The Tide Doesn't Go Out Anymore- The Effect of Bulkheads on Urban Bay Shorelines

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ABSTRACT

The rate of armoring of the shoreline of an urban bay Mobile Bay, Alabama, has been investigated with historical air photos and video. The amount of armoring of the shoreline has increased from 8% in 1955 to 30% in 1997. The rate of armoring corresponds with the rate of population growth in the area. Vertical bulkheads are the most common type of armoring. "Trash revetments" and rubble-mound revetments are not as common. Loss of intertidal habitat due to the presence of bulkheading is roughly estimated at 10 to 20 acres or about 6 miles of intertidal beach shoreline. The question is raised whether the fate of all urban estuaries is to become "bathtubs" with vertical walls and no intertidal fringe areas.

Key words: bulkheads, estuaries, erosion, bay shorelines, shore protection, Mobile Bay, Alabama.

INTRODUCTION

BULKHEADS ARE A POPULAR erosion solution along the shorelines of many bays and estuaries. Vertical wall structures such as seawalls, bulkheads or revetments are not, however, currently popular along much of America's open-coast beaches. The function of the walls is similar enough along both open and sheltered coasts that some of the same problems occur.

It has long been understood by the coastal engineering community that building a seawall along a receding shoreline can lead to the loss of the sandy beach in front of the wall (US Army 1977). The most popular solution during the past several decades to open-coast beach erosion problems has been beach nourishment.

On bays and estuaries, beach nourishment is rarely attempted. Property owners along such shorelines that are eroding are usually faced with only two realistic choices. One, allow their property to erode. Or, two, build a bulkhead to protect the upland property. Although a well-built bulkhead will protect the upland areas from erosion by waves, it does not address the sediment deficit that was causing the erosion problem. The sediment deficit that was producing landward recession of the shoreline will be converted to vertical erosion in front of the wall. Areas in front of the wall, which were intertidal or dry beach, will eventually become underwater (see Figure 1).

Figure 2 shows a picture and surveyed profile of a location where this process has occurred. The bulkheads were initially built about 25 years ago when the shoreline was receding. At the time they were built, and for some period thereafter, there was an intertidal beach in front of the bulkheads. There is no intertidal beach seaward of the bulkhead now. This location is near Mullet Point in Mobile Bay, Alabama (see Figure 3 for location).

This process has both ecological and societal implications. Stopping landward shoreline recession with a bulkhead eventually removes all intertidal habitat except for that up and down the vertical wall. Ecologists have found that the intertidal and adjacent sub-tidal areas can be some of the most productive habitat for organisms (Odum 1971).

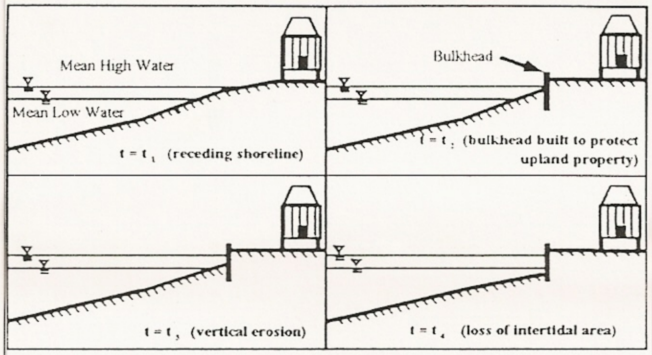

Figure 1. Conceptual diagram of how a bulkhead built on a naturally receding shoreline modifies the nearshore coastal processes as it protects upland property. Landward recession is converted to vertical erosion and areas in front of the wall that were dry beach or intertidal habitat begin to disappear and eventually become underwater (modified from Griggs, et al. 1994).

Loss of the intertidal zone also restricts public walking along the shoreline, particularly in those areas with a riparian right of access below mean high water. If there is no intertidal beach, walking requires trespassing at all times and is often difficult because of the water depth.

The societal implications of the loss of the intertidal habitat may also include the loss of the access to shellfish resources at low tide. Many parts of the country have different local customs and traditions regarding shellfish resources. For example, in Alabama some areas have exposed oyster beds at extreme low tides that are traditionally harvested for individual consumption. Vertical erosion in front of a bulkhead can lead to the loss of this tradition. In the words of one Alabama resident, "the tide doesn't go out anymore," because there are no exposed oyster beds in front of their bulkhead anymore!

This paper investigates bulkheading along urban shorelines. The primary focus is on characterizing the issue. The existing literature on the effects of seawalls, bulkheads and revetments on the littoral system is reviewed in the context of its implications for urban bays and estuaries. Mobile Bay, Alabama is then used as a case study of the extent, rate and type of bulkheading of urban bays and estuaries. The implication is that the dual pressures of more people wanting to live next to the water in the face of rising sea level will continue to reduce intertidal habitat. This will result in a loss to both the natural systems and society. Some alternative solutions, including beach nourishment-like engineering, are outlined.

