels. Table 5 and Figure 3 summarize the results of this analysis. Models suggest that Nova Scotia and Maine sites are currently at similar risk of erosion, with more than 60% of sites threatened. In contrast, by 2100, 78% of Nova Scotia sites and 65% of Maine sites are threatened. Each region's sites are predicted to be destroyed at catastrophic rates.

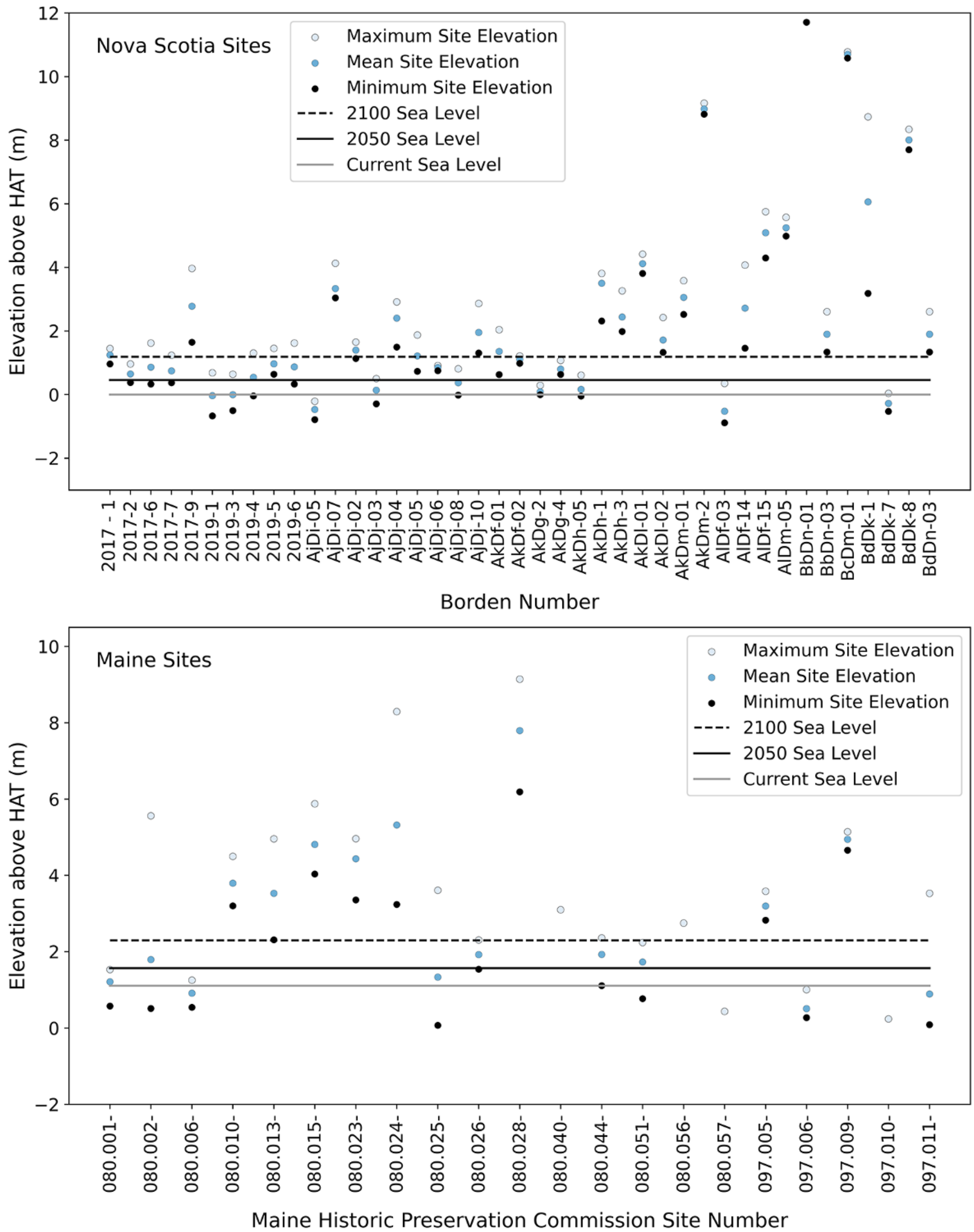

Figure 3. Elevation above highest astronomical tide (HAT) (m) of sites in Maine (Maine Historic Preservation Site number) and Nova Scotia (Borden number) compared to modeled sea levels. Maximum, mean, and minimum elevations within a 5 m radius of the site were used in comparisons. Current sea levels indicate the highest documented sea levels of HAT plus storm surge reported in 2024; 2050 indicates predicted maximum sea levels for 2050 (+ 0.457 m); 2100 indicates predicted maximum sea levels for 2100 (+ 1.189 m). Sites in Maine and Nova Scotia appear to be at similar risk of erosion.

Discussion

The erosion of the coastal archaeological record complicates research because archaeologists must attempt to consider what has already been lost. They must also attempt to inform communities and rights holders about what sites are most at risk to coastal erosion, what sites may retain the most research potential, and what coastal sites may best address gaps in the archaeological record.

The implication of this work is clear and unsurprising: coastal archaeological sites on the Maritime Peninsula are rapidly eroding and have been substantially eroded. As others (e.g., Young et al. 1992) have suggested, coastal erosion has preferentially obliterated older portions of the archaeological record in this region. This creates a culture-historical challenge, because it means that the coastal or potential coastal record is obliterated for all but the most recent precontact periods, except in unique geological circumstances. Intact coastal components in such unique preservation contexts should be prioritized, and archaeologists should be cognizant of the temporal biases that erosion has introduced.

Based on the results of our surveys, we do not believe that further substantial systematic professional coastal survey is warranted on the Maritime Peninsula. Instead, ongoing engagement with residents will result in the reporting of previously unrecorded sites. To that end, programs such as the Maine Midden Minders (see Dawson et al. 2020) that engage the public with professional archaeologists may be valuable. However, as we discuss elsewhere (DeWater et al. 2024), professional archaeological site audits are still needed to support desktop modeling of archaeological site erosion, especially on large regional-site locational datasets that report sites with varying levels of precision.

