



DETERMINING LIVING SHORELINE DISTRIBUTION IN NORTH CAROLINA:
A MIXED METHODS STUDY

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EXECUTIVE SUMMARY

Coastal landowners in North Carolina have traditionally deployed hardened structures like seawalls and bulkheads to protect coastal development from erosion and inundation. However, living shorelines have emerged in recent decades as a more ecologically integrated solution, incorporating natural and human-made components to address erosion. To date, few studies have used geospatial tools to understand the deterministic factors driving the distribution of living shorelines in North Carolina. We consider how the distribution of living shorelines varies with a community's socioeconomic demographics, proximity to enabling institutions, and vulnerability to coastal inundation. We explore the barriers that homeowners face in acquiring a living shoreline and the perceptions that inform their decisions. Using a mixed methods approach, our study uses geospatial tools, decision-tree analysis, and semi-structured interviews with coastal landowners to distill the primary determinants governing the distribution of living shorelines across North Carolina's coast. We find that among coastal census tracts in North Carolina, the distribution of living shorelines has a significant negative correlation with the percent of the population living in poverty, suggesting that income constrains implementation of these projects. In contrast, vulnerability to coastal inundation and proximity to enabling institutions are not predictive of living shoreline distribution. Interviews elucidate that access to information and relevant networks, capacity to navigate the installation process, and ability to pay informed many homeowners' decisions to install a living shoreline. Taken together, our findings shed light on the need to consider equity and vulnerability in shoreline protection and coastal restoration.

CONTENTS

FIGURES	3
TABLES	3
GLOSSARY	3
1. ACKNOWLEDGEMENTS	6
2. INTRODUCTION	7
<i>2.1. Policy landscape</i>	9
<i>2.2. Research questions and hypotheses</i>	10
3. METHODS	12
3.1. Geospatial analysis	12
3.1.1. <i>Unit of analysis and scope</i>	12
3.1.2. <i>Data acquisition</i>	12
3.1.3. <i>Geospatial methodology</i>	17
3.1.4. <i>Multivariate analysis</i>	17
3.2. Narrative analysis	19
3.2.1. <i>Study selection</i>	19
3.2.2. <i>Participant recruitment</i>	19
3.2.3. <i>Study activities</i>	19
4. RESULTS	20
4.1. Geospatial analysis	20
4.2. Narrative analysis	26
4.2.1. <i>Themes</i>	26
4.2.2. <i>Barriers to implementation</i>	29
5. DISCUSSION	30
5.1. Implications and significance	30
5.1.1. <i>Wealth attributes</i>	30
5.1.2. <i>Sea-level rise</i>	31
5.1.3. <i>Enabling institutions</i>	31
5.1.4. <i>Homeowner perceptions</i>	32
5.1.5. <i>Barriers to implementation</i>	32
5.2. Limitations	32
5.3. Future research	33
6. CONCLUSION	34
References	35
APPENDICES	42
Appendix A: Semi-Structured Interview Questions	42
Appendix B: Informed Consent	43
Appendix C. General permit trends in North Carolina	45

FIGURES

Figure 1. Shoreline stabilization techniques ranging from green (soft) to gray (hard).....	8
Figure 2. Living shoreline with sill made of QuickReef	9
Figure 3. North Carolina shoreline by ESI classification as a percent of total shoreline.	13
Figure 4. Model 3. Quantifying the length of ESI shoreline within each census tract.	17
Figure 5. Model 1. Selecting census tracts, summarizing count of living shorelines.	17
Figure 6. Model 2. Quantifying proximity to enabling institutions using a 3 kilometer buffer. ...	17
Figure 7. Screen grab of institutions with a 3 kilometer buffer (intermediate step).	17
Figure 9. Map symbolizing U.S. Census tracts by count of living shorelines in North Carolina .	21
Figure 10. Map of census tracts symbolized by percent of population living below the poverty line and living shorelines in North Carolina.	22
Figure 11. Map of enabling institutions and living shorelines in coastal North Carolina.	23
Figure 12. Sea-level rise projections by 2050 in North Carolina	24
Figure 13. Regression decision tree (simplified) illustrating the relationship between thresholds of explanatory variables and the predicted value of living shorelines per thousand people.....	25
Figure 14. Erosion of a shoreline on a high-energy water body.....	26
Figure 15. Failing bulkhead in the foreground with “deadman” exposed from storm damage.	26

TABLES

Table 1. Enabling institutions (academic, contractor, government, nonprofit).	14
Table 2. Environmental Sensitivity Index (ESI) Shoreline Classification. Environment code: E = estuarine, L = lacustrine, R = riverine, P = palustrine	15
Table 3. Top 20 census tracts in North Carolina by length of shoreline	20
Table 4. Negative binomial model coefficients.	24

GLOSSARY

AIC	Aikake's Information Criterion
BIPOC	Black, Indigenous & people of color
CMRA	Climate Mapping for Resilience and Adaptation
CAMA	Coastal Area Management Act of 1974
CEJST	Climate and Economic Justice Screen Tool
CMAST	NC State Center for Marine Sciences and Technology
DCM	North Carolina Division of Coastal Management
DUML	Duke University Marine Lab
ECU	East Carolina University
ESI	Environmental Sensitivity Index
FEMA	U.S. Federal Emergency Management Agency
NCCF	North Carolina Coastal Federation
NCDEQ	North Carolina Department of Environmental Quality
NCDOT	North Carolina Department of Transportation
NOAA	U.S. National Oceanic and Atmospheric Administration
TNC	The Nature Conservancy
UNC-IMS	University of North Carolina Chapel Hill Institute of Marine Science

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2. INTRODUCTION

Sea-level rise threatens the livelihoods, development and existence of coastal communities (Wu et al., 2002; Buchanan et al., 2020; Kulp et al., 2019; Lane et al., 2013). With low land elevation, high wave and tidal energies, and exposure to intense tropical storms, the southeastern coast of the United States is particularly at risk to coastal inundation and increased rates of erosion (Gornitz et al., 1994). In North Carolina, the unique vulnerabilities that a community faces vary between urban and rural communities (Jurjonas and Seekamp, 2018). Despite the vulnerabilities and natural dynamism of coastal environments, human coastal settlements persist.

North Carolina has more than 10,000 miles of estuarine shoreline (McVerry, 2012). Estuarine and bayfront properties are subject to erosion from multiple sources (Boruff, 2005). Severe storms affecting the U.S. East Coast in winter months called “nor’easters” contribute to the problem of shoreline erosion (National Weather Service, n.d.). In addition to storm events, boat wakes and removal of shoreline vegetation can exacerbate erosion, which is undesirable to property owners (Stockdon, et al., 2012; Bilkovic, et al., 2017; Silliman et al., 2019). Historically, property owners have employed vertical, “hardened” or “armored” structures such as seawalls and bulkheads to protect their shorelines (Fear & Currin, 2012; Dugan et al., 2011). Bulkheads can be constructed from wood, concrete, vinyl, or metal. Armored structures aim to mitigate erosion of a shoreline by attenuating wave action. Interestingly, a mapping project estimated that North Carolina has a substantially lower rate of estuarine shoreline hardening (~6 percent) compared to the national average (14 percent) (McVerry, 2012; Gittman et al., 2015).

North Carolina’s estuarine shorelines often include fringing salt marshes, dynamic habitats which respond to changes in relative sea-level rise by promoting vertical accretion, redistributing vegetation, and migrating landward (Kirwan & Megonigal, 2013). It is estimated that salt marshes can withstand limited relative sea-level rise, however the combined low elevation and pressure from development exacerbates their vulnerability (Janowski et al., 2017; Kirwan et al., 2016b). Since hardened coastal structures inherently divide the land-water interface, they prevent landward migration of marsh habitat and contribute to marsh loss (Borchert et al., 2018; Burdick, 2018). This phenomenon, termed “coastal squeeze,” impedes salt marshes from their naturally adaptive response to rising seas (Borchert et al., 2018; Kirwan et al., 2016a). Hardened structures can lead to a loss of marsh habitat biodiversity and consequently, reduce ecosystem services (Gittman et al., 2014; Perkins et al., 2015). Additionally, armored structures have been shown to perform worse than marsh vegetation during a category 1 hurricane and exhibit less resistance to landward erosion following a category 5 hurricane (Gittman et al., 2014; Smith et al., 2018).

An alternative method of shoreline stabilization, called “living shorelines,” mitigates erosion by incorporating natural and human-engineered structures to deliver human and ecological benefits (Currin, 2019; Polk and Eulie, 2018). In contrast to hardened structures, living shorelines maintain the ecological continuity between land and water. On shore, living shorelines often involve planting and restoring salt marsh species to exploit the natural ability of marsh grasses to attenuate wave energy, trap sediment, and facilitate vertical and lateral accretion (Spalding et al., 2014; Gleason et al., 1979). In North Carolina, the native marsh grass species smooth cordgrass (*Spartina alterniflora*) and saltmeadow hay (*Spartina patens*) are most commonly planted in a zoned pattern to mimic natural patterns (Bertness, 1991). Living

shorelines may employ breakwaters or offshore sills made from granite rocks, *QuickReef*¹, mesh bags of recycled oyster shells (“oyster bags”), or other proprietary materials to reduce wave energy and facilitate oyster recruitment (Scyphers et al., 2011; NOAA, 2015). Site-specific environmental conditions like wave action and tidal range determine whether a living shoreline is a suitable intervention and which materials are appropriate (NC Estuarine Work Group, 2006). Since designs vary, living shorelines can be conceptualized on a spectrum ranging from “greener” and “softer” (i.e., more natural features) to “grayer” or “harder” (i.e., more artificial features) designs (**Fig. 1**).

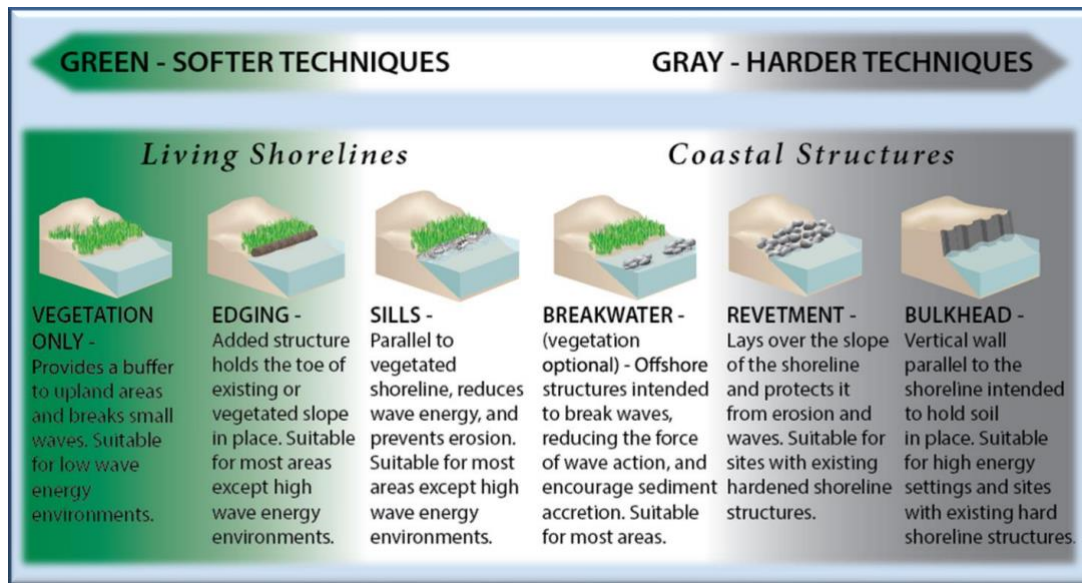


Figure 1. Shoreline stabilization techniques ranging from green (soft) to gray (hard).²

The ecosystem services that living shorelines deliver extend beyond erosion control, conferring enhanced nitrogen and carbon storage (Onorevole et al., 2018; Davis et al., 2015), higher abundances and species diversity of fishes (Gittman et al., 2016), enhanced nursery habitat for fish and wildlife (Gittman et al., 2016), and enhanced resilience to storm events (Smith et al., 2018; Gittman et al., 2014). The effectiveness of living shorelines to reduce erosion is well-documented (Polk and Eulie, 2018; Smee, 2019; Polk et al., 2022); however, the line between a living shoreline and a hardened structure is contentious. Pilkey et al. (2012) argue that their broad definition renders living shorelines vulnerable to appropriation and dilution. As the benefits and potential drawbacks of living shorelines become clearer, researchers, practitioners, homeowners, government bodies, and non-governmental organizations must work collaboratively to develop consensus around the best designs, materials and practices to deploy living shorelines responsibly and equitably.

