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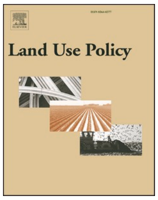

How does the removal of federal subsidies affect investment in coastal protection infrastructure?

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ABSTRACT

Shoreline armoring, which involves the installation of hardened structures to protect coastal property, dramatically alters shoreline composition and resulting ecological functions. Accelerating hazard threats to growing coastal communities compounds this problem, creating demand for more armoring. We examine whether designation by the U.S. Coastal Barrier Resources Act (CBRA) – enacted to disincentivize urban development on hazardous coastal barriers – is associated with lower propensities to armor shorelines. In designated areas, CBRA removes access to federally-subsidized flood insurance, infrastructure subsidies, and disaster assistance. Using logistic regression modeling, we examine armoring at the parcel scale across the State of Florida (USA), controlling for CBRA designation, land use, and local population density. Our findings reveal a significant negative relationship between CBRA designation and the odds of armoring, particularly for residential and vacant properties. As coastal areas grapple with increasing impacts from coastal hazards, removal of public subsidies may be an effective non-regulatory method for maintaining the ecological and protective benefits of natural shorelines.

1. Introduction

Despite exposure to hurricanes and other hazards, low lying U.S. coastal areas have experienced explosive growth in population and development; the Atlantic and Gulf coasts are home to 51 percent of all new housing units built in the U.S. from 1970 to 2016 (Klotzbach et al., 2018). This building boom has placed more people and assets in the path of hurricanes and tropical storms, resulting in escalating storm-related damage along the U.S. coastline. Nine of the ten most costly U.S. hurricanes have occurred since 2005 (NOAA, 2019), culminating in the costliest hurricane season in U.S. history in 2017 (Halverson, 2018).

Efforts to shield development along the coast through the placement of coastal protection infrastructure have changed the composition of shorelines along the U.S. coast (Gittman et al., 2015). Coastal protection infrastructure, also called shoreline armoring or hardening, is composed of physical structures that are placed along open and sheltered coastlines in order to offer protection from storm surges and flooding, or stabilize coastal land and halt erosion. Examples of these types of structures include seawalls, bulkheads, rock revetments, and retaining structures (Titus et al., 2009a).

By the early 2000s, 14 percent of the total U.S. shoreline was armored, with much of the armoring in the sheltered (i.e., a bay, sound, or tidal river) coasts of major metropolitan areas (Gittman et al., 2015). Today, continued development in low-lying coastal areas is expected to result in increasing investments in coastal protection infrastructure (Titus et al., 2009b); indeed, along with retreat, protection is a primary adaptation strategy available to coastal communities to address risks from hurricanes and sea level rise (Woodruff et al., 2018; Bedsworth and Hanak., 2010). Despite their protective intent, a growing body of literature has questioned the effectiveness of armored shorelines in reducing storm and erosion damage, finding armored structures increase property damages (Smith et al., 2017) or that natural shorelines offer equivalent protection (Arkema et al., 2013; Feagin et al., 2015; Narayan et al., 2016). Furthermore, the placement of protective structures with the intent to enhance safety can produce a paradox that increases risk of disaster by inducing further development behind these structures and disincentivizing relocation away from hazardous coastal areas (Armstrong et al., 2016; Burby, 2006; Kittinger and Ayers., 2010).

While armored shorelines are a popular method for addressing shoreline erosion, these structures can have a number of negative

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ecological effects. Replacing natural shorelines with armored structures can lead to a loss of marine habitat that fragments and reduces the abundance of marine life and shorebird populations (Bulleri and Chapman., 2010; Dugan et al., 2008); seawalls in particular can reduce biodiversity by 23 percent and marine organisms by 45 percent (Gittman et al., 2016a). As the development of coastal areas coincides with increases in sea levels and erosion, the placement of armored structures impedes inland migration of wetlands and reduces the area available for natural shoreline habitats (Gittman et al., 2016b). Still, given the expectation that demand for erosion control measures will continue with increases in sea level (Titus et al., 2009b), a growing body of work supports the use of living shorelines (using native vegetation and natural features to stabilize shorelines) in order to provide protective benefits, maintain important ecosystem services, and accommodate future shoreline migration (Davis et al., 2015; Bilkovic et al., 2016; Currin et al., 2010).

