2.0 Nearshore Areas of Bainbridge Island

The focus of this analysis is to present information not included Battelle (2003) either because the topic was not covered in the original analysis or because new work has been published since 2003. The conceptual ecological model used in Battelle (2003) (based upon Williams and Thom 2001) is fully consistent with recent scientific literature. However, some impacts that were previously only hypothesized in Battelle (2003), have now been formally documented in the peer-reviewed literature.

The nearshore analysis is broken into two parts. The first part focuses on the general physical environment of Bainbridge Island, with particular emphasis on the effects of climate change, which was not discussed in Battelle (2003). The second part addresses specific environments on the island, which are delineated by a new method that characterizes shorelines based on geomorphological conditions. This section also includes environments not addressed by Battelle (2003), such as rocky coasts. Both of these sections provide the physical template used for the analysis of the ecological impacts of human activities.

2.1 Physical Environment

2.1.1 Climate

The climate of Bainbridge Island is maritime and typified by cool dry summers and wet winters. The background climatology of the island is well characterized by Battelle (2003). However, there has been a large volume of recent scientific literature addressing climate change and its impact on the Pacific Northwest within the last few years. Climate change has been shown to increase stream temperatures (particularly in the summertime: Mantua et al. 2010), compromise habitat restoration actions (Battin et al. 2010), change the hydrology of stream basins (Elsner et al. 2010), and increase sea level (Canning 2005; Mote et al. 2008). Altered seasonal rainfall and effects on streamflow patterns and increased stream temperatures (Mantua et al. 2010) are likely to have significant effects on Bainbridge Island. Other effects, such as reduction in snowmelt, are expected to be negligible as alterations to basin hydrology attributed to snowmelt cited by recent climate change studies are dependent on seasonal changes to the transition from spring snowmelt to fall runoff typical of Cascadian rivers (Elsner et al. 2010). Since snowmelt is a negligible contributor to stream flow on Bainbridge, snow-based hydrologic effects are expected to be inconsequential on the island.

It has been shown that total precipitation will increase by the 2040s in the Puget Lowland, but this precipitation will fall increasingly in the winter, resulting in reduced summer precipitation and therefore lowering summer streamflow (Elsner et al. 2010). Because most of the work done on climatic effects on streamflow hydrology has been focused on the larger rivers that still tap snowmelt in a significant way (Elsner et al. 2010, Mantua et al. 2010, Battin et al. 2010), the influence of changing precipitation resulting from climatic change on the small streams on Bainbridge Island is uncertain.

Sea level rise is produced by the combined effects of global sea level rise and local factors, such as vertical land deformation (e.g., tectonic movements) as well as seasonal seawater surface elevation changes due to atmospheric circulation effects (Mote et al. 2008). In the case of Bainbridge Island, there is slight tectonic subsidence (Verdonck 2006), which somewhat increases the overall effect of global sea level rise (Canning 2005; Mote et al. 2008). This explains the relatively modest sea level rise observed at nearby Seattle in the twentieth century (2.06 mm/year: NOAA 2010), which would be indistinguishable from sea level rise observed on the island. It is important also to couch these changes in terms of interannual sea level variability associated with El Niño. Mojfeld (1992) has shown that during El Niño years the average water level can be up to one foot higher than in ordinary winters. This explains why (in light of sea level rise) the highest ever water level in Seattle was recorded in the early 1980s (NOAA 2010). It is unclear whether, and how, this particular effect will change in the future.

2.1.2 Waves and Currents

The overall oceanographic context of Bainbridge Island is well summarized by Battelle (2003). However, two recent observational studies have better documented conditions within Puget Sound and on the island (Finlayson 2006; Curtiss et al. 2009). As hypothesized in Battelle (2003), waves are the dominant mode of sediment transport alongshore for most of the County's shorelines (Finlayson 2006; Curtiss et al. 2009). It is likely that in areas where tidal currents are in excess of one knot or where vessel wakes are large (e.g., Rich and Agate Passage), tides and vessel wakes may play a secondary role (Curtiss et al. 2009). However, for most of the island, waves are generated exclusively by local winds, just as they generally are within the confines of Puget Sound (Finlayson 2006). As documented by these studies, the short-period, locally generated waves typical along the shores of Bainbridge Island are steep and can generate significant local shear stress (a physical process that strongly influences sediment transport), but these waves do not penetrate far down into the water column. This is important because any man-induced alteration of the wave's characteristics by the placement of structures along the shoreline could potentially affect the way sediment is transported although generally only along the portion of the shoreline where the influence of the waves is felt, due to reflected and refracted wave energy. For a full discussion of the physical impacts of shoreline armoring, see Section 5.1.1.

