EROSION MAPPING AND RISK ASSESSMENT FOR ARCHAEOLOGICAL SITES ALONG THE COQUILLE RIVER ESTUARY, BULLARDS BEACH STATE PARK, OR

by

CONNOR N. THORUD

A THESIS

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Scott M. Fitzpatrick

Research demonstrates that archaeological sites along the Oregon Coast are subject to the deleterious effects of earthquakes, landslides, tsunamis, aeolian processes, and coastal erosion. Preliminary survey and excavations of archaeological material at Bullards Beach State Park, Oregon have demonstrated that bank erosion along the Coquille River estuary poses a threat to archaeological sites in the area. There is an urgent need for resource assessment and damage mitigation to protect sites throughout the park before they are completely destroyed. This thesis uses Bullards Beach State Park as a case study to explore problems facing Oregon's coastal archaeological resources, and to test aerial imagery data as a tool for estimating estuarine erosion rates. Aerial imagery dating between 1939 and 2016 was mapped in ArcGIS. By measuring the relative position of the riverbank in each set of images, it was possible to achieve estimates of erosion rates at Bullards Beach through the past eight decades. Results demonstrate annual erosion rates as high as 3.56 m/year at certain localities of the park, with an overall average of 1.44 m/year. These results may inform management efforts by tribal, state, and university groups working with archaeological material in the park.

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Introduction

Erosional forces are a hindrance to the goals of archaeology as a field of study. Two of the primary missions of archaeology are to preserve the archaeological record and interpret that record to holistically reconstruct the past. However, erosional processes pose an inherent threat to the preservation of archaeological materials, which is a finite and limited resource. The more the archaeological record deteriorates, the less archaeologists will be able to learn from those remains.

This should be cause for both concern and action on the part of archaeologists and other people with vested interested in preserving the past. Because we are working with a finite resource, archaeological research in coastal settings must often proceed with erosion in mind, and researchers must take urgent measure to document sites before they are destroyed due to the effects of tidal action, heightened wave activity due to storms, wind energy, and catastrophic events such as tsunamis and earthquakes. Additionally, global sea levels have risen significantly over the past 20,000 years (Clark et al. 2009). This has caused catastrophic damage to the archaeological record and will likely continue to do so: if sea levels rise another meter in the next century, countless archaeological sites throughout all coastal regions of the world will face drowning, inundation, and destruction (Erlandson 2012; et al. 1999; Fitzpatrick et al. 2015).

In some areas, immediate action is necessary to address erosion and sea level risks at archaeological sites. The Oregon Coast is one such region. Oregon is characterized by a highly dynamic geomorphology, meaning that its structure is prone to movement and change by various geological processes. Additionally, the Oregon Coast has some of the most extreme wind and wave energy of any region on Earth

(Komar 1997, 44). Both of these factors cause heightened erosion rates throughout the Oregon Coast. It is likely that much of the archaeological material that was once present throughout the region has already been destroyed by erosion or inundated by sea level rise (Erlandson et al. 1999).

In spite of this fact, the Oregon Coast has been relatively understudied in recent archaeological research. Much of the work currently taking place on the Pacific Coast of North America is focused on the Northwest Coast region (Alaska and British Columbia) and the California Channel Islands, which have more favorable conditions for the preservation of archaeological material (Moss & Erlandson 1995). While work in these regions is important, it has to some extent, overshadowed archaeological research on the Oregon Coast and projects focused on the region have diminished over the last decade or so. Fortunately, there is a renewed interest in the development of a comprehensive archaeological research program in the region. The Department of Anthropology at the University of Oregon recently began a research program along the southern Oregon Coast, which is intended to train students in archaeological field methods and encourage interest by various stakeholders, including researchers, tribes, and state agencies.

The University of Oregon funds and develops the Oregon Coast Project, but our department is only one of several stakeholders in this program. The Coquille Indian Tribe and the Confederated Tribes of Coos, Lower Umpqua and Siuslaw Indians have an equally vested interest in studying their cultural heritage. Federally recognized tribes in the United States oversee the management of cultural material and archaeological sites. This means that archaeological researchers must develop some level of collaboration with the tribes in their region of study. In many cases, these relationships are structured such that researchers pursue their own aims of study while interfacing with tribes in order to work together toward common aims. While some tribal governments are less receptive to archaeological work, many tribes are very amenable to pursuing specific projects and research questions, particularly in cases where answering these questions can aid in the development of a region's cultural history or when archaeological evidence might hold bearing on modern policies that affect these tribes.

This thesis was conceived as a part of the Oregon Coast Archaeology Project, and is intended to help pursue the interests of the tribes with which the project has worked. I participated in the Oregon Coast Project field school in August 2016, and returned as a volunteer and student researcher in September 2017. This fieldwork took place at Bullards Beach State Park, across the Coquille River estuary from the city of Bandon, Oregon. The archaeological sites in the area of the State Park are the focus of my thesis. In the interest of assisting management efforts by the Coquille Indian Tribe and Oregon State Parks, this thesis uses Bullards Beach State Park as a case study to investigate estuarine erosion and its impact on archaeological sites.

There are numerous archaeological site loci present throughout the park. However, because there has been relatively little research on the coast in recent decades, and because of the often-limited resources available to management agencies, the extent to which these sites have been affected by erosional processes is largely unknown. This thesis project is intended to determine historic erosion rates along the Coquille River estuary, and to assess the risk that this erosion poses to the archaeological sites within Bullards Beach State Park.

Without long-term monitoring, it is impossible to determine the exact rate at which erosion is taking place at Bullards Beach. However, it may be possible to estimate past erosional activity in a relatively short amount of time by using historical aerial imagery data. By mapping and comparing this imagery in ArcGIS, we can begin to assess what areas of the park have been most impacted by natural and anthropogenic erosional processes over recent decades. Combined with the results of 2016 and 2017 archaeological survey at Bullards Beach, this imagery data will allow for the prediction of the threat that erosion poses to archaeological sites in the future.

Predicting the future impacts of erosion on archaeological sites will improve the efficacy of management and conservation efforts at those sites. Research to account for erosional impacts will help inform the work of management agencies by allowing them to more effectively prioritize management efforts and allocate resources toward damage mitigation. These outcomes are also in the interest of academic archaeological research: improving the preservation of archaeological material will provide future researchers a larger record with which to work. Site preservation is therefore at the intersection of academic archaeology and cultural resource management, presenting an opportunity for collaboration and partnership between tribal, state, and academic stakeholders.

The application of aerial imagery mapping along the Coquille River estuary indicates that the Bullards Beach sandspit has undergone a high rate of bank erosion over the past century. This erosional activity poses dire consequences to the archaeological sites in the area, many of which will be destroyed in a matter of decades if erosion continues unchecked. By addressing the impacts of erosion on these archaeological sites, the results of this study may aid in future archaeological research and cultural resource management at Bullards Beach State Park. Furthermore, the method presented herein has the potential to be applied for rapid erosion estimation and archaeological risk assessment in other localities throughout the Oregon Coast.

Background

The Coastal Migration Theory and Archaeology on the Oregon Coast

The Oregon Coast is under-studied in contemporary archaeological research, with significantly less research taking place here than in other regions of the Pacific Coast of North America. For example, there are thousands of radiocarbon dates for archaeological material from the California Channel Islands, while there are only a few hundred for the entire Oregon Coast (Erlandson & Moss 1999; Scott M. Fitzpatrick & Nicholas P. Jew, personal communication, 2016). The Channel Islands have only a fraction of the land area, but there is a tremendous amount of information now known about their prehistory (see Glassow 2010) demonstrating that there is disproportionally more archaeological work taking place there than on the Oregon Coast.

This disparity is due in part to an emphasis on identifying and documenting archaeological sites that are the earliest remnants of paleoindian colonization of the Americas. Parts of the archaeological community are perhaps overly focused on documenting the oldest artifacts, sites, features, etc. While these types of archaeological evidence are critical for pursuing certain inquiries, particularly the development of clearer chronologies of human history, there is a tendency for this focus to overshadow archaeological work in areas where these interests may not be paramount.

For the Pacific Coast, this is evident in discourse surrounding the Coastal Migration Theory (CMT). The CMT proposes that the first humans to migrate into the Americas did so ca. 14,000 years before present (BP) following a maritime route, traveling by boat from East Asia along the shores of the Pacific Rim (Aikens et al.

2011: 219-220). This theory diverges from the traditional hypothesis of the Interior Ice-Free Corridor migration view of human population dispersal into the Americas by an overland route across Beringia land bridge from Asia and through a corridor between two large ice sheets into lower North America.

A number of key arguments have been used to support the CMT. Glaciological research has demonstrated that an overland route between the Cordilleran and Laurentide ice sheets in North America would not have been passable nor hospitable for human migration until ca. 12,600 BP (Pedersen et al. 2016). Research throughout the Americas has identified a number of archaeological sites that date to the end of the Pleistocene, pre-dating ca. 12,600 BP (Bever 2001; Dillehay et al. 2008; Dixon et al. 1997; Erlandson 2007; Erlandson et al. 1996; Erlandson et al. 2011; Jenkins et al. 2012; Mann & Hamilton 1995; Meltzer et al. 1997; Rick et al. 2013). This means that the earliest migrations into the Americas must have occurred before the opening of a hospitable ice-free corridor, and thus some alternate route must have been taken to enter lower North and South America. Paleoecological evidence suggests that near-shore kelp forest ecosystems throughout the Pacific Rim may have facilitated a coastal migration, offering continuous access to a rich diversity of marine resources along the coastline from Japan to Mexico (Erlandson et al. 2015; Erlandson et al. 2007). Given a contiguous ecosystem with a richness of familiar resources throughout the entire northern Pacific Rim, migrant human populations could have quite rapidly traveled along coastlines from Asia into the Americas, unhindered by glacial ice and requiring little technological or lifeway changes to different biomes.

