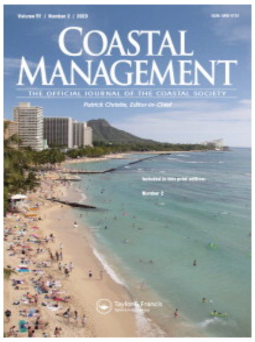


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# The Cost of Shoreline Protection: A Comparison of Approaches in Coastal New England and the Mid--Atlantic

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# The Cost of Shoreline Protection: A Comparison of Approaches in Coastal New England and the Mid-Atlantic

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**ABSTRACT**

Shoreline hardening is a method of coastal hazard protection that is often implemented by government agencies and individual property owners. As awareness of the potential negative effects of shoreline hardening has increased, natural and nature-based approaches have gained in popularity. Most research related to shoreline protection has focused on understanding the environmental and ecological effects. However, for hybrid, nature-based approaches, in particular, there is limited information available to compare their monetary costs. To fill this gap, this study used information collected from public shoreline protection projects within the New England and Mid-Atlantic areas to estimate the costs of these measures based on the materials used, such as vegetation, sand, and/or stone. This approach allows for a detailed measurement of potential project inputs and provides needed cost information on the types of materials local governments and other stakeholders may use in their shoreline protection approaches. Results suggest that approaches that use natural materials tend to cost less than those that use more traditional, engineered materials, and nature-based approaches tend to cost somewhere in-between. Specifically, projects can be divided into four subgroups based on their average per-unit costs: (A) walls (mean: $5,628, se: $680) or stone at exposed sites (mean: $4,943, se: $725); (B) sand for beach nourishment (mean: $3,094, se: $397) or stone at low exposure sites ($3,014, se: $379); (C) stone and vegetation at low exposure sites (mean: $1,626, se: $217), stone and sand for other purposes at low exposure sites (mean: $1,411, se: $173), or sand for other purposes (mean: $1,384, se: $151); and (D) stone and sand for other purposes at low exposure sites (mean: $1,411, se: $173), sand for other purposes (mean: $1,384, se: $151), vegetation (mean: $1,300, se: $159), or vegetation and sand for other purposes (mean: $1,285, se: $172). Finally, monitoring and maintenance costs are often not accounted for, which may negatively affect the long-term success of shoreline protection efforts. Coupled with information on environmental and ecological effects of these different approaches, this information will allow for more informed decisions on how coastal and inland communities can best adapt to coastal risks.

**KEYWORDS**
coastal management; cost analysis; shoreline protection

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## Introduction

Sea level rise and coastal storms present a variety of risks, such as flooding and erosion, to both coastal and inland communities (IPCC 2014). To adapt, governments and individual property owners often build engineered shoreline protection measures, such as bulkheads, riprap revetments, and seawalls. These conventional structural, or "gray," measures physically alter the natural area and resist, attenuate, or deflect incoming wave energy and height, both of which increase during extreme storms and weather events. Therefore, they are best suited to protect shorelines that face large waves and wave energy, large fetch, or have steep slopes (Hardaway et al. 2017; SAGE 2015). However, these gray approaches have a limited lifetime and require regular maintenance (Glick et al. 2020; Sutton-Grier et al. 2018). They can also negatively affect nearby areas and ecosystems. For example, seawalls and revetments may exacerbate erosion both seaward and to surrounding unarmored beaches (Beuzen et al. 2018; Balaji, Kumar, and Misra 2017; Dugan et al. 2008; Campbell, Benedet, and Thomson 2005) and can cause losses of certain types of shorebirds and aquatic organisms (Gittman et al. 2016; Bilkovic and Roggero 2008; Dugan et al. 2008; Seitz et al. 2006). Further, seawalls and revetments may limit the ability of beaches and salt marshes to act as buffers and may inhibit landward migration in response to storms and sea level rise (Schuerch et al. 2018; Enwright, Griffith, and Osland 2016; Shepard, Crain, and Beck 2011; Morgan, Burdick, and Short 2009; Bozek and Burdick 2005).