2.1.3 Geology

Geology was not addressed in detail by Battelle (2003), partly because much of the work characterizing the geology of Bainbridge Island has been published since 2003 (i.e., Nelson et al. 2003a; Hagerud 2005; Kelsey et al. 2008; MacLennan 2010). In particular, the Seattle Fault Zone, which crosses the southern end of the island, has recently been the subject of intense study. The geophysical origin of the fault system is related to north-south shortening of the Cascade forearc (Wells et al. 1998). Uplift along the Seattle Fault Zone has displaced Eocene rocks 8 to 10 kilometers higher than similar rocks underlying the Seattle Basin and Bainbridge Island to the north (Blakely et al. 2002). Nelson et al. (2003a) identified the Toe Jam Hill Fault as a north-dipping backthrust of the Seattle Fault Zone. The recurrence of slip on the Toe Jam

Hill fault has also been investigated by trenching the surface expression of that fault, which is apparent in LIDAR (Nelson et al. 2003a). The potential for blind thrusts (i.e., faults that do not have a surface expression) to be related to the Seattle Fault Zone has been investigated by Kelsey et al. (2008). This work found that blind thrusts are likely associated with the fault zone and interact with the surface faulting over geologic time scales. The locations of potential blind faults cannot be predicted until they break the surface, thereby imposing a seismic hazard uncertainty within the Seattle Fault Zone, south of Winslow.

In addition to these focused studies on the Seattle Fault Zone, the overall geology of the island was recently mapped and described by Hagerud (2005). As is typical of high-resolution geologic maps (i.e., 1:24,000 maps), a narrative description of the recent geologic history is provided, including the most recent glacial advance and its relationship to underlying sedimentary deposits and bedrock. MacLennan et al. (2010) mapped the feeder bluffs throughout the island, and Hagerud (2005) and MacLennan et al. (2010) describe the site specific details of shoreline geomorphology throughout the island, which is useful for understanding the geologic context of human modifications and their impact on the nearshore environment.

2.2 Nearshore Classification System

Battelle (2003) did not use any formal geomorphic classification scheme, but rather organized their literature around common island shoreforms (e.g., spits, marshes, etc.). Williams et al. (2004) used a geomorphic classification system based upon Terich (1987) to characterize all Bainbridge Island shorelines. A classification system was recently assembled by Ecology to reflect the most recent advancements in nearshore geomorphology (Shipman 2008). The Shipman (2008) classification scheme is hierarchical, with geomorphic systems comprised of different landforms, which each have a set of components. Shipman (2008) points out that this is the most effective means to identify the impacts to species from physical modifications. The new classification scheme is nearly identical and broadly consistent with Terich (1987); in fact, this earlier work was used as a template for the more recent, broader effort. However, because Battelle (2003) used somewhat different terminology than Shipman (2008), it is important to link the shoreline types developed in the Williams et al. (2004) characterization with the geomorphic systems in the new classification scheme. Table 1 summarizes how these two classification schemes interrelate.

Shipman (2008) divides Puget Sound shorelines into four broad geomorphic systems: 1) rocky coasts, 2) beaches, 3) embayments, and 4) large river deltas. Bainbridge Island has a relatively limited amount of rocky coast, but there are some shorelines that exhibit these characteristics along the southern edge of the island within the Seattle Fault Zone. Rocky coasts were not discussed in Battelle (2003), so a complete characterization is covered in this addendum.

Beaches and embayments are common on Bainbridge Island shorelines. Although these environments were addressed by Battelle (2003), updates of the latest science are provided for these areas because of their relative importance and the quantity of research that has been conducted since 2003. Finally there are no large river deltas on Bainbridge Island, but there are a number of small creek deltas. Smaller creek deltas were addressed by Battelle (2003), but because of the relative lack of more recent research about them, they are not treated in depth in this addendum.

Table 1. Comparison of the nearshore geomorphic classifications schemes used by Shipman (2008) and Terich (1987).