In the interest of further substantiating the CMT, contemporary archaeological research throughout the Pacific Coast of North America has placed emphasis on identifying late Pleistocene coastal sites in the region. Investigations at coastal archaeological sites of this age would help support the theory of a coastal migration route and provide greater insight into the earliest cultures that inhabited North America. However, late Pleistocene sites are exceedingly rare in coastal zones, and none have been found thus far on the Oregon Coast. The observed absence of late Pleistocene archaeological material throughout the region is due to sea level change, and extreme erosional impacts on archaeological preservation.

In his 1997 book *The Pacific Northwest Coast,* Paul Komar outlines the patterning of sea level change throughout Earth's history. Komar notes that global sea level change occurs in a cycle between low and high stands that corresponds to glacier formation (1997: 14). The Quaternary period (2.58 MYA – Present) is characterized by the growth and shrinking of continental ice sheets, corresponding with fluctuation in global sea surface temperature (Denton et al. 2010). The water that formed these ice sheets came from Earth's oceans. As such, the expansion of glacial ice causes sea levels to decrease and the shrinking of glacial ice causes sea levels to increase. During the Last Glacial Maximum ca. 20,000 BP, sea level was ~400 feet (~100 m) lower than it is today (Komar 1997: 21). The subsequent melting of glacial ice caused a rapid increase in sea level, meaning the geographic area that constituted the Pacific coast during the end of the Pleistocene epoch is now between 20-30 miles (30-50 km) west of the modern shoreline, submerged under ~100 meters of seawater (Komar 1997: 24).

Accordingly, most archaeological evidence for late Pleistocene human habitation of the Pacific Coast has now been inundated (Erlandson 2008; Moss & Erlandson 1995).

The reality of coastal archaeological research throughout the world is that many early sites are likely drowned and may have been completely destroyed in certain localities. In response to this factor, archaeologists have worked to develop more efficient survey methods to help locate and document late Pleistocene archaeological sites in coastal zones. These efforts include targeted surveys based on local resource availability and interpretations of local geomorphology to identify late Pleistocene paleosols (Davis 2006; Punke & Davis 2006; Rick et al. 2013). This search has yielded three sites on the Channel Islands dating between ~12,200 and ~11,200 cal BP (Erlandson et al. 2011), though no chronological corollaries in Oregon or Washington.

The Problem of Preservation in Oregon Coast Archaeology

The dearth of late Pleistocene sites on the Oregon coast speaks to differential preservation regimes for archaeological material throughout the Pacific West Coast: fewer late Pleistocene sites have been preserved on the Oregon coast than in other areas of the Pacific Coast. This outcome is a combination of Oregon’s coastal tectonic regime, its geomorphology, and substantial wave action in the region. Given the paleogeography of the Oregon Coast, archaeological material in the region is under particular threat from the effects of wave, fluvial, and tectonic action. These factors can all cause erosion, and much of the region’s archaeological record is located in the areas that are most vulnerable to their effects.

The coastline of Oregon and Washington are situated along the Cascadia subduction zone (CSZ), the convergent plate boundary between the North American continental plate and the Juan de Fuca oceanic plate. These two tectonic plates move towards each other, colliding at an oblique angle at a rate of ~3-5 centimeters per year (Atwater 1970; Engebretson 1985; Schmalzle et al. 2014). As the two plates converge, the Juan de Fuca plate is shoved beneath the North America plate. Compressional strain builds along the CSZ until the force of the strain exceeds the force of friction between the two plates. At this point, potential energy is released from the two plates in the form of massive thrust earthquakes (Atwater et al. 1995; Clague 1997). Tectonic activity on the Oregon coast has an adverse impact on archaeological preservation in the region. As an oceanic plate subducts underneath a continental plate, the continental plate gradually undergoes lateral compressional deformation, shortening parallel to the movement of the subducting oceanic plate. This compression causes the continental crust to uplift vertically. During thrust earthquakes, the plate undergoes abrupt extension—the continental plate extends laterally and subsides downward as strain is released from the plate (Punke & Davis 2016).

This tectonic action is often accompanied by massive ocean waves called tsunamis. Subsidence events cause massive amount of water to be rapidly displaced as the continental and oceanic plates undergo abrupt movement—this displacement manifests in the form of tsunami waves, which transfer massive amounts of energy to coastlines and deposit sediments on the shores when they break. Tsunamis can cause archaeological sites to become destroyed, buried, or inundated (Hall 1999). Along the CSZ, thrust earthquakes and major tsunami events occur about once every 400-600 years (Atwater et al. 1995; Clague 1997). This has likely caused the destruction of thousands of archaeological sites throughout the coastlines of Oregon and Washington.

Wave action poses an additional threat to Oregon coast archaeological sites. Waves can be considered as a vector for the transfer of kinetic energy: irregularities on the ocean surface obtain energy from the wind, creating waves that carry that energy across the ocean until they break, delivering that energy to the coastline (Komar 1997, 42). The resulting energy transfer contributes to the erosion of coastal landforms.

Wave energy on the Oregon coast is higher than anywhere else on the Pacific seaboard. Using seismometers and National Oceanic and Atmospheric Administration (NOAA) data buoys, researchers have assessed the extent of wave energy on the Oregon coast. Breaker wave heights were measured from 1981 until at least 1997, and averaged to demonstrate monthly variation in wave heights. Average summer waves reach a height of ~2 meters, while average winter waves reach a height of ~3.5 meters (Komar 1997: 43-44). However, maximum wave heights deviate significantly from this average. Winter storm conditions can cause average wave heights to reach ~10 meters, with individual waves reaching as high as 20-30 meters (Komar 1997: 44). These are among the most extreme wave conditions anywhere in the world.

The Oregon Coast is characterized by short stretches of sandy beach punctuated by mountainous headlands. Many of these beaches host estuaries where rivers meet the Pacific (Komar 1997: 1-3). These estuaries were optimal locations for paleoindian settlement on the Oregon Coast. Estuaries serve as the confluence of large riverine watersheds, and they are zones where riverine freshwater mixes with marine saltwater. This means that estuaries are host to a high diversity and density of nutrients, creating habitat for a wide variety of plant and animal species with substantial biotic activity. The headlands along the Oregon Coast shelter the lowland beaches and estuaries from the more extreme wave and storm conditions. Furthermore, the rivers themselves offer transportation and access to resources in the interior. These factors all make Oregon's estuaries favorable areas for human settlement. This is reflected in linguistic geography and settlement patterning among the Oregon coast's native peoples—permanent settlements were established on estuaries and watersheds, and language communities were aligned with the rivers throughout the Coast Mountain Range (Aikens et al. 2011: 212-217; Cressman 1952).

Unfortunately, this settlement patterning means that the areas with the richest archaeological material on the Oregon Coast are also the areas most threatened by erosion. Because hydraulic action affects unconsolidated sediments more severely than solid rock, beaches and estuaries are more heavily impacted by tidal and wave erosion than headlands. Additionally, rivers meander and change shape over time as banks are eroded. As such, these and other factors can have deleterious effects on the preservation of archaeological sites along beaches and estuaries. The extreme erosional regime on the Oregon coast—combined with the patterning of native settlements along resource-rich estuary environments—has likely contributed to the apparent dearth of late Pleistocene archaeological sites, and has negatively impacted the entire archaeological record in the region.

Making a Case for Oregon Coast Archaeology

Unfavorable preservation conditions have contributed to a lack of investment in archaeological research on the Oregon Coast. While efforts to find late Pleistocene archaeological sites in the region have thus far been fruitless, there are many other coastal sites throughout Oregon. While these sites are relatively young, and while they may not be of significance to the discourse of the Coastal Migration Theory, they are still inherently valuable as cultural resources, and should be treated with the same degree of consideration and scrutiny as any other archaeological material. What follows is an explanation of the importance of these archaeological materials, and a case for developing a more holistic archaeological research program throughout the region.

In archaeology, the interests of Native American tribal organizations must be considered. Archaeological materials throughout the Americas belong to the heritage of modern indigenous peoples. Tribal governments have the right to determine how their heritage is managed, and thus cultural resource management must be carried out in collaboration with these groups. Archaeologists can work with tribal historic preservation offices (THPOs) to pursue common goals. Extensive correspondence and partnership would allow for these groups to pool resources and develop comprehensive research and management programs. This degree of partnership would allow academic and tribal organizations to make archaeology a more collaborative, community-oriented field.

The Oregon Coast presents an opportunity for the development of a thriving archaeological research and management program. The Coquille Indian Tribe and the Confederated Tribes of the Coos, Lower Umpqua, and Siuslaw Indians have a vested interest in pursuing archaeological research in the region. Partnering with these tribes, the Oregon Coast Archaeology Project intends to begin developing such a program.

The extreme erosional regime in the region should serve as cause for more investment on the part of archaeological research, not less. Archaeological material is a non-renewable resource. Regardless of a site's ascribed value, it is a constituent to a larger archaeological record. In order to develop a holistic reconstruction of the past, archaeologists must account for the entire archaeological record. Therefore, archaeological sites threatened with destruction by erosional processes and climate change should be considered endangered resources. These sites require urgent attention in order to protect the cultural material they contain, and should be treated as the first priority for archaeological investigation.

In regions with unfavorable preservation conditions, threatened sites may not be of immediate interest to archaeological research. However, sites of this nature present archaeologists with an opportunity to develop more efficient methods for conservation and management. Researching the deleterious effects of erosional processes on archaeological material will allow management agencies to better prescribe and apply conservation efforts at threatened sites. As such, these efforts would improve the ability of archaeologists to account for all extant archaeological material.

For these reasons, it is necessary that archaeological research be pursued throughout the Oregon Coast. By developing a research program focused on improving methods of archaeological resource management, we can work with tribal and governmental agencies to better investigate and preserve the region’s archaeological record. A major first step in such a program is to develop an expedient means for assessing erosion risks for archaeological sites in and around Oregon’s estuaries.

