Fishing Effects Model
Percent Sediment Type
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Prepared for:
Northeast Regional Ocean Council (NROC)
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1 INTRODUCTION

The Northeast Fishing Effects Model combines seafloor data (sediment type, energy regime) with fishing effort data and parameters related to the interactions between fishing gear and seafloor habitats to generate percent habitat disturbance estimates in space and time. Fishing gear interacts with both living (biological) and non-living (geological) seafloor features. Diverse seabed types comprised of various combinations of biological and geological features occur in the Northwest Atlantic Ocean off the northeastern United States. These seabed structures constitute merely one element of complex fish habitats that also include the overlying water column and its features. Because sediment type data were available at a reasonable spatial resolution and representativeness across the model domain, sediments were used as a proxy for the diverse array of seabed types occurring in the region, with biological habitat elements inferred on the basis of sediment and energy classifications. This allows appropriate habitat/gear interaction parameters to be applied when the model is run.

Generally, the model domain extends north to south from the U.S./Canadian border to the N.C./S.C. border, and inshore to offshore from the coastline to the Exclusive Economic Zone boundary. The sediment grid covers this entire domain. Data inputs and outputs to Fishing Effects are gridded at a 5 km by 5 km resolution, with the exception of cells along the edge of the domain which are clipped to the coastline or Exclusive Economic Zone boundary and are therefore smaller.

This dataset constitutes a portion of the input data for the Fishing Effects Model. Five different sediment grain sizes plus a steep and deep habitat type are represented in the dataset, which indicates the proportion of each grain size occurring within each 5x5 grid. Each record in the dataset represents a unique grid cell with corresponding grid identification number. For each grid cell, the proportions across the five grain sizes and steep and deep habitat type sum to 1, such that the area of the grid cell is fully allocated to one or more of the six conditions.

Additional information about the model can be found in NEFMC (2019) and in the report for the precursor to Fishing Effects, the Swept Area Seabed Impact (SASI) Model (NEFMC 2011). Smeltz et al. (2019) details the North Pacific implementation of the model and provides additional background.

2 PURPOSE

The primary purpose of this dataset is to serve as a base layer for the Northeast Fishing Effects Model. A secondary purpose for this map of sediment grain sizes is to inform various spatial planning issues where seabed type is a consideration for decision making. It is important to understand caveats and limitations associated with both the underlying source data and this compilation when using the data for spatial planning. These limitations and caveats influence the Fishing Effects Model percent habitat disturbance results as well.

3 SOURCES AND AUTHORITIES

Various sources and types of sediment data were combined to generate this product. See section 11 for a map showing the footprint of each of these data sources.

Table 1. Sources of sediment data used in the Northeast Fishing Effects Model.

Source	Spatial geometry and size	Presence/absence mapping process
Bethoney, N. D. and K.D.E., Stokesbury. 2018. Methods for image-based surveys of benthic macroinvertebrates and their habitat exemplified by the drop camera survey of the Atlantic sea scallop. JoVES, 137: 1-10; DOI: doi:10.3791/57493.	Points, 187,720	Data was coded as presence/absence. We used 'silt' to denote mud habitat; 'sand' and 'sandRipple' to denote sand habitat; 'gravel' to denote gravel habitat; 'cobble' to denote cobble habitat; and 'rock' to denote boulder habitat.
U.S. Geological Survey. 2014. U.S. Geological Survey East Coast Sediment Texture Database. U.S. Geological Survey, Coastal and Marine Geology Program. Woods Hole Coastal and Marine Science Center, Woods Hole, MA.	Points, 27,784	'Clay', 'silt', 'sand', and 'gravel' are coded as proportions. We used 'clay' and 'silt' together to denote mud category. If proportions were greater than zero, the sediment was assumed present. These data points were excluded from the cobble and boulder interpolations.
Barnhardt, W. A., Kelley, J. T., Dickson, S. M., & Belknap, D. F. 1998. Mapping the Gulf of Maine with side-scan sonar: a new bottom-type classification for complex seafloors. Journal of Coastal Research, 646-659.	Polygon, 10,312 sq. km	Polygons were coded with a capital and lowercase letter for dominant and subordinate substrate, respectively. If a habitat category was coded by either the dominant or subordinate substrate, it was assumed present. 'M' was used to denote mud habitat; 'S' for sand habitat; 'G' for gravel habitat; and 'R' was used to denote boulder habitat. In this dataset 'R' corresponds to rock outcrops which are different from boulder habitats occurring elsewhere in the domain.
Regional Sediment Resource Management Workgroup (2014). Work Group Report: 2014 Massachusetts Ocean Management Plan Update. Massachusetts Office of Coastal Zone Management, 57pp.	Polygon, 9,572 sq. km	Polygons were coded with a capital and lowercase letter for dominant and subordinate substrate, respectively. If a habitat category was coded by either the dominant or subordinate substrate, it was assumed present. 'M' was used to denote mud habitat; 'S' for sand habitat; 'G' for gravel habitat; and 'R' was used to denote boulder habitat. The data set used here was

		updated by the Regional Sediment Resource Management Workgroup in 2014.
Narragansett Bay Estuary Program. 2017. Chapter 13: Benthic Habitat, in State of Narragansett Bay and Its Watershed: 2017 Technical Report (pp 246 – 259). Providence, RI.	Polygon, 2,191 sq. km	Polygons annotated by 'mud', 'sand', and 'gravel' denote the presence of each. 'Gravel mixes' denote gravel, and 'Muddy sand' denotes presence of both mud and sand.
ACUMEN. 2012. Atlantic Canyons Undersea Mapping Expedition Project Summary. https://oceanexplorer.noaa.gov/okeanos/explorations/acumen12/welcome.html.[1]	Polygon, 165 sq. km	Boundaries of all polygons indicate presence of deep/rocky category. ACUMEN is a 25 m^2 resolution digital elevation model. To develop this data product, a slope dataset was derived from the DEM, and then cells with values equal to or greater than 30 degrees were selected and dissolved into polygons. These areas with steep slopes tend to have rocky outcrops suitable for attached sessile fauna and were shown to contain corals almost all the time when observed with remotely operated vehicles or towed cameras.

4 COLLABORATORS

The Fishing Effects Model was developed collaboratively by the New England Fishery Management Council's Habitat Plan Development Team and the Fisheries, Aquatic Science, and Technology Laboratory at Alaska Pacific University. Team members included:

- Michelle Bachman, NEFMC staff
- Peter Auster, University of Connecticut/Mystic Aquarium
- Jessica Coakley, Mid-Atlantic Fishery Management Council
- Geret DePiper, NMFS/Northeast Fisheries Science Center
- Kathryn Ford, Massachusetts Division of Marