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Reversing a tyranny of cascading shoreline-protection decisions driving coastal habitat loss

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Abstract
Shoreline hardening is a major driver of biodiversity and habitat loss in coastal ecosystems yet remains a common approach to coastal management globally. Using surveys of waterfront residents in North Carolina, USA, we sought to identify factors influencing individual shore-protection decisions and ultimately impacting coastal ecosystems, particularly coastal wetlands. We found that neighboring shore condition was the best predictor of respondent shore condition. Respondents with hardened shorelines were more likely to have neighbors with hardened shorelines, and to report that neighbors influenced their shore-protection choices than respondents with natural shorelines. Further, respondents who expressed climate-change skepticism and preference for shoreline hardening were opposed to shoreline-hardening restrictions. Despite preferring hardening, respondents ranked wetlands as highly valuable for storm protection and other ecosystem services, suggesting a disconnect between the ecological knowledge of individuals and social norms of shore-protection decisions. However, our results also suggest that efforts to increase the installation of living shorelines have the potential to conserve and restore important coastal habitats and support biodiversity along shorelines that may otherwise be degraded by hardening. Further, encouraging waterfront-property owners who have adopted living shorelines to recommend them to neighbors may be an effective strategy to initiate and reinforce pro-conservation social norms.

KEYWORDS
bulkhead, coastal protection, ecosystem service, green infrastructure, marsh, nature-based approach, neighbor interactions, tyranny of small decisions

1 | INTRODUCTION

Human degradation of ecosystems has intensified over the last two centuries, leading many to refer to this epoch as the Anthropocene (Levin & Poe 2017; Steffen, Crutzen, & McNeill, 2007). Human behavior, and more specifically, individual lifestyle and resource consumption decisions, can drive local to global patterns of ecosystem change and biodiversity declines (Byerly et al., 2018; Odum, 1982). Regulating individual decisions at the national or international scale can be bureaucratically complex and often politically impractical, given the level of coordination and financial investment needed to enforce such regulations (Kuh, 2012; Odum, 1982; Vandenbergh, 2004). Thus, a "tyranny of small decisions" (TSD) will continue to pose one of the greatest challenges and threats to the conservation of species and habitats for the foreseeable future (Odum, 1982).

TSD can be defined as a series of decisions made by individuals or small groups that often result in a less than optimal outcome for a community or ecosystem (Odum, 1982). TSD consequences are readily apparent in coastal ecosystems, where individual waterfront-property owners remove and replace native vegetation with bulkheads or other artificial hard structures (Cook, Hall, & Larson, 2011; Gittman et al., 2015; Titus et al., 2009). These artificial waterfront structures can result in eutrophication of coastal waters and reduced abundance and diversity of marine habitats and associated fauna (Bozek & Burdick, 2005; Gittman et al., 2016; Gittman, Scyphers, Smith, Neylan, & Grabowski, 2016; Scyphers et al., 2015; Valiela & Bowen, 2002). Furthermore, shoreline hardening exacerbates erosion and prevents upslope transgression of coastal habitats with sea level rise (Currin, 2019; Pontee, 2013).

Despite growing evidence of the ecological consequences of shoreline hardening, adoption of natural and nature-based alternatives to shoreline hardening, often termed "living shorelines", has been slow (Scyphers et al., 2020; Sutton-Grier et al., 2018; Titus et al., 2009). Under current regulatory scenarios, private property owners exert near complete control over the method used to protect their shorelines (Hilke et al., 2020). For example, new construction of the most common and also potentially the most ecologically damaging type of shoreline hardening, a seawall or bulkhead, is permitted without Federal agency review in many U.S. states, including North Carolina (NC), if the proposed construction meets review exemption requirements (Gittman, Peterson, et al., 2016). Recent changes in shoreline stabilization permitting in the United States, such as the adoption of the United States Army Corps of Engineers (USACE) Nationwide Permit 54 and a subsequent joint USACE and NC Division of Coastal Management (DCM) Regional General Permit for living shorelines, have streamlined permitting of nature-based alternatives to shoreline hardening in NC and elsewhere. However, these changes in permitting alone are not likely to result in a significant shift from traditional shoreline hardening to greener shoreline stabilization techniques (Sutton-Grier et al., 2018) because waterfront-property owners must also have knowledge and awareness of living shorelines and trust that these approaches will protect their coastal properties (Scyphers, Picou, & Powers, 2015; Smith et al., 2017).

There have been repeated calls for more education and outreach about the socio-ecological benefits of living shorelines (Du Bois, 2017; Erdle, Davis, & Sellner, 2006), yet educating decision makers may not be sufficient to solve environmental problems or conserve natural shorelines (Schultz, 2011; Schultz et al., 2005). However, if mutually beneficial goals among stakeholders can be identified and collectively embraced, conservation and management of resources can result in positive environmental outcomes (Ostrom, 2000, 2009). Identifying common goals among stakeholders requires knowledge and understanding of the motivations for individual decisions and behaviors (Reddy et al., 2017; Schultz, 2011; Schwartz et al., 2019). It has been previously reported that waterfront- property owners in Mobile Bay, Alabama (AL), and coastal NC value effectiveness, durability, and cost when selecting a shoreline stabilization approach (Scyphers, Picou, & Powers, 2015; Smith et al., 2017). However, NC waterfront-property owners also perceived bulkheads to be the costliest shoreline stabilization approach and reported higher maintenance and damage repair costs for bulkheads than other shore protection approaches (Smith et al., 2017). Among waterfront residents in Gloucester, Virginia (VA), effectiveness and cost also most influenced stabilization decisions for waterfront residents with bulkheads, but not for property owners with living shorelines (Stafford & Guthrie, 2020). Although effectiveness was perceived to be important, property owners in Gloucester with living shorelines reported that their desire to restore the shoreline was the most influential factor in their selection of a shore protection approach (Stafford & Guthrie, 2020). Given these varied values and perceptions, studies that can further elucidate shared motivations and values among waterfront-property owners will help coastal managers and policymakers determine the appropriate balance of regulation, incentivization, and education to promote conservation and restoration of coastal ecosystems (Scyphers et al., 2020).

