Shoreline Armoring Impacts and Management Along the Shores of Massachusetts and Kauai, Hawaii

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Abstract. Shoreline armoring has both beneficial and adverse effects. On the beneficial side, shoreline armoring continues to save millions of dollars of valuable waterfront real estate, thus preserving valuable upland by reducing direct exposure to damaging coastal storm waves and flooding (fig. 1). Shoreline stabilization can also help waterfront property owners protect the sales value of individual properties. The financial benefits of maintaining the value of waterfront construction as a result of shoreline armoring, however, appear to remain only with the waterfront dwellings or dwellings within very close proximately of the shore. Property values only several rows inland lowers with the on-going effects of shoreline armoring, and even waterfront property values decline as more and more waterfront property owners rely on shoreline stabilization/armoring.

On the adverse side, shoreline armoring along eroding shores continues to be responsible for the reduction in the beneficial functions and sometimes complete loss of valuable coastal resources, such as beaches, dunes, and intertidal areas. This results in the loss or alteration of associated marine habitat. Lateral beach access can also be restricted or completely lost.

These impacts, particularly the loss of sandy beaches, have great relevance in states such as Hawaii, where the public has the right of use of all beaches statewide. Beaches also provide important social, cultural and ecological benefits to Hawaii’s residents and visitors. Hawaii’s beaches are the backbone of a $13 billion dollar visitor economy that provides approximately 171,900 jobs, the bulk of the state’s jobs and income. More than 60 percent of all jobs in Hawaii are related to tourism, which depends on the appeal of sandy beaches (Genz and others, 2007). Similarly, 16.9 million people work in the travel and tourism industry that contributes $1.2 trillion to the U.S. Gross Domestic Product and $223 billion in taxes (World Travel and Tourism Council, 2010). Beach tourism is by far the largest tourism industry in the U.S. (Houston, 1996).

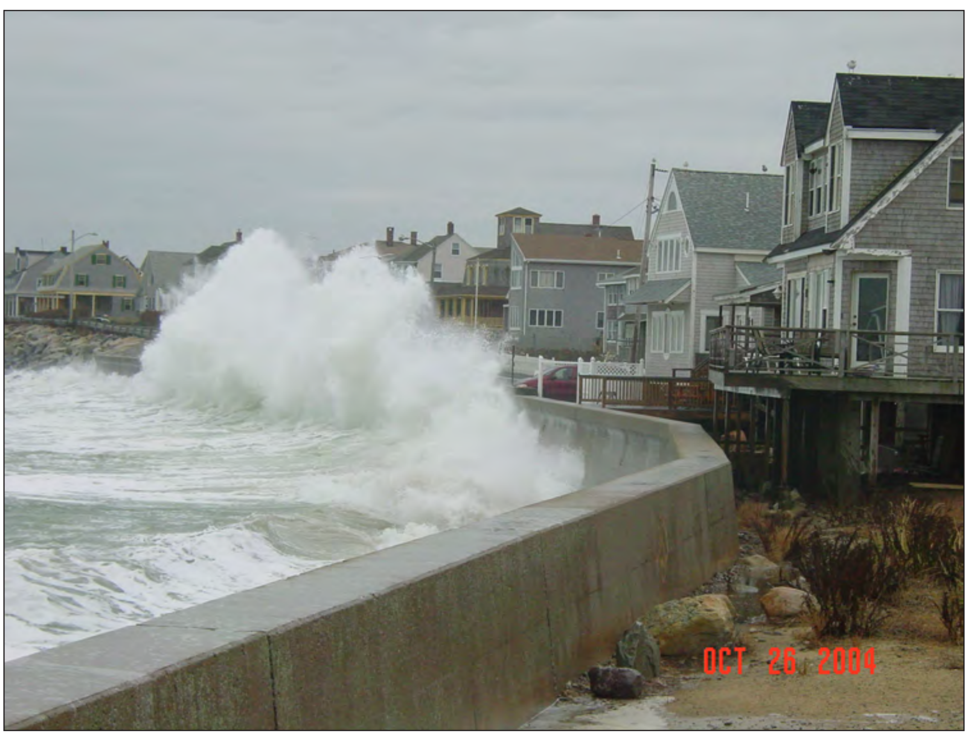

Figure 1. Vertical concrete seawall with toe stones protecting waterfront buildings from the direct impact of storm waves along the South Shore of Massachusetts.