¹ *QuickReef* is a patent-pending living shoreline system in which the marsh sill substrate is made from a proprietary mixture of natural calcium carbonate materials cemented together (Native Shorelines, n.d.).

² Guidance for considering the use of living shorelines. 2015. National Oceanic and Atmospheric Administration.



Figure 2. Living shoreline with sill made of *QuickReef*. Sediment accretion is visible landward and oyster recruitment waterward.³

2.1. Policy landscape

The North Carolina Department of Environmental Quality (NCDEQ) Division of Coastal Management (DCM) issues permits for shoreline stabilization. In 2004, the state issued a general permit for “rip raps sills for wetland enhancement and shoreline protection in estuarine and public trust waters” (S.L. 2003-427). However, a systemic bias toward harder structures persisted. A bulkhead-bias could be attributed to the burdensome policy hurdles that living shorelines faced. Historically, installing a living shoreline required a Major Permit pursuant to the Coastal Area Management Act of 1974 (CAMA). Applications for a Major Permit were costly and required an estimated 75 to 90 day review by ten state and four federal agencies prior to potential approval of the permit activity (NCDEQa, n.d.). In 2019, the Coastal Resource Commission, a rulemaking body established under CAMA, approved a rule that streamlined the permitting process for living shorelines (NCDEQb, n.d.; NCDEQ, 2019). The rule established a general permit (G.P.2700), which halved the permitting fee from \$400 to \$200 and reduced the processing time, positioning the permit for living shorelines as a more competitive option to hardened structures. Today, a permit to install a living shoreline in North Carolina requires that homeowners pay the permit fee, notify their neighbors, and submit a drawn schematic of the proposed structure (NCDEQ, 2019). These requirements more closely mirror the requirements for a bulkhead, helping mitigate a policy-bias toward armored structures. Permit limitations include a maximum structural length of 500 feet, restrictions on filling, and prohibited construction in Areas of Environmental Concern or where submerged aquatic vegetation or oyster reefs already exist (NCDEQ, 2019). G.P.2700 was readopted in 2022 (NCDEQ, 2022).

³ Photo by Kathryn Lienhard, 2023

Although the financial burden of installing a living shoreline falls primarily on property owners, state taxpayer dollars are implicated. Over the last four years, the North Carolina General Assembly has allocated at least four million dollars toward the construction of living shorelines. Two million dollars were allocated to the North Carolina Department of Transportation (NCDOT) in 2019 to construct living shorelines in areas close to vulnerable infrastructure (S.L. 2019-251) and another two million dollars allocated to a local nonprofit, the North Carolina Coastal Federation (“the Federation”), in 2021 to operate a cost-share program (S.L. 2021-180). The 2023 budget appropriations bill, recently passed by the North Carolina House of Representatives, earmarks another two million dollars in directed grant funding to the Federation to implement the cost-share program for living shorelines (H.B. 2023-259).

The Federation operates three offices along the state’s coast. One of the organization’s focuses is the “increased use of living shorelines so our coastal waters are clean and productive and sound front properties are better protected from erosion” (NCCF, 2022). The Federation is a key player in promoting the adoption of living shorelines as an alternative to hardened structures in North Carolina. The Federation provides a wealth of educational materials, marine contractor training, volunteer opportunities and resources for construction of living shorelines (NCCF 2021). The Federation also administers the state-funded living shorelines cost-share program to fund up to half the cost of a homeowner’s living shoreline installation (S.L. 2021-180). The Federation’s work was instrumental in the 2019 policy change that yielded a streamlined and cheaper permit for living shorelines.

Academic institutions like East Carolina University (ECU) in Greenville, the University of North Carolina Chapel Hill Institute of Marine Sciences (UNC-IMS) in Morehead City and the Duke University Marine Lab (DUML) in Beaufort act as local research hubs for coastal protection and nature-based solutions. The U.S. National Oceanic and Atmospheric Administration (NOAA) Beaufort Laboratory also supports research and policy efforts. In fact, the earliest study to use the word “living shorelines” was published in 2008 by Currin et. al, a group of researchers based at the Piver’s Island NOAA Lab (Currin et al., 2008; Smith et al., 2020).

At the Federal scale, the Biden-Harris Administration has promulgated the “Justice40” Initiative to allocate 40 percent of federal climate spending toward disadvantaged communities (The White House, 2022). Climate spending may encompass any federal investments in clean energy, climate resilience and justice, housing, clean water and legacy pollution to overburdened, marginalized and disadvantaged communities (The White House, 2022). To that end, the Climate and Economic Justice Screen Tool (CEJST) uses eight criteria (“categories of burden”) to evaluate census tracts under the Justice40 framework. Tracts are designated “disadvantaged” based on their vulnerability to climate change, energy insecurity, health and housing disparities, legacy pollution, transportation injustice, water quality and wastewater infrastructure, a slew of occupational metrics, and income (The White House, 2022). Since Justice40 designations describe intersecting forms of socio-ecological vulnerability, this initiative may be of interest in the context of climate resilience strategies like shoreline modification.

2.2. *Research questions and hypotheses*

Living shorelines may be an attractive shoreline stabilization method to shorefront property owners for the aesthetic, cost-savings, and ecosystem benefits they confer, but they are not uniformly distributed along North Carolina’s coast. Our analysis aims to elucidate the factors driving this uneven distribution.

Previous research has demonstrated that “neighboring shore condition” (i.e., whether a neighboring homeowner has a living shoreline or bulkhead) is the strongest predictor of a homeowner’s decision to harden or soften their shoreline (Gittman et al., 2021). However, no research to date has used spatial modeling tools in concert with semi-structured interviews to explore this question. This study uses mixed methods tools to understand the factors driving the distribution of living shorelines across North Carolina. Our analysis encompasses the influences of socioeconomic indicators (i.e., the percent of the population living below the poverty line, percent Black, Indigenous and people of color (BIPOC)⁴, and Justice40 designation), geographic proximity to marine contractors, research hubs, nonprofits and vulnerability to sea-level rise (using the projected area inundated by 2050 under an “intermediate sea-level rise scenario” as a proxy). In summary, we seek to understand the roles of socioeconomic demographics, proximity to enabling institutions, and vulnerability to sea-level rise as determinants of living shoreline distribution. These disparate factors, though not comprehensive, encompass some aspects of a tract’s socio-economic composition, access to information and science, and vulnerability to coastal hazards.

We hypothesize that tract poverty and percent BIPOC population will correlate negatively with living shorelines distribution, since coastal property in the South is largely occupied by whiter, wealthier demographics due to historical land dispossession and heirs property laws (McGee and Boone, 1977; Dyer et al., 2008; Bailey and Thomson, 2022) and because shoreline modification—whether hard or soft—is costly (Gonyo et al., 2023). We also hypothesize that, despite facing heightened social and climate vulnerabilities by definition, Justice40 “disadvantaged” communities will be less likely, on average, to host living shoreline projects due to presumptive barriers to coastal property ownership, government funding, education and political power. We predict that tracts with higher proximity to enabling institutions will have higher counts of living shorelines on average, since we expect awareness and popularity of living shorelines to be highest near these institutions. Since previous research demonstrates a correlative relationship between wave height and shoreline hardening (Gittman et al., 2015), we expect more living shorelines projects in regions that have higher projected areas of coastal inundation by 2050, a proxy for anticipated sea-level rise.

Within the narrative analysis, we seek to understand the narratives (i.e., perceptions) that homeowners hold about their living shorelines and distill the primary obstacles they face to install a living shoreline. Regional studies have highlighted the following barriers to widespread adoption: familiarity with, and systemic policy bias for, the status quo (hardened structures), lack of awareness for the science and broader context for shoreline management decisions (e.g., habitat connectivity), lack of advocacy on behalf of the beneficiaries of living shorelines, lack of service provider expertise, and lack of clear, environmentally-specific design standards, among others (RAE, 2015; Hilke et al., 2020). We expect that most participants will report erosion control and prevention of property loss as the primary reasons for installing a living shoreline. We predict that participants will report some or all of the barriers sourced from the literature. We hypothesize that the permitting process, ability to pay for a living shoreline installation, and ability to identify a trained marine service provider will emerge as the primary obstacles.

⁴ Our data on BIPOC folks is derived from the U.S. Census (2019) “non-white” statistic. We note here that the 2020 U.S. Census undercounted many marginalized identities, including Hispanic, Black and Native American peoples (Wines and Cramer, 2022). We use the term “BIPOC” in place of “Non-white” in an effort to decenter whiteness.

3. METHODS

3.1. *Geospatial analysis*

Our research aimed to distill the prevailing socio-ecological determinants of living shoreline distribution. Our analysis sought to: (1) determine whether select socioeconomic demographics (i.e., percent poverty, percent BIPOC population, Justice40 designation) influence the distribution of living shorelines; (2) explore the geographic influence of proximity to enabling institutions; (3) and determine if, and to what extent, 2050 coastal inundation projections predict the outcome of living shorelines. Our analysis employed geospatial tools in ArcGIS Pro (version 3.0.3) and statistical packages in RStudio (version 4.2.2) to answer these research questions. All data were projected in the WGS-1984 geographic coordinate system for analysis and visualization.

3.1.1. *Unit of analysis and scope*

The 2019 U.S. Census Bureau Tract (henceforth “tract”) served as the unit of analysis; the number of living shorelines, and all demographic, spatial and biophysical variables, were aggregated at the tract level. We chose this unit of analysis because counties did not provide sufficient spatial resolution and TIGER blocks and block groups provided such high resolution that the ratio of presence to absence for living shorelines was too highly skewed toward absences (zero-inflation) to sustain meaningful inference. Tracts are “small, relatively permanent statistical subdivisions of a county or statistically equivalent entity” and “generally have a population size between 1,200 and 8,000 people, with an optimum size of 4,000 people” (U.S. Census Bureau, 2022). Only census tracts containing a living shoreline-compatible shoreline type (type=9B, 10A, 7 or 10D) were analyzed (201 tracts).

Our geographic scope was bounded by North Carolina state borders since differences in state policies, permits, perceptions and management may confound or complicate our results. In other states, explanatory variables may interact with or shape the outcome in dissimilar ways. We then duplicated and repeated our analysis for only those tracts within Carteret and Onslow counties, where most living shorelines projects are concentrated (62 tracts). Thus, we explored the effects of our explanatory variables at two spatial scales to understand if trends are conserved at both scales.

3.1.2. *Data acquisition*

Living shoreline spatial point data (n=97) was supplied by the Federation. The spreadsheet listed each living shoreline installation as a unique row with columns describing the project’s shoreline type, total acres restored, latitude and longitude, and year constructed. We cross-referenced the Federation’s dataset with a publicly available dataset from the NOAA Office of Response and Restoration. NOAA’s Restoration Atlas supplies publicly available spatial data for restoration projects across the United States (NOAA, 2023). At time of acquisition, the Restoration Atlas had been last updated January 3rd, 2023. We determined the Federation’s dataset to be more comprehensive. The data from both sources represent living shoreline projects as point data, although these projects may span many acres in reality.

Census tract polygons and demographic data were derived from the Climate Mapping for Resilience and Adaptation (CMRA) dataset, which combines multiple government datasets to summarize data at the intersection of climate and other federal information products (CMRA, n.d.). The CMRA dataset includes hundreds of columns describing demographic data collected from the U.S. Census (e.g., percent BIPOC, percent below poverty line, etc.), climate risk

proxies (e.g., flood hazard areas, FEMA national risk index data, etc.) and Justice40 designations.