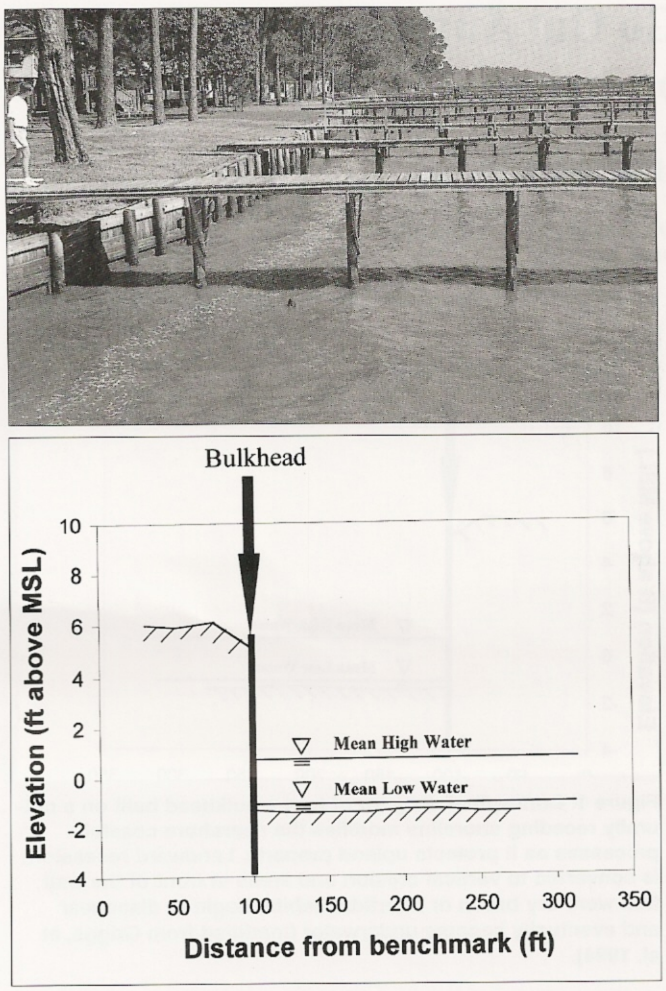

Figure 2. An example of an area with no intertidal habitat seaward of a bulkhead in the Mullet Point area of Mobile Bay, Alabama. (Note: The walkways go to boathouses to the right of the photo offshore.)

EFFECTS OF BULKHEADS ON BEACHES

Seawalls, bulkheads and revetments have similar functions ñ they protect upland property. The relative importance of wave action in the design of the structure is often used to make the distinction between the three types of structures. Seawalls are designed to "withstand the full force of waves," bulkheads are designed "to retain fill, and [are] generally not exposed to severe wave action," and revetments are "designed to protect shorelines against erosion by currents and light wave action" (US Army 1984).

Few studies have been undertaken on the interactions between bulkheads or revetments and sediment distribution in low-energy environments. However, there is a large body of knowledge on the interactions between seawalls and sediment distribution on the open coast beaches (e.g., Kraus and McDougal 1996). Nordstrom (1992) states that estuaries are not scaled-down versions of open coast systems. His argument is based primarily on chemical and biological processes.

Although there are some distinct differences between estuaries and open-coast systems, it is argued in this paper that there are enough similarities between the dominant physical processes in these two environments that they can be considered as shown in Figure 4. The primary difference between physical impacts of stabilization on bay shorelines and open-coast beaches is the magnitude of the wave-driven processes.

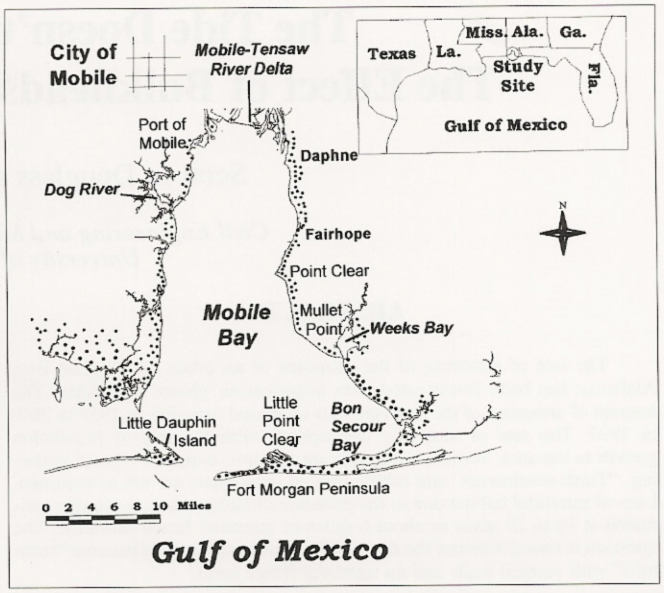

Figure 3. Location map of Mobile Bay, Alabama.

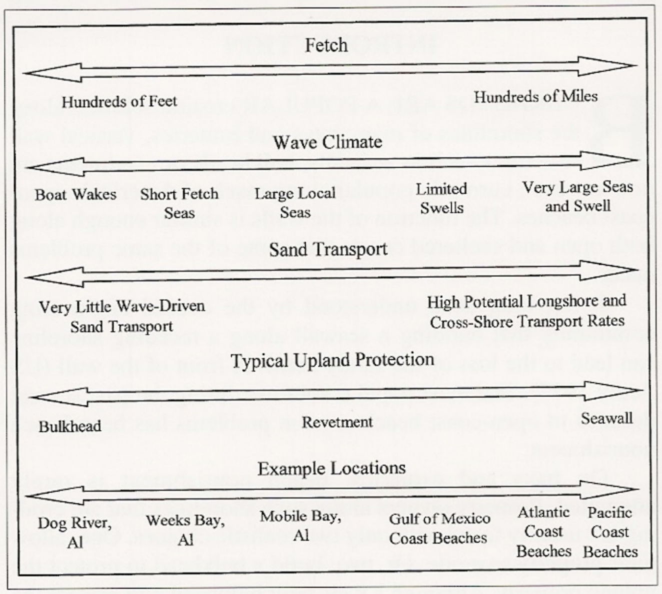

Figure 4. The relationship between four related variables; fetch, wave climate, sand transport and the typical upland protection. As fetch length increases, wave energy and sediment transport increase.

