Modeling the Impact of Coastal Wetlands on Shoreline Armoring Decisions

George Gardner – ICF – george.gardner@icf.com

Robert J. Johnston – Department of Economics – rjohnston@clarku.edu

Background

- The value of coastal (or salt) marsh ecosystems is recognized as an important motivation for coastal adaptation to sea-level rise (Barbier et al., 2011; Duran Vinent et al., 2019).
- Until recently marshes have been largely resilient to changes in sea level due to natural adjustments in elevation via vegetation growth and sediment accretion, and by migrating landward as sea levels rise (Kirwan et al., 2016).
- The persistence of salt marshes has come under threat due to the combination of rising sea levels and shoreline hardening or armoring, creating a 'coastal squeeze'—the progressive drowning of marshes that are trapped behind those structures (Torio and Chmura, 2013).
- Recent calls for urgent attention and pre-emptive planning to set aside key coastal areas for wetland migration imply that ongoing development and armoring are occurring in ways that threaten marsh migration (Runting et al., 2017).
- Despite the potential for marsh loss due to future armoring, it is unclear whether human decisions to armor the coastline are currently being made in a way that threatens remaining marshes.

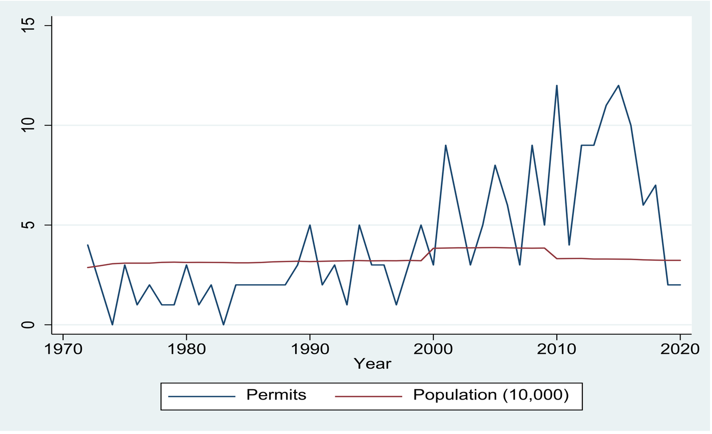
Purpose of the Study

- The main research objective is to answer the question: are armoring decisions currently being made in ways that threaten marsh migration?
- The research aims to provide empirical insight into coastal armoring decisions and whether they are motivated by marsh migration risk, or alternatively, by factors such as erosion, and/or flooding risk.
  - This is accomplished through the development of a theoretically grounded discrete-choice, random utility model that includes factors relevant to armoring motivations such as these.