Primary Document	Williams et al. (2004)	This Study
Geomorphic classification scheme	Terich (1987)	Shipman (2008)
Geomorphic systems (shoreline types)	Rocky	Rocky coast
	Marshes/lagoon	Embayment
	Spit/barrier/backshore	
	Low bank (and beach)	Beach
	High bluff (and beach)	

2.3 Nearshore Geomorphic Systems

The following nearshore geomorphic systems are those described by Shipman (2008) (see Figure 2). Only those nearshore geomorphic systems with substantial occurrence on the island are included along with discussions of scientific advances made since 2003.

2.3.1 Rocky Coasts

Rocky coasts are relatively rare on Bainbridge Island, but they represent an important environment at the southern end of the island within the Seattle Fault Zone. Shipman (2008) identified three landforms that typically occur along rocky coasts in Puget Sound: 1) plunging, 2) platform, and 3) pocket beaches. Plunging shorelines are virtually non-existent on Bainbridge Island, with the possible exception of a few small promontories at the east end of the Seattle Fault Zone. Most of the rocky coasts on Bainbridge Island are a hybrid of the platform and pocket beaches described by Shipman (2008). In particular, there is a bedrock platform along the southern shoreline of the island that was formed by the uplift associated with the most recent earthquake on the Seattle Fault Zone (Nelson et al. 2003a). This platform was the Holocene bench formed from wave erosion prior to the earthquake. As a consequence, the shoreline in this area is classified as a platform rocky shoreline. However, there is a modest amount of coarse substrate remaining on the upper beach (above the mean tide level) that forms a coarse sediment beach face throughout this area. These coarse sediment beach faces are continuous along the southern shoreline; therefore, they are not strictly pocket beaches since they are not contained within a "pocket" of bedrock.

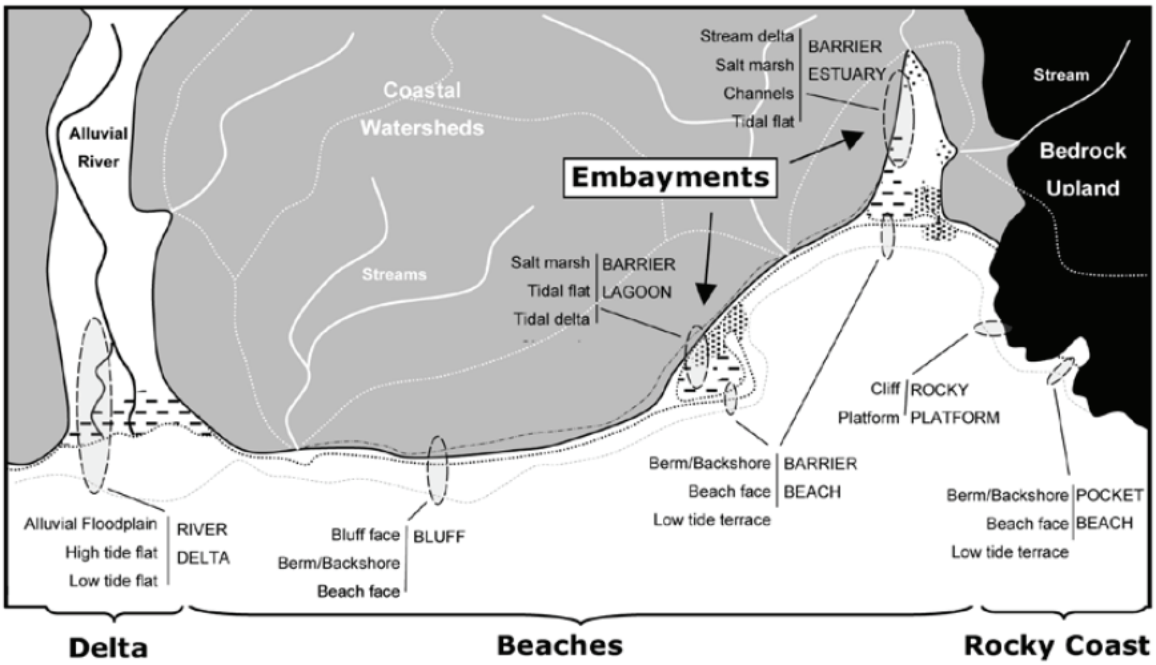

Figure 2. Coastal landforms typical of Puget Sound as identified in Shipman (2008).

Because of this, some of these areas were interpreted by Williams et al. (2004) to be barrier beaches. However, they likely behave similar to smaller, localized pocket beaches in that they are sediment starved and limited in vertical extent. Sediment transport is dominated by waves, but locally enhanced by strong tidal flows and boat and ferry traffic in the area (Curtiss et al 2009).