Here, we conducted surveys of waterfront residents in NC to identify individual motivations, as well as associated socio-ecological factors, that influence decisions regarding how to stabilize and protect residential shorelines.

Specifically, we tested the hypothesis that individual decisions to harden a shoreline are associated with lower perceived ecological value of coastal wetlands. Further, we explored how these motivations and factors may relate to an individual's support for policies that could lead to a reduction or complete prohibition of shoreline hardening locally.

2 | METHODS

2.1 | Waterfront-property owner survey design and data collection

To assess how waterfront-property owners make shore-protection decisions and support coastal policies, we conducted dual-method surveys (mail, online) of waterfront residents of 16 and 13 NC coastal counties in 2014 and 2016, respectively. Our 2014 survey instrument was comprised of 75 questions developed and tested by an interdisciplinary team of scientists, coastal managers, and waterfront-property-owners. Questions were aimed at partitioning and quantifying the relative importance of social motivations, economic incentives, and environmental values on waterfront-property-owner decision-making and willingness to adopt alternative shoreline stabilization approaches, such as living shorelines. The survey included a question which asked respondents to indicate if they would support different policy options for future management of shoreline stabilization (Appendix A). There were three policy options: no action, a policy to reduce shoreline hardening, and a policy to prohibit shoreline hardening. Initial surveys responses were recorded from May 2014 to February 2015 (see Smith et al., 2017).

For the 2014 survey, waterfront properties were selected from county tax assessor websites using a stratified random sampling design. Properties that had been listed as for sale or sold during the previous 12 months were excluded. The number of properties sampled per county was determined by calculating the percentage of the cumulative calculated population, number of houses, and shoreline length for all the counties accounted for by each county, averaging these three numbers, and using that final percentage to weight the survey distribution across the 16 counties (see Smith et al., 2017). Survey participants were recruited using a modified Dillman method, which involved an initial mailing of postcard invitations to complete an online survey and one follow-up reminder postcard (Dillman, Smyth, & Christian, 2014). Survey responses for the 2014 survey were recorded from May 2014 to February 2015. Printed surveys were mailed to all individuals who requested them. The online survey was hosted and administered using Qualtrics Research Suite.

Of the 689 respondents to the original 2014 survey, 398 provided an email address and consented to being contacted for follow-up surveys, sent in June 2016. This survey consisted of 19 questions, one of which asked respondents about the resources that they used to gather information about various shoreline-protection options. The goal of this survey question was to examine the sources of information that respondents use to inform their shoreline-protection decisions and opinions. The first email invitation was followed by two reminder emails sent in July 2016.

2.2 | Classification of shore conditions

In the 2014 and 2016 surveys, respondents were asked to identify the current state of their own and their neighbors' shorelines from the following options with the ability to select all that apply: bulkhead; riprap revetment; groin; breakwater or sill; natural wetlands; planted vegetation; beach; wooded; and other. Respondents were also asked "if forced to protect your unaltered but eroding shoreline today, which method would you choose?" from the above options.

Prior to analyses, we classified a respondent's current shore condition as "hardened" if the respondent selected bulkhead and/or riprap revetment or as a "living shoreline" if the respondent selected breakwater/sill with or without planted vegetation or planted vegetation alone. Shorelines with planted vegetation was classified as natural shorelines by Smith et al. (2017), but we alternatively classified them as "living shorelines" per the 2015 NOAA definition (NOAA, 2015) to distinguish respondents that were actively altering the condition of their shoreline. Shorelines were considered "natural" only if no shore protection structure or intervention was selected. We also classified a respondent's neighboring shorelines using the same methods as above. Finally, a respondent's preferred shoreline protection approach was classified as "both" if the respondent selected approaches classified as both hardened and living shorelines.

2.3 | Statistical analyses

All analyses were conducted using R version 3.6.2 (R Core Development Team, 2019). Classification and regression trees constructed using the package *rpart* (Therneau & Atkinson, 2019) were used to evaluate and identify the relative importance of social, physical, geographic, and demographic predictors of respondents' shoreline condition and expressed beliefs related to shoreline protection and coastal habitats. Classification and regression tree analysis correlates variation of a single variable using a combination of predictor variables through repeated partitioning of increasingly homogeneous groups based on serial, binary splits of measured continuous and categorical variables (De'ath & Fabricius, 2000). Six separate trees were constructed evaluating the relative importance of potential predictors on waterfront property owner's (a) current shore condition, (b) shore protection preference, (c) perceived effects of a respondent's shoreline on his/her neighbor's shoreline, (d) perceived effects of a neighbor's shoreline condition on the respondent's shoreline, (e) reported influence of a neighbor's shore condition on a respondent's choice of shore protection; and (f) position on changing shoreline hardening regulations (Appendix A).

All trees considered a suite of social (i.e., average perceived value [ranked 1–10, with 10 being the highest value] of coastal wetlands for tourism, fisheries, water quality, and storm protection; belief in climate change [yes/no]), physical (i.e., respondent's current shoreline condition—[unless otherwise specified], shoreline condition of the adjacent waterfront properties, average and maximum fetch [per Smith et al., 2017], and mean tidal range [NOAA NOS, 2013]), geographic (i.e., county and region [north, central, or southern NC]), and demographic (i.e., respondent gender, age, annual household income, coastal resource dependence [i.e., what percentage of a respondent's job depends on environmental conditions in the local waterways, bays, and beaches], and years lived in current residence) factors as independent variables. The potential for overfitting was assessed using k-fold cross-validation, an approach which uses subsets of the whole dataset as training data to evaluate the explanatory power of the tree, using the 1-SE rule (De'ath & Fabricius, 2000). Conditional probabilities were reported for each split of the classification tree, with P [A|B] referring to the conditional probability that event A occurs, given that event B has occurred.