Methodology

2016 Pedestrian Survey of Bullards Beach

Pedestrian survey of archaeological sites was performed at Bullards Beach State Park in August 2016. This survey had two goals: to locate and assess Running Fox Midden (35-CS-131), an archaeological site identified over two decades earlier in a previous survey (Erlandson & Moss 1994), and to identify and assess other archaeological sites and/or isolates on the Bullards Beach sandspit. The survey was carried out in east-west transects beginning at the south end of the sandspit and moving north. Global Positioning System (GPS) data points were recorded for site loci, including shell midden material, isolated artifacts found on the surface, and notable features of site destruction, such as fluvial erosion and looters pits.

Drs. Jon Erlandson and Madonna Moss first reported site 35-CS-131 in a 1994 survey of the Oregon coast. By comparing their site report with data collected in the 2016 survey, it was observed that site 35-CS-131 has significantly degraded in the two decades since the 1994 survey. The density of vegetation in the survey area complicated site relocation, and a portion of site 35-CS-131 appeared to have been overgrown by shore pine and other low shrubbery. In addition to this overgrowth, the sand dunes that constitute the site area have been heavily impacted and deflated by erosion, and there was a dearth of cultural material present. Only a small quantity of shell and bone was visible on the surface of the site. These observations contradict the 1994 report for the site, which refers to rich shell midden material, animal bones, chipped stone debris, and a corner-notched projectile point on the site's surface (Moss & Erlandson 1994).

Additional site loci were identified north of the Running Fox locus, dotting the length of the river bank on the east side of the sand spit. These sites consisted of shell midden and small scatters of lithic material. Given the limitations of surface survey, visibility was hampered by vegetation, and it was impossible to accurately assess the extent of the site area for any individual locus. Rough estimates of site boundaries were made based on observation of areas with relatively minimal vegetation.

Site deposits were observed in a low bluff at the bank of the Coquille River, and there were clear signs of tidal and riverine erosion along the eastern edges of these sites. At each site locus, we observed shell midden material eroding from the embankment. The sites appear to be unaffected by the estuary at low tide. However, high tides and storm surges cause the water to reach the embankment, heightening the erosional impact of the estuary on archaeological sites. In addition to erosional activity, we observed as many as eight separate looters' pits, likely created by people hunting for projectile points or other such stone artifacts. These pits were reported to Kassandra Rippee and Mollie Manion, the Historic Preservation Officer for the Coquille tribe and the coastal archaeologist for Oregon State Parks, respectively.

2017 Sub-Surface Testing at Gaper Midden

Among the sites observed in the 2016 survey, Gaper Midden (35-CS-220) was the most extensive. 35-CS-220 is a shell midden site located in the embankment at the northwest corner of the Bullards Beach sandspit. This site was recorded in a 2004 survey carried out by archaeologists from the University of Oregon's Museum of Natural and Cultural History (Tasa et al. 2004). Data presented in the site report aligned with observations made in the 2016 survey, and we confirmed with the Oregon State

Historic Preservation Office that we had located site 35-CS-220. The authors of the report named this site “Gaper Midden” because they observed a high proportion of gaper clam remains on the site’s surface (Tasa et al. 2004). Being the largest shell midden locality identified in the 2016 survey and with evidence of looting and erosion, site 35-CS-220 was chosen as the next step for the Oregon Coast Archaeology Project and permits were obtained for excavation at the site during the 2017 field season.

Test excavations took place at Gaper Midden in September 2017. Field school students under the direction of Drs. Scott Fitzpatrick and Nicholas Jew provided assistance in excavation and processing of material from the site. Permits allowed for the excavation of up to twenty 50 × 50 cm shovel test pits and five 1 × 1 m test units. This allotment was used to establish a sense of scale for the site. Four shovel test pits were dug along a north-south baseline. From this point, it was possible to estimate where the center of the midden was located based on the quantity of material observed in each test pit. An east-west baseline was put in across this portion of the site, and additional test pits placed along it to the west and east of the north-south baseline.

Consistent with the initial survey report for 35-CS-220, the majority of the shell midden material present was gaper clam (*Tresus capax*) remains. Many of these shell valves were still articulated with their opposite valves, and some shells were observed to have barnacle shells grown onto their interior. These are unusual qualities for cultural shell midden material because they are indicative of clams that died while still underwater. Furthermore, the homogeneity of the material is not typical of shell midden material from other Oregon Coast sites. Compared to shell midden material housed at the Coquille THPO, the proportion of gaper clams is unusually high. These observations gave us doubts as to whether or not the site was a pre-contact shell midden, and it was proposed by the Coquille THPO that the site might be a deposit of modern dredge spoils. However, we found two small stone projectile points and a small amount of lithic debitage in one of our test pits near the center of the site.

Three shell samples from 35-CS-220 were submitted for radiocarbon dating, along with two charcoal samples from above and below the strata from which the shell samples were collected. The shell samples returned dates 3440-2770 calibrated years BP (cal BP); one of the charcoal dates failed, but the other returned 3330-3000 cal BP (Table 1). These results indicate that Gaper Midden is likely a pre-contact shell midden. Furthermore, it is relatively old compared to other shell midden sites throughout the region. In an assessment of radiocarbon results from archaeological sites on the Oregon Coast, it has been observed that as few as 15% of known sites in the region predate 1,500 BP (Erlandson & Moss 1999). Regardless of its age, this site could serve as an ideal proxy for investigating the effects of erosion on a shell-bearing site in the area.

Overall, the data obtained during the 2016 and 2017 field seasons demonstrates a need for further archaeological research and conservation programs at Bullards Beach State Park. There are multiple site loci succumbing to the effects of erosion in the area of the Coquille River estuary, among them at least one site dating to ca. 3000 BP. To ensure the maximum efficacy of future archaeological work at Bullards Beach, it is necessary for erosional processes to be accounted for in the area.

Sample ID	Sample type	Depth (cm)	Fraction of modern		Radiocarbon age		cal BP
			pMC	**1σ Error**	**BP**	**1σ Error**	**95.4% 2σ**
35CS220-TP4-4-001	Charcoal	30-40	68.97	0.33	2984	38	3330-3000
35CS220-TP4-5-002	Shell	40-50	68.86	0.40	2997	47	3340-3000
35CS220-TP4-9-004	Shell	80-90	67.73	0.24	3130	28	3440-3250
35CS220-TP4-10-005	Shell	90-100	71.10	0.24	2740	27	2900-2770

Table 1: Gaper Midden Test Pit 4 ^{14}C dates, calibrated using OxCal 4.3

Aerial Photography and Georeferencing

By collating a series of aerial images from different dates for the same location, a chronology of the landscape can be created and observed. This type of data set allows for the assessment of geographical information relative to time. If the photos are organized in chronological order by date, consecutive images can be compared to one another, and inferences about the history of that landscape can be made. Using a geographic information system (GIS) allows us to take this concept further. Aerial images can be aligned precisely with a reference map, and measurements can be made between them to assess quantifiable geospatial data. These ideas are applied to the Bullards Beach case as a means of assessing the extent of erosion that has taken place in recent decades.

Aerial and satellite imagery were compiled for Bullards Beach State Park in order to create a series of chronological maps. Historical aerial photos of the Bullards Beach sandspit were retrieved from the University of Oregon Map & Aerial Photography Library. These photos were taken on flights carried out by various government agencies, including the Bureau of Land Management, the Army Corps of Engineers, the U.S. Geological Survey, and the U.S. Department of Agriculture. Historical imagery was obtained from 1939, 1942, 1954, 1967, 1978, 1986, and 1997 (Appendix, Fig. A1-A7). To achieve coverage between 1997 and the present, satellite imagery from 2007 was retrieved using Google Earth (Appendix, Fig. A8). Satellite imagery from 2016 was retrieved from ArcGIS World Imagery data, and is the most recent among available aerial imagery data for Bullards Beach (Appendix Fig. A9).

Historical photos were scanned to high-resolution JPEG files, and prepared in Adobe Photoshop CC 19.1.0 for use in ArcGIS. For sets of photos that divided Bullards Beach into multiple prints, JPEG images were stitched using the “Auto-Align” and “Auto-Blend” tools in Photoshop. This procedure was also applied to the 2007 Google Earth imagery in order to achieve the highest possible image resolution. For each year listed above, this procedure provided a single high-resolution aerial image covering the entire area of the Bullards Beach sandspit.

In order to accurately map data layers in the ArcMap program, they must be overlaid on one another such that the geospatial locations depicted in each data layer align to their actual location on the surface of the earth. To achieve this, corresponding spatial reference-points must be identified on the data layer and on a coordinate map of the earth’s surface, and then these points must be aligned with one another. The process of registering and aligning corresponding geographical data is referred to as georeferencing (Gillings & Wheatley 2005: 377).

Georeferencing for data layers that include known geographic coordinates is done by aligning the coordinates on those layers to matching coordinates on a base map. However, for layers without known geographic coordinates, georeferencing is less straightforward. Corresponding geospatial features must be identified in the data layer and on the base map to serve as reference points. For aerial and satellite imagery, georeferencing can be achieved by identifying and linking landmarks that are visible in both the imagery layer and an imagery base map.

Accurate georeferencing can be accomplished in ArcMap using one reference point in each corner of an image layer, and a handful of additional reference points throughout the middle of the layer (Esri 2017). A minimum of three points is required to scale and align a layer using a first order polynomial transformation in ArcGIS. Additional points introduce residuals, distances by which the reference points are offset because they cannot be perfectly aligned with corresponding points on the base map without causing distortion to the layer being georeferenced. A statistical measure of the error produced by this offset is represented by the root mean square error (RMS error) of all residuals present in a set of georeference points. In general, having an RMS error closer to zero indicates more accurate georeferencing for a layer. However, because of the potential for user error in identifying accurate control points, it is best to identify more than three points and to adjust which points are used to achieve the lowest possible RMS error.

