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State and local governments plan for development of most land vulnerable to rising sea level along the US Atlantic coast*

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Abstract

Rising sea level threatens existing coastal wetlands. Overall ecosystems could often survive by migrating inland, if adjacent lands remained vacant. On the basis of 131 state and local land use plans, we estimate that almost 60% of the land below 1 m along the US Atlantic coast is expected to be developed and thus unavailable for the inland migration of wetlands. Less than 10% of the land below 1 m has been set aside for conservation. Environmental regulators routinely grant permits for shore protection structures (which block wetland migration) on the basis of a federal finding that these structures have no cumulative environmental impact. Our results suggest that shore protection does have a cumulative impact. If sea level rise is taken into account, wetland policies that previously seemed to comply with federal law probably violate the Clean Water Act.

Keywords: climate change, adaptation, land use planning, sea level rise, wetland migration, shore protection

S Supplementary methods, tables, and figures are at the end of the main text.

* The opinions expressed in this letter do not necessarily reflect the official positions of either the US Environmental Protection Agency, the National Oceanic and Atmospheric Administration, any state or national Sea Grant Program, or the US Government.

1. Introduction

Changing climate is expectd to cause global sea level to rise approximately 20–60 cm during the 21st century if polar ice sheets remain stable [1] but possibly more than 1 m if ice sheets become unstable [2]. Rising sea level inundates low-lying lands, erodes shorelines [3, 4] exacerbates coastal flooding [4, 5] and increases salinity in estuaries [4, 6, 7] and aquifers [6, 8, 9].

Site-specific responses to sea level rise are broadly classified into two pathways: shore protection and retreat [10]. Shore protection (e.g. bulkheads, dikes, beachfill) can minimize disruptions to coastal communities from floods and shore erosion, but it prevents the inland migration of coastal ecosystems, which are instead squeezed between the rising sea and bulkheads built to protect the communities [4, 11–13]. Retreat (e.g. prohibiting or removing hazardous construction) can allow ecosystems to migrate inland [10, 14], but land and structures can be lost [12]. The resulting disruption can be minimal in undeveloped areas [10, 12] but potentially severe in populated areas, especially if retreat occurs after shore protection fails during a storm [15].

Property owners and land use agencies have generally not decided how they will respond to sea level rise, nor have they prepared maps delineating where shore protection and retreat are likely [10]. The absence of such maps prevents a realistic assessment of the consequences of rising sea level, and can impair efforts to prepare for those consequences [10]. For example, the Clean Water Act allows the US Army Corps of Engineers to routinely issue permits for a class of activities, provided that the activities do not have a cumulative environmental impact [16]. The Corps has issued a regulatory finding that shore protection will not have a cumulative impact [17] and used it to justify a policy under which property owners are routinely granted permits to build bulkheads [18]. Yet no one has estimated (and the regulatory finding did not consider) the portion of coast likely to be bulkheaded as sea level rises [10, 19].

This letter maps and quantifies a baseline, business-as-usual scenario of coastal development and shore protection for the Atlantic coast of the United States from Massachusetts to Florida. Taken together, land use plans, existing land use, regulations, and shore protection policies can provide a baseline expectation regarding the composition of future shore protection and retreat. With this analysis, planners from the local to national level can assess the extent to which coastal wetlands might migrate inland or be lost (and identify infrastructure that would eventually require remedial attention) and then evaluate other options. The following sections describe methods, results, and some implications for policies to protect coastal wetlands; additional methods, tables, and maps are in the supplementary material. Although this letter provides summary maps and tables, we are also making our results available as shapefiles and raster data sets with a 30 m grid suitable for ArcGIS and other geographical information systems software [20].

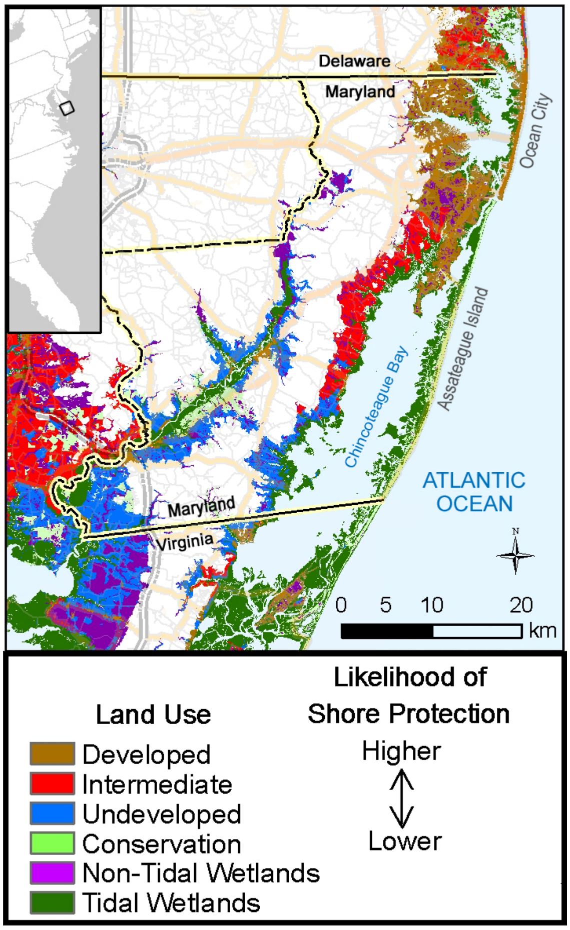

Figure 1. Land use and likelihood of shore protection along the Maryland coast. This map shows lands within 5 m above spring high water. Along the Atlantic Ocean, Ocean City is densely developed and the state government is committed to shore protection, while Assateague Island is owned by the National Park Service, which is committed to allowing natural shoreline processes to operate in conservation lands. Along the coastal bays, the northern areas opposite Ocean City are developed with many shores already bulkheaded. The southern areas along Chincoteague Bay shown in blue are generally farms with agricultural-preservation easements that prevent residential development; although the easements allow shore protection, farmers in this area have rarely erected bulkheads in the past. The land use plan shows future development for most of the area shown in red.

2.Methods

With the assistance of local planners responsible for land use in 131 jurisdictions from Massachusetts to Florida (table S1), we used available planning data (table S2 and table S3) and identified relevant government policies (tables S4 and S5) to divide coastal dry lands into four categories representing different likelihoods of shore protection. We used wetlands data (table S6) to distinguish dry lands from wetlands, and made no attempt to account for future development in wetlands. Our initial classification focused on land use. *Developed* lands have generally been protected in the past when threatened by erosion or flooding [12, 13]; hence they are most likely to be they are most likely to be protected in the future [10, 21]. At the other extreme, *conservation* lands are generally allowed to respond naturally to shore processes [22] and hence are least likely to be protected [10]. We used available land use/land cover data for moderate and high-density development to define *developed*, and conservation lands data sets to define *conservation* (table S2).

We divided the remaining dry lands into two categories: areas expected to remain *undeveloped* and an *intermediate* category consisting of existing low-density development, places where land use plans anticipate future development, and military bases in rural areas. Undeveloped lands are rarely protected [10]; but even lightly developed lands are generally protected along estuaries [13], which account for most of the shoreline along the US Atlantic coast. Hence, under current policies, shore protection is more likely in *intermediate* lands but less likely in *undeveloped* lands [10]. In urban counties and other places where near-total development is expected, we used parks and agricultural-preservation data to identify the relatively few lands unlikely to be developed (table S2). In rural areas,state or local planning documents identify lands where development *is* expected.

With our classification of coastal land use as a starting point, we then visited the local planners to further refine the maps. The planners indicated that our four land use categories generally correspond to the land that is most likely, likely, unlikely, or least likely to be protected as sea level rises (assuming a continuation of current policies and practices). Given that correspondence, our tables and figures 1 and 2 have land use labels instead of likelihood labels so that our primary source of information is more transparent. (The supplementary information provides additional detail and caveats on this issue, as well as descriptions of the data, study area boundaries, and GIS processing methods.) We created county-specific maps for the land within approximately 5 m above spring high water, which we sent to the planners for additional refinements (except for Florida, whose local governments only provided land use data below the USGS 3 m contour). We also calculated the area of each land category at various elevations between 0 and 5m aboves spring high water.

The planners provided us with four types of refinements.

- Specific parcels of land that had been developed since the published data was created.
- Specific data sets (table S3) that more accurately defined the land use within their jurisdictions than the general data sets in table S2).
- Land use policies expected to alter development trends (table S4) in specific areas,such as prohibitions on development within a 100-year floodplain.
- Shoreline policies that cause the likelihood of shore protection in some areas to diverge from what would be expected considering land use alone (table S5). For example, dikes are being constructed to protect (undeveloped) farmland in North Carolina, and cliff regulations in Calvert County (Maryland) prohibit shore protection along *developed* cliffs (table S5).

Figure 1 maps the four land classifications (as well as wetlands) for an example county in Maryland.

Limitations in available data almost certainly cause our results to understate the level of existing and future development. Most land use data are 5–10 years old and thus omit recent development. More importantly, rural land use plans identify priority growth areas where local governments are encouraging development to concentrate, but not all areas where d evelopment will eventually occur. Development often takes placeinotherareas,especially oncethepriorityareas have been developed.

3. Results and implications

Most of the ocean coast is *developed* or *intermediate*, but *conservation* lands account for most of the Virginia ocean coast, and large parts in Massachusetts, North Carolina, and Georgia. Figure 2 shows the entire study area; figures S2–S23 show specific counties and/or states. Measured by area, more than 80% of the land below 1 m in Florida or north of Delaware is *developed* or *intermediate* (table 1 and table S8). Only 45% of the land from Georgia to Delaware is *developed* or *intermediate*, by contrast, because Maryland and Delaware restrict coastal development (table S4) and most coastal lands from Virginia to Georgia are farther from major population centers.

The composition of the four land categories shifts modestly as a function of elevation (figure 3). The percentage of *conservation* lands declines with increasing elevation in 10 states and is relatively constant in the other 4 states (figure S1). The concentration of conservation lands at the lowest elevations is consistent with the acquisition priorities of the national refuge system and other conservation organizations. Many refuges include habitat immediately along estuaries, but do not extend far inland [23]. The proportion of *undeveloped* land is also greater at the lowest elevations, especially in Delaware (where two counties prohibit development in floodplains) and Maryland (where state law prevents development within 300 m of the shore in rural areas). New Jersey is an exception to the general pattern, possibly because all but one of its barrier islands are developed, and the past practice of filling marshes for development [24] has created a legacy of very low-lying development.

Considering our entire study area, 42% of the dry land within 1 m above the tidal wetlands is developed and most likely to be protected given business-as-usual (table 1). Some development either exists or is expected in the land use plans for another 15% of the area. Thus, almost 60% of the lowest dry land is likely to be developed and eventually protected as

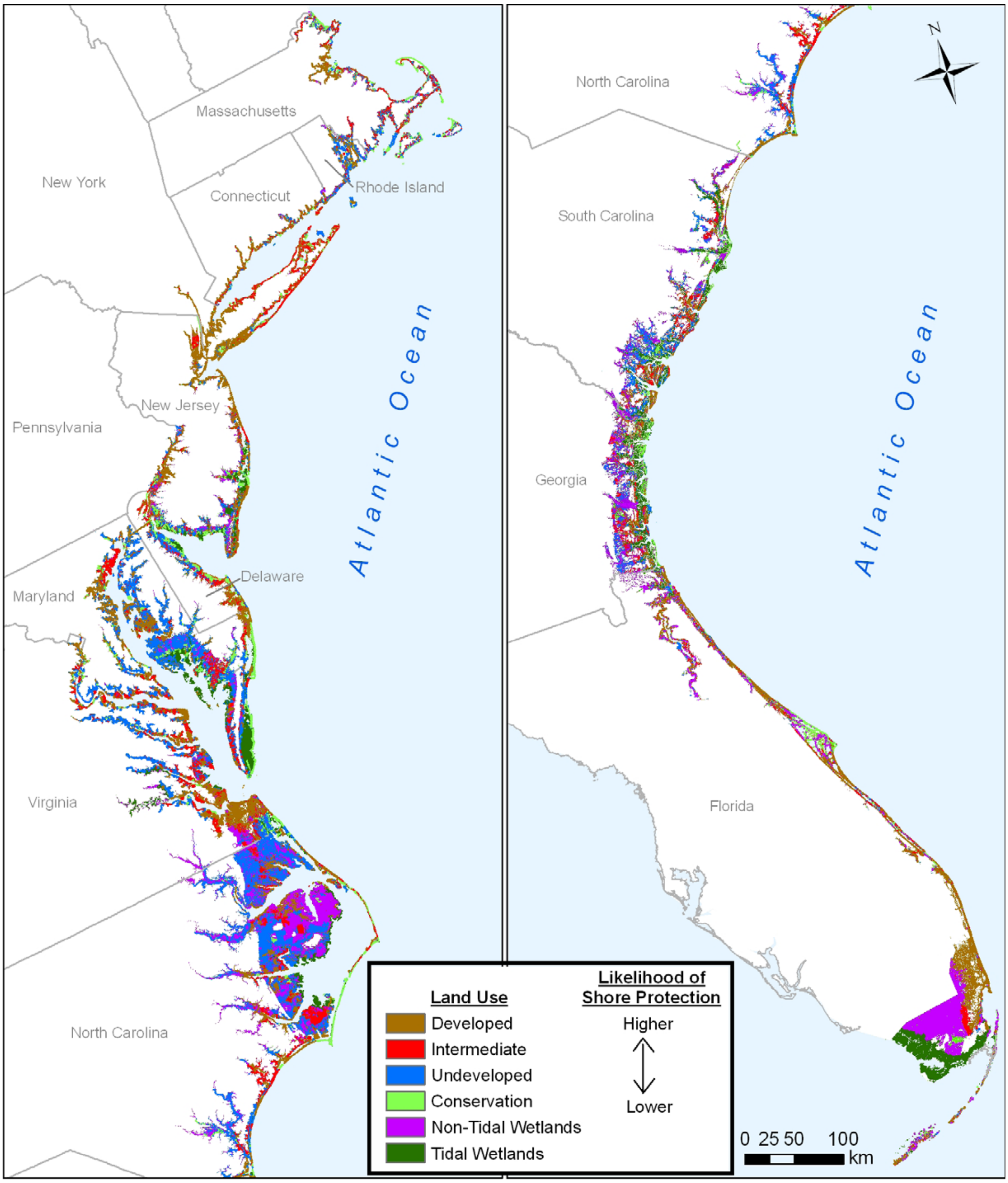

Figure 2. Categories of land use and likelihood of shore protection along the Atlantic coast of the United States. Coastal development is most intense north of Delaware Bay, in Florida, and elsewhere close to metropolitan areas such as Washington, Norfolk, and Charleston. The study area is generally the land within 5 m above spring high water, except for Florida where planning departments provided data for lands below the USGS 3 m contour.

sea level rises. By contrast, only 9% of this land has been set aside for conservation purposes that would allow coastal ecosystems to migrate inland. Land use plans do not anticipate development of the remaining 33%, which is mostly rural today. Eventually, some of those areas may be developed as well, especially from Virginia to Georgia, where there are few institutional limitations on coastal development.

Our results suggest that the majority of low-lying lands along the US Atlantic coast will become populated if business-as-usual development continues. Maintaining this development as sea level rises would require increasingly ambitious shore protection [10]. The US experience protecting populated areas below sea level from flooding is mostly limited to metropolitan New Orleans [15]. Sea level rise could leave communities similarly vulnerable throughout the US Atlantic coast.

The resulting shore protection could imperil a key environmental objective in the United States: the preservation of tidal wetlands. In the 1970s, the United States

Table 1. Land within 1 m above high water by intensity of development along US Atlantic coast.

	Likelihood of shore protection High ⟷ low; Per cent of dry land, by land use type[a]				Area		
State	Developed (%)	Intermediate (%)	Undeveloped (%)	Conservation (%)	Dry land (km^2)	Nontidal wetlands (km^2)	Tidal wetland (km^2)
MA	26	29	22	23	110	24	325
RI	36	11	48	5	8	1	29
CT	80	8	7	5	30	2	74
NY	73	18	4	6	165	10	149
NJ	66	15	12	7	275	172	980
PA	49	21	26	4	24	3	6
DE	27	26	23	24	126	32	357
MD	19	16	56	9	449	122	1116
DC	82	5	14	0	4	0	1
VA	39	22	32	7	365	148	1619
NC	28	14	55	3	1362	3050	1272
SC	28	21	41	10	341	272	2229
GA	27	16	23	34	133	349	1511
FL	65	10	12	13	1286	2125	3213
Total	42	15	33	9	4665	6314	12 882

[a] Calculated as the statewide area of a given land use category divided by the area of dry land in the study area. Percentages may not add up to 100% due to rounding.

collectively decided to stop creating new coastal communities by filling marshes and swamps [25, 26], and enacted other policies [13, 19, 26–28] to preserve tidal wetlands along the Atlantic coast. But these ecosystems may not be sustained if sea level accelerates. At the current rate of sea level rise, most tidal wetlands are able to keep pace through sedimentation and peat formation; but their ability to keep pace with a rate greater than 5–10 mm yr^{-1} is doubtful [10]. To survive, these ecosystems would have to migrate inland [4, 10, 11]. With only 9% of the lowest land set aside for conservation, a large-scale migration would require either a halt to construction in most coastal floodplains or an eventual abandonment of many developed areas [10, 19]. But current policies promote the opposite [10].

The existing nationwide permit for shore protection [18] authorizes almost any owner of a small- or medium-sized lot to erect a shore protection structure that prevents ecosystems from migrating inland. The Clean Water Act allows this type of general permit only if it has a minimal cumulative environmental impact [16]. The Corps of Engineers found that the impact is minimal, based on the assumption that building a shore protection structure threatens an area of habitat equal to the footprint of the construction, but that no additional habitat is lost over time [17, 29]. Ignoring the habitat eventually lost by blocking wetland migration is unreasonable, in our view, because preventing the landward migration of aquatic habitat (wetlands, beaches, floodplains, and shallow waters) onto the land being protected is the main reason for shore protection [13, 29]. The Corps should re-evaluate its finding to incorporate the impact on wetland migration.

We think that such a re-evaluation should find that shore protection has a cumulative environmental impact. The Clean Water Act does not explicitly define the term, but the context implies that an impact need not be large to be considered a ‘cumulative environmental impact’:

- The Corps of Engineers has also declined to define the term or even the magnitude of wetland loss necessary to constitute a cumulative impact under the Clean Water Act [30]. However, its finding of minimal cumulative impact was based on its estimate that the nationwide permit affects about 1 km^2 of wetlands per year (the area of the footprint of the shore protection structures) [17, 28], which is less than 0.01% of the current area of coastal wetlands. When public comments suggested that the loss from all the nationwide permits was ten times what the Corps’ estimated, the Corps did not dispute the assertion that such a large impact would be a cumulative impact, but instead asserted that its lower estimate is more accurate [30].
- Under the Clean Water Act, the existence of a cumulative impact does not cause a permit to be denied; it merely requires that the impact of each permit be considered through the issuance of an individual permit, instead of being ignored under a nationwide permit [16].
- Under the National Environmental Policy Act, cumulative impact has been defined as the impact of an activity ‘added to other past, present, and reasonably foreseeable future actions’ regardless of who takes the other actions [31]. An impact need not be large to satisfy that definition.

