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Recent Changes To The Dynamic Sandy Beach System At The Mouth Of The Kennebec River, Mid-Coast Maine

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Abstract

The geomorphic features of the Popham and Seawall Beach barrier complexes and the pocket beaches of Cape Small, in Phippsburg, Maine are influenced by long-term changes such as sea level rise due to climatic variability, causing beaches to migrate. Short-term and seasonal changes, such as storms, longshore transport, and anthropogenic activity on the beaches, cause quick changes to the surrounding environments. Over the past decade, changes occurring on these beaches have happened quickly and on a large spatial scale (hundreds of meters). One feature of barrier beaches is their capability to act as an erosional buffer between mainland and ocean; due to the highly dynamic nature of the study area, it is important to monitor morphologic change closely to insure they retain this buffering capacity. Satellite imagery, time-lapse photography and historical photos are used in this study to compare long-term and short-term morphological changes along the barrier beach and pocket beach systems. Through topographical surveying, weather data, and GPS tracking of the frontal dunes, a recorded documentation of beach morphology during the summer of 2015 was collected and compared to archived profiles extending back to the summer of 2000.

Chapter 1. Introduction

Purpose of Study

The study of long-term and short-term changes in coastal environments aids in understanding the way in which beaches are morphologically changing due to different processes affecting the beaches- such as climate change, rising sea-level, storms, and cyclical sedimentation patterns. The Popham Beach and Seawall Beach complexes in Phippsburg, Maine began to form approximately 4000-4500 years BP when the rate of sea level rise slowed and sedimentation was abundant (FitzGerald et al. 2000). Coastal Maine has experienced a complex history due to a change in sea-level rise in relation to isostatic rebound during a time of eustatic sea-level rise (FitzGerald et al. 2000). This history included an early Holocene transgression followed by a regression and a second late Holocene transgression.

The geomorphic features of the Popham and Seawall Beach barrier complexes and the pocket beaches of Cape Small, in Phippsburg, Maine are influenced by long-term changes such as sea level rise due to climatic variability, causing beaches to migrate with rise and fall. Short-term and seasonal changes, such as storms, longshore transport, and anthropogenic activity on the beaches, cause quick changes to the surrounding environments. Over the past decade changes occurring on these beaches happen quickly and on a large spatial scale (hundreds of meters). One feature of barrier beaches is their capability to act as an erosional buffer between mainland and ocean; due to the highly dynamic nature of the study area, it is important to monitor morphologic change closely.

The focus of this study is directed towards looking at past and currents changes in morphology at Popham Beach State Park, undeveloped Seawall Beach, and the Cape Small pocket beaches. Satellite imagery, time-lapse photography and historical photos will be used to compare long-term and short-term morphological changes along the barrier beach and pocket beach systems. Through topographical surveying, weather data, and GPS tracking of the frontal dunes, a recorded documentation of beach morphology during the summer of 2015 was collected and compared to archived profiles extending back to the summer of 2000 to look at changes over time.

Physical setting

Phippsburg, ME, is located along the rocky indented south-central coastline of Maine along the Phippsburg Peninsula just 20 km south of Bath. The beaches along this rocky coastline obtain their shape due their paraglacial coastal setting and indented shorelines due to the Late Holocene transgression and the dominant east-southeast approach of waves (Kelley et al., 1993). Due to the paraglacial coastal setting, nearly 25% of the middle-latitude paraglacial coast of New England contains barriers (Hein et al., 2012), making Phippsburg an ideal barrier beach study location. Only 2% of Maine's coast is comprised of sand beaches while much of the coast is dominated by cliffs of bedrock (Kelley, 2013). Maine's glacially scoured coastline, leaves the Phippsburg Peninsula a very prominent bedrock-framed feature among the northeastern beach complexes (Schuler, 2010). The Popham and Seawall Beach barrier complexes make up a majority of the peninsula's southern shoreline, facing into the Gulf of Maine. These sand barrier beach complexes are only found in the southern region of the state and are located at the mouth of the largest river in the state, the Kennebec (figure 1.1) (Kelley, 2013). Accompanying these two sand beaches are the two sandy bedrock bounded bedrock pocket beaches on Cape Small, Little Beach and Icebox Beach.

The Popham barrier beach complex, 4 km in length, consists of three shoreline segments: from west to east are State Park Beach, Hunnewell Beach, and Riverside Beach. The beaches are going west to east and is directly sourced by the Kennebec River and the Kennebec River Paleodelta to the east. Popham Beach is bordered by the Kennebec River to the east and the Morse River Inlet to the west. West of Popham Beach and the Morse River Inlet lies the undeveloped, swash-aligned Seawall barrier beach complex. Seawall Beach is 2.2 km in length and lies between the eastern bank of the Morse River to the east and the western bank of the Sprague River to the west. The Seawall barrier complex stretches, northeast to southwest in direction, with the beach facing southeast and the accompanying pocket beaches facing east-southeast and east. Seawall Beach is part of the 574 acre Bates-Morse Mountain Conservation Area. The area stretches from the beach face back to Route 216. The associated pocket beaches that lie adjacent to the western boundary of Seawall Beach are Little Beach and Icebox Beach. Icebox and Little Beaches are bedrock bounded pocket beaches. Icebox Beach lies directly to the west of Seawall Beach while Little Beach lies northwest of the western boundary.

Figure 1.1 Aerial photograph of the Phippsburg Beach barrier complex and the associated studied transects (Bates College Imaging Center)

Bedrock Geology

Due to glacial erosion of the bedrock in the Gulf of Maine, a distinguishable complex coastline was left, separating this coastal region from the rest of the east coast by its bedrock framework and glacial overprint (Kelley, et al., 1992). The 3,478 mile long coast of Maine is framed by Paleozoic igneous and metamorphic rocks. The resulting geologic structure forms four coastal compartments characterized by varying bedrock orientation and environments; southwest, south-central, north-central, and northeast (figure 1.2) (Kelley, 2013 ; Kelley, et al., 1989). The Phippsburg Barrier complex falls into the south-central (Penobscot to Casco Bay) compartment, the Indented Shoreline compartment, which stretches from Cape Elizabeth to Penobscot Bay (figure 1.3). The Phippsburg complex's Indented Shoreline formed from the glacial scouring of a high grade metasedimentary fold belt that strikes in a northeast-southwest direction along with the formation of many elongated peninsulas (FitzGerald et at., 1989). The bedrock in this region is characterized by "isoclinically folded Proterozoic-Ordovician meta-sedimentary and metavolcanic rocks with localized intrusions of Devonian granites and pegmatites," striking in a northeast-southwest direction (Buynevich and FitzGerald , 2003).

Three rock units comprise Small Point in Phippsburg, ME: Scarboro, Diamond Island, and Cape Elizabeth Formations, all of which are subunits of the Casco Bay Group (figure 1.3). Covill (1980), suggested these units were deposited during the Ordovician and underwent metamorphism in the Devonian-Silurian. The exposed bedrock seen on Cape Small Headland are mainly comprised of the Scarboro and Diamond Island Formations. The Scarboro Formation as described by Covill (1980) is a garnetiferous mica-schist with scattered amphibolite quartzite beds throughout the formation. The Cape Elizabeth Formation, which underlies most of Seawall Beach, much like the Scarboro Formation is characterized by a garnetiferous mica-schist, without the presence of quartzite beds. According to Covill (1980), towards the eastern end of Seawall, a younger aged Silurian granite is visible; continuing and underlying most of Popham Beach State Park. Lastly, the Diamond Formation is a sulfidic schist containing quartz, muscovite and graphite (Covill, 1980).

Figure 1.2 Bedrock geology of Maine compartmentalized into four regions with the study location falling within the south-central region. This region is characterized by highly metamorphosed and deformed marine and volcanic sediment (Kelley, et al. 1989)

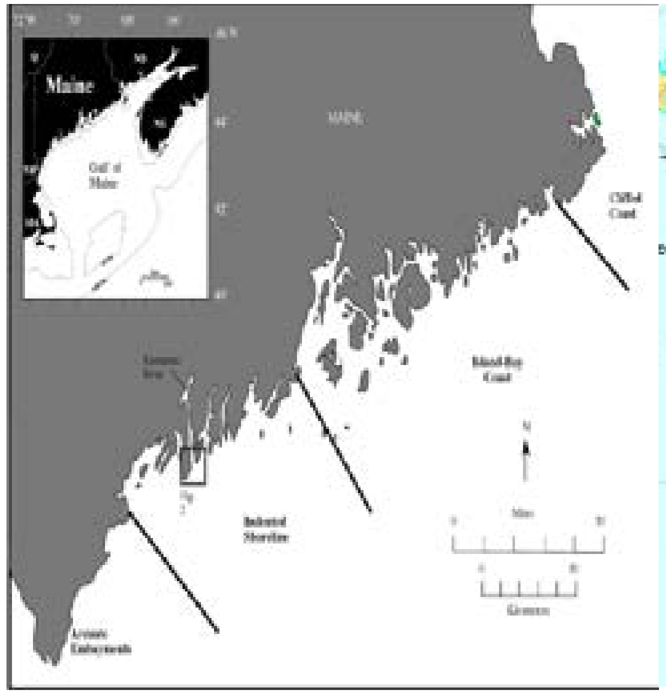

Figure 1.3 Shoreline characterization of the south-central study region (Kelley, 2013)

Figure 1.4 Bedrock geology map of Phippsburg, Maine, done by Hussey and Marvinney (USGS, 2006)

Glacial History

The coast of Maine contains one of the most dynamic beach systems due to its intense glacial history. Maine's coastal region, and more specifically, the southwestern Gulf of Maine and inner continental shelf have undergone in the past 14,000 yr. B.P., two marine transgressions separated by a regression and emergence of at least one part of the shelf (Kelley, et. al., 1992). The Late Wisconsinan Laurentide ice sheet retreated to the near present coastline by 15,000 yr B.P. Due to the glacial retreat, the Laurentide Ice Sheet sculpted and scoured this paraglacial coast, eroding the crystalline bedrock, leaving exposed and glacially modified bedrock (Belknap, et al., 2002 ; Kelley et al., 1989). This ice sheet advanced southeast across Maine and into the Gulf of Maine; reaching its maximum extent 20,000 yr B.P. (figure 1.5) (Belknap et al., 2002).

Approximately 14,000 yr B.P. the Laurentide Ice Sheet retreated from the continental self to the present coastline (Retelle and Weddle, 2001). During retreat, marine waters followed the ice sheet landward across the isostatically depressed coastal lowland before isostatic rebound resulted in regression of the postglacial sea to the Holocene lowstand, around 10,000 yr B.P. Continuous melt of the Laurentide Ice Sheet through the Holocene resulted in a transgression through the Holocene and the current shoreline migrated inland towards its present location, as described in more detail below.

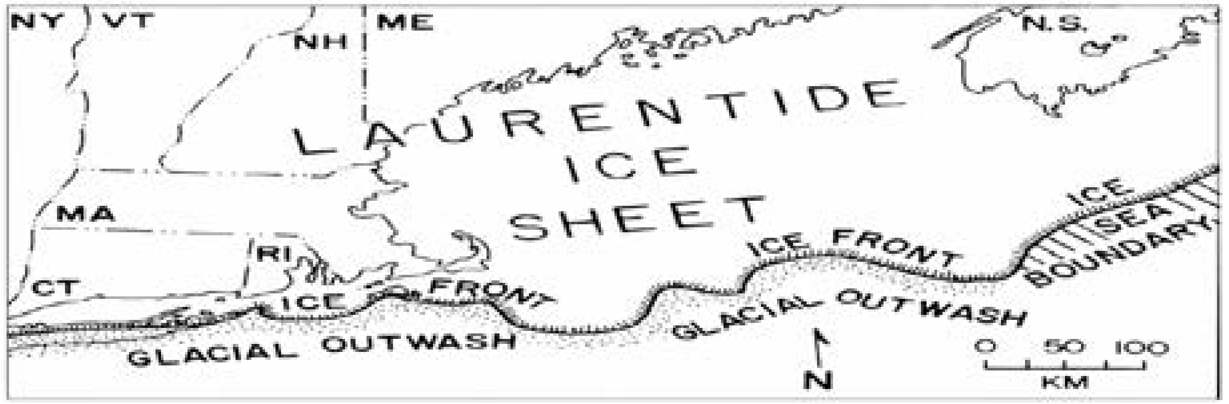

Figure 1.5 Extent of the Laurentide Ice Sheet coverage of Maine during the last glaciation 20,000 yrs B.P. (Kelley, et al., 1989)

Beach Morphology

Due to the complex glacial history of Maine and the resulting formation of its compartmentalized coast, sandy barrier beaches along the midcoast of Maine are highly dynamic and constantly being reworked. Sandy beaches are influenced by the environmental boundary conditions and the external hydrodynamic forces (waves and tides) (Hine, 1979). Therefore a significant change seen the beach profile is due to seasonal processes and the accompanying hydrodynamic forces.

The morphology of the studied beaches is typically characterized by a sloping profile with secondary morphological features superimposed, including, nearshore bars, swash bars, and rip channels (Hine, 1979). Starting from the mainland moving seawards, a typical cross-section view of a beach profile includes the backshore, the foreshore and the nearshore (figure 1.6) (Stanica and Ungurean, 2010).

The backshore environment is the most landward zone, composed of the beach berm and dunes. This zone begins at the berm crest and stretches landward to the dunes. The backshore is characterized by subaerial, predominantly wind-generated depositional processes. The berm is a constructional, morphological feature resulting from the onshore transport of sediment due to the repeated deposition of particles in the swash zone (Stanica and Ungureanu, 2010 ; Hine,1979). Moving landward from the berm lays the dune front; commonly found in association with sandy beaches. Dune development is characterized by aeolian and hydrodynamic processes, supplying sediment to the dune area, which acts as sand reservoirs.

The foreshore is the zone of the beach that extends from the active berm crest in a seaward dipping direction terminating at the ridge. The landward sloping zone of the foreshore is the beach face, the region also identified as the swash zone. The wash zone, located seaward of the beach face, is the area in which waves crash either suppling or uplifting sediment from the beach face. Due to the variability in wave height and energy, associated with storms and seasonal processes, the beach face is a zone of continuous change. Continuing seaward from the beach face is a slight dip called the runnel followed by the ridge (a sand bar). The ridge collects coarse sediment until the crest is above water, where the washed over sediment from the ridge fills in the runnel, forming a new berm that will eventually migrate towards the landward and weld onto the beachface (Stanica and Ungurean, 2010).

The nearshore region is characterized by submerged bars separated by troughs, creating the breaker and surf zone. The breaker zone is the response of the beach to the action of waves breaking over the seabed (Stanica and Ungurean, 2010). The growth of beaches and their morphological features is dependent on sediment dynamics and the deposition of sediment onto the beach, beginning in the nearshore region where sediment is driven landward by the different bathymetric features of the offshore and nearshore regions.

The typical beach profile varies dependent upon season (figure 1.7a). During winter months, wave action, wave energy, and wind speed all increase causing more erosion of the sand on the beach face, as well as, scarping of the dunes (figure 1.7b). The sediment that is eroded from the beach face is transported into offshore bars which aid in protecting the beach by causing these highly energized waves to break further offshore. In the Gulf of Maine, strong northeast storms occur frequently causing high energy waves which lead to the scarping of the dune front and erosion of the beach face. When waves become milder and calmer during the summer months, sediment from the offshore bars migrate onshore, building the beach back up. The summer processes typically restore the beach creating well-developed berms, unless sediment is lost offshore (figure 1.7c). However, large unusual storm events can result in disequilibrium in the beach profile and sand may be permanently lost to deep water. During the study period of June through August, little to no storm activity was recorded that would hinder the beach from progressing into a summer characterized profile.