Using government addresses and Google Earth satellite data, we created point-feature classes storing locations for select institutions (n=32) (see **Table 1**). We included academic institutions with campuses within any of the 20 CAMA coastal counties or with perceived influence on living shorelines. ECU, though not located in a CAMA county, was included since this institution's research has made a significant contribution to literature on living shorelines. We created points within the feature class for two non-profits who may have an outsized influence on living shorelines deployment: The Nature Conservancy (TNC), which has one office in North Carolina (Wilmington), and the Federation. We also created points for government offices that may influence access to living shorelines educational materials or science: NOAA's Beaufort Laboratory on Piver's Island and the National Estuarine Research Reserve office in Dare County. We acquired a list of living shoreline-trained marine contractors from the Federation (2018).

A line-type feature class comprising the North Carolina coastline was acquired from the NOAA Office of Response and Restoration's Environmental Sensitivity Index (ESI) dataset (ORR, 2023). The ESI dataset classifies shoreline segments into 27 distinct classifications based on their sensitivity to oil spills (see **Table 2**). Only census tracts containing an ESI shoreline compatible with living shorelines were analyzed (201 tracts); salt and brackish water marshes make up the vast majority of North Carolina shorelines (for relative composition of North Carolina shoreline type by ESI classification see **Fig. 3**). The latest ESI data for North Carolina (2016) was used in the analysis.

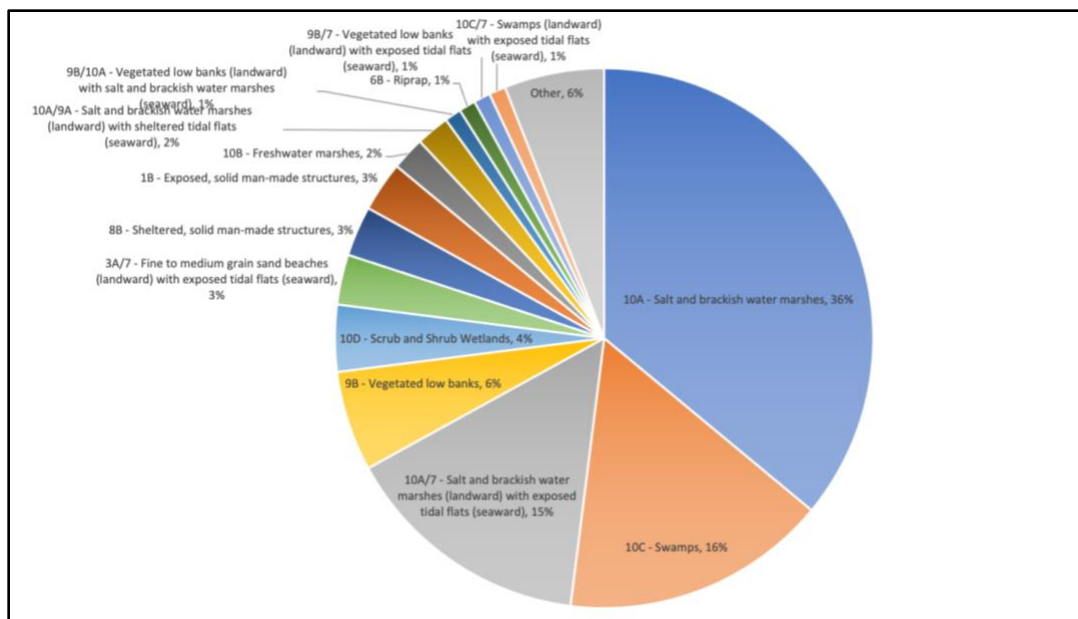


Figure 3. North Carolina shoreline by ESI classification as a percent of total shoreline.

Table 1. Enabling institutions (academic, contractor, government, nonprofit).

Institution	Type
Carteret Community College	Academic
Duke University Marine Lab	Academic
University of North Carolina Chapel Hill Institute of Marine Sciences	Academic
NC State University Center for Marine Sciences and Technology	Academic
Coastal Studies Institute	Academic
Coastal Carolina Community College, Jacksonville	Academic
Eastern Carolina University	Academic
University of North Carolina Wilmington	Academic
Cape Fear Community College	Academic
Craven Community College - New Bern	Academic
Carteret Marine Services, Inc.	Contractor
Total Marine Services (closed)	Contractor
Bissell Professional Group	Contractor
Quible & Associates	Contractor
Albemarle & Associates, Ltd. - Kill Devil Hills	Contractor
Albemarle & Associates, Ltd. - Elizabeth City	Contractor
Quible & Associates PC	Contractor
Sandbar Oyster Company	Contractor
Bobby Cahoon Construction	Contractor
Mud Bucket Dredging, Inc.	Contractor
Mud Bucket Dredging - AB	Contractor
Brooks Dredging & Marine Construction, Inc.	Contractor
TD Eure Marine Construction Eastern North Carolina	Contractor
Connaway Marine Construction	Contractor
Maritech, LLC.	Contractor
Outer Banks Excavating, Inc.	Contractor
National Oceanic and Atmospheric Administration - Beaufort Lab	Government
North Carolina National Estuarine Research Reserve	Government
The Nature Conservancy - Wilmington Office	Non-profit
North Carolina Coastal Federation (Central Office)	Non-profit
North Carolina Coastal Federation (Southeast Office)	Non-profit
North Carolina Coastal Federation (Northeast Office)	Non-profit

Table 2. Environmental Sensitivity Index (ESI) Shoreline Classification. Environment code: E = estuarine, L = lacustrine, R = riverine, P = palustrine⁵

ESI Code	Environment Code	Shoreline Classification Description
1A	E/L	1A: Exposed, Rocky Shores
1A	R	1A: Exposed, Rocky Banks
1B	E/L/R	1B: Exposed, Solid Man-Made Structures
1C	E/L/R	1C: Exposed, Rocky Cliffs w/Boulder Talus Base
2A	E	2A: Exposed, Wave-Cut Platforms (Bedrock/Mud/Clay)
2A	L	2A: Shelving Bedrock Shores
2A	R	2A: Rocky Shoals and Bedrock Ledges
2B	E	2B: Exposed Scarps and Steep Slopes (Clay)
3A	E	3A: Fine to Medium Grained Sand Beaches
3B	E	3B: Scarps and Steep Slopes (Sand)
3B	L	3B: Eroding Scarps (Unconsolidated Sediment)
3B	R	3B: Exposed, Eroding Banks (Unconsolidated Sediment)
3C	E	3C: Tundra Cliffs
4	E	4: Coarse Grained Sand Beaches
4	L	4: Sand Beaches
4	R	4: Sand Bars and Gently Sloping Banks
5	E/L	5: Mixed Sand and Gravel Beaches
5	R	5: Mixed Sand and Gravel Bars and Gently Sloping Banks
6A	E/L	6A: Gravel Beaches
6A	E	6A: Gravel Beaches (Granules/Pebbles) – used in Alaska
6A	R	6A: Gravel Bars and Gently Sloping Banks
6B	E/L/R	6B: Riprap
6B	E	6B: Gravel Beaches (Cobbles/Boulders) – used in Alaska
6D	E	6D: Boulder Rubble
7	E/L	7: Exposed Tidal Flats
8A	E/L	8A: Sheltered Scarps (Bedrock/Mud/Clay)
8A	E	8A: Sheltered, Impermeable, Rocky Shores
8B	E/L/R	8B: Sheltered, Solid Man-Made Structures
8B	E	8B: Sheltered, Permeable, Rocky Shores
8C	E/L/R	8C: Sheltered Riprap
8D	E	8D: Sheltered, Rocky Rubble Shores
8E	E	8E: Peat Shorelines
8F	R	8F: Vegetated, Steeply Sloping Bluffs
9A	E	9A: Sheltered Tidal Flats
9A	L	9A: Sheltered Sand and Mud Flats
9B	E/L/R	9B: Vegetated Low Banks
9C	E	9C: Hyper-Saline Tidal Flats
10A	E	10A: Salt and Brackish Water Marshes
10B	E/L/P/R	10B: Freshwater Marshes
10C	E/L/P/R	10C: Swamps
10D	E/L/P/R	10D: Scrub and Shrub Wetlands
10E	E	10E: Inundated Low Lying Tundra
10F	E	10F: Mangroves

⁵ Adapted from NOAA [U.S. National Oceanic and Atmospheric Administration]. (2019, Apr). *ESI Guidelines*. Version 4. NOAA Office of Response and Recovery. Retrieved December 2022 from www.response.restoration.noaa.gov

3.1.3. *Geospatial methodology*

To ensure reproducibility, we documented the entire geospatial analysis in a python script created using ArcGIS Pro ModelBuilder. To parse the data to the desired scope, we selected only those tracts within the state of North Carolina. We described the length of ESI shoreline present in each census tract (**Table 3; Fig. 4**). We narrowed the scope further by selecting only those census tracts containing an ESI shoreline type with a living shorelines-compatible typology. Using ESI definition criteria, we assume the following ESI shoreline types to be compatible with living shorelines: 9B (sheltered, vegetated low banks), 10A (salt and brackish water marshes), 7 (exposed tidal flats), and 10D (scrub and shrub wetlands) (NOAA, 2019). If a census tract did not include at least one segment of compatible shoreline type, the census tract was excluded from our analysis. Ultimately, 201 census tracts were analyzed with 42 census tracts having at least one living shoreline. We converted the living shorelines dataset into a point-type feature class using the “XY Table to Point” tool. We enumerated the quantity of living shoreline projects in each census tract (**Fig. 5; Fig. 9**); the count of projects per census tract served as the dependent variable in the multivariate analysis. To estimate proximity to enabling institutions, we created a 3-kilometer radial buffer from each institution and quantified the number of buffered institutions contained by or intersecting with each census tract (**Fig. 6-7**). We estimated tract vulnerability to sea-level rise for each census tract by calculating the percent total area inundated by 2050 under an “intermediate” sea-level rise scenario (**Fig. 8**). We calculated the total area of each census tract that is projected to be below sea-level by 2050 then divided that area by the total area of the tract to yield a value for percent area inundated. According to NOAA, an “intermediate sea-level rise scenario” is generated based upon “emissions uncertainty and process uncertainty” (2022). With all spatial data aggregated at the tract-level, we exported the attribute table of the output layer to a comma delimited file (.csv) for statistical analysis using R.

3.1.4. *Multivariate analysis*

We conducted multivariate analysis in R using generalized linear regression and decision tree analysis. We prepared the data frame by mapping the Justice40 “disadvantaged status” to a binary column where 1=disadvantaged, 0=not. To account for differences in population size, we divided the number of living shorelines by the total population and multiplied by 1,000 to find the number of living shorelines per thousand people. We explored the relationships between variables using the scatterplot matrix from the *GGally* package (function=*ggpairs*). We determined that the socioeconomic covariates—percent of the population that identifies as “non-white,” percent of the population living in poverty, and Justice40 designation—exhibited high multicollinearity; we hence removed two of the highly correlated independent variables (–percent BIPOC, –Justice40 designation). Our rationale for retaining percent poverty relies on the assumption that percent poverty is the most direct proxy for wealth and, thus, has the most direct relationship with shoreline modification. The response variable for our analysis was the number of living shorelines per thousand people per census tract. With <100 living shorelines projects mapped in North Carolina, our analytical power was constrained by the low sample size and positive skew of the response variable. Since our response variable was “count data,” we chose the Poisson distribution. To account for overdispersion, we modeled the data in a negative binomial distribution. We suspect that the overdispersion can be attributed to the excess zeros (zero-inflation) in our data. We used pairwise model selection and Aikake’s Information Criterion (AIC) scores to identify the most parsimonious model. The coefficients from the negative binomial model were exponentiated to interpret the values on a meaningful scale. The

same statistical analysis was repeated for a subset of the data containing only census tracts within Carteret and Onslow counties. We used the *rpart* package to generate a non-parametric regression decision tree (Fig. 13). The regression decision tree uses the distribution of the data to show how factors explain the predicted number of living shorelines per thousand people. We did not explore interactions between factors.