Habitat on rocky coasts is distinctly different than the more common sediment-rich shorelines in Puget Sound. Not only do rocky coasts lack the substrate required for a variety of habitat types (e.g., sand lance and surf smelt spawning), but the resident invertebrate and plant communities are also different. Key indicator species (species that can indicate physical, chemical, and biological habitat conditions) for rocky intertidal environments include rockweed (*Fucus gardneri*) (Jenkins et al. 2002) and bull kelp (*Nereocystis luetkeana*) (Battelle 2003). For example, kelp species require, and are indicative of, rocky (or otherwise coarse) substrates with low sedimentation levels. Physical habitat can be influenced by kelp presence as it creates structure for numerous organisms, providing nursery, foraging, and refuge opportunities. Kelp forests also contribute to the food web as a source of direct consumption and through the addition of carbon in the form of detritus (Mumford 2007). For a full discussion of kelp and its role in enhancing nearshore productivity, see Section 3.1.3. Invertebrates including limpets and barnacles are also common on rocky coasts; however, these smaller creatures do not generally create physical habitat structure to the same extent as macroalgae communities.

Rockweed communities have been shown to be prone to human disturbance in the Salish Sea (Jenkins et al. 2002). Even barnacles have been shown to be impacted negatively by pedestrian traffic (Brosnan and Crumrine 1994). Unlike mixed sediment beaches, mud flats and salt marshes, which can be difficult to traverse, rocky coasts can often be easy to travel across, encouraging disturbance and potentially heightening the impacts of trampling. Kelp was identified as key indicator species by Battelle (2003) and more recent research is discussed further in Section 3.1.3 *Kelp Forests*.

2.3.2 Beaches

Beaches are by far the most common nearshore environment on the island. Shipman (2008) identifies two landforms associated with beaches: bluffs and barriers. Because these landforms have been studied independently, they are addressed individually in the subsections below.

Bluffs

Battelle (2003) describes the importance of bluffs, particularly the presence of landsliding, as a key aspect of the shoreline ecosystem through the delivery of large woody debris (LWD) and sediment to the nearshore. Landsliding is used to describe any type of downslope sediment transport due to slope instability. On Bainbridge Island, there are significant feeder bluffs (i.e., actively eroding and landsliding bluffs); however, bluffs in equilibrium with the shoreline and depositional shorelines (i.e., barrier beaches) are more common (Williams et al. 2004). A complete high-resolution catalog of landsliding was not available at the time of Battelle (2003), however, since that time, a geologic map of the City has been developed by Hagerud (2005). This map documents all of the landslide deposits on the island at a higher resolution than existed before. This map provides not only a record of existing geologic hazards, but also a record of past nearshore disturbance which can have legacy effects on nearshore ecology. MacLennan et al. (2010) have further documented bluff shorelines, particularly as they contribute sediment to the nearshore (i.e., feeder bluffs), using a methodology that has been applied to numerous areas throughout Puget Sound.

Barriers

Barriers (or barrier beaches), as defined by Shipman (2008), represent the most common landform along the Bainbridge Island shoreline. Because of their commonality throughout the region, they have been the subject of considerable research within the last few years, including some work that has occurred on the island. The two most relevant research studies on Puget Sound barrier beach dynamics are Finlayson (2006) and Curtiss et al. (2009). These efforts, which are both peer-reviewed and complementary in terms of approach, refine the more generic description provided in Battelle (2003). Both of these efforts had some portion of the research work performed on Bainbridge Island shorelines.

Finlayson (2006) examined a number of factors that influence the geomorphology of Puget Sound beaches and their nearshore ecology. His work highlights the complexity and mobility of sediment transport on Bainbridge Island shorelines. Finlayson (2006) is an amalgam of three different, complementary studies, along with a review of the literature describing Puget Sound beaches to date. The literature documents the relative uniqueness of the Puget Sound beaches.

The literature review found several factors that make Puget Sound shorelines an unusual physical setting:

- *Low energy* –Swell is precluded from the interior of Puget Sound, including all of Bainbridge Island. As a result, swash dominates transport. The waves that do interact with the shoreline are highly dependent on shoreline aspect and fetch because of the convoluted shoreline.