The immediate result of recognizing the cumulative impact would be to require property owners to apply for individual permits [16, 18], which could substantially delay permit approval and disrupt the Corps’ ability to review other permit applications [17]. To avoid overwhelming the regulatory process, an alternative framework is needed. It might be possible to issue a revised nationwide permit that truly has a minimal cumulative impact, through a combination of shore protection techniques that preserve wetlands [13] and/or requirements to mitigate lost opportunities for wetland

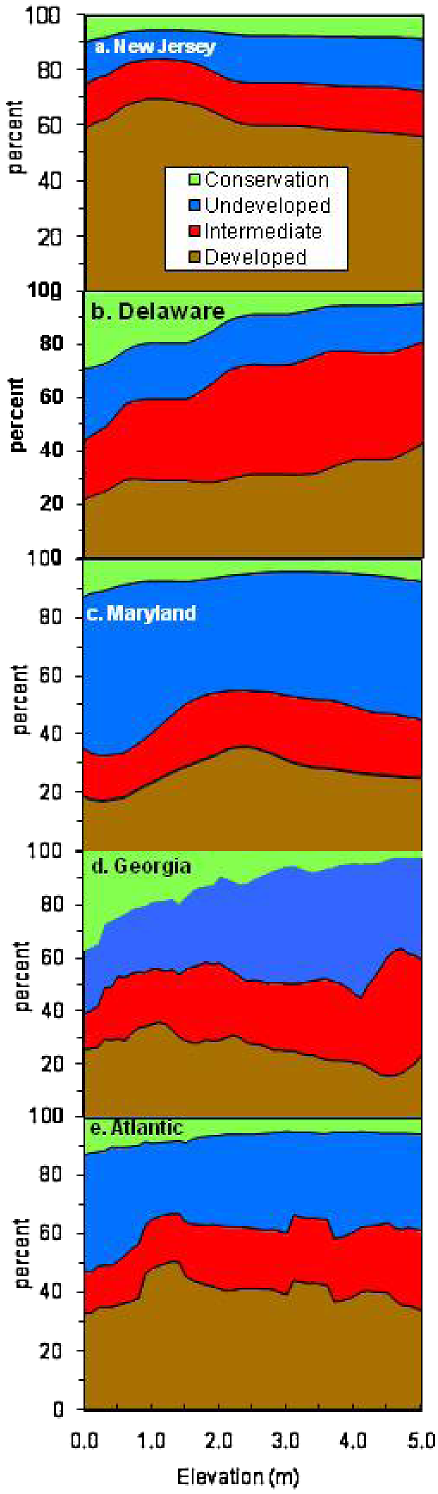

Figure 3. Percentage of dry land within four land use classifications, by elevation. In most states the portion of conservation and undeveloped lands is greatest below 1 m and gradually tapers off at higher elevations, because nature reserves include low land adjacent to wetlands and development is discouraged in floodplains. (a) New Jersey is an exception, primarily because the densely developed coastal communities tend to be in areas with the greatest amount of very low land, such as barrier islands and filled wetlands. (b) Delaware, (c) Maryland and (d) Georgia all follow the typical pattern. (e) Atlanticwide, the portion of developed land decreases above 1.5 m largely because Florida (which is highly developed) accounts for about 35% of the dry land below 1.5 m but only 15% of the dry land above 1.5 m.

migration by facilitating such opportunities elsewhere [19]. A more comprehensive approach would be to consciously manage the impacts of shore protection as sea level rises with estuary-wide plans that define the fates of shorelines as sea level rises [29]. A wide variety of planning and legal mechanisms are available for implementing a planned retreat without hurting property owners [10, 19].

The maps provided by this study can serve as an initial benchmark for evaluating the environmental consequences of the business-as-usual response to sea level rise and possible alternatives that would better preserve the environment and comply with the law. They can also be used to focus efforts on the 30% of low-lying land that is neither developed nor conservation land. Ensuring that some of these lands are abandoned to a rising sea so that ecosystems can adjust would face economic, political, and legal challenges; but defending the entire coast seems even more difficult in the long run [10, 12, 19, 21]. If environmental policies must eventually be revised to ensure that wetlands migrate inland, now is the best time for wetland regulators to update policies to recognize that sea level is rising. It is also a good time for all of us to ask whether this generation should continue to build new communities in vacant land vulnerable to a rising sea.

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Supplementary Information

Contents

Supplementary Methods Discussion

Land Use, Wetlands, and Elevation Data. Table S2 lists the land use and planning data used to implement our general approach. Depending on jurisdiction and data type, those data are maintained and distributed by state, city/county, and regional planning departments or nongovernmental agencies. Most of the data are available in digital format compatible with geographical information systems (GIS). Particular zones with a given land-use type are each represented as polygons. The best data on conservation lands is generally available from different sources than data on the other type of land use. In rural portions of North Carolina and Virginia where local land use maps were unavailable, we either relied on land-cover data based on remote sensing or digitized hand renderings of existing and proposed development drawn on 1:250,000 scale USGS topographic maps. We digitized land use maps from printed comprehensive plans for several rural counties between Maryland and Georgia.

The planning departments also provided supplemental data sets (table S3) and corrections to the published data. Available land use data are often 5-10 years old. The planning departments reviewed our draft maps and provided site-specific map corrections to account for recent and newly approved development in areas otherwise shown as *undeveloped* or *intermediate*, flood-prone neighbourhoods where abandonment and conversion to wetlands are planned, and new parks or conservation lands in areas otherwise shown as *intermediate*.

We obtained wetland polygons from the National Wetlands Inventory [1] for 9 states; the other 5 states provided newer data (table S6). We used EPA's coastal elevation data set [2] for the 8 Mid-Atlantic States, and the US National Elevation Dataset for other states [3].

Study Area. Our intended study area was all dry land either within 300 m of the shoreline, or below the nationally available USGS 6-m contour. The actual study area was smaller in three cases (see table S7): (1) the regional planning councils in Florida, only provided information for lands below the 3-m contour, barrier islands, and lands within 300 m of the shore; (2) some inland counties with small amounts of low land were omitted; and (3) Suffolk County (New York) provided land use data for the 500-year floodplain, which generally extends to about the 4-m contour.

We created an "out of study area" mask using the elevation data and a GIS-buffer along the shoreline to exclude land outside the study area from maps and data tabulations.

Data Flattening. For Pennsylvania and some counties in New York, Georgia, and Florida, we found a single data set that had already subdivided all land into mutually exclusive polygons with attributes corresponding to classifications useful for our analysis. But for most locations, the conservation, land use, and planning data came from different sources; and in some cases the policy-based reclassification also required us to obtain a data set delineating floodplains, preservation easements, or existing infrastructure. "Flattening" the data (i.e. creating a single set of mutually-exclusive polygons that are each associated with one of the land categories) required a process implementing a set of GIS decision rules to carry out the intended classification.

Using ESRI's ArcGIS, we applied the built-in union function to combine each of the data sets and preserve all of the associated attribute data necessary to identify current land use and development plans. Then, using the combined attribute table, we selected the polygons that meet specific criteria and assigned each to a development category. For example, in a typical case, the intermediate category would be assigned to all land that is (a) undeveloped today according to the land use data, (b) expected to be developed according to the land use plan, and (c) not part of a conservation area according to the conservation data set. We generally resolved apparent data conflicts by deferring to the data set with the more restrictive purpose, e.g. if land cover data shows an area to be developed while the conservation layer shows it to be a conservation land, we treat it as conservation land.

Overlay with Elevation and Wetlands Data. For the eight mid-Atlantic states, we used an available interpolation model [4] to quantify the area within each land use category. Except where high resolution elevation data are available, that approach relies on published topographic contours to create an interpolated estimate of the amount of land within a given elevation above spring high water, which is generally 30-100 cm above the zero-elevation reference used for topographic maps. Because that model had not been applied to the other states, we followed the same procedure to derive elevations relative to spring high water from the National Elevation Dataset [4], and directly overlaid these elevation estimates with our land classifications.

Caveats concerning expert elicitation. A task force of the US Environmental Protection Agency (EPA) [5] and others have recommended the use of experts for assessing likelihoods of environmental results when other possible sources of likelihood estimates are unavailable. Recent assessments have used expert panels to subjectively estimate the likelihood of wetland loss [6] and barrier island deterioration [7] at specific locations as sea level rises. Our classification is based on published land use data and existing shore protection policies, rather than subjective assessments (see section 2 of the main text). But our attribution of the likelihood of shore protection associated with those classifications was defined by the planners.

We followed the general approach recommended by the EPA task force [5] to elicit planner assessments of the land that could be classified in each of four categories of likelihood of shore protection: very likely, likely, unlikely, and very unlikely. A key limitation in that approach is that no one has assessed the ability of land use planners to project long-term shore protection. As a result, we can suggest two way of viewing our results:

- Those who need an assessment of the likelihood of shore protection can view our likelihood categories as *conditional* estimates of likelihood from the perspective of state and local land use planners, assuming that current policies continue.
- Those who do not need a probability assessment and are not interested in relying on land use planners for an assessment of shore protection, can use the more objective classification that is highlighted in the text of this article (i.e. *developed, intermediate, undeveloped,* and *conservation).*

Error and uncertainty. The accuracy of our analysis is also limited by recent and prospective changes in land use. There are also errors in the planning and elevation data, and discrepancies between the boundaries in the different data sets; but those limitations are unlikely to significantly affect our results.

Our results rely primarily on land use data created at a scale of 1:250,000 or better (i.e. accurate to 125 meters). Although some of that data is too coarse for regulatory decisions, this imprecision has little impact on maps or tabular results at the scale of an entire state; and in most cases localities provided us with better data. A more serious problem is that land use data are usually 5-10 years old. To some extent, the planners provided more recent supplements or site-specific corrections to update the data; but the supplemental data sets were often several years old and site-specific corrections tend to only account for major developments. Thus, the use of land use data almost certainly leads us to underestimate the land that is currently *developed* and overestimate the area of *undeveloped* land.

Land use plans understate future development, especially in the rural coastal areas from Georgia to Virginia. In those rural areas, land use plans generally identify future development for the purposes of setting priorities for the provision of roads, water, sewer, schools, and other public facilities. Although these priority growth areas tend to be developed first, nothing prevents other undeveloped areas from becoming developed as well. Therefore, our results for Virginia to Georgia probably understate the amount of *intermediate* lands while further overstating the amount of land likely to remain *undeveloped*. In the more urban jurisdictions, by contrast, plans assume total buildout except for parcels where there is a specific impediment to development (e.g. regulation, conservation easement, or existing land use as a park or conservation area).

The standard error of elevation data varies from around 20 cm throughout North Carolina and Maryland's Eastern shore (where high-resolution data was available) to 75 cm throughout most coastal areas south of Delaware Bay, to about 150 cm in most areas north of New Jersey [2]. A comparison of high- and low-resolution data concluded that about half of the error is random and half is systematic, and hence the vertical error of a cumulative distribution function would be about half the vertical error for a specific location [8]. If that result is applicable to our study, our results for the area of land vulnerable to a one-meter rise in sea level (Table S8) are probably accurate to within about 10% in Maryland and North Carolina, a factor of 1.5 along most of the coast, and a factor of 2 in the areas with the worst data [8]. Hence one should be cautious in citing our point estimates for the area of vulnerable land. Nevertheless, these errors are unlikely to have a significant effect on the percentages of land associated with the various land categories (table 1). As figures 3 and S1 show, the percentages are not very sensitive to elevation; and there is no evidence that errors in elevation data depend on the density of present or future development.

Finally, gaps in our land use data led us to omit some areas. We excluded inland counties that collectively account for about 1% of the land along the Atlantic Coast within one meter above spring high water (table S7), and local governments in Florida (as well as one county in New York) declined to provide land use data more than 3 or 4 meters above spring high water. The absence of these data prevents us from providing maps depicting likelihood of shore protection for the excluded areas; but it does not significantly affect our aggregate results because these areas account for such a small portion of the land at risk to sea level rise. Within our study area, data limitations prevented us from classifying about 3% of the (apparently) dry land, including 10% in Virginia and 25% in Massachusetts. Most of that omission resulted from boundary discrepancies between the land use data and the wetlands data that we used to define dry land. Often the land use data do not extend all the way to the wetlands, or the county classified specific locations as wetlands or open water (and hence we did not assign a development classification) but our wetlands data identified the land as dry land. Most of the discrepancies were one or two 30-cm cells wide. This mismatch is unlikely to affect the percentages in table 1, because the cause of the error was independent of the type of land use. Moreover, much of this land may actually be wetland or open water.

Contributions of specific authors and other study team members.

Manny Cela, Walter F. Clark, Andrew Hickok, and Maurice Postal were full partners in the underlying study and would have been listed as authors but for the author fee. D.L.T. coordinated data collection and analysis for Florida, while D.E.H. coordinated all other states except for the District of Columbia and portions of New York. D.E.H. also prepared figures 1 and 2. J.G.T. designed the study and wrote the manuscript, based on the results of data collection, analysis, and expert elicitation provided by specific authors: Massachusetts (J.F.O and D.E.H), Rhode Island (J.M.K.), Connecticut (A.H. and D.E.H.), New York (J.J.T.), New Jersey (M.C., J.M.K., and J.G.T.), Pennsylvania (C.J.L.), Delaware (D.E.H. and J.G.T), Maryland (D.E.H., W.H.N., and J.G.T.), Virginia (C.H.H., J.G.T., and D.E.H), North Carolina (W.F.C., J.M. K., and J.G.T), South Carolina (A.H., D.E.H., and J.G.T.), Georgia (D.E.H.), Northeast Florida (M.P. and D.L.T), East-Central Florida (T.M.M), Treasure Coast, Florida (P.G.M. and M.C) and South Florida (M.C. and J.G.T). J.W. undertook the elevation/planning GIS overlay.

The author fee was split by the authors. The employing institutions listed on the title page paid the shares for Hudgens, Kassakian, Tanski, Linn, Hershner, McCue, Merritt, O'Connell, and Trescott.

Explanation of Supplementary Tables and Figures

Tables S1-S7 provide additional documentation of our study approach. Table S1 lists the (mostly local) planners who provided data and expert judgment on how those data should be interpreted for this study. Tables S2, S3, and S6 list the specific data sources used. Tables S4 and S5 list the policies that we used to classify the data. Table S7 quantifies the area of land excluded from our study area due to data limitations or our decision to omit jurisdictions with very little vulnerable land.

Table S8 and figure S1 provide estimates of actual areas of land for the various classifications, corresponding to Table 1 and Figure 3, respectively, which provide the same results as percentages of dry land.

Figures S2-S23 are maps that display our results at different locations and different scales. The map colors are the same as Figures 1 and 2. However, because these maps were prepared as part of our collaboration with county planners, they use the likelihood of shore protection category labels (almost certain, likely, unlikely, no shore protection) that we originally employed when we met with the planners, rather than the land-use labels (developed, intermediate, undeveloped, conservation). Because different members of our study team worked on different states, the map formats also exhibit some variation. Most of the Florida maps depict a single county, and include a few major highways or landmarks. The mid-Atlantic maps use dark and light shades to distinguish degree of vulnerability. For a given likelihood category a darker shade signifies land that is either less than 2 meters above spring high water or within 300 meters of the shore, and a lighter shade represents land that is 2 to 5 meters above spring high water and more than 300 meters from the shore. The maps of Georgia and New England also use the two elevation bands, but do not consider distance from the shore. Higher resolution versions of these maps will be available at http://risingsea.net/ERL .

The reader who closely examines these maps may have many site-specific questions about why particular locations are depicted in a certain way. The authors have prepared 13 state-specific reports plus 4 reports for Florida, which explain the study assumptions in great detail for each county. Those reports will hopefully be published in the near future. The status of their availability will also be kept up-to-date at http://risingsea.net/ERL.

Supplementary References

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Table S1 Planners who provided updates on actual land use or articulated policies on land use or shore protection		
State (number of localities providing input)		
	Name	Jurisdiction
Massachusetts (1)		
	Stephen Tucker	Cape Cod Commission
	Stephen McKenna	Massachusetts Coastal Zone Management
Rhode Island (0)		
	Janet Freedman	State of Rhode Island
Connecticut (7)		
	Linda Krause	Connecticut River Estuary Regional Planning Agency
	Dick Guggenheim	Southeast Connecticut Council of Governments
	Jay Northrup	Town of Westbrook
	Bob Wilson	South Western Regional Planning Agency;
	James Wang	Greater Bridgeport Regional Planning Agency
	David Elder	Valley Council of Governments;
	Emmeline Harrigan	South Central Region
New York (5)		
	Bill Daley	New York State
	Fred Anders	New York State
	Dewitt Davies	Suffolk
	Ron Masters	Hempstead
	John Armentano	Nassau
	Robert Doscher	Westchester
	Wilbur Woods	New York City
	Edward Greenfield	New York City
New Jersey (11)		
	Sarah Sundell	NJ Meadowlands Com
	David Boyd	Essex
	John Lane	Hudson
	Edward Sampson	Monmouth
	David McKeon	Ocean
	Brian M. Walters	Atlantic
	James J. Smith	Cape May
	Robert Brewer	Cumberland
	Ron Rukenstein	Salem
	Rick Westergaard	Gloucester
	Mark Remsa	Burlington
	Mark Mauriello	NJ Department of Environmental Protection
Pennsylvania (3)		
	Michael Roedig	Bucks
	Marty Soffer	Philadelphia
	Karen Holm	Delaware
Delaware (3)		
	Dave Culver	New Castle

	Kelly Crumpley	Kent
	Lawrence Lank	Sussex
Maryland (17)		
	Sandy Coyman	Worcester
	Joan Kean	Sommerset
	David Nutter	Wicomico
	Steve Dodd	Dorchester
	Elizabeth Krempasky	Caroline
	Dan Cowee	Talbot
	Steven Kaii-Zeigler	Queen Anne's
	Gail Owings	Kent
	Eric Sennstrom	Cecil
	Pat Pudelkewicz	Harford
	Bruce Johnson	Harford
	Don Outen	Baltimore County
	Peter Conrad	City of Baltimore
	Rich Josephson	Anne Arundel
	Ginger Ellis	Anne Arundel
	David Brownlee	Calvert
	Sue Veith	St Mary's
	Theresa Dent	St Mary's
	Steve Magoon	Charles
	Karen Wiggen	Charles
	Brian Willsey	Prince George's
District of Columbia (1)		
	Uwe Brandes	Washington
Virginia (25 plus 5 planning districts)		
	Katherine Mull	Northern Virginia RC
	Jim Van Zee	Northern Virginia RC.
	Doug Pickford	Northern Virginia RC
	Don Demetrius	Fairfax
	Ray Ultz	Prince William
	Mike Stafford	Caroline
	Steven Hubble	Stafford
	Kathy Baker	Stafford
	Mark Remsberg	King George
	Stuart McKenzie	Northern Neck PDC
	E. Luttrell Tadlock	Northumberland
	Jack Larsen	Lancaster
	Chris Jett	Richmond
	Lewis Lawrence	Middle Peninsula PDC
	Tom Brockenbrough	Middle Peninsula PDC
	Mathew Higgins	Middlesex
	Alyson Cotton	King William
	Carissa Lee	King and Queen
	R. Gary Allen	Essex
	Jay Scudder	Gloucester
	Jim McGowan	Accomack-Northampton PDC