Linear models conducted using the package *stats* (R Core Development Team, 2019) were used to evaluate whether respondent's perceived overall value [ranked 1–10, with 10 being the highest value] of coastal habitats varied by habitat type (Wetlands, SAV, Oyster, Beach, and Hard Bottom), whether perceived overall value of coastal habitats varied as a function of respondent's shoreline type, and whether respondent's shoreline typed influenced their overall valuation of the five coastal habitats about which they were surveyed. Habitat valuation was entered as the response variable and habitat type, respondent's shoreline type, and a habitat type*respondent's shoreline type interaction term were entered as fixed factors in the model. Four additional linear models, one for each class of coastal habitat benefit, were conducted to test for effects of the same fixed factors (habitat type, respondent's shorelines type, habitat type * respondent's shoreline type) on respondent's valuation of coastal habitats for tourism, fisheries, water quality, and storm protection. A final linear model was run to test for differences in respondent's valuation of coastal wetland benefits, whether overall coastal wetland valuation differed as a function of respondent's shoreline type, and whether valuation of coastal wetland benefits differed as a function of respondent's shoreline type. Benefit type, respondent's shoreline type, and a benefit type * respondent's shoreline type interaction term were entered as fixed factors in this model. Prior to running each linear model, data were tested for normality and homoscedasticity using Shapiro-Wilks tests and Bartletts tests, respectively. Where violations were detected, the appropriate transformation to rectify violations was identified using the package *bestNormalize* (Peterson, 2019) and implemented. Transformations ($Log_{10}[x]$, Box-Cox, or ordered quantile normalization) successfully resolved violations of model assumptions. Post hoc multiple comparison analysis was conducted where significant fixed effects were detected using the *multcomp* procedure, which conducts simultaneous tests and confidence intervals for linear models (Hothorn et al., 2016). The *multcomp* procedure mitigates issues associated with multiplicity by employing exact multivariate *t* distributions or asymptotic multivariate normal distributions (Bretz, Hothorn, & Westfall, 2010).

3 | RESULTS

We received 689 completed surveys (response rate of 18%) from waterfront property owners in 2014–2015 (see Smith et al., 2017 for additional details). In the 2016 follow-up survey, we received 215 responses from waterfront residents of 13 coastal NC counties (54% response rate). Among respondents to the 2014 survey, 58% of property owners ($n = 399$) reported that their shorelines have been hardened (bulkheads, $n = 282$, riprap revetments, n = 66, or a combination of hard structures, "hybrid", $n = 51$), 36% had unaltered or "natural" shorelines ($n = 245$), 6% ($n = 38$) had "living shorelines", and <1% reported having groins ($n = 7$), which were excluded from further analyses due to small sample size. For the 2016 survey, 186 of the 215 respondents provided information about their shorelines, with 63% having hardened shorelines (bulkheads, $n = 88$, riprap revetments, n = 19, hybrid shorelines, $n = 10$), 28% having natural shorelines ($n = 53$), 8% percent having living shorelines ($n = 15$), and 1% having groins ($n = 1$).

Of respondents who reported being the property owner at the time of installation, 148 reported installing a bulkhead, with the time since installation being 21 ± 2 (mean ± *SE*) years and 40 reported installing a riprap revetment, with the time since installation being 20

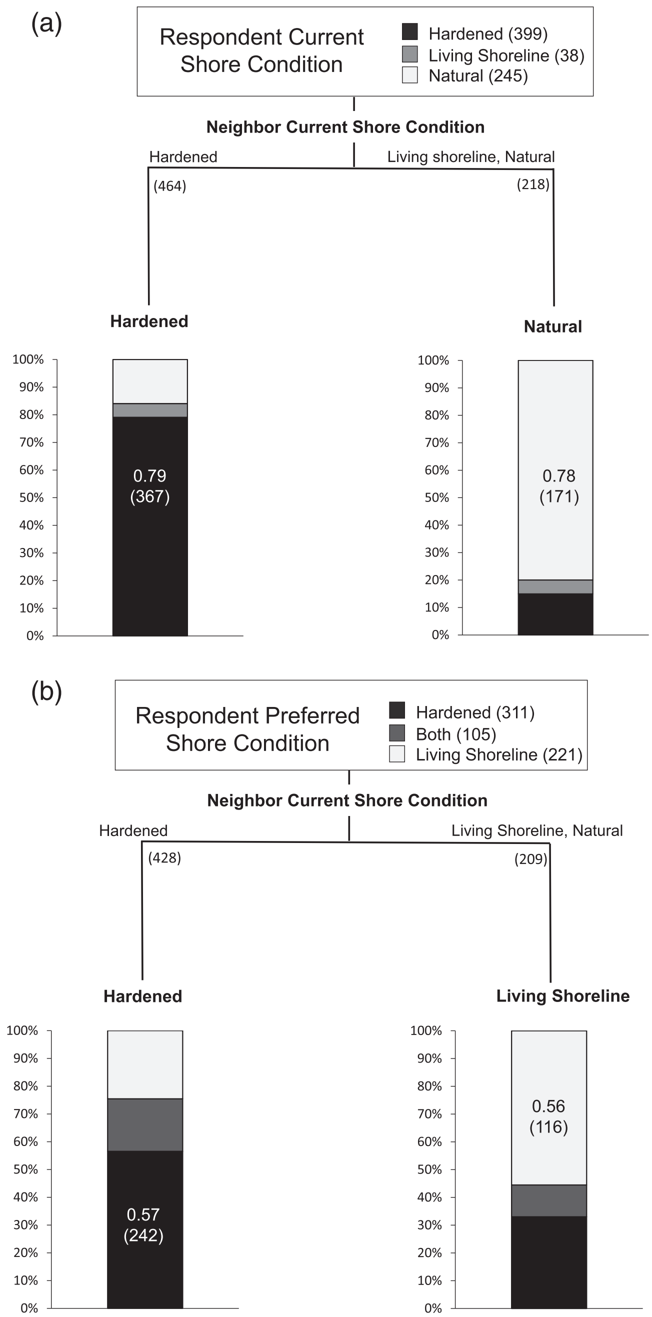

FIGURE 1 Classification tree showing the most important predictors of (a) NC waterfront respondent current shore condition (b) preferred shore condition of NC waterfront respondents with unaltered but eroding shorelines. Values overlaid in graphs are conditional probabilities of respondent having (a) or preferring (b) a given shoreline type and sample sizes ()

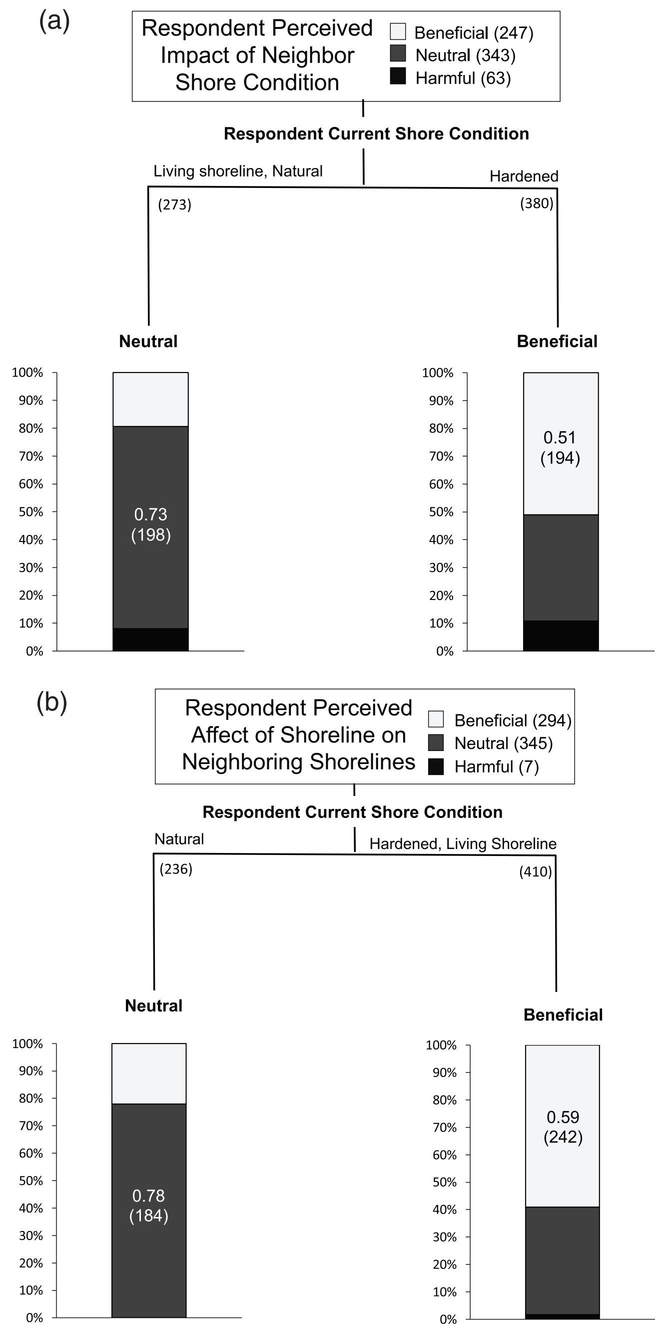

FIGURE 2 Classification tree showing the most important predictors of (a) NC waterfront respondents' perception of neighbors' shore condition effect on their property; and (b) NC waterfront respondent perception of their shore condition effects on neighbor's property. Values overlaid on graphs are conditional probabilities of respondent beliefs about the directionality of their neighbor's shoreline condition on their property (a) or vise versa (b) and sample sizes ()

$\pm$ 2 years in 2014. Seventeen respondents reported being the property owner when a living shoreline was installed, with time since installation being 24 $\pm$ 5 years in 2014, with older living shorelines consisting primarily of just marsh plantings. Respondents with bulkheads or riprap revetments made up 65% and 43% of respondents with stabilized shorelines, respectively. Living shoreline respondent to our 2014 survey (n = 38) represent 8.6% of the respondents who reported having some form of shoreline stabilization. An additional 12% of respondents had some combination of bulkhead and riprap stabilization structure (hybrid). Between 2014 and 2016, 11%