Additionally, it may be necessary to apply a second order polynomial transformation to a layer to achieve accurate georeferencing when using aerial imagery. This type of transformation accounts for curvature on the earth's surface by creating slight curvature in the image layer, instead of simply scaling and rotating the image on a two-dimensional plane. This type of transformation allows for more reference points to be used with a lower RMS error, thus achieving a more accurate map projection for the image layer.

Aerial imagery data layers for Bullards Beach were georeferenced using visible landmarks as reference points. Around 15 landmarks were identified for each imagery layer and then linked to corresponding locations on the base map. A second order polynomial transformation was applied to each layer and reference points were adjusted until 10-12 points were linked with an RMS error of 5 or lower. RMS error was recorded for consideration during data analysis.

Shoreline Mapping and Offset Measurements in ArcMap

To assess the extent of erosion through time at Bullards Beach, it was necessary to create measureable features in ArcMap to represent the location of the bank cut in each image layer. Line segment features in ArcMap consist of a line of specified length and direction, with a vertex point at each end. It is possible to connect these lines at their vertices to create contiguous polylines. For each layer, polyline features were drawn in 20 m segments, corresponding to the observed location of the Coquille River's west bank cut. These features include the extent between the northernmost point of the river bank within the area of Bullards Beach State Park, and the point where the bank cut was observed to intersect with the river's north jetty.

The "Near" tool in ArcMap was used to measure distances between line features for consecutive imagery layers. For each pair of chronologically adjacent polylines (1939-1942, 1942-1954, 1954-1967, etc.), distance was measured between each vertex on each line and the closest point on the opposite line. This process created two tables of distance measurements for each pair of lines (i.e., one table with distances between vertices on Line A and their nearest points on Line B, and one table with distances between vertices on Line B and their nearest points on Line A). The values returned were averaged to obtain the average offset distance between each line and each chronologically adjacent line. Averages serve as a measure of the average distance of erosional or depositional offset that occurred between each year represented in the imagery dataset. To assess net offset for the entire chronology, this method was also applied to the 1939 and 2016 bank cut polylines.

Because this method does not provide direction between measured points, average offset values cannot differentiate between erosional and depositional change. Average offset values provide a useful measure of the amount of landscape change that has taken place through time at Bullards Beach, but they alone cannot provide actionable information about the erosion in the area. That being said, distances can be measured with relative ease to assess erosion or deposition for smaller areas within the study area. Distances can be measured between any two points on the bank cut polyline features using the "Measure" tool in ArcMap. By measuring distance between nearest points on defined stretches of each line feature and then dividing that distance by the number of years covered between all lines measured, rates of erosion in m/year can be derived for specific sites in the study area. This method was applied to assess erosion rates in areas with consistent observable erosional action throughout the chronology of aerial imagery data for Bullards Beach.

Using data collected during the 2016 and 2017 field seasons at Bullards Beach, the locations of archaeological sites and surface isolates throughout the study area were mapped. Operating under the assumption that erosion rates will continue at the rates observed throughout the historical imagery dataset, it is possible to estimate the amount of time a given archaeological site has before it is destroyed by erosional processes. This is done by measuring the distance between a given site and the nearest point on the 2016 bank cut polyline, and dividing that distance by the rate of erosion observed for the given river bank locality. This was applied to assess risk to archaeological sites throughout Bullards Beach.

Accounting for Error

The method for erosion mapping presented herein is limited by the content and quality of available imagery data. Photographic prints are only capable of depicting detail at the magnification of the original photograph. Scanning these prints into digital images allows them to be manipulated, magnified, and inspected in greater detail than is possible by simply observing the print. However, magnifying a scanned photo does not improve its resolution. At a certain level of magnification, the pixels that compose a digital image obscure the details of its content. Because this limits the ability of the user to identify geographic features in an aerial image, it increases the likelihood of human error when georeferencing the image in question, and when mapping the location of the bank cut in each image. To account for this error, measurements were taken in meters for the pixel width in each imagery layer. These values were added to the RMS error for the corresponding image to achieve a measure of error for the positioning of each aerial imagery layer and its associated polyline feature.

Analysis

Erosional/Depositional Offset at Bullards Beach State Park, 1939-2016

Measurements of the distance between vertices and nearest points on the line features for each bank cut yielded between 621 and 732 values for each pair of consecutive imagery dates. The mean of each set of measurements represents the average distance between the observed position of the bank cut in a given imagery layer and the position of the bank cut in the next imagery layer in the chronology. Annual erosional/depositional offset rates were derived in m/year by dividing each average offset value by the number of years accounted for in each pair of aerial photographs (Table 2).

Imagery Dates	Number of measurements	Average Offset (m)	Timespan (years)	Offset Rate (m/year)
1939-1942	630	16.77	3	5.59
1942-1954	621	39.54	12	3.29
1954-1967	629	25.66	13	1.97
1967-1978	688	38.91	11	3.54
1978-1986	722	19.26	8	2.41
1986-1997	714	16.77	11	1.52
1997-2007	724	16.89	10	1.69
2007-2016	732	6.34	9	0.7
1939-2016	688	110.93	77	1.44

Table 2: Erosional/depositional offset between Coquille River estuary bank cut positions observed in aerial imagery data, 1939-2016.

The highest rate of offset occurred between 1939 and 1942 at 5.59 m/year, more than three times the average offset rate for the entire dataset. Because this rate only represents a 3-year timespan, it appears to be subject to bias from a small sample size. This bias may be the result of a particularly severe storm season, or some other erosional event; further historical research is necessary to assess this possibility. However, the 1942 imagery has the lowest resolution among aerial images in the dataset, presenting a heightened probability of human error in georeferencing and observations of the bank cut. Additionally, the 1939 and 1942 imagery layers have a relatively high RMS error in their georeferencing (Table 3). These factors are both likely to have some level of impact on the accuracy of the derived rate of offset.

Imagery Date	**RMS Error**	**Pixel width (m)**	**Total Error**
1939	4.88	0.79	5.67
1942	3.95	3.16	7.11
1954	4.58	2.41	6.99
1967	4.1	2.46	6.56
1978	1.35	2.66	4.01
1986	2.53	1.5	4.03
1997	2.32	1.47	3.79
2007	2.56	1.21	3.77

Table 3: Error measurements for georeferencing and imagery pixel width.

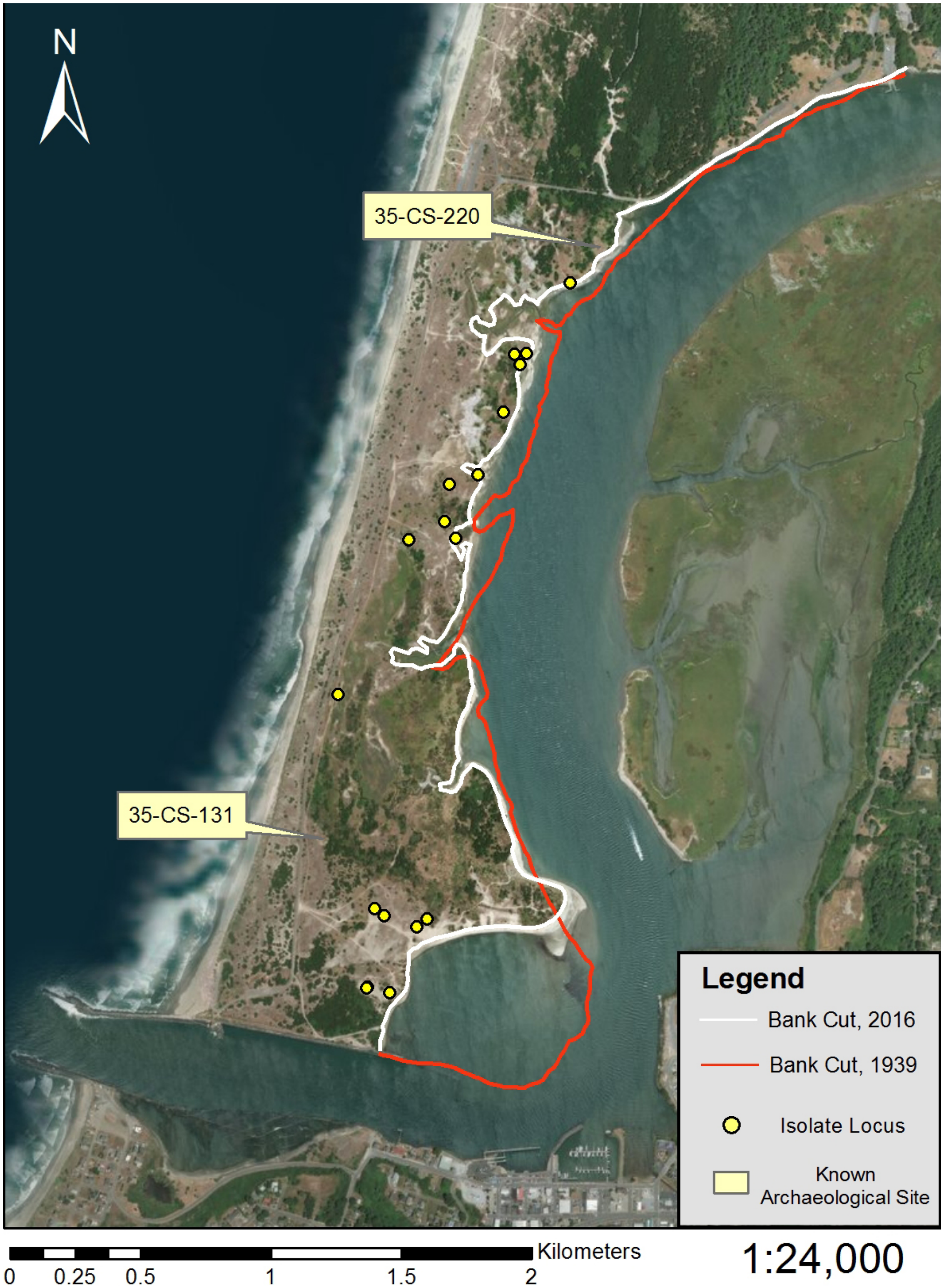
The lowest rate of offset occurred between 2007 and 2016 at 0.7 m/year. This value represents a 10-year timespan, with high-resolution imagery and relatively low georeferencing RMS error. This coincides with a general decrease in the offset rate through time from 1967 to 2016. This may indicate that there are natural variables that have caused the rate of erosional/depositional offset to decrease throughout the study area.