Studies of drivers of shoreline armoring in the U.S. have characterized these landscape transformations as the result of macro-scale influences, such as increasing urban development, or as the result of individual-level social dynamics. For example, Gittman et al. (2015) found that shoreline armoring is correlated with county-level housing density, GDP, and past storm frequency, while Siders and Keenan (2020) similarly found protection to be the preferred adaptation strategy in areas correlated with high housing values, incomes, and population density at the Census block group-level. On the other hand, Scyphers et al. (2015) found that many coastal homeowners install armored structures in response to the negative impacts resulting from neighbors' armored shorelines. Yet, despite an array of local, state, and federal government roles in permitting and funding these structures, research into the relative impact of public funding on the propensity to install coastal protection infrastructure is limited or outdated (Titus et al., 2009a). In this paper, we examine how land use characteristics and access to public subsidies are associated with an owner's propensity to armor their shoreline. Drawing on the work of Armstrong et al. (2016), we focus on individual characteristics and decision-making by assessing this relationship at the parcel-level.

This study explores the role of public subsidies in the development of coastal protection through the lens of the 1982 U.S. Coastal Barrier Resources Act (CBRA; 16 USC §3501), which aims to disincentivize development in high-hazard areas by removing federal funding for infrastructure, flood insurance, and disaster assistance on undeveloped coastal barriers. Considered a subsidy removal policy approach, CBRA functions similarly to urban service boundaries (USBs), which restrict development subsidies (e.g., funding for transportation, water, and sewer infrastructure) without directly prohibiting development. Thus, in the case of CBRA, some of the cost of development is transferred from the federal government to private developers or state and local governments. Property owners also face increased long-term costs due to a lack of access to the subsidized National Flood Insurance Program (NFIP). As a result, CBRA is an excellent vehicle for studying the role of federal subsidies in stimulating investment in coastal protection, allowing us to explore how the transfer of development costs to other public and private entities affects investment in shoreline armoring and whether this impact is moderated by land use.

In this paper, we ask, what are the relationships between federal infrastructure and flood insurance subsidies and the prevalence and placement of coastal protection infrastructure? How are these relationships moderated by land use? We examine these questions at the parcel level within the State of Florida (USA), which has an extensive shoreline (2276 miles), substantial amount of land in CBRA, and a complete, contemporary set of shoreline composition data[1] (NOAA, 2018).

Given the increased cost and difficulty of urban development, we expect land located within CBRA to be associated with a lower likelihood of shoreline armoring relative to non-CBRA areas; however, we also anticipate that this relationship will be moderated by land use, with more intense land uses (e.g., industrial, commercial, multi-family residential) exhibiting higher likelihoods of armoring both inside and outside of CBRA. Specifically, given the land use categories utilized in this analysis (see Table S1, Supp. Material 2), we hypothesize that commercial/institutional and industrial land uses will exhibit the highest likelihood of shoreline armoring, followed by multi-family residential, single-family residential, and military lands. Conversely, we expect armoring to be substantially less likely for government, recreational, and agricultural/vacant lands.

Our findings demonstrate that CBRA designation has a substantial negative relationship with the probability that a parcel is armored; however, this relationship is moderated by land use, with land utilized by federal and state governments, as well as industrial, commercial, and recreational uses, counteracting this trend. Given the federal government's historically supportive role towards coastal development (Bagstad et al., 2007), along with the increasingly erosive forces from sea level rise and more intense coastal storms, this study's findings are particularly relevant for coastal policymaking for climate adaptation and habitat conservation.

2. Methods

2.1. Data

Geospatial parcel boundary data, along with the land use information for all thirty-five coastal counties in Florida was acquired from the Florida Geographic Data Library (FGDL, 2017). Detailed geospatial shoreline location and composition data for the Florida coast was acquired from NOAA's Environmental Sensitivity Index (ESI; NOAA, 2018); this dataset also includes hydrology polygons that were used to identify and extract those parcels that share a boundary with the coastline (which we refer to as "coastal parcels"). Finally, geographic boundary data of CBRA areas were obtained from the U.S. Fish and Wildlife Service (USFWS; 2019) (Fig. 1).

Substantial pre-processing efforts were required to prepare data for analysis; please refer to Supp. Material 1 and 2 for more details on these efforts.

2.2. Analytical techniques

This analysis assesses the relationship of land use and CBRA on the propensity of armoring on individual property using binary logistic regression. We do *not* seek to comprehensively describe all of the underlying environmental, political, and economic factors affecting the propensity to armor the coastline; instead, we explore how the relationship between CBRA and armoring is moderated by coastal land use through an interaction term.