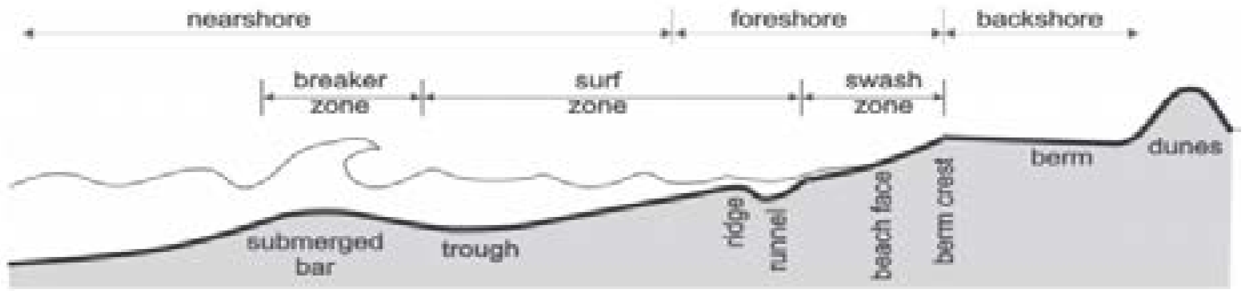

Figure 1.6 Cross-section view of a typical beach profile and the three main zones of a beach (nearshore, foreshore, and backshore) and their most noted morphological characteristics (submerged bar, trough, ridge, runnel, beach face, berm crest, berm, and dunes). The relevant regions for wave dynamics and sediment transport on to the beach are identified are the breaker zone, surf zone, and swash zone.

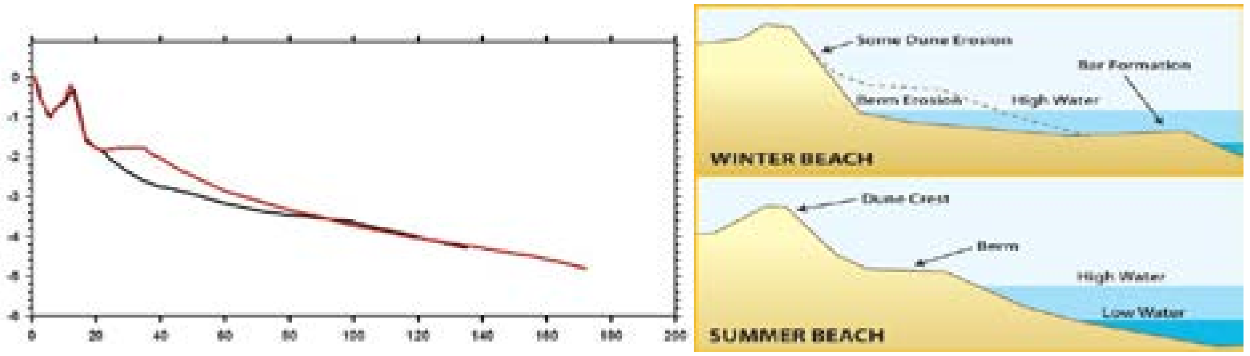

Figure 1.7 a) Seasonal beach profile depicting: winter (black) and summer (red) b) Representation of a winter profile showing loss in sediment c) Summer profile showing increased sediment accumulation and the development of a strong berm

Storms

Short term processes affecting the Maine coastline are mainly tied to meteorological processes. In the Gulf of Maine, strong northeast storms occur frequently causing high energy waves that drastically rework the beachface and nearshore region. The study period from June to August, presented a very mild summer. However, over the decades the Phippsburg barrier beach complex has been highly susceptible to strong storms processes, causing major change to the different beaches studied.

Study Site Morphology

The Phippsburg, Maine sandy barrier beach complex in Phippsburg began its initial growth and formation during the Holocene, about 4-4.5 yrs. B.P. (FitzGerald, et al., 2000). The Kennebec River estuary and its offshore paleodelta serve as the main sediment sources for Popham Beach, Seawall Beach and the accompanying pocket beaches, Little Beach and Icebox Beach. The process of transporting marine sediment onshore laid the foundation for the barrier complexes studied today. Abundant marine sediment, from the Kennebec Paleodelta, present offshore which could be reworked, eroded and welded onshore forming the Seawall and Popham beach systems as sea level rose in the late Holocene.

Sediment Source Dynamics

The Phippsburg, Maine barrier beach complex receives small amounts of sediment from the accompanying small river inlets- Morse River and Sprague River. The Kennebec River Estuary receives sediment inputs from the converging Kennebec and Androscoggin Rivers (Fitzgerald et al. 2002). Both the Kennebec River and Androscoggin River join to their confluence in Merrymeeting Bay, which is approximately 20km from the outlet of the Kennebec into the ocean (figure 1.8) (FitzGerald et al. 2002). The Merrrymeeting Bay is a large contributor of sediment supply for the beaches located at mouth of the Kennebec River.

Located at the mouth of the Kennebec River lies a large clockwise sediment gyre, which circulates sand along Popham Beach and in the offshore region (figure 1.9). The clockwise sand gyre involving the mouth, nearshore region and adjacent barriers shows a seaward fining trend that moves sand in a net seaward direction. The gyre circulates bedload among the beach, estuarine channel and nearshore in a net easterly direction by dominant easterly longshore currents (FitzGerald et al., 1989). An undefined amount of the sand transported down the estuary is conveyed to the mouth of the ebb-spillover channel between Wood and Pond Islands, characterized in figure 1.9 as the outer bar (FitzGerald et al. 2000). The bar is described as a large, shallow terminal lobe around 2 meters thick. During storms, waves crash along this terminal lobe and supply sediment to a shallow bar that completely extends for Fox Island (about 1.5km) (FitzGerald et al. 1989). As storms increase in strength, wave height increases- leading to an increase in sediment transport rates due to greater wave energy uplifting sediment and transporting it parallel to the shore as well as a longer duration of breaking wave conditions (FitzGerald et al. 2000). The increase in sedimentation, due to increased wave energy and height, leads to the formation of swash bars that coalesce as they move onshore, forming a large bar complex. The final phase in the completion of the clockwise sediment gyre is the landward migration and attachment of these offshore bars to the beach and the eastward sand transport along the beach by wave action and added to the Kennebec River (FitzGerald et al. 1989 ; FitzGerald et al., 2000). This sediment cycle has accounted for both shoreline progradation and erosion (>100 m), over the past 30 years (FitzGerald and Fink, 1987).

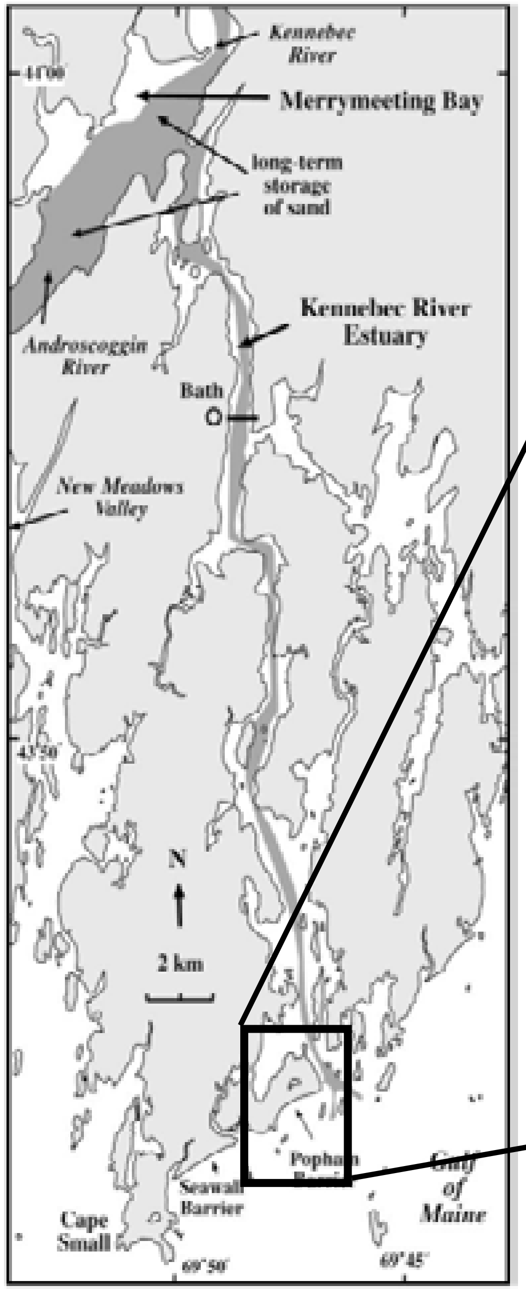

Figure 1.8 The convergence of the Kennebec River and Androscoggin River at Merrymeeting Bay and the sedimentation pattern (FitzGerald et al., 2000)

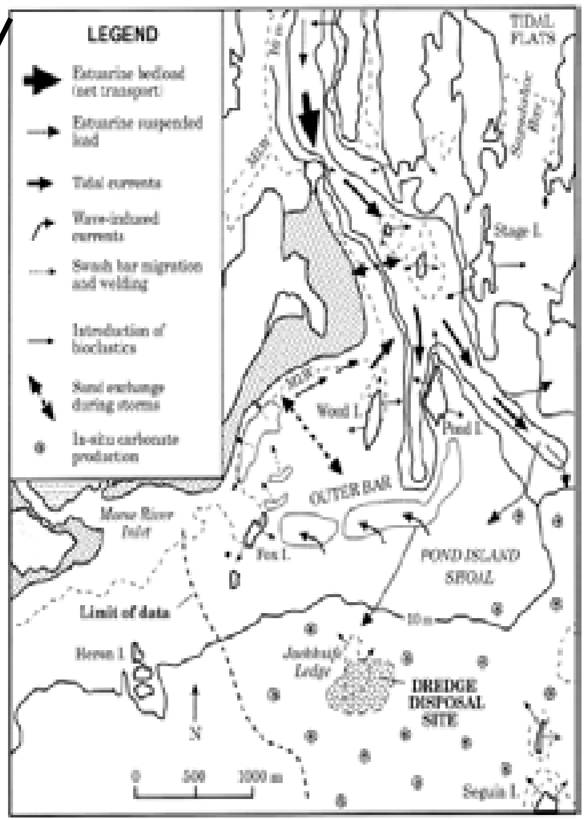

Figure 19 Popham Beach sediment gyre depicted by the arrows Buynevich and FitzGerald, 2003)

Tidal Inlets

Progradation and erosion of the shoreline at the study locations is not only impacted by the sedimentation cycle and associated wave energy and storms welding on bar complexes but also tidal inlets and their migration. In the Gulf of Maine most tidal inlets are located in the south-central and southwestern coastal physiographic compartments (Table 1.1) (FitzGerald et al., 1989). The abundance of tidal inlets within these compartments is the result of an abundant resupplying sediment source, as well as an "embayed coastal configuration and adjacent low-lying upland topography" (FitzGerald et al., 1989).

Tidal inlet development and evolution is constrained by sediment supply, sea-level rise, and regional slope, which in turn determine the location of the barrier within a bedrock-framed compartment over time (figure 1.10).

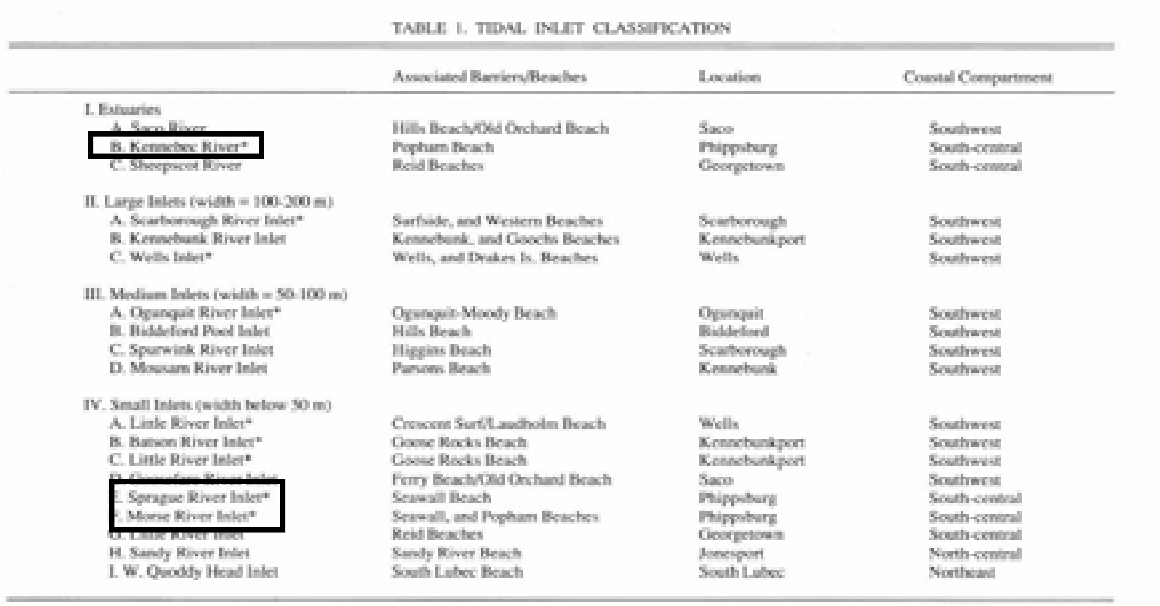

TABLE 1. TIDAL INLET CLASSIFICATION

	Associated Barriers/Beaches	Location	Coastal Compartment
I. Estuaries			
A. Saco River	Hills Beach/Old Orchard Beach	Saco	Southwest
B. Kennebec River*	Popham Beach	Phippsburg	South-central
C. Sheepscot River	Reid Beaches	Georgetown	South-central
II. Large Inlets (width = 100-200 m)			
A. Scarborough River Inlet*	Surfside, and Western Beaches	Scarborough	Southwest
B. Kennebunk River Inlet	Kennebunk, and Goochs Beaches	Kennebunkport	Southwest
C. Wells Inlet*	Wells, and Drakes Is. Beaches	Wells	Southwest
III. Medium Inlets (width = 50-100 m)			
A. Ogunquit River Inlet*	Ogunquit-Moody Beach	Ogunquit	Southwest
B. Biddeford Pool Inlet	Hills Beach	Biddeford	Southwest
C. Spurwink River Inlet	Higgins Beach	Scarborough	Southwest
D. Mousam River Inlet	Parsons Beach	Kennebunk	Southwest
IV. Small Inlets (width below 30 m)			
A. Little River Inlet*	Crescent Surf/Laudholm Beach	Wells	Southwest
B. Batson River Inlet*	Goose Rocks Beach	Kennebunkport	Southwest
C. Little River Inlet*	Goose Rocks Beach	Kennebunkport	Southwest
D. Goosefare River Inlet	Ferry Beach/Old Orchard Beach	Saco	Southwest
E. Sprague River Inlet*	Seawall Beach	Phippsburg	South-central
F. Morse River Inlet*	Seawall, and Popham Beaches	Phippsburg	South-central
G. Little River Inlet	Reid Beaches	Georgetown	South-central
H. Sandy River Inlet	Sandy River Beach	Jonesport	North-central
I. W. Quoddy Head Inlet	South Lubec Beach	South Lubec	Northeast

Table 1.1 Tidal Inlet Classification Chart showing the 3 tidal inlets studied- Kennebec River, Morse River and Sprague River (circled in blue)(FitzGerald et al., 1989)

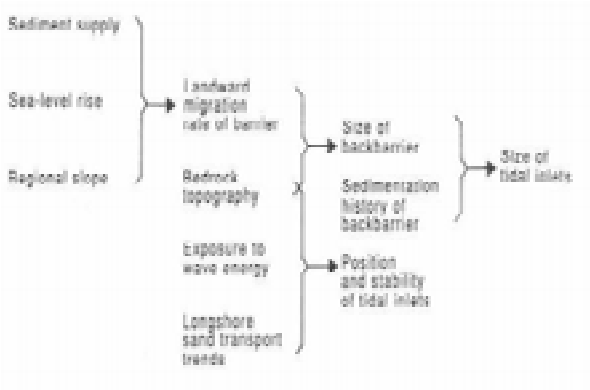

Figure 1.10 Flow chart of the processes and controls in the development of a tidal inlet system (FitzGerald et al., 1989)

Sea Level Rise and Climate Change

Morphological changes affecting the beach system are due to long term and short term events. Sea level changes through the Holocene in the Gulf of Maine is related to the retreat of the Laurentide Ice Sheet and its partnered isostatic rebound, which dominates the late Quaternary (Barnhardt, et al., 1995). The zone in which coastal processes operate is affected by sea level change, and thus influence the long term evolution of the coastal zone (Hancock and Skinner, 2000). Complex relative sea-level (RSL) changes near the former ice-sheet edge and isostatic depression of the land during glaciation (15-13,000 yrs. B.P.), allowed sea level to submerge the coastal region of Maine to a depth of approximately 70-130m above present sea level (figure 1.1) (Kelley, 2013 and Belknap, et al., 2005). The coast emerged rapidly during continuing isostatic rebound (13-11,000 yrs. B.P.), while sea level fell to about 60m below present 12,5000 yrs. ago B.P. (Kelley, 2013). By 11-10,500 yrs. B.P., the release of the ice from the land has allowed the isostatic rebound of the land to outpace the rate of global sea level, creating a lowstand shoreline at -55m (Barnhardt, et al., 1995). Beaches and dunes characteristically respond to rising sea-level through the process of overwash and rising tides as means of depositing sand behind the dunes or carrying sediment back out to offshore sandbars. However, if the rate of SLR exceeds the rate of sediment delivery to these barrier beach complexes, this could result in sediment loss and ultimately land loss, leading to the degeneration of beaches along the coast.