As awareness of the potential negative effects from gray approaches has increased over the past several decades, natural, and nature-based approaches have gained more attention and research (Roberts 2010; Currin, Delano, and Valdes-Weaver 2007). Natural approaches rely on the protective and resilient functions of existing or restored ecosystems, such as floodplains, wetlands, riparian zones, beaches, and dunes. Nature-based solutions provide coastal protection by using the natural features of the environment, often coupled with human engineered measures that mimic the natural environment (Glick et al. 2020; Bridges et al. 2015, USACE, 2013). These nature-based, or hybrid, solutions combine gray and natural approaches to varying degrees (O'Donnell 2017; Bridges et al. 2015; Sutton-Grier, Wowk, and Bamford 2015). Natural materials may be primarily used, but these solutions will have added structural components, such as revetments, sills, or groins. For example, a marsh toe revetment placed at the eroding edge of a marsh or breakwater oyster reefs seaward of an armored shoreline would be considered nature-based approaches. These approaches can help control erosion and dissipate wave energy (Smith et al. 2018; Gittman et al. 2014; Barbier et al. 2013; Scyphers et al. 2011; Meyer, Townsend, and Thayer 1997), as well as provide a variety of ecosystem services (Bilkovic et al. 2016; Barbier et al. 2008, 2011). However, they are most effective for shorelines that do not face high wave energy (Currin, Davis, and Malhotra 2017; SAGE 2015).

The costs associated with these shoreline approaches depend heavily on their size, the existing site conditions, and site access. Costs can include design, materials, labor, equipment, permitting, surveying, and administrative and clerical costs. Labor can include engineers who design and oversee construction, biologists to address ecosystem aspects, landscape architects for plant palette and visual aspects, and construction laborers who complete the work. Heavy machinery, such as bulldozers and excavators, may be needed to move soil, sand, or large rocks from one location to another. Beach nourishment projects also often require sand to be dredged from an offshore borrow site and transported to the nourishment site through pipelines or on vessels (Dean 2003).

When homeowners, community planners, and local governments are considering their options for shoreline protection, a variety of factors, including effectiveness, durability, ecological impacts, and costs, must be evaluated (Sutton-Grier et al. 2018; Ives and Furuseth 1988; Ricketts 1986). Most research thus far, however, has been dedicated to understanding the environmental and ecological effects of these different approaches and there is little research comparing monetary costs. Homeowners may believe natural shorelines are less expensive, but require more long-term maintenance (Kochnower, Reddy, and Flick 2015; Scyphers, Picou, and Powers 2015) and are less effective at protecting their property than traditional measures (Smith et al. 2017; Friesinger and Bernatchez 2010), and contractors tasked with designing and constructing shoreline protection structures may be unfamiliar with nature-based techniques (Sauvé, Bernatchez, and Glaus 2020; CCRM 2014).

Six existing studies, to-date, have estimated and compared the costs of various shoreline protection approaches (Table 1). This limited existing research suggests that shoreline protection approaches that incorporate natural and nature-based materials, such as vegetation and biodegradable fiber, may have lower per-unit costs than approaches that only include gray materials (Gittman and Scyphers 2017; Peek, Schupp, and Babson 2016; SAGE, NOAA, and USACE 2014; CCRM 2014; Georgia DNR 2013; Seachange Consulting 2011). However, as these studies have small sample sizes and geographic scopes, and often do not provide their methodology, more robust cost analyses are critical, particularly related to newer, nature-based approaches.