Pre-processing of parcels produced a final dataset of 313,152 coastal parcels, complete with shoreline attributes, land use, and location in CBRA. We also control for whether a parcel is located in a municipality, given that local policies and development practices can impact armoring prevalence (e.g., Kittinger and Ayers., 2010), and include the population density of the Census tract in which the parcel is located, as local population density and resulting infrastructure needs tend to be correlated with armoring (Siders and Keenan., 2020).

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[1] This dataset represents the most detailed categorization of the location and composition of U.S. shorelines, however the fractal nature of shorelines means that any length measurements will be a product of the spatial accuracy of the given dataset.

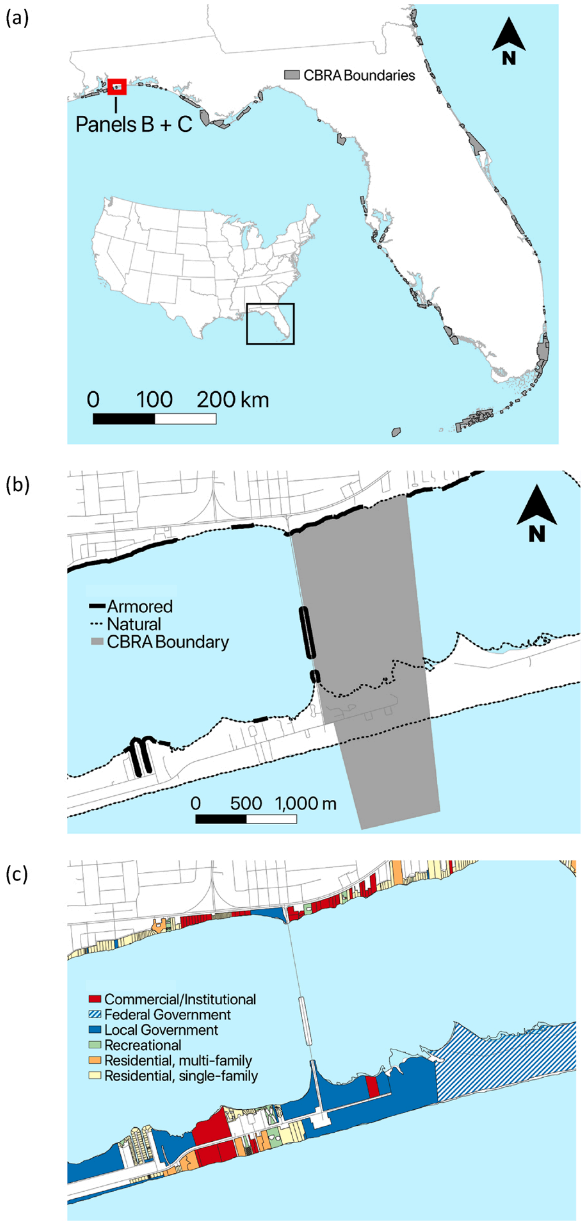

Fig. 1. A) CBRA units along Florida shoreline; B) Example of CBRA unit boundary and shoreline classification; C) Extracted parcels with land use and shoreline classification.

To model the relationship of shoreline armoring and designation in CBRA, we use a logit model with the following specification:

$$\ln\left(\frac{p}{1-p}\right) = \beta_0 + \beta_1\gamma + \beta_2 C + \beta_3(CBRA) + \boldsymbol{\beta_4 L} + \boldsymbol{\beta_5}\,(\boldsymbol{L} * CBRA)$$

where, p = probability of shoreline armoring in parcel, γ = dummy indicating a municipality, C = US Census tract population density (in 1000s), CBRA = dummy indicating whether a parcel is within a CBRA unit, $\boldsymbol{L}$ = a vector of land use dummy variables (with agricultural as the base case), $\boldsymbol{\beta}$ = vector of regression coefficients.

In their assessment of development in CBRA, Onda et al. (2020) found that land located within CBRA exhibits less development than land outside CBRA; however, the development that occurs within CBRA is characterized by bigger houses, larger parcels, and higher land values. As a result, we do not include controls for land value or parcel size, since this would introduce multicollinearity issues in our model. Furthermore, while the approach we use in this analysis facilitates exploration of CBRA's direct relationship with shoreline armoring, its cross-sectional nature is unable to account for the causal reasons underpinning armoring due to endogeneity. Regardless of cause, this analysis will allow us to determine the relationships between CBRA designation and the propensity to armor different coastal land uses.