As discussed earlier many of the short term factors have a daily effect on the beach face causing constant change and keeping the beach system in a state of constant flux. However, in recent years, there has been a growing concern on increasing sea-level rise (SLR) (long-term) due to an increase in greenhouse gas emissions. Natural and anthropogenic substances and processes that alter the Earth's energy budget are the main drivers of climate change seen in recent years (IPCC, 2014). Due to these increased rates of greenhouse gases, climate change acts as the primary contributor to current sea level rise with the expansion of oceans as it warms and the transfer of water stored on land (glaciers and ice sheets) moves into the oceans. Global mean sea level rose by 0.19 meters over the period 1901-2010. During this period it is likely that the mean rate of averaged global sea level rise was 1.7mm/yr and 3.2mm/yr between 1993 and 2010 (IPCC, 2014). Modern day measurements at a tidal gauge in Portland shows that sea level is rising at a relatively steady rate of about 2mm/yr. There are three key elements which help in better understanding why sea level is rising along the Maine coast: a) thermal expansion as the atmosphere get warmer from an increase in GHG emissions, the ocean heats up and expands; b) the volume of the ocean increases with an influx of water from melting glaciers and land-based ice sheets; c) there is a slight regional subsidence of the coast (UMaine, 2010).

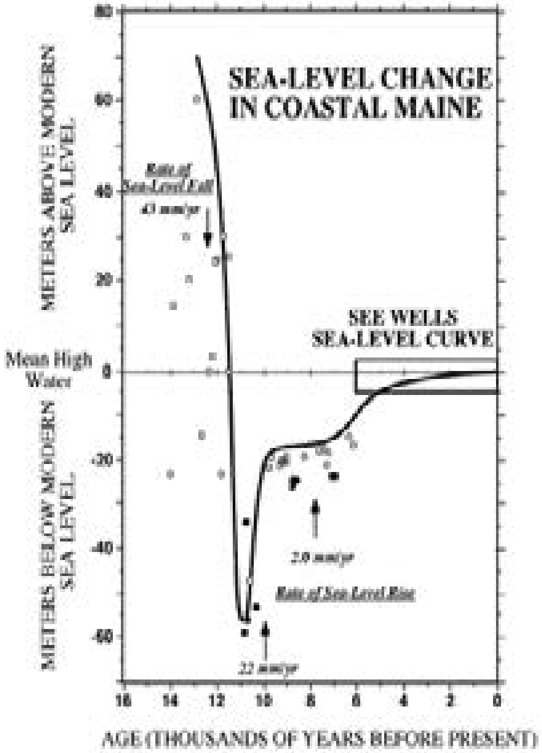

Figure 1.11 Due to isostatic rebound, sea level submerged the Maine coastal region to a depth of approximately 70-130 meters about present sea level.

Chapter II. Methodology

Field research was conducted from June 2015 to August 2015 on the beaches of Phippsburg, Maine. The primary method of data collection was topographic beach profiling. The secondary methods used were tracking the dune systems with a global positioning system (GPS), time-lapse photography and weather data collection. ArcGIS was used to create a finalized map showing dune migration from 1990 to 2015. Analysis was done at Bates College.

Topographic Profiling

Beach profiling was conducted monthly from June 2015 to August 2015 using the auto-level method. Transects were established at each beach from previous studies and were recorded with a GPS unit. Transects ran perpendicular to the shoreline and extend from the back dune or other identifiable point to the low tide water extent. There are 17 transects in total: Bailey Beach (2), Icebox Beach (3), Little Beach (2), Seawall Beach (5), and Popham Beach (5), each of which are identified by a stake or spike in the backdune area (figure 2.1).

Figure. 2.1 Aerial photograph showing Popham Beach, Seawall Beach, Little Beach, and Icebox Beach transects.

Transects

All beach surveying was conducted on previously established transects. Transects located on the Small Point Pocket Beaches and Seawall beach have historical data from the 1990's while Popham Beach has a limited recorded history starting from the mid 2000's, due to more recent thesis research as well as limited aerial photographs starting in the late 1990's. Transects at Icebox, Little, and east Popham Beaches are identified by spikes or rebar driven into hard sediment or rock. Seawall Beach transects are identified by green stakes located on the front and back dunes.

The Seawall Beach transects have been part of ongoing study of the changing beach topography since the 1990's. Transects run from the back dune, an erosional scarp that was produced in 1978 from a severe winter storm, over the frontal dune and down the berm seaward to the low tide water extent line. Metal stakes were placed on the 1978 storm scarp, marking the location of each transect. Transect location is measured as distance from the Bates-Morse Mountain access trail. Each transect is identified with a distal measurement and a directional orientation (East or West), in reference to the access trail. There are 5 transects total on the beach named: E100, E200, W100, W300, and W500.

The Small Point Pocket Beach transects on Icebox and Little Beaches were established in the spring of 2008. The topographic profiles of these beaches are shorter in distance and do not have a backdune. Rather, these beaches are bound by bedrock features on both the east and west sides. Transects of the Pocket Beaches are identified with spikes or rebar. Little Beach is home to 2 transects (East and West), which are located at the base of a manmade rock seawall. Icebox beach contains 3 transects (1, 2 & 3), with spikes anchored into the headland bedrock, equally distanced about 100 meters from each other.

The beach profile transects on Popham Beach were established in June of 2010. Five transects line the Popham Beach system; 2 on Popham Beach to the west of Fox Island and 3 on Hunnewell Beach located to the east of Fox Island, all varying in length due to varied sedimentation patterns. Each transect was identified by a marker running perpendicular to the orientation of the beachfront from a fixed position onshore behind the berm. These transects stretch from west to east acting as directional markers for each profile: Popham West, West Bathhouse, Popham East Stairs, Popham East Sea Acres, and Popham East Yellow Stake.

Autolevel Method

Profiles were measured using an automatic level surveyor, metric stadia rod, and a 100m measuring tape (figure 2.2). Depending upon the topography of the given transect line, distance between measurements varied. Where topographic changes are more abrupt and prominent, i.e. from the dune crest to the plunge step, measurements were made at 1meter intervals. Along flatter areas such as the low tide terrace, measurements were made at 3meter increments, due to little vertical change over a longer measurement. The autolevel surveying method records elevation change along a chosen transect line, each of which were identified by the transect stake or rebar in the back beach area. Each survey is completed in reference to a benchmark point, which were all previously positioned and recorded with GPS points to verify.

For each transect profile surveyed, the transit was placed on the backdune, leveled out due to uneven topography, and lined up with the stake on the frontal dune. Once the tripod and transit were set up, an initial height of the instrument was taken with the stadia rod. The measuring tape was strung along the transect line to measure distance between survey points. Each survey point along the transect has two dimensions: a horizontal distance measurements, and a vertical (elevation) measurement. The tape measure was 100m in length and was repositioned on transects longer than the given length. This method takes two people to complete, one individual held the stadia rod and moved with increasing measurements while the second individual read the stadia rod measurements from the cross hairs of the autolevel scope and recorded the elevation differences.

Figure. 2.2 Autolevel survey method.

High-Resolution GPS Tracking

A Trimble GeoXH handheld GPS unit was used for mapping dune positioning on all the studied beaches from June to August 2015 (figure 2.3). GPS tracks were taken on each beach once a month. Each set of tracks ran along the frontal dune, extending from one end of the beach to the opposing end. The data collected by the GPS unit was processed using the Trimble software. The data was then downloaded and exported to ArcGIS in order to be plotted. The plotted tracks were overlain on a recent aerial satellite image to show dune positioning. The final map shows the recession of the beach over the 3-month study period.

Figure 2.3 Walking of the frontal dune with high-resolution GPS unit to record dune migration.

Time Lapse Photography

Two time-lapse cameras were used in conjunction with surveying the beach condition in order to obtain a frame-by-frame shift in the beaches condition. A Pentax K200D Digital SLR camera was used, using a DigiSnap 2100 time-lapse programmer. These cameras ran on a 12-hour schedule taking pictures hourly from 6am to 6pm. These cameras were used to monitor changes along the Sprague River inlet channel from the cliff at Small Point, as well as, at Popham Beach State Park, with the camera placed on the apex of the west bathhouse, which monitored the course of the ebb tidal Morse River Channel, which cuts along the west beach (figre 2.4).

Figure 2.4 Time lapse camera set up (middle) and the accompanying locations on Cape Small (left) and Popham Beach Bathhouse (right).

Satellite Images

Over the course of the years, using Quickbird satellite imagery, changes along the whole of the Popham Beach complex has been documented. These high-resolution images have been georeferenced-using ArcGIS and serve as aids in documenting morphological changes throughout the beach complexes. Along with the Quickbird, Worldview2 and GeoEye imagery commissioned by Bates College Imaging Center, different features of the Phippsburg Beach Complex have been documented through earlier Google Earth satellite photography.

ArcGIS

High-resolution Quickbird images of the Popham Beach barrier complex were used in order to track dune recession. Using ArcGIS, each image was created as a layer in which the dune front line to each accompanying year was traced. After the dune front tracking of different years was completed, the final layer displaying all the dune front lines, was overlain onto the 2015 satellite image of Popham Beach. The final map portrayed dune migration along the entirety of the beach from 1990 to 2015.

Chapter III. Results

All field data were collected from mid-June to mid-August, during the summer of 2015. Topographic profiles were derived from data collected using an autolevel transit and from past theses students- reaching back to 2009. The second component of the results comes from high-resolution GPS tracks taken from walking along the front dunes of Seawall Beach, Little Beach, Icebox Beach and Popham Beach. Through the analyses of this data an understanding on how the beaches are moving and morphologically changing will be derived.

Topographic Profiles

Seawall Beach

Seawall Beach faces north with topographic profiles on the west and east side of the beach, relative to the recreational beach path entrance and large pegmatite outcrop. West transects SW100, SW200, and SW300 are named respectively to their distance, in meters, from the entrance path, as do, east transects SE100 and SE200.

Transects on the west side of Popham Beach show a predominant accretionary trend throughout the 3 months of surveys. Figure 3.1 shows a very consistent profile throughout the 3 months with the development of a slight berm during the month of August at a distance of 35 meters. This berm development is fed by the accumulation of about .5 meters of sand seen in the month of July at around 52 meters. To the west, 200 meters in distance from SW100, lies SW300 (figure 3.2) showing similar beach building characteristics. Over the three months a steady buildup of sand on the beach face is evident. At 35 meters a newly developed berm has been constructed as well as the filling in of an erosional feature present in June. Transect SW500 (figure 3.3) on Seawall Beach presents the most change on Seawall Beach. During the month of August a steady accretionary trend in sand volume of about .5 meters is seen throughout the whole transect.

Seawall Beach east shows less variation among transects SE100 and SE200 over the course of three months as opposed to Seawall west transects. Figure 3.4 shows transect SE100 with a net erosional trend. Although, SE100 shows an overall trend of erosion at around 70 meters seaward, July’s high volume of sand from 52-92 meters develops into a berm in August. Further to the east, by contrast with SE100, SE200 shows little erosion (figure 3.5). During July at around 45 meters a berm migrates landward and grows in August to establish a strong berm at about 30 meters, with close to 1 added meter in sand elevation.