	David Fluhart	Accomack
	Sandy Manter	Accomack
	Sandra Benson	Northampton
	Hugo Valverde	Hampton Roads PDC
	Jonathan Hartley	Isle of Wight
	Deborah Vest	Poquoson
	Wayland Bass	James City
	Anna Drake	York
	Kathy James Webb	Newport News
	Cynthia Taylor	Suffolk
	Tyrone Franklin	Surry
	Fred Brusso	Portsmouth
	Amy Ring	Chesapeake
	Clay Bernick	Virginia Beach
North Carolina (18)		
	John Thayer	NC DCM Elizabeth Cty District
	Lynn Mathis	NC DCM Elizabeth Cty District
	Dennis Hawthorne	NC DCM Elizabeth Cty District
	Gary Ferguson	Currituck
	Carl Classen	Camden
	Julie Stamper	Pasquotank
	Bobby Darden	Perquimans
	Chad Sary	Chowan
	Jane Dautridge	NC DCM Washington
	Terry Moore	NC DCM Washington
	Bill Early	Hertford
	Allen Castelloe	Bertie
	Ann Keyes	Washington
	Debby Askew	Washington
	J.D. Brickhouse	Tyrell
	Ray Sturza	Dare
	Greg Ball	Dare
	Alice Keeney	Hyde
	Kathy Vinson	NC DCM Moorehead City
	Tedd Tyndall	NC DCM Moorehead City
	Jeremy Smith	Beaufort
	Miriam Prescott	Pamlico
	Don Baumgardner	Craven
	Katrina Marshal	Carteret
	Zoe Bruner	NCDCM Wilmington
	Alex Marks	NCDCM Wilmington
	Angie Manning	Onslow
	Dexter Hayes	New Hanover
	Leslie Bell	Brunswick
South Carolina (7)		
	James Bichard	Horry County
	Allen Burns	Georgetown County

	Madelyn Robinson	Berkeley County
	Andrea Pietras	Charleston County
	Kevin Griffin	Colleton County
	John Holloway, Jr.	Beaufort County
	Hal Jones	Jasper County
Georgia (6)		
	Tom Wilson	Savannah/Chatham MPC
	Christy Stringer	Bryan
	Brandon Wescott	Liberty
	Boyd Gault	McIntosh
	York Phillips	Glynn
	Eric Landon	Glynn
	Tish Watson	Camden
Florida (18, plus 4 regional planning councils)		
	Chip Patterson	Duval County
	Ray Ashton	St. Johns County
	Troy Harper	Flagler County
	Nancy Freeman	Nassau County
	Ben Dyer	Volusia County
	Anne Rembert	Brevard County
	Nelson Lau	Cocoa
	Anthony Caravella	Cocoa Beach
	Mark Rokowski	New Smyrna Beach
	Bruce Cooper	Satellite Beach
	David Watkins	Palm Bay
	Bob Keating	Indian River
	Sasan Rohani	Indian River
	Diana Waite	St. Lucie
	Vanessa Bessey	St. Lucie
	Ross Wilcox	Martin
	Nicki van Vonno	Martin
	Lorenzo Aghemo	Palm Beach
	Isaac Hoyos	Palm Beach
	Peter Schwarz	Broward
	Ryan Williams	Broward
	Paula Church	Miami-Dade
	Frank Reddish	Miami-Dade
	Jonathan Lord	Miami-Dade
	Andrew Trivette	Monroe County
	Jeff Stuncard	Monroe County

	Table S2: GIS Data Layers used In Our General Approach to Identifying Existing Development, Future Development, and Conservation Lands		
	Existing Development	**Distinguish Future Development from Undeveloped**	**Conservation Lands**
MA	Land use[1]	Zoning Districts [2]	Protected and Recreational Open Space[3] Major Dune Areas[4]
RI	1995 Land Use/Land Cover [5]	Buildout[B]	Protected Open Space[5] Audubon Lands[6]
CT	Land Use/Land Cover[7] Land Cover[8]	Development Priority Areas[9]	State Owned Lands[10] Federally Owned Lands[11] Municipal and Private Open Space[12]
NY	Land Use[13,14,15,16,17]	Same [D]	Same [D]
NJ	1995/1997 Land Use/Land Cover[18] 2002 State Plan[19] Planning Centers[20] Pinelands Management Areas[21]	2002 State Plan[22] 1995/1997 Land Use/Land Cover[23] Pinelands Management Areas[24]	State Open Spaces[25] Federal Open Spaces[26] Nonprofit Conservation Lands [27] Conservation lands[28]
PA	Land Use[29]	Same [D]	Same [D]
DE	Land Use/Land Cover[30]	Buildout[B] Agricultural Preservation Districts[31]	State Owned Lands??? State Parks[32] State Resource Areas[33]
MD	Land Use/Land Cover[34] Maryland Property View [35] Comprehensive Plan[36,37,38,39, 40,41,42] Western Shore: Local Plan[C]	Resource Conservation Area (RCA) Boundaries [E,43] Buildout[B] Conservation Easements[44,45,46] County-owned lands[47]	Federally Owned Lands[48] State Owned Lands[49] Private Conservation Lands[50]
DC	Buildout[B]	n/a	National Park Boundaries[51,52,53,54,]
VA	Land Cover[55] Land Use/Land Cover[56] Hampton Roads Urban Land Use[57]	Comprehensive Plan[58,59,60,61,62.63] Future Land Use[64] Zoning[65,66] Parks[67]	Federally Owned State Owned Parks[68] Nature Conservancy Lands in Virginia[69]
C	Land Use Plan[70,71,72,73,74,75,76,77, 78,79,80,81,82]	Same [D]	Conservation Lands[83]
SC	Comprehensive Plan [84, 85,86,87,88, 89, 90,]	Horry County: Buildout[B] Berkeley County: Future Land Use[91] Charleston Settlement Area Study[92] Draft revisions to Comprehensive Plan[D]	Federal Forest[93] State Parks[94] Refuges[95] Wildlife Management Areas[96]
GA	Land Use/Land Cover [11]	Same [D]	Conservation Lands[97]
FL, NE	Future Land Use[98, 99, 100, 101, 102, 103, 104, 105, 106]	Same [D]	Same [D]
FL, EC	Future Land Use[107, 108, 109, 110, 111, 112, 113, 114, 115, 116, 117, 118, 119, 120, 121, 122, 123, 124, 125, 126, 127, 128, 129, 130,]	Same [D]	Sam [D]
FL, TC	Future Land Use[131, 132]	Same [D]	Same [D]
FL, S	Future Land Use[133], Monroe County Tier Overlay District [134]	Same [D]	Same plus Public Lands[135]

Notes:

A Unless otherwise noted, all sources provide data for the entire state.
B. Complete buildout of the coastal zone generally anticipated by the comprehensive plan. Data in this table entry identifies lands that are expected to remain undeveloped. Future development assumed to include all other lands that are neither currently developed nor identified as conservation.
C. Planners provided hard copy map, generally based on comprehensive plan.
D. "Same" means "same as the data sources listed immediately to the left."
E. In addition to the data layer, the boundaries of RCAs established by Critical Areas Act generally were embodied in the county comprehensive plans, many of which discourage development inland from the landward boundary of the RCA.

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[122] Daytona Beach Shores, FL. 2003. Future Land Use
[123] Edgewater, FL. 2003. Future Land Use
[124] Holly Hill, FL. 2003. Future Land Use
[125] New Smyrna Beach, FL. 2003. Future Land Use
[126] Oak Hill, FL. 2003. Future Land Use
[127] Ormond Beach, FL. 2003. Future Land Use
[128] Ponce Inlet, FL. 2003. Future Land Use
[129] Port Orange, FL. 2003. Future Land Use
[130] South Daytona, FL. 2003. Future Land Use
[131] Future Land Use, 1995 South Florida Water Management District. West Palm Beach, FL.
[132] Indian River County 1995, Future Land Use.
[133] Future Land Use, 1995 South Florida Water Management District. West Palm Beach, FL.
[134] Monroe County Tier Overlay District Map. 2005. Marathon, FL.
[135] Public Lands. 2001. South Florida Water Management District. West Palm Beach, FL.

Table S3 Supplemental GIS Data Layers Suggested by Local Planners

State	Data Layer Description	Used to Identify[A]:				Policy-Based Reclass-ification? [B]
		Developed	Intermediate	Undeveloped	Conservation	
Several States	MA[1], RI[2], CT[3], NY[4], VA[5], FL[6]: Shoreline Armoring	√				√
	Military Lands[7, 8, 9, 10 C]		√			
MA	1985 Land Use [D]	√	√			√
	Undeveloped barrier beaches[23]			√		√
	Recreation Lands		√			√
RI	Historic Districts[11]	√				
	Undeveloped Barrier Beaches[12]			√		
	Rock Outcrops[13]				√	√
CT	Sewer Service Areas[14]	√				
	Neighborhood Conservation Areas[15]	√				√
	Land Use in Southeastern Region[16]	√	√	√		
	Tribal Settlement Areas[17]	√				
NJ	Salem County: State Plan[18]		√			
	Salem County: urban areas[19]	√				
	Salem County: open spaces[20]				√	
DE	New Castle agriculture preservation[21]			√		
	New Castle approved development[22]	√				
	100-year floodplain[23,24,]			√		
MD	Worcester County Conservation Lands[25]			√	√	
	Calvert County Cliff Categories[26]				√	√
	Baltimore County land use[27]	√	√	√		
	Baltimore County parks[28]			√		√
	Dorchester County: digital orthophotoquads[2966]	√				
DC	Buffers along Anacostia River[30]			√		√
VA	City of Alexandria Tax Parcel Data [31]	√				
	Stafford County Land Use[32]	√	√			
	King George County Land Cover[33]	√	√			
	Richmond refuge data[34]				√	
	Arlington County Parks [35]			√		
NC	Perquimans County Subdivisions[3687]	√				
	Pender County: Areas of Piping			√		

	Plover Habitat[37]					
	Pasquotank County Zoning[38]	√	√	√		
	Camden County Zoning[39]	√	√	√		
	Dare County Zoning[40]	√	√	√		
	Existing and Planned Dikes[41],[42]	√				√
	CoBRA Zones[43]		√	√		√
SC	Berkeley County: Conservation Easements[44]			√		
GA	Evacuation Routes[102]	√				√
	Chatham County: Future Land Use[45]	√	√			
Treasure Coast FL	Water & Sewer Service Areas[46] [47]		√			
	CoBRA Zones[48]		√			√
South FL	Hurricane Evacuation Zones[49] [50]		√	√		`
	Water & Sewer Service Areas[51] [52]		√			
	Canals and Levees[53]	√				√
	Urban Development Boundary[54]		√			
	CoBRA Zones[55]		√			√

A. These supplemental data sets were used to improve the accuracy of our land categorization. We started with the data in Table S2, and later used the supplemental data sets listed here to identify lands in the category that is checked. For example, in CT, an area with sewer service is identified as *developed* regardless of what the (older) land use data showed. Conversely, in South Florida, a residential area *without* sewer service is identified as *intermediate*.
B. These supplemental data sets were used to identify lands for the policy-based reclassification of the likelihood of shore protection. See Table S5 for enumeration of the policies considered in that reclassification.
C. For other states, military lands are shown by the land use data described in Table S2
D. Shoreline armoring is prohibited for post-1978 homes. We used these data to estimate development in 1978.

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[1] National Oceanographic and Atmospheric Administration and Massachusetts Executive Office of Environmental Affairs. 1999. *Environmental Sensitivity Index*. Seattle: Hazardous Materials Response Division, NOAA.
[2] Research Planning, Inc. (RPI) 2002. *Environmental Sensitivity Index*. Seattle: National Oceanic and Atmospheric Administration Hazmat Office.
[3] Research Planning, Inc. (RPI) 2002. Environmental Sensitivity Index (ESI). Seattle: National Oceanic and Atmospheric Administration Hazmat Office.
[4] Nassau County GIS Department. 2002. Nassau County Bulkheads
[5] Northern Neck Planning District. 1998. *Northern Neck Armoring* .
[6] Florida Marine Research Institute (now *Fish and Wildlife Research Institute)* 2001. Environmental Sensitivity Index St. Petersburg, Florida
[7] ESRI, 2004. Federal and Indian Land: Connecticut. In: *National Atlas of the United States*. Environmental Systems Research Institute
[8] ESRI, 2004. Federal and Indian Land: Delaware. In National Atlas of the United States. Environmental Systems Research Institute.
[9] Bureau of Transportation Statistics, 2001. *Military Installations*. Washington, D.C. United States Department of Transportation.
[10] South Carolina Department of Natural Resources, 1999. *Military Installations*. Columbia, South Carolina.
[11] Rhode Island Geographical Information System. 1989. *Historic Districts*. University of Rhode Island. Providence, Rhode Island.
[12] Rhode Island Geographical Information System. 1999. *Barrier Beaches*, University of Rhode Island. Providence, Rhode Island.
[13] Rhode Island Geographical Information System. 1988. *Wetlands*. University of Rhode Island. Providence, Rhode Island.
[14] Connecticut Department of Environmental Protection. 1998. *Sewer Service Areas*. Hartford: Bureau of Water Management.
[15] Connecticut Department of Environmental Protection. 2005. *Development Priority Areas*. Hartford: Office of Policy and Management.
[16] Southeastern Connecticut Council of Government (SCCOG), 2000. *Land Use in Southeastern Connecticut*. Norwich, Connecticut.
[17] Connecticut Department of Environmental Protection. 2005. *Tribal Settlement Areas*. Hartford: Office of Policy and Management.
[18] Salem County. 2004. *Salem County State Plan*.
[19] Salem County. 2001. *Salem County: urban areas*.
[20] Salem County. 2001. *Salem County: Open Spaces*.
[21] New Castle County Department of Land Use. 2005. *New Castle Agriculture Preservation*
[22] New Castle County Department of Land Use. 2005. *New Castle Approved Development*
[23] New Castle 100-year floodplain. New Castle Department of Land Use. 1996

[24] Federal Emergency Management Agency. 2005. *Kent County 100-year floodplain*. ESRI
[25] Worcester County Conservation Lands. 2003. Worcester Regional GIS. Snow Hill, Maryland.
[26] Calvert County Planning Department, 2001. *Calvert County Cliff Categories.*
[27] Baltimore County, 1998. *Baltimore County Land Use.*
[28]. Baltimore County, 2004. *Baltimore County Parks*
[29] Maryland Department of Natural Resources. 1991. Digital Orthophotoquads.
[30] District of Columbia Office of Planning, 2003. *The Anacostia Waterfront Framework Plan*.
[31] City of Alexandria, 2004. City of Alexandria Tax Parcel Data
[32] Stafford County, 2003. Stafford County Land Use
[33] King George County, 2000. King George County Land Cover
[34] Richmond County, 2004. Richmond refuge data
[35] Arlington County, 2003. Arlington County parks
[36] Perquimans County, Department of Planning and Zoning. 2002. Perquimans County Subdivisions.
[37] Federal Register Vol. 66, No. 132, Tuesday, July 10, 2001, Rules and Regulations, at 36087.
[38] Pasquotank County Zoning. Pasquotank County Planning Department. 2003.
[39] Camden County Zoning. Camden County Planning and Code Enforcement Department. 2003.
[40] Dare County Zoning. Dare County Planning Department. 2003.
[41] "Swan Quarter Supplemental Watershed Plan and Environmental Assessment". Natural Resources Conservation Service, U.S. Department of Agriculture. 2002.
[42] Tyrell County. 2002. Gum Neck Dike (hard copy map).
[43] Coastal Barrier Resources System. Maps. US. Fish and Wildlife Service. 1992.
[44] Conservation easements. Berkeley Charleston Dorchester Council of Governments (BCD COG)/ 2004
[45] Metropolitan Planning Commission (MPC) 2005. *Future Land Use.* Savanah, Georgia.
[46] Public Water Use Permits. 2003. St John's River Water Management District.
[47] Public Water Use Permits. 2003. SJRWMD
[48] Coastal Barrier Resource Protection Act (CBRA) zones within Special Flood Hazard Areas. 2003. NOAA Coastal Services Center, Charleston, SC.
[49] Hurricane Evacuation Zones. 1997. Miami-Dade County.
[50] Hurricane Evacuation Zones. 1997. Broward County
[51] Water & Sewer Service Areas 1998 Miami-Dade County.
[52] Water & Sewer Service Areas 1998 Broward County.
[53] Canals and Levees. 1997. South Florida Water Management District. West Palm Beach, FL.
[54] Urban Development Boundary. Miami-Dade, 2003.
[55] Coastal Barrier Resource Protection Act (CBRA) zones within Special Flood Hazard Areas. 2003. NOAA Coastal Services Center, Charleston, SC.

Table S4. Policies the Limit Coastal Development Incorporated into Analysis

State	Policy	Direct Effect on Analysis
NJ	State plan strongly discourages development in designated planning areas	Planning data classifies large area as *undeveloped*.
PA	State policies require public access along waterfront when industrial sites are redeveloped, often resulting in undeveloped coastal buffer.	Change industrial facilities from *developed* to *intermediate*
DE	Kent and New Castle County regulations prohibit development in 100-year floodplain	Change *intermediate* to *undeveloped* in 100-year floodplain.
MD	Critical Areas Act limits development to one home per 20 acres within 300 meters of tidal wetlands or water, along 90% of rural shores.	Change *intermediate* to *undeveloped* within 300 meters of shore.
VA	Virginia Beach prevents most development below designated rural line.	Planning data classifies large area as *undeveloped.*
SC	General policy of discouraging development within one statutory mile of air force base for security reasons.	Development not expected near Air Force base on otherwise growing island.
FL	Monroe County growth management policy	Planning data classifies large areas as *undeveloped*

Table S5 Shore Protection Policies that Over-Ride Land-Use Classification		
State	Policy	Direct Effect on Analysis
Along Estuarine Shores		
MA, RI	Regulations prohibit shore protection structures (but not beach nourishment) in designated areas.	Reclassify *developed* to *intermediate*
RI	Regulations prohibit shore protection in areas with rock outcrops.	Reclassify to *conservation*
RI	Coastal regulations prohibit the filling/elevation of lands along the shore. Hence septics would fail as sea rises. Towns generally unwilling to extend sewer to low-density areas.	Reclassify low-density development along lagoons from *intermediate* to *undeveloped*
NY	Agencies have authority to prohibit shore protection along large lots.	Reclassify *developed* to *intermediate*
MD	Calvert County cliff policy prohibits all shore protection along designated cliffs	Reclassify *developed* to *conservation*
MD	Sommerset County expectation that existing dikes protecting Crisfield would be extended to protect entire neck rather than Crisfield becoming an island.	Reclassify *undeveloped* to *intermediate*
DC	Anacostia River policy to dismantle bulkheads and maintain environmental buffer in designated areas.	Reclassify *developed* to *undeveloped*
VA	Virginia Beach policy against infrastructure in designated rural area applied to shore protection	Reclassify isolated development in rural area as *undeveloped*
NC	Specific plans for dikes to protect farmland from excessive flooding	Reclassify *undeveloped* to *developed*
FL, NC, VA, DE	Plans to remove development from specific flood-prone areas	Reclassify to *conservation* or *undeveloped*, depending on whether ownership transferred.
All	Existing shore protection and water infrastructure is generally exempt from policies limiting future shore protection.	Classify as *developed* regardless of existing land use, unless plan for removing shore protection.
All	Protecting lands from shore erosion inherently protects lands immediately behind the lands protected.	Reclassify *undeveloped* to *developed or intermediate*
All	Developed and intensively used parks in developed areas—including historic parks and neighborhood conservation areas--are often designated as "parkland" but they are essential parts of community infrastructure.	Reclassify *undeveloped* to *intermediate or developed*
Along Ocean Coasts		
All	Development on selected lands designated by Coastal Barrier Resources Act ineligible for federal shore protection and other subsidies	Reclassify *developed* to *intermediate*
All	Federal cost-benefit test excludes shore protection for moderate-density development	Reclassify *developed* to *intermediate*
All	Intervening undeveloped areas would be protected rather than numerous inlets forming, unless the undeveloped areas are at least several kilometers long.	Reclassify *undeveloped* to *developed or intermediate*.
NY, NJ, DE, NC, FL	Major roads through undeveloped areas are protected to maintain road access to existing communities	Reclassify *undeveloped* to *intermediate*
NJ	Authorized shore protection projects for beaches in specific recreational parks	Reclassify *undeveloped* to *intermediate*
FL	Shore protection discouraged along designated turtle beaches in the Florida Keys	Reclassify *developed* to *intermediate*
All	Existing shore protection	Classify as *developed* regardless of existing land use.