The net average offset for the entire 1939-2016 chronology is 110.93 m (Figure 1). This result yields an average annual offset rate of 1.44 m/year, indicating a highly dynamic erosion regime throughout the past century.

Localized Erosion Rates

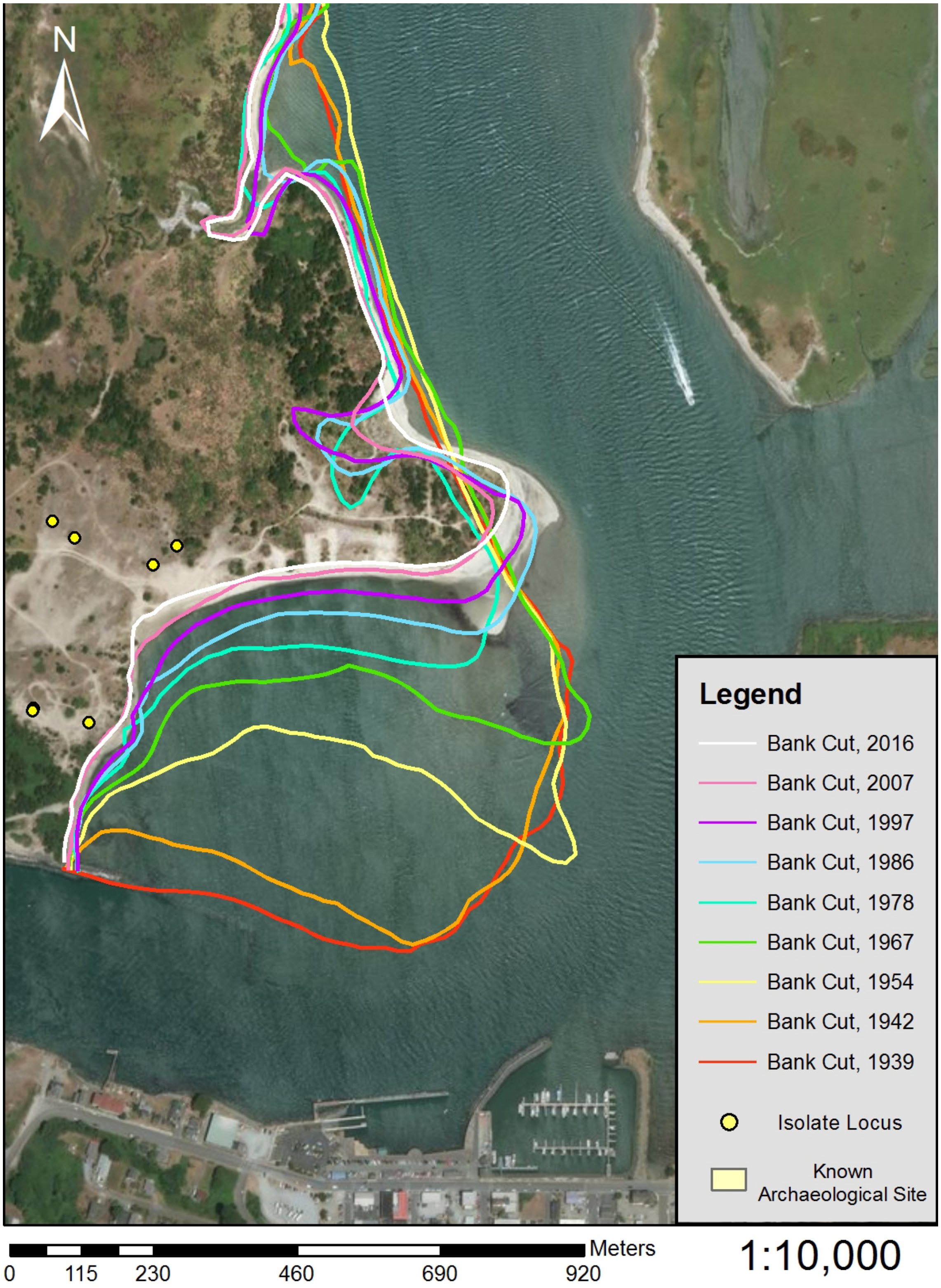
The area with the most extreme rate of bank offset is located at the southeast corner of the Bullards Beach sandspit, along a 1 km long stretch of the bank (Figure 2). Erosion measurements for this area yielded nearest distances reaching as high as 600 m between the 1939 and 2016 bank cut features. The average erosional offset for this extent is 273.93 m between 1939 and 2016. Based on this figure, erosion has occurred in this area at a rate of 3.56 m/year. A measure of the area constrained by the 1939 and 2016 bank cut features indicates that ~380,000 m^2 of land has been lost to erosion at this locality. If erosion persists at this rate, archaeological material observed in the area will be destroyed within ~20 years. The isolate loci closest to the shoreline in the area could be destroyed in as few as 10 years.

Another area with high erosion rates was observed ~1.8 km north of the jetty (Figure 3). The bank in this area is observed to consistently recede between each pair of consecutive imagery layers. At this locality, nearest-point measurements yield as much as 200 meters of offset between 1939 and 2016, with an average of 111.05 m of offset. This yields an erosional offset rate of 1.44 m/year. It is estimated that ~40,500 m^2 of land area has been lost at this locality. The 2016 survey identified archaeological materials along the bank cut in this area, and further inland within ~50 m of the bank. At an erosion rate of 1.44 m/year, these site loci face destruction within ~30 years.



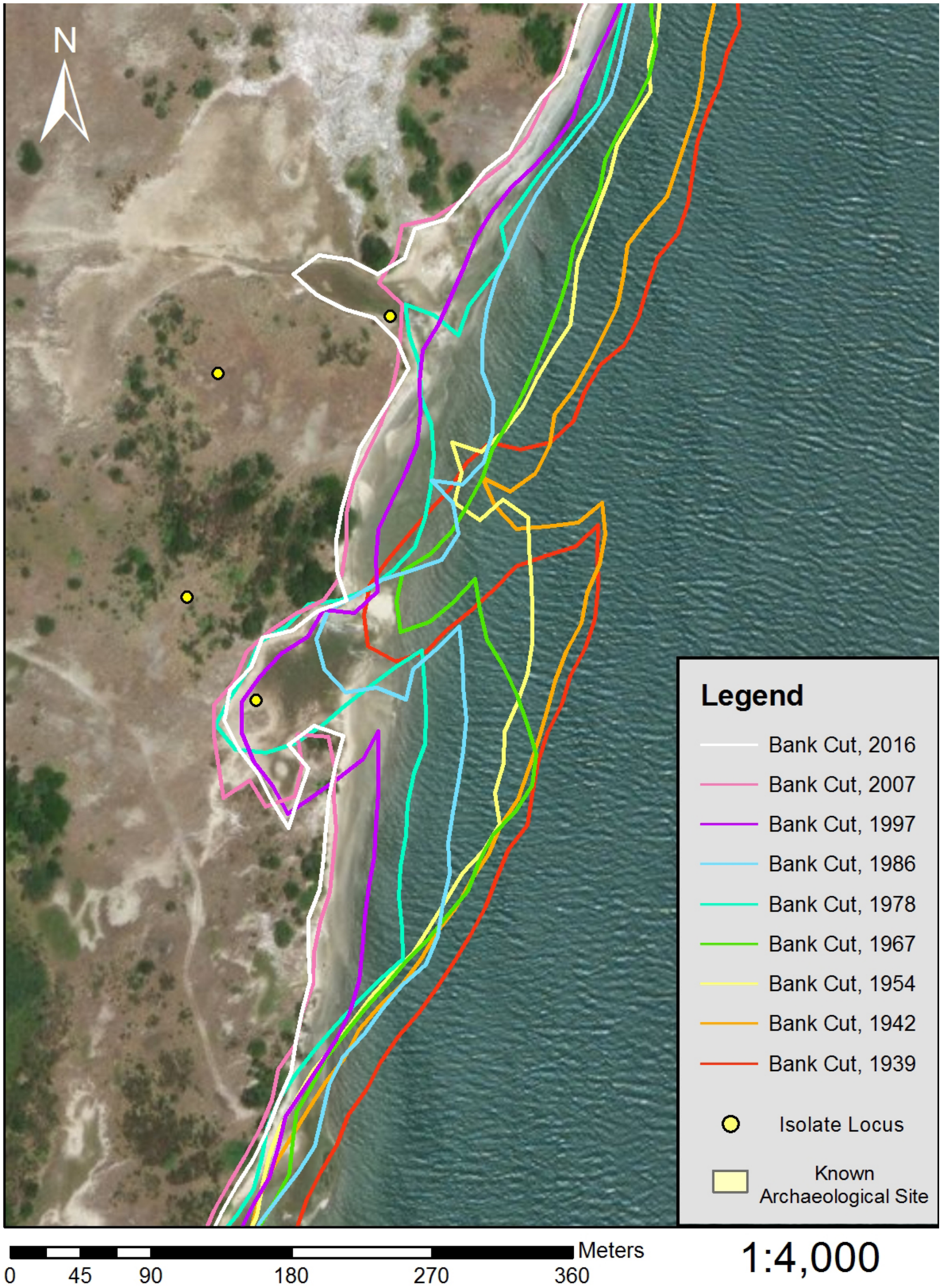
Service Layer Credits: Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

Figure 1: Erosional offset of river bank, Bullards Beach State, 1939-2016.