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Introduction

Worldwide sea level is continuing to rise and the rate of rise is predicted to accelerate (International Panel on Climate Change, 2007). In fact, a short-term acceleration in the rate of sea level rise has been recently documented (International Panel on Climate Change, 2007; Rahmstorf, 2007). Due to this continuing rise in sea level, accompanied by a growing coastal population, requests for coastal erosion control in the form of engineered shoreline armoring structures, such as seawalls, revetments and bulkheads could be anticipated to concomitantly increase. However, growing awareness of the actual, potential, and perceived impacts of coastal armoring has lead, in part, to shoreline armoring prohibitions or significant restrictions. States such as Oregon, North Carolina, Maine, Rhode Island, South Carolina, and Texas have banned shoreline armoring or imposed significant restrictions (Mohan and others, 2003). More than 30 years ago, Massachusetts banned shoreline armoring of landforms that are sediment sources to beaches, dunes and barrier beaches, and recently the County of Kauai, Hawaii, has prohibited ‘fixing the shoreline’, without a regulatory variance. Even non-structural erosion control alternatives, such as biodegradable coir (coconut husk) or fiber roll revetments are being scrutinized more closely due to site-specific potential impacts, such as the loss of or alterations to associated coastal habitats and the temporary loss of source sediment to fronting and adjacent beaches (compare figs. 2*A* and 2*B*).

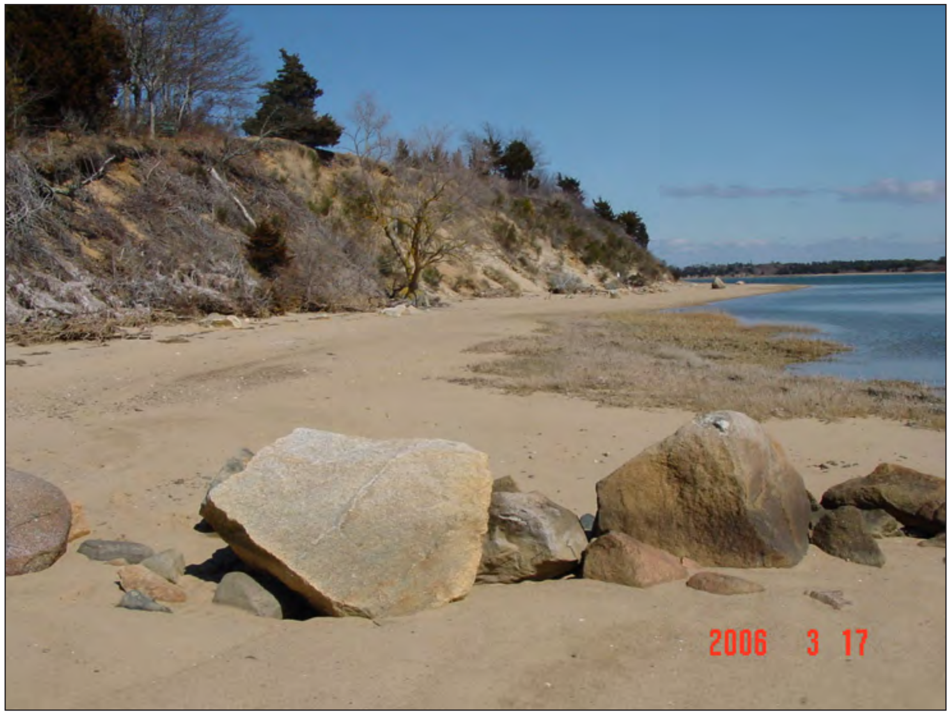

Figure 2*A*. An eroding coastal bank/bluff acting as a sand source to fronting and adjacent beaches and dunes on Cape Cod, Massachusetts.

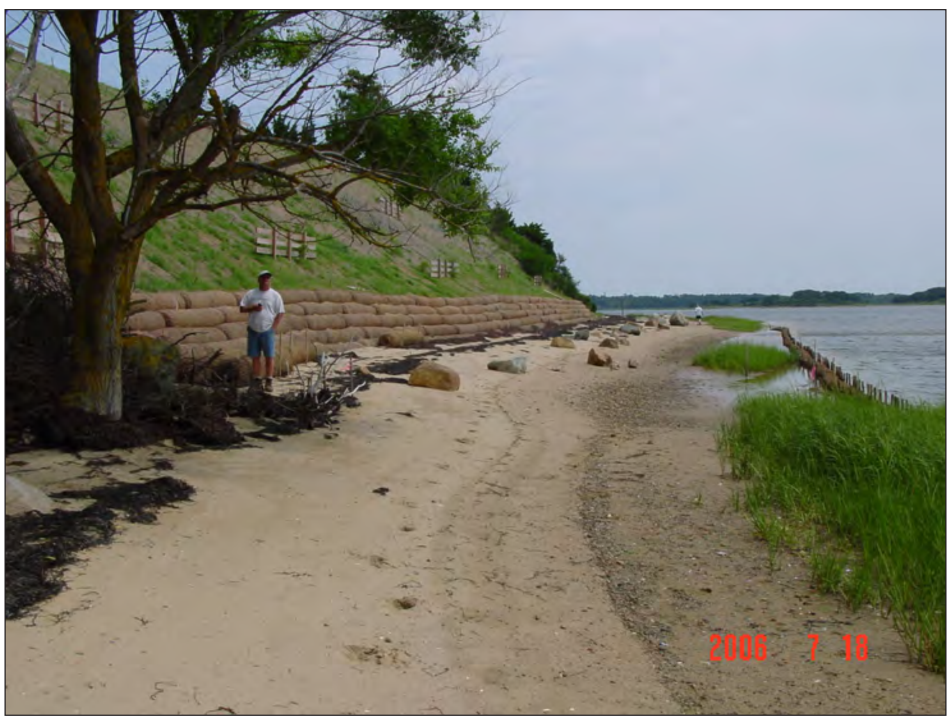

Figure 2*B*. The same coastal bank/bluff as shown in figure 2*A* showing a coir fiber roll revetment, that is, non-structural coastal armoring, that is preventing sand from eroding from the bank and feeding the fronting and adjacent beach and dunes.