Prior Research

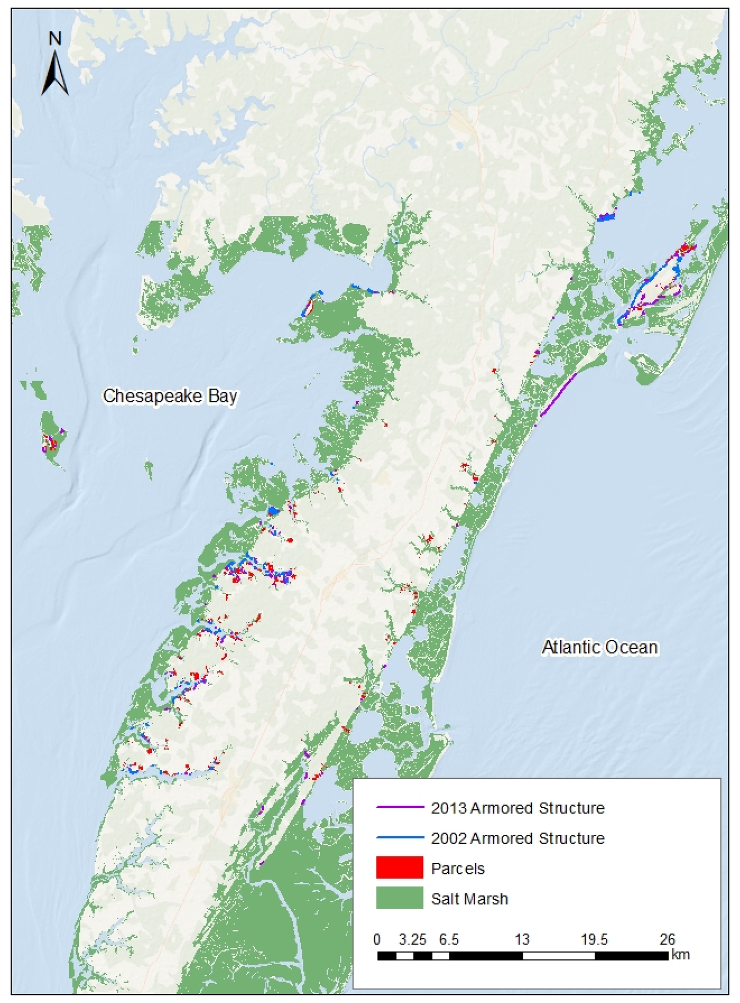
- Beasley and Dundas (2020) study the installation of beachfront protective structures in Oregon using a micro-level behavioral model of shoreline armoring decisions.
  - Beachfront armoring is influenced by geomorphological factors (e.g., erosion rate) and the presence of armored neighbors.
- Peterson et al. (2019) examine the determinants of armoring by individual landowners along the Georgia estuarine coastline.
  - Armoring is more likely to occur among parcels with steeper shoreline slopes, in higher energy shoreline environments, and with a greater presence of armored neighbors.
- Some of the major reported drivers of armoring include erosion, storm surge, and flooding (Dugan et al., 2011; Gittman et al., 2015; Peterson et al., 2019; Prosser et al., 2017), along with the structure's cost, effectiveness, and durability (Scyphers et al., 2015).
- No prior paper focuses on armoring as a response to marsh migration.

Armoring Permits Issued in Study Area



- The number of permits issued for riprap and bulkhead structures in Accomack County, VA have risen dramatically in recent years despite a relatively flat population growth (sources are the Virginia Marine Resources Commission and the U.S. Census Bureau).

Data



- Data was drawn from Accomack County, on Virginia's Eastern Shore.
- An original database was created by combining coastal single-family residential parcels, riprap and bulkhead shoreline structures, shoreline characteristics, and land cover.
- Parcel data (2013) come from the Accomack County Office of the Assessor.
- Data on shoreline structures built by 2002 and 2013 come from the Virginia Institute of Marine Science's Shoreline Inventory Reports.
- Shoreline conditions in 2013 come from the Virginia Institute of Marine Science's Shoreline Management Model.
- Land cover data comes from the 2011 National Land Cover Database.

Summary Statistics

Variable	Full Sample Mean	*Arm13*=1 Mean	*Arm13*=0 Mean
DwlgVal1	159,739	163,806	155,697
Acreage	1.744	0.942	2.541
Beachdist	9,477	7,975	10,970
SMdist	44.38	73.34	15.58
Fordist	41.47	68.56	14.54
SM100M	0.236	0.141	0.330
SM200M	0.231	0.174	0.289
Marshplant	0.786	0.592	0.980
Wavenrgy low	0.596	0.475	0.717
Forestshore	0.0679	0.0133	0.122
Elev	1.205	1.019	1.390
Fld	0.840	0.877	0.804
Chincoteague	0.274	0.419	0.1305
Coast_Frnt	0.198	0.209	0.186
ChsBay	0.540	0.392	0.687
Neighb500M	0.202	0.248	0.157
Neighb1KM	0.205	0.238	0.171
N	1,665	830	835

Wilcoxon rank-sum tests show that the means between parcels armored (Arm13=1) and unarmored (Arm13=0) by 2013 are all statistically significantly different from one another at the 1 percent level.