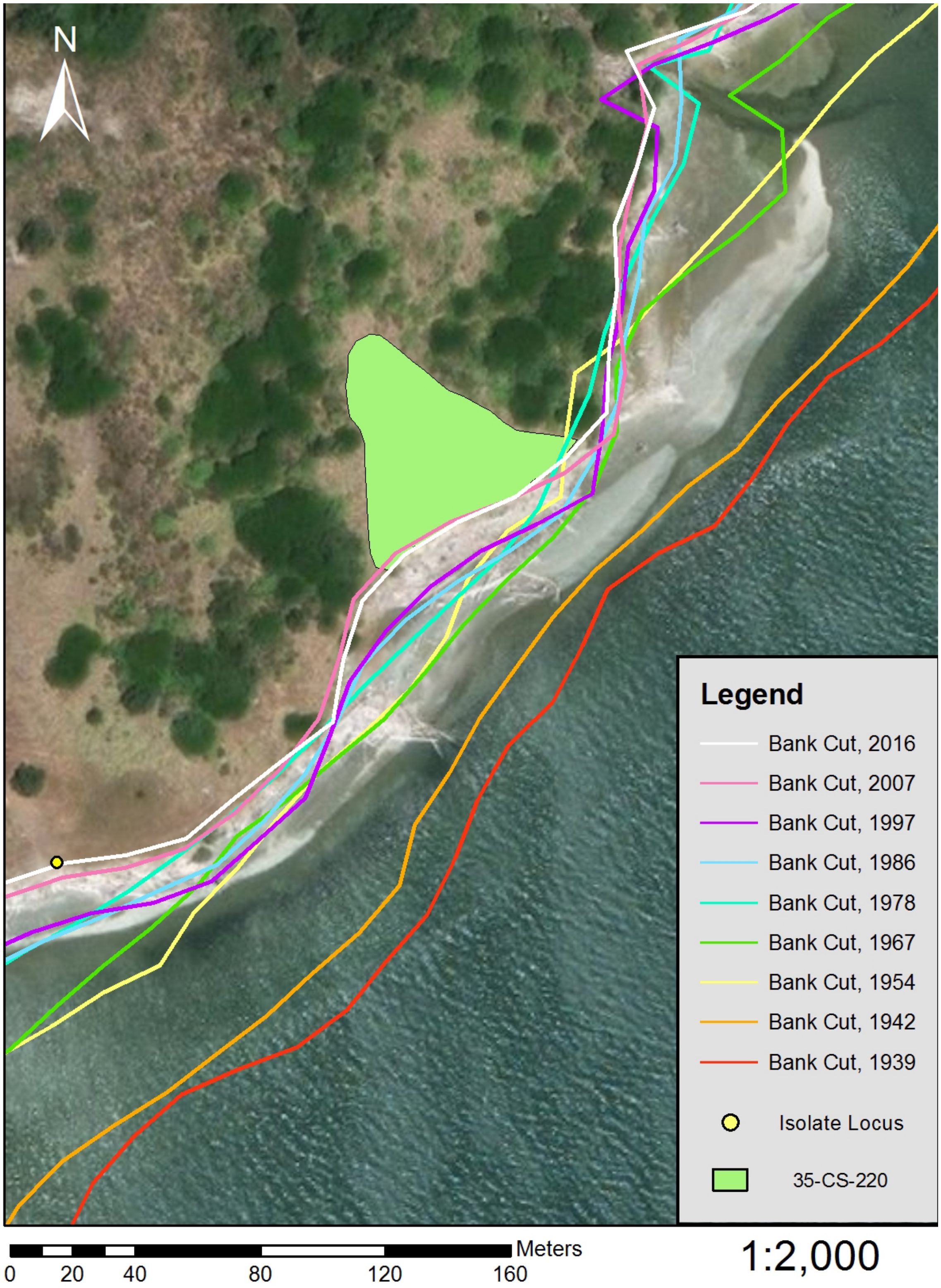
Service Layer Credits: Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

Figure 2: Erosional offset at the south end of Bullards Beach State Park, 1939-2016.



Service Layer Credits: Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

Figure 3: Erosional offset 1.8 km north of jetty, Bullards Beach State Park, 1939-2016.



Service Layer Credits: Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

Figure 4: Erosional offset at Gaper Midden, Bullards Beach State Park, 1939-2016.

At site 35-CS-220, the net bank offset is 52.45 m between 1939 and 2016, returning an annual erosion rate of 0.68 m/year. In our 2016 survey, we identified a midden lens ~25 cm thick eroding from the bank at this locality. The observed site area stretches inland ~65 m from the riverbank (Figure 4). If erosion continues at 0.68 m/year, the site would be destroyed in ~100 years and undergo severe deterioration over the next two decades: by 2040, as much as ~45% of the site's observed area may be destroyed. By multiplying this area by thickness of the midden lens eroding from the bank, it is estimated that ~300 m^3 of shell midden material will be lost.

Discussion

Erosion and Risk to Archaeological Sites at Bullards Beach

As my research suggests, erosion at Bullards Beach State Park has occurred at an alarming rate in recent decades. Since 1939, the west bank of the Coquille River estuary has been offset by as much as 110.93 m, returning an average bank erosion rate of 1.44 m/year. Localized erosion rates throughout the park are as high as 3.56 m/year. These rates are of dire consequence for archaeological preservation at Bullards Beach.

If erosion rates continue at the modeled pace, site loci at the southern end of the park are the most threatened. Archaeological material throughout the area faces immediate threats from bank erosion, and certain site loci throughout the area may be destroyed within 20 years. However, our surveys have only observed isolated archaeological materials in this area. Subsurface surveys would be necessary to achieve more precise estimates of how much material might eventually be lost.

Based on investigations at site 35-CS-220, archaeological material faces immediate threat from erosional degradation. Urgent efforts are necessary to investigate the site and/or to protect it from further damage due to erosion. It is likely that a significant portion of the site's original area and archaeological constituents have already been destroyed.

However, it is possible that erosion at Bullards Beach could be slowing. Erosional offset rates have consistently decreased since 1978. One potential reason for this is the spread of vegetation throughout Bullards Beach that acts as a stabilizer of the loose, sandy soils. Observation of aerial imagery throughout the dataset demonstrates a significant increase in vegetation throughout the area between 1997 and 2007, and a further increase between 2007 and 2016. It is possible that this expansion of vegetation has helped dune stabilization and alleviate erosion in the site area due to more widespread vegetation.

Methodological Viability

Given the constraints of aerial imagery as a dataset, it is impossible to achieve a high resolution reconstruction of erosion history using this method. However, it does allow for a viable means of quickly estimating historic erosion rates for a given study area and projecting trends into the near future. The results obtained provide baseline data for archaeological risk assessment and for informing heritage management efforts to take mitigation measures.

A major limitation in applying this method is its dependence upon the resolution of available aerial imagery data. Georeferencing and the production of accurate line features depend upon human observation of aerial imagery data. As such, the quality of aerial imagery data used has bearing on the accuracy of the results: the lower the quality of imagery used, the lower the expected accuracy of data collected.

A further hindrance is posed by potential limitations to the availability of aerial imagery data. Assuming that georeferencing and observation of aerial images are carried out with accuracy, the resolution of erosion data obtained should increase if more years are represented in the aerial imagery dataset. It may be possible to obtain a higher-resolution erosion chronology for Bullards Beach if additional spatial imagery were obtained that was different than what was available in the University of Oregon's Map & Aerial Photography Library.

It is important to note that the resolution, abundance, and quality of aerial imagery will vary between regions. The level of modeled accuracy and reconstruction of historical erosion rates is highly dependent on the available data and should include at least one year from each decade under study.

With these variables in mind, this method has a number of advantages that must be considered. While it cannot provide a high-resolution erosion history, aerial imagery mapping allows for a baseline and expedient risk assessment for archaeological sites. Measuring erosion as it occurs requires years of consistent monitoring, whereas this approach can produce actionable results in a matter of weeks.

Aerial imagery mapping has potential applications for archaeological risk assessment in other areas. Aerial imagery archives provide an expansive dataset, and some degree of aerial imagery data exists for most public land. The University of Oregon Map & Aerial Photography Library houses imagery from throughout Oregon, with relatively complete coverage for most cities, national forests, and BLM districts throughout the state (University of Oregon Libraries 2018). This method of erosion measurement could be thus applied in other estuaries and littoral cells on the Oregon Coast, and at localities throughout the entire state.

By accounting for historical erosion in a scale of decades, aerial imagery data allows for inferences beyond a mere measurement of the erosion that has taken place. For example, it was possible to make observations about the change in erosion rates through time at Bullards Beach, and to explore vegetation expansion as a possible cause for this change. This demonstrates that historical aerial imagery can be applied to achieve a more thorough understanding of long-term erosion in estuaries.

The greatest advantage of this method is that the erosion data it produces can be easily shared. State and tribal historic preservation offices throughout the United States typically maintain an ArcGIS database of the archaeological sites within their management jurisdiction. As such, erosion data plotted in ArcMap can be readily shared with state and tribal stakeholders. If maps were created in a shared database, it would be possible for continuous collaboration between stakeholders to create and refine an erosion chronology for a given study area.

Significance

Because of the deleterious effects of erosional processes on site preservation, it is necessary for archaeological research to take erosion into account. This is particularly true for coastal regions, where human activity, wave and wind energy contribute to a heightened erosional regime and where sea level rise threatens to inundate archaeological material. If erosion risks can be easily predicted for archaeological sites, then conservation efforts can be carried out with greater efficiency. By using aerial imagery data to predict erosional impacts on shoreline-adjacent sites, this approach can inform the targeting and implementation of archaeological preservation and damage mitigation efforts.