Figure 4 attempts to outline the relationship between four related variables: fetch, wave climate, sand transport and the typical upland protection. As fetch length increases, defined as the distance that waves can be generated by winds, the wave climate and sand transport increase. For example, if the fetch length is on the order of thousands of miles (Pacific Ocean), both local seas and large, distant swells dominate the wave climate with a high potential for longshore and cross-shore sand transport. On the other extreme (small bayous such as Dog River, Alabama; see Figure 3 for location), the fetch length is on the order of hundreds of feet, the wave climate is dominated by boat wakes, and there is little wave-driven sand transport.

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Weggel (1988) created a classification scheme to characterize seawall impacts on nearshore processes that could also be used for bulkheads. The classification scheme is based on the position of the seawall relative to the beach and the water depth at its toe. As background erosion continues, Weggel's classification would change. At the extreme, a seawall can extend across the active beach and function secondarily as a groin (Komar 1998). The presence of a seawall can alter littoral transport in front of and downdrift of the structure. Investigations of these alterations have considered a wide range of wave climates - from small scale laboratory investigations to prototype field investigations in the Great Lakes, Gulf of Mexico, and Pacific Ocean coasts. Several different alteration mechanisms have been considered.

The primary mechanism for the alteration of littoral processes by seawalls, that almost all investigators have found, is the wallís effect on the local sediment budget. Fixed seawalls contribute to the narrowing and eventual loss of intertidal beaches immediately seaward of the walls if the shoreline is receding anyway. This process has been called "passive erosion" (Griggs, et al. 1994). Essentially, the wall fixes the landward edge of erosion on an eroding coast.

Seawalls also remove sand that would have been available to downdrift beaches. For example, Birkemeier (1980) analyzed surveyed beach profiles to show that the shoreline and bluff line erosion directly downdrift of a seawall on Lake Michigan equaled the amount of littoral material protected, and thus removed from the littoral system, by the wall. Essentially, this was additional erosion to the overall background erosion rate. The wall exacerbated the existing erosion problem on the downdrift coast. Similar results have been found elsewhere in field investigations (Morton 1988; McDougal, et al. 1987) and for short-term, storm-induced erosion. Walton and Sensabaugh (1979) found that beaches adjacent to seawalls suffered more than average erosion, landward recession, and property damage during hurricane conditions on the Florida Gulf of Mexico panhandle coast.

Many other mechanisms have been investigated by which seawalls influence littoral processes including wave-induced scour at the toe of the wall (e.g., Barnett and Wang 1988), post-storm recovery (Kreibel 1987), sand bar systems (Davis and Andronaco 1987), and swash mechanics (Plant and Griggs 1992). This study considers only the primary mechanism described above because it seems so ubiquitous across a wide range of wave climates and is probably the dominant process on the estuarine shorelines of Mobile Bay, the shoreline investigated here.

METHODS

The study area was the roughly 100-mile bay shoreline of Mobile Bay, Alabama. A video recording of the bay shoreline was made from an airplane in 1997 to document the present conditions. Aerial photographs were examined to document historical conditions in 1955, 1974 and 1985. Some site visits were made on the ground as part of the air photo analysis.

The analysis procedure for the 1997 video was as follows. While watching the video, the location and type of shoreline armoring were initially written by hand on copies of U.S. Geological Survey (USGS) topographic maps made from digitized forms of the maps at a scale of 1:12,000. These data were then transferred to a digital geographic information system (GIS) program. This intermediate use of the paper copies at a large scale was found to be the most effective way to transfer the visual information seen on the video monitor to the digital GIS format.

The analysis procedure for the historic air photos was as follows. The presence or absence of armoring at each location and time period was detected with a magnifying glass. The location of shoreline armoring at each time period was drawn on the same paper copies of USGS topographic maps used for the 1997 data and then transferred to the GIS program. The distance covered by shoreline armoring for each time period was calculated using the GIS program. The video was also inspected to determine the type of coastal armoring present in 1997 using the same techniques described above.

Loss of intertidal habitat due to the presence of bulkheading was estimated by reference to surveyed beach profile elevations at numerous locations along Mobile Bay. The profiles were used to estimate a typical width of intertidal habitat based on the mean spring tidal range (1.8 ft). This distance was multiplied by the total linear distance of shoreline around Mobile Bay to obtain a rough estimate of the total amount of intertidal area possible. The result was then multiplied by the percent of shoreline bulkheaded and a correction factor to account for the observation that not all intertidal habitat was lost in front of all bulkheads (some bulkheads have an intertidal beach in front of them).

RESULTS

The primary results are the changes in bulkheading at the four time periods and the types of armoring present in 1997. Also, the total loss of intertidal habitat to date attributed to bulkheading was roughly estimated.

Changes in Bulkheading From 1955 to 1997

The location of bulkheads (including all armoring) around Mobile Bay at the four times is shown in Figure 5. In 1955, bulkheads were located at only a few locations along the bay. The extent of bulkheading was about 8% of the total shoreline (Figure 5a). The longest bulkheaded section was between Point Clear and Mullet Point on the eastern shore of the bay

By 1974, the amount of shoreline with bulkheads increased to 14% of the entire bay shoreline (Figure 5b). Bulkheads continued to be built between Point Clear and Mullet Point and began to be built south of Mullet Point in those two decades between 1955 and 1974. Also, a significant number of bulkheads appeared on Fort Morgan Peninsula in Bon Secour Bay (part of Mobile Bay) and more bulkheads appeared on the western shore of the bay.

By 1985, the amount of shoreline with bulkheads increased to 26% of the entire bay shoreline (Figure 5c). Most of the change in that decade, 1974 to 1985, occurred on the western shore of Mobile Bay. Bulkheads continued to be constructed south of Mullet Point to Weeks Bay and north of Point Clear towards Fairhope.

