frontiers | Frontiers in Marine Science

TYPE Original Research
PUBLISHED 04 April 2023
DOI 10.3389/fmars.2023.1031012

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SPECIALTY SECTION
This article was submitted to
Coastal Ocean Processes,
a section of the journal
Frontiers in Marine Science

RECEIVED 29 August 2022
ACCEPTED 17 March 2023
PUBLISHED 04 April 2023

CITATION
Guthrie AG, Stafford S, Scheld AM, Nunez K and Bilkovic DM (2023) Property owner shoreline modification decisions vary based on their perceptions of shoreline change and interests in ecological benefits.
Front. Mar. Sci. 10:1031012.
doi: 10.3389/fmars.2023.1031012

Property owner shoreline modification decisions vary based on their perceptions of shoreline change and interests in ecological benefits

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Even under current sea level conditions, many communities are working to protect their coastlines against flooding and shoreline erosion. Coastal communities often protect their shorelines against excessive erosion by using armoring techniques (e.g., bulkheads, riprap). Yet hardened structures reduce many of the natural adaptive mechanisms present in coastal ecosystems and reduce the sustainability of the coastal system. In contrast, natural and nature-based features (e.g., living shorelines) can better protect coastal properties from storm damage and reduce erosion while also having the potential to adapt to new conditions. Since property owners are installing armoring structures more often than living shorelines, we sought to understand the factors motivating their shoreline modification decision. We surveyed property owners in Virginia, U.S. that applied for a shoreline modification permit. Most property owners, regardless of modification sought, perceive riprap revetment to be effective, able to withstand storm damage, and able to adapt to sea level rise. Interestingly, property owners that sought out living shorelines were not highly confident in living shorelines' protection benefits. While most property owners perceived the ecological benefits of living shorelines, these benefits did not substantially impact the decision over what type of shoreline modification to implement. Our work highlights pathways that can improve coastal resilience given the important role that shoreline property owner decisions contribute to coastal community resiliency. Our results indicate there is a need to better engage property owners about the protection and adaptation benefits of living shorelines as their perceptions were not aligned with scientific assessments of living shorelines. Concurrently, coastal policies could be strengthened to support more natural approaches to shoreline management, as the more common armoring techniques are not resilient to sea level rise or storm damage.

KEYWORDS

social science, private property, adaptation, living shorelines, shoreline armoring, coastal erosion, ecosystem service, decision making

1 Introduction

Climate change is reducing the sustainability and resiliency of coastal communities. Rural and urban coastal communities are highly vulnerable to flooding due to storm surges and sea level rise (Kleinosky et al., 2007). Sea level rise will compound damages and effects from storm surges making coastal communities even more vulnerable in future years, particularly as storms are predicted to become more intense (Webster et al., 2005; Kleinosky et al., 2007; Lin et al., 2012). Intense storms are discrete events that can contribute to property erosion and damage, yet routine wave action (e.g., wind-driven waves, boat wakes) and sea level rise also contribute to coastal erosion (Schwimmer, 2001). As modeled along sandy shores, higher sea levels can enable higher erosion rates which exacerbate coastal property loss and more frequent, moderate wave energy events (storms) result in more erosion than less frequent, intense storms (Leatherman et al., 2000; Leonardi et al., 2016).

Coastal wetlands, including salt marshes, potentially might adapt to new sea levels through vertical accretion or landward migration (Kirwan et al., 2016; Mitchell et al., 2017). As water levels rise, accreting marshes are expected to maintain shoreline protection from wave action by dissipating wave energy (Möller et al., 2014). However, marshes are lost because of anthropogenic stressors, including coastal development and shoreline armoring (Kennish, 2001). Shoreline armoring (i.e., hard, engineered structures used to stop erosion) replaces natural shoreline ecosystems (e.g., marshes or beaches) with hardened structures and substantially decreases the ecosystem services provided from these shoreline habitats, such as nutrient removal or wave attenuation (Bozek and Burdick, 2005; Bilkovic et al., 2006; Currin et al., 2010; Gittman et al., 2015). Alternatively, natural and nature-based infrastructure (e.g., living shorelines) can lessen shoreline erosion and flooding effects by utilizing natural ecosystem functions and ecosystem services, such as sedimentation, reducing storm damage, and marsh migration (Davis et al., 2015; Bilkovic et al., 2016; Smith et al., 2017; Polk et al., 2022).

Although living shorelines have more sustainable property protection and ecological benefits, they are not being installed in all locations that are viable (Pace and Morgan, 2017; Berman et al., 2018). To increase implementation, property owners will need a more complete understanding of the effectiveness and benefits of living shorelines compared to other more commonly used modification methods as well as the ability to find qualified contractors that can install living shorelines. Many coastal states have implemented policies or initiatives to further the use of living shorelines. Virginia, U.S. was an early adopter of a living shoreline policy to encourage the use of living shorelines (Jones and Pippin, 2022). In Virginia, a living shoreline is defined as “a shoreline management practice that provides erosion control and water quality benefits; protects, restores, or enhances natural shoreline habitat; and maintains coastal processes through the strategic placement of plants, stone, sand fill, and other structural and organic materials” (Va. Code §28.2-104.1). From 2011 until 2020, Virginia identified living shorelines as the “preferred” erosion management strategy but were not required (Va. Code §28.2-104.1; CCRM, 2010). Since the law was updated in summer 2020, Virginia regulations now require living shorelines to be installed where suitable (Va. Code §28.2-104.1), but the effect and implementation of this new law needs to be evaluated, as it is expected that some property owners will continue to be hesitant about installing living shorelines or will need to be convinced of the living shoreline benefits. Thus, it is important to understand how and why property owners are making their shoreline modification decisions.

Stakeholders such as conservation organizations and local governments have expressed interest in being better included in the development of natural resource management and policy. More specifically, there have been calls to further integrate social impacts and ecosystem services into land-use and spatial decision making (Karrasch et al., 2014; Longato et al., 2021). The transition to incorporating ecosystem services should include community values and perspectives, as science alone is not expected to support more inclusive and more comprehensive decision making (Fisher et al., 2009). An improved understanding of community interests can both help account for different perspectives and priorities and can provide community members with more targeted information on topics to increase their education and awareness.