Shoreline Armoring: A Two State Perspective—Hawaii and Massachusetts

The state of Massachusetts promulgated regulations that prohibit shoreline hardening or structural erosion control measures to protect buildings constructed after the promulgation date of the regulations, and the County of Kauai, Hawaii recently passed an ordinance that prohibits fixing the shoreline for any proposed construction or activity on shoreline lots within their jurisdiction.

Massachusetts

Massachusetts has approximately 1,500 mi of tidal shore, with approximately 70 percent of the state's population residing in coastal counties and 36,000 people living within 500 ft of the shore (Heinz Center for Science, Economics, and the Environment, 2000). Approximately 78 percent of the Massachusetts ocean-facing shore is exhibiting a long-term erosion trend, based on data generated by Thieler and others (U.S. Geological Survey, written commun., 2001; see O'Connell, 2002). Massachusetts coastal regulations, in part, prohibit armoring active coastal dunes, and prohibit armoring eroding coastal banks (coastal bluffs) when the proposed activity is intended to protect buildings constructed after the August 10, 1978, promulgation date of these regulations (State of Massachusetts, 2009). Coastal banks are defined in the Massachusetts regulations as, 'an elevated landform, other than a coastal dune, that lies at the landward edge of a beach, land subject to tidal action or other wetland'.

Massachusetts' regulatory prohibition on armoring eroding coastal banks is based on the recognition that these eroding coastal landforms are the main source of sediment to beaches, dunes and barrier beaches. Armoring coastal dunes is implicitly prohibited by a regulatory performance standard that states that structures and activities shall not interfere with the natural migration and constant changing of shape of coastal dunes in response to wind and waves. Furthermore, an activity cannot prevent a coastal dune from eroding and providing sand to other coastal resources, such as fronting and downdrift beaches.

Thus, being the primary source of sediment, these eroding coastal landforms allow for the continued existence of beaches, dunes and barrier beaches and their associated habitats in Massachusetts. Sediment eroded from coastal banks and subsequently transported along shore is also responsible for forming 681 mapped barrier beaches, which in turn create landward bays and estuaries and habitat for abundant marine organisms.

Approximately 26 mi (or ~30 percent) of the South Shore shoreline of Massachusetts is fronted by coastal engineering structures, not including regions that may be protected by shore-perpendicular structures (for example, groins and jetties). Prior to construction of these shore protection structures, sediment contained in the coastal banks was available to downdrift shorelines (State of Massachusetts, 2010). This armoring has resulted in extensive loss and narrowing of recreational beaches, reduction or loss of lateral beach access, and the elimination or alteration of marine habitat in many areas along the South Shore (compare figs. 3*A* and 3*B*).

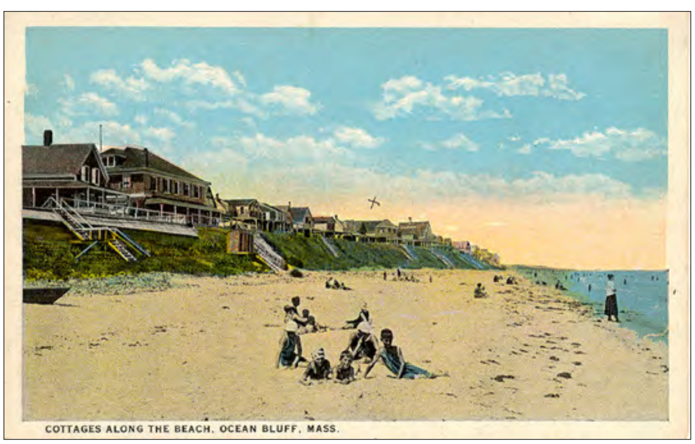

Figure 3*A*. A post card from the early 1900s showing a sandy beach and a vegetated coastal bank/bluff along the South Shore of Massachusetts, prior to coastal armoring.