<table>
<tr><th colspan="4">Table S6 Sources of Wetlands and Elevation Data</th></tr>
<tr><td colspan="4">Wetlands Data</td></tr>
<tr><td>Area</td><td>Date of Imagery</td><td>Source</td><td>Rest of Citation</td></tr>
<tr><td>MA</td><td>1990s</td><td rowspan="3">U.S. Fish and Wildlife Service (2008)</td><td rowspan="3">National Wetlands Inventory. Washington, D.C.</td></tr>
<tr><td>RI</td><td>1988</td></tr>
<tr><td>CT</td><td>1980s</td></tr>
<tr><td>NY</td><td>1974-1990</td><td rowspan="8">U.S. Environmental Protection Agency (2008)</td><td rowspan="8">Titus, J.G. and J. Wang. Maps of Lands Close to Sea Level along the mid-Atlantic coast of the United States. In J.G. Titus and E. Strange (eds). “Background Documents for CCSP 4.1”. Washington, D.C.</td></tr>
<tr><td>NJ</td><td>1995</td></tr>
<tr><td>PA</td><td>1980</td></tr>
<tr><td>DE</td><td>1092</td></tr>
<tr><td>MD</td><td>1988-1995</td></tr>
<tr><td>DC</td><td>1983</td></tr>
<tr><td>VA</td><td>1990-2000</td></tr>
<tr><td>NC</td><td>1981-1994</td></tr>
<tr><td>SC</td><td>1989</td><td rowspan="2">U.S. Fish and Wildlife Service (2008)</td><td rowspan="2">National Wetlands Inventory</td></tr>
<tr><td>GA</td><td>1981-2001</td></tr>
<tr><td>N. FL</td><td>2000</td><td>St. John’s River Water Management District</td><td>Land Use/ Land Cover 2000. Palatka, Florida.</td></tr>
<tr><td>S. FL</td><td>1994-1995</td><td>South Florida Water Management District</td><td>Land Use/Land Cover. 1995. West Palm Beach, Florida.</td></tr>
<tr><td colspan="4">Elevation Data</td></tr>
<tr><td colspan="2">New York to North Carolina</td><td>U.S. Environmental Protection Agency</td><td>Titus and Wang 2008 (same as wetlands data).</td></tr>
<tr><td colspan="2">All Other Locations</td><td>United States Geological Survey</td><td>National Elevation Dataset. 2007.</td></tr>
<tr><td colspan="4"></td></tr>
</table>

Table S7. Area of Land Excluded from Study by State (square kilometers)

	Below 1m				Below 5 m			Explanation for significant exclusions.
	Area Excluded		Total Dry Land		Area Excluded		Total Dry Land	
	Data Limits	Study area			Data Limits	Study area		
MA	27	0	110		29	0	511	Seaward boundary issue[1]
RI	0	0	8		0	0	61	Seaward boundary issue[1]
CT	3	0	35		23	0	147	Seaward boundary issue[1]
NY	1	4	165		2	54	811	Suffolk County planning data provided only for the 500-year floodplain.
NJ	0	0	275		0	0	663	n/a
PA	1	0	24		9	0	112	Inland study boundary issue[2]
DE	0	0	126		1	0	659	Seaward boundary issue[1]
MD	2	0	449		4	0	2297	Seaward boundary issue[1]
DC	0	0	4		0	0	17	n/a
VA	50	16	349		234	134	2606	Excluded inland counties along the James River. Seaward boundary issue. [1]
NC	19	6	1362		167	115	5989	Inland counties excluded. Inland study boundary issue. [2]
SC	22	0	341		301	0	2366	Inland study boundary issue. [2]
GA	20	0	235		335	0	2333	Seaward boundary issue[1]
FL	31	39	2448		467	5222	7959	Planning data only provided for land below the 3-meter contour. Inland study boundary issue. [2]
Total	176	65	5929		1572	5525	26530	

1. Planning data polygons provided by state and local governments do no always extend all the way to the inland boundary of the wetland polygons.
2. Inland boundary of study area was originally defined by elevation contour from a data set different from the data employed in our final overlay.

Table S8. Area of Land within One Meter above High Water by Intensity of Development along US Atlantic Coast (km^2)

State	Dry Land						Nontidal Wetlands	Tidal Wetland
	Likelihood of Shore Protection High←------------------------→Low							
	Developed	Intermediate	Undeveloped	Conservation	No Data[1]	Total Dry Land[2]		
MA	22	24	18	19	27	110	24	325
RI	3	1	4	0	0	8	1	29
CT	25	2	2	2	3	30	2	74
NY	117	29	6	9	4	165	10	149
NJ	177	41	33	19	6	275	172	980
PA	11	5	6	1	1	24	3	6
DE	33	32	28	30	3	126	32	357
MD	85	70	251	41	2	449	122	1116
DC	3	0	0	0	0	4	0	1
VA	122	71	91	15	50	365	148	1619
NC	374	192	742	41	13	1362	3050	1272
SC	90	67	130	33	22	341	272	2229
GA	31	18	27	39	17	133	349	1511
FL	798	125	141	161	62	1286	2125	3213
Total	1889	678	1479	408	210	4665	6314	12882

1. No land use data was available. See Table S-8 and supplemental text on study area for further details.
2. Equal to the sum of developed + intermediate + undeveloped + conservation + no data.

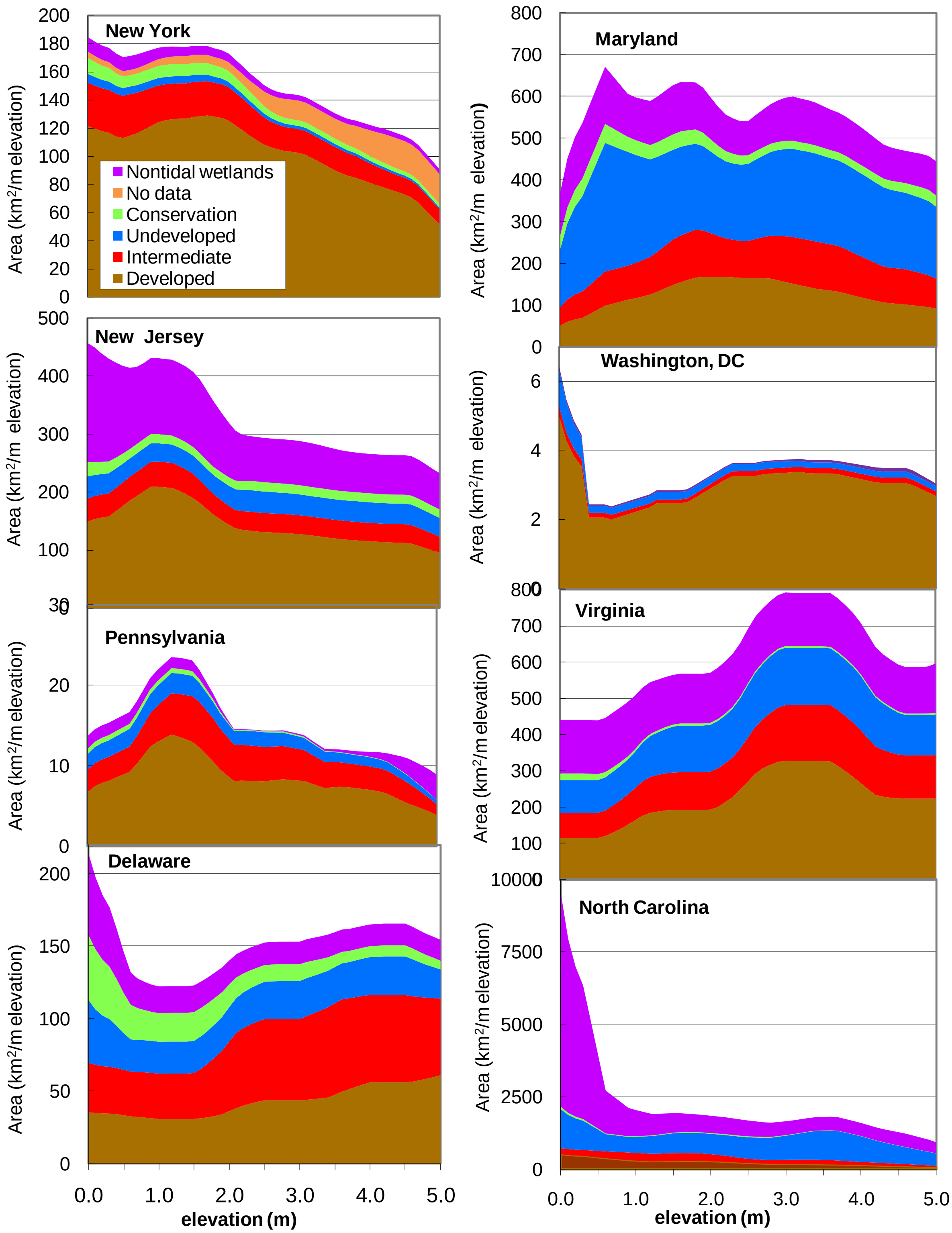


Figure S1. Area of nontidal wetlands and dry land within each of the four land use classifications, by elevation for each coastal state.

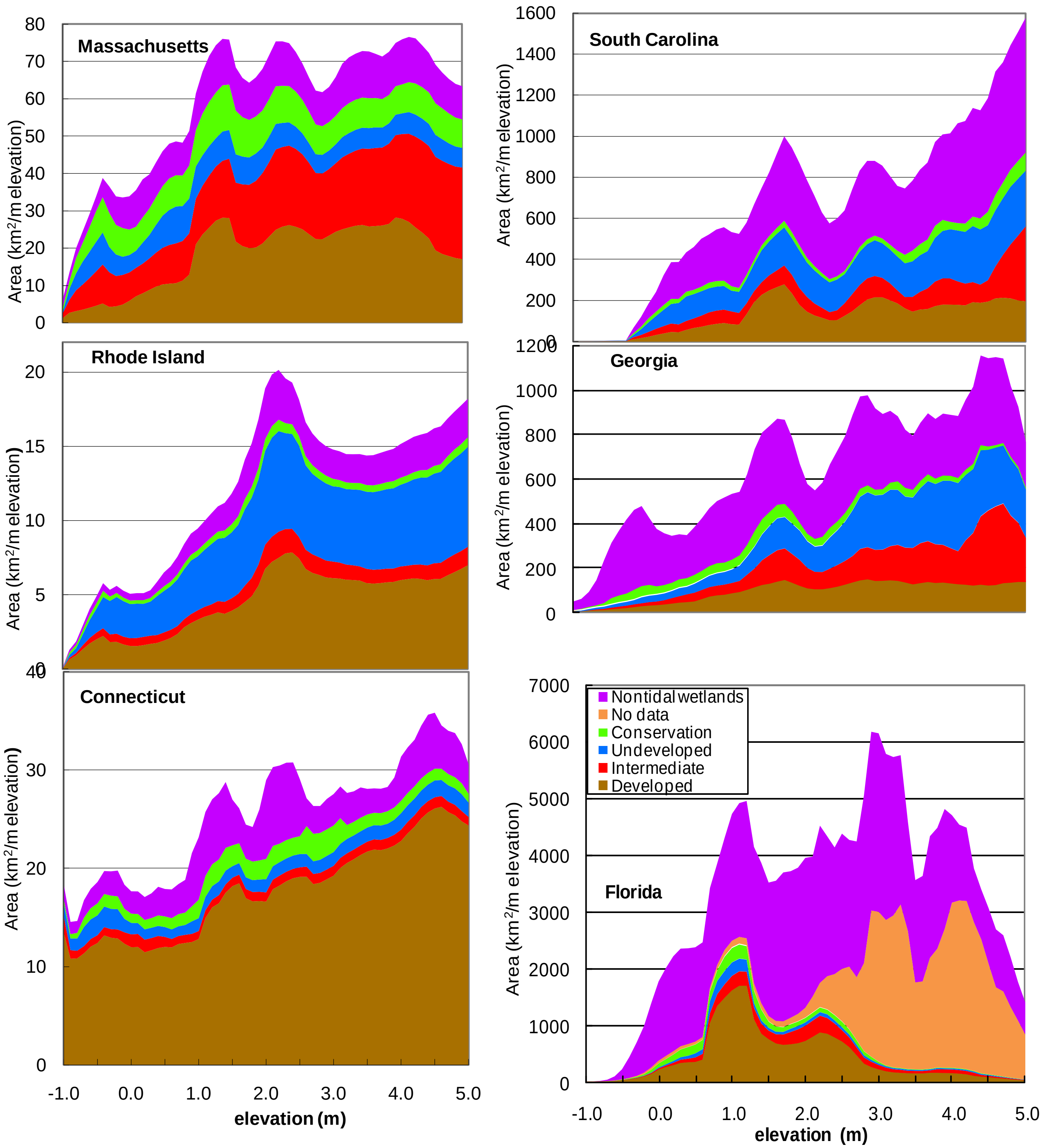


Figure S1 (continued). Area of nontidal wetlands and dry land within each of the four land use classifications, by elevation for each coastal state.

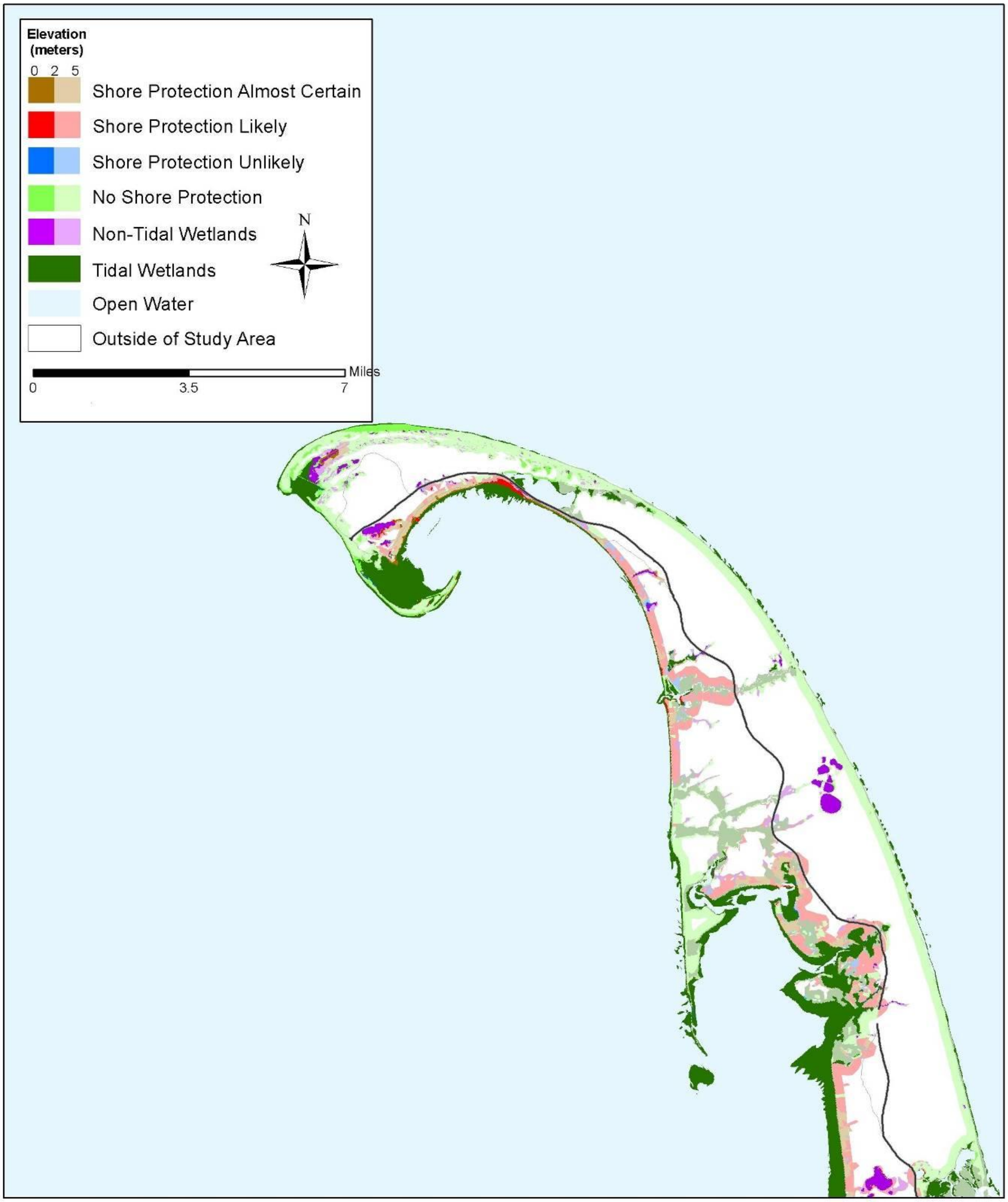


Figure S2. Northern Cape Cod (Barnstable County) Massachusetts.