For academic archaeology, accounting for erosion risks stands to make research designs more effective for field studies. The method outlined in this thesis requires relatively minimal time expenditure. Therefore, it can be carried out in advance of a long-term field project to obtain actionable predictions of erosion impacts at archaeological sites. With this information, researchers could make better-informed decisions about which archaeological sites to investigate. Specifically, this approach would allow researchers to prioritize excavation efforts at sites that face the most immediate threat of destruction from erosional processes.

While the sites that are most threatened by erosion will not necessarily be the richest or most extensive sites within a given study area, it is imperative that those sites are still investigated and reported. In order to achieve an accurate reconstruction of the human past, we must work to protect and conserve as much archaeological evidence as possible. Therefore, it is necessary to prioritize research at archaeological sites that are threatened by the deleterious effects of natural and artificial processes, regardless of the ascribed value of material at those sites. Therefore, accounting for the effects of processes like erosion will improve the efficacy of archaeological research. The most important goal that archaeology can pursue as a field of study is the preservation of archaeological material. Doing so will provide future researchers with a more complete archaeological record, and thus will expand the body of knowledge that archaeology stands to produce.

Future Research

Further research is necessary to develop and improve different methods for resource management in archaeology. Working to develop methods for accurate and expedient risk assessment will improve the efficiency of damage mitigation and ultimately increase the amount of archaeological material that is preserved for future study. The following section explores these topics, and discusses avenues for future archaeological research at Bullards Beach State Park.

The accuracy of this method stands to be improved with further research and experimentation, both at Bullards Beach State Park and in other areas throughout the

Oregon Coast. Creating chronological maps with a greater number of aerial images will likely improve the resolution of the erosion data produced. Furthermore, this thesis assesses risk to archaeological sites under the assumption that erosion will continue at the rate observed throughout the chronology produced. As discussed previously, it is possible that erosion rates at Bullards Beach have slowed down over time. By incorporating research on river dynamics, future research could improve the accuracy of predictions made using aerial imagery data.

It may be possible to achieve high-resolution erosion mapping by using aerial imagery data from a short span of recent years. This could produce results that have more direct bearing on future erosion rates, and as such could inform more accurate risk assessment for archaeological sites. Finally, as satellite and drone imagery become more accessible, the ability to produce high-resolution aerial image chronologies of this kind will only improve. With further development, aerial imagery mapping could become a reliable tool for erosion measurement and archaeological risk assessment in littoral zones throughout the Oregon Coast.

Efforts to prioritize management and research efforts must also begin to account for future sea level rise and its bearings on archaeological preservation. As sea level rise continues, archaeological researchers will have to account for shoreline erosion in study areas that do not currently face any threat from erosional activity. By working to improve methods for shoreline archaeological conservation, archaeologists can begin to account for sea level rise before it becomes a threat to archaeological sites at higher elevations.

In areas like the Coquille River estuary, rising sea level threatens to inundate massive areas of land within a relatively short period of time (Thieler & Hammar-Klose 2000). It may be necessary to pursue widespread archaeological excavations in order to collect and successfully preserve the archaeological record in these areas. Excavations could prioritize sites in deposits at sea level, and then move on to areas at increasingly higher elevations. Any such excavation program would require archaeologists to develop thorough, expedient, and accessible means of documentation in order to ensure that the material obtained could be put to more effective use by future lab-based archaeological research.

Finally, archaeologists must strive to improve their efforts toward communication with a public audience and park stewards,particularly in regard to issues of conservation. Preservation practices of archaeological material, particularly in public lands, will benefit from greater awareness in the public sphere. At Bullards Beach, this is evident in the presence of multiple pits left behind by looting. By educating the public on archaeological research practices and the necessity for conservation, archaeologists in both the academic and public sectors stand to improve the preservation of the archaeological record. Developing an improved awareness on issues like erosion and site destruction has the potential to garner necessary funding for the pursuit of more effective conservation efforts.

At Bullards Beach State Park, further archaeological work is necessary to help answer a number of important questions regarding prehistoric site use and preservation. Presently, it is unclear how much archaeological material is present throughout the area. Because of difficulties faced in pedestrian survey, it was impossible to determine the exact quantity and composition of archaeological sites in the park. Subsurface surveys throughout Bullards Beach would contribute to a more thorough understanding of the archaeological material present in the area. By incorporating data from archaeological investigations into the aerial imagery approach, it may be possible to estimate how much archaeological material has been lost throughout Bullards Beach, as was conducted by Fitzpatrick et al. (2006) in the Caribbean.

In order to test the accuracy of the predictions made in this thesis, it is necessary for erosion to be continually monitored at Bullards Beach. By combining the aerial imagery data presented herein with erosion data collected via active monitoring vis-à-vis detailed site mapping and/or photographic representations, it will be possible to make more accurate determinations about erosional impacts on archaeological sites throughout the area.

Finally, the impacts of vegetation expansion on archaeological material at Bullards Beach should be explored in further detail. It is possible that vegetation has helped to stabilize dune deflation throughout the park, thus aiding in archaeological preservation along the Coquille River estuary. However, plant roots or other bioturbation such as burrowing animals, or birds collecting materials for nesting, can also disturb and churn the sediment. When an archaeological site becomes overgrown, plant roots can cause material to shift and be moved out of original context. Taphonomic studies of vegetation expansion at Bullards Beach could inform future archaeological management efforts throughout the area of the park.

Conclusion

Indigenous cultures on the Oregon Coast were built around estuaries. Native peoples developed their economies around the access to resources and mobility that estuaries could provide. The region's archaeological record is thus tied to its estuaries. Because these areas have extreme erosional regimes, it is critical that researchers work to understand estuarine erosional processes and their impacts on archaeological sites. Left unchecked, erosion in Oregon's estuaries will degrade and destroy the region's archaeological record.

To help inform future management efforts at Bullards Beach State Park, the data produced in this thesis will be provided to the Oregon State Historic Preservation Office, to Oregon State Parks, and to the historic preservation offices of the Coquille Indian Tribe and the Confederated Tribes of the Coos, Lower Umpqua, and Siuslaw Indians. Drs. Scott Fitzpatrick and Nicholas Jew will also incorporate my findings into future archaeological research projects at Bullards State Beach Park.

For Bullards Beach and for the Oregon Coast as a whole, archaeological resource management necessitates expedient erosion measurement and risk assessment. Aerial imagery data presents a means of risk assessment that can produce actionable results within a short amount of time. The approach outlined herein has potential applications throughout the Oregon Coast, and should be explored in further studies. The Oregon Coast presents an opportunity for researchers to develop more effective methods for archaeological risk assessment, damage mitigation, and conservation.

While it bears unfavorable conditions for archaeological preservation, the Oregon Coast bears a rich cultural history, and should be made a focus for research toward management and preservation of archaeological sites in coastal regions.

Appendix: Aerial Imagery

Provided in the following pages are scans of the aerial imagery dataset mapped in this thesis, for reference purposes. Images are credited to the organizations that created them, and are presented at 1:24,000 scale.

Figure A-1: Bullards Beach State Park imagery, 1939. U.S. Army Corps of Engineers.

Figure A-2: Bullards Beach State Park imagery, 1942. U.S. Geological Survey.