The decision-making process is complex and depends on multiple factors and has been studied extensively in several different disciplines, including psychology, economics, sociology, and management. The decision-making process also differs dramatically depending on whether the decision is made by a group or an individual (Mukherjee et al., 2016). For coastal zone management, understanding individual decision-making is critical as private property owners have a strong influence on shoreline management decisions on their property (Stafford and Guthrie, 2020) in many settings. When an individual makes a decision, they explicitly and implicitly evaluate a variety of factors, including culture, norms, economics, experiences, beliefs and preferences (Scyphers et al., 2015; Bennett, 2016). Since property owners hold diverse perspectives and perceptions, face differing economic and environmental contexts, and have different values and objectives, it can be difficult to model or predict the cumulative impact of individual decisions on the environment if such factors are not considered. Thus, it is critical to increase our understanding of how property owners make their decisions in order to better model how shorelines are likely to evolve under climate change and to determine the most effective ways to encourage property owners to make more sustainable decisions. If we can determine the key factors influencing property owner decision making, coastal managers can develop more targeted messages and products (e.g., flyers, websites), revise regulations, or increase monitoring and enforcement to drive future behavior in a more sustainable direction.

Our goal was to assess the factors related to property owner shoreline modification decision making for erosion control, by examining property owner perceptions of 1) shoreline modification ecosystem services (e.g., erosion protection effectiveness, water quality benefits), and 2) shoreline risk (e.g., erosion, flooding, storm damage). We anticipated that property owners that were aware of the protection benefits of living shorelines would be more likely to apply for a living shoreline permit. Based on prior studies (Stafford, 2020; Stafford and Guthrie, 2020) which find that property owners with recent experiences of property flooding and erosion would be more likely to install living shorelines, but those that had property storm damage would be more risk averse and be more likely to install shoreline armoring (e.g., bulkheads, riprap), we hypothesized that experiences with flooding, erosion and storm damage would impact shoreline modification choice as well.

2 Methods

2.1 Survey design

To better understand property owner decision making about shoreline modifications, we mailed surveys to 528 Virginia shoreline property owners in 2020. As shoreline modification structures require a permit from the Virginia Marine Resources Commission (VMRC), the mailing list was all the applicants that applied for a shoreline modification permit for erosion control in 2019. We focused on permit applicants from 2019, the year prior to the survey, to reduce recall bias. Although Virginia law changed in summer of 2020 to require living shorelines where suitable, all the applicants included in the survey applied for their permit in 2019 – before the law was changed. At the time the permits were applied for, living shorelines were the “preferred” management option where suitable, but were not required in Virginia (Va. Code §28.2-104.1; CCRM, 2010). We designed the survey to assess how respondent decision making related to the shoreline protection strategy for which they applied. As property owner perception and values have been shown to influence shoreline modification decisions in North Carolina and Alabama, U.S. (Scyphers et al., 2015; Gittman et al., 2021), our focus was to evaluate Virginia property owner perceptions of ecosystem service benefits of shoreline modification types. Following Bennett (2016), we use the term perceptions to refer to the way an individual “observes, understands, interprets, and evaluates” ecosystem services. We further asked questions based on respondents’ experiences with shoreline erosion, flooding, and storm damage on their property. We were interested in their reported experience as a previous econometric analysis in Virginia indicates that properties with higher storm surge are more likely to be modified (Stafford, 2020). To account for other relevant experiences and concerns, we asked how they use their property (i.e., primary residence, secondary use), and the top factors explicitly considered during their decision-making process. To confirm that questions were applicable and understood by property owners, we sent a pilot survey to 50 property owners that applied for a shoreline modification permit in 2018. We made minor changes to clarify wording.

Because multiple shoreline modifications could be implemented under one permit, we categorized the respondent shoreline modifications into five categories based on their reported modification: riprap revetment, bulkhead, armoring mix (combinations of armoring techniques, including: riprap, bulkheads, groins), living shoreline (combinations of living shoreline techniques that meet the legal definition of living shorelines in Virginia, including: marsh with oyster castles, marsh with a rock sill, and breakwater/beach), and living shoreline mix (combinations of shoreline armoring and living shoreline techniques). Breakwater beach nourishment projects are considered living shorelines because they restore or maintain natural beach habitats of high energy settings. Pictures and definitions were included with the survey to help reduce confusion about modification types (Figure 1). We linked the respondent to their permit application – where they listed their intended modification(s) – to assess accuracy of reported modifications to permitted modifications However, we chose to use their survey response for modifications rather than those listed in the permit as 1) the installed modification(s) may not be the same as the modification(s) requested on the permit and 2) the survey response better reflects the property owner’s belief about their modification at the time of the survey.

2.2 Ecosystem service perception

To understand how property owner perceptions of ecosystem services may influence shoreline modification decisions, we surveyed respondents about their perception of ecosystem service provision (erosion protection, storm damage protection, sea level rise protection, aesthetic benefits, water quality benefits, wildlife benefits) for three modification types (bulkheads, riprap, and living shoreline). These possible responses were a five-point Likert scale (e.g., extremely effective, moderately effective, no effect, moderately not effective, extremely not effective), with an additional “unsure” response. This ordinal scale implied a range of effectiveness with “no effect” as the center point for effective or not effective perceptions. For example, “moderately not effective” and “extremely not effective” suggest the modification was worse than “no effect” while the other two options are better than “no effect.” As respondents had varying baselines about the perceived benefits of shoreline modification types, we analyzed the respondents’ perception of the services provided by each modification relative to their perception of that ecosystem service provision across all three modifications. More specifically, we demeaned (i.e., centered) responses (excluding “unsure” responses) for each respondent for each ecosystem service so that positive values indicate the respondent perceived that modification as relatively more beneficial compared to the other modifications. For example, if a respondent selected both living shoreline and riprap to be “extremely not effective” (i.e., raw scores of 1) at withstanding sea level rise and bulkhead as “moderately effective” (i.e., raw score of 4) at withstanding sea level rise, we rescaled these values, centering them on 0. Thus, both the living shoreline and riprap modification would have new scores of -1 (previously “extremely not effective”) and the bulkhead would have a new score of +2 (previously “moderately effective”), indicating that the respondent thought the living shorelines and riprap were slightly worse and that bulkheads were better than their baseline perception. As we were interested in evaluating the relative differences in perception and how that relates to decision making, we did not include any

FIGURE 1
Shoreline modification types Shoreline modification types that were defined in the survey with the accompanying pictures of **(A)** riprap revetment, **(B)** bulkhead, **(C)** groins, which are classified as shoreline armoring and **(D)** breakwaters, **(E)** marsh with a rock sill, which are classified as living shorelines. Photo credits from the Center for Coastal Resources Management, Virginia Institute of Marine Science.