The purpose of this study is to provide cost estimates for shoreline protection measures in coastal New England and the Mid-Atlantic, as well as contribute to the general literature on how best to estimate these costs. As nature-based approaches are still novel, more information is needed on their relative costs to inform decisions on their use compared to conventional structural or natural approaches (Sutton-Grier, Wowk, and Bamford 2015; Sutton-Grier et al. 2018; Powell et al. 2019). Therefore, this study uses information collected from 105 public shoreline protection projects to estimate the costs of shoreline protection measures based on the materials used, such as vegetation, sand, and/or stone. Compared to strictly binning projects as gray, natural, or nature-based, this materials-based approach better accounts for potential project inputs and the complexities of nature-based approaches. Furthermore, it can help local natural resource managers more accurately estimate costs when considering various approaches to shoreline protection.

## Materials and methods

Using similar methodologies to CCRM (2014) and Peek, Schupp, and Babson (2016), a database of shoreline protection projects within coastal New England and the Mid-Atlantic was compiled using sources including (1) federal agencies, such as the US Army Corps of Engineers (USACE) Civil Works and National Oceanic and Atmospheric Administration (NOAA) National Marine Fisheries Service; (2) university

**Table 1.** Summary of past cost analyses of shoreline protection approaches.

| Study | Location | Methodology | Project type | Average cost per meter (2020$) |
|---|---|---|---|---|
| Seachange Consulting (2011) | North Carolina Estuaries | Not specified | Vegetation planting | $28 (do-it-yourself) to $377 (full-service landscaper) |
| | | | Stone sill | $283 to $566 |
| | | | Riprap revetment | $340 to $566 |
| | | | Bulkhead | $302 to $4,530[a] |
| Georgia Department of Natural Resources (Georgia DNR) (2013) | Sapelo and Little St. Simons Island, Georgia | Real material and construction costs for three projects | Living shoreline | $1,293 to $1,338 |
| | | Not specified | Revetment | $1,597 to $1,709[b] |
| | | | Bulkhead | $2,360 to $3,725[b] |
| Center for Coastal Resources Management (CCRM (2014) | Maryland, Delaware, Florida, and the Northern Gulf of Mexico | Not specified | Non-structural (e.g., planting vegetation and regrading) | $177 to $832 |
| | | | Hybrid (e.g., marsh-sill living shoreline) | $394 to $3,698 |
| | | | Structural (e.g., revetments) | $454 to $5,548 |
| SAGE, NOAA, and and USACE (2014) | Not specified | Not specified | Estuarine vegetation planting | Initial construction: up to $3,583<br>annual maintenance: up to $358 |
| | | | Edging or sill in combination with vegetation planting | Initial construction: $3,586 to $7,165<br>annual maintenance: up to $358 |
| | | | Beach nourishment, with or without vegetation on dune | Initial construction: $7,169 to $17,913<br>annual maintenance: $362 to $1,791 |
| | | | Revetment | Initial construction: $17,916 to $35,825<br>annual maintenance: $362 to $1,791 |
| | | | Bulkhead | Initial construction: up to $7,169 to $17,913<br>annual maintenance: $362 to $1,791 |
| | | | Seawall | Initial construction: up to $17,916 to $35,825<br>annual maintenance: over $1,791 |
| Peek, Schupp, and Babson (2016) | US | Real costs for eight projects | Beach nourishment | $1,061 to $3,538 |
| | | Real costs for nine projects | Onshore, shore-parallel structures (e.g., seawalls, revetments, and bulkheads) | $7,076 to $10,614<br>Up to $35,379 |
| Gittman and Scyphers (2017) | North Carolina | Household survey of 1,000 waterfront owners | Living shoreline | $375[c] |
| | Alabama, Florida, and North Carolina | | Riprap revetment | $180 to $496[c] |
| | | | Bulkhead without riprap revetment | $645 to $795[c] |
| | | | Bulkhead with riprap revetment | $859 to $961[c] |

[a]The large range provided is due to the variability of factors determining the cost, including water access, equipment, shoreline conditions, materials, and size of bulkhead.
[b]The estimated costs do not include the cost to barge materials to the barrier islands or housing for contractors on the barrier islands.
[c]Average cost estimates

research centers, such as the Program for the Study of Developed Shorelines at Western Carolina University and the Center for Coastal Resource Management at the Virginia Institute of Marine Science at the College of William & Mary; (3) the New Hampshire Aquatic Resource Mitigation Program; and (4) personal communication with individuals with first-hand knowledge of specific shoreline projects.