By 1997, the amount of shoreline with bulkheads had increased to 30% of the entire bay shoreline (Figure 5d). At present the shoreline between Fairhope and south of Weeks Bay is characterized by almost complete coverage by bulkheads. The western shore of Mobile Bay and Fort Morgan Peninsula are also covered by an extensive amount of bulkheads. Approximately 153,400 ft (29 miles) of the 1997 shoreline is

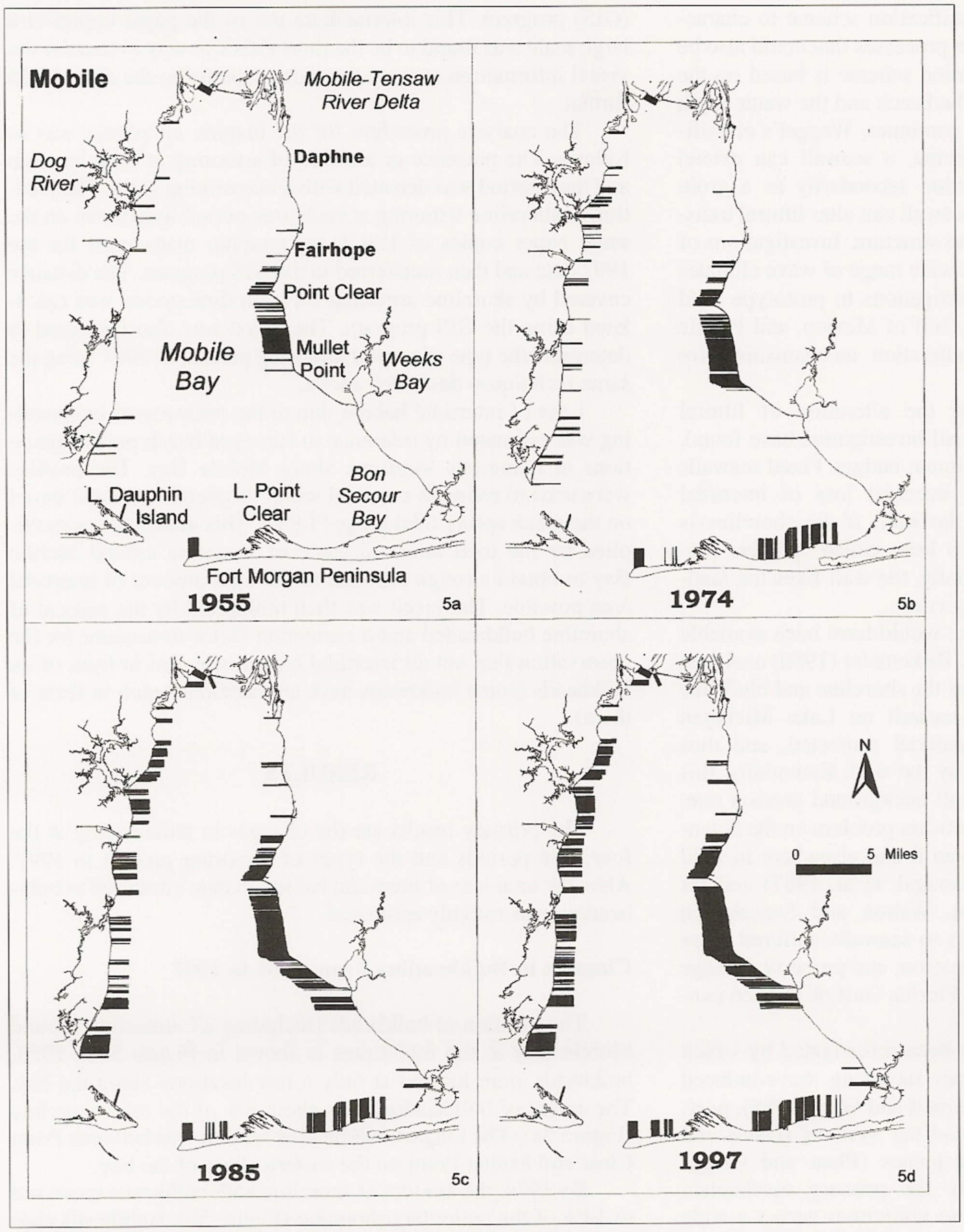

Figure 5. The location of bulkheads in 1955 (4a), 1974 (4b), 1985 (4c), and 1997 (4d) in Mobile Bay, Alabama. The solid black bars represent bulkhead location.

Table 1. Length of Shoreline Armoring along Mobile Bay, Alabama		
	Armored Shoreline	Natural Shoreline
1955	39,900 ft (8%)	475,600 ft (92%)
1974	72,000 ft (14%)	443,500 ft (86%)
1985	132,000 ft (26%)	383,500 ft (74%)
1997	153,400 ft (30%)	362,100 ft (70%)

armored while 362,100 ft of the shoreline is not armored. Table 1 summarizes the length of shoreline armoring at the four times.

Types of Armoring in 1997

The shoreline armoring present in 1997 was separated into three types: vertical bulkheads, rubble-mound revetments, and "trash" revetments. Trash revetments include all non-rock rubble solution attempts, such as broken pavement, fill dirt and failed solutions that were no longer functioning as upland protection. This includes vertical bulkheads that have not been maintained and have rotted away in-place to such an extent that the shoreline has receded landward of the bulkhead.

Vertical bulkheads are the most common shoreline armoring type in Mobile Bay. In 1997, 71% of shoreline armoring was vertical bulkheads. Rubble-mound revetments and trash revetments made up 21% and 8%, respectively, of the bay shoreline.