"unsure" selection in the demeaning calculation and the final score of any unsure selection as determined to be 0 (i.e., centered mean) as we assumed this uncertainty was not a perception for (positive score) or against (negative score) any modification type.

We assessed if there were any mean differences in relative perceptions of ecosystem services based on the respondent's modification type. All tests were conducted in R (R Core Team, 2020). Homogeneity of variance of respondent perceptions was analyzed with the Levene Test for Equality of Variances (Weisberg and Fox, 2019). We applied Tukey Honest Significant Difference tests to determine which pairs had statistically different mean perceptions. For these pairwise comparisons, we used adjusted p-values (i.e., rescaled p-values to maintain a 95% family-wise confidence level) to assess significance.

2.3 Shoreline risk assessments

To understand how a respondent's modification selection was related to independent assessments of shoreline risk, we used previously developed datasets that modeled shoreline erosion, coastal flood duration, and wave height during two major storms. Shoreline erosion rate was determined by a shoreline change analysis from the Virginia Institute of Marine Science Shoreline Studies Program that used transects to assess the distance that a shoreline had retreated landward or advanced waterward from 1937 and 2009 (Hardaway et al., 2017). The erosion rate for the shoreline was extrapolated between transect points (Isdell et al., 2020). Storm risk was determined based on the modeled storm surge wave height for two scenarios: Hurricane Isabel [Category 2, 2003, North Carolina landfall, Nunez et al., (2022a)] and a 2009 Nor'easter (Nunez et al., 2022b). Storm surge was modeled using an unstructured grid in Semi-implicit Cross-scale Hydroscience Integrated System Model (SCHISM; Zhang et al., 2016) which allowed for a highly resolved model along complex shoreline geography. The maximum wave height experienced during Hurricane Isabel and the 2009 nor'easter storm were determined by selecting the peak of the storm, and then extracting the maximum wave height experienced within that 24-hour period. Lastly, we used a dataset from Mitchell et al. (2022), where they determined flooding risk using a spatial analysis of average annual flooding duration for coastal Virginia based on overlaying National Oceanic and Atmospheric Administration hourly tidal gauges, from 2000-2020, on lidar-derived digital elevation models (Danielson and Tyler, 2016). All shoreline risk datasets and the respondent's property location were spatially joined using different geoprocessing tools (e.g., spatial join, near tool) in ArcGIS Pro v.2.7. Seventeen respondents were removed from further modeled risk analysis because their property was more than 500 m form the shoreline. In these cases, it was not clear which segment of the shoreline they owned or were responding to, which made it not feasible to link the respondent location to the modeled risk assessments. These respondents were not removed from other analyses.

We developed multinomial logistic regression models to assess how property owner experiences and shoreline risk were related to the respondent modification type. All statistical analysis was completed in R with the models run using *nnet* and *marginaleffect* packages (Venables and Ripley, 2002; R Core Team, 2020; Arel-Bundock, 2022). Property owner shoreline experience consisted of three binary variables indicating the respondent's experience of 1) shoreline erosion in the prior year, 2) property flooding in the prior year, and 3) storm damage in the two years prior. Modeled risk assessments which consisted of erosion risk, flooding risk, and storm risk, and were binned into zero/very low, low, medium, and high categories. Zero erosion was considered either 0 m per year (1 property) or shoreline accretion (27 properties). Following Bilkovic et al., 2019, low erosion was considered less than 0.15 m per year, medium erosion was 0.15-0.3 m per year, and high erosion was more than 0.3 m per year. Very low flooding was 0-5 hr per year, low flooding was 5-100 hr per year, medium flooding was 100-200 hr per year, and high flooding was over 200 hr per year. Hurricane Isabel and the nor'easter wave heights were binned based on their respective quartiles, then the bins were averaged and reclassified into quartiles. Before reclassification, the median wave height for the Nor'easter was 0.002 m. There was a strong right skew with 89 parcels (out of 206) with 0 m wave height. For Hurricane Isabel the median wave height was 0.4 m. We assessed the Pearson correlation within the property owner shoreline experiences and within the modeled risk assessments. As some of the data were moderately or highly correlated, we analyzed the data as univariate assessments to reduce collinearity. For all models, bulkhead respondents were the reference category (eq 1, Y_i^*.)The independent variables (eq 1, X_i.) representing experience or modeled risk were analyzed separately resulting in six models based on 1) erosion experience, 2) flooding experience, 3) storm experience, 4) erosion risk, 5) flooding risk, or 6) storm risk. Errors were assumed to be independent. The property owner shoreline modification decision was modeled as

$$Y_i^* = f(X_i) + \varepsilon_i \tag{1}$$

Where Yi^* was defined as the net benefit to the property owner associated with the modification choice i, X_i was a vector that included one of six the property risk or experience variables, and ϵ_i was an unobserved error term for each property owner i. The latent variable Y_i^* corresponds with the observed binary variable Y_i which is equal to 1 if modification i was selected by the property owner. Model intercept was allowed to vary based on modification type. Variable significance was set at $\alpha = 0.05$.