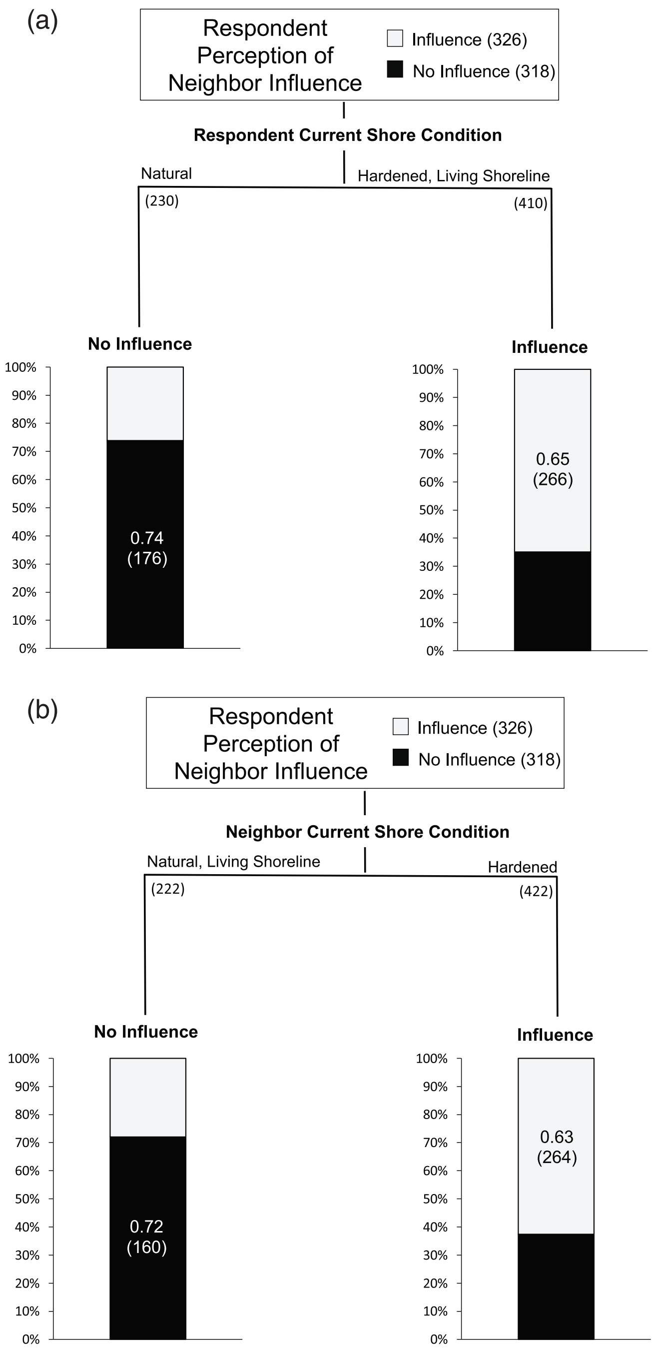

FIGURE 3 Classification tree showing (a) respondents' perceptions of their neighbors' influence on their shoreline stabilization decisions; and (b) respondents' perceptions of their neighbors' influence on their shoreline stabilization decisions without the respondent's current shoreline included as a predictor variable. Values overlaid on graphs are conditional probabilities of respondent perceptions about the influence of their neighbors' influence on their shoreline stabilization decisions and sample sizes ()

(n = 13) of the respondents reported converting from a bulkhead or riprap shoreline to another stabilization approach, with three of those conversions being to living shorelines (Table A1). Ten (16%) respondents reported stabilizing their natural shorelines in the 2016 survey, with half of those respondents electing to install a living shoreline (Table A1).

When one or both neighboring shorelines had a hardened shoreline, respondents to the 2014 survey were most likely to have a hardened shoreline ($P[A|B]$ = 0.79, Figure 1a). When a respondent's current shoreline was removed from the analysis, respondents were also more likely to report preference for hardened shorelines over living or natural shorelines when neighboring shorelines were hardened ($P[A|B]$ = 0.57, Figure 1b). In contrast, when respondents' neighbors had living shorelines or natural shorelines, respondents were most likely to have natural shorelines ($P[A|B]$ = 0.78, Figure 1a). Further, respondents were more likely to report a preference for living shorelines when neighbors' shorelines were natural or living shorelines ($P[A|B]$ = 0.56, Figure 1b). No other factors included in the classification tree analysis were identified as contributing to partitioning of a respondent's current shore condition or shore protection preference into increasingly homogenous groups.

When a respondent's shoreline was hardened, respondents were most likely to perceive their neighbors' shorelines to be beneficial for their properties (Figure 2a, $P[A|B]$ = 0.51) with 97% of respondents reporting beneficial shoreline effects having hardened neighboring shorelines. When respondents had natural or living shorelines, respondents were most likely to perceive their neighbors' shoreline to have no effect on their property (Figure 2a, $P[A|B]$ = 0.73) and 72% of those respondents also had neighbors with natural or living shorelines. No other factors included in the classification tree analysis were identified as contributing to partitioning of perceived effects of a respondent's shoreline on his/her neighbor's shoreline into increasingly homogenous responses.

Not surprisingly, respondents with modified shorelines, including both hardened and living shorelines, were more likely to perceive their shorelines to be beneficial for their neighbors' properties (Figure 2b, $P[A|B] = 0.59$), while respondents with unmodified, natural shorelines were more likely to perceive that their shorelines had no effects on their neighbors' properties (Figure 2b, $P[A|B]$ = 0.78). Further, respondents were most likely to report being influenced by their neighbors when they had a modified shoreline, either a hardened or a living shoreline (Figure 3(a), $P[A|B]$ = 0.65), while respondents with unmodified, natural shorelines reported no influence of their neighbors (Figure 3a, $P[A|B] = 0.74$). When a respondent's current shoreline condition was removed from the analysis, respondents with neighboring hardened shorelines were most likely to report that their neighbors influenced their shoreline management decision (Figure 3b, $P[A|B] = 0.63$), with 88% of those respondents

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TABLE 1 Count and percentage of responses to resources used for shoreline stabilization information reported by respondents in 2016 follow-up survey by shoreline type and cumulatively. Respondents could select multiple resources

	Source of shoreline stabilization information									
Shoreline type	**Government**	**Neighbors**	**Private engineer/marine contractor**	**Family & Friends**	**Internet**	**NGO**	**Peer-reviewed literature**	**Books**	**Other**	**None**
Hardened	26 (21%)	25 (20%)	20 (16%)	18 (15%)	10 (8%)	4 (3%)	3 (2%)	4 (3%)	5 (4%)	8 (7%)
Living shoreline	1 (10%)	2 (20%)	2 (20%)	2 (20%)	1 (10%)	2 (20%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)
Natural	4 (21%)	2 (11%)	1 (5%)	2 (11%)	4 (21%)	3 (16%)	1 (5%)	1 (5%)	0 (0%)	1 (5%)
Total	31 (21%)	27 (18%)	23 (15%)	22 (15%)	15 (10%)	9 (6%)	4 (3%)	5 (3%)	5 (3%)	9 (6%)

having hardened shorelines themselves. In contrast, respondents with neighboring natural or living shorelines largely reported that their shoreline management decisions were not influenced by their neighbors (Figure 3b, $P[A|B] = 0.72$), with 84% of those respondents having natural or living shorelines themselves. No other factors included in the classification tree analysis were identified as contributing to partitioning of perceived effects of a respondent's shoreline on his/her neighbor's shoreline or reported influence of a neighbor's shore condition on a respondent's choice of shore protection into increasingly homogenous responses.