As there is a range of materials with varying costs that can be used in shoreline protection approaches, nature-based in particular, project descriptions were used to determine whether each project included the addition or removal of the following materials: walls (e.g., seawalls and bulkheads), stone (e.g., riprap and other revetments), vegetation (e.g., beach grass, marsh grass, trees), sand for beach nourishment, and sand for other purposes. Sand for beach nourishment refers to sand that was dredged offshore and placed onto the beach, whereas sand for other purposes refers to sand that was already on site, but required regrading or some other modification, or was brought in from a nearby location. The two were separated from each other because beach nourishment projects, typically performed by USACE, involve much larger quantities of sand and additional costs related to dredging, transportation, and excavation.

Per-unit costs, adjusted for inflation, were calculated for each project, and average per-unit project costs then were calculated for each material. T-tests with unequal variances were then used to test if per-unit costs varied based on site exposure, as low exposure sites, such as estuaries, bays, or lagoons, are subject to lower wave energy than exposed sites, which directly face the ocean, and, therefore, may require fewer or smaller materials. Potential outliers were identified and examined using the Tukey fence method (Tukey 1977). Finally, difference-of-means tests for the overlapping groups (as projects often used more than one material) were estimated using the following two steps. First, per-unit project costs were regressed against a binary variable indicating the presence or absence of the material for each material. Second, a statistical method called "seemingly unrelated estimation" was used to test if these estimated coefficients differed significantly from each other. If the coefficient for a given material is significantly different, then that suggests that projects that use that material have a significantly different per-unit cost than projects that use other materials. All analyses were performed using Stata/SE 16.1, and all p-values are provided for the reader to assess statistical significance.

## Results

A total of 122 projects were found within the study area (Figure 1). However, only 114 had sufficient information on the size (linear meters), costs (2020$), and the completion date (year) of the project, as well as information on the materials used. Of those remaining projects, nine outliers were identified and removed. Therefore, 105 projects were included in the analysis. As only one project documented costs associated with monitoring and maintenance, the analysis focused on initial costs, which include design, permitting, and construction.

Project characteristics by the types of materials used are summarized in Table 2. While most ($n = 64$) projects used only one of the identified materials, roughly a quarter ($n = 24$) used two, and the rest ($n = 17$) used three or four. Projects that used sand for beach nourishment were most likely to use a single material, and projects