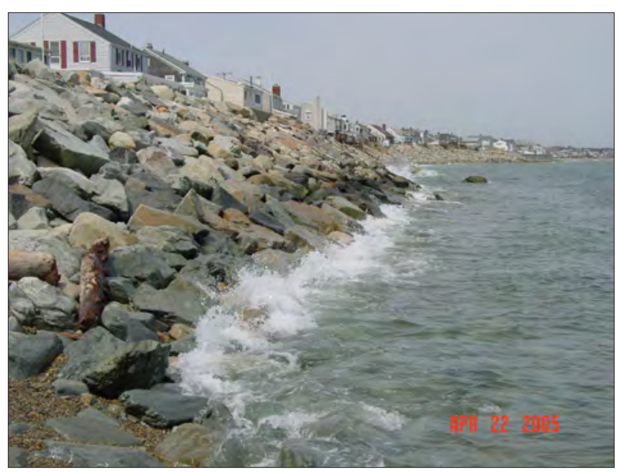

Figure 3*B*. The same coastal bank/bluff along the South Shore of Massachusetts (shown in fig. 3*A*) now structurally armored. As a result of 'passive erosion' and source sediment impoundment, the fronting beach has completely eroded away.

County of Kauai, Hawaii

The County/Island of Kauai, Hawaii, has approximately 110 mi of shore, with almost half of this length consisting of unconsolidated sandy beaches. Approximately 71 percent of the sandy beaches on the Island of Kauai are exhibiting a long-term erosion trend, eroding at an average rate of approximately -0.4 ft/yr (Fletcher and Coastal Geology Group, 2009). Due to the mountainous terrain, the majority of Island population resides in low-lying areas adjacent to the shore.

In January 2008, County government on the Island of Kauai promulgated the *Shoreline Setback and Coastal Protection Ordinance #863* (County of Kauai, 2008). The ordinance requires new buildings on small lots (<160 ft) to be setback a predetermined distance from the shoreline, based on the average lot depth, and for large lots (>160 ft) to utilize an erosion rate multiplied by 70, plus a buffer of 40 ft. The primary purpose of this setback ordinance is to preserve the beneficial functions of coastal resources, preserve lateral public beach access, improve public safety and property value protection, and to avoid shoreline armoring.

The ordinance also, in part, prohibits private and public facilities that may ‘artificially fix the shoreline’ and prohibits the alteration of primary coastal dunes (except for the addition of compatible sand). This prohibition on artificially fixing the shoreline can be overridden only as a result of the issuance of a ‘variance’. A shoreline setback variance may be considered for a structure or activity otherwise prohibited by the ordinance if the County Planning Commission finds, in part, that the proposed ‘private or public facility or improvement that artificially fixes the shoreline does not adversely affect beach processes and all alternative erosion control measures, including retreat, have been considered’.

The ordinance also states that any structure approved within the shoreline setback area by variance shall not be eligible for protection by shoreline hardening during the life of the structure. Furthermore, if a structure is permitted in the shoreline setback area by variance, the fact that the structure could be subject to coastal erosion and high wave action ‘shall be written into a unilateral agreement that is recorded by the Bureau of Conveyances of Land Court’.

The implementation of shoreline setbacks and limitations on shoreline hardening is the result of the recognition of documented adverse impacts of shoreline armoring along the state of Hawaii’s shores. For example, following an analysis of an aerial photographic time series of Oahu, Hawaii’s shoreline Fletcher and others (1997) reveal that historical seawall and revetment construction (coastal armoring) to protect eroding lands has caused the narrowing of approximately 11 mi and loss of 6.4 mi of sandy beach over the period between 1928 or 1949 and 1995. This is approximately 24 percent of the 72 mi of original shoreline on Oahu.

The County of Maui (Hawaii) Planning Department mapped 15.6 of 56 mi surveyed as ‘hardened’, including seawalls, revetments, sandbags and groins (Surfrider Foundation, 2008). The Island’s sandy shorelines are retreating inland an average rate of approximately 1.0 ft/yr. This has resulted in the loss of approximately 5 mi of dry beach since 1949 due to the effects of high water against hard engineering structures and natural rock outcrops on the Island of Maui, Hawaii (Fletcher and others, 2007).

The loss of dry sandy beach at high tide due to armoring on the Island of Kauai has occurred as well (fig. 4). Based on a preliminary unpublished analysis, slightly less than 4 mi of sandy beach has been lost due to shoreline armoring on the Island of Kauai (O’Connell, 2010).

Despite the efforts of Kauai County to preserve its valuable sandy beaches and minimize interference with beach processes by implementing progressive shoreline setback standards and prohibiting fixing of the shoreline, the state of Hawaii regulations and policies continue to permit shoreline armoring. The main issue in regulating shoreline armoring is jurisdictional: County vs. state jurisdiction in the coastal zone. Each Hawaiian island is a county, for example, the Island of Kauai is Kauai County.

The ‘shoreline’ delineates state vs. County jurisdiction. ‘Shoreline’ in Hawaii means, ‘the upper reaches of the wash of the waves, other than storm or seismic waves, at high tide during the season of the year in which the highest wash of the waves occurs, usually evidenced by the edge of vegetation growth, or the upper limit of debris left by the wash of the waves’ (HRS Ch. 205A-1). Therefore, the jurisdictional ‘shoreline’ is often well inland of a sandy beach or seaward eroding face of a coastal landform, for example, coastal dune. So, the jurisdiction for permitting coastal armoring of an eroding coastal landform that lies at the landward edge of a coastal beach is most often with the state, not the County. Before a proposed project can be permitted, the location of the shoreline on a lot must be certified by the state. All area seaward of a ‘certified shoreline’, which includes coastal beach and often some upland area adjacent to the beach, is designated for public use.