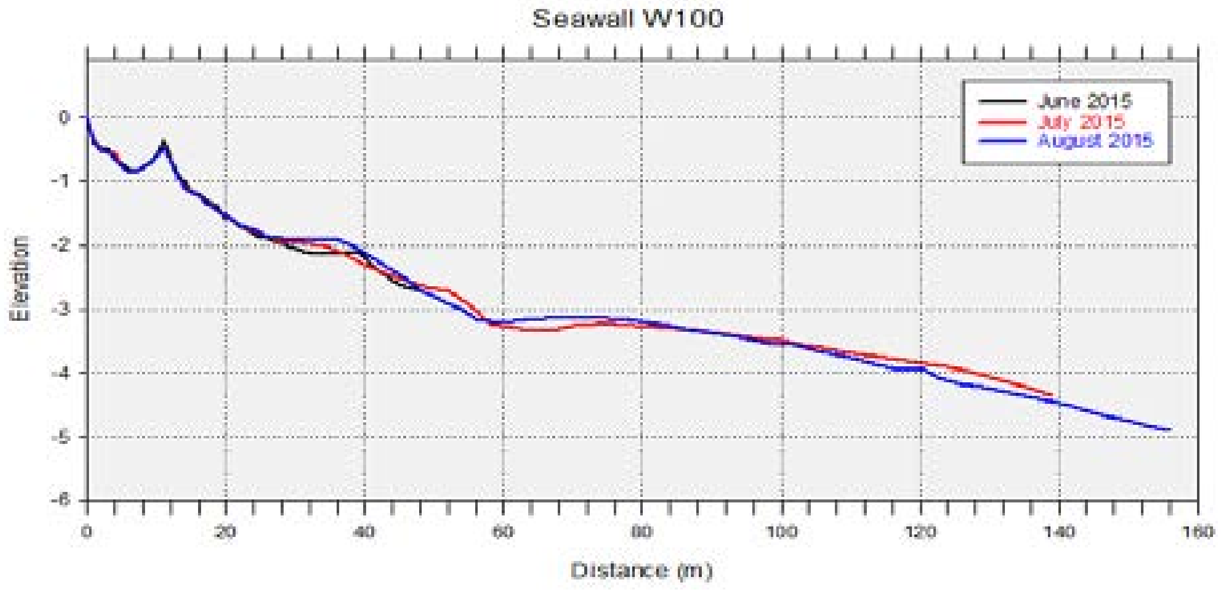

Figure 3.1 Topographic profile of Seawall Beach transect SW100

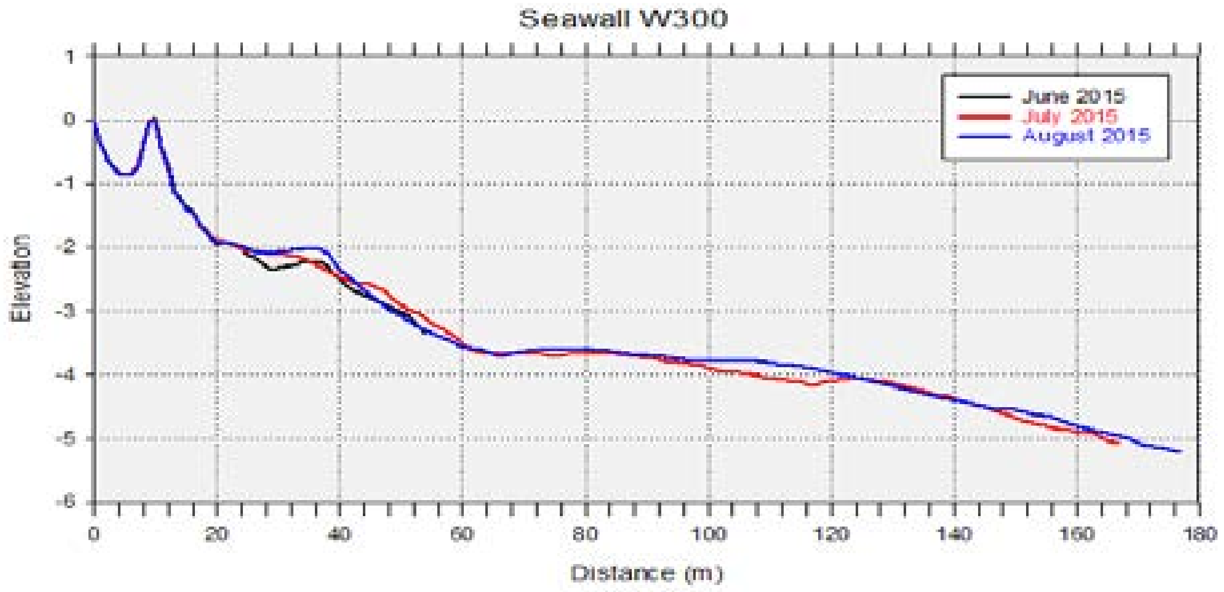

Figure 3.2 Topographic profile of Seawall Beach transect SW300

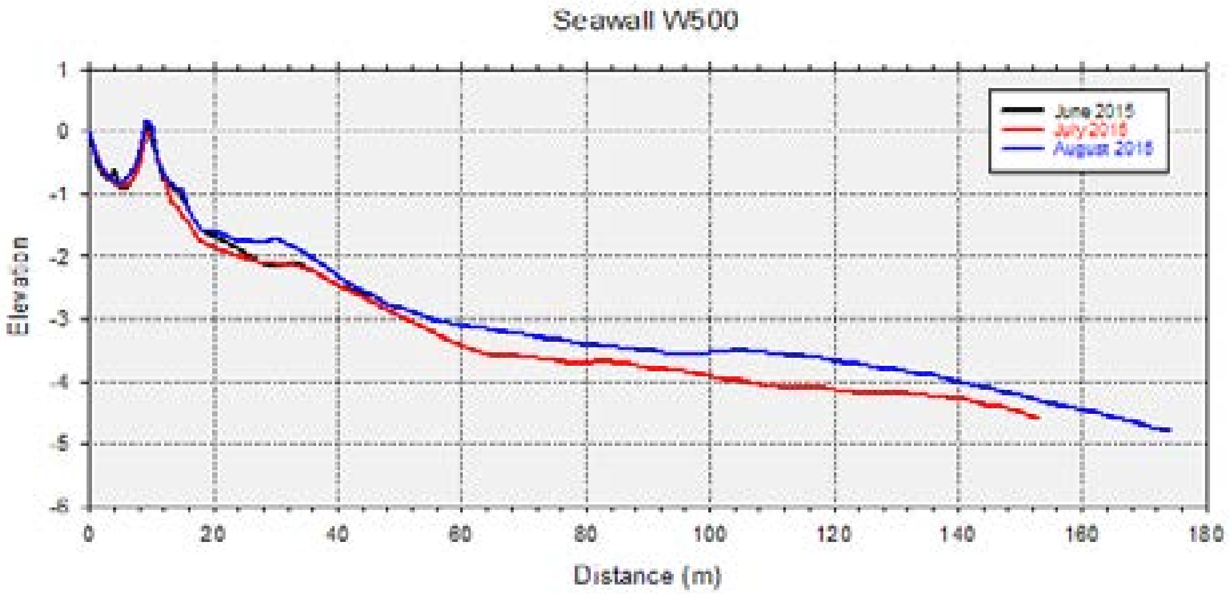

Figure 3.3 Topographic profile of Seawall Beach transect SW500

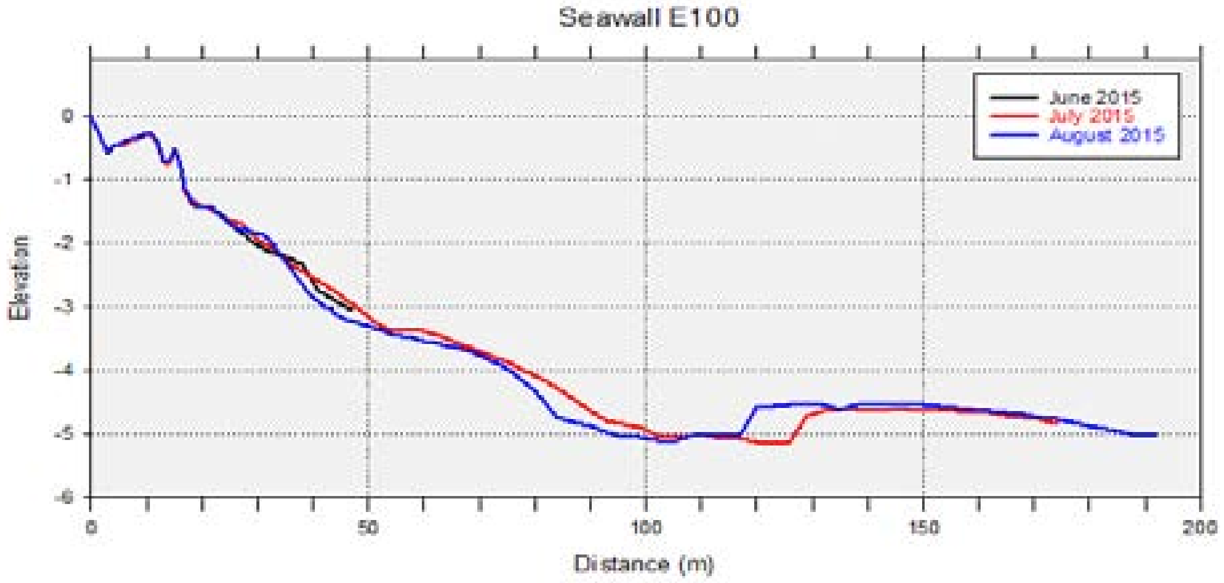

Figure 3.4 Topographic profile of Seawall Beach transect SE100

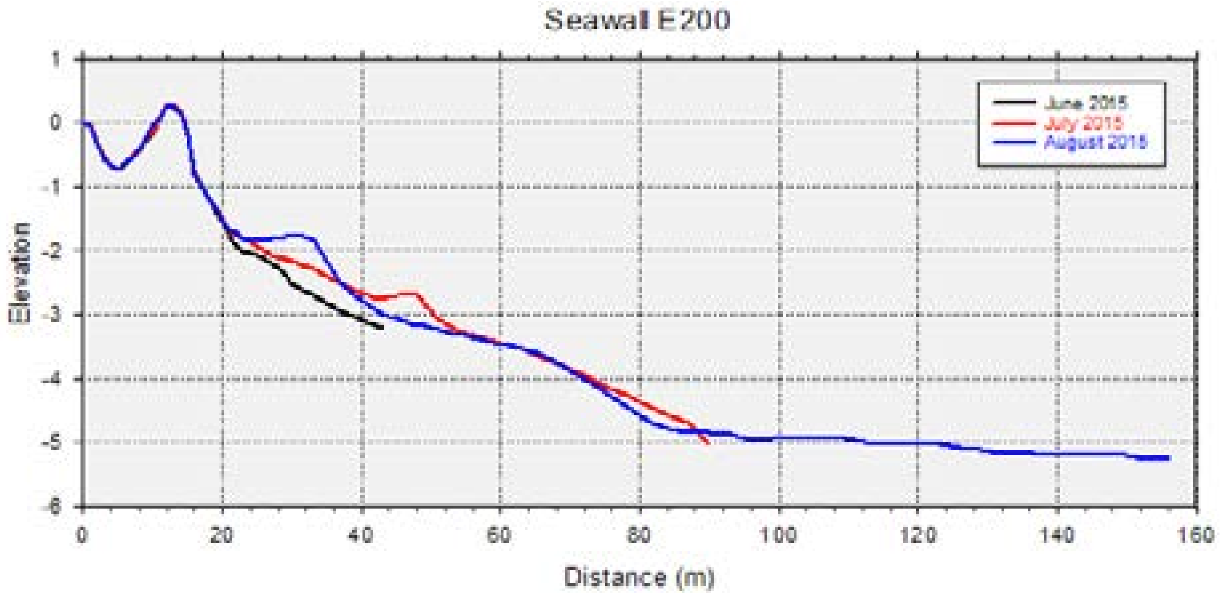

Figure 3.5 Topographic profile of Seawall Beach transect SE200

Icebox Beach

Icebox Beach, a bedrock bounded pocket beach, lies directly west of Seawall Beach. The profile measured is named: I1, at the most eastern side of the beach. Figure 3.6 shows transect I1 clearly displaying an erosional trend over the three months heading down the beach face. Landward at around 40 meters a crest has gradually formed. Seaward from the identified crest, the beach steeply loses about .7 meters of sand down to the low tide water mark.

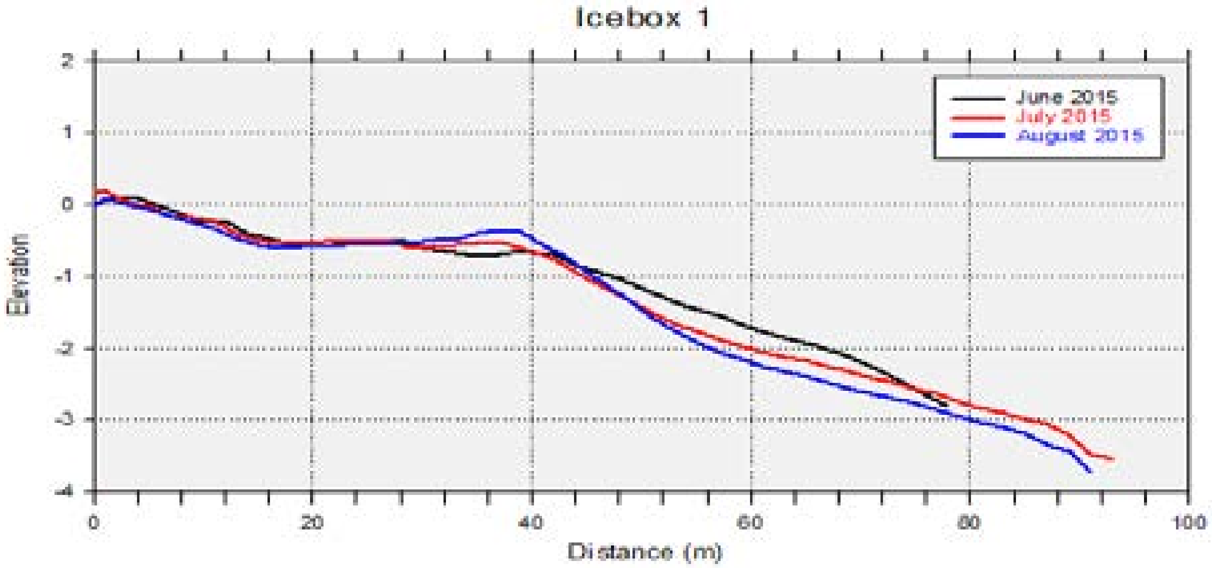

Figure 3.6 Topographic profile of Icebox Beach transect I1

Little Beach

Little Beach is a pocket beach that lies alongside the western boundary of Seawall Beach in front of the Small Point Club and faces northeast. The Little Beach transects are named: LE and LW. Both transects East (figure 3.7) and West (figure3.8) show very little change from June to August. Little East(LE) shows no change while Little West(LW) shows less than a .5 meter increase in sand accumulation from around 55 meters to the low tide line from June to August.

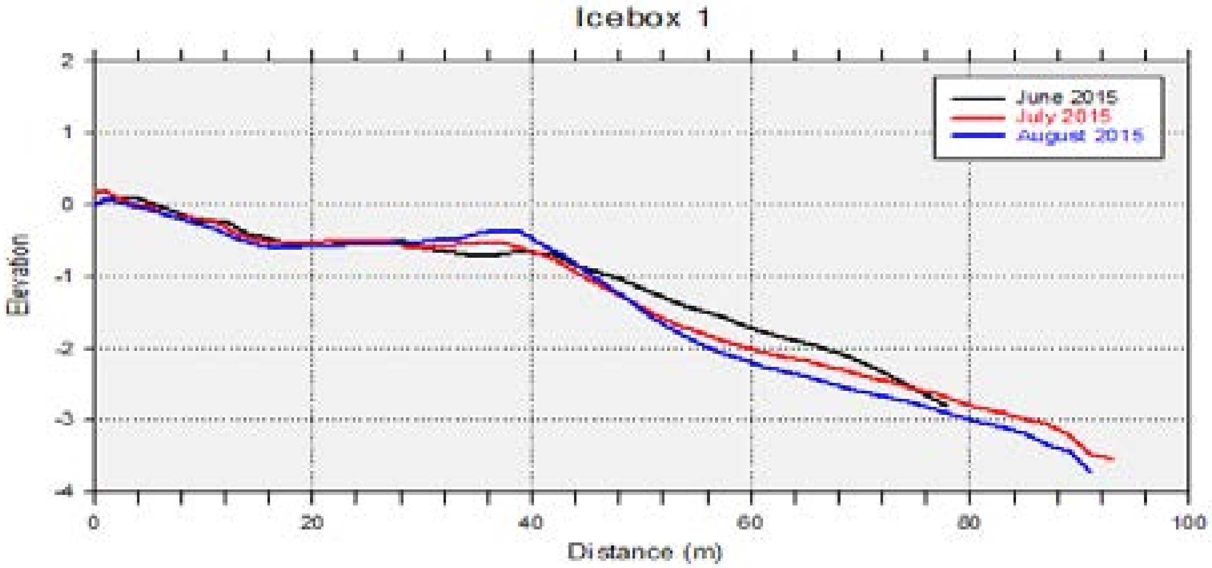

Figure 3.6 Topographic profile of Icebox Beach transect I1

Little Beach

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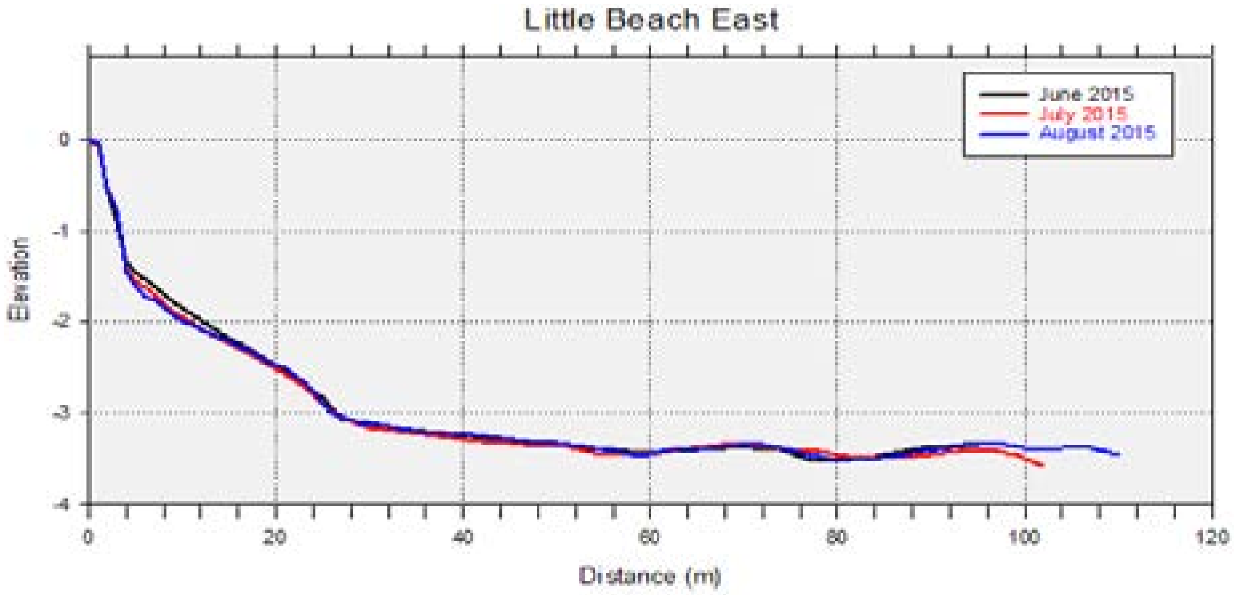