- Armored parcels are, on average, further away from salt marsh (and therefore have smaller proportions of marsh nearby) and not in areas suitable for planting salt marsh.
- Armored parcels are more likely to be in areas with high erosion risk (not in areas with low wave energy).
- Armored parcels have greater coastal exposure and are near greater proportions of armored neighbors.

Theoretical Framework

- The homeowner's armoring choice is grounded in a random-utility model (RUM) that emphasizes characteristics of the property relevant to marsh migration among other potentially relevant factors.
- The model can be represented as:

$$U(R(A=1,\boldsymbol{Z},N),m-c) > U(R(A=0,\boldsymbol{Z},N),m)$$

Where utility, U, is a function of:

- the capitalized value of the future flow of all anticipated losses on the parcel (R), income (m), and the cost of armoring (c).
- R is a function of armoring, (A), a vector of environmental factors that may prevent or exacerbate anticipated losses, ($\boldsymbol{Z}$), and armoring on neighboring properties (N).

Empirical Approach

- Grounded in theoretical RUM, binary logit models are used to assess homeowners' probability of armoring by 2002 and 2013, $P_{A=1}$.
  - $P_{A=1} \equiv P(\epsilon_{A=0} - \epsilon_{A=1} < V(R(A=1,\boldsymbol{Z},N),m-c) - V(R(A=0,\boldsymbol{Z},N),m))$
- Armoring is defined using the parcel's edge distance to a (bulkhead or riprap) structure.
  - Results are robust to alternative definitions of armoring using 20- and 0-meter distance thresholds (results shown use the 20-meter definition).
- Since shoreline conditions were only available for 2013, the model of armoring by 2002 requires the assumption that these conditions remained relatively unchanged and hence apply to the earlier time period.
- The model of armoring by 2013 is the primary model, and the model of armoring by 2002 is used to evaluate robustness over the two time periods.

Results: Armoring By '02 And '13

Variables	Dependent Variable = *Arm02*	Dependent Variable = *Arm13*
DwlgVal1	-0.00201	0.0189**
Acreage	-0.190*	-0.0221
SMdist	0.00339***	0.0105***
Beachdist	0.000365***	0.000127***
Fordist	-0.00201	0.00552***
SM100M	-0.590	-1.150***
SM200M	-3.213***	-0.393
Marshplant	-1.571***	-2.652***
Wavenrgy_low	-0.636***	-0.981***
Forestshore	-2.731**	-1.043***
Elev	-0.167	-0.299**
Fld	-0.273	-0.188
Chincoteague	2.036***	1.258***
Coast_Frnt	1.156**	1.173**
ChsBay	-2.473***	-1.298*
Wald χ^2	336.44	449.94
P-value	0.0001	0.0001
N	1,665	1,665

*, **, and *** indicate levels of significance at 10, 5, and 1 percent levels, respectively. Huber-White robust standard errors are shown in parentheses.

Results: Armoring By '02 And '13 With Neighbor Effects

Variables	Dependent Variable = *Arm02*	Dependent Variable = *Arm13*
DwlgVal1	0.00433	0.0146*
Acreage	0.0231	0.0288
SMdist	0.00589***	0.00786***
Beachdist	0.000229	0.0000203
Fordist	0.000717	0.00214
SM100M	-0.763	-1.142**
SM200M	-1.827*	-0.0237
Marshplant	-1.244***	-1.804***
Wavenrgy_low	-0.737***	-0.583***
Forestshore	-2.152**	-0.842**
Elev	-0.426***	-0.218*
Fld	0.175	-0.115
Chincoteague	-0.00846	0.379
Coast_Frnt	0.456	1.119**
ChsBay	4.545***	-0.707
Neighb500M	7.914***	3.905***
Neighb1KM	-0.789	0.132
Wald χ^2	635.14	648.02
P-value	0.0001	0.0001
N	1,665	1,665

*, **, and *** indicate levels of significance at 10, 5, and 1 percent levels, respectively. Huber-White robust standard errors are shown in parentheses.