The location of each type of armoring around the bay is shown in Figure 6. Vertical bulkheads are found throughout the bay, whereas rubble-mound revetments and trash revetments are more prevalent along the western shore of the bay and the Fort Morgan Peninsula.

Examples of Typical Bay Shorelines

Figures 2, 7, and 8 show photographs and beach profiles at three different locations around Mobile Bay. These are presented as typical examples of the different types of shorelines along the bay today. Figure 2 shows a typical location in Mobile Bay with a bulkhead and no dry or intertidal beach. This is one of the older bulkheaded shores in Mobile Bay. Historically, this area had an intertidal beach that residents enjoyed.

Figures 7 and 8 are examples that show some of the Mobile Bay shorelines that have not yet been armored. Figure 7 is a public swimming beach in the City of Fairhope on the eastern shore of Mobile Bay. The photograph shows several debris lines from previous high tides. The beach profile shows that the intertidal zone here is fairly narrow due to the relatively steep beach slope (about 1:12).

Figure 8 is an eroding bluff on the northwestern shore of Mobile Bay. This area is typical of unarmored shorelines throughout the bay. There is a steep bluff that actively erodes during high water storms. The one-year recurrence water level is about +3 ft above mean sea level (MSL) or 2 ft above mean high water in Mobile Bay. These high water levels typically occur due to strong southeast winds for several days that set the shelf of the Gulf of Mexico up several feet and also cause some wind setup in Mobile Bay. Much higher water levels occur during tropical storms. The 100-year flood level is about +12 ft

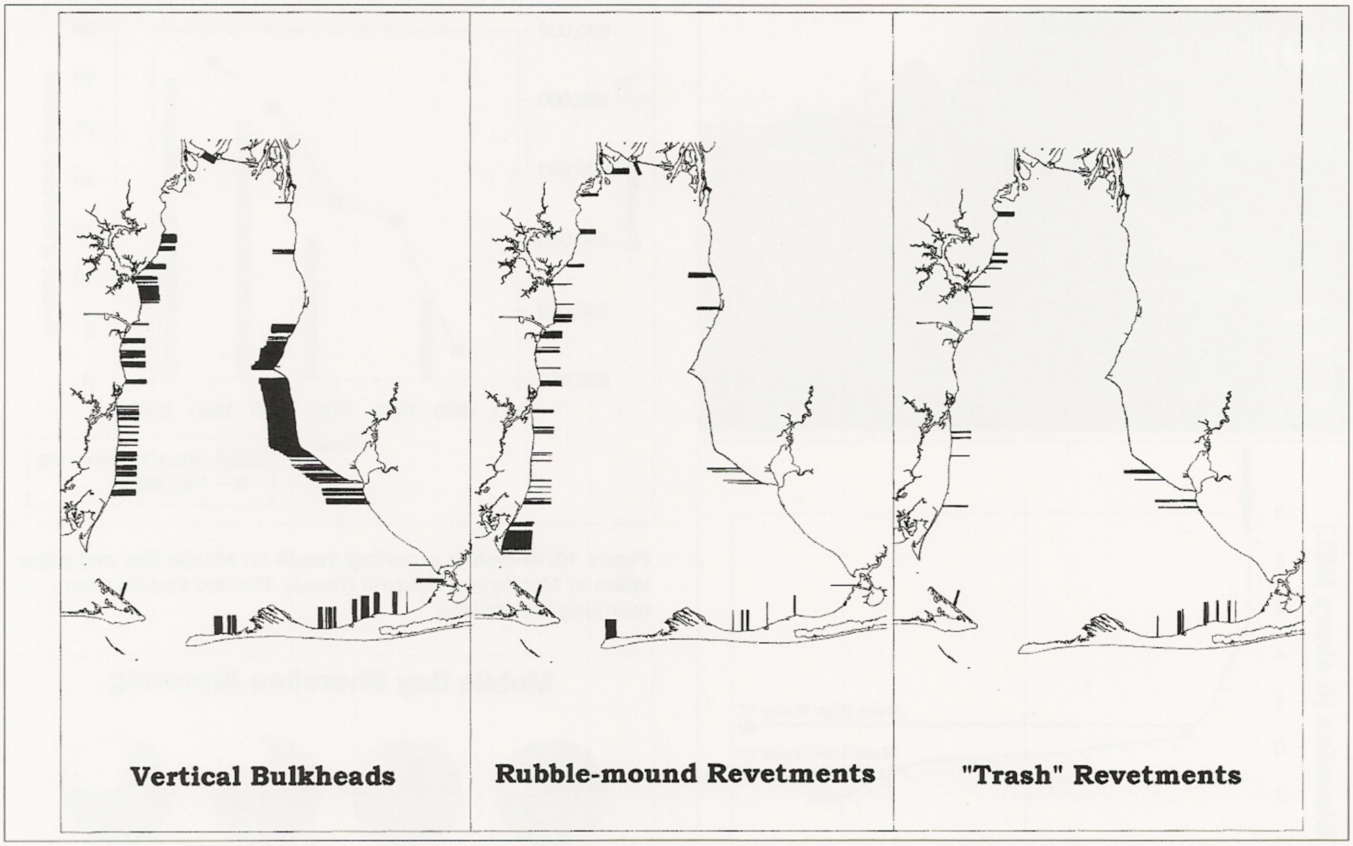

Figure 6. The location of the different types of armoring in 1997 in Mobile Bay, Alabama. The solid, black bars represent location.