Hawaii Coastal Zone Management Program Policies for ‘Beach Protection’, Hawaii Revised Statutes, Chapter 205A-2(c)(9)(B) states, in part, ‘prohibit construction of private erosion-protection structures seaward of the shoreline, except when they result in improved aesthetic and engineering solutions to erosion at sites and do not interfere with existing recreational and waterline activities; and (C) ‘minimize the construction of public erosion-protection structures seaward of the shoreline’.

The Hawaii Department of Land and Natural Resources, Office of Conservation and Coastal Lands, is, in part, responsible for permit review and processing proposed activities within private and public State Land Use Conservation Districts which include lands seaward of the ‘shoreline’, that is, beaches and potential sediment sources to beaches and dunes. Hawaii Administrative Rules Chapter 13-5, Conservation Districts (CD), identifies land uses that may be permitted in Conservation District sub-zones. The ‘Resource Sub-zone’ includes lands and state marine waters seaward of the shoreline, that is, coastal beaches. In the Resource Sub-zone, seawalls, shoreline protection devices, and shoreline structures are listed as identified land uses. The objective of this sub-zone, however, is to develop, with proper management, areas within it to ensure sustained use of the natural resources of this area. So, while coastal armoring is a listed land use, alternatives to structural coastal armoring are preferred and no permanent coastal armoring has been permitted in at least in the past 7 years (D. Eversole, HI Sea Grant Program, oral commun. 2009). However, temporary, emergency coastal erosion control structures, for example, sand-filled geo-textile revetments and biodegradable sand bag revetments, continue to be permitted on a case by case basis.

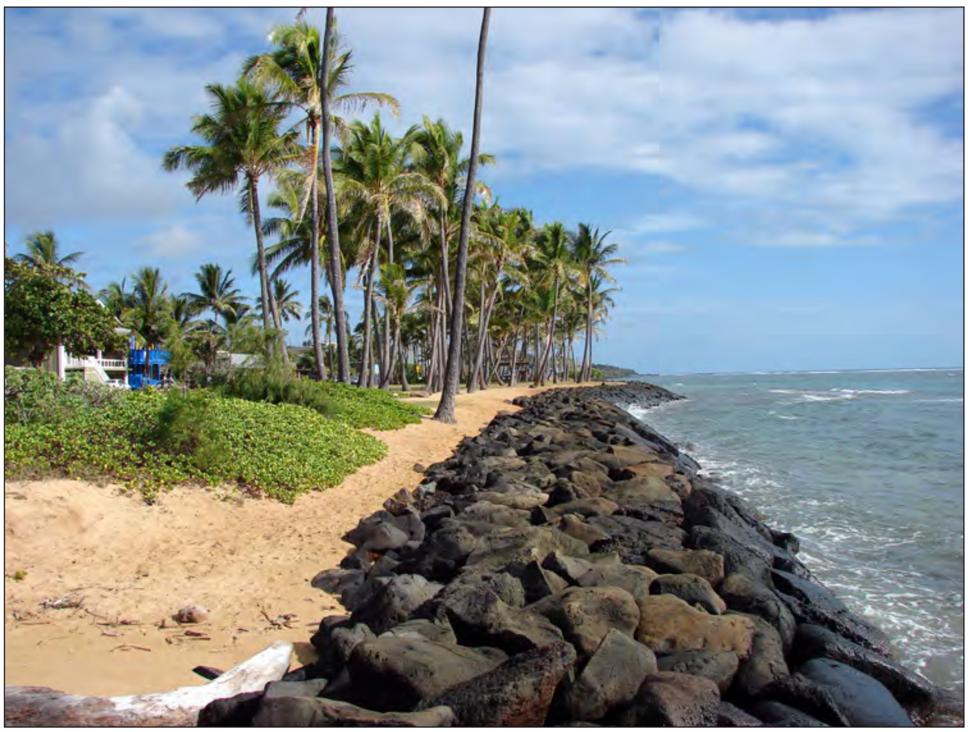

Figure 4. Coastal armoring along the central coast of the Island of Kauai, Hawaii resulting in the loss of the fronting beach due to passive erosion and source sediment impoundment.

The Impacts of Shoreline Armoring: Benefits and Detriments

Shoreline Armoring Can Result in Benefits and Detriments

Benefits of shoreline armoring may include:

- stabilizes the upland;
- protects infrastructure; and,
- maintains property values (caveat: The first few waterfront property owners to stabilize their shoreline achieve significant benefits, but as more and more of their neighbors follow suit, property values drop to about where they started. In contrast, shoreline stabilization appears to lower property values a few rows in-land (Kriesel and Friedman, 2003).