3 Results

3.1 Shoreline modification decision factors

We received 228 completed responses out of 523 delivered surveys (N=528, 5 were undeliverable addresses) for a response rate of 43% (Table 1). To analyze if there was a response bias, we compared the proportion of modification types of the received responses with the proportion of modification types of the survey universe. The survey respondents were representative of the modification categories in the survey universe, as the proportion of respondents for each modification differed by 5% or less of the corresponding proportions of the survey universe. Because we chose to use the respondents reported modification rather than the permit application information, we evaluated how well the reported modification reflected the permit application. We found some discrepancies between the respondent's reported modification type and the permit application information, with 52 of 226 respondents reporting a different modification than was applied for in the permit. Of those respondents, most of the discrepancies (52%) were due to inconsistencies in the type(s) of armoring indicated by recipient compared to the permit (e.g., bulkhead and riprap were included on the permit [Armoring mix], but the respondent only selected riprap on the survey [riprap]). A little less than a third of respondents (30%) had inconsistencies associated with living shoreline and riprap designations. Twelve respondents reported having a living shoreline or living shoreline mix when the permit only referenced riprap, and four respondents said they had riprap when the permit only referenced living shorelines. For the analysis, we used the respondent reported modification type as it reflects the respondent's perspective and belief about the modification type and accounts for the possibility that the installed modification differs from the requested modification on the permit. Respondents that returned a survey and applied for a permit but were not in tidewater Virginia (i.e., within the tidal plain) were removed from additional analysis (n=4).

We also compared the response rate based on the respondents' location as measured by zip code. Across the survey universe, 64 zip codes had more than two applicants and of those, only 10 zip codes had underrepresentation (i.e.,< 30% responded) and 3 had overrepresentation (i.e., > 70% responded). Counties that had zip codes with underrepresented responses included Middlesex, Essex, Lancaster, Richmond, Virginia Beach, York, and Accomack counties while Lancaster, James City, and Accomack had zip codes with overrepresented responses.

The proportion of respondents who were applying for a modification for their primary residence ranged from 81% for armoring mix respondents to 93% for living shoreline respondents. Other respondents were applying for property that had secondary uses, such as undeveloped land, rental property, or a second home (Appendix 1). Fairly consistently across all modification categories and all property types, most respondents felt the cost of the modification was appropriate, ranging from 69% (bulkhead respondents) to 83% (armoring mix respondents) agreeing with the cost. A quarter or less of respondents within each modification category felt the cost was too high. Only 4

TABLE 1 Number of respondents for each modification category.

Modification type	Number of returned responses	Number of mailed surveys
Bulkhead	52	151
RipRap	82	206
Armoring Mix	28	71
Living Shoreline Mix	29	45
Living Shoreline	37	54
Not Applicable	0	1
Total	228	528

Number of respondents that returned the survey for each modification category and the number of surveys mailed for each modification category. The "Not Applicable" count was an application of pond impoundment with no modification requested.

respondents in total reported that they would have paid more (6% of bulkhead respondents and 4% of living shoreline respondents, Appendix 1). Similarly, most respondents would recommend their selected modification, ranging from a low of 68% for those with living shorelines alone to a high of 89% for those with a living shoreline mixed with armoring (Appendix 1).

The purpose of the modification varied based on the type of modification applied for. For riprap, living shoreline mix, and living shoreline respondents, more than half were installing new modifications (54%, 57%, and 79% respectively) and less than a third were repairing modifications (33%, 26%, and 15% respectively). Most of the bulkhead respondents were repairing an existing modification (63%) while about a quarter (27%) of bulkhead respondents were applying for new modifications. For armoring mix respondents, less than half (44%) were applying for new structures and a slightly smaller proportion (41%) were applying to repair an existing modification. Any remaining respondents were both repairing and installing new modifications (Appendix 1).

Respondents were asked to select up to five factors that influenced their shoreline modification decision. As shown in Table 2, the stated factors influencing property owner decisions varied based on the respondent modification type. For all modification types, overall erosion control effectiveness and ability to withstand storms were considerations for more than half of respondents, ranging from 81% of riprap respondents to 56% of bulkhead respondents. More than three quarters of riprap, armoring mix, and living shoreline mix respondents considered the effectiveness against storm damage. Over half of living shoreline mix respondents also considered the effect on property value, and visual aesthetics. Most armoring mix, riprap, living shoreline, and living shoreline mix respondents considered how the modification contributed to restoring the shoreline, with living shoreline and living shoreline mix respondents having the highest proportions (95% and 82% respectively, Table 2).

3.2 Ecosystem service perception

Ecosystem service perception responses were often correlated. There was a positive correlation among living shoreline perceptions (Tables 3, 4), as those that perceived living shorelines to provide erosion protection also viewed living shorelines as able to withstand storms and able to withstand sea level rise. Respondents who perceived living shorelines to be protective against erosion tended to view bulkheads as less adaptable to sea level rise (Table 3). Respondents that perceived bulkheads to be protective against sea level rise often responded that bulkheads were also protective against storm damage, and the same trend was true for positive views of riprap (Table 3). Those that rated living shorelines as supportive for water quality often rated living shorelines as supportive of wildlife, and this same trend holds true for bulkhead and riprap perceptions (Table 4). Similarly, looking across modifications, those that viewed living shorelines as supportive of water quality felt that bulkheads were not supportive of wildlife (Table 4).

Overall, there were more property owners that were uncertain about the ecological benefits and fewer property owners were uncertain about the protection benefits of shoreline modifications. They had the least certainty about the impacts of various modifications on water quality and wildlife support, with between 17% and 25% of property owners marking that they were not sure of the impact. In contrast, between 0% and 15% of respondents marked unsure of their perception of aesthetic benefits, sea level rise protection, erosion effectiveness, and storm damage protection.

Ecosystem service perception of storm and sea level rise protection, water quality and wildlife benefits varied depending on a respondent's modification. There were significant pairwise differences (adjusted $p<0.05$, Table 5) between respondent modification categories about the perception of 1) bulkhead storm protection, 2) living shoreline water quality benefits, 3) riprap water quality benefits, 4) living shoreline wildlife support, and 5) bulkhead wildlife support. Not surprisingly, respondents tended to have higher perceptions about the effectiveness of the modifications that they installed compared to the perceptions of those modifications from respondents that had installed other modifications. Thus, respondents with bulkheads perceived bulkheads to have higher storm protection than did respondents who installed living shoreline and living shoreline mixes. Respondents with living shorelines perceived living shorelines as better for water quality than respondents with riprap or bulkhead. Similarly, respondents who installed bulkhead and respondents that

TABLE 2 Top factors considered.