In the 2016 follow-up survey, when asked what resources were used to gather information about shoreline stabilization options, respondents with hardened shorelines most commonly reported the government and their neighbors as resources for shoreline stabilization information, respondents with natural shorelines most commonly reported the government or internet, and respondents with living shorelines listing a variety of sources, including neighbors, private engineers or marine contractors, family & friends, and NGOs (Table 1).

Climate change perception, followed by shoreline protection preference, were the best predictors of respondent support for changes to shoreline management policies (Figure 4). Respondents were most likely to prefer the "No Action" option, where no changes in shoreline hardening policies would be made, if they did not believe or were unsure whether the climate is changing (Figure 4, $P[A|B] = 0.68$, Appendix A). However, if respondents expressed belief in climate change, shoreline preference determined the likelihood of their support, or lack thereof, for changes to shoreline hardening policies. Specifically, respondents were most likely to support prohibition of future shoreline hardening (i.e., bulkheads and riprap revetments would be prohibited along shorelines with bordering salt marsh, see Appendix A) if they believe that climate is changing and also prefer living shorelines (Figure 4, $P[A|B] = 0.68$). In contrast, of the

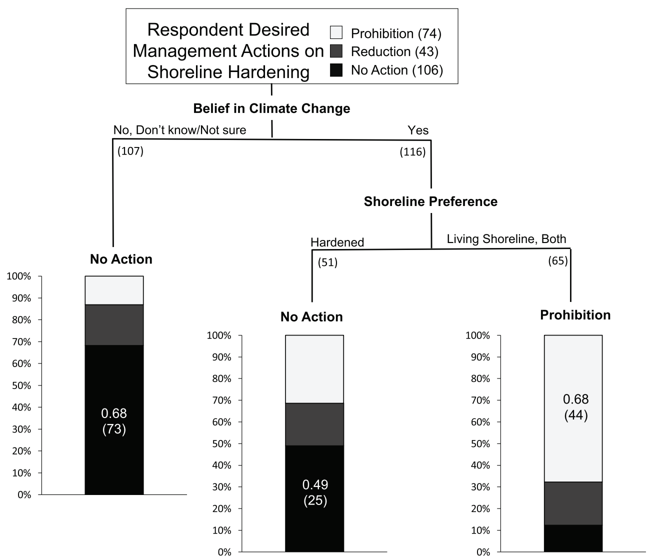

FIGURE 4 The most important factors predicting a respondent's desired management action on shoreline hardening. Values overlaid on graphs are conditional probabilities of respondents' desire for a given management action on shoreline hardening and sample sizes (). See Appendix A for a description of proposed shoreline management policy options

respondents that believe in climate change, those with hardened shorelines were most likely to prefer the "No Action" option and thus prefer no changes to current shoreline hardening policies (Figure 4, $P[A|B] = 0.49$). A majority of respondents with hardened (53%), natural (58%), and living shorelines (55%) reported that they believe in global climate change, while 24%, 27%, and 32% of respondents with hardened, natural, and living shorelines said they do not believe in global climate change, respectively. The remaining 20% of respondents said that they did not know or were unsure. Thus, interestingly, belief in climate change did not differ appreciably as a function of respondents' shoreline condition. No other factors included in the classification tree analysis were identified as contributing to partitioning position on

TABLE 2 Respondents' perceived values of coastal wetlands for protection from storms, fisheries production, water quality enhancement, and tourism by respondent shore type from 2014 survey

		Coastal habitat service				
Respondent shore type	**No. responses**	**Storm protection**	**Fisheries**	**Water quality**	**Tourism**	**Overall**
Hardened	399	8.9 ± 0.1	9.1 ± 0.1	9.3 ± 0.1	7.3 ± 0.2	8.6 ± 0.1
Living shoreline	38	8.5 ± 0.4	8.5 ± 0.4	8.8 ± 0.3	7.6 ± 0.4	8.4 ± 0.3
Natural	245	8.9 ± 0.1	9.3 ± 0.1	9.3 ± 0.1	7.0 ± 0.2	8.6 ± 0.1
Overall	682	8.9 ± 0.1	9.1 ± 0.1	9.3 ± 0.1	7.2 ± 0.2	8.6 ± 0.1

Note: Values reported are the mean ± *SE* and are out of a possible range of values from 1 to 10, with 10 being the highest value and 1 being the lowest value.

changing shoreline hardening regulations into increasingly homogenous responses.

Respondent shoreline type did not affect their overall valuation of coastal habitat value ($p = 0.49$), but perceived value of coastal habitats did differ as a function of habitat type ($F_{4,3,186} = 95.6$, $p < 0.001$, $R^2 = 0.11$). On a ten-point scale of increasing value, respondents scored coastal wetlands as having an average overall value of 8.6 ± 0.1 (mean ± 1 *SE*) out of 10 (Table 2), which was higher than any other coastal habitat (beach (8.0 ± 0.1), SAV (7.6 ± 0.1), oyster (7.4 ± 0.1), and hard bottom (6.3 ± 0.1) about which they were surveyed. Respondent shoreline type did not affect their valuation of coastal habitat types ($p = 0.80$). Of the coastal habitat benefits that respondents were asked to value, water quality (9.3 ± 0.1) and fisheries production (9.1 ± 0.1) benefits of coastal wetlands were valued more highly than their tourism value (7.2 ± 0.2; $F_{3,2,415} = 140{,}107.7$, $p < 0.001$, $R^2 = 0.12$). The average value assigned to coastal wetlands for their storm protections services (8.4 ± 0.1) was lower than the average value assigned for water quality, higher than for tourism benefits, and did not differ from fisheries production benefits. The average value assigned to coastal wetlands for their fishery production ($F_{4,2,761} = 109.7$, $p < 0.001$, $R^2 = 0.14$) and water quality benefit ($F_{4,2,708} = 92.1$, $p < 0.001$, $R^2 = 0.12$) benefits were higher than the values assigned to those services for SAV, oyster, beach, or hard bottom. Coastal wetlands and beach tied for the highest storm protection valuation among all coastal habitats ($F_{4,2558} = 93.8$, $p < .001$, $R^2 = 0.13$) and coastal wetlands' tourism value ranked second only to beach. ($F_{4,2648} = 190.3$, $p < .001$, $R^2 = 0.22$). Habitat type was the only significant factor in all four models used to evaluate coastal habitat valuation for tourism, fisheries, water quality, and storm protection benefits.