Detriments of shoreline armoring may include:

- 'source sediment impoundment' resulting in increased erosion of the fronting and adjacent beach due to sediment budget reduction;
- 'passive erosion' resulting in the eventual loss of the dry beach and possibly the loss of the inter-tidal area along eroding shores;
- 'loss of lateral beach access';
- 'loss or changes to marine habitat';
- 'reduction of and possible loss of marine organisms and associated ecological functions';
- 'adjacent property impacts', such as end scour or flanking erosion; and,
- 'placement loss' resulting in the direct loss of beach and possibly habitat.

Source Sediment Impoundment

In Massachusetts, with few exceptions, the primary source of sediment to beaches, coastal dunes and near-shore areas is sediment eroded from coastal landforms, such as outwash plains, kames, drumlins and ground moraine (fig. 5). Thus, armoring these primary sediment sources reduces the sediment budget, resulting in the loss or reduction in the volume of source sand and gravel otherwise available to adjacent beaches and dunes. Accompanying the loss of beach and dune volume and form, the beneficial functions of storm and flood damage reduction to landward development and resources provided by these coastal landforms are diminished.

In Hawaii, the primary source of sediment that constitutes beaches is from the breakdown of coralline and calcareous algae, corals, mollusks, echinoderms, and to a minor extent the weathering and erosion of volcanic rock. Most sediment in reef systems is produced on the shallow nearshore platform, where carbonate productivity and erosion are the highest. Sediment exchange between near-shore reef-top sand bodies deposited in relic reef platform depressions and the beach face could be an important component of beach stability; however, their role in littoral processes needs to be better understood (Bochicchio and others, 2009). At present, the greatest accumulations of stored sands are found in formally accreting and now, for the most part, eroding coastal plains. Thus, long-term sediment budgets experiencing chronic deficits rely upon erosional release of sand from the adjacent coastal plain (Fletcher and others, 2007). In other words, the present-day primary source of sand for beaches is from the erosion and release of sand from the coastal plain.

Thus, along eroding shores with diminished sediment input due to source sediment impoundment as a result of coastal armoring, the loss of dry beach and eventually the loss of the inter-tidal area results as the beach and inter-tidal area continue to diminish in width as the high water line moves towards a shoreline armoring structure (fig. 6).

Passive Erosion—Loss of Dry Beach and Inter-tidal Habitat

Along a shoreline undergoing long-term erosion in response to a sediment deficit and/or relative sea-level rise, the high water line will continuously migrate landward. This process is termed 'passive erosion'. In response to relative sea-level rise, the shoreline will continue to migrate landward until it reaches a hardened surface, such as a revetment or seawall. The loss of dry beach results with high water forced against the structure.

This process of passive erosion is perhaps the most significant long-term effect of shoreline armoring, and cannot be mitigated, except through an on-going and permanent beach nourishment program which is only a temporary solution (Griggs, 2005). The process of passive erosion is accelerated if coupled with source sediment impoundment (as described above).

Figure 5. An eroding coastal bank/bluff along the south shore of Massachusetts providing source sand to the fronting and downdrift beaches.

Figure 6. The loss of beach and thus public lateral beach access due to shoreline armoring and chronic erosion along the east coast of the Island of Kauai, Hawaii. Note the sandy beach in the background where no coastal armoring exists.

Loss of Lateral Beach Access

As the beach width narrows and is eventually lost along eroding, armored shores, lateral access is diminished and ultimately lost (fig. 7), unless long-term beach nourishment is feasible. The site in figure 7 had a permit condition associated with the approval of the revetment to maintain lateral dry beach access fronting the revetment at all tides. However, after a short time following revetment construction it was recognized that lateral beach access was impossible to maintain and the permit condition was removed. The lateral beach access (fig. 7), which is now lost, led to a U.S. Fish and Wildlife coastal property.

Loss of Marine Habitat, Marine Organisms, and Alteration of Ecological Function

As in the loss of lateral beach access along an armored eroding shore, as the beach and intertidal area narrows and is ultimately lost, marine organisms and their habitat are affected. For example, marine organisms that rely on inter-tidal habitat can be lost and possibly replaced with an entirely different assemblage of marine organisms that thrive on a rocky marine environment, that is, rip-rap revetment. In a study of ecological effects of coastal armoring on sandy beaches in California, Dugan and others (2008) found the abundance, biomass and size of upper intertidal macro-invertebrates were significantly lower on armored vs. unarmored shoreline segments, as well as concomitant lower species richness and abundance of foraging shorebirds. Further investigation of ecological responses to coastal armoring is needed for the management and conservation of ecosystems (Dugan and others, 2008).