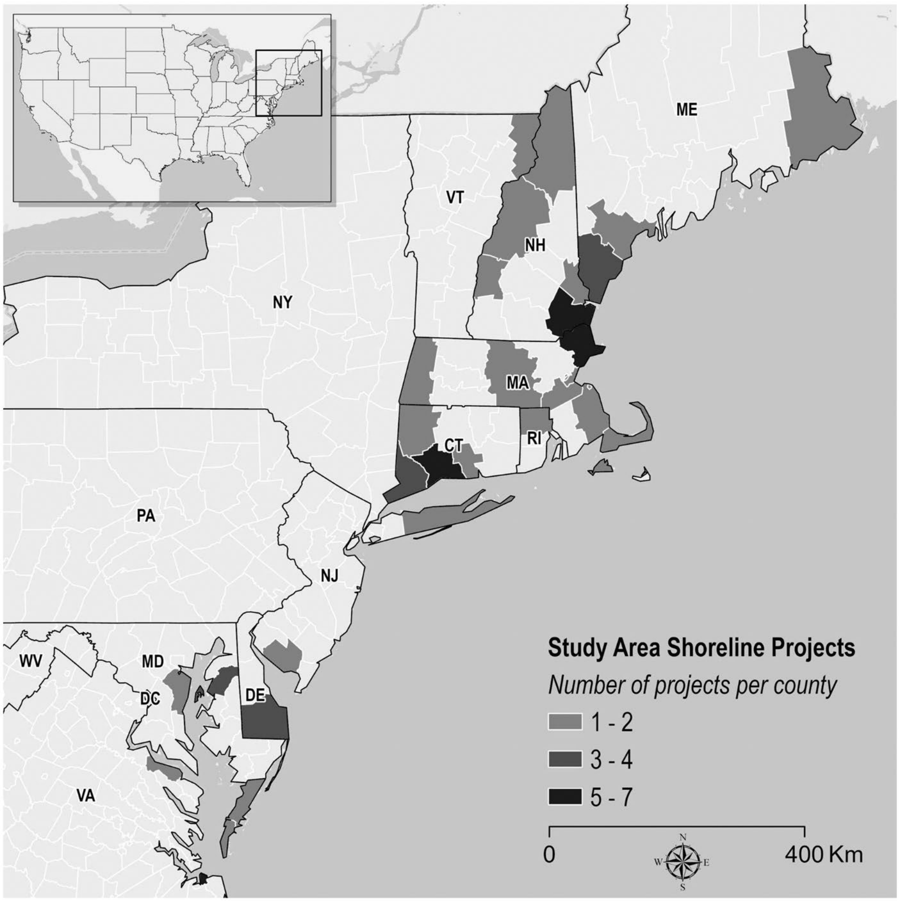


**Figure 1.** Map of the geographic distribution of the 122 projects found within the New England and Mid-Atlantic coastal study area. Gray to black shading indicates the number of projects within each county.

**Table 2.** Summary of project characteristics by material.

| Material(s) | Project count (N) | Only material(s) (%) | Average age (Years) | Average size (Meters) | New England (%) | Low exposure site (%) |
|---|---|---|---|---|---|---|
| Stone | 58 | 37.9 | 20.5 | 522.1 | 67.2 | 75.9 |
| Vegetation | 33 | 24.2 | 7.2 | 475.0 | 36.4 | 84.8 |
| Sand (beach) | 28 | 75.0 | 35.7 | 1,725.9 | 67.9 | 25.0 |
| Walls | 24 | 50.0 | 15.5 | 486.0 | 83.3 | 62.5 |
| Sand (other) | 21 | 4.8 | 5.7 | 771.2 | 19.0 | 81.0 |
| Stone + Vegetation | 20 | 25.0 | 5.8 | 418.9 | 15.0 | 95.0 |
| Vegetation + Sand (other) | 17 | 23.5 | 6.5 | 483.1 | 17.6 | 82.4 |
| Stone + Sand (other) | 16 | 18.8 | 5.4 | 901.1 | 6.3 | 93.8 |
| Total | 105 | 61.0 | 20.1 | 801.8 | 68.6 | 59.0 |

that used sand for other purposes were least likely. The most common material combinations were vegetation and stone, vegetation and sand for other purposes, and stone and sand for other purposes.

The majority of projects occurred in New England and were completed in 2000 or later (61%); however, the oldest project was completed in 1955. On average, projects

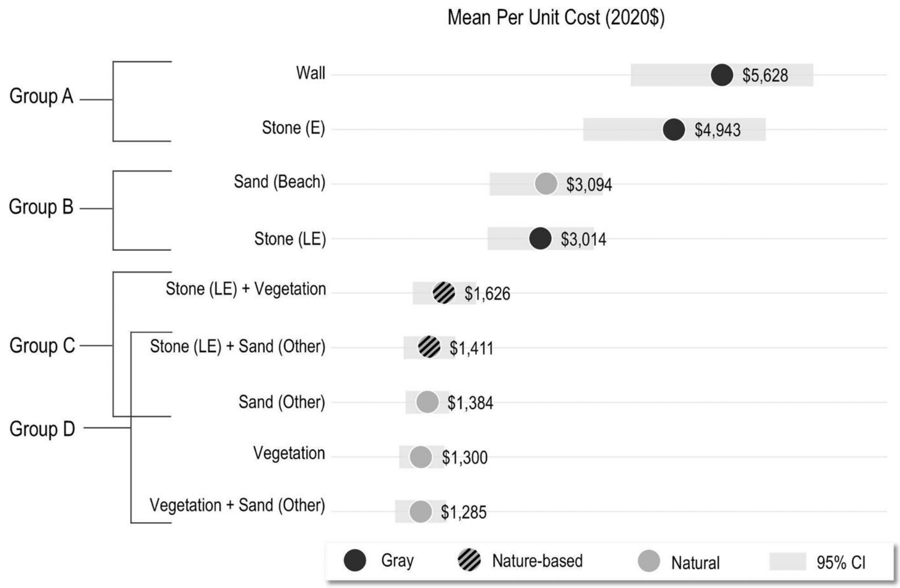


**Figure 2.** Average per-unit project costs for each material and material combination, including 95% confidence intervals. Gray materials are shown in dark gray, natural in light gray, and nature-based are striped.

that incorporated vegetation or sand for other purposes tend to be more recent and projects that incorporated sand for beach restoration tend to be the oldest. Most projects that used stone, sand for beach nourishment, or walls took place in New England. Finally, over half of the projects (n = 62) took place at low exposure sites (e.g., estuaries, bays, lagoons). While per-unit costs tend to be more expensive at exposed sites compared to low exposure sites, the only significant relationship found was for projects that used stone (t = 2.4, $p = 0.01$). Therefore, projects that used stone were further divided into categories of low exposure (n = 44) versus exposed sites (n = 14).

Average per-unit costs, adjusted for inflation, for each material or combination of materials are shown in Figure 2. Four subgroupings of projects emerged based on the results of the seemingly unrelated estimation:

- Group A: Projects that used walls or stone at exposed sites (z = 0.75, $p = 0.45$)
- Group B: Projects that used sand for beach nourishment or stone at low exposure sites (z = 0.15, $p = 0.88$)
- Group C: Projects that used stone and vegetation at low exposure sites, stone and sand for other purposes at low exposure sites, or sand for other purposes ($0.27 < z < 1.28$, $0.20 < p < 0.27$)
- Group D: Projects that used stone and sand for other purposes at low exposure sites, sand for other purposes, vegetation, or vegetation and sand for other purposes ($0.10 < z < 1.56$, $0.12 < p < 0.92$)

Average project size was also estimated for each material or combination of materials and is shown in Figure 3. On average, projects that used sand for beach nourishment are significantly larger than other projects ($2.39 < z < 5.05$, $0.01 < p < 0.02$) except for projects that used sand for other purposes and stone at low exposure sites (z = 1.64,