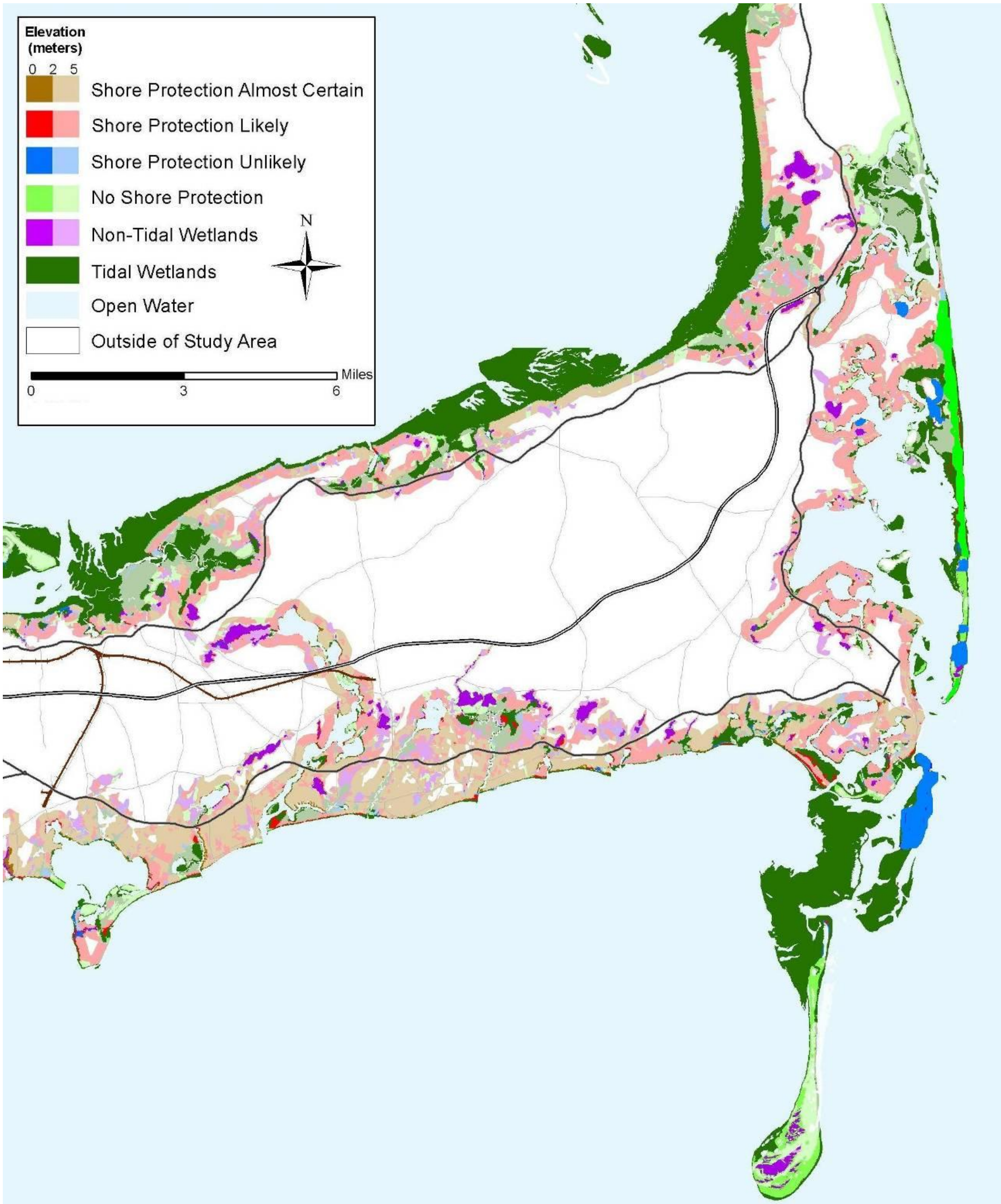


Figure S3. Southeastern Cape Cod (Barnstable County)

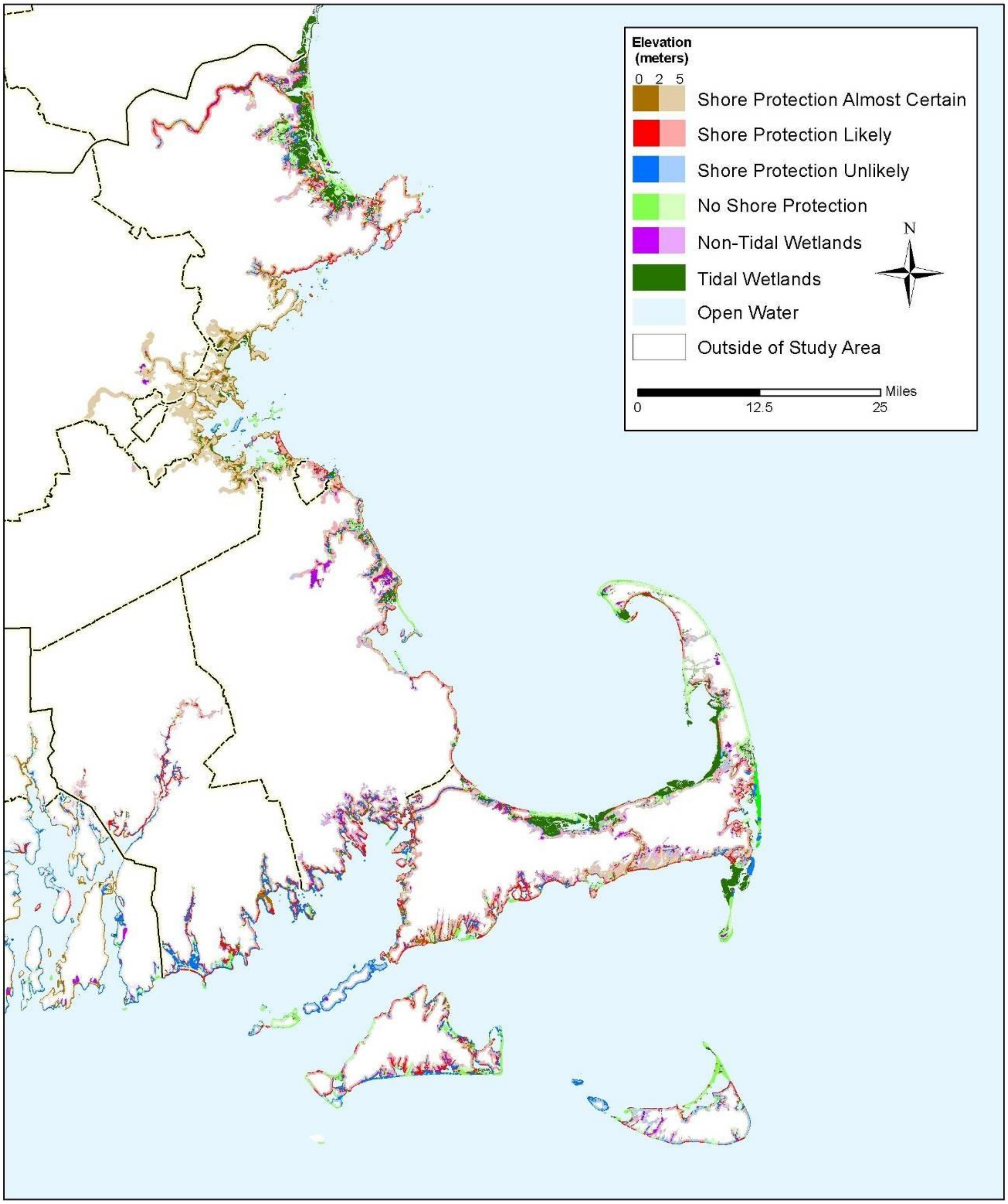


Figure S4. Massachusetts

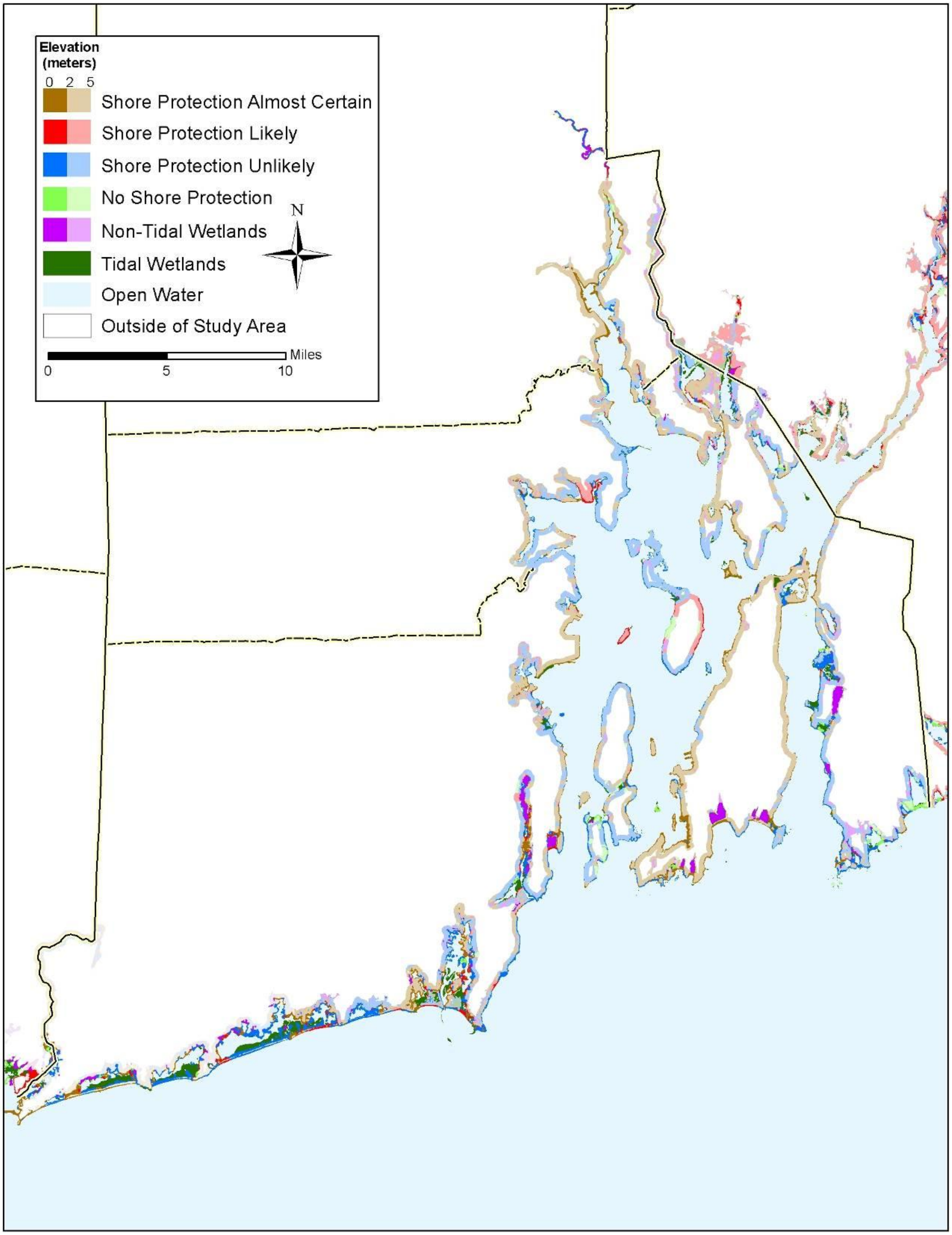


Figure S5. Rhode Island.

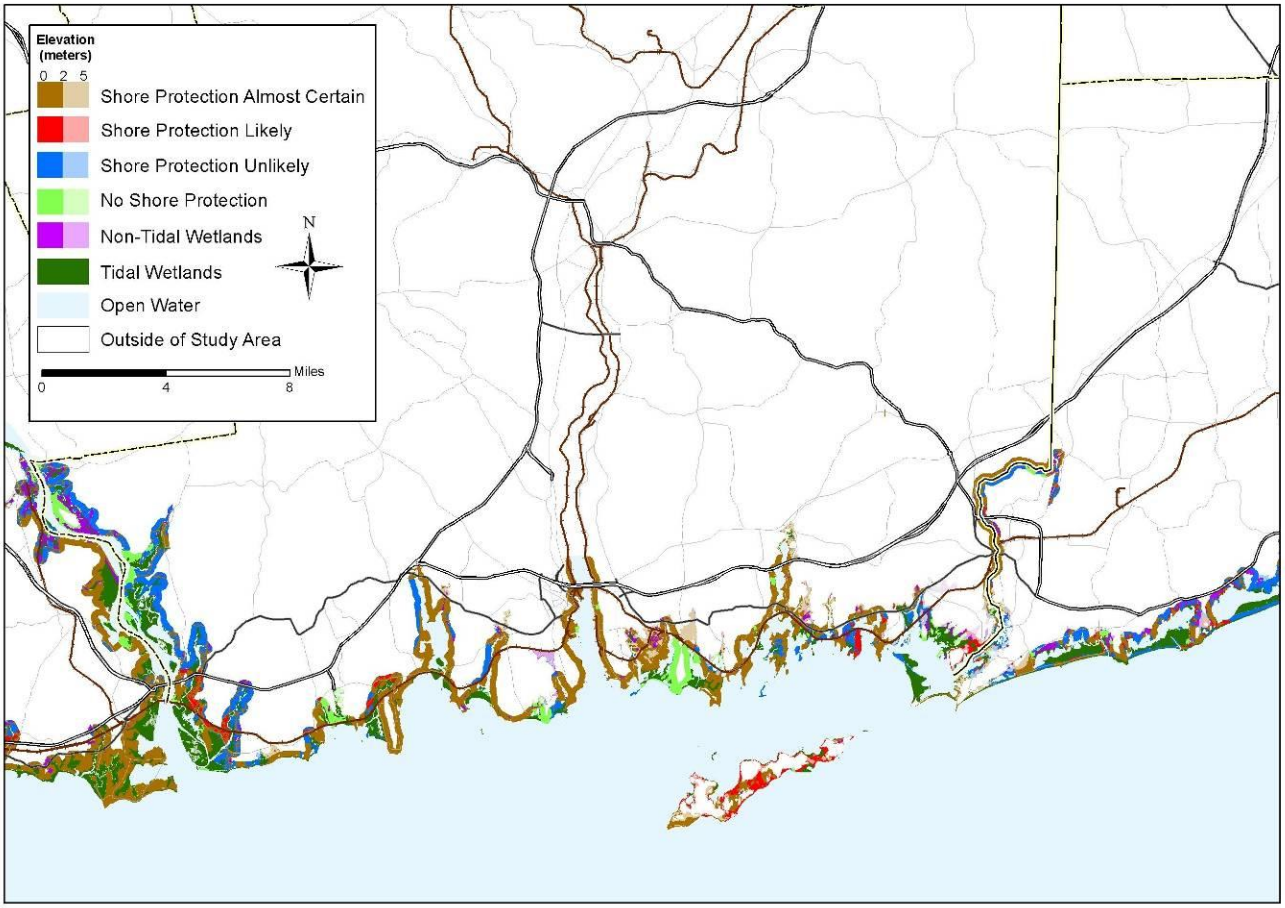


Figure S6. New London County, Connecticut.

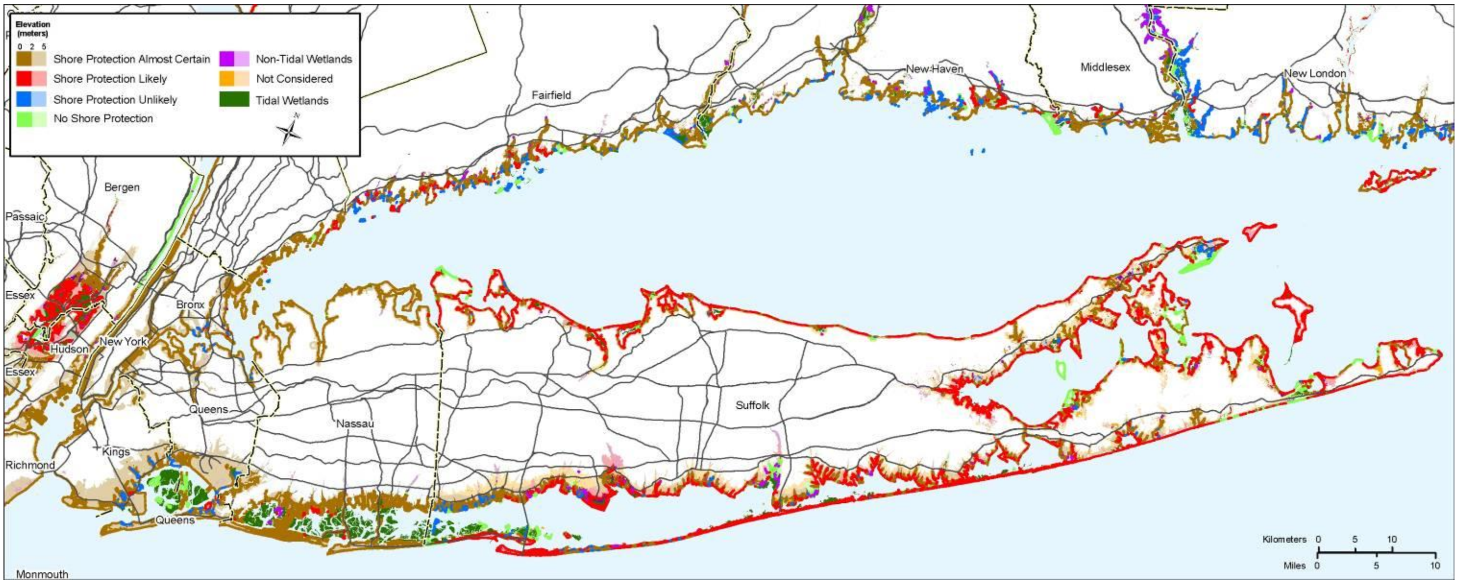
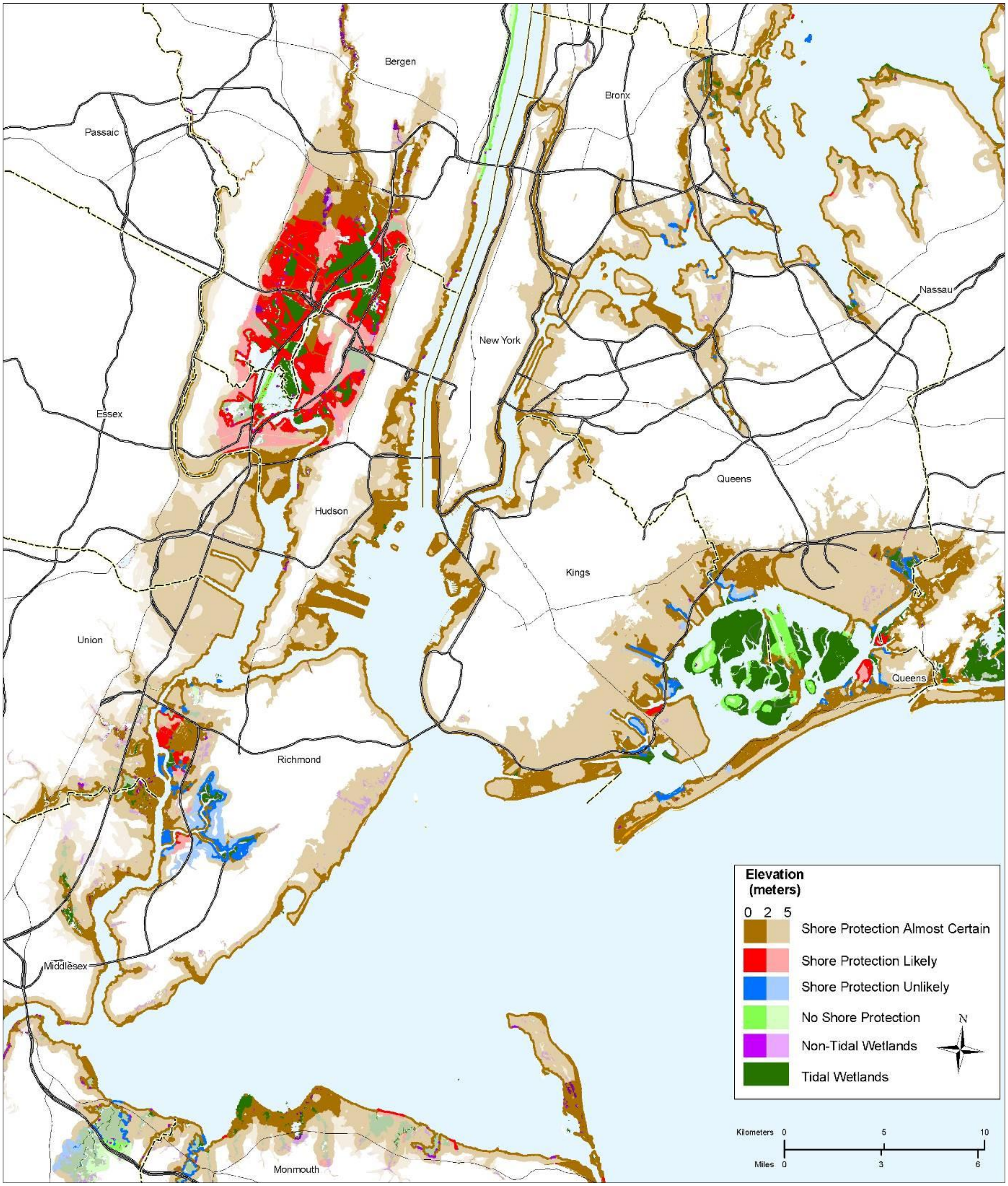


Figure S7. Long Island and the Shores of Long Island Sound



Figures S8. Greater New York City.