Figure 3.7 Topographic profile of Little Beach transect LE

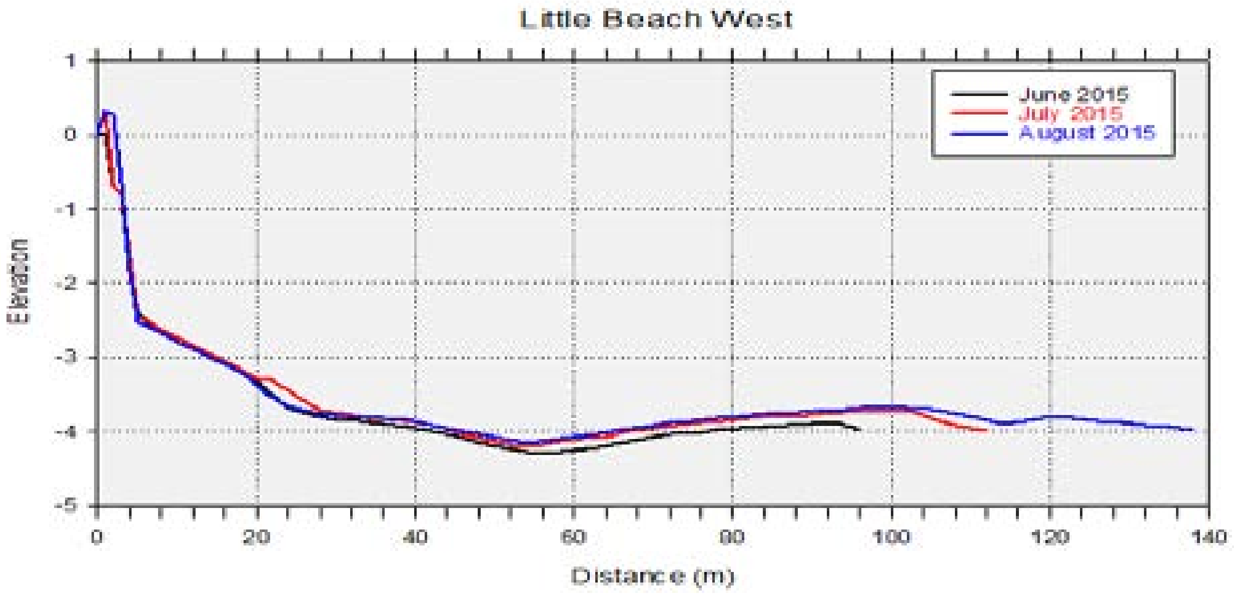

Figure 3.8 Topographic profile of Little Beach transect LW

Popham Beach

Seawall Beach is a barrier beach complex, 4 km in length, facing south in direction. Popham Beach lies between the Sprague River on the west and the Kennebec River Estuary on the east. Transects taken at this site are named: Popham West (PW), West Bathhouse (PWB), Popham East (PE), Sea Acres (PSA), and East Stake (PES), respective to Fox Island.

The two west Popham transects, PW and PWB, have transects that run down the shore face to a small tidal channel that closed off in front of PW during June and opened up again and spit across PW and PWB by August. PW (figure 3.9) shows consistency in elevation/distance from July to August, while building from the June profile at about 20 meters and on seaward. At around 40 meters the beach shows a steep drop during the months of July and August as opposed to the steady decline in the June transect. The PWB profile (figure 3.10) shows little change up until 80 meters where less than a .3 meter difference in sand elevation occurs between the months.

Popham Beach west and east transects are separated by the Fox Island Tombolo which lies about 100 meters west of the first east transects. Popham Beach east transects are: PE, PSA, and PES. The PE transect is indicated by a piece of rebar adjacent from the picnic tables with a berm scarp of about 3.5 meters extending onto the beach face seaward to the low tide water mark. Popham east (figure 3.11), up until 30 meters shows little variation in sediment elevation. At around 30 meters, over the course of June, July and August the accretion of a sand bar is seen feeding the beach about .5 to 1 meter of sand to build a berm at around 35 meters. Further to the east, the PSA profile (figure 3.12) shows similar and more dramatic change than PE, with a high volume of about 1.2 meters of added sand in July. The large accretion of sand during July forms into a well-developed berm at around 70 meters in August. Furthest to the east lies transect PES (figure 3.13) displaying parallel sand volume and the development of a berm as seen in transect PSA.

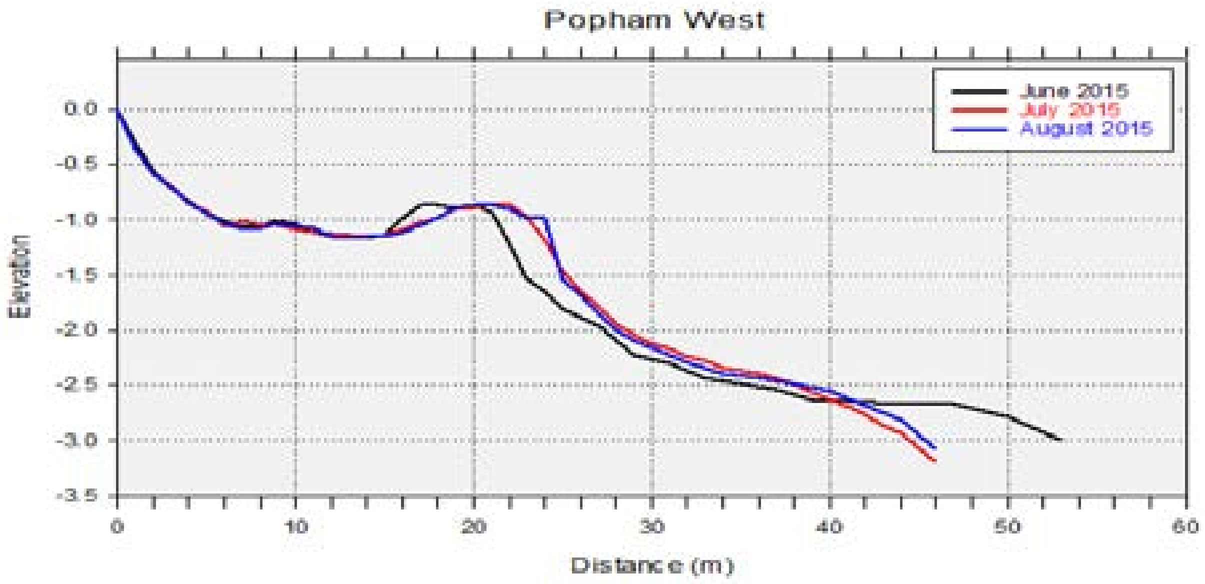

Figure 3.9 Topographic profile of Popham Beach transect PW

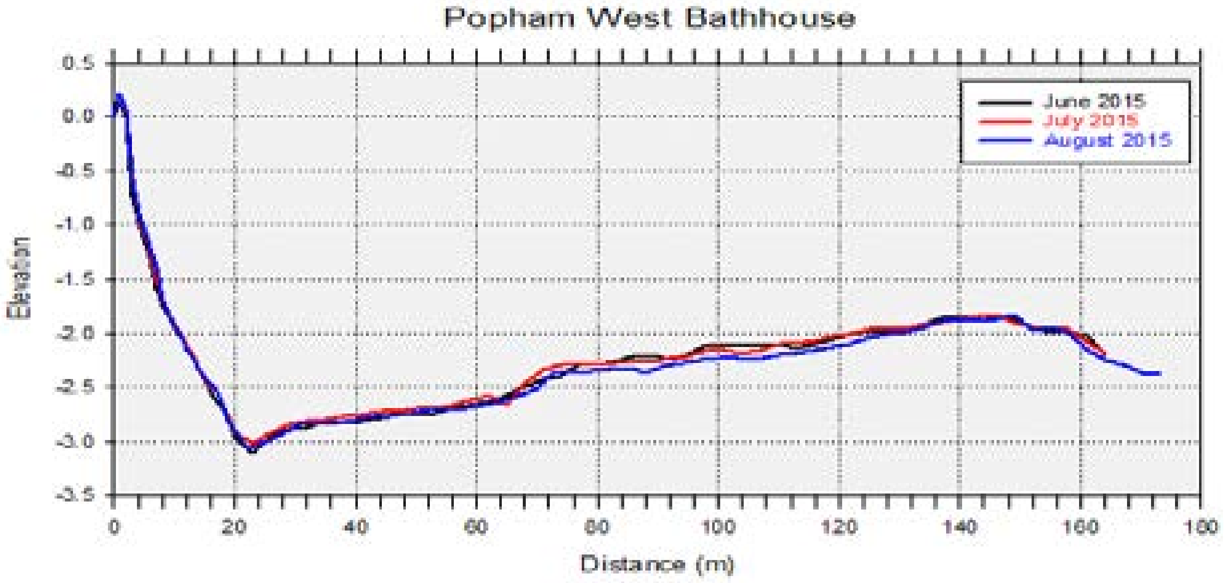

Figure 3.10 Topographic profile of Popham Beach transect PWB

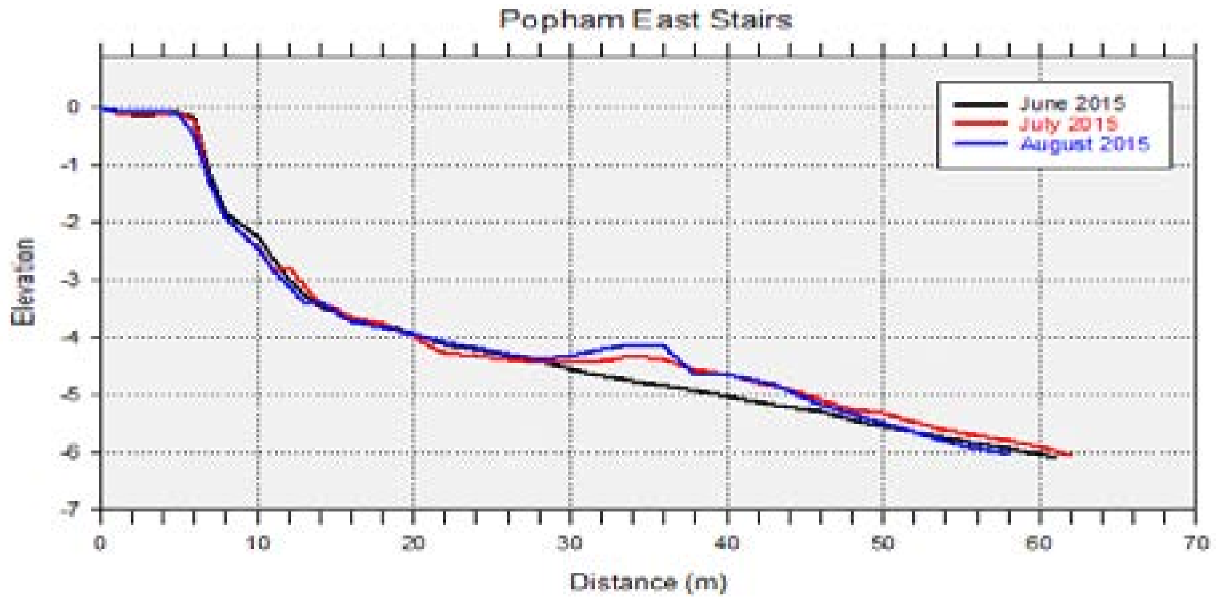

Figure 3.11 Topographic profile of Popham Beach transect PE

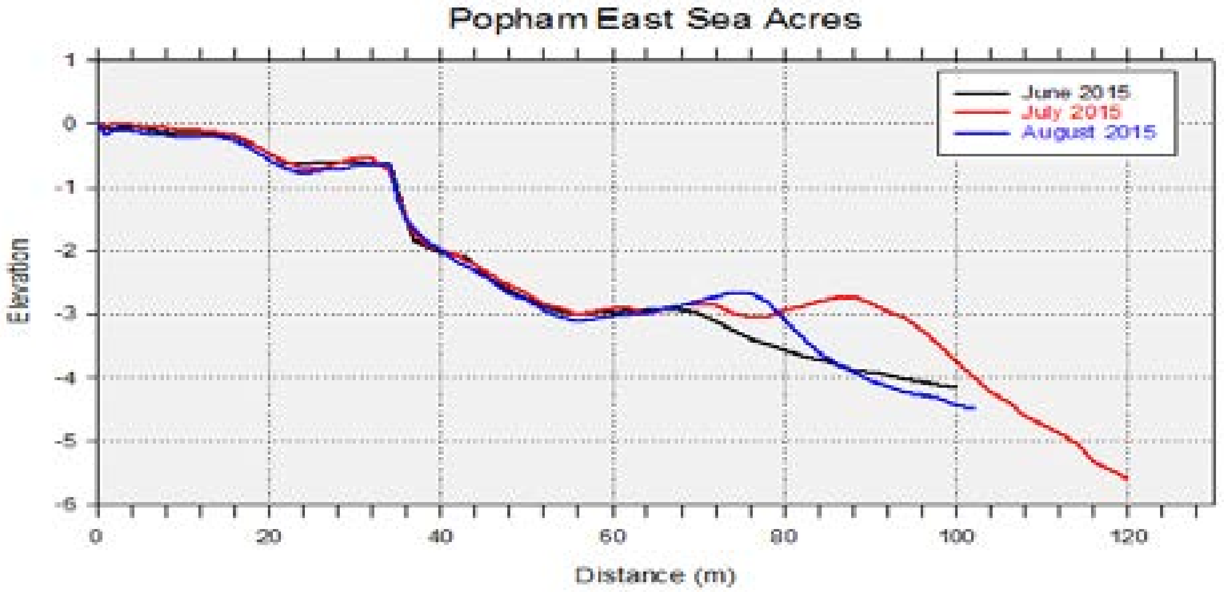

Figure 3.12 Topographic profile of Popham Beach transect PSA

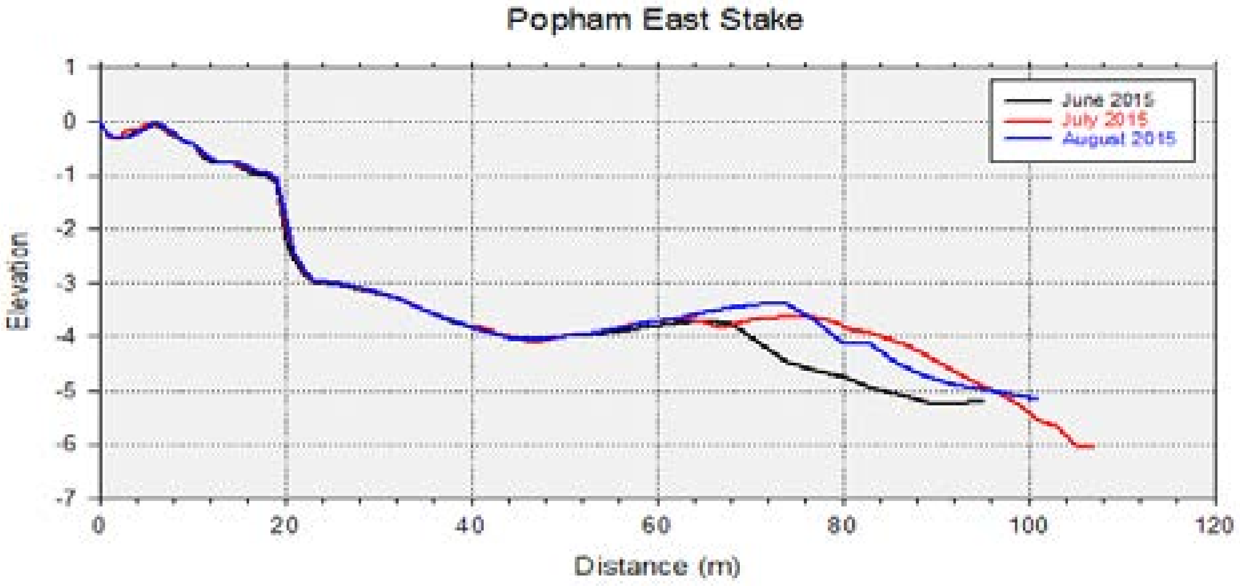

Figure 3.13 Topographic profile of Popham Beach transect PES

GPS Tracks of Frontal Dune Ridge Migration

The Popham Beach dune fronts have shown great variability over the years. Using the Trimble High-Resolution GPS unit, dune front tracks were taken during the months of June, July, and August. Satellite images from 1990 to 2015 have been compiled in order to show dune front recession, represented in figure 3.14. Each colored line corresponds to varying years: 1990 (blue), 1998 (purple), 2003 (green), 2007 (yellow), 2010 (orange), and 2015 (pink). Dune front lines prove not to be consistent throughout the entirety of their track. From west to east, most variability is concentrated to the west and most middle section of the beach, with the east containing less change. Furthest west, the greatest extent line is represented by 2007 with a recession of about 139 meters landward to the 2015 track. The central recreational part of Popham Beach shows that from the 1990 track to the 1998 track there was a total accretion of about 50 meters, with the dunes migrating seaward. From the furthest extent in 1998 to the 2015 track, the greatest recessional area shows a landward migration of about 215 meters in the mid-section of the beach. To the east the greatest dune extent is represented in 2003, with a landward dune recession of about 64 meters by 2015.