3. Results

3.1. Descriptive statistics

Parcels in CBRA account for 2.64 percent (n = 8280) of the total number of parcels we analyzed. These parcels tend to be larger than non-CBRA parcels, averaging 10.47 ha compared to 2.61 ha, respectively. CBRA covers 9.84 percent (86,692 ha) of the total land area of coastal parcels analyzed (880,736 ha); this difference is mostly due to the greater prevalence of subdivided parcels outside CBRA. We find substantial differences in total shoreline armoring on parcels inside (10.47 percent) and outside (70.14 percent) of CBRA, with considerable variation across land uses.

Outside of CBRA, several land uses exhibit armoring in more than half of all parcels and substantially more than other land uses: single-family residential (78.9 percent), multi-family residential (69.7 percent), commercial/institutional (65.2 percent), and industrial (50.4 percent; Table 1). The prevalence of armoring inside CBRA is substantially lower across all categories with the exception of industrial (53.9 percent) and federal government (11.7 percent) land uses. For instance, vacant parcels experience 84 percent less armoring in CBRA than outside CBRA, while multi-family residential (75 percent) and single-family residential (72 percent) land uses exhibit similar trends.

Vacant land uses comprise a substantial portion of the parcels within CBRA (45.0 percent) and have armored shorelines on only 7.8 percent of those parcels; outside CBRA, vacant parcels exhibit considerably higher rates of armoring (48.7 percent). State and regional government parcels are the next most prevalent within CBRA (21.8 percent) and experience similarly low rates of armoring (8.2 percent). Amongst the public sector, local government parcels have the most prevalent coastal protection infrastructure, with 50.3 percent armored outside CBRA and 16.7 percent inside CBRA.

3.2. Regression analyses

Overall, parcels within CBRA have 78 percent lower odds of being armored than parcels located outside CBRA (Table 2). Single-family residential (50 percent), vacant (49 percent), and multi-family

Table 1
Armoring statistics by CBRA and land use.

Land Use Category	% Armored		Parcels (count)		Area (ha)	
	CBRA	Non-CBRA	CBRA	Non-CBRA	CBRA	Non-CBRA
Agricultural	2.7	12.3	849	4161	4136	97,456
Commercial/ Institutional	38.3	65.2	81	6601	618	16,408
Federal Government	11.7.	7.1	103	969	7934	35,774
Industrial	53.9	50.4	13	1122	221	9158
Local Government	16.7	50.3	261	2820	3306	21,674
Military	7.7	27.4	13	175	1746	51,718
Recreational	10.7	20.9	731	3125	15,415	215,015
Residential, multi-family	17.5	69.7	217	30,761	356	15,217
Residential, single-family	22.2	78.9	1254	203,722	812	37,363
State/Regional Government	8.2	13.6	1802	2719	27,309	88,122
Vacant	7.8	48.7	3724	48,697	34,759	206,138

Table 2

Binary logistic regression of armoring in parcel, controlled by land use and CBRA designation. * $p < 0.05$, ** $p < 0.01$, *** $p<0.001$. n=313,152. AUROC indicates "area under Receiver Operator Characteristic" (Fawcett, 2006), which indicates how model estimates improved on those of a random (empty) model.

		Odds ratio [95 % interval]
	In CBRA (yes/no)	0.22 [0.14; 0.32]***
	Parcel is in municipality (yes/no)	1.25 [1.23; 1.28]***
	Tract population density per sq. mile (in 1000s)	1.15 [1.15; 1.16]***
Land Use	Commercial/Institutional	9.65 [8.69; 10.75]***
	Federal Government	0.60 [0.46; 0.78]***
	Industrial	5.56 [4.78; 6.47]***
	Local Government	5.63 [5.00; 6.35]***
	Military	2.70 [1.89; 3.79]***
	Recreational	1.49 [1.31; 1.70]***
	Residential, multi-family	12.98 [11.80; 14.30]***
	Residential, single-family	20.00 [18.23; 21.99]***
	State/Regional Government	1.17 [1.01; 1.35]*
	Vacant	5.84 [5.32; 6.43]***
Land Use * CBRA interactions	Commercial/Institutional	2.17 [1.18; 4.08]*
	Federal Government	7.63 [3.42; 16.36]***
	Industrial	6.25 [1.91; 21.14]**
	Local Government	1.17 [0.69; 2.04]
	Military	1.15 [0.06; 6.47]
	Recreational	2.75 [1.71; 4.60]***
	Residential, multi-family	0.55 [0.32; 0.97]*
	Residential, single-family	0.50 [0.33; 0.80]**
	State/Regional Government	2.05 [1.25; 3.45]**
	Vacant	0.51 [0.34; 0.82]**
	Intercept	0.12 [0.11; 0.13]***
	Log Likelihood	−168,534.08
	AIC	337,116.15
	AUROC	0.727