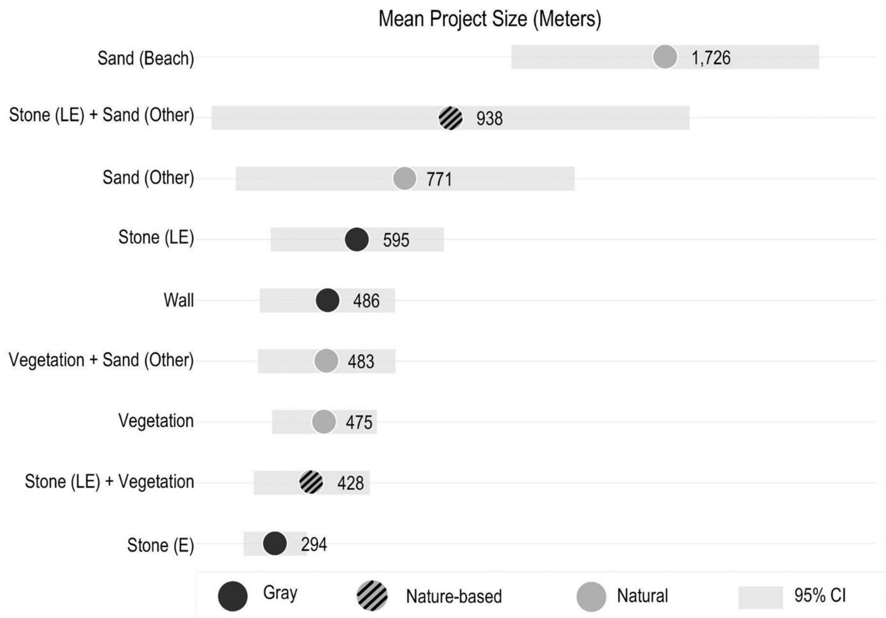


**Figure 3.** Average project size for each material and material combination, including 95% confidence intervals. Gray materials are shown in dark gray, natural in light gray, and nature-based are striped.

$p = 0.10$); however, projects that used the latter materials also have the greatest variation in size (standard error = 408.96). All other projects are not significantly different from each other in size except for projects that used stone at exposed sites are significantly smaller than projects that used stone at low exposure sites ($z = 1.82$, $p = 0.07$) or vegetation ($z = 1.80$, $p = 0.09$).

## Discussion

Results suggest that shoreline protection approaches that use natural materials (Group D) tend to have lower per-unit costs than those that use more traditional, gray materials (Group A). Further, nature-based approaches (Group C) tend to cost somewhere in-between the two depending on the materials used. The main exception to this finding is that beach nourishment tends to cost the same as projects that use stone at low exposure sites (Group B). This is likely due to the high cost of specialized equipment or practices, such as dredging and transportation via pipelines or vessels, required for beach nourishment (Dean 2003) coupled with the fact that low exposure sites are subject to lower wave energy than exposed sites and, therefore, fewer or smaller materials are likely required. For example, exposed sites likely require larger stones, such as riprap, whereas low exposure sites likely require smaller stones, such as cobblestone. This difference in the types of stones used could also explain why projects that used walls and those that used stone at exposed sites tend to have similar costs.

This high cost of specialized equipment or practices could also explain the relatively higher costs of gray approaches. Another potential explanation could be that exposed sites are more likely to use gray infrastructure due to either real or perceived concerns over protection effectiveness. Therefore, it is difficult to disentangle the effects of materials, equipment, and practices from site conditions when estimating project costs. However, given that costs at exposed sites were only more expensive for projects that used stone, this is unlikely a major concern.

One potential explanation for the lower cost of natural approaches, especially those that use vegetation, is the ability to use volunteer labor (Hardaway et al. 2017). For example, over half of the projects (n = 21) that used vegetation in the database specifically mentioned using volunteer labor. Conversely, the specialized equipment or practices required for traditional shoreline armoring are unlikely to be performed by volunteers.

Other important findings are that beach nourishment projects tend to be the largest, and projects that use stone are smaller at exposed rather than at low exposure sites. The first finding is likely because beach nourishment projects tend to occur along the entire shoreline, whereas the other project types focus on replacing, repairing, or otherwise augmenting portions of the shoreline. This relates to the second finding, as stone is often used to support existing shoreline approaches, such as beaches and seawalls, at exposed sites. While the entire site may be relatively large, stone is only added to the specific segments that need additional support. Alternatively, at low exposure sites, projects in the database tended to use stones to form sills, which are usually continuous along the shoreline.

Compared to previous studies, these cost estimates are much higher than those found by Seachange Consulting (2011) and Gittman and Scyphers (2017), which both focused on the costs to homeowners, and much lower than SAGE, NOAA, and USACE (2014). These cost estimates are also slightly higher than those found by Georgia DNR (2013). This is likely due to differences in material and labor costs, as well as different physical settings of tidal ranges, ice and winter stresses, and construction windows in New England and the Mid-Atlantic as compared to those in the southern US. Estimates for gray and nature-based approaches are most similar to the upper end of the wide range of cost estimates found by CCRM (2014), and estimates for beach nourishment are most similar to those found by Peek, Schupp, and Babson (2016). These similarities are likely due to the fact that these studies focused on relatively large-scale projects implemented by federal, state, or local governments, similar to the shoreline projects analyzed in the present paper.