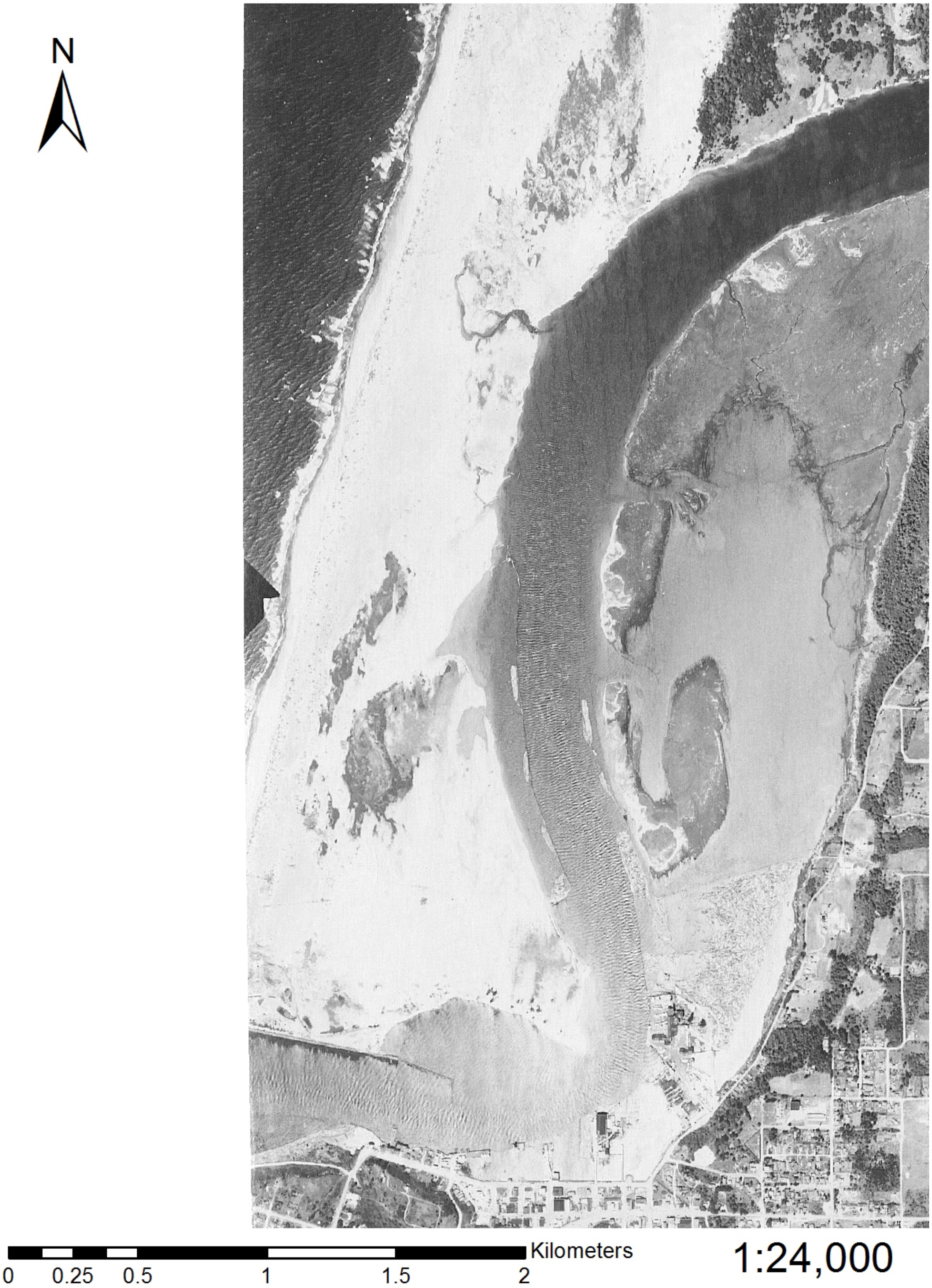


Figure A-3: Bullards Beach State Park imagery, 1954. U.S. Department of Agriculture.

Figure A-4: Bullards Beach State Park imagery, 1967. U.S. Department of Agriculture.

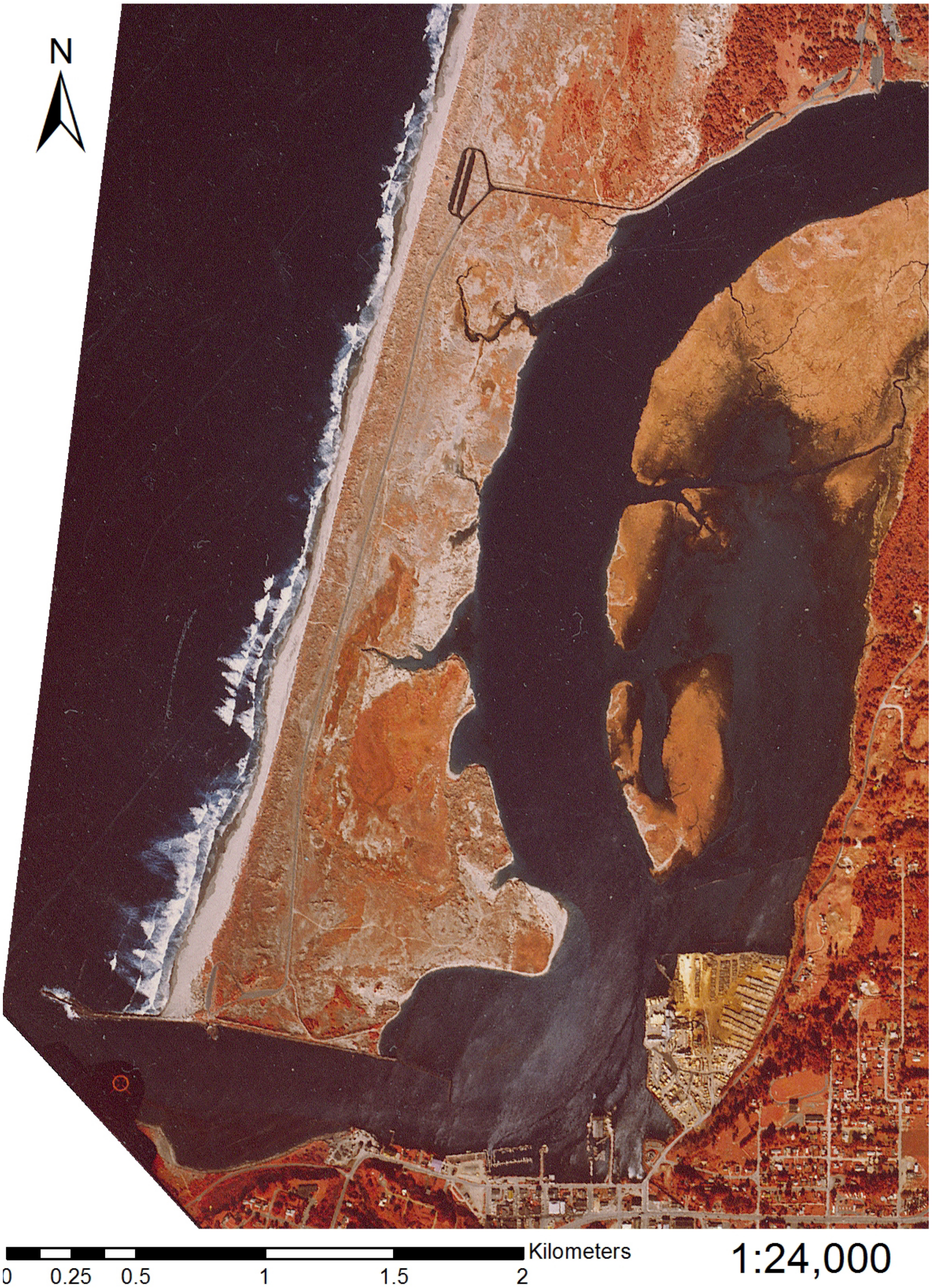
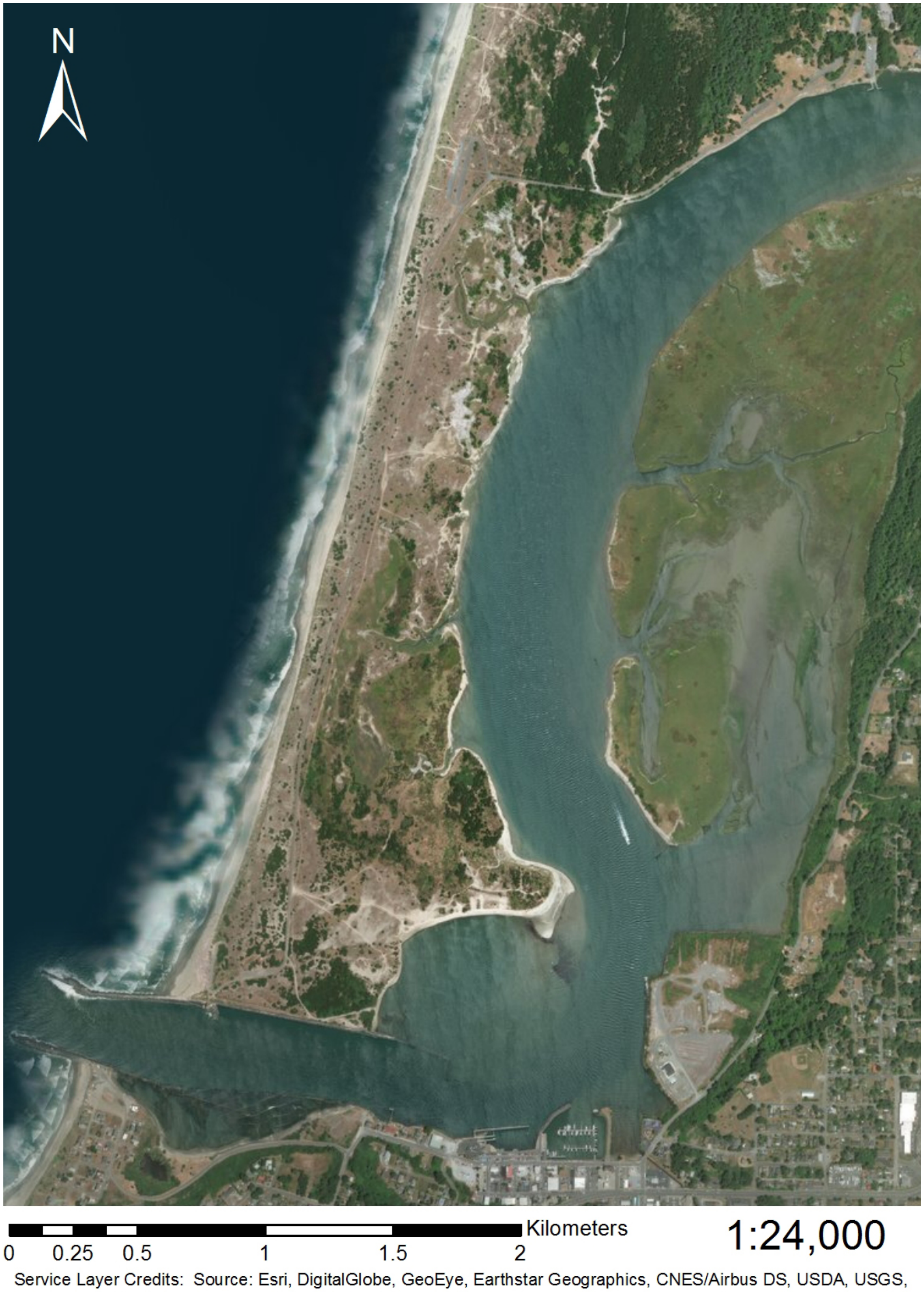


Figure A-5: Bullards Beach State Park imagery, 1978. U.S. Army Corps of Engineers..

Figure A-6: Bullards Beach State Park imagery, 1986. Bureau of Land Management.

Figure A-7: Bullards Beach State Park imagery, 1997. Bureau of Land Management.

Figure A-8: Bullards Beach State Park imagery, 2007. Google LLC.



Service Layer Credits: Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

Figure A-9: Bullards Beach State Park imagery, 2016. Esri Inc.

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