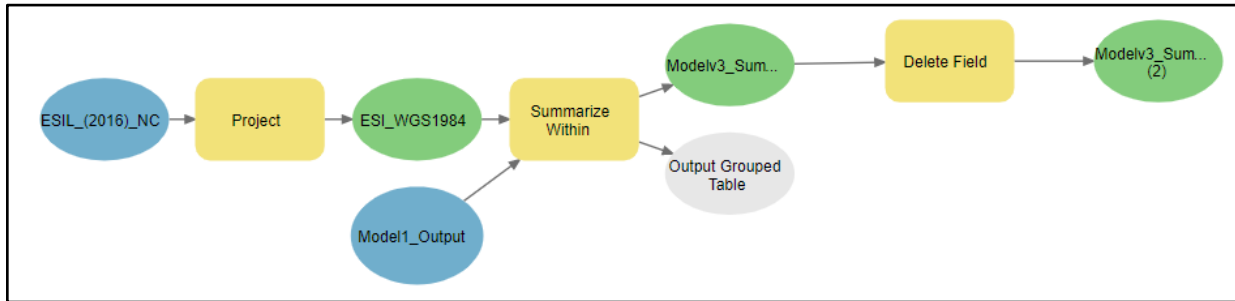


Figure 4. Model 3. Quantifying the length of ESI shoreline within each census tract.

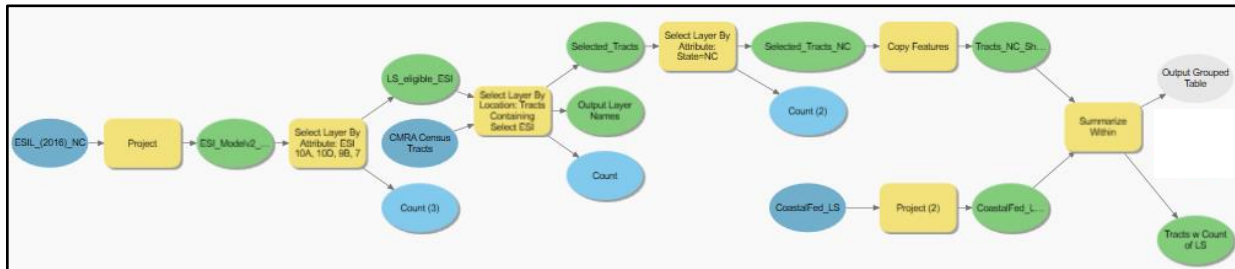


Figure 5. Model 1. Selecting census tracts, summarizing count of living shorelines.

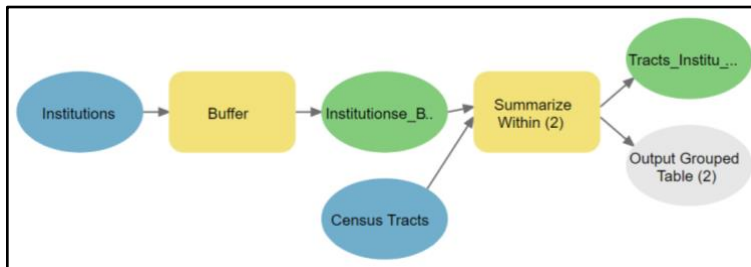


Figure 6. Model 2. Quantifying proximity to enabling institutions using a 3-kilometer buffer.

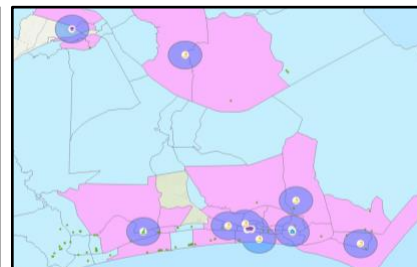


Figure 7. Screen grab of institutions with a 3-kilometer buffer (intermediate step).

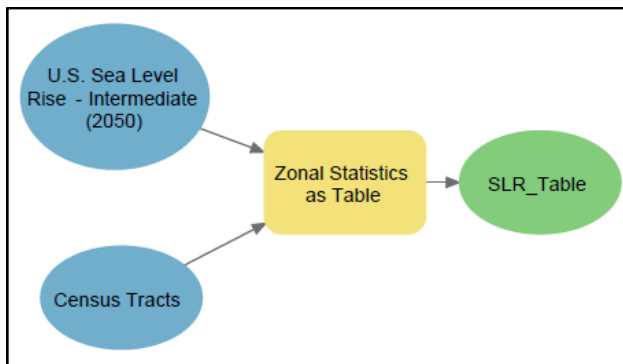


Figure 8. Model 4. Quantifying the area of inundated land within each census tract under an “intermediate” sea-level rise scenario by 2050.

3.2. *Narrative analysis*

We used semi-structured interviews to examine homeowner perceptions of and barriers to obtaining living shorelines. While the geospatial study explored parameters at two spatial scales, the narrative analysis introduced a third scale by studying the parameters that affect individual decision-making (homeowner scale).

To distill perceptions and barriers, we employed a type of narrative analysis called inductive thematic analysis. Here, we are interested in the individual, subjective experience of the homeowner (personal narrative). To that end, we conducted a narrative analysis, which is characterized as “having a storied form” and uncovers ways of knowing through storytelling (Riessman 2005). Riessman (2005) outlines four approaches to narrative analyses: structural, thematic, interactional and performative. We chose a thematic approach for its emphasis on distilling patterns and main ideas from “immersing oneself in the data” (Peterson, 2017). In the context of qualitative research, an inductive approach (sometimes called “data to theory”) is characterized as a “widely used...accessible and theoretically flexible approach” to condense and derive findings from raw data (Braun & Clarke, 2006; Thomas, 2006). Inductive qualitative research differs from deductive approaches in that we developed and refined the coding structure based on the data (*ex-post*), rather than preconceived theories (*ex-ante*). We thus use an inductive thematic narrative analysis to elucidate the underlying themes and identify shared ideas and beliefs about shorelines, erosion, and stabilization techniques across interviews.

3.2.1. *Study selection*

We conducted in-person and virtual interviews of homeowners with living shorelines (Group 1) and homeowners without living shorelines who plan to or are in the process of obtaining living shorelines (Group 2). To be eligible for this study, the subject must be a property owner living in coastal North Carolina *and* either have or plan to construct a living shoreline. Group 1 included thirteen participants and Group 2 included five participants.

3.2.2. *Participant recruitment*

Potential interviewees for study groups were identified by the Federation’s existing networks and internal database of property owners who have expressed interest in, have implemented, or plan to implement a living shoreline on their private property. The Federation recruited participants via email. Approximately 30 property owners were contacted with the initial recruitment email. Researchers received initial responses from 21 prospective participants and 18 ultimately agreed to be interviewed. Participants' properties were located in eastern North Carolina, primarily in Carteret County.

3.2.3. *Study activities*

Study participants agreed to one-hour semi-structured interviews. Virtual interviews were conducted via the Zoom web video conferencing platform (8). In-person interviews were conducted at participants’ properties (10). Photographs of participants’ shorelines were taken with verbal and written consent from participants for use only in this report. All interviews were audio-recorded and transcribed using Zoom audio transcription. Interviews consisted of twelve pre-designed questions intended to solicit personal experiences with and perception of living shorelines (**Appendix A**). Subsequently, we reviewed transcriptions and recordings for patterns. We used emergent patterns (e.g., mentions of permitting or financial constraints as barriers; mentions of erosion or flooding as motivators for installation) to create an iterative coding

structure. Ultimately, the patterns we coded were: concern for cost, the role of science, policy and service providers, who bears responsibility for protecting the coast, and evaluation of their overall experience. Interview questions and responses were compiled in Microsoft Excel. Codes were assigned to relevant responses and themes were constructed from coded data.

4. RESULTS

4.1. *Geospatial analysis*

Two of the top five census tracts with the most shoreline by length are located in Carteret county (tracts 9701.02 and 9801) (**Table 3**). The tract with the most shoreline is tract 9201 in Hyde County. Interestingly, 80 percent of living shoreline projects are concentrated in just two counties, Carteret and Onslow (see blue polygon in **Fig. 11**). With respect to socioeconomic attributes, census tracts further inland tended to have higher percentages of people living below the poverty line, while whiter, wealthier populations made up a larger share of census tracts to the East (**Fig. 10**). This trend was consistent across poverty rates, Justice40 “disadvantaged” designations, and the distribution of BIPOC populations. Census tract 5, represented in dark purple, exhibited anomalously high rates of poverty (53.3 percent) and BIPOC populations (44.7 percent) relative to its surroundings (**Fig. 10**). We suspect that this may be due to skew from small population size (1,518 people) or the presence and unique circumstances of Camp Lejeune, a U.S. Marine Corps base. Enabling institutions were clustered in the Wilmington-Wrightsville area, in Carteret County, and in the Outer Banks (**Fig. 11**). The Carteret County area, and the communities around Bogue Sound in particular, stands out as a regional hub of high institutional capacity; UNC-IMS, DUML, a NOAA Lab, the North Carolina University State Center for Marine Sciences and Technology (CMAST), one of three offices of the Federation, and many marine contractors are located in this region. Likely due to low elevation, projected coastal inundation appears greatest in tracts located in the Northeastern part of the state (**Fig. 12**). Census tract 205.12, which borders Pamlico Sound, had the highest sea-level rise vulnerability with almost half the tract projected to be inundated by 2050 (49 percent). If our hypothesis held true, we would expect more living shoreline projects per capita in this region of heightened vulnerability to sea level rise. Comparing the distribution of living shorelines to sea-level rise projections, it is visually apparent that living shorelines are not more prevalent in tracts with higher predicted inundation values. Our multivariate model, which does not find inundation to be a significant predictor, supports this conclusion.

The results of the model determining the best predictor of living shoreline distribution (**Table 4**) indicate that percent poverty has a statistically significant negative correlation with the distribution of living shorelines ($p < 0.001$). Based on the coefficients from the model, we expect 9 to 14 percent⁶ fewer living shoreline projects with every 1 percent increase in percent poverty. That means that for any census tract with greater than approximately 8.7 percent of the population living below the poverty line, the predicted value of living shorelines goes to zero (less than 1). In contrast, tract area inundated by 2050 under an intermediate scenario and proximity to enabling institutions did not emerge as statistically significant explanatory variables.

⁶ A range is given because we ran the model at two spatial scales (statewide and subsetted to Carteret and Onslow counties); the effect size was greater at the two-county level (~14%) and smaller (~9%) at the state-level.

Table 3. Top 20 census tracts in North Carolina by length of shoreline

	Census Tract	County	Length of shoreline (km)
1	9201	Hyde	1714.7
2	9701.02	Carteret	818.8
3	9201.01	Pender	751.1
4	9801	Carteret	707.7
5	1101.01	Currituck	629.9
6	9501.02	Pamlico	582.0
7	5	Onslow	553.7
8	9705.01	Dare	515.8
9	9601	Tyrrell	452.5
10	118	New Hanover	430.7
11	28	Onslow	429.8
12	9502.02	Pamlico	398.4
13	308	Beaufort	396.0
14	1.02	Onslow	386.3
15	9705.02	Dare	384.8
16	9307	Beaufort	357.2
17	9501.02	Camden	336.8
18	123	New Hanover	314.7
19	9604	Bertie	290.6
20	1104.02	Currituck	286.5

The regression decision tree (**Fig. 13**) relies on a computation called “recursive partitioning” to parse the data into meaningful thresholds that describe the influence of factors and their directionality. The root node of the tree tells us that, across census tracts analyzed, we observe a mean of 1.3 living shorelines per thousand people. Based on the tree, the most prevalent factor (strongest predictor) in determining where living shorelines are deployed is the percent of people living below the poverty line. If a census tract has greater than or equal to 11 percent poverty, we expect less than one (0.42) living shoreline in the tract. For tracts with lower rates of poverty (<11 percent) our predicted value is nearly double the mean (2.1 living shorelines). About half the data falls above the 11 percent threshold and half below. The next most predictive factor is coastal area inundated by 2050. Tracts with higher percent area inundated (≥ 10 percent) have fewer living shorelines (0.5), while areas with lower projected inundation (<10 percent) have nearly three times the mean (3.1 living shorelines). Of the 50 percent of tracts with less than 11 percent poverty, a larger share are predicted to have 3.1 living shorelines than 0.5 (31 percent and 19 percent of census tracts, respectively).