- *Large tide range* – The tide range in Puget Sound is large relative to most of the world's coasts. The tide-height distribution is also skewed, meaning that the median tide elevation is significantly higher than the average elevation. This, in combination with small wave heights leads to a concentration of wave energy on the highest portion of the beach. This gives rise to a well-defined, coarser upper beach (beach face, or in the terminology of Finlayson [2006], foreshore) and a broad, fine-grained lower beach (low-tide terrace).

- *Steep antecedent topography* – The post-glacial surface throughout the island is steep at the elevation of the modern shoreline. This leads to a convoluted coast with most of the shorelines being dominantly erosional. The erosional shorelines are backed by steep bluffs of glacially derived sediment. Depositional (or accretionary) shorelines are often comprised of sediments from adjacent shorelines.

- *Diversity in sediment supply* – Most Puget Sound shorelines have a diversity of sediment types available both from adjacent bluffs and from small local seasonal creeks. This leads to barrier beaches with a large size diversity of sediment, otherwise called mixed sediment beaches. This has ramifications for the mobility of sediment and groundwater interactions. The diversity of sediment is somewhat reflected in the cross-shore distribution of sediment into two distinct zones: a coarser steeper beach face and broad, finer low-tide terrace.

The first study within Finlayson (2006) was an investigation of beach shape (beach face slope, low tide terrace slope) and structure (sediment size) as it relates to forcing variables (proximity to a riverine sediment source, fetch and predicted wave variables). Finlayson (2006) analyzed the correlation of the geomorphic features on 23 beaches throughout Puget Sound, including at Fay Bainbridge State Park and Fort Ward State Park on Bainbridge Island, using a cluster analysis called AGNES. He found that there was limited statistical correlation between the various parameters, arguing that antecedent geology played a more crucial role in setting than modern environmental parameters. Further evidence of this was found subsequent to the publication of the thesis, which correlated the break in beach face and low-tide terrace slopes to the presence of and distance from local fluvial sediment supply (David Finlayson, personal communication).

In his second study, Finlayson (2006) documented beach change for more than two years through repeated surveys of Cama Beach on Camano Island, Washington (See Figure 3).

Figure 3. Photograph of Cama Beach where a bulkhead was constructed on an accreting beach. Note upland vegetation (red alder) growing in front of the bulkhead.

Change was observed between many of the observation events, particularly on the uppermost portion of the beach; however, the net change over the entire time period was small. Change below the beach-face-low-tide-terrace transition was always negligible. Sediment transport direction was highly seasonal, with sediment moved northward during the winter and southward during the summer. This differs from the classic description of Puget Sound drift cells and unidirectional transport. Transport was also highly variable in time, with only the strongest wind storms producing significant erosion and deposition, which typically occur in the wintertime. Erosion in the largest event was significant at the toe of a seawall in a particular area (approximately two vertical feet), though recovery was nearly complete after about a year. Since the study, the wall failed in this area and was replaced.

In the final analysis of Finlayson (2006), waves were modeled with a recent two-dimensional wave model using a time series of observed winds and compared to the presence of eelgrass along a three-mile long reach near Lofall, Washington, to determine the influence of wave energy on eelgrass. Despite significant variability in the eelgrass population along the reach, modeled wave disturbance was not correlated to eelgrass presence. Along with the earlier literature review, this led to the hypothesis that wave-induced shear stress is concentrated high on the beach (in the beach face, near MHHW) and eelgrass is controlled by other factors, such as water quality. It also supports the hypothesis that the low-tide terrace and the beach face are sedimentologically distinct. The beach face, dominated by swash from local wind-waves, transports coarse bluff-derived sediment, while the low-tide terrace, dominated by a combination of waves and currents, transports sand and mud (though much less actively) derived from bluffs and local streams. Dominant net transport in the beach face and low-tide terrace need not be in the same direction owing to the different forces acting on them.

Curtiss et al. (2009) tracked sediment using radio-frequency identification (RFID) tags to track gravel on Point White on Bainbridge Island for nearly a year. They point out that from a sedimentological point of view; the beaches at Point White are similar to Cama Beach. However, Point White lacks the northern exposure found at Cama Beach, and even the fetches to the south are much smaller. As a result they found significant transport only in the winter – and only to the northeast. During the summer, transport was less and more random, implicating the increased importance of tides and vessel wakes during this time period. At Cama Beach, tides were not significant, but it is likely that tides influence a portion of Bainbridge Island shorelines, particularly throughout Rich Passage in the south and Agate Passage in the north. Although the beaches were all backed with bulkheads, Curtiss et al. (2009) made no attempt to assess the influence on the physical processes imposed by the bulkheads.