	Cost	Visual aesthetics	Erosion effectiveness	Restore the shoreline	Effect on property value	Ability to withstand storms
bulkhead	**62%**	27%	**56%**	31%	**75%**	**65%**
riprap	**56%**	**25%**	**81%**	**53%**	**55%**	**84%**
armoring mix	43%	29%	**71%**	**61%**	**50%**	**93%**
living shoreline mix	**36%**	**54%**	**64%**	**82%**	**57%**	**89%**
living shoreline	49%	41%	**73%**	**95%**	38%	**62%**

Respondents were asked to select the top five factors influencing their decision. Table 2 includes the factors that were selected by at least half of respondents within a modification category. Bold values indicate respondent proportions over 50%. The survey also provided additional options as potential factors: 1) presence of birds, 2) preserve access to the water, 3) maintenance requirements, 4) presence of fish or crabs, 5) oyster habitat, 6) similarity to neighbors' shoreline, 7) adapt to changing sea conditions, 8) impact on water quality, and 9) control nuisance animals. But these nine options were selected as one of the "top five factors" by fewer than 50% of respondents for each modification category.

TABLE 3 Perceived protection benefits correlations.

		Erosion protection			Sea level rise protection			Storm protection		
		LS	bulkhead	riprap	LS	bulkhead	riprap	LS	bulkhead	riprap
Erosion protection	LS	–	–	–						
	bulkhead	–	–	–						
	riprap	–	–	–						
Sea level rise protection	LS	**0.64**	**-0.54**	-0.37	–	–	–			
	bulkhead	**-0.53**	**0.65**	0.10	–	–	–			
	riprap	-0.37	0.08	0.47	–	–	–			
Storm protection	LS	**0.61**	-0.47	-0.41	**0.58**	-0.44	-0.39	–	–	–
	bulkhead	-0.44	**0.62**	-0.01	-0.42	**0.54**	0.02	–	–	–
	riprap	-0.38	-0.01	**0.58**	-0.36	0.04	**0.52**	–	–	–

Correlation among respondent perceptions of ecosystem services contributing to shoreline protection. Bolded values indicate correlations that were stronger than ± 0.5. Diagonal values within each variable type (e.g., erosion protection) were excluded as they were not independent of each other and are marked with a dash "–". Correlations between living shoreline and bulkhead or riprap were always negative, while correlations between bulkhead and riprap were sometimes negative and sometimes positive. Living shoreline was abbreviated as LS.

installed riprap perceived riprap as more supportive of water quality than the respondents who installed living shorelines. Living shoreline respondents perceived living shorelines as more supportive of wildlife than respondents with armoring mix, riprap, or living shoreline mix. Armoring mix, riprap, and living shoreline mix respondents perceived bulkheads as more supportive of wildlife than respondents with living shoreline respondents (adjusted p<0.05). Respondents' reported experience (i.e., yes, or no) with erosion, flooding, and storm damage did not appear to relate to the mean perception of modifications' ability to provide erosion, flooding, and storm protection, respectively (Appendix 2).

As the respondent's modification type did not significantly relate to their perception of protection benefits (except for bulkhead storm protection), we determined the relative rank order of how respondents viewed the modification types based on the overall mean (Table 6) and also reported it based on the mean per each respondent modification category (Appendix 3). Respondents generally perceived riprap to be the most effective and living shorelines the least effective against erosion, storm damage, and sea level rise. In contrast, respondents often perceived living shorelines to be the most supportive of ecosystem benefits while bulkheads were often seen as the least supportive of ecosystem benefits, such as aesthetic, water quality, and wildlife benefits. There were nuances in the perceived ecosystem benefits as respondent modification type was related to perceived water quality and wildlife benefits.

3.3 Shoreline risk factors

The survey asks respondents to provide information about their experiences with erosion in 2019 (i.e., the year of their permit application) and flooding since 2018. We found that only 58% of bulkhead respondents reported erosion, while at least 78% of

TABLE 4 Perceived ecological benefits correlations.

		Aesthetic benefits			Water quality benefits			Wildlife support		
		LS	bulkhead	riprap	LS	bulkhead	riprap	LS	bulkhead	riprap
Aesthetic benefits	LS	–	–	–						
	bulkhead	–	–	–						
	riprap	–	–	–						
Water quality benefits	LS	0.45	-0.27	-0.31	–	–	–			
	bulkhead	-0.29	0.24	0.12	–	–	–			
	riprap	-0.32	0.10	0.33	–	–	–			
Wildlife support	LS	0.43	-0.24	-0.31	**0.78**	**-0.59**	-0.44	–	–	–
	bulkhead	-0.28	0.17	0.19	**-0.58**	**0.66**	0.04	–	–	–
	riprap	-0.30	0.15	0.24	-0.45	0.04	**0.64**	–	–	–

Correlation among respondent perceptions of ecosystem services contributing to ecological benefits. Bolded values indicate correlations that were stronger than ± 0.5. Diagonal values within each variable type (e.g., aesthetic benefits) were excluded as they were not independent of each other and are marked with a dash "–". Correlations between living shoreline and bulkhead or riprap were always negative, while correlations between bulkhead and riprap were always positive. Living shoreline was abbreviated as LS.

TABLE 5 Shoreline modification perception comparisons.

Ecosystem service perception	Tukey HSD: Pairwise differences		
	Group 1	Group 2	p -value
Storm protection *(bulkhead)*	living shoreline	**bulkhead**	0.011
	living shoreline mix	**bulkhead**	0.040
Water Quality *(living shoreline)*	**living shoreline**	bulkhead	0.03
	living shoreline	riprap	<0.001
Water Quality *(riprap)*	living shoreline	**bulkhead**	0.035
	living shoreline	**riprap**	0.002
Wildlife support *(living shoreline)*	**living shoreline**	armoring mix	0.041
	living shoreline	riprap	0.044
	living shoreline	living shoreline mix	0.004
Wildlife support *(bulkhead)*	living shoreline	**armoring mix**	0.027
	living shoreline	**riprap**	0.019
	living shoreline	**living shoreline mix**	0.035

Group in bold is the respondent modification group that perceived the modeled ecosystem service as higher (e.g., bulkhead respondents viewed the storm protection of bulkheads as higher than living shoreline respondents). Only significant results were reported (familywise α = 0.05).

respondents for all other modification types reported erosion. When asked what caused the erosion – with the survey options as storms, waves, boat wakes, or unsure – over 70% or more of respondents attributed the erosion to storms. Over half of armoring mix, living shoreline mix, and living shoreline respondents attributed erosion to wind-driven waves. Further, a little more than half of living shoreline mix respondents (55%) attributed erosion to boat wakes. The vast majority of respondents had an expectation of what was causing the erosion, with 14% or less of respondents, across all modification types, reporting they were unsure of what caused their erosion.