A key finding while compiling the shoreline protection projects database is that monitoring and maintenance costs are often not accounted for due to uncertainty in project lifespans and the mechanisms, such as grants, used to fund these projects (Sauvé, Bernatchez, and Glaus 2020). This lack of information highlights a major challenge to ensuring the success of these shoreline approaches.

The lifespans of all shoreline protection projects primarily depend on sea level rise, as well as storm events and unexpected human interference, and monitoring and maintenance is needed to better understand and extend their lifespans (Sutton-Grier et al. 2018; Bridges et al. 2015; Cunniff and Schwartz 2015; Nicholls et al. 2013). Initial monitoring and maintenance are especially critical for natural approaches to allow vegetation to become established and, eventually, take over the functions of other materials, such as coir products, that degrade over time. However, monitoring and maintenance are generally not well-understood by funding bodies, such as local and federal governments and nonprofits, and there is little follow up. As there is no one-size-fits all approach to newer, nature-based approaches, there is additional difficulty in finding contractors capable of constructing these methods in a sound manner. Alternatively, while the initial investments required for gray projects are fairly predictable, as the design, construction methods, and materials for gray projects are familiar to engineers and contractors, sea level rise and storm events still contribute to uncertainty in maintenance costs.

While uncertainty regarding these costs is likely to persist, certain measures can be taken to reduce it (Sauvé, Bernatchez, and Glaus 2020). For example, local governments can ensure that their public works departments are adequately funded for not only initial construction but also long-term maintenance and monitoring. While these additional costs are not entirely predictable, establishing a sufficient funding stream is a good first step. Another measure would be to engage local communities during the planning phases of natural and nature-based projects as volunteers may be able to assist in construction and long-term maintenance, as was the case for several projects within the database. Finally, these barriers may naturally dissipate as awareness of nature-based approaches to shoreline protection increases.

There are three main caveats to these findings. First, since all projects included in the analysis are relatively large-scale and implemented by federal, state, or local governments, cost estimates may not be generalizable to smaller or privately funded projects. Second, while the cost estimates provided are based on the materials used in a given project, they are also assumed to include costs beyond the materials themselves, such as planning and design, permitting, engineering, and equipment. This assumption has two implications. First, the cost estimates are not intended to be additive across materials and, as shown in Figure 2, projects that use a combination of materials are likely to cost less than simply summing cost estimates for individual materials. Second, if costs were not consistently reported for all projects prior to their incorporation into the database, then this would lead to an underestimate of costs and potentially an increase in uncertainty (larger standard errors). Third, as information on monitoring and maintenance costs and project lifespans is generally not reported and, therefore, not accounted for in this analysis, these relative results may not hold if this information varies substantially by material type. Future research should attempt to compile more detailed cost breakdowns; however, these estimates can be used as an informed first step when budgeting for future shoreline protection projects.

## Conclusion

The results of this study can help managers more accurately estimate costs when considering various approaches to shoreline protection, particularly within the New England and Mid-Atlantic regions. This is a critical area of research that must be addressed through robust analyses, as the few existing estimates are based on a limited number of observations and often do not provide their methodologies. This study highlights the importance of considering a variety of potential material inputs to shoreline protection, especially when comparing the costs of new, more complex nature-based approaches to gray or natural approaches. Coupled with information on the environmental and ecological effects of these different approaches, this information will allow for more informed decisions on how coastal and inland communities can best adapt to risks, such as flooding and erosion.

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## Disclosure statement

No potential competing interest was reported by the authors.


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