The modeled current and potential exposure of sites to erosive sea levels in Maine and Nova Scotia suggest continued catastrophic levels of erosion. Here we considered minimum site elevations in comparison to current and future maximum sea levels because any exposure of a site to an erosional water level causes damage. At this broad scale, there is little obvious difference between Nova Scotia and Maine in the near term. However, our modeling approach took a broad view, and we think that geoarchaeological analysis in the future could help refine understanding of erosion threats and histories. Certainly, local factors such as bedrock pinning will protect specific sites (e.g., Belcher and Sanger 2017), but a geoarchaeological perspective that is more localized and could be incorporated into future modeling would be useful for refining erosion models.

Conclusion

In this article, we presented an approach that applies survey, collections analysis, excavation, and modeling to characterize the extent of erosional damage to archaeological records to guide future research. Such an approach is useful for understanding what aspects of the archaeological record have already been lost and which are most threatened. We highlighted the need to combine modeling with survey and excavation and argue that in other coastal regions such an approach may help guide research prioritization and complement archaeological interpretation. On the Maritime Peninsula specifically, our work has quantified the magnitude of the erosion crisis and illuminated patterns within it. The erosion that has already occurred, representing about 2,000 years of lost culture and history at the Sipp Bay and the complete destruction of many of the region's archaeological sites since the mid-twentieth century, foreshadows the looming effects of the further erosion we predict here. This analysis shows the immediate need to direct salvage efforts toward the region's oldest remaining archaeological sites. Because of the sequential destruction of older components, combining collections analysis with excavation, as we have done here, can be valuable for creating an extended picture of coastal lifeways through time.

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