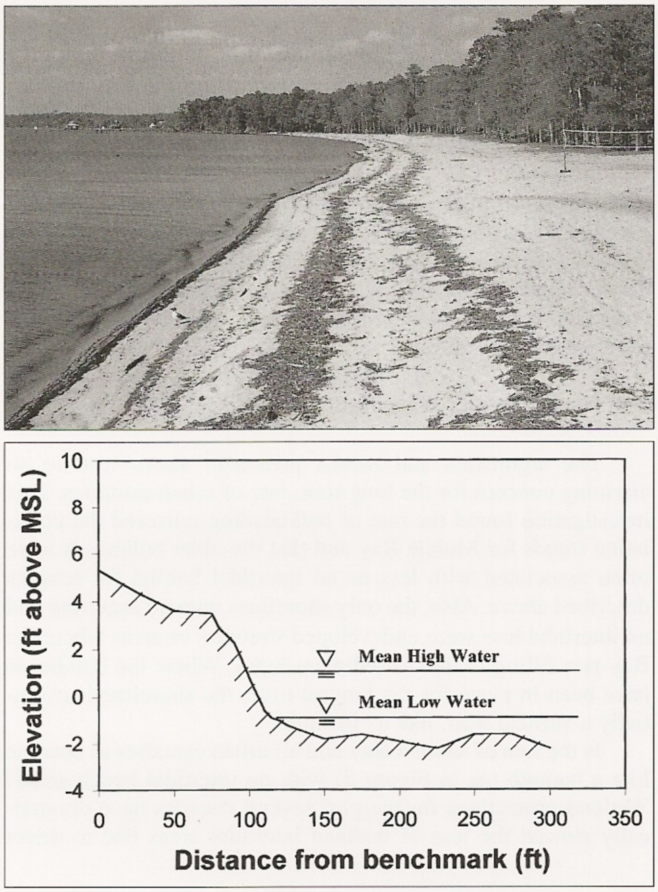

Figure 7. Photo and beach profile showing intertidal zone at the Fairhope public beach on the eastern shore of Mobile Bay.

above MSL. Figure 8 shows a beach at the base of the bluff that is littered with logs and trees that have floated out of the Mobile/Tensaw River systems. The profile shows that the intertidal beach is very wide here. More than 200 ft of tidal flat is exposed at low tide. The land shown in Figure 8 is managed as a golf course by the University of South Alabama.

Estimate of Intertidal Area Loss Due to Bulkheads

An estimate of the intertidal area that has been lost due to historic bulkhead construction on Mobile Bay can be made using the data and reasonable assumptions. As mentioned above, about 30% of the 100-mile long shoreline of Mobile Bay is presently armored. A baywide average, intertidal beach width of 20 ft is assumed. This is probably an underestimate of the intertidal area since some areas have very broad, flat intertidal areas such as shown in Figure 8. Because most bulkheaded areas still have some intertidal zone remaining, a correction factor of 15 to 30% is assumed based on the authors' knowledge of the bay shorelines. That is, it is assumed that the intertidal area has been lost in front of 15% to 30% of the existing bulkheads in the bay. The result is that the amount of intertidal habitat lost due to historic bulkheading is roughly estimated as 10 to 20 acres. In terms of beach shoreline lost, this is 4 to 8 miles. In other words, of the 29 miles of shoreline that is bulkheaded, roughly 6 (+/- 2) of those miles have lost the intertidal beach (Figure 2).

DISCUSSION

The results show that almost one-third of Mobile Bay's shoreline is stabilized by structures, predominantly vertical bulkheads. Canning and Shipman (1994) found a similar result,

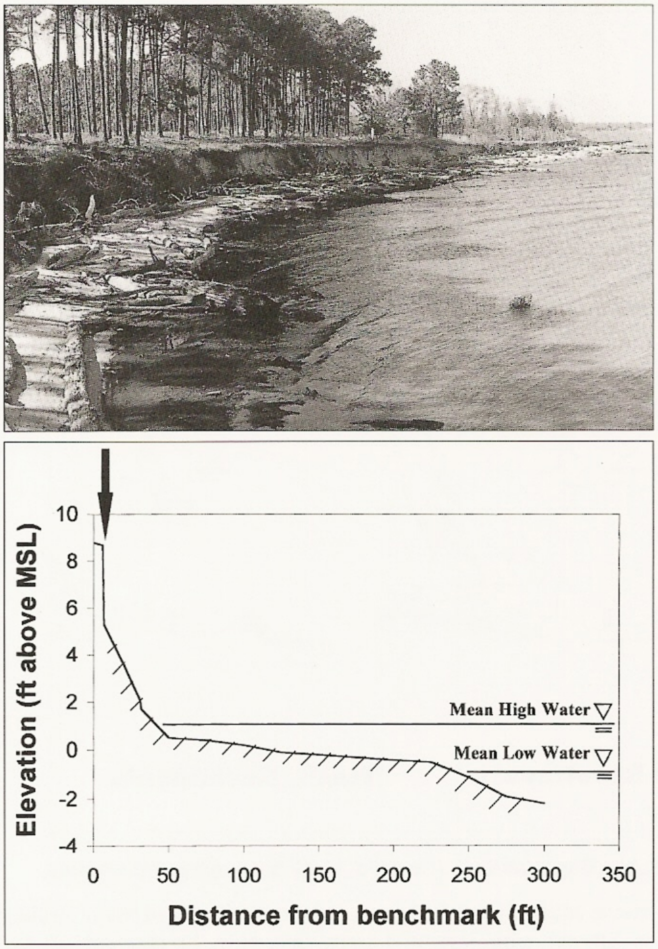

Figure 8. Photo and beach profile showing intertidal zone at the Gulf Pines Golf Course on the western shore of Mobile Bay.