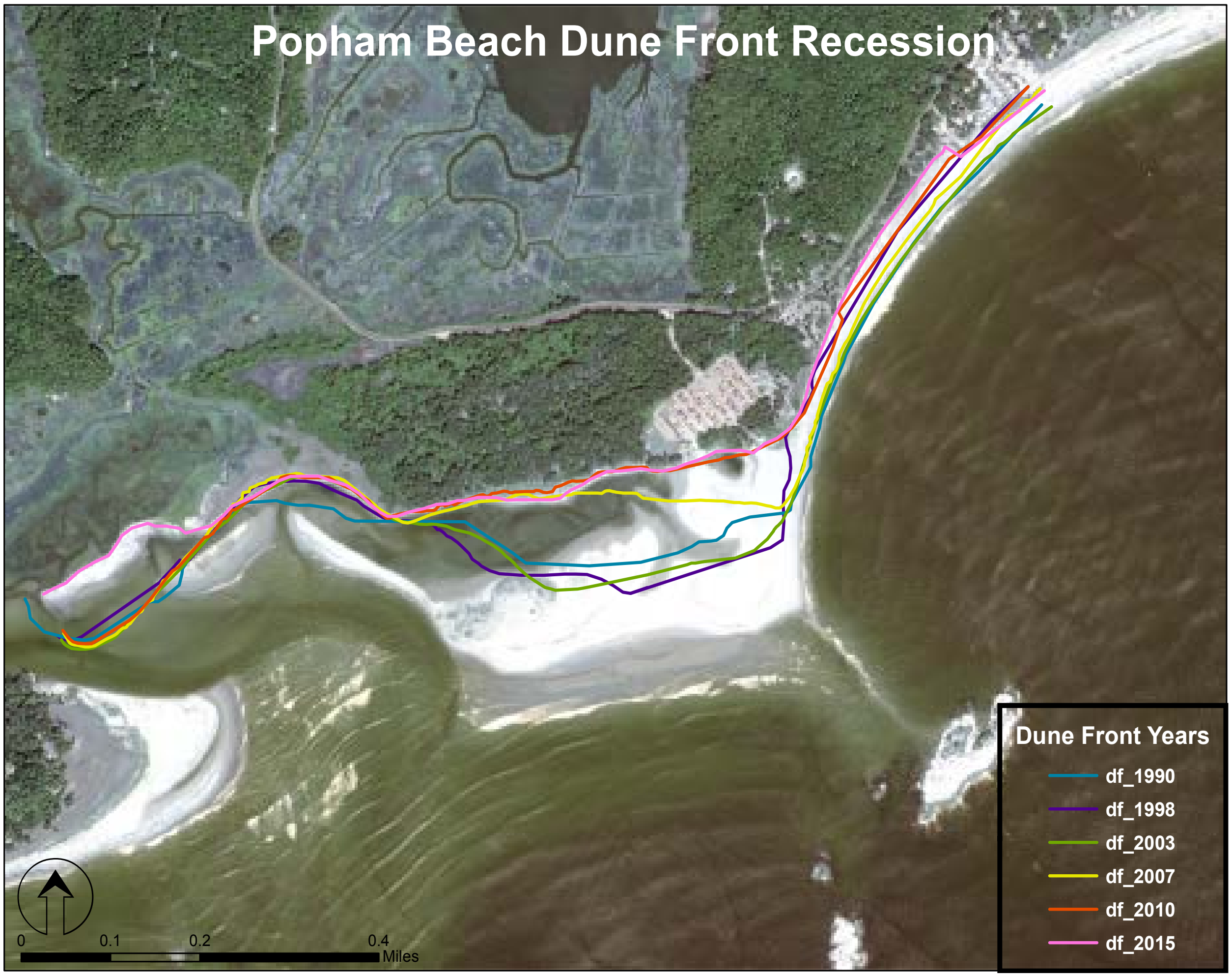

Figure 3.14 Popham Beach Dune Front Recession map, showing dune migration from 1990-2015, overlain on a 2015 ortho image

Chapter IV. Discussion

BARRIER BEACH PROCESSES

Barrier beach systems are dynamic by nature and are always in a constant state of flux due to their sandy composition and interactions of wind, waves, and longshore currents as well as the presence of tidal inlets and their regimes (Davis and FitzGerald, 2004). Changes seen at Popham Beach, Seawall Beach and the accompanying pocket beaches, Little Beach and Icebox Beach occur on a temporal scale with long term and short term processes. The varying contributing factors associated with long term and short term change seen at these beaches and adjacent pocket beaches are: tidal inlet migration, seasonal rebuilds, sea level rise, along with, meteorological and hydraulic processes.

GENERAL BEACH RESPONSE

Seawall Beach and Adjacent Pocket Beaches

Topographic profile data were collected from five transects from June to August 2015. During this surveying period, general topographic measurements revealed a typical summer morphology for Seawall Beach. This trend displayed the rebuilding of the beach system from an end of the winter profile to a summer profile depicting a period of consistent accretion along the entirety of beach face along with the development of well-defined berms. Rates of accretion along the beach face remained relatively consistent between east and west transects, with the exception of W500. Profile W500 showed increased rate of accumulation in comparison to profiles: W100 and W300. This trend of increased sedimentation along W500 is well documented by Cary (2005) and Chandler (2009) in a bathymetric map, portraying the nearshore region of Seawall Beach.

The beaches directly influenced by the nearshore bathymetry and its role in the change of wave energy and reorientation are: Seawall Beach and the adjacent Barrier Pocket Beaches, Little Beach and Icebox Beach. Due to the bathymetric nearshore region of Seawall Beach and Cape Small as well as the accompanying Sprague River Inlet Channel, Little Beach and Icebox Beach showed varying trends along their topographic profiles. With the protection of a built up sand platform from the Sprague River Inlet Channel, Little Beach experienced little change over the course of the study period (figure 3.6). However, due to the shifting of the Sprague Channel and its bedrock bound flow, Icebox Beach exhibited erosion along the foreshore.

Topographic Trends and Near Shore Region

Although topographic profiles along Seawall Beach show similar accretionary trends, not all profiles share the same accumulation rate. These varying accumulation rates can be attributed to Cary's (2005) nearshore bathymetric map (figure 4.1). Due to the bedrock outcrops in the nearshore region waves are being refracted and the orientation in which waves are approaching the beach have shifted, making Seawall Beach generally a swash-aligned barrier beach system (FitzGerald et al., 1989).

Using the nearshore map to better understand the varying rates of sedimentation, Cary concluded that the increased rates of accumulation seen along W500 are attributed to the outlying bedrock outcrops. Due to the presence of these nearshore outcrops and the location of transect W500 along the beach face, varying accumulation rates are attributed to wave refraction, sediment dissipation and longshore transport of suspended sediment. Cary (2005) and Chandler (2009) both recorded increased rates in sedimentation along profiles W500 and W1500, with contrasting results of erosion at W1100. With the consistent trends seen at W500, W1100 and W1500 profiles, Cary's schematic aids in understanding the discrepancy seen in sediment patterns working at W500.

Through the study of the nearshore region of Seawall Beach, Cary (2005) noted inhibiting factors along the way in which waves approached the beach. Figure 4.1, shows these zones in yellow, while areas uninhibited from bedrock outcrops are considered wave corridors (in blue). Waves uninterrupted by bedrock outcrops and the Cape Small headlands (wave corridors) experience more direct wave energy, in turn having a greater effect on the beach face. However, areas sheltered by these outcrops experience wave energy dissipation due to wave refraction, therefore having a lesser effect on the beach face and profiles in these zones. According to measurements taken by Cary (2005) and Chandler (2009) at profile W1100, increased rates of erosion are seen, confirming the presence of the southwestern wave corridor and the effect of strong unaffected wave energy. In contrast to the erosion seen taking place at W1100, W500 shows varying trends of increased accretionary rates- higher than W300 and W100 as well. Therefore, waves experiencing wave refraction show lesser signs of erosion due to the dissipation of wave energy. Concluding that areas, such as the southwest wave corridor, with more direct wave energy affecting the beach face (W1100) cause sediment to be eroded, suspended, and transported. From here, the suspended sediment is transported, via longshore transport, and deposited to the adjacent profiles, W1500 and W500, areas inhibited by nearshore bedrock outcrops.

In comparison to previous work done at these beaches Seawall Beach east and west transects have shown similar trends over the years. The similarities seen along Seawall Beach transect W500 from 2002 to present are seen in figure 4.2. This comparison chart shows similar sediment accumulation trends along the beach face with little characteristics attributed to a summer beach profile, such as, a well-defined berm. However, a clear landward migration of the dune system from 2002 to 2008 can be seen, leading to the conclusion that over the long term, W500 has retreated the most. In contrast to the non-typical summer profile seen consistent over the years at W500, E200 (figure 4.3) depicts a profile, characteristic of a summer building beach with the welding of a large body of sand and a well-developed berm.

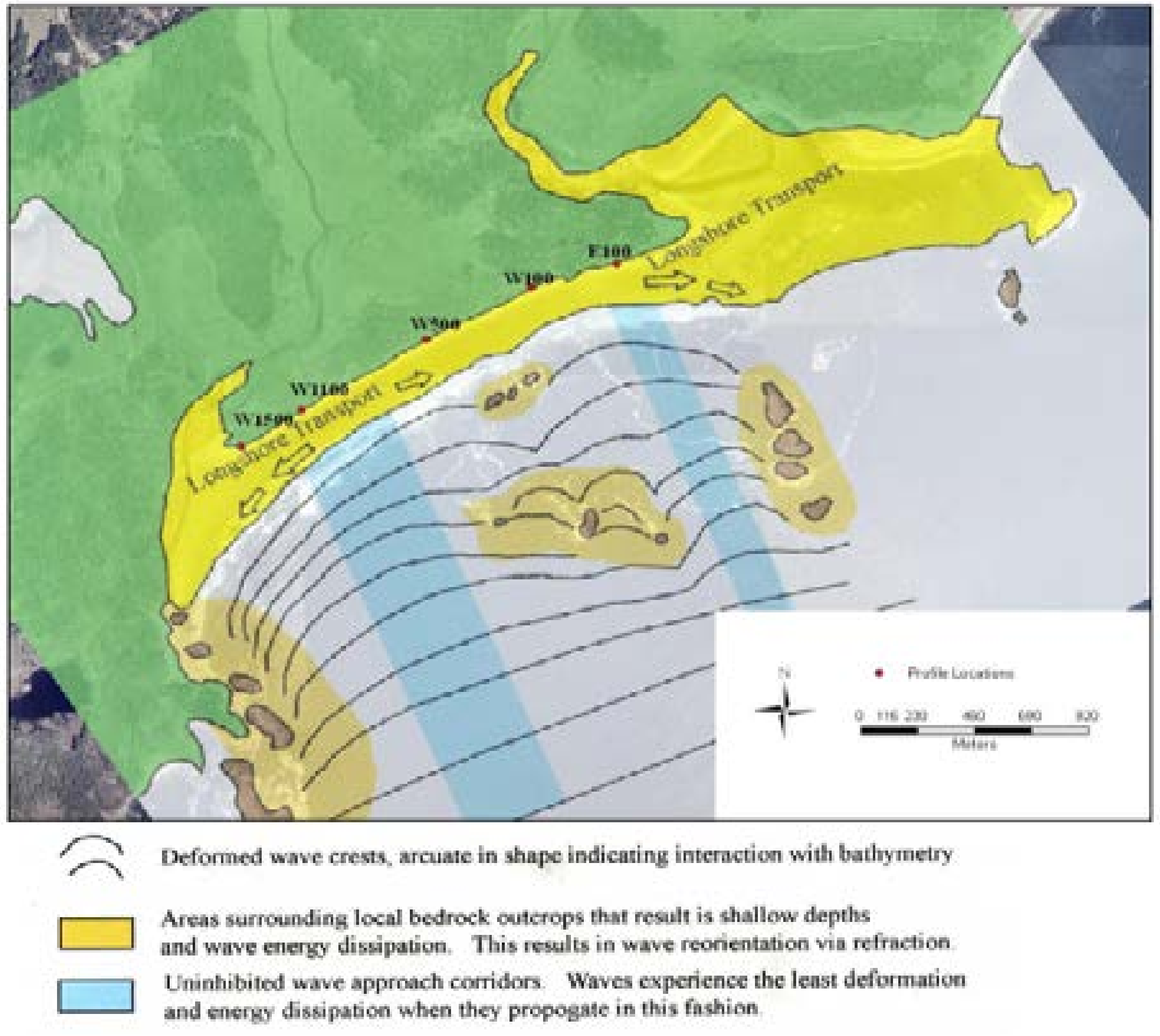

Figure 4.1 A near shore bathymetric map of Seawall Beach created by Cary (2005) and refined by Chandler (2009)

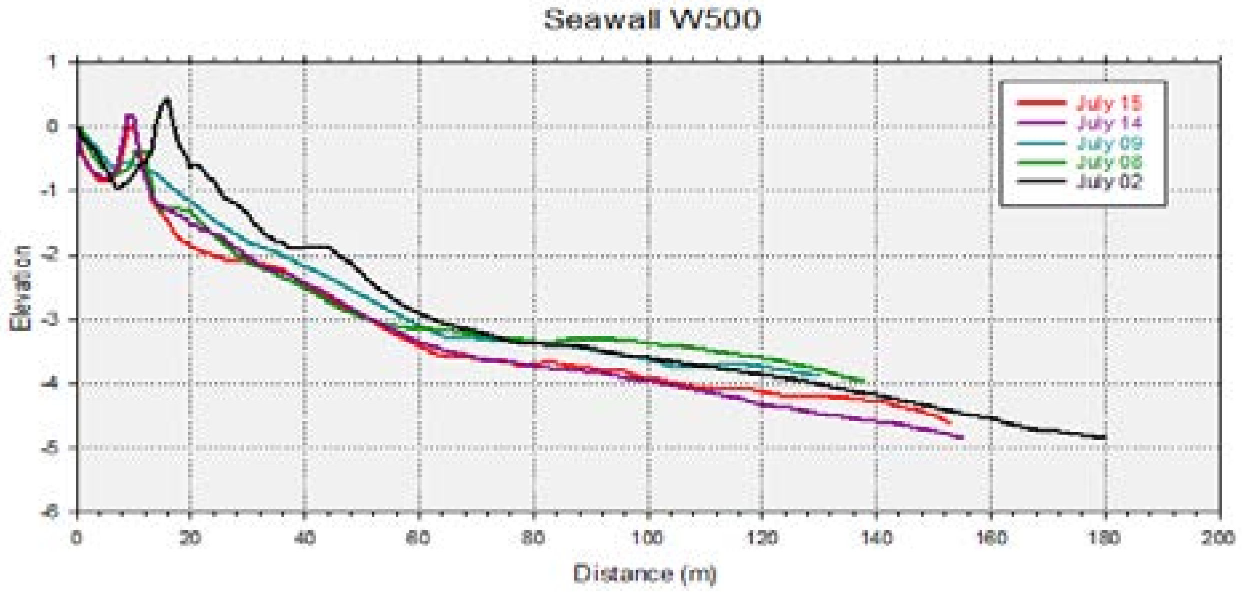

Figure 4.2 Comparison topographic profile of Seawall Beach transect W500, showing trends from 2002-2015