For respondents that reported experiencing erosion on their shoreline, there is a higher probability that they applied for a living shoreline instead of a bulkhead (i.e., model reference category), and a lower probability that they applied for armoring mix, living shoreline mix, and riprap rather than a bulkhead (i.e., living shoreline > bulkhead > armoring mix, living shoreline mix, and riprap; Tables 7, 8). In addition to the respondent's experience with erosion, we also modeled the erosion rate for each property. We did find a difference in reported and modeled erosion. We found 16% of respondents reported no erosion where erosion was occurring, and 11% of respondents reported erosion in areas that were not eroding, totaling to 27% of mismatch (i.e., 73% of agreement) between measured erosion and experience of erosion (Appendix 4). We also found that those with higher modeled erosion risk were more likely to apply for armoring mix than for a bulkhead (i.e., armoring mix > bulkhead, living shoreline, living shoreline mix, riprap; Table 8).

Applicants across modification types had different levels of reported flooding on their shorelines, with at least half of respondents for bulkhead, living shoreline, and living shoreline mix reporting flooding. In contrast, over 70% of respondents for armoring mix or riprap did not report flooding. When asked what was causing the flooding – with the survey options as daily tides,

TABLE 6 Mean perception of ecosystem services.

	Living shoreline	Bulkhead	Riprap
	mean (SD)	mean (SD)	mean (SD)
Erosion protection	-0.29 (0.88)	**0.02 (0.63)**	**0.27 (0.59)**
Storm protection	-0.51 (0.93)	**0.06 (0.71)***	**0.45 (0.67)**
Sea Level Rise protection	-0.18 (1.14)	-0.10 (0.86)	**0.29 (0.71)**
Aesthetic benefits	**0.34 (1.11)**	-0.22 (0.94)	-0.126 (0.81)
Water quality benefits	**0.67 (0.85)***	-0.59 (0.55	-0.09 (0.55)*
Wildlife benefits	**0.70 (0.83)***	-0.62 (0.71)*	-0.08 (0.52)

Mean perception and standard deviation (SD) of how living shoreline, bulkhead, and riprap contribute to six different ecosystem services. Bolded values are mean perceptions higher than 0 which indicate a more favorable perception. An asterisk (*) indicates that there were differences in the perception of ecosystem services based on respondent modification type (α = 0.05). Refer to Appendix 3 for the mean perception and SD of how living shoreline, bulkhead, and riprap contribute to six different ecosystem services, separated by respondent modification types.

TABLE 7 Marginal effect estimates of property owner experience.

	Erosion experience		Flooding experience		Storm experience	
	estimate (SE)	p -value	estimate (SE)	p-value	estimate (SE)	p-value
riprap	-0.30 (<0.01)	p<0.01	-0.18 (0.04)	<0.01	0.03 (0.02)	0.12
armoring mix	**-0.17 (<0.01)**	**p<0.01**	**-0.09 (0.03)**	**p<0.01**	**0.09 (<0.01)**	**p<0.01**
LS mix	**-0.19 (<0.01)**	**p<0.01**	0.06 (0.07)	0.39	**-0.06 (<0.01)**	**p<0.01**
LS	**1.16 (<0.01)**	**p<0.01**	**0.04 (0.01)**	**p<0.01**	**0.11 (<0.01)**	**p<0.01**

Marginal effect estimates of a respondent's experience indicate the percent change that a respondent would install a bulkhead relative to the listed modifications if they experienced shoreline change (i.e., erosion, flooding, or storm damage). Bolded values indicate a significant difference of the marginal effect ($\alpha = 0.05$). SE refers to standard error. Living shoreline was abbreviated as LS.

king tides, and storms – more than half of all respondents reported the flooding was due to storms and 50% or more respondents across all modification types, except for bulkhead respondents (only 41%), indicated they experienced King Tide driven flooding. There was a disparity between flooding experience and modeled flooding as 33% of respondents reported flooding but the model estimated no flooding and 5% of respondents reported no flooding while the model estimated flooding at those locations, totaling to 38% mismatch (i.e., 62% agreement) between the survey respondents and the model (Appendix 4).

Respondents that experienced flooding had a higher probability that they applied for a living shoreline and a lower probability that they applied for armoring mix or riprap than for a bulkhead (i.e., living shoreline > bulkhead, living shoreline mix > armoring mix, riprap; Table 7). If a respondent had higher modeled flooding risk, it was less likely that they applied for armoring mix and riprap than for a bulkhead (i.e., bulkhead, living shoreline mix, living shoreline > armoring mix, riprap; Table 8).

Over half of respondents reported shoreline storm damage, ranging from a low of 56% (bulkhead) to a high of 88% (armoring mix). The reported locations of storm damage — with the survey options of shoreline vegetation, dock or boathouse, and shoreline modification – varied based on the modification a respondent applied for, with large variations even within the modification categories. The most consistent trend was that 71% of living shoreline respondents reported storm damage to the shoreline vegetation, and over half (56%) of bulkhead respondents reported storm damage to a modification structure.

Respondents that experienced prior storm damage had a higher probability that they applied for a living shoreline or armoring mix and a lower probability that they applied for living shoreline mix than for a bulkhead (i.e., living shoreline, armoring mix > bulkhead, riprap > living shoreline mix; Table 7). The results from modeled storm risk indicate that the properties that had higher storm risk were more likely to have applied for armoring mix than for a bulkhead (i.e., armoring mix >bulkhead, living shoreline, living shoreline mix, riprap; Table 8). There were differences in modeled storm risk and experience of storm risk, with 15% of respondents reported storm damage but the model estimated minimal or no storm risk, and 22% of respondents reported no storm damage while the model estimated there was storm risk at those locations, totaling to 37% mismatch (i.e., 63% agreement) between the respondents' experiences and the model (Appendix 4).