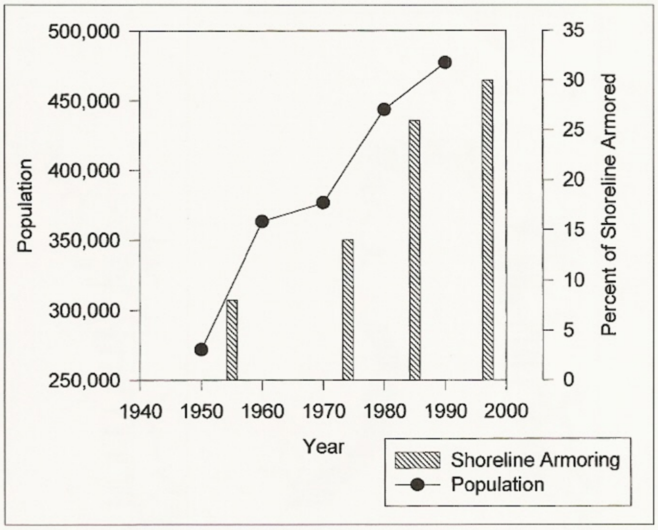

Figure 10. Shoreline armoring trends for Mobile Bay and population of Mobile and Baldwin County, the two counties surrounding Mobile Bay.

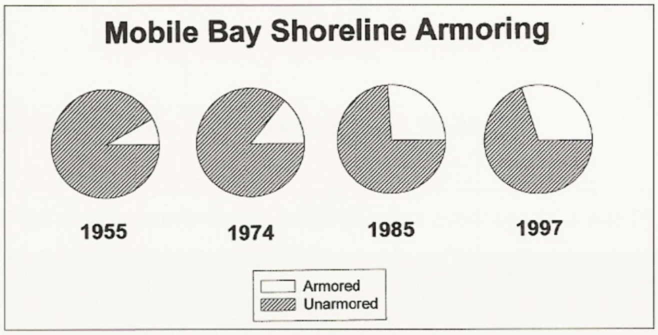

Figure 9. Percentage of shoreline armoring in 1955, 1974, 1985 and 1997 for Mobile Bay, Alabama.

29%, for Puget Sound, Washington. The rate of increase in armoring in Mobile Bay has not been constant. The percentage of armoring through time is shown in Figure 9. The rate of armoring increased between 1974 and 1985. Expressed in terms of percent of shoreline armored per year, the rate varied between 0.3% per year and 1.1% per year (Table 2).

Table 2. Annual Rate of Change in Shoreline Armoring along Mobile Bay, Alabama

	Feet/Year	Percent/Year
1955-1974	1,700	0.3
1974-1985	5,500	1.1
1985-1997	1,800	0.3

These trends in coastal armoring correspond with the population trends in the two counties that border the bay, Mobile County and Baldwin County. Figure 10 shows the upward trend of armoring that roughly parallels the upward trend in population. From 1974-1985, there was an increase in shoreline armoring rate that corresponds with the increased rate of population growth in the 1970's.

Five areas on Mobile Bay have shorelines with almost no armoring. Four of these areas are the undeveloped shorelines of the Mobile-Tensaw River Delta, the northeast shore of the Bon Secour Bay portion of Mobile Bay, Little Point Clear on Fort Morgan Peninsula, and Little Dauphin Island. All four are specially managed public areas, either wildlife refuges or research reserves. One developed area, the City of Daphne, located in the northeast corner of Mobile Bay directly below the Mobile-Tensaw River Delta also has very little coastal armoring. This portion of the bay has little recession because it is shoaling due to riverine sediment input.

The Fate of Urban Estuaries?

The arguments and results presented above lead to an alarming concern for the long-term fate of urban estuaries. This investigation found the rate of bulkheading mirrored the population trends for Mobile Bay and that the older bulkheads were often associated with less or no intertidal habitat for reasons described above. Also, the only shorelines with no armoring and no intertidal loss were undeveloped stretches or areas where the Bay was filling in due to sediment input. Where the bulkheads have been in place for the longest time, the shoreline is essentially a vertical wall, like a "bathtub."

Is the fate of Mobile Bay and all urban estuaries to become like a bathtub (as in Figure 2) with no intertidal beach areas? Wetland protections for the past several decades have dramatically slowed the loss of wetland intertidal areas due to direct filling and dredging. However, the process outlined in this paper is much less obvious. The loss of intertidal habitat over the past half century, estimated in Mobile Bay as 10 to 20 acres or 4 to 8 miles of primarily sandy beach habitat, is that due to the passive influence of bulkheads on local sediment budgets. Many other investigators (Kraus 1988; Fletcher et al. 1997) have attributed the degradation and loss of open coast beaches to this process. It is argued here that the same process is damaging estuarine beaches and intertidal habitats.

Alternatives to Bulkheading

The alternatives to bulkheads on urban shorelines are similar to the alternatives on open-coast beaches, retreat or beach nourishment. Both alternatives will save the intertidal beach, but only nourishment will save the beach and the upland property. Nourishment has been attempted on some estuarine beaches but is not as widely recognized as a feasible engineering alternative. This is unfortunate because the reduced wave climates of estuaries would probably provide for much longer nourishment life than is commonly found on open coast beaches. Also, suitable fill sand may be more available for estuarine shorelines.

The use of some structures to extend the life of beachfills on estuarine shorelines may be more acceptable than on open coast beaches. For example, a headland pocket beach project was recently built along the receding bluff shown in Figure 7. The project was built as a demonstration of an alternative to bulkheads. A beach nourishment was stabilized with artificial rock headlands (Douglass and Pickel 1999). The use of such structures with sand fill can protect upland property and preserve beach and intertidal habitat (Hardaway, et al. 1995). Similar use of structures in conjunction with fills for intertidal marsh construction are also possible. More research into these types of engineered solutions is needed.