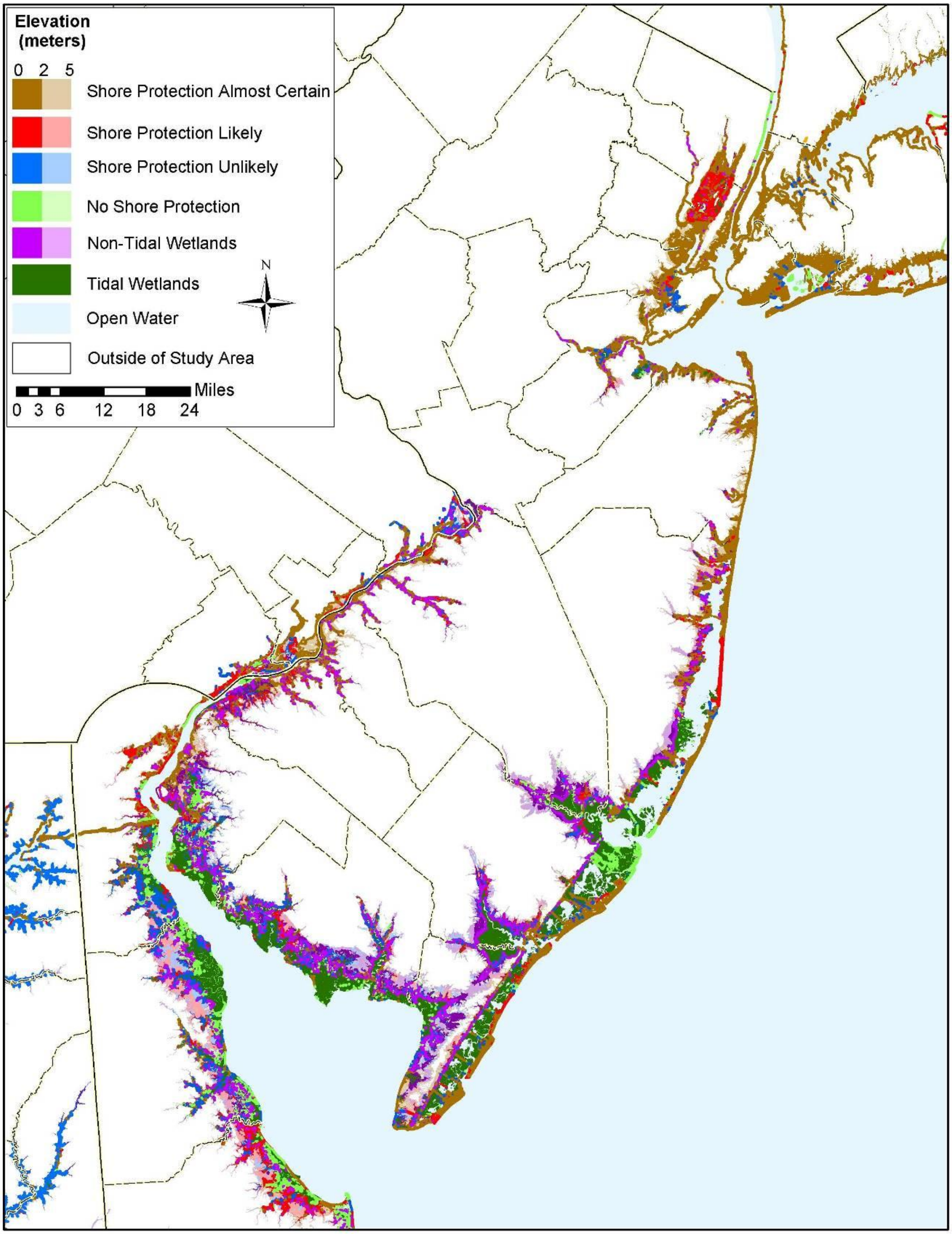
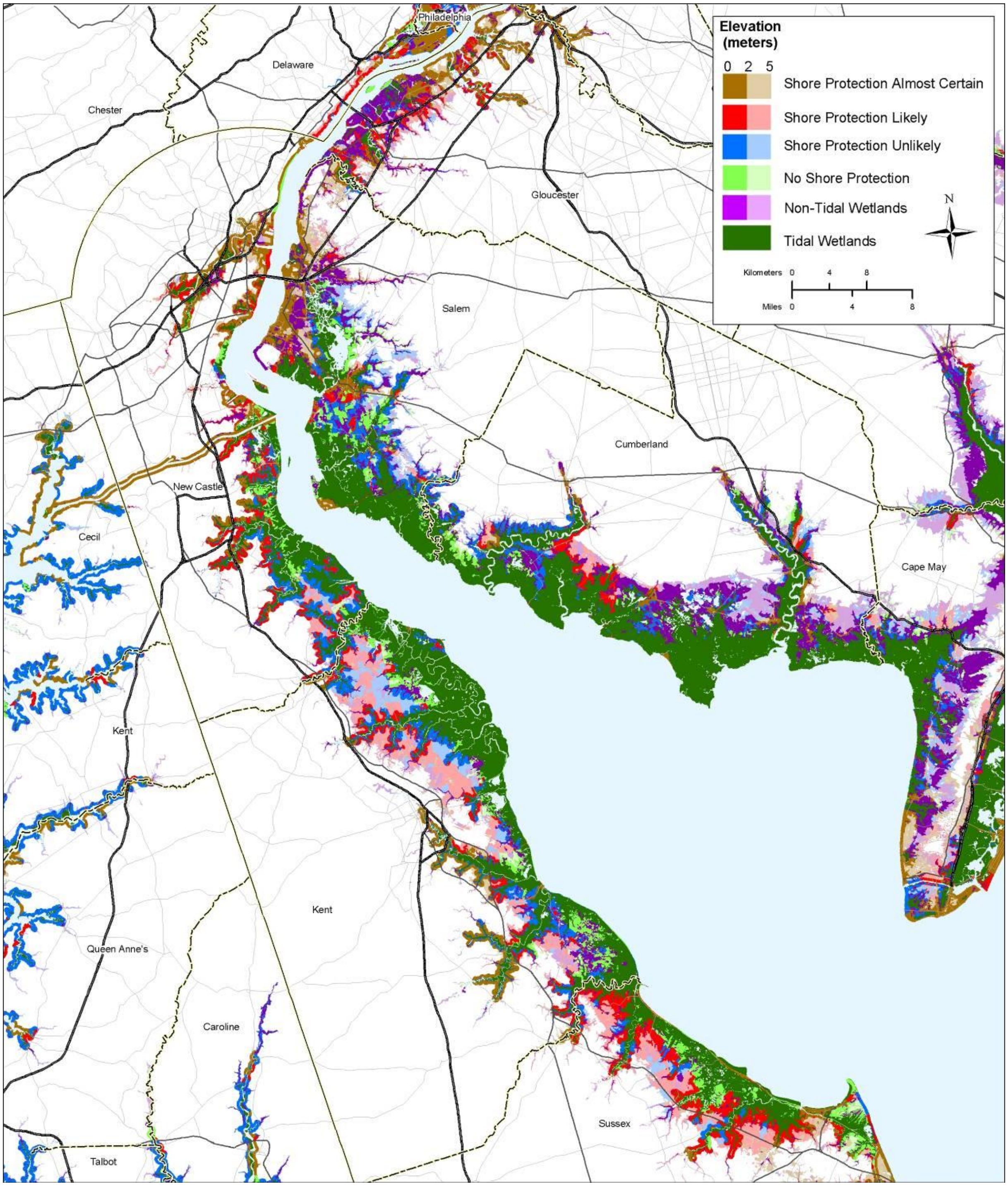


Figure S9. New Jersey.



Figures S10. Delaware Bay.

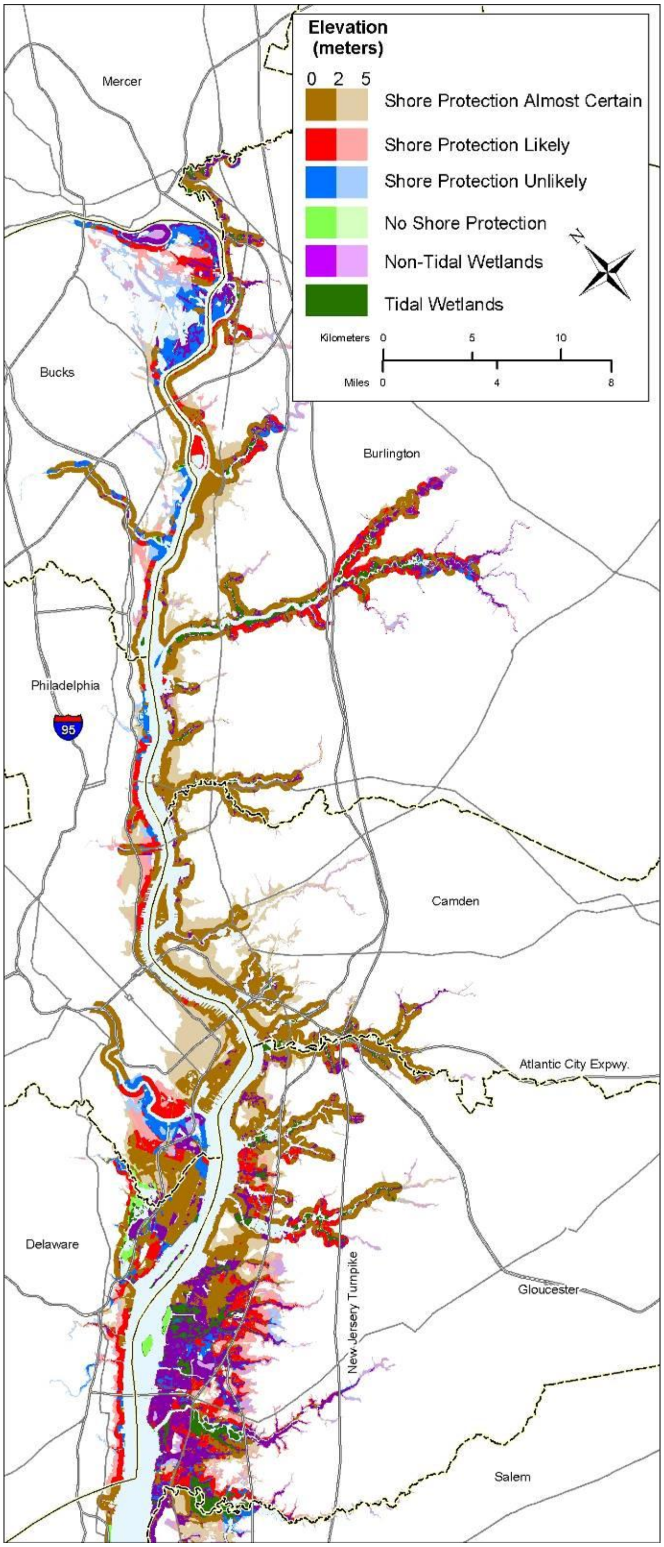


Figure S11. The Delaware River.