Adjacent Property Impacts: End Scour or Flanking Erosion

Local scour or flanking erosion at the ends of shoreline armoring structures, such as seawalls and revetments, can affect the existing structure and/or adjacent property (fig. 8). Unarmored, unconsolidated landforms on either side of a coastal armoring structure will continue to erode and the high water line will continue to migrate landward on either side of the armoring. Eventually, the frequency of interaction between waves and the armoring structure will increase and affect adjacent property, as well as the revetment or seawall itself, through a process known as end scour or flanking erosion. The intensity and frequency of the interaction between storm waves and a shoreline armoring structure can be related to placement of the structure along the beach profile, that is, landward vs. seaward, and this relates to the degree of impact or scour. In addition, local scour at the ends of coastal armoring structures is the result of the end configuration of the armoring structure, angle of wave approach, and wave height and period (Griggs, 2005).

Placement Loss: Type of Armoring

The type of armoring structure, for example, revetment vs. seawall, will affect the amount of total beach and inter-tidal area permanently lost by displacement (fig. 9), along with the loss of associated habitat and lateral beach access reduction or loss. Vertical structures displace less coastal resource area than do sloping revetments. However, the perception that sloping structures such as revetments have less of an impact on active beach processes due to its slope and permeability than vertical seawalls or bulkheads is the subject of on-going debate (Griggs, 2005).

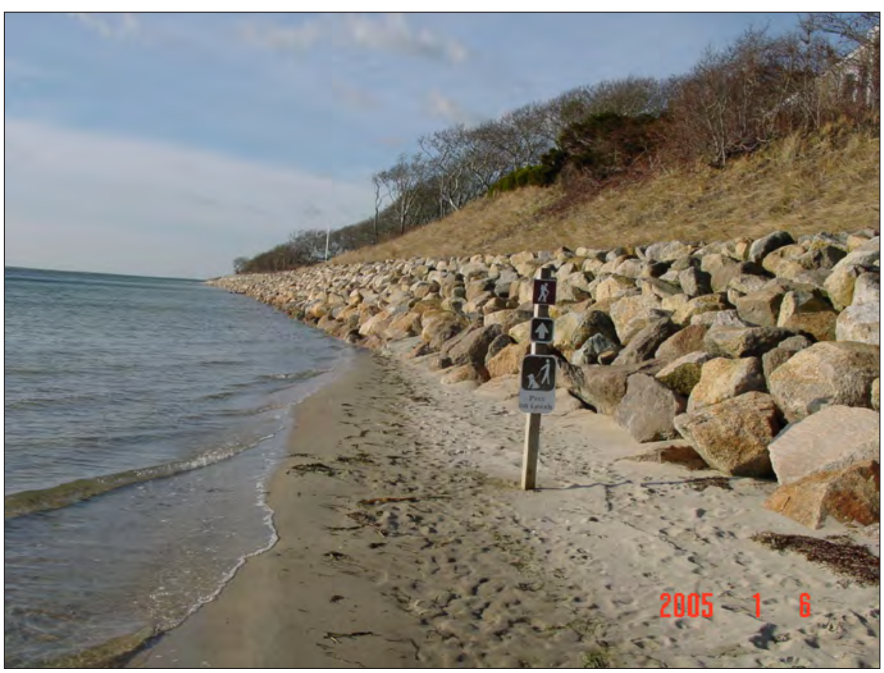

Figure 7. The loss of public lateral beach access due to shoreline armoring along the shore of Chatham, Massachusetts. Prior to revetment construction, a dry sandy beach provided lateral public beach access to a U.S. Fish and Wildlife property.