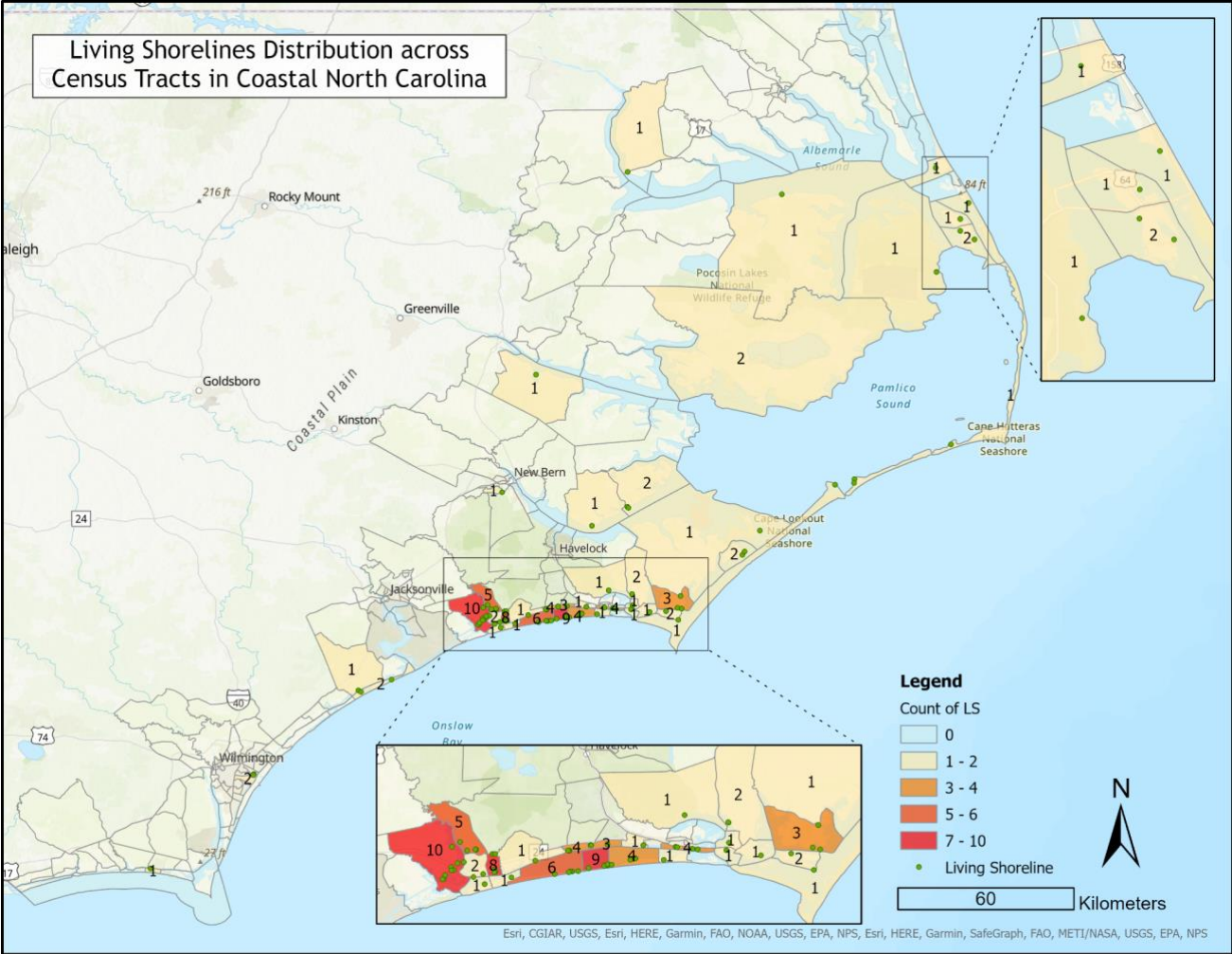


Figure 9. Map symbolizing U.S. Census tracts by count of living shorelines in coastal North Carolina. Darker shades represent higher counts of living shorelines. Numerical labels report the number of living shoreline projects within each tract.

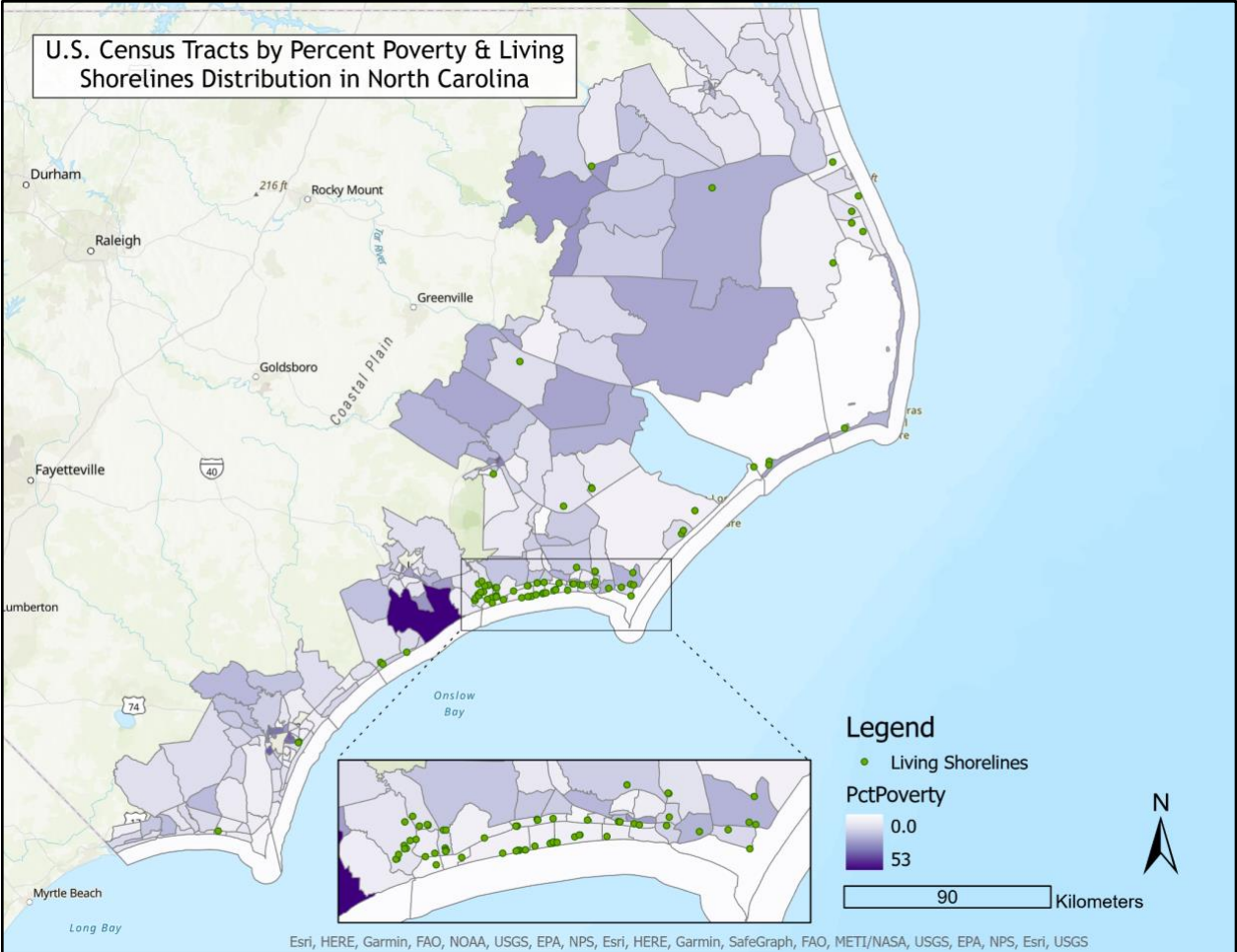


Figure 10. Map of census tracts symbolized by percent of population living below the poverty line and living shorelines in North Carolina.

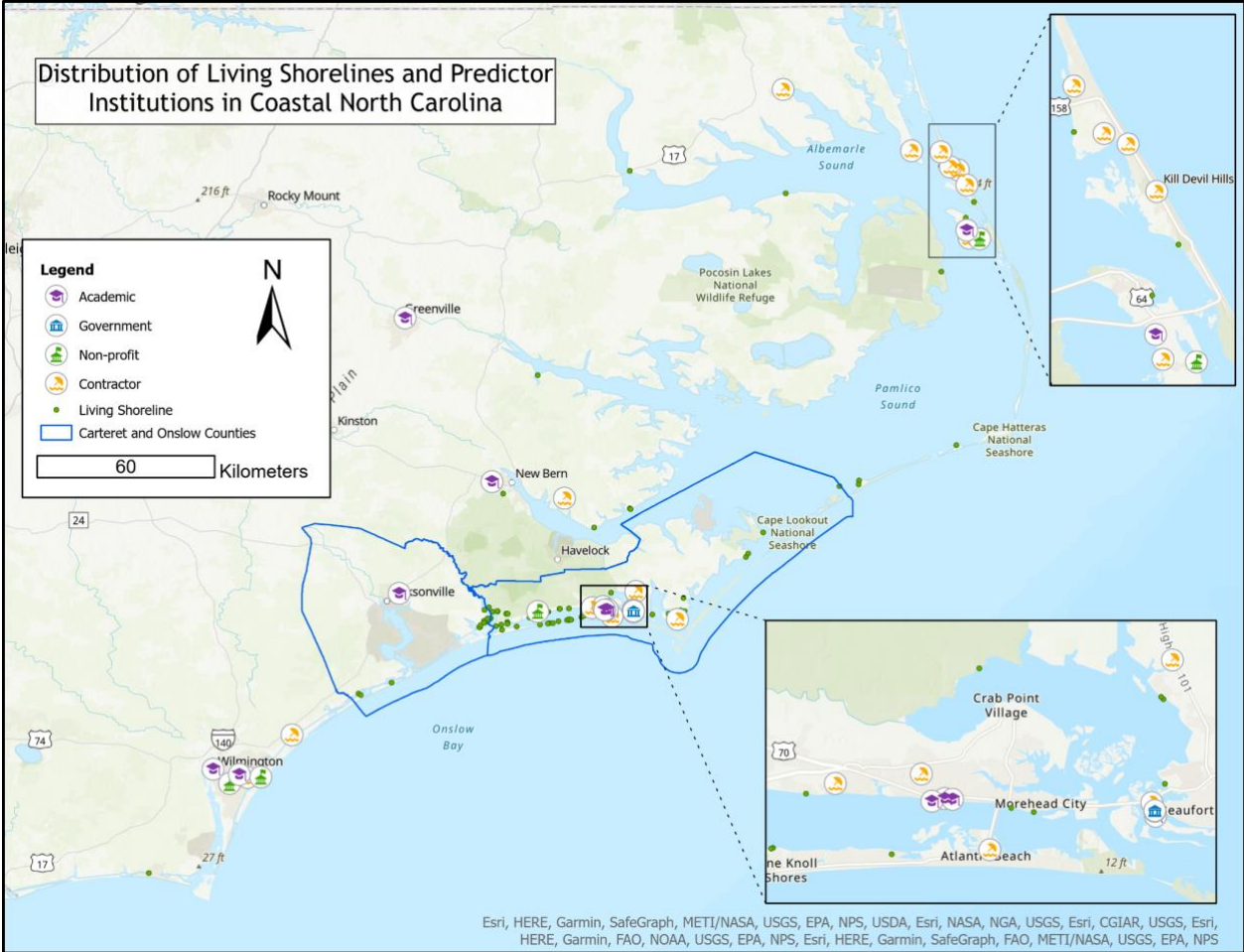


Figure 11. Map of enabling institutions and living shorelines in coastal North Carolina.