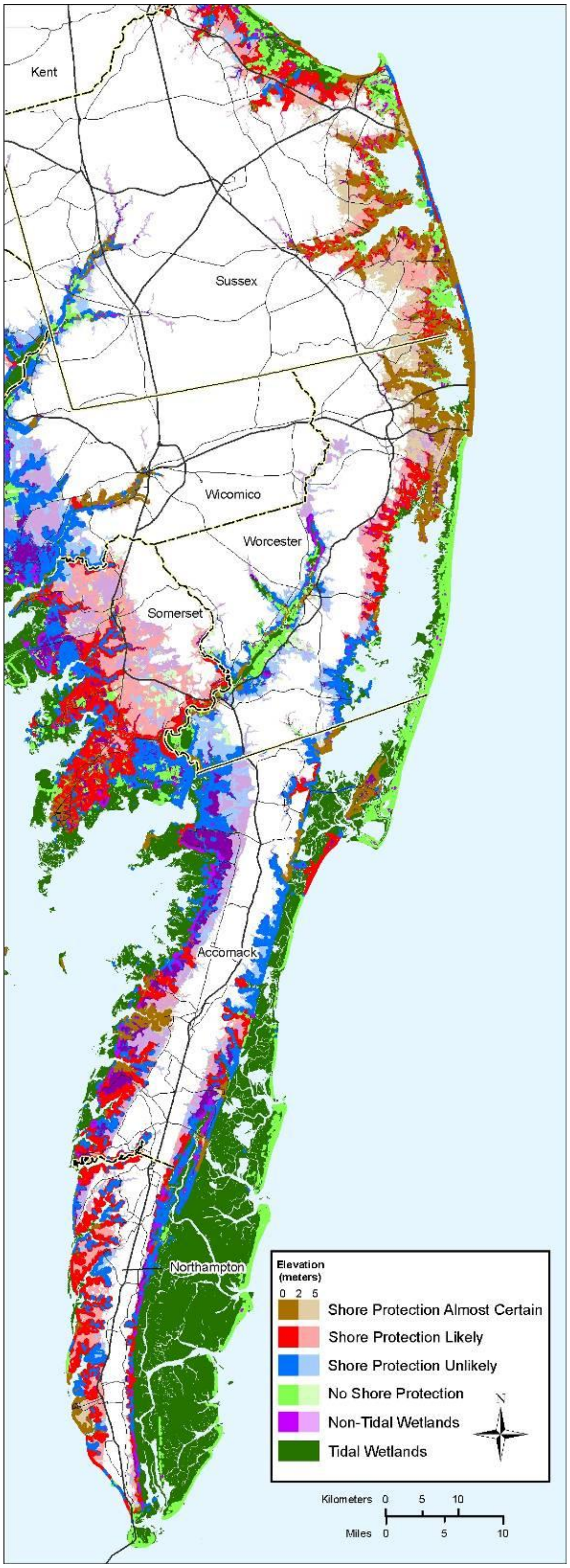


Figure S12. The Atlantic Coast of the Delmarva Peninsula

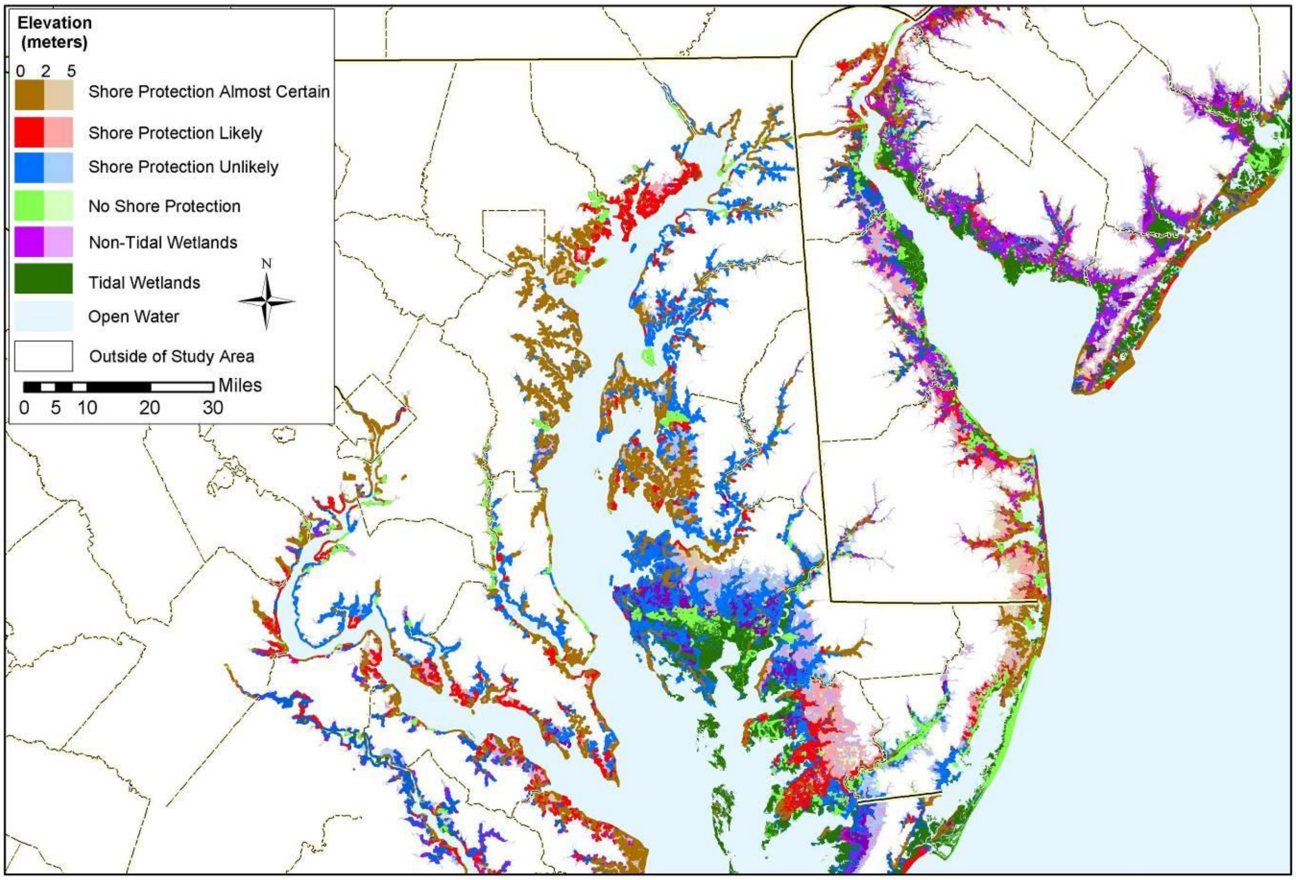


Figure S13. Maryland, Delaware, the Potomac River, and Delaware Bay

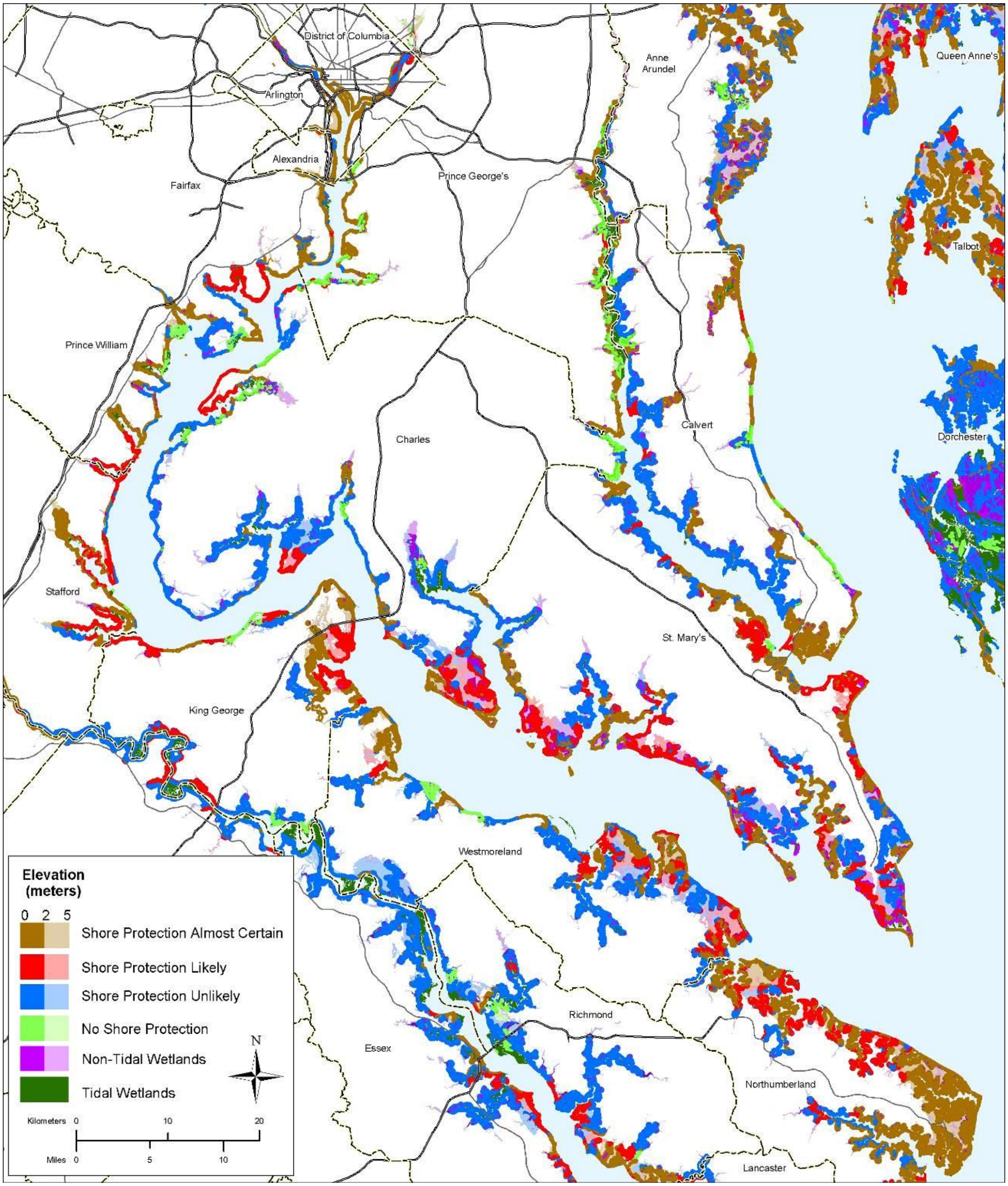


Figure S14. The Potomac and Patuxent Rivers.

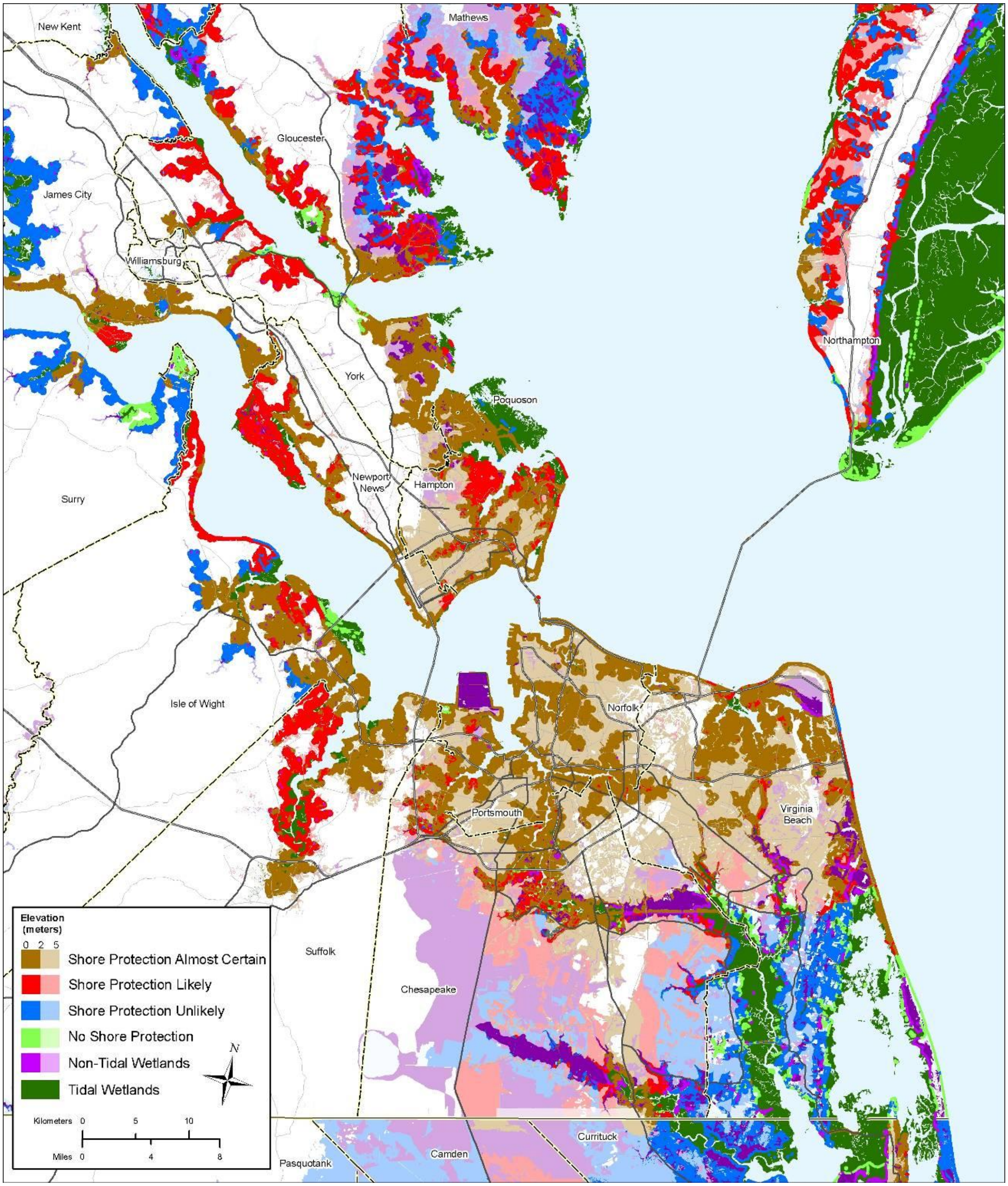


Figure S15. Hampton Roads and Vicinity.

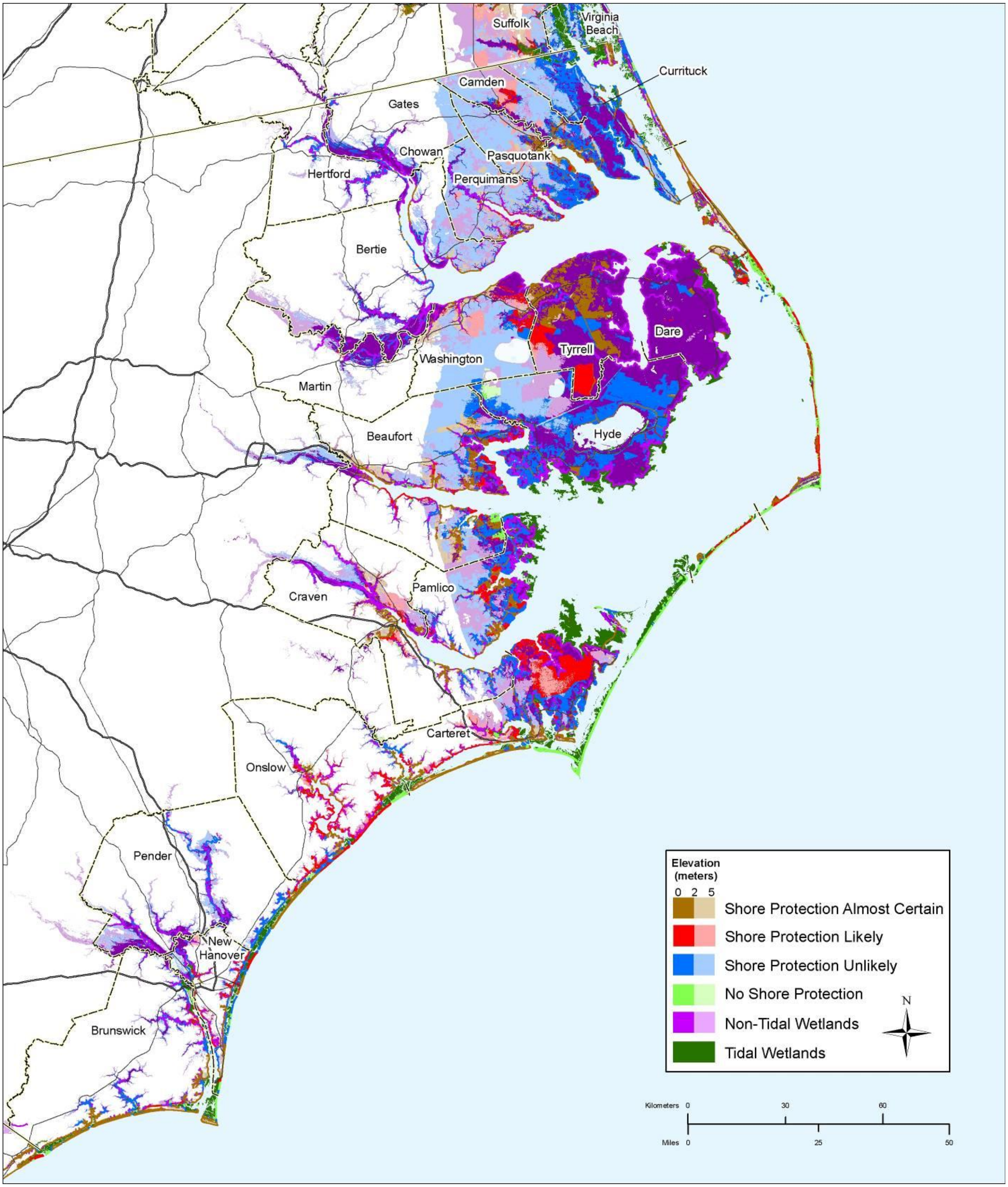


Figure S16. North Carolina.

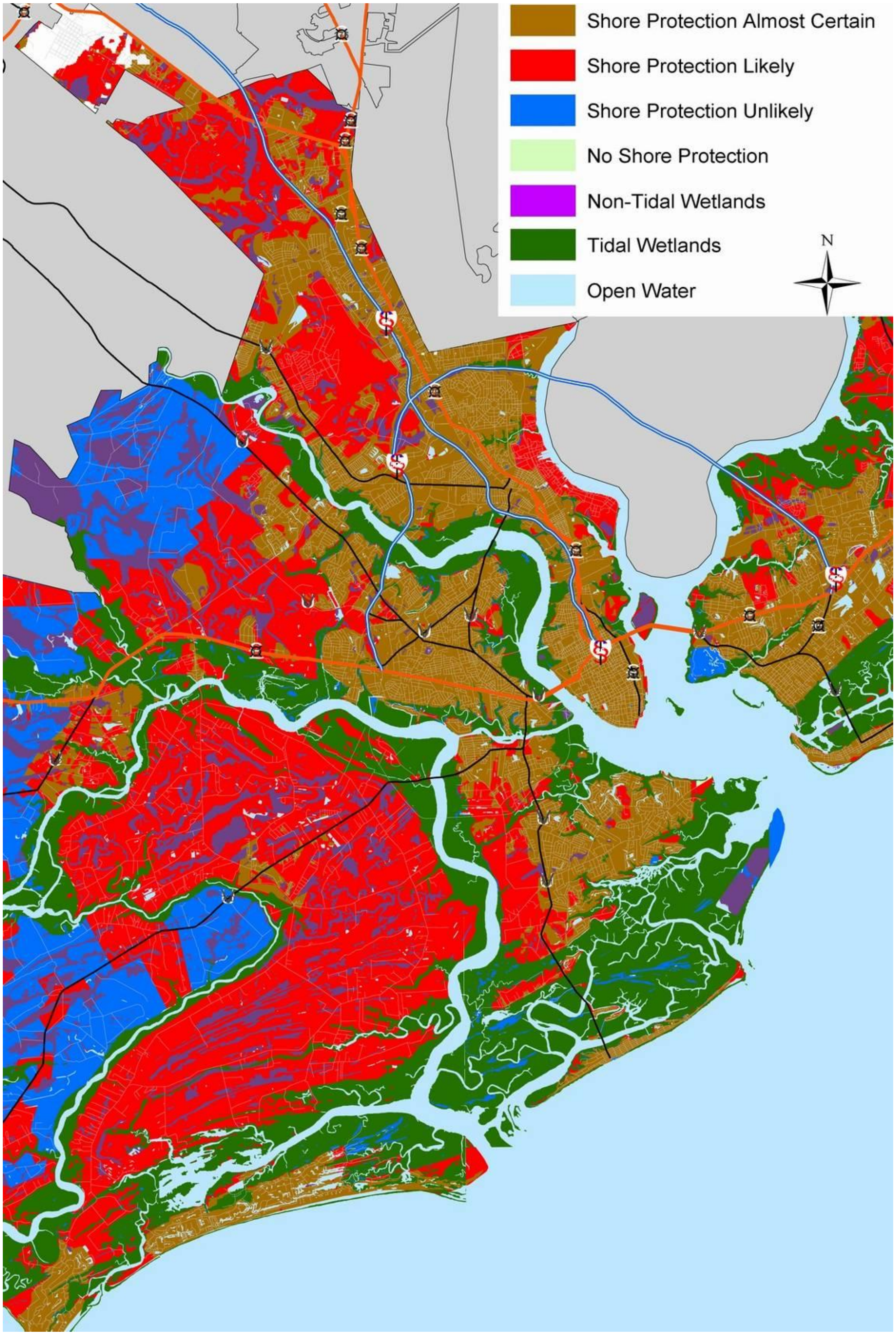


Figure S17. Charleston, South Carolina and Vicinity.

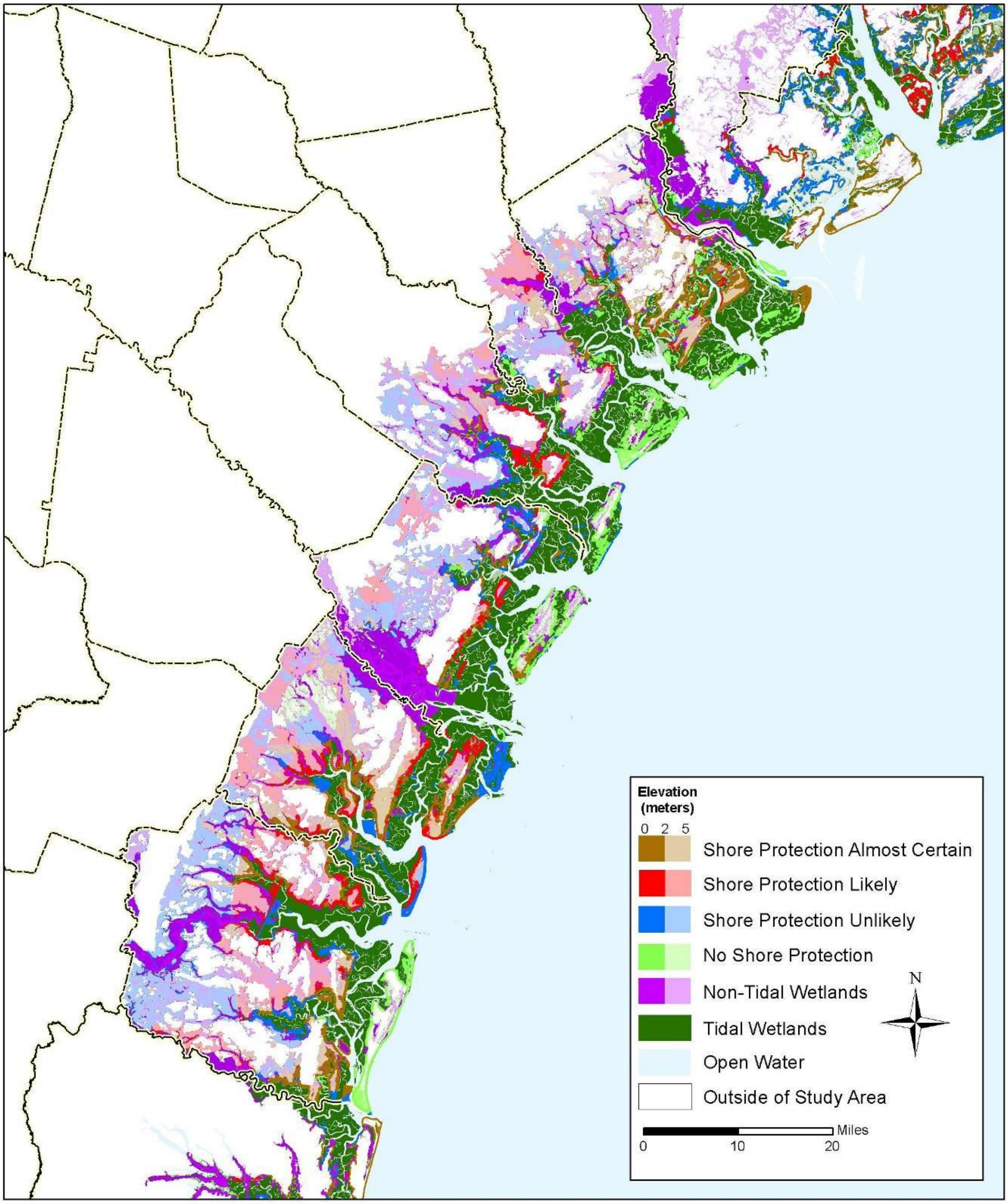


Figure S18. Georgia.