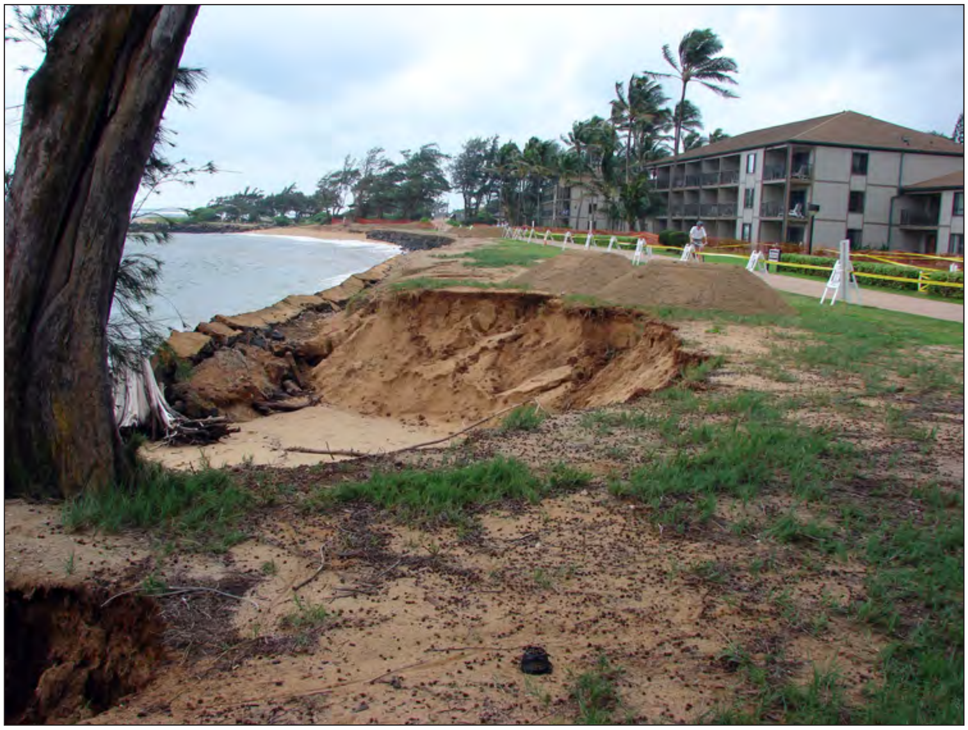

Figure 8. End scour or flanking erosion at a seawall along the east coast of the Island of Kauai, Hawaii.

Figure 9. Depiction of the extent of placement loss of beach and marine habitat by comparing the extent of loss due to a revetment vs. a bulkhead.

Discussion

Importantly, placement location of coastal armoring, that is, at the shoreline, seaward vegetation line, or along the back beach, along with a host of other site-specific factors, play a large role in potential impacts to beach and near-shore processes, as well as potential impacts to marine organisms and their habitat.

Griggs and Tait (1988) and Griggs and others (1994) documented minimal long-term adverse impacts in an 8-year field study of the effects of shoreline armoring on fronting and adjacent beach processes along California's Monterey Bay shore. They documented that the berm is cut-back sooner in front of seawalls during the summer to winter erosional beach profile transition. In addition, during the winter to summer accretional transition phase, the berm builds seaward on the unarmored adjacent area until the seaward berm edge reaches the seawall, then the berm begins to build seaward in front of the seawall. Therefore, while short-term differences in seasonal and storm-recovery beach processes were measured where this seawall exists, minimal long-term (8 years) impacts were documented. This appears to be consistent with a comprehensive review of more than 100 technical papers on the effects of seawalls on the beach that concluded that beach change near seawalls, both in magnitude and variation, is similar to that of beaches without seawalls, *if a sediment supply and a wide surf zone exists* (*emphasis added*) (Kraus, 1988). In addition, the position of the seawall with respect to the surf zone is a critical parameter controlling the amount of local erosion and the beach recovery process (Kraus, 1988). The fact that an alongshore sediment source existed (225,000 m^3/yr) feeding the beach fronting the armoring that was studied along California's Monterey Bay shore (Griggs and Tait, 1988; Griggs and others 1994, described above), and placement of the armoring was landward along the back beach may have contributed to minimal measured impacts to long-term beach processes.

Importantly, retention of sediment behind the wall (impoundment) and flanking erosion or end scour are mechanisms that can be firmly identified by which seawalls may contribute to erosion of the coast (Kraus, 1988). Placement loss is also a major consideration in the loss of beach area and potential loss of marine habitat. Furthermore, if sea (or lake) level is rising at a site, erosion is more likely to occur at armored beaches as compared to unarmored beaches (Kraus, 1988), that is, passive erosion. An updated literature review including 40 additional papers on the effects of seawalls on the beach can be found in Kraus and McDougal (1994).

Conclusions

Coastal armoring can potentially affect physical, biological, and ecological characteristics of a shoreline, as well as property values and community considerations. The generalized impacts of coastal armoring, which can be both beneficial and adverse, are well documented. Impacts can be site- or littoral-cell specific and vary considerably based on a variety of factors, such as placement location, type of landform armored, structure type, seasonal changes in wave and beach form, and the density of armoring structures. With accelerating sea-level rise and continuing population migration towards the shore, coastal armoring will continue to be a subject of great debate. Much of the U.S. shore is already developed and most states allow consideration of protecting existing development that pre-date regulations governing waterfront development and armoring of the shore.

Managed retreat, in the form of shoreline setbacks, for example, is being widely considered - at least for 'new' or substantially re-constructed buildings. This may be the best method to mitigate damage and beach loss on a lightly populated coast, where the economic impact of erosion is relatively small and there is no threat to a resource of significant economic importance, for example, critical coastal road, or unique historical or ecological value (Mohan and others, 2003). Coastal armoring may be an economic choice along a heavily populated and developed coast. However, hard structures are often not considered desirable because of their possible impact on local or downdrift beaches (Mohan and others, 2003).

Identifying the potential impacts of coastal armoring on a site- or littoral-cell specific basis is critical in assisting coastal managers with decisions on whether to permit coastal armoring, to suggest alterations that may have less impact, or to assist in developing mitigation techniques for potential adverse impacts, if possible or feasible.

Shoreline and beach management plans identifying areas that should be preserved for their unique natural and beneficial functions, such as important sediment sources to adjacent beaches, dunes and barrier beaches, or beaches of economic importance, are vital to the preservation of coastal community character, and maintain a viable economic base.

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