CONCLUSIONS

The rate of armoring of the shoreline of Mobile Bay, Alabama has been investigated with historical air photos and video. The amount of armoring of the roughly 100-mile shoreline has increased from 8% in 1955 to 30% in 1997. The rate of armoring corresponds with the rate of population growth in the area. Vertical bulkheads are the most common type of armoring. "Trash revetments" and rubble-mound revetments are not as common. Loss of intertidal habitat due to the presence of bulkheading is roughly estimated at 10 to 20 acres in Mobile Bay, a loss of about 6 miles of intertidal beach shoreline.

These data are discussed in terms of the population trends and site specific framework of Mobile Bay but also as a case study of a wider phenomenon. There appears to be a continuing loss of intertidal bay beach habitat as bulkheads are built to protect upland property along naturally receding bay shorelines. The bulkheads do not address the local sediment deficit causing the recession. The landward recession becomes vertical erosion in front of the bulkheads that leads to a loss of tidal flats at low tide. From the perspective of the homeowners that cannot walk out and pick up oysters at low tide in front of their home, "the tide doesn't go out anymore." The question is raised whether the fate of all urban estuaries is to become "bathtubs" with vertical walls and no intertidal fringe areas.

ACKNOWLEDGEMENTS

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REFERENCES

1. Barnett, M. R. and H. Wang. 1988. Effects of a Vertical Seawall on Profile Response. *Proc. 21st Coastal Engineering Conference*, ASCE Press, 1493-1507.
2. Birkemeier, W. A. 1980. The Effect of Structures and Lake Level on Bluff and Shore Erosion in Berrien County, Michigan, 1970-74. Coastal Engineering Research Center, *Miscellaneous Report No. 80-2*, U.S. Army Corps of Engineers.
3. Canning, D. J. and H. Shipman. 1994. Coastal Erosion Management Studies in Puget Sound, Washington: Executive Summary. Coastal Erosion Management Studies Volume 1. Shorelands and Water Resources Program, Washington Department of Ecology, Olympia, WA.
4. Davis, R. A., and M. Andronaco. 1987. Hurricane Effects and Post-Storm Recovery, Pinellas County, Florida (1985-1996). *Proc. Coastal Sediments 87*, ASCE Press, 1023-1036.
5. Douglass, S.L. and B.H. Pickel. 1999. Headland Beach Construction on Bay Shorelines, *Proc. 12th Annual National Beach Preservation Technology*, FSBPA, Tallahassee, FL, in press.
6. Fletcher, C. H., R.A. Mullane and B.M. Richmond. 1997. Beach Loss Along Armored Shorelines on Oahu, Hawaiian Islands. *J. Coastal Research*. 13(1), 209-215.
7. Griggs, G.B., J.F. Tait and W. Corona. 1994. The Interaction of Seawalls and Beaches: Seven Years of Monitoring, Monterey Bay, CA., *Shore and Beach*, 62(3), 21-28.
8. Hardaway, C.S., J.R. Gunn and R.N. Reynolds. 1995. Headland Breakwater Performance in Chesapeake Bay. *Proc. 1995 Nat. Conf. on Beach Preservation Technology*, FSBPA, Tallahassee. FL, 365-382,
9. Komar, P. D. 1998. *Beach Processes and Sedimentation*. Second Edition. Prentice Hall, Inc. Upper Saddle River, NJ.
10. Kreibel, D. L. 1987. Beach Recovery Following Hurricane Elena. *Proc. Coastal Sediments 87*, ASCE Press, 990-1005.
11. Kraus, N.C. 1988. The Effects of Seawalls on the Beach: An Extended Literature Review. *J. Coastal Research, The Effects of Seawalls on Beaches*, N.C. Kraus and O.H. Pilkey (editors). Special Issue No. 4,1-28.
12. Kraus, N.C. and W.G. McDougal. 1996. The Effects of Seawalls on the Beach: Part I, An Updated Literature Review. *J. Coastal Research*, 12(3), 691-701.
13. McDougal, W.G., M.A. Sturtevant, and P.D. Komar. 1987. Laboratory and field investigations of the impact of shoreline stabilization structures on adjacent properties. *Proceedings of Coastal Sediments '87*, ASCE press, 961-973.
14. Morton, R.A. 1988. Interactions of Storms, Seawalls, and Beaches of the Texas Coast. *J. Coastal Research, The Effects of Seawalls on Beaches*, N.C. Kraus and O.H. Pilkey (editors). Special Issue No. 4, 113-134.
15. Nordstrom, K.F. 1992. *Estuarine Beaches*. Elsevier Applied Science, NY.
16. Odum, E.P. 1971. *Fundamentals of Ecology*, W.B. Saunders Co., Philadelphia, PA.
17. US Army. 1977. *Shore Protection Manual*. 3rd ed. U.S. Army Engineer Waterways Experiment Station, Coastal Engineering Research Center, U.S. Government Printing Office, Washington D.C.
18. U.S. Army. 1984. *Shore Protection Manual*. 4th ed., 2 vols. U.S. Army Engineer Waterways Experiment Station, Coastal Engineering Research Center, U.S. Government Printing Office, Washington D.C.
19. Walton, T.L. and W. Sensabaugh. 1979. Seawall Design on the Open Coast. Florida Sea Grant College, Report No. 29, 24p.
20. Weggel, J.R. 1988. Seawalls: The Need for Research, Dimensional Considerations and a Suggested Classification. *J. Coastal Research, The Effects of Seawalls on Beaches*, N.C. Kraus and O.H. Pilkey (editors). Special Issue No. 4, .29-39.