These works highlight the complexity and mobility of sediment transport on Bainbridge Island shorelines. The traditional notion of drift cells as outlined by Battelle (2003) is helpful in certain contexts, but transport is commonly bi-directional, even in areas protected from certain kinds of waves (Curtiss et al. 2009). Finlayson (2006) also highlights the physical processes altered by those features, which can have ecological consequences. Alterations to physical processes from these features are discussed in Section 5.1.1.

2.3.3 Embayments

The convoluted nature of Puget Sound shorelines and the limited sediment supply mean that there are many embayments along Bainbridge Island. These features were originally classified in Williams et al. (2004) as marshes and lagoons. Shipman (2008) identified four different landforms associated with embayments: open coastal inlets, barrier estuaries, barrier lagoons, and closed lagoons and marshes.

Embayments are key features in the Pacific Northwest landscape that produce physical and habitat complexity for a variety of organisms. In particular, pocket estuaries, a particular type of embayment, have been recently identified as important habitat type for juvenile salmonid survival and recovery. Strictly speaking, Shipman (2008) would classify a pocket estuary as a barrier estuary. However, there has been documentation of other landforms typical of embayments in Puget Sound performing the same habitat function as a barrier estuary (e.g., Ala Spit, an open coastal inlet: Beamer 2007, Herrera 2008a). The geomorphic context of Bainbridge Island means that all embayments delineated in Williams et al. (2004) as "marsh/lagoons" have the habitat attributes of pocket estuaries.

Generally speaking, pocket estuaries are typically tidally influenced, protected areas with fringing unvegetated flats, saltmarsh and tidal channels although they do not necessarily need to have extensive marshes associated with them. For instance, Hidden Cove likely meets most of the criteria set forth for pocket estuaries producing physical conditions similar to other pocket estuaries, though marshes in this area are relatively rare and the marshes, where they do occur, are not protected by barrier beaches. A considerable body of work has been developed since Battelle (2003) that has demonstrated the importance of these features to native salmon populations by documenting utilization and prey items, particularly during the juvenile life stage (Beamer 2003, 2005, Puget Sound Action Team 2005). Most of this work has been done in northern Puget Sound by the Skagit River System Cooperative, but it is expected that is generally applicable other similar environments in Puget Sound at large (Puget Sound Action Team 2005).

Juvenile Chinook salmon, along with other juvenile salmonids, are known to utilize pocket estuaries (Beamer et al. 2003, 2005, Puget Sound Action Team 2005). All Chinook utilizing pocket estuaries must find them via migration because typically the freshwater source is too small to support resident salmon. Although Bainbridge Island does not contain Chinook bearing streams, several other salmon bearing streams are present (Dorn and Best 2005) and eight species of salmon are known to use the nearshore habitat of Bainbridge Island (Battelle 2003).

Another species typical of Bainbridge Island embayments is pickleweed (*Salicornia virginica*). Pickleweed is a common plant of protected intertidal areas in Puget Sound, and is often used to delineate the ordinary high water mark in intertidal areas. Abrasion from sand and gravel often precludes it from most beach settings, but in areas where protection from waves is significant, pickleweed is common and therefore considered an indicator of pocket estuary habitat that is important to and likely used by sensitive species such as juvenile salmon.

The most significant and common impact to embayments has been shoreline modifications (see Section 5.1.1). Bainbridge Island's shoreline is already heavily modified (approximately 51 percent) (MacLennan et al. 2010), primarily by bulkheads (49 percent, R. Ericson, City of Bainbridge Island, personal communication with A. Azous, Herrera Environmental Consultants, December, 1, 2010) but also by significant fill and seawalls in former industrial areas (MacLennan et al. 2010). Armoring adjacent to marsh areas has been shown in similar settings to negatively affect the persistence and quality of habitat features by changing natural patterns of erosion and deposition (Bilkovic and Roggero 2008). Therefore proximity to an embayment, as well as to other sensitive habitats such as salmon streams or aquatic vegetation, is an important factor in determining the environmental impact of a particular bulkhead installation. Impacts can be most significant when armoring is placed near the MHHW elevation or below on the beach, and in moderate or high energy environments (MacLennan et al. 2010). Therefore, these conditions should also be considered in evaluating the potential or likely impacts of bulkhead placement.