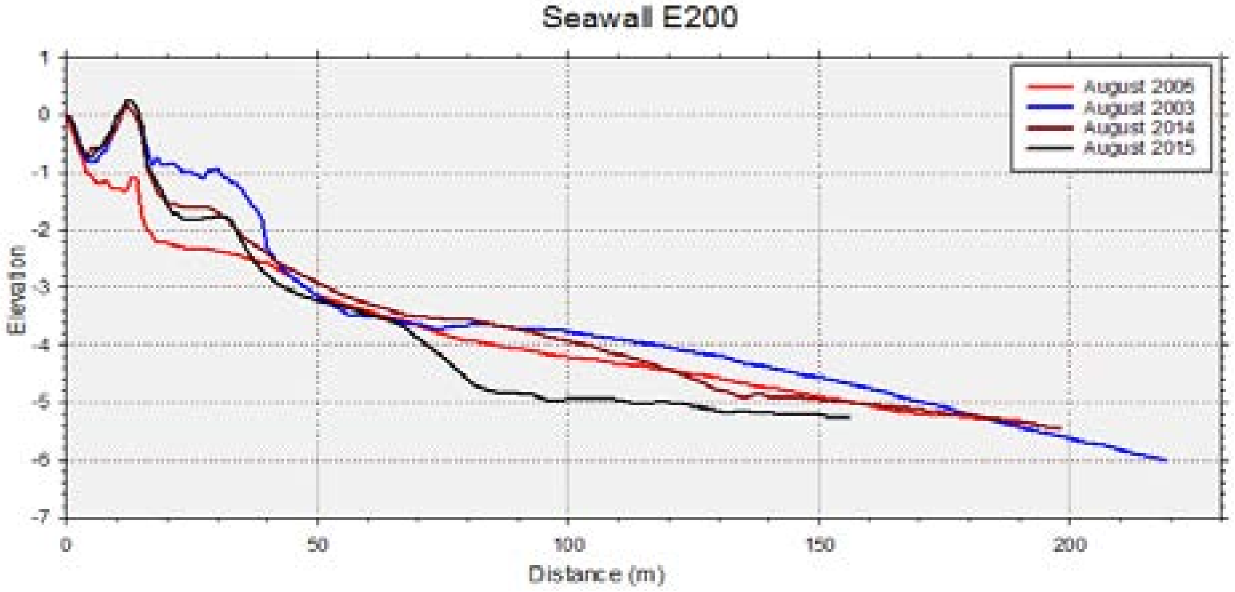

Figure 4.3 Comparison topographic profile of Seawall Beach transect E200, showing profiles from 2003-2015

BARRIER SPIT SHIFTS AND RIVER CHANNELS

Seawall Beach as portrayed in the diagram by Cary (2005) depicts a parallel approach of waves to the beach face within the wave corridors. On either end of Seawall Beach there is a presence of a barrier spit; indicative of some form of littoral toward the spit end, which can be attributed to the wave corridors high energy waves picking up sand, contributing sedimentation to the barrier spits (Nelson and Fink, 1980). As a result to the wave refraction occurring along the bedrock outcrops and Cape Small headlands surrounding Seawall Beach and the transport away from the noted wave corridors and towards the southwest and northeast along the beach, sediment is deposited at the extent of the beach system forming spits; pushing the inlet channel against the bedrock (FitzGerald et al., 1989).

Using time-lapse photography taken from the Cape Small Headlands and historic satellite images of the Sprague River Inlet channel it is evident that the channel is dynamic and migratory. The “Sprague River Inlet Migration” map by Chandler (2009), highlights the constant meandering of the inlet channel around two separate sandbars located landward behind the barrier complex (figure 4.4). From 1953 to 2009 a constant shift between landward and seaward meandering and migration of the inlet is seen along the barrier complex. The Sprague River has historically varied in position from an easterly position to a more westerly position, against the Cape Small headland (figure 4.5). This position of the channel against the headlands is due to the southwest and northeast positioning of the outwardly extended spits (Dickson, 2008). However, the dynamic nature of this channel during the surveying period is best portrayed in a series of time-lapse photographs from the months of June to August, taken from the headlands of Cape Small (figure 4.6). Since profiling began during the summer of 2015, the path of the Sprague River has shifted from a course lying eastward in direction, to a course of confinement along the bedrock headlands of Small Point.

Over the course of the river inlets westward migration towards the Cape Small bedrock cliff during the study period, the channel is seen meandering away from Little Beach and along the beach face at Icebox Beach. In 4.6 the channel bends seaward, away from Little Beach and further north cutting back along the headlands. However by image 4.6a a “cut bank” characteristic present with the growth of a sand bar. In image 4.6c the channel widens along with the desertion of the meander and the addition of the channel cutting completely through the sand bar slightly below the meander and jutting directly to the Cape Small bedrock. Further north, beyond the pictured channel migration zone, lies Icebox Beach. The period of extreme channel shift experienced along the Cape Small headland, during the summer months, is a contributing factor to the erosional trend measured at Icebox 1 (figure 3.6). This trend shows that as the river began to meander closer and closer to the headland, until its final cut across the sand bar, sediment along Icebox 1 began to gradually erode. However, during the time of these shifts, Little Beach is protected by a large sand barrier platform from any erosional influences of the channel, thus keeping sedimentation along the transects consistent. Comparing past years, it is clear that the profiles of Icebox Beach (figure 4.7) and Little Beach (figure 4.8) are constantly being reworked and are greatly influenced by the position of the Sprague River Inlet.

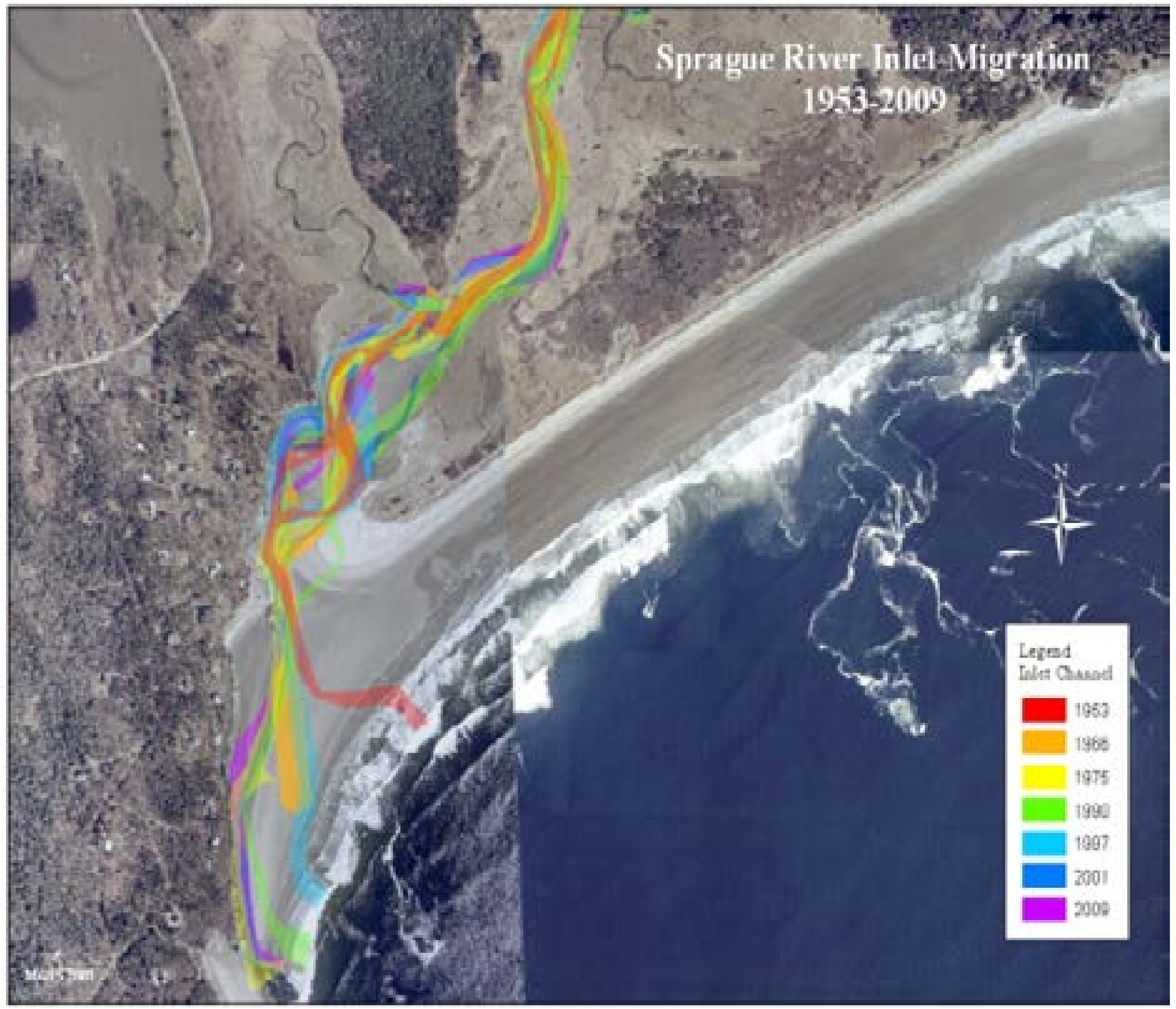

Figure 4.4 Historical record of the Sprague River Inlet migration from 1953-2009 (Chandler, 2009)

Figure 4.5 Historic shifts in the Sprague River Inlet seen through satellite photography from 1997-2015

Figure 4.6 Time lapse photographs of the Sprague Inlet Channel in front of Little Beach. (A-top left; B- top right; C- bottom left; D- bottom right)

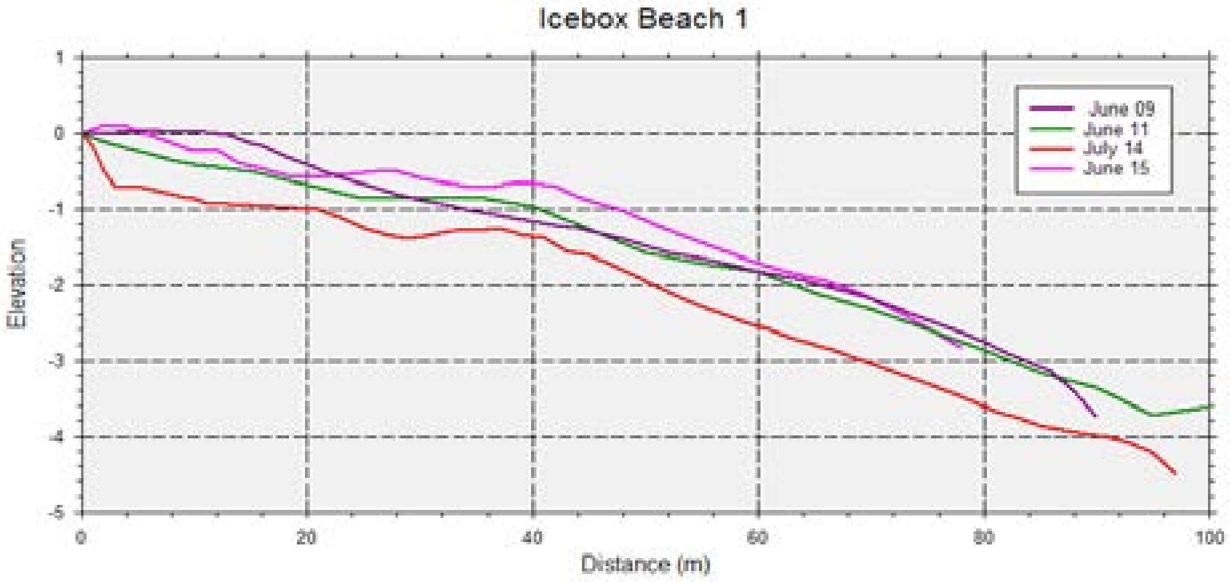

Figure 4.7 Comparison topographic profile of Icebox Beach transect 1 from 2009-2015

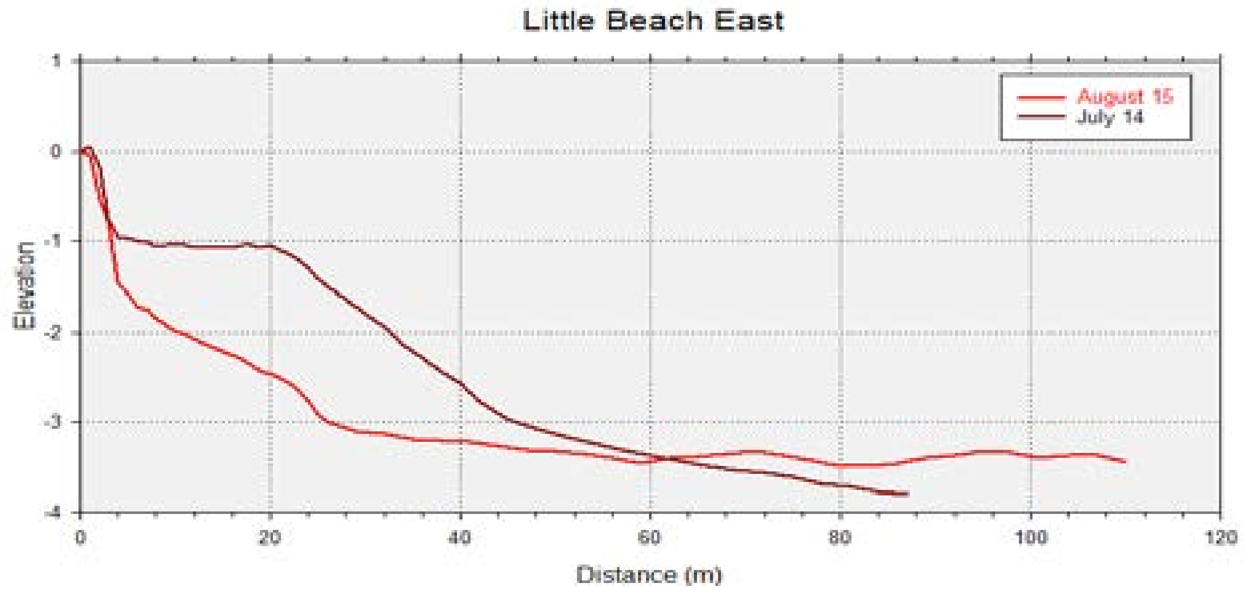

Figure 4.8 Comparison topographic profile of Little Beach East from 2014-2015

GENERAL BEACH RESPONSE

POPHAM BEACH

All eastern Popham profiles over the study period showed the beach rebuilding from an end of winter profile into a summer profile, with the addition of an offshore sandbar welding onto the beach face as well as, the development of well-defined berms (figures 3.11-3.13). To the west, past Fox Island, Popham west profiles showed varying trends with PWB showing patterns of erosion starting at the toe of the dune, while PW showed minimal signs of erosion but rather a large build up from June (figure 3.9-3.10). Some variability on west Popham can be attributed to the encroachment and widening of the Morse River Inlet Channel cutting through the upper beach face.