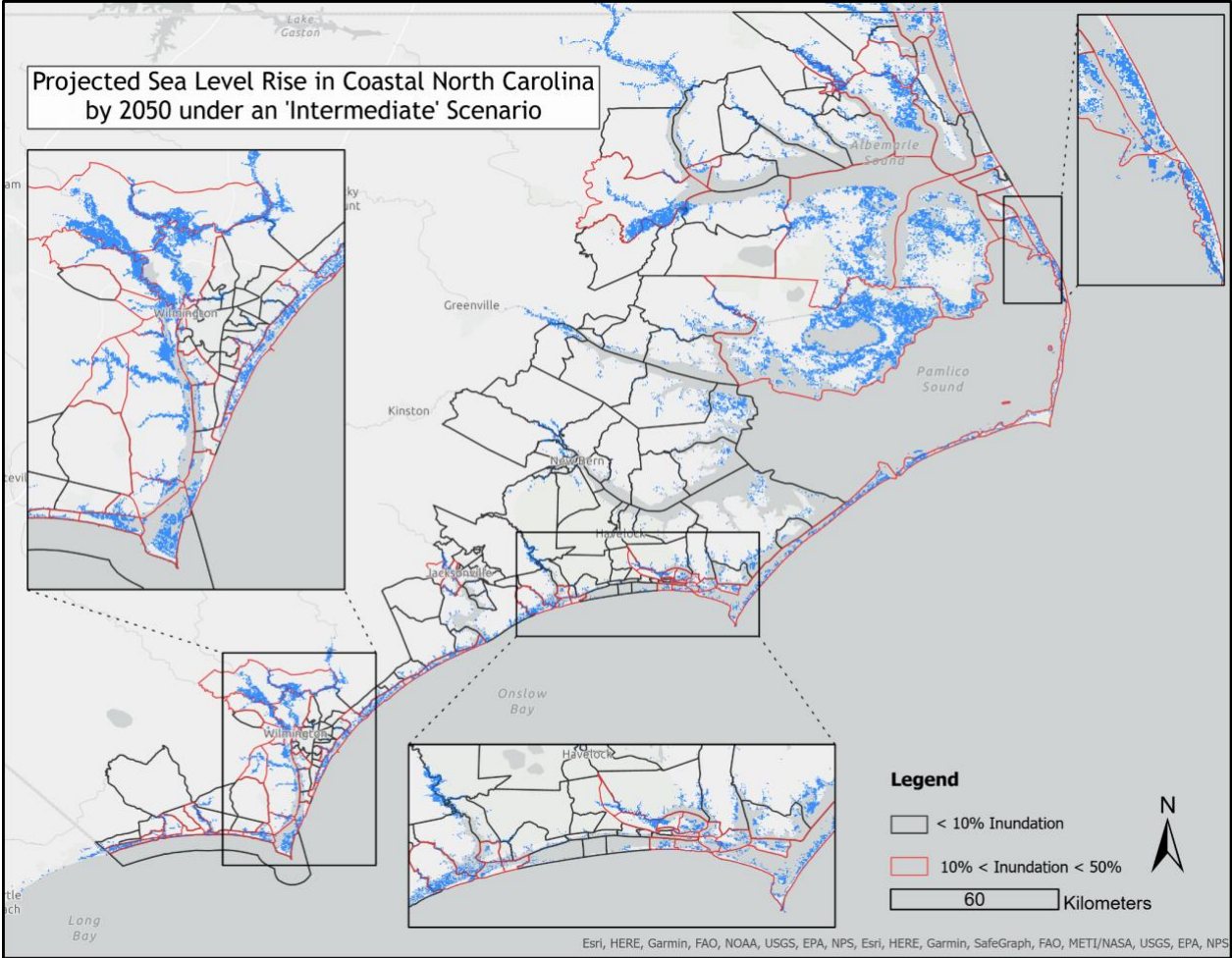


Figure 12. Sea-level rise projections by 2050 in North Carolina under an “intermediate sea-level rise scenario” binned as vulnerable (>10% area inundated) and less vulnerable (<10% area inundated).

Table 4. Negative binomial model coefficients.

Significance codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

	<i>Estimate</i>	<i>z value</i>	<i>Pr(> z)</i>
<i>intercept</i>	1.53421	2.549	0.010794 *
<i>proximity to institutions (km)</i>	-0.06138	-0.663	0.507386
<i>area inundated (%)</i>	-2.23749	-0.586	0.5576
<i>poverty (%)</i>	-0.14278	-3.349	0.000811 ***

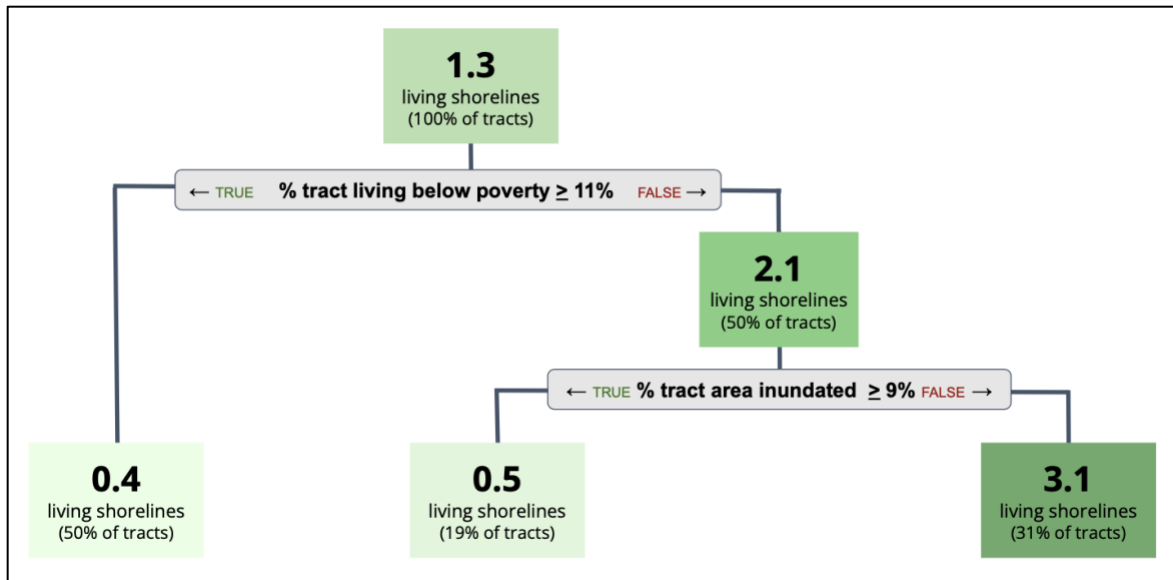


Figure 13. Regression decision tree illustrating the relationship between thresholds of explanatory variables and the predicted value of living shorelines per thousand people. Darker shades of green represent higher predicted values.

4.2. Narrative analysis

4.2.1. Themes

Four main themes emerged regarding homeowner perceptions of living shorelines: 1) reasons for installing living shorelines vary among homeowners; 2) there is an apparent disconnect between science and decision-makers; 3) homeowners hold mixed beliefs about who is responsible for promoting living shorelines; and 4) most homeowners are satisfied with their living shorelines projects.

Thirteen participants identified erosion reduction as the primary reason for stabilizing their shorelines. Specifically, participants identified wind, hurricanes, boat wakes, and other storms including nor'easters as causes of erosion of their shorelines. Five participants identified proactive protection of their shorelines as the primary reason for installing living shorelines, noting that their shorelines were not experiencing severe erosion at the time of interview. Participants espoused goals of preserving existing marsh habitat, preventing loss of trees at the shoreline, and protecting property value as auxiliary reasons for installing living shorelines. A common theme, the desire to take action to protect property from land loss, is embodied by the comment: "If I don't do something, I'm not sure what's gonna happen to keep the property...it's definitely an investment." It was common for participants to detail histories of their properties and shorelines when describing their motivations for installation.

When participants described why they chose a living shoreline over a hardened structure, the most common responses encompassed concerns for marine life, water quality, and oyster recruitment. Some participants sympathized with property owners who choose to harden their shorelines; one homeowner remarked, "when your shore is sloughing into the water, a living shoreline is a tough sell." Homeowners with living shorelines and those with armored structures were not always mutually exclusive. In some cases, a bulkhead was constructed prior to purchasing the property or as an additional shoreline protection measure.

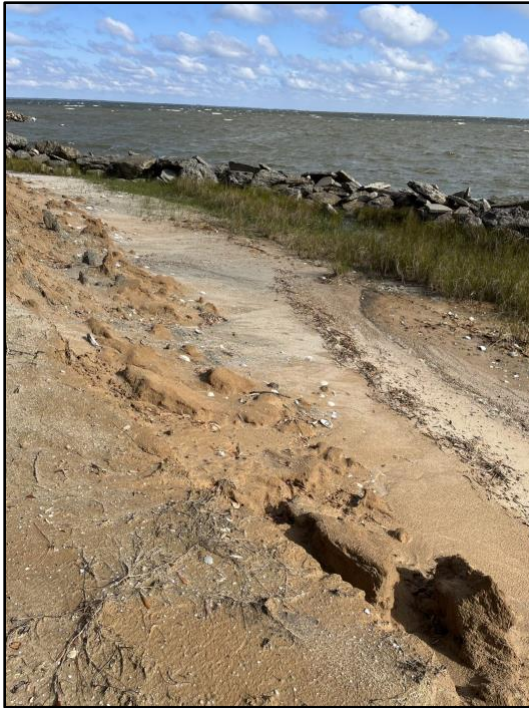


Figure 14. Erosion of a shoreline on a high-energy water body. Riprap revetment holds remaining marsh grasses in place while storms and extreme tides have washed away the rest (Photo by Kathryn Lienhard, 2023).

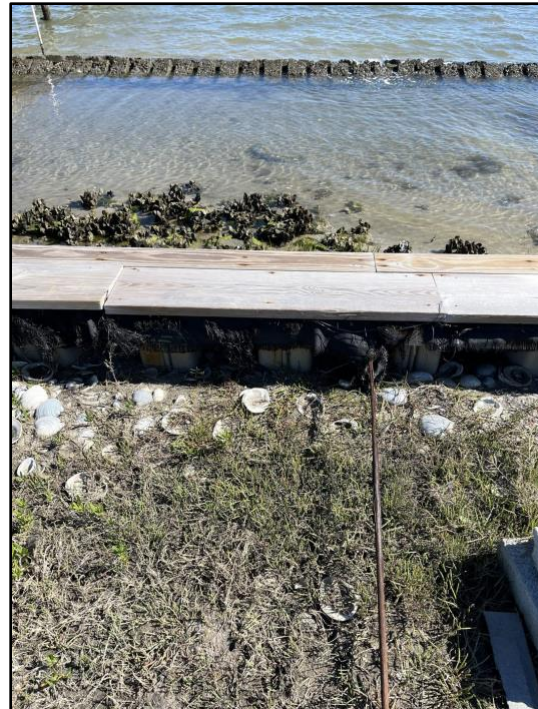


Figure 15. Failing bulkhead in the foreground with “deadman” exposed from storm damage. Living shoreline with *QuickReef* sill in the background. (Photo by Kathryn Lienhard, 2023)

Many participants voiced a disconnect between the scientific research which demonstrates the efficacy of living shorelines and shoreline stabilization policies. One participant commented, “we need our local governments to be more aware of the innovative property management practices that are in place that have data to support them.” Another participant underscored the inaccessibility of research on living shorelines by academic institutions: “there’s a lot of wonderful research on [living shorelines] and the effectiveness of [them]. But it’s hidden, you know.” Another subject shared sentiments that “North Carolina is quick to permit seawalls,” recommending “more preservation-oriented policies.” They postulated that living shorelines are not the default, and it shows: “when people get desperate, then they start to look for solutions [to shoreline erosion], and ...it might be too late.” The problem of scale in effective communication was emphasized; one participant noted, “there’s a huge difference between grad-level research and marine contractor...and then that same difference to the property owner.” Despite disconnects and paywalls, most participants felt that practitioners who install living shorelines, such as the Federation, were “so helpful” and have a “clear agenda to getting living shorelines installed.” One participant shared, “it’s the customer service of the Coastal Federation that makes them successful.”