4 | DISCUSSION

Our results reveal key social and environmental influences on cascading shoreline hardening and coastal habitat loss, where a single decision to harden a shoreline results in an increased likelihood that adjacent shorelines will subsequently be hardened. Converting and hardening a natural shoreline can modify the geophysical (Nordstrom, Jackson, Rafferty, Raineault, & Grafals-Soto, 2009; Pope, 1997; Smith, Puckett, Gittman, & Peterson, 2018), ecological (Bilkovic & Roggero, 2008; Gittman, Scyphers, et al., 2016), and socioeconomic (Scyphers, Picou, & Powers, 2015; Smith et al., 2017; Smith & Scyphers, 2019) characteristics of the local ecosystem. Further, converting a hardened shoreline back to its previous state requires considerable, and often costly, human intervention (Nordstrom et al., 2009; Scyphers et al., 2019). Because the decision to harden a shoreline often lies with an individual waterfront property owner (Hilke et al., 2020), understanding individual motivations for choosing a shore-protection approach is critical for developing strategies for conserving natural shorelines and preventing future regime shifts caused by hardening before they occur (Beasley & Dundas, 2021; Hilke et al., 2020; Scyphers, Picou, & Powers, 2015; Smith et al., 2017; Stafford & Guthrie, 2020).

Our finding that NC waterfront-property owners' shoreline hardening decisions are influenced by the presence of neighboring hardened structures (Figure 1) is consistent with inferences drawn from similar surveys of waterfront-property owners conducted in Mobile, AL (Scyphers, Picou, & Powers, 2015), Gloucester, VA (Stafford, 2020; Stafford & Guthrie, 2020), and coastal Georgia (Peterson, Landry, Alexander, Samples, & Bledsoe, 2019). Further, Beasley and Dundas (2021) found evidence of "spillover effects" within neighborhoods as important influencers of private shoreline-adaptation decision process along the Oregon coast. However, our study is the first to have respondents with hardened shorelines acknowledge the influence of their neighbors on their shoreline protection decisions (Figure 3). Despite waterfront property owners generally being aware of living shoreline approaches and their shoreline-protection efficacy (*see* Scyphers et al., 2020; Smith et al., 2017; Stafford & Guthrie, 2020), knowledge and awareness may be outweighed by social pressure or simply mimicking what their neighbors have done (Reddy et al., 2017). Potentially confounding factors, such as being in the same geographic region or having similar physical shoreline characteristics (e.g., fetch, geomorphology) and property values, have been previously suggested to influence neighboring shore-protection decisions (Beasley & Dundas, 2021; Scyphers, Picou, & Powers, 2015; Stafford & Guthrie, 2020); however, none of these factors were strong predictors of current or preferred shore condition in our study.

Our hypothesis that individual decisions to harden a shoreline would be associated with lower perceived ecological value of coastal wetlands was not supported by the survey responses, as perceived values of coastal wetlands were high (8–9 out of 10) across all shoreline types (Table 2). However, more than half of respondents reported having no wetlands seaward of their bulkheads, suggesting either a lack of wetlands along those shorelines initially, or potentially, losses of wetlands over time post hardening. Thus, there may be a temporal disconnect between the action of hardening a shoreline and the resultant wetland degradation and loss, potentially because wetland loss associated with shoreline hardening may happen at timescales (decades) not easily perceived by waterfront residents (Enwright, Griffith, & Osland, 2016; Pontee, 2013; Titus et al., 2009).

The disconnect between perceptions of the direct impacts associated with bulkhead construction and subsequent loss of wetlands occurring over several decades may be exacerbated by skepticism of climate change (Figure 4) and its consequences (e.g., sea-level rise). However, even when a majority of respondents with hardened shorelines believe in climate change (54%), they still may not perceive how shoreline hardening and climate change can interact to cause wetland loss (Pontee, 2013). Scyphers et al. (2019) found that property owners with hardened shorelines were more concerned about SLR than property owners with natural shorelines, suggesting that shoreline hardening may be viewed as insufficient protection. Furthermore, coastal property protection may be more important to the homeowner than the ecological consequences of shoreline hardening (Smith et al., 2017). Thus, these conflicting concerns and motivations may in part explain why respondents with hardened shorelines can believe in climate change and value wetlands but still not support restrictions on future shoreline hardening that will likely damage surrounding wetlands (Figure 4).

Our results also suggest the potential for reversing the cascading effect of hardening along shorelines, with property owners who currently have living shorelines reporting that they are influenced by their neighbors shore protection decisions (Figure 3a). Because of the small number of respondents with living shorelines ($n = 38$), property owners with hardened shorelines made up most of the respondents' neighbors with modified shorelines (Figure 3b). Therefore, the influence of neighboring bulkheads on respondents opting for living shorelines has likely been primarily negative. A recent study reported a 116% increase in living shorelines (additional 0.4 km) along 39-km of shoreline in NC between 2011 and 2016, and we also saw the conversion of hardened shorelines and natural shorelines to living shorelines from our 2014 to 2016 surveys, suggesting that living shorelines are increasing in popularity (Smith et al., 2017). As the use of living shorelines increases, we hypothesize that the influence of property owners with living shorelines on neighboring shoreline property-owner decision-making may also increase.