Sediment Sources and the Gyres Effect

The modern-day output of the Kennebec River estuary and the offshore lowstand Kennebec River Paleodelta serve as the main sources of sedimentation for the Popham Beach barrier complex (Fenster & FitzGerald, 1995; FitzGerald et al., 1989). It was through the reworking of these fine-sandy sediments onto the shore face that Popham Beach was formed (FitzGerald, 1987). The sediment along Popham Beach State Park is deposited by a large clockwise sediment gyre, known as the Hunnewell Beach Sediment Gyre.

The Hunnewell Beach Sediment Gyre exists out of the mouth of the Kennebec River in a straight flow until it begins its clockwise circulation pattern along Popham Beach and in the offshore region (figure 4.9) (FitzGerald and Fink, 1987). Sedimentation along the southward-facing beach, Hunnewell, is “transported in a net easterly direction by dominant easterly longshore currents” (FitzGerald et al., 1989). Sediment flows out of the Kennebec River mouth and moves southward between Pond Island and Wood Island, where it then turns clockwise, passing Fox Island continuing east along the offshore bars where it completes in circulation. Between Pond and Fox Islands, an “outer bar” deposit occurs where ocean waves break regularly. Through the continuation of waves breaking along this bar, along with easterly storms that break within this zone, sand from this bar feeds into smaller bar complexes that ultimately weld onto Hunnewell and Popham Beaches (Kelley, 2012; Fenster and FitzGerald 1995). It is through this gyre that shoreline propagation and erosion can be accounted for along Popham Beach.

Along Popham transects PE, PSA, PES, measurements and profiles indicate the process of the outer bar welding onto the beach face, with increased levels of sedimentation and the large volume of sand forming into well-developed berms over the course of 3 months. This landward migration and attachment of the bar complex to the beach completes the clockwise sediment gyre and is well documented during the period of study. However, in previous studies conducted by Newton (2011), approximately 5 years ago, she did not see measurements accompanying the attachment of a sand bar but rather, increased rates of erosion in areas usually noted for their erosional characteristics. According to FitzGerald et al (1989), this is a process that occurs every 6 to 10 years, and has been repeatedly recorded during the past 30 years.

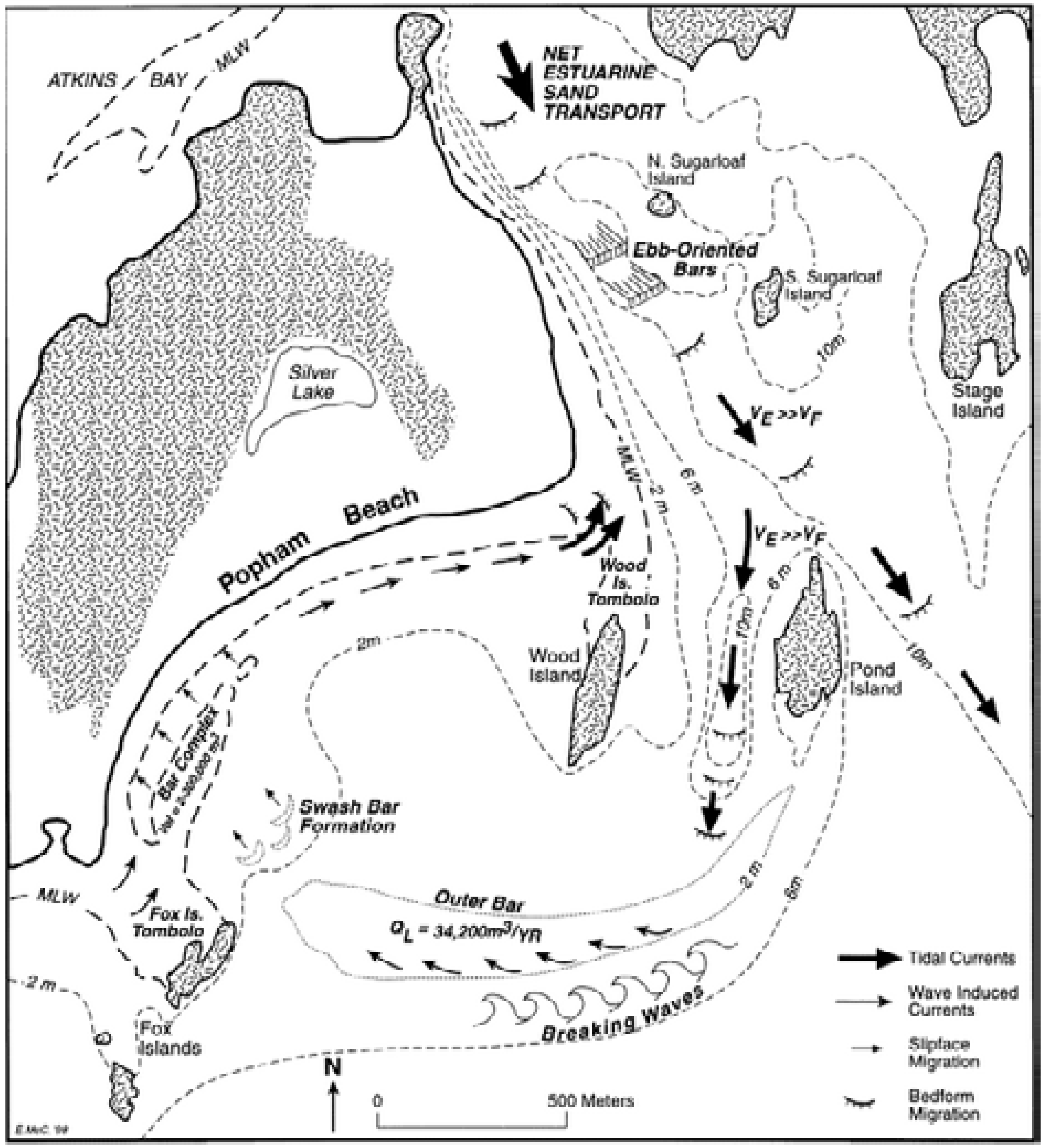

Figure 4.9 Summary diagram of net and transport trends at the mouth of the Kennebec Estuary. Indicated by bedform orientations, bar migrational trends, and dominant current directions (FitzGerald et al., 2000)

Historic Shoreline Changes

The Popham Beach shoreline complex studied has undergone significant changes over the past couple decades. The Popham Beach complex studied is composed of two beaches: State Park extending from the west to the Fox Island tombolo and Hunnewell Beach to the east of Fox Island. Kelley (2013) studied the various changes that have occurred to the shoreline and recreational area of Popham Beach from 1953-present.

The Popham Beach shoreline, due to its varying sand sources and reservoirs, is very dynamic and has dramatically changed throughout history. As early as 1856, the Hunnewell Beach shoreline showed an extremely landward position. However, by 1942 Hunnewell had accreted significantly along with some small recession accounted for at State Park. Just over 10 years later in 1953, the State Park eroded dramatically with some loss of the maritime forest while less erosion was seen at Hunnewell Beach. Although State Park Beach and Hunnewell beach showed inverse accretion/erosion phases, by the 1990's both beaches were seen experiencing sand accretion along their beach face (Kelley, 2012). The recession of the Popham Beach State Park shorelines and dunes has continued to vary significantly over the years with an overall landward migration (figure 3.14). From 1990-2015 Popham West's recreational beach has seen about an overall 200m landward migration of the frontal dunes with the 1998 dune location displaying its most seaward position. East Popham displays similar trends as west Popham with an overall landward migration of the dunes, but with lesser migrational rates. An overall, landward migration of the Popham Beach dune fronts has continuously and looks to continuously impinge towards State Route 209 on the east and the bathhouse on the east.

Morse River Tidal Inlet Migration

One of the biggest contributors to the changing Popham Beach shoreline over time is the Morse River Inlet; very dynamic by nature. More specifically, the Morse River main ebb tidal delta constitutes for much of the change see along Popham. This undeveloped tidal delta is controlled "by the shifting location of its main ebb channel over time" (Kelley, 2012). The beach is affected by two varying shifts in the inlet; when the inlet heads seaward in a more westerly direction, sand accretes the State Park, juxtaposed to that position, when the inlet migrates to the east it erodes the State Park (Kelley, 2012). However these shifts in the tidal inlet affect State Park, the adjacent Hunnewell Beach complex does not always express the same change. Therefore, changes in the Popham profiles do not always reflect one another on the west and east ends of the beach. State Park, through aerial photography shows that the inlet is currently situated in an easterly position. Though not as extreme as 1953, the position of the inlet during the study period did account for small amounts of erosion and inconsistency throughout the 3 months surveying period.

Throughout the years in which Popham Beach and its accompanying River Inlet have been monitored, observations about the changes occurring throughout the Inlet have been well documented through satellite imagery (figure 4.10). In 1997, the Morse Inlet Channel is displayed with a meandering bend about 680m from the bathhouse, where by 2002 the Inlet cut across the west end of Popham Beach directly in front of the bathhouse. It was due to this shift of the River Inlet that Popham Beach west experienced increased rate of erosion. Fear of the bathhouse being eroded away by the river were plausible up until 2010 when the River cut through the outer sand spit. The Morse River now flowed out through the new cut feature while west Popham began accreting sand again. Today it is the main ebb channel that flows along Popham west with little erosion accompanying. Therefore, these images confirm that the positioning of Morse Rive ebb channel leads to excessive erosion or accretion of the State Park beach face. Over the last half century, continuous inland migration and seaward accretion of the State Park shoreline has been largely due to the easterly and westerly excursions of the Morse River (Dickson, 2010).

Figure 4.10 Satellite images displaying the different shifts in the Morse River Inlet Channel from 1997-2012

Sea level affects along Popham Beach & Future Predications

Sea level rise as a long term factor affecting the beaches of coastal Maine have been recorded and studied over the past decades. Studies have shown a steady sea level increase of 2mm/yr. However, along the Northeast Coast of North America, north of New York City, coastal sea levels have displayed an extreme increase in SLR during 2009-2010, on the long term tidal gauge records (figure 4.11). An extreme increase of sea level rise jumped by an unprecedented 128mm during this 2-year period. With SLR indicating the interannual sea-level changes. Two factors have been identified as contributing factors to the extreme increases: a “30% downturn of the Atlantic meridional overturning circulation and the wind stress anomalies associated with the significant negative North Atlantic Oscillation index,” along the east coast of North America (Goddard et al., 2015).

The Northeast Coast of North America (North Atlantic Ocean) sea levels are greatly influenced by the Atlantic meridional overturning circulation (AMOC) (Goddard et al., 2015). Satellite altimetry data collected by Goddard et al (2015) shows that most of the variability seen in the interannual dynamic sea level occurs at the ocean interior, most specifically along the Gulf Stream (figure 4.12). The Popham Beach shoreline and dune front migration, located along the Gulf Stream, shows that during a 3-year period spanning from 2007-2010 there was a recession of 82m by Fox Island and a 34m on east Popham. However, over a longer time period, from 2010-2015 a recession of 84m is seen in front of Fox Island along with only a 32m migration to the east. Therefore concluding that during the period of increased sea level, Popham Beach shows slight increased characteristics of sea level rise, such a shoreline and dune migration, even without the apparent weather processes.

Although, sea level rise as remained rather constant over the years with the exception of the unprecedented jump seen in 2009-2010, increased rates can be predicted to occur. As Goddard et al (2015) explain, “similar to extreme temperatures and precipitation events SLR events on the interannual time scale may be also linked to human-induced climate change.” Therefore, with increasing rates of anthropogenic outputs of greenhouse gases and increasing rates of CO2 in the atmosphere, sea level with be directly influenced. These influences in turn will contribute to increasing rates, although the exact rates are unknown, of global sea level rise.

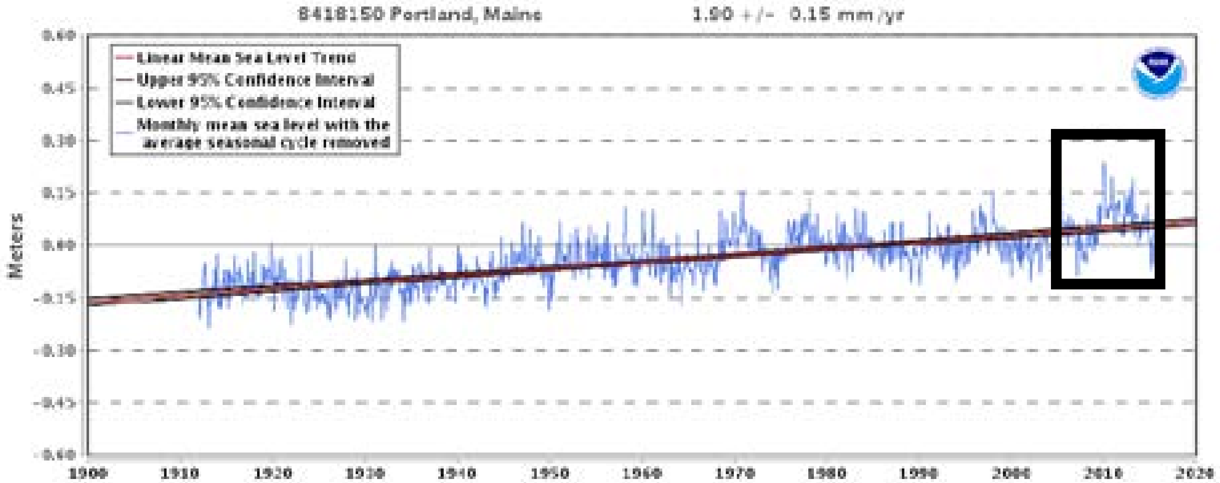

Figure 4.11 Mean sea level trends in mm/yr, based on monthly mean sea level data (NOAA, 2013)

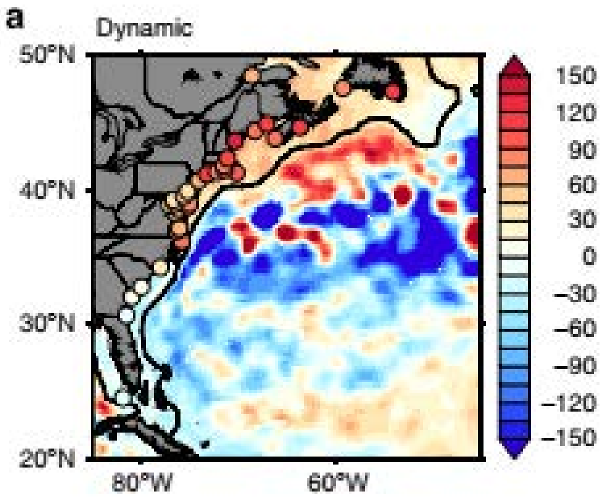

Figure 4.12 Satellite altimetry data showing sea-level increase (mm) between 2008-2010.

Chapter V. Conclusion

Surveying during the months of June to August at Popham Beach, Seawall Beach, Little Beach, and Icebox Beach lead to the understanding of the beaches seasonal processes. Most of the beaches between June to August accreted sand and developed a strong berm over a period of no storms and a mild wave climate persisted. \ A comparison of Seawall Beach over a long time scales shows the affect of the nearshore region on the beaches' general response to seasonal changes. Due to the nearshore bathymetric area around Seawall varying trends occur along the west transects while the east transects present normal summer change. Popham Beach transects and Cape Small transect changes are related to the Tidal Inlets adjacent to the beaches. Popham Beach west varied over the course on three months in relation to the inland migration of the Morse River Tidal Inlet. Little Beach and Icebox beach profiles are greatly influenced by the positioning of the Sprague River Inlet.

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Recent Changes To The Dynamic Sandy Beach System At The Mouth Of The Kennebec River, Mid-Coast Maine

Bates College Geology Department Thesis

Presented to the Faculty of the Department of Geology, Bates College,
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by
Nicole Cueli
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