residential (45 percent) land uses all have significantly lower odds of being armored than their counterparts outside CBRA. The odds of federal government (663 percent) and industrial (525 percent) land uses being armored, however, are substantially higher inside CBRA. Similarly, recreational (175 percent), state and regional government (105 percent), and commercial/institutional (117 percent) lands have higher odds of being protected inside CBRA. Coastal lands used by local governments or the military exhibit no significant difference in armoring expectations from agricultural lands.

Most coastal parcels outside of CBRA have substantially higher odds of having protected shorelines than agricultural parcels outside of CBRA; parcels owned by the federal government is the notable exception, with odds of armoring reduced by 40 percent. Local government parcels, on the other hand, have odds of armoring 463 percent higher than agricultural lands. Several land uses have considerably higher odds of protection, with single-family residential land having the highest increase (1900 percent), followed by multi-family residential (1198 percent), commercial/institutional (865 percent), vacant (484 percent), and industrial (456 percent) land uses. Location within a municipality has a small but positive effect (25 percent) on the odds that a parcel's shoreline is protected, while a 1000-person increase in Census tract population density increases the odds of armoring by 15 percent.

4. Discussion and conclusions

This analysis finds a substantial negative relationship between location in CBRA and the odds that a shoreline is protected, demonstrating that the removal of federal subsidies is associated with reduced investments in shoreline armoring. In particular, land uses that tend to be associated with private residential development are far less likely to be armored in CBRA, including the two land uses – single-family and multi-family residential – that exhibit the highest likelihoods of being armored outside CBRA. Similarly, vacant lands exhibit the second lowest odds of armoring inside CBRA despite high odds of armoring outside CBRA.

On the other hand, we find that commercial/institutional land uses are slightly more likely to be armored in CBRA, while industrial armoring is very similar both inside and outside CBRA. We also find federal and state/regional government, as well as recreational, lands are more likely to be armored in CBRA despite relatively low armoring outside of CBRA. These patterns suggest CBRA may be effective at deterring investments in shoreline protection of traditional residential development, yet less effective at reducing armoring for other land uses.

Our findings regarding armoring trends among land uses outside CBRA generally aligned with our expectations, with high armoring rates on multi-family and single-family residential as well as commercial/institutional lands. Perhaps the most unexpected result is the prevalence of armoring on vacant land outside CBRA. We hypothesize that this is due to the preponderance of dredge-and-fill residential developments along the coast of Florida, which tend to be characterized by armored shorelines for the entire development; many of these developments have a substantial number of parcels that remain undeveloped, yet nevertheless feature armored shorelines. We also find that local government land is more likely to be armored, suggesting that municipalities play a key role in the development of shorelines not only as a side-effect of urban density but also through active development of government-owned property. Overall, our findings reveal that few types of land uses outside of CBRA are unlikely to be armored.

It is important to emphasize that this analysis is cross-sectional, and therefore unable to account for endogeneity in CBRA designation decisions or the prevalence of armoring *prior* to the creation of CBRA. For instance, lower prevalence of shoreline armoring in CBRA units may be attributable to land characteristics that pre-dated CBRA designation, and which make the installation of shoreline armoring infrastructure infeasible. Therefore, we must be careful not to attribute causality to these findings, which would only be possible using a time series analysis of changes in shoreline armoring, beginning prior to the enactment of CBRA.

While future work is needed to definitively understand the *causal effects* of CBRA's disincentives, we instead note the existence of a relationship between CBRA and the reduced odds of having coastal protection infrastructure. The notable lack of present-day armoring in CBRA of lands that experience significant armoring outside CBRA suggests that the removal of infrastructure, disaster assistance, and NFIP subsidies may reduce the likelihood of future coastal protection.

We offer three possible explanations for this trend, each of which may occur in combination with the others. One possible explanation is that the lack of access to post-disaster assistance inside CBRA makes it financially difficult to repair or replace protective infrastructure damaged during a storm (see Kunreuther, 2006; Gallagher and Hartley., 2017). Thus, over time, armored infrastructure might decrease in prevalence within CBRA as tropical storms and hurricanes inflict costly damages, necessitating either repair or removal.