4 Discussion

Shoreline property owners were predominantly concerned about the ability of shoreline modifications to protect their property against erosion and storm damage. Except for bulkhead property owners who had a more favorable perception of bulkhead storm protection, most respondents perceived riprap to be relatively better at protecting the shoreline than living shorelines or bulkheads. These perceived protection benefits of riprap are evident in the permitting trends in Virginia during the last decade as most permits include riprap (Figure 2; CCRM, 2023). Although living shoreline usage has increased in recent years, living shoreline property owners perceive living shoreline as less protective than riprap and bulkheads. Prior experience with erosion, flooding, and storm damage did not appear to relate to how respondent's perceived modification erosion effectiveness, sea level rise protection, and storm protection of living shorelines, riprap, or bulkheads. Property owners' concerns

TABLE 8 Marginal effect estimates of modeled risk.

	Modeled Erosion		Modeled Flooding		Modeled Storm Risk	
	estimate (SE)	p -value	estimate (SE)	p-value	estimate (SE)	p-value
riprap	-0.01 (0.01)	0.07	-0.08 (0.02)	p<0.01	-0.04 (0.03)	0.11
armoring mix	**0.03 (0.01)**	**0.01**	**-0.03 (0.11)**	**p<0.01**	**0.03 (0.01)**	**p<0.01**
LS mix	**0.03 (0.03)**	**0.32**	**-0.01 (0.00)**	**0.89**	**0.02 (0.18)**	**0.90**
LS	-0.02 (0.04)	0.63	0.01 (0.22)	0.82	-0.01 (0.12)	0.94

Marginal effect estimates of modeled risk that indicate the percent change that a respondent would install a bulkhead relative to the listed modifications, with a one unit increase in the risk variable (i.e., erosion, flooding, or storm risk). Bolded values indicate a significant difference of the marginal effect ($\alpha = 0.05$). SE refers to standard error. Living shoreline was abbreviated as LS.

about living shoreline erosion effectiveness was also evident in a 2013 evaluation of shoreline property owners in Virginia (Appendix 5), indicating that this perception has been prevalent for many years. Historically and recently, living shoreline property owners had more favorable perceptions of and more interest in living shoreline ecosystem benefits, which may have contributed to their decision to install a living shoreline.

Property owners may not be accurately assessing the causes of their shoreline change as results based on their experience differed from modeled risk assessments. Property owners mostly reported that storms caused their erosion, and this expectation may be because storms are discrete events rather than frequent gradual changes from wave action. Moderate wave energy breaking along a shoreline has been shown to cause more erosion, overall, than severe storms (Leonardi et al., 2016). However, significant coastal flooding and storms appear to engender a higher perception of risk compared to coastal erosion which is typically not well known or understood by non-experts (Navarro, 2021). The biggest mismatches between respondents' experiences and estimated risks were due to 1) respondents reporting no erosion where erosion was estimated, 2) respondents reporting no storm damage but the model estimated storm risk, and 3) respondents reporting flooding where there was minimal flood risk estimated. The perception of a risk by non-experts often differs from the perception and knowledge of the experts in the field (Lemée et al., 2019). Differences in perception are not surprising given that perceptions depend on a person's history, surroundings, values, beliefs, preferences, and knowledge (Bennett, 2016). While we did find differences in perception, there were high rates of agreement where respondents reported erosion, storm damage, and flooding with corresponding model estimates. The comparison between modeled risk and respondent experiences could be used to validate future studies that compare stakeholder perspectives of risk and damage with model assumptions.

Throughout Virginia, bulkheads have been permitted at relatively high rates. In the early 1970s, almost all (>90%) permits were for bulkheads and the proportion of bulkhead permits has decreased to about a third of all permits applied for within a year (Figure 2, CCRM, 2023). Many of recent bulkhead permits may be repairs, as we found that more respondents with bulkheads were applying for a permit to repair than were applying for new structures. Bulkhead respondents perceive bulkheads as better for storm protection than living shorelines, but research done in North Carolina, U.S. shows that bulkheads sustained more damage after a hurricane than living shorelines (Gittman et al., 2014; Smith et al., 2017). Similar work in Alabama, U.S., indicates that property owners tend to perceive bulkheads as more cost-effective and durable than living shorelines, even though reported cost and durability of the two modifications show the opposite (Scyphers et al., 2015). Some respondents' lived experiences differed from modeled risk assessments which indicates that respondents may not be aware of what is causing shoreline change. Model effect sizes (i.e., marginal effect estimates, Tables 7 and 8) were generally larger for respondents' lived experiences, compared to modeled risk factors, indicating that their experiences and perception likely drive their behaviors. Model error could also contribute to this divergence of modeled risk relative to property owner experience and perceptions.

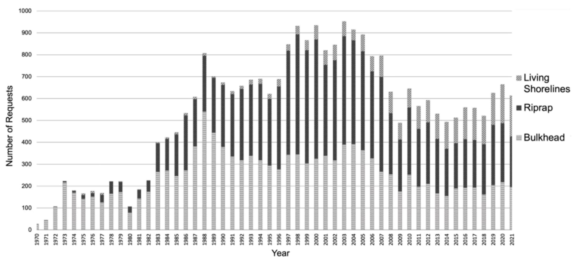

FIGURE 2

Shoreline modification permit applied for in Virginia, from 1970-2021 Virginia shoreline modification permits that were applied for in Virginia, since 1970. The horizonal stripped pattern is the bulkhead permit applications, the dark solid color is the riprap permit applications, and the diagonal stripped pattern is the living shoreline permit applications Data source: Center for Coastal Resources Management Tidal Shoreline Permit Database, (CCRM, 2023).

Across all modifications, we found around a quarter of respondents said that the cost of shoreline modification was too high, which is aligned with a previous survey of Virginia waterfront property owners that found that a quarter of property owners with unmodified shorelines felt the cost was too high and prevented them from installing a modification (Stafford and Guthrie, 2020). Based on a 2013 evaluation of Virginia shoreline property owners (Appendix 5), some property owners that applied for shoreline armoring might be more willing to consider a living shoreline if financing was available. In our recent 2020 survey, we found that bulkhead respondents were more often concerned about the cost of the modification and how the modification would affect their property value. Additionally, bulkhead respondents had the smallest proportion of respondents satisfied with the cost. These concerns may be due to maintenance costs because bulkheads are more likely to need repairs after severe storms and the total cost of installing and maintaining a bulkhead can be more than for living shorelines (Smith et al., 2017).