As of 2012, North Carolina Division of Coastal Management's Estuarine Shoreline Mapping reported 8136 bulkheads, 3039 riprap revetments, 79 sills, and 187 breakwaters across the 16 NC coastal counties from which homeowners were surveyed in the present study (NCDCM, 2015). Bulkheads and riprap revetments represent 71% and 27% of shoreline stabilization structures in the 16 coastal counties, respectively, while breakwaters and sill represent only 1.6% and 0.7%, respectively. Both sills and breakwaters can be included as part of living shorelines; however, the definition of "sill" is most commonly applied by NC DCM staff when permitting a living shoreline installation (NCDCM, 2015). Living shorelines with sills represented <1% (no more than 2% if all breakwaters are included) of the shoreline stabilization structures in the NC coastal counties surveyed, which in conjunction with only a small percentage of survey respondents having living shorelines, suggests that living shorelines had not been widely adopted in coastal NC. However, marsh plantings are not represented in at the NC shoreline mapping efforts, thus living shorelines as defined in this study may be more common and widespread. Consensus on the definition of a living shoreline (Smith et al., 2020), as well as data on shoreline modifications are needed to improve estimates of living shoreline implementation in North Carolina and elsewhere.

Proponents of living shorelines have largely followed the "Reasoning Pathway", which focuses on changing the precursors to behavior (e.g., knowledge, awareness, attitudes, motivations) by promoting awareness of living shorelines through workshops and providing economic incentives via living shoreline cost-share programs (RAE, 2019; Reddy et al., 2017). We suspect that these approaches, combined with recent streamlining of permitting requirements, may contribute to increasing popularity of living shorelines (see Scyphers et al., 2020; Smith et al., 2017; Stafford, 2020; Stafford & Guthrie, 2020). Encouraging waterfront-property owners, who have already adopted living shorelines, although still limited in number, to "nudge" their neighbors towards living shorelines through information sharing may be an effective strategy to initiate and reinforce pro-conservation social norms. Thus, we recommend that in addition to continuing to increase awareness through living shoreline workshops and to adopting social and economic incentive programs, such as those adopted in Maryland, Virginia, and Oregon (Pace, 2010; Scyphers et al., 2020), coastal managers should encourage current living shoreline property owners to share information and resources with their neighbors.

In areas where armoring is strongly preferred, more robust and restrictive policies against future shoreline armoring may be needed to prevent a tyranny of small decisions from driving coastal habitat loss. Some states have prohibited hardening along oceanfront shorelines (North Carolina and Washington, Gittman et al., 2015), however, prohibiting shoreline hardening was not a popular choice among NC waterfront respondents (Figure 4). Where prohibiting shoreline hardening is not politically feasible, strategies adopted in Maryland and Virginia, such as requiring or encouraging property owners to consider living shorelines before hard options (Hilke et al., 2020; Pace, 2017), may be more tractable. Additionally, prioritizing living shoreline demonstration projects in areas with few or no living shorelines could increase awareness locally, and thus could result in the conservation and restoration of valuable wetlands along shorelines that may have otherwise been hardened.

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CONFLICT OF INTEREST

The authors declare no conflict of interests.

AUTHOR CONTRIBUTIONS

Rachel K. Gittman, Steven B. Scyphers, F. Joel Fodrie, and Jonathan H. Grabowski conceived of and developed the 2014 survey design and Carter S. Smith and Anna Brodmerkel conceived of and developed the 2016 survey design. Abigail K. Poray, Mariah Livernois, Christopher J. Baillie assisted with survey administration and data compilation. Rachel K. Gittman and Christopher J. Baillie analyzed the response data. Rachel K. Gittman drafted the manuscript and all authors reviewed and edited the manuscript.

ETHICS STATEMENT

This research was conducted under UNC-CH IRB#13-1666 and this study is not published elsewhere.

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APPENDIX A.

Shoreline hardening policy question options

Coastal property owners in NC may choose to harden their shoreline with bulkheads (vertical walls) or riprap (rock) revetments to protect their property, gain access to the water, and for aesthetics (State general permit cost = $400). Approximately 5–10% of NC shorelines are currently hardened. However, bulkheads/riprap may cause erosion of salt marshes located seaward of hardened shorelines. Two potential options to prevent or mitigate salt marsh losses related to shoreline hardening are presented as Options A and B. You may disagree with either/both options, and prefer that no changes occur regarding shoreline permitting (The No Action Option). Please select your preferred option.

- No action option: No changes are made

Resulting Ecological Condition.

If neither option is chosen, shoreline hardening will continue along the NC coast at its current rate. Salt marshes may continue to be lost as a result of shoreline hardening. *Total cost to your household would be $0 in new 2014 state taxes*.

- Option A: Reduction in shoreline hardening

Coastal property owners are required to pay a higher permit fee (50% increase in the current fee) for installation of a hard shoreline structure (bulkhead, riprap, etc.). The permit fee is reduced by 25% for property owners using marsh planting, oyster shell placement, or other natural methods for erosion protection.

Resulting Ecological Condition.

Rates of shoreline hardening are reduced. Rates of salt marsh loss are reduced. Restoration of salt marsh habitat increases.

Total cost to your household would be $0 in new 2014 state taxes because the increased fees for shoreline hardening would cover the cost of waiving permit fees for marsh planting or other natural methods.

- Option B: Prohibition of shoreline hardening

TABLE A1 Reported change in shoreline type of respondents from 2014 to 2016 survey

	Current shoreline type						
Former shoreline type	**Bulkhead**	**Riprap**	**Hybrid**	**Living shoreline**	**Natural**	**Other**	**Total**
Bulkhead	84	2	9	2	0	0	97
Riprap	0	16	1	1	0	0	18
Hybrid	0	0	1	0	0	0	1
Living shoreline	0	0	0	8	0	0	8
Natural	3	1	0	5	53	1	63
Other	0	0	0	0	0	0	0
Total	88	19	10	15	53	1	186

The use of bulkheads and riprap revetments is prohibited along shorelines bordering salt marsh. Shoreline hardening is permitted at the current fee along shorelines without salt marsh. Along shorelines without salt marsh, the permit fee is waived completely for property owners using natural shoreline stabilization methods such as marsh planting and oyster reef construction.

Resulting Ecological Condition.

Loss of existing salt marsh to new shoreline hardening is prevented. Restoration of salt marsh habitat increases.

Total cost to your household would be $5 in new 2014 state taxes to cover the cost of waiving permit fees for marsh planting or other natural methods.