A second possibility is that CBRA is associated with different types of development that are less reliant on shoreline armoring for viability or are built less proximate to water. For example, "dredge-and-fill" residential developments directly adjacent to the water are common throughout Florida, particularly outside CBRA (Cummings, 2006; Johnston, 1981); this type of development often uses bulkheads to retain the fill on which the house is placed, leading to high rates of protection. It is possible that dredge-and-fill developments are prohibitively expensive to develop inside CBRA or that reduced land scarcity within CBRA makes such operations unnecessary, leading to fewer of these types of development that necessitate armoring for their viability. The notable differences in armoring trends between residential and vacant lands located inside and outside of CBRA lends credence to this explanation.

Third, we theorize that CBRA may be associated with reductions in development rates on land designated by the Act, which in turn reduces the likelihood of armoring (given that there are fewer assets to be protected). In a similar fashion, CBRA was intended to reduce the incentive for private developers to purchase and improve land in designated units, which could lead to a different combination of actors and landowners inside CBRA. Recent research by Onda et al. (2020) finds that areas within CBRA tend to exhibit less development than surrounding areas, and the preponderance of vacant coastal parcels within CBRA reinforces this finding. However, while this explanation likely accounts for some of the reductions in shoreline armoring we observe, it does not account for the observed variability in armoring across land uses, particularly those that are *more* likely to be armored than their counterparts outside CBRA. More importantly, it does not explain the wide variation in armoring of vacant parcels, which are significantly less likely to be armored inside CBRA than vacant parcels outside CBRA.

This analysis finds that designation within CBRA coincides with reduced investments in shoreline armoring, which may increase the short-term risk of erosion for current residents. However, this is likely to have little effect on damages from hurricanes and tropical storms; strong evidence now demonstrates that maintaining natural shorelines can be more effective at reducing storm surge and flood risk, meaning fewer armored structures may decrease storm damages while also eliminating the need to repair damaged armored segments (Gittman et al., 2014; Arkema et al., 2013). Avoiding shoreline armoring can also reduce risk for potential future residents by eliminating the reinforcing feedbacks that incentivize rebuilding and further new development behind armored infrastructure after disasters (Woodruff et al., 2018; Burby, 2006).

As climate change and sea level rise increase in severity, coastal cities and states will need to look for ways to manage landscapes that reduce future liabilities (e.g., deteriorating and ineffective infrastructure) and maintain the benefits and amenities of natural ecosystems. Broader efforts to shift investments towards uses of natural infrastructure, such as using oyster beds for storm surge protection (NYGOSR, 2020) or adopting green infrastructure for flood management (Carter et al., 2018; Liu and Jensen, 2018; Soz et al., 2016), attempt to create pathways towards preserving valuable natural amenities while simultaneously offering practical benefits. Recently, the U.S. Army Corps of Engineers has shifted towards a policy promoting the use of living shorelines (e.g., using natural materials for protective purposes), approving a Nationwide Permit (allowing expedited establishment) for living shorelines in early 2017 (USACE, 2017).

CBRA's subsidy removal appears to be an effective, non-regulatory method for avoiding further development of natural shorelines and helping to maintain their amenities and protective qualities. While other policy prescriptions, such as coastal zone management programs implemented by US states, have demonstrated efficacy at reducing shoreline armoring (Kittinger and Ayers., 2010), these regulatory approaches may be more difficult to implement. Future research is needed to understand how state and local policies, such as coastal management programs or development incentives, might interact with CBRA to influence shoreline armoring. Policy alignment on the part of state and local governments that can further disincentivize investments in shoreline armoring may help avoid continued degradation of marine habitats and wildlife (Dugan et al., 2008; Gittman et al., 2016a), allow for the natural inland migration of coastal ecosystems (Gittman et al., 2016b), and preserve the amenity values of natural shorelines and beaches, which are the dominant attraction of most coastal states.

Author contributions

T.B., N.K., and D.S. conceptualized the research objectives and questions. J.B., K.O., N.K., and T.B. contributed to the research design. J. B and K.O. collected and prepared data for analysis. J.B. led data analysis with input from all authors. J.B. led the writing of the manuscript, with substantial input, additions, and revisions from T.B., N.K., and D.S.

Declaration of Competing Interest

The authors declare that no competing interests exist.

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Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.landusepol.2020.105245.

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