Conclusions

- Armoring is not taking place in order to prevent marsh migration and is rather less likely to occur in areas suitable for future salt marsh habitats.
  - Results on marsh-related variables are robust across both periods.
- Armoring is less likely to occur:
  - when parcels are closer to salt marsh.
  - when parcels have greater proportions of salt marsh nearby (within 100 meters in the model of armoring by 2013 and 200 meters in the model of armoring by 2002).
  - in areas suitable for planting salt marsh.
  - in areas with low wave energy where salt marsh tends to exist.

Discussion and Limitations

- Current armoring patterns suggest that armoring is not being constructed in ways that will directly prevent marsh migration in the study area.
- Results do not imply that armoring is unimportant for future marsh migration in the study area. Observed patterns in armoring may be the result of successful rules and regulations whose purpose is to mitigate impacts to wetlands.

References

Barbier, E. B., Hacker, S. D., Kennedy, C., Koch, E. W., Stier, A. C., & Silliman, B. R. (2011). The value of estuarine and coastal ecosystem services. *Ecological Monographs, 81*(2), 169-193. doi:10.1890/10-1510.1

Beasley, W.J., Dundas, S.J. (2020). Hold the line: Modeling private coastal adaptation through shoreline armoring decisions. Journal of Environmental Economics and Management. doi: https://doi.org/10.1016/j.jeem.2020.102397

Dugan, J., Airoldi, L., Chapman, M., Walker, S., Schlacher, T., Wolanski, E., & McLusky, D. (2011). 8.02-Estuarine and coastal structures: environmental effects, a focus on shore and nearshore structures. Treatise on estuarine and coastal science, 8, 17-41.

Gittman, R. K., Fodrie, F. J., Popowich, A. M., Keller, D. A., Bruno, J. F., Currin, C. A., . . . Piehler, M. F. (2015). Engineering away our natural defenses: an analysis of shoreline hardening in the US. Frontiers in Ecology and the Environment, 13(6), 301-307.

Vinent, O. D., Johnston, R. J., Kirwan, M. L., Leroux, A. D., & Martin, V. L. (2019). Coastal dynamics and adaptation to uncertain sea level rise: Optimal portfolios for salt marsh migration. Journal of Environmental Economics and Management, 98, 102262.Loomis, J., Rameker, V., & Seidl, A. (2004). A hedonic model of public market transactions for open space protection. *Journal of Environmental Planning and Management, 47*(1), 83-96.

Kirwan, M. L., Temmerman, S., Skeehan, E. E., Guntenspergen, G. R., & Fagherazzi, S. (2016). Overestimation of marsh vulnerability to sea level rise. Nature Climate Change, 6(3), 253.

Peterson, N. E., Landry, C. E., Alexander, C. R., Samples, K., & Bledsoe, B. P. (2019). Socioeconomic and environmental predictors of estuarine shoreline hard armoring. Scientific reports, 9(1), 1-10.

Prosser, D. J., Jordan, T. E., Nagel, J. L., Seitz, R. D., Weller, D. E., & Whigham, D. F. (2017). Impacts of coastal land use and shoreline armoring on estuarine ecosystems: an introduction to a special issue. Estuaries and Coasts, 1-17.

Scyphers, S. B., Picou, J. S., & Powers, S. P. (2015). Participatory conservation of coastal habitats: the importance of understanding homeowner decision making to mitigate cascading shoreline degradation. Conservation Letters, 8(1), 41-49.

Torio, D. D., & Chmura, G. L. (2013). Assessing coastal squeeze of tidal wetlands. Journal of Coastal Research, 29(5), 1049-1061.

Runting, R. K., Lovelock, C. E., Beyer, H. L., & Rhodes, J. R. (2017). Costs and opportunities for preserving coastal wetlands under sea level rise. Conservation Letters, 10(1), 49-57.