Sea level rise was not a common factor considered in the modification decision which indicates that property owners are not explicitly considering how to adapt their property to future conditions. Many property owners experienced tidal flooding from King Tides, which are proxies for future water levels (Simoniello et al., 2019), but property owners have not linked King Tide levels to future sea level rise and corresponding adaptation needs. As riprap was perceived to be the most adaptable to sea level rise, our survey responses suggest that property owners had minimal awareness of the potential natural adaptive capacity of marshes to sea level rise (Morris et al., 2002; Mitchell et al., 2017). The short-term focus of property owner decision making indicates there is a need to provide guidance and understanding about future conditions and how modifications will – or will not – be able to withstand more severe, future conditions.

Although we show that living shoreline respondents' perceptions of living shoreline protection benefits are not different from those that applied for other modifications, living shoreline respondents had more favorable awareness of and interest in living shoreline ecosystem benefits than bulkhead and riprap respondents

(Tables 2–4). Property owners have reported favoring the aesthetics of natural shorelines over armored shorelines (Scyphers et al., 2015). As evident by their perception of living shoreline benefits and desire to restore shoreline, living shoreline property owners had different motivations for installing their modification than other respondents. These trends have likely been true for years as a 2013 Evaluation found that property owners often selected living shorelines for their environmental and aesthetic benefits (Appendix 5). Research that spanned the U.S., including Maryland, North Carolina, and California, indicated that groups (e.g., government officials, engineers) involved in implementing natural infrastructure did so because they perceived ecological benefits to be greater than perceived costs (Kochnower et al., 2015). We found that while those that applied for shoreline armoring techniques felt that their armoring decision was supportive of the shoreline environment, environmental benefits were not key factors motivating their decision. Respondents' belief that their shoreline modification had more ecosystem benefits than other modifications is similar to other research in Virginia that shows property owners feel that their shoreline modification decisions were beneficial to the Chesapeake Bay (Stafford and Guthrie, 2020).

In many cases, there is a disconnect between the actions a property owner takes on their shoreline and how that contributes to the overall effects of the bay. Our work demonstrates there is a need to better engage property owners about the protection benefits of living shorelines as property owner perceptions were not aligned with scientific assessments of living shorelines. Outreach should focus on living shoreline protection benefits, rather than ecological benefits, as most property owners are not persuaded by ecological benefits. Friesinger and Bernatchez (2010) show that even though coastal residents recognize that shoreline armoring can negatively impact coastal ecosystems, they still favor large-scale shoreline armoring. As most Virginia permit application decisions have been approved with only minor changes (Berman et al., 2018), one avenue to influence decisions is to provide guidance on appropriate siting, design, and construction of living shorelines before the permit application is submitted. Marine contractors and nonprofit organizations may be successful messengers to provide property owners with more scientific-based guidance on protection benefits and longevity of living shorelines (Saitgalina et al., 2022).

However, it is unlikely that simply educating property owners on the consequences of their decisions will be sufficient. Coastal policies should be strengthened to support more natural approaches to shoreline management, such as living shorelines, to help support coastal community sustainability and ecological resilience. Shoreline armoring modification trends are reducing ecosystem functions and services (Peterson and Lowe, 2009; Gittman et al., 2015). The ecological benefits from living shorelines and natural habitats are common pool benefits whereas shoreline protection is a private good and benefit (Beasley and Dundas, 2021). Because property owners are more focused on the protective (private) benefits of shoreline modification types than of common pool benefits, the ecosystem (common pool) benefits are not typically considered and are underprovided (i.e., market failure). There was also the highest uncertainty about water quality and wildlife benefits indicating that property owners are not actively seeking out this information in their decision process – perhaps because they do not care, or they are not aware of the connection to shoreline modifications. More property owners are installing riprap than other modifications resulting in an inherent trade-off between private and public goods. Shoreline armoring, such as riprap, provides benefits to the property owner (private benefit) by reducing erosion but shoreline armoring also eliminates or reduces natural tidal habitat (e.g., salt marshes; Balouskus and Targett, 2016) which provides benefits (public goods) to a larger area, such as nursery habitat and nutrient removal (Isdell et al., 2021; Guthrie et al., 2022) and may have the capacity to be adaptive to sea level rise in the right setting (Mitchell and Bilkovic, 2019). Furthermore, shoreline armoring often increases erosion and scour nearby areas (Hardaway and Anderson, 1980). Opposingly, living shorelines provide protection and ecological benefits, but property owners are not installing this modification as they do not perceive or are not aware of their protection (private) benefits. In conjunction with improved and targeted education, coastal policies could focus more on the use of living shorelines to enhance ecosystem and public resource benefits that improve socio-ecological resilience.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary Material. Further inquiries can be directed to the corresponding author.

Ethics statement

The studies involving human participants were reviewed and approved by William and Mary's Protection of Human Subjects Committee. Written informed consent for participation was not required for this study in accordance with the national legislation and the institutional requirements.

Author contributions

AG, SS, DB designed and carried out the survey. AG completed statistical analysis and wrote the first draft of the manuscript. All authors contributed to data analysis, model development, manuscript revision, and read and approved the submitted version.

Funding

This material is based upon work supported by the National Science Foundation under Grant Number 1600131. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the National Science Foundation This work was further supported by the William & Mary Green Fee Fund. Our 2020 survey protocol was approved by William and Mary's Protection of Human Subjects Committee (Protocol # PHSC-2020-03-10-14129-agguthrie), the 2013 Evaluation (Appendix 5) was retroactively

approved by William and Mary's Protection of Human Subjects Committee (Protocol # PHSC-2022-06-26-15705-slstaf).

Acknowledgments

We thank Jessica Hendricks, Evan Hill, Catherine Riscassi, Dan Schatt, Christine Tombleson, Dr. Molly Mitchell, and Dr. Robert Isdell for their time working on the modeled datasets and for their assistance with spatial data analysis.

Conflict of interest

Publisher's note

Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fmars.2023.1031012/full#supplementary-material

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