Participants responded with uncertainty and mixed beliefs when asked who they believe should be responsible for promoting living shorelines. When participants were asked who they

believe is currently responsible for promoting awareness of living shorelines, many noted that the Federation has been instrumental in education initiatives for living shorelines and helping homeowners secure funding through the cost-share program. When asked who they believe *should* bear the responsibility of promoting, installing, funding living shorelines, responses varied. In participants' eyes, responsible parties include state government, local governments, nonprofits, universities, marine contractors, and individual property owners (alone or in combination).

Nearly all participants voiced satisfaction with their living shorelines even when effectiveness could not yet be determined. Among participants who had recently installed living shorelines, a “too soon to tell” mentality was common. That is, homeowners could not be certain about whether the living shoreline was reducing erosion yet. Despite this uncertainty, we documented shared sentiments of optimism and satisfaction with the intervention overall.

“On a real windy day, when the sound is rough, in front of our living shoreline, there’s a little... tidal pool...and it will be virtually calm there. It’s clear and you can see minnows... it’s like what I remember it used to look like in the whole sound...”

Participants who had not yet installed living shorelines (Group 2) reflected positively on their experience, too. Group 2 subjects frequently expressed gratitude for the help they received from local contractors and the Federation. We observed a marked connection between homeowner satisfaction and appreciation for wildlife. We

noticed that homeowners who reported the most enthusiasm about their living shoreline had high perceived emotional investment in the wellbeing of marine ecosystems. Birds, fishes, and invertebrates were among the fauna that homeowners associated with their living shoreline.

While homeowner satisfaction was consistent, homeowner preferences for substrates varied. One participant, whose shoreline experienced high wave action, expressed a preference for *QuickReef*: “we felt the [oyster] bags weren’t as useful because we’d have to do a lot of maintenance on it.” Another participant noted “a downside to the [oyster] bags is that they can be knocked out of place.” One participant recounted how their living shoreline was affected by a storm event and noted that the marine contractor and the Federation responded through efficient repair: “the upside is [oyster bags] are kind of easy to put right back.” One participant, regarding the use of plastic mesh bags for an oyster shell sill, shared “the plastic is a concern.” They noted “there’s a tradeoff...I think you kind of have to balance that early adoption of something with the fact that it will get refined and improved along the way.” Other participants also expressed concern over the use of plastic for mesh oyster shell bags but were hopeful that new plastic-free techniques will become more common in the future. Thus, despite varying preferences for substrate type, satisfaction remained consistent.

4.2.2. *Barriers to implementation*

Three main barriers to implementation were identified from homeowner accounts of experiences with living shorelines: 1) cost; 2) awareness of living shorelines as an option for shoreline stabilization; and 3) ability to navigate the process of obtaining a living shoreline.

When participants were asked what they perceived as the primary barrier of living shoreline installations, almost all answered that cost was a deterrent. One homeowner noted that without a cost-share program, they may have been unable or unwilling to pay for their shoreline project. They postulated that for those who decide against a living shoreline, “money is spent on other things...it’s a priority thing.”

**“When you live on this waterway,
it’s not for the faint of heart.”**

Our narrative analysis identified awareness of living shorelines as a common barrier to their implementation. When participants were asked about perceived community awareness of living shorelines, responses were mixed. One participant said they “can’t imagine anyone that has a shoreline problem...that doesn’t know about living shorelines,” while another remarked, “I don’t think anyone knows about [living shorelines].” One homeowner recalled influencing their neighbor’s understanding and awareness of living shorelines as a more environmentally friendly approach. This anecdote is consistent with research that demonstrates the role of neighboring properties in influencing shoreline management decisions (Gittman et al., 2021). Another participant remembers being asked of their living shoreline: “what the hell is in front of your yard?” by another member of the community, suggesting that recognition and awareness of these projects vary. Even for homeowners who are knowledgeable about living shorelines, understanding whether to harden or soften the shoreline may require professional consultation. Prior to seeking a living shoreline, one participant inquired “is my project too small to be looked at?” Awareness was not just a barrier for homeowners, but for marine contractors too. Not all marine contractors are trained to install living shorelines, and some actively discourage them. One participant shared that “three different contractors all said: bulkhead. And when [they] asked about living shorelines, [the contractor] said, ‘oh, you don’t want to do that.’” One participant’s response epitomizes the perceived role that awareness plays in determining where living shorelines are installed: “if people knew [living shorelines] existed, and that there’s grant money available, most people would say ‘why not!’”

Ability to navigate the process of obtaining a living shoreline emerged as a barrier to implementation. If an eligible property owner is first primed to know that living shorelines exist as a shoreline stabilization option, they must also have the capacity to navigate the process from inquiry to installation. In one case, “not knowing the [funding] cycle” (i.e., when grants are made available) and what season marsh grass can be successfully restored resulted in delayed installation. Many participants, whose experiences were generally positive, viewed the initial steps as the hardest part; one said, “people may think about [getting a living shoreline] but it’s a hard thing to initiate.” Thus, we gather that some institutional knowledge of grant funding, seasonal restoration constraints, and knowing where to start created real, yet surmountable obstacles. Despite these barriers, the people we interviewed emphasized positive experience and strong personal connections with the entities responsible for their implementation.

5. DISCUSSION

Our analyses sought to elucidate the deterministic factors driving living shoreline distribution. Results from both analyses shed light on overlapping and disparate phenomena underpinning implementation of living shorelines. The geospatial analysis relies on the extant distribution of living shorelines as a proxy for many interacting forces that shape the outcome.

The narrative analysis complements the former approach by providing insights into the perceptions and experiences that inform decision making at the homeowner scale.

5.1. Implications and significance

5.1.1. Wealth attributes

Within the multivariate analyses, we find the clearest and strongest relationship between wealth attributes and the presence of living shorelines. Our findings are consistent with research that has demonstrated a correlation between GDP and shoreline hardening at the national scale (Gittman et al., 2015) and between households with income over \$200,000 and shoreline armoring in North Carolina (Siders & Keenan, 2020). In contrast, Siders & Keenan (2020) did not find a statistically significant relationship between percent poverty and shoreline armoring. This suggests that trends between wealth attributes and shoreline modification may vary between softer and harder interventions. Since the percent of people living below the poverty line coastal North Carolina correlates highly with untested parameters (i.e., race and Justice40 designation), we expect to see similar, negative correlations between the number of living shorelines and other dimensions of marginalization. The model findings align with the cost-barrier identified in the narrative analysis. The prevalence of a cost-barrier across both analyses suggests that affluence may play an important role at the community and homeowner scales.

The negative correlation between poverty and the distribution of living shorelines could entail equity implications. To understand why equity is implicated, it is instructive to apply an environmental justice framework. “Procedural justice” concerns the fairness of the decision-making process that produces the outcomes we observe, while “distributive justice” concerns the outcomes themselves (Villa et al., 2020). Distributive justice asks how “environmental bads (e.g., toxic waste) and goods (e.g., green space)” are distributed. Viewing living shorelines as an “environmental good,” it becomes clear that their distribution, and the factors that drive it, matter. Without proper consideration of procedural and distributive justice, nature-based solutions risk contributing to green gentrification and “[serving] elite economic players at the expense of widespread socio-ecological benefits” (Gould and Lewis, 2012; Kotsila et al., 2021). The stark spatial trends in poverty and race that we observe across coastal census tracts (**Fig. 11-13**) can be contextualized by a history of racial and economic injustices in the South. North Carolina’s history of systemically sanctioned coastal land dispossession from Black landowners is inseparable from such patterns and may inform interpretation of our results. Kahrl (2016) documents a shared experience of African American coastal landowners that includes declining revenues, hostile public officials, and predatory land speculators. Kahrl retells the “rush to the sea [that] led to a rush to privatize the shore,” especially in North Carolina where “four of the coastal counties, which until the 1960s remained among the state’s most sparsely populated, gained residents at a rate two to six times greater than the rest of the state” (2016). Forced partition sales and weak protections under heirs property laws have contributed to a whiter, wealthier population occupying North Carolina’s coastal properties today (Bailey and Thomson, 2022). Understanding “how African Americans lost millions of acres of valuable land to white speculators and developers—through deceit, fraud, and other unethical but often legal actions,” we can better contextualize the correlations we observe in our study (Kahrl, 2016). Our findings are further complicated by the reality that living shorelines are not suitable for all shorelines or environments, and thus may not always be the best response to communities experiencing sea-level rise. Further, because coastal land ownership is heavily influenced by dispossession, our findings may be more indicative of the socioeconomic factors that characterize coastal property

owners, rather than of the deployment of living shorelines themselves. In any case, the results are not sufficient to draw conclusions about causation and instead raise more questions about observed patterns and correlation.

5.1.2. Sea-level rise

The lack of correlation between coastal inundation projections and living shoreline distribution suggests that deployment and funding of living shoreline projects could better align with sea-level rise vulnerability. However, percent area inundated by 2050 is just one, coarse metric of vulnerability that may not reflect the reality of cumulative impacts. Based on our findings, it is possible that a disconnect may exist between where living shorelines are most needed (assuming living shorelines are suitable for addressing sea-level rise) versus where they are installed. This is consistent with broader trends in the field, which evidence a disconnect between ecological knowledge and shoreline management decisions (Gittman et al., 2021) as well as “spatial mismatches between wetland loss and restoration” (Gittman et al., 2019). For comparison, Keenan & Siders (2020) found no relationship between mean sea level rise and shoreline armoring, although percent land in 100- and 500-year floodplains were significant predictors in their models. Comparing our results to those of shoreline armoring shows that sea-level rise predictions may not drive the distribution of shoreline protection measures in coastal North Carolina, regardless of soft or hard. However, exploring the effect of 100-year and 500-year floodplains as drivers of living shorelines distribution may produce new insights. Given the lower presence of living shorelines in marginalized and flood-vulnerable communities, our findings shed light on the imperative for policy makers and local governments to ensure nature-based solutions are distributed equitably. Policymakers should consider prioritizing funding for living shorelines in low-income communities of color and those vulnerable to sea-level rise. Of course, efforts to protect shorelines in marginalized communities should center the perspectives, goals and priorities of the communities they seek to serve.

5.1.3. Enabling institutions

The lack of spatial correlation between proximity to enabling institutions and presence of living shorelines suggests that the geography of institutions may have a negligible impact on the distribution of living shorelines. From this theory, we infer that the ability to install a living shoreline is not constrained by geographic proximity to research hubs, trained nonprofits and marine contractors. At face value, this finding instills confidence in institutional competence to reach homeowners no matter their distance. However, more research is needed to verify that our methodology is a reliable metric of geographic influence. An alternate interpretation of our findings suggests that reviewing our approach to tease out these relationships (i.e., test the impact of each institution separately, rather than binned) or that the statistical significance remains undetectable due to low sample size of the response variable.