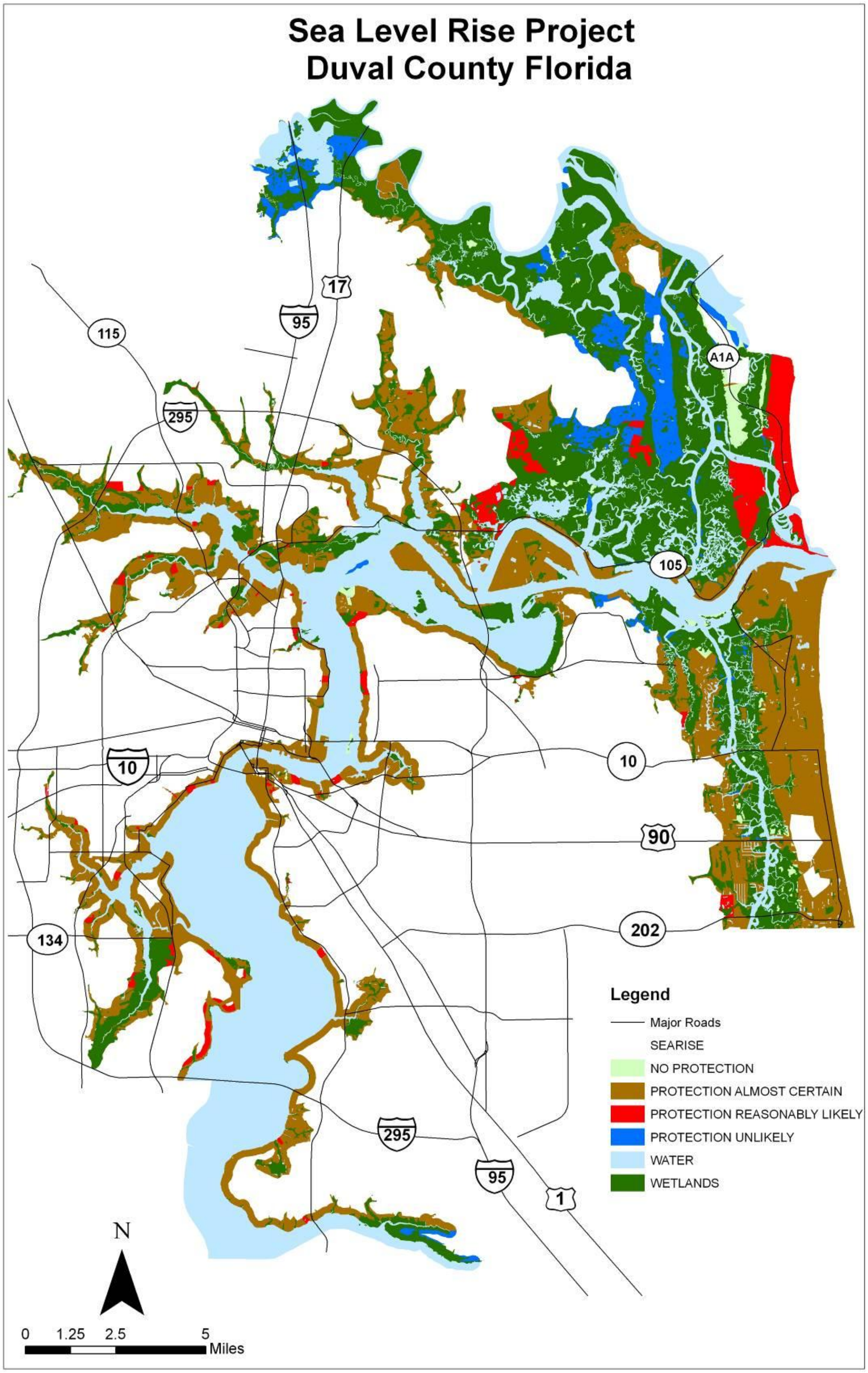


Figure 19. Duval County, Florida

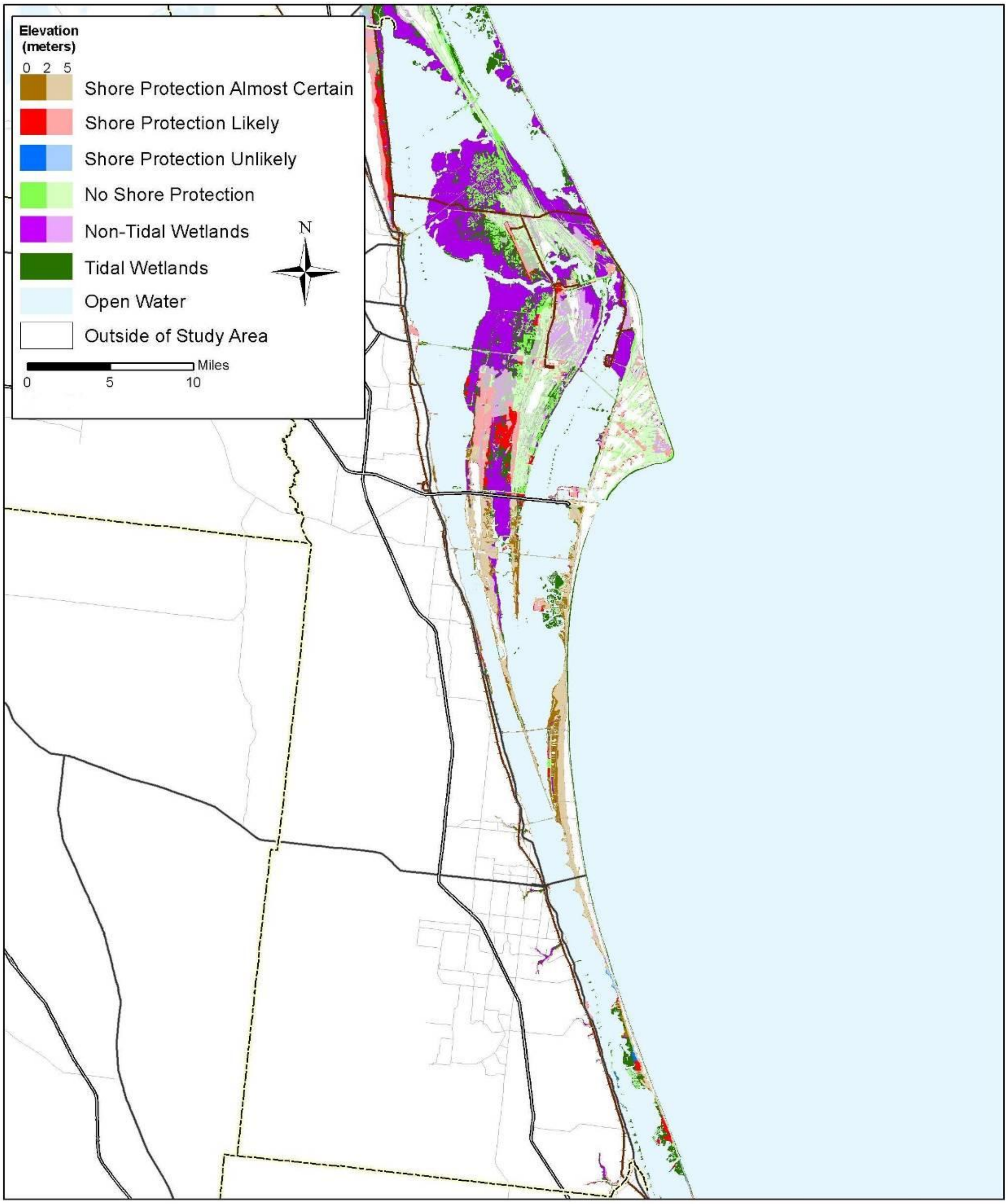


Figure S20. Cape Canaveral and Vicinity (Brevard County), Florida

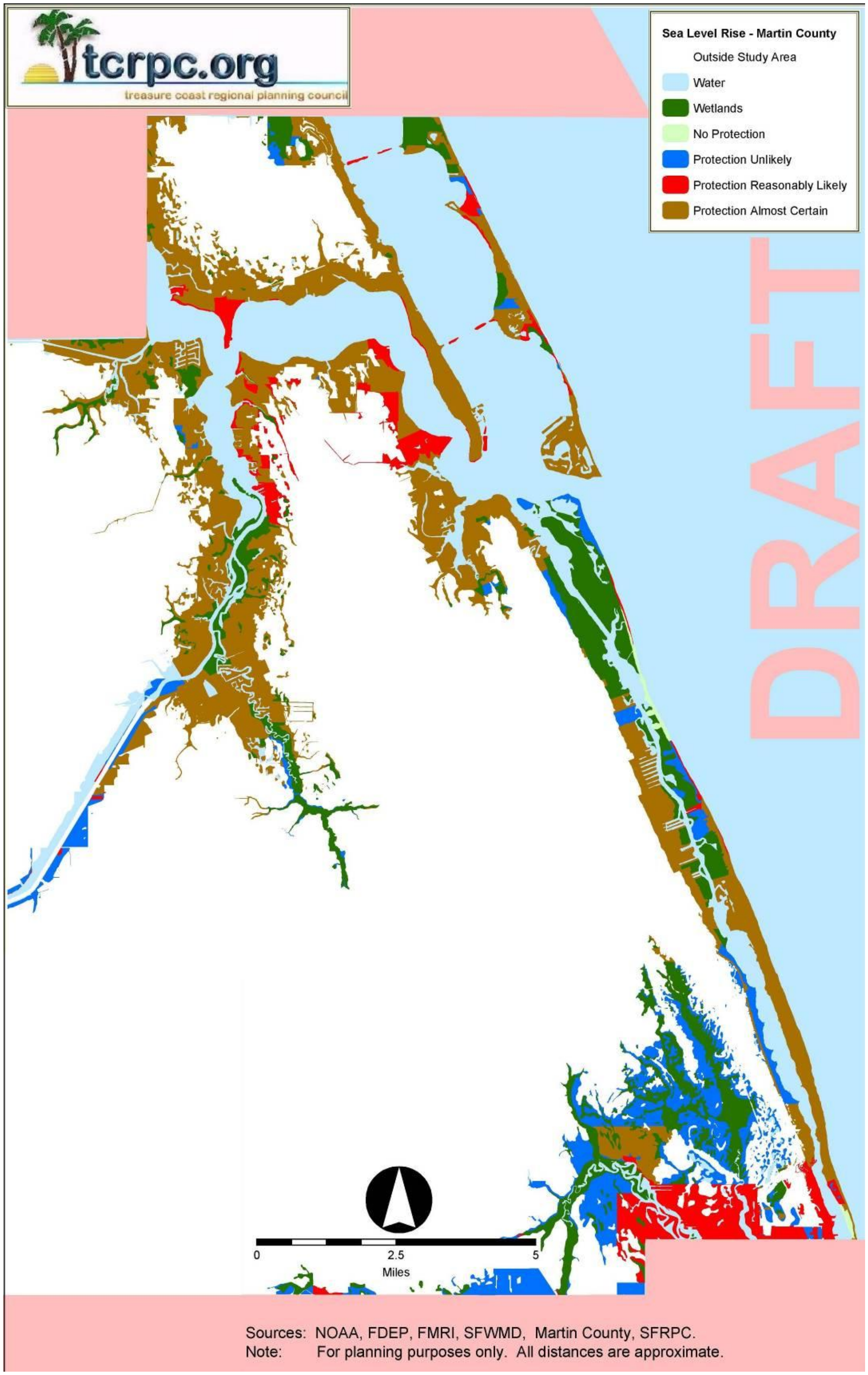


Figure S21. Martin County (Florida).

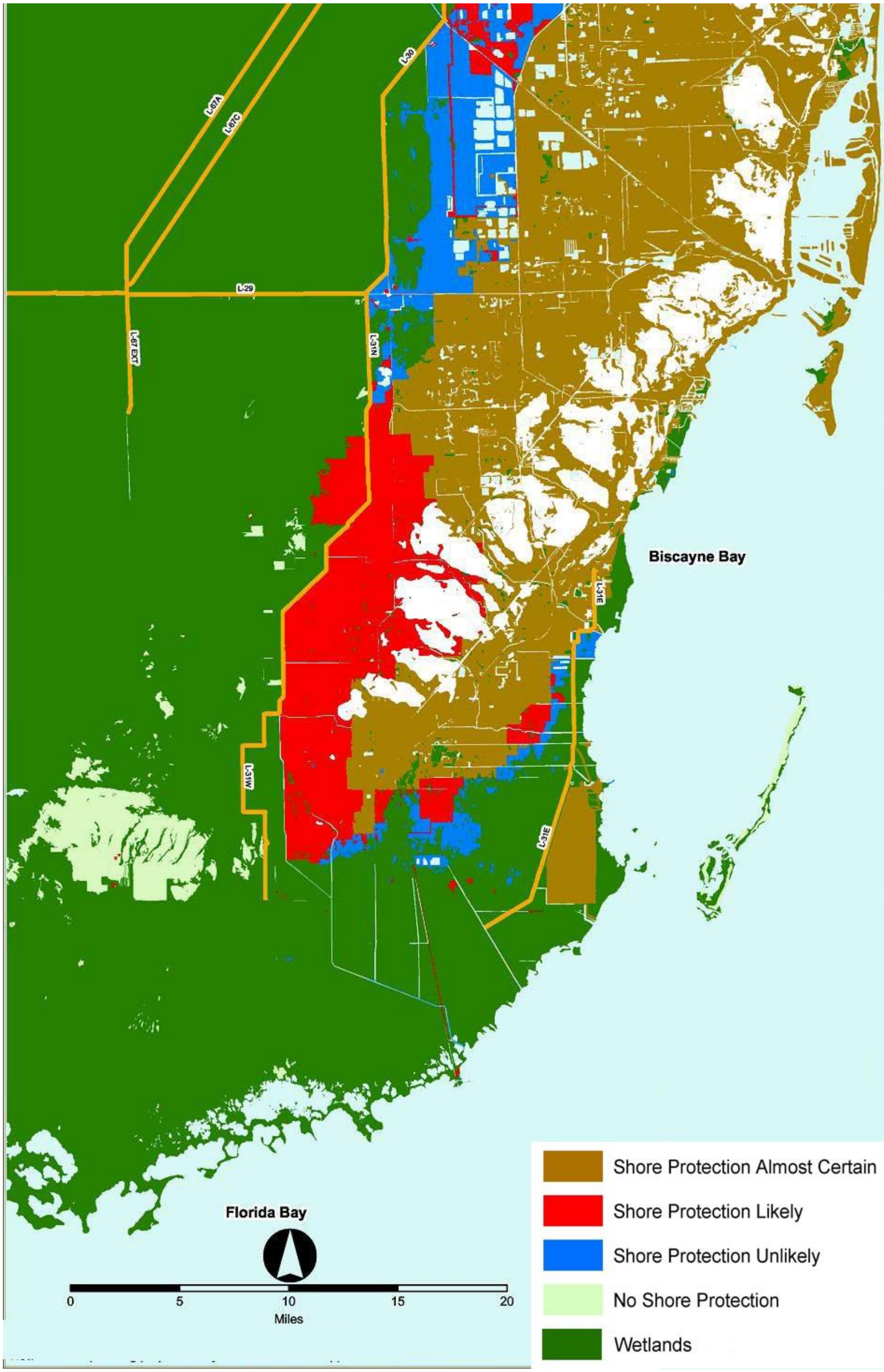


Figure S22. Miami-Dade County, Florida.

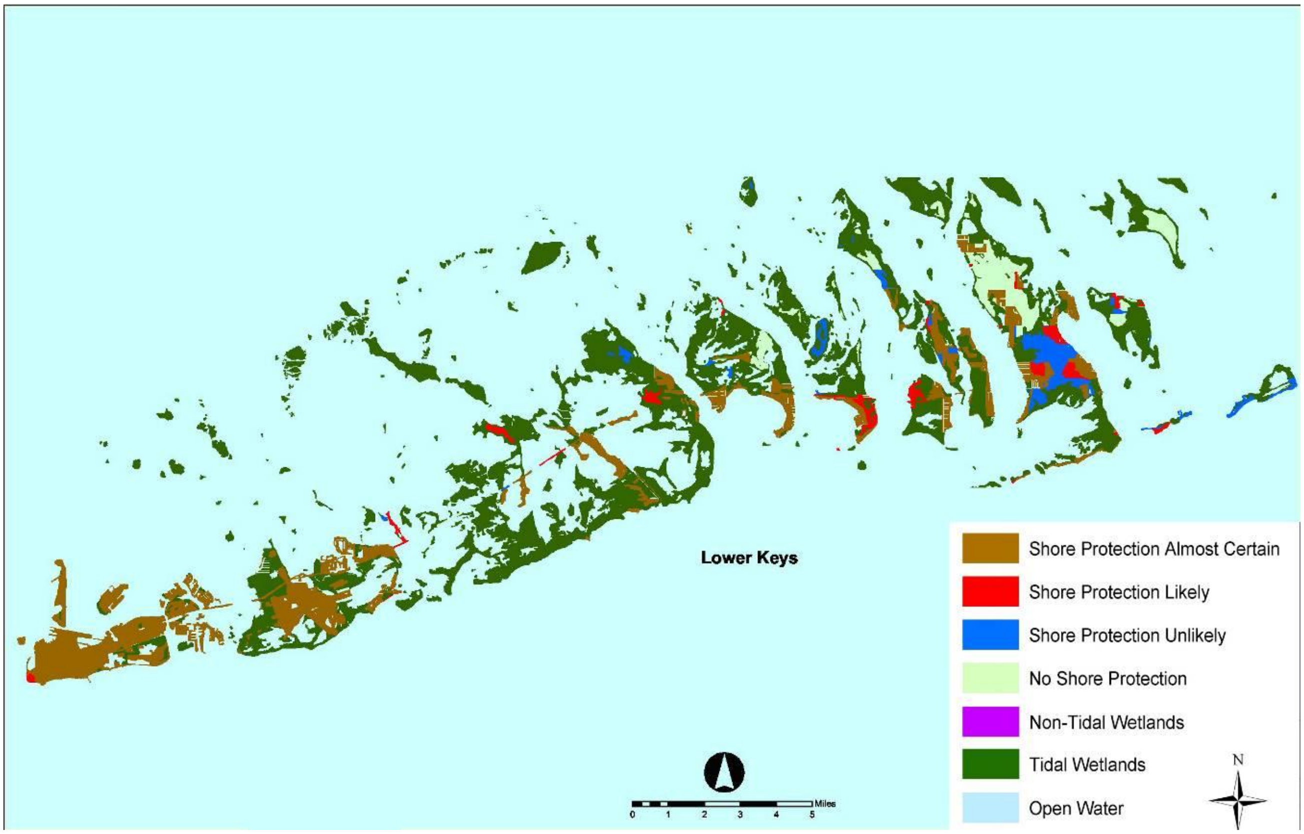


Figure S23. The Lower Florida Keys, including Key West and Big Pine Key.