5.1.4. Homeowner perceptions

Unsurprisingly, preventing erosion was the primary reason homeowners installed living shorelines, but we uncover additional drivers behind their decisions. Our findings suggest a homeowner’s values regarding marsh preservation and marine life may impact their decision to install a living shoreline. When homeowners reflected upon their motivations for installation and their satisfaction, we learned that homeowners with living shorelines generally have extensive knowledge about substrate types, local waterways and the wildlife that visits their shoreline. An

analysis of public opinion of environmental legislation found that citizens in North Carolina “have a high degree of concern and personal responsibility for environmental issues” (Cato, 1995), which is consistent with our results. We thus posit that emphasizing the fragility and diversity of coastal ecosystems in combination with efforts to highlight the environmental benefits offered by living shorelines may drive increased adoption. Moreover, shared homeowner concerns about the materials used to install living shorelines, and criticism from some academics (Pilkey et al., 2012), suggest that the concept of a living shoreline may evolve in order to meet the environmental standards and expectations held by homeowners and taxpayers.

The disconnect we documented in interviews—between science, policy, and contractors—mirrors the disconnect we distilled in the spatial analysis, which implies living shorelines are not deployed in a manner reflective of sea-level rise projections. This shared conclusion indicates a need for enhanced coordination between stakeholder groups. Bilkovic et al. (2016) find that “enhanced public acceptance and coordination among regulatory and advisory authorities will be essential to expand [the use of living shorelines].” Better communication and coordination between scientists, policymakers, and marine contractors could improve design and restoration techniques, ameliorate barriers to installation and lessen emerging disparities in living shoreline distribution.

The discordant beliefs about who should be responsible for ensuring coasts are protected equitably reflects our geospatial findings. Namely, we found that proximity to academic, nonprofit, and government institutions and marine contractors is not predictive of where living shorelines are built. Perhaps the narrative and geospatial findings together tell us that the onus for ensuring equitable distribution of living shorelines rests not with one group but is shared across them. This question fits into a broader debate about who is responsible for managing and protecting environmental resources on an increasingly privatized coastline (Kahrl, 2016).

5.1.5. Barriers to implementation

Despite the streamlined permitting process for living shorelines and the extensive efforts by the Federation to implement living shorelines, our thematic coding revealed homeowner barriers to obtaining living shorelines. Our results, including a lack of awareness of living shorelines and limited availability of trained contractors, align with previously identified barriers to living shoreline implementation (Hilke et al., 2020). These barriers may provide insight into the variance in living shoreline distribution that could not be explained by the multivariate model. These barriers may also explain why some property owners continue to harden their shorelines. Our interviews elucidate that consistent, recurring government funding allocated to cost-share programs is crucial to the widespread adoption of living shorelines, but implementation must consider marginalized populations. In addition to funding, the lack of awareness may be addressed through increased advertising, education, and outreach. There is potential for state or federal funding to increase capacities of marine contractors to address constraints in contractor availability (RAE, 2016).

The use of a mixed methods approach to test and compare findings demonstrates the merits of interdisciplinary research. The culmination of our spatial and narrative analyses highlight urgent considerations in equity and access to information regarding living shorelines. As public funds are allocated to install living shorelines, agencies who manage these funds should consider disparities in homeowner ability to pay and socioeconomic factors. Further research to understand drivers and disparities is necessary as the popularity of living shorelines increases. We find support for this argument in the literature; Arkema et al. (2017) state that “the

ecological, physical, and social context in which [living shorelines'] benefits occur needs to be better understood." Our study aims to contribute to that end.

5.2. *Limitations*

Across both analyses, small sample size was a limitation. For the narrative analysis, having only 18 interviewees constrains the generalizability of our conclusions. Moreover, our interviewees were limited to subjects with existing relationships with the Federation. Our sampled subpopulation was limited to homeowners who already built or were in the process of building a living shoreline, which may bias narratives that support the use of living shorelines over other coastal protection measures. Also, the tendency for thematic analyses to condense and generalize responses presents another limitation; generalizing themes tends to obfuscate ambiguous, unspoken, or divergent responses (Riessman, 2005).

The power of the multivariate analysis was also hampered by the relatively small sample size of the dependent variable ($n < 100$). Also, the living shoreline data points reduce the total area of a project to a singular point. Additionally, regression decision trees are prone to overfitting and error due to variance. Thus, the decision tree is illustrative for understanding meaningful thresholds and directionality within the distribution.

Alternatively, our findings may suggest that a different or more sophisticated geospatial methodology (e.g., Esri's "Geographically Weighted Regression" tool) is necessary to adequately capture the influence of "enabling institutions." Our approach tested the use of the "Near" tool to calculate the distance to each institution, individually. This approach produced a model that was too complex to interpret meaningfully. Thus, the "enabling institutions" were binned into one explanatory variable for the multivariate analysis. This presents another opportunity to improve our analysis in future research by testing the relationship between living shoreline distribution and individual categories or institutions.

5.3. *Future research*

Future interview-based studies in this field should seek to interview subjects across diverse socioeconomic backgrounds. Collecting socioeconomic information (e.g., income, education, race) could inform future findings and test our conclusions in addition to emergent hypotheses. Interviewing a broader range of stakeholders (e.g., restoration practitioners, government employees, marine contractors and engineers) could provide a more holistic view of the perceptions and barriers surrounding living shorelines. Also, interviewing homeowners with hardened structures may generate new insights by giving voice to perspectives not captured in our study.

Future geospatial research will likely benefit from expanded datasets with an increased number of living shoreline installations. With a larger sample size for the response variable, flexibility of effect size and statistical power are likely to improve, lending more confidence to model outputs. Expanding the geographic scope (e.g., the entire East Coast) may distill trends that complement or contradict trends that are specific to North Carolina. We recommend exploring a broader array of socioeconomic and biophysical factors to generate novel insights, support or challenge our findings. For instance, exploring the relationship between living shorelines distribution and erosion rates, wave height, area in A-zone floodplain, median household income, or population density may be instructive (see Siders & Keenan, 2020). We recommend exploring the interaction between covariates like wealth attributes and indices of climate vulnerability to tease out the primary drivers and mechanisms for the outcomes we

observe. Researchers should review the literature to infer whether proximity to institutional categories (academic, nonprofit, government, contractor) has a demonstrated, measurable effect on the outcome of other restoration or adaptation measures. We recommend exploring and sharing methodologies for assessing influence through geographic proximity to strengthen future analyses.

Our analysis may also serve as a feasibility case study for future research that endeavors to use spatial, statistical and social science-based tools in conjunction to answer overlapping or related research questions. We recommend finding new ways to integrate these approaches, such as mapping the interview participants and incorporating their spatially associated responses into the geospatial analysis.

6. CONCLUSION

In summary, the results do not find support for a relationship between where living shorelines are constructed and vulnerability to coastal inundation nor proximity to enabling institutions. However, our findings suggest that socioeconomic factors play a role in determining where living shorelines are distributed. Although correlations exist between socioeconomic attributes and the presence of living shorelines, causation for this trend is likely the product of multiple, interacting forces. Our findings evidence the need to consider equity and vulnerability at state, county and community-level decision-making about shoreline management. Who is responsible for ensuring equity is a thornier question, which elicits mixed responses from homeowners. Overall, homeowners express satisfaction with their living shorelines, despite barriers like cost, awareness and navigating the process. Taken together, the mixed-method analyses facilitated a broader and deeper understanding of deterministic factors driving the distribution of living shorelines. We hope that our findings can inform future research, policy and efforts to ensure coastal protection is equitably distributed across North Carolina.

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APPENDICES

Appendix A: Semi-Structured Interview Questions

- Where are you/where is your property located?
 - How long have you lived here?
 - What kinds of changes or patterns have you noticed, if any?
- We're here to learn from you/we care about your experience. LS are so broad. There is no right answer, but let's start with this: in your words, what is a "living shoreline"?
- Why did you decide to stabilize your shoreline?
 - Optional follow-up: what were the primary reasons motivating your decision?
- Why did you choose LS?
 - Did you consider other options?
- Can you recall where or when you first learned about LS?
- For how long has your living shoreline been in place?
 - How long did it take to permit your living shoreline? Install?
- If addressing erosion was part of your reasoning for installing LS, has it delivered on that objective?
- How would you describe your experience with the living shoreline...
 - Are you satisfied?
 - Why or why not?
 - Would you recommend a LS to a neighbor or friend?
- If you're comfortable sharing, how much did your living shoreline cost?
- Dimensions: how long is your living shoreline?
- What do your friends and neighbors and community think re: LS vs. bulkhead or seawall?
- What barriers or obstacles did you face in obtaining a living shoreline?
- If you could pose a guess, what do you think is the primary factor determining who gets a LS and who doesn't?
- Who is largely responsible for making folks aware of LS and who should be responsible?
- Anything else you want to tell us about your shoreline that we didn't yet cover or you'd like to dive into deeper?

Appendix B: Informed Consent

Informed Consent

Title of Research Study: Living Shorelines: A Narrative and Spatial Analysis

Campus IRB Protocol ID#: [REDACTED]304

Key Information & Introduction

This research study is conducted by Kathryn Lienhard, Nicholas Fairbairn and Hall Welborn of the Nicholas School of the Environment at Duke University.

Purpose:

Coastal estuarine shorelines experience erosion due to natural and human-caused impacts such as hurricanes, waves from boat wakes, and removal of shoreline vegetation. Property owners of these shorelines seek measures to protect their shorelines from loss of land. Shoreline stabilization methods can range from nature-based approaches like “living shorelines” to more “hardened” approaches like seawalls and bulkheads. We hope to understand what influences the distribution of coastal restoration projects and living shorelines in North Carolina. We hope to understand homeowner preference for living shorelines or bulkheads and the processes they encountered during the shoreline stabilization process.

What will I be asked to do?

You will be asked a variety of questions about your decisions on shoreline stabilization. Interviews may be conducted virtually via the Zoom online meeting platform, or in-person as requested by researchers and permitted by participants. Interview audio will be recorded for transcription and subsequent analysis. Interviews are expected to last 45 minutes with a maximum duration of 1 hour. Where possible, and with your permission, we will photograph your shoreline to complement our study with visual renderings. You will be able to view the photos taken to ensure you’re comfortable with them being used in the study and may decline that they be used.

How long will I be in the study?

Each participant will be asked to answer questions within one interview at a previously agreed upon date, time, and location. The interviews will last no longer than 1 hour.

What are the risks and benefits of this study?

Researchers do not anticipate any risks for participants of this study. Participants will not be required to meet the researchers in any physical location besides the participants’ properties, if agreed upon. There are no anticipated direct benefits to participants. We hope our research will inform local environmental management and governmental decision-making in regard to shoreline management.

Compensation:

Participants will not be compensated for engaging in this study.

Confidentiality:

Your identity and responses will be kept confidential; the researchers will use pseudonyms to collate participant responses, while preserving confidentiality. Final products (e.g., report, presentation, publication) may be shared publicly or with other research institutions, but participant identity will remain confidential. The dataset will not be used in future research and will not be shared with other researchers. Direct identifiers for this project include phone number, email address, county of residence, and audio recordings. All contact information, identifiers and audio recordings will be destroyed at the conclusion of our study or following the conclusion of Hall’s graduation project. Indirect identifiers include county-level demographics that may be linked to your responses, such as county-level statistics regarding race, income, and distance to nearest shoreline restoration contractor.

Voluntary nature of participation:

Your participation in this study via interview is completely voluntary. You may skip any question in the interview for any reason if you choose to participate. You may choose to decline participation at any time, including during recruitment, during an interview, or prior to the conclusion of our research.

Whom do I call if I have questions or problems?

You may contact the researchers via email at [redacted]@duke.edu or [redacted]@duke.edu, or advisor [redacted] at [redacted]@duke.edu.

If you have any questions or concerns about your rights as a volunteer in this study, please contact Duke University’s Campus Institutional Review Board via email at [redacted]@duke.edu or via telephone at 919-[redacted]. If writing to the Campus IRB, please reference protocol ID# [redacted]304

Statement(s) of Consent:

If you agree to take part in the study, please indicate below.

Printed Name and Signature

Date

If you agree to allow researchers to photograph your shoreline for use in their study, including in their final reports and presentations, please indicate below.

Printed Name and Signature

Date

Appendix C. General permit trends in North Carolina for permits 7H.2100, 7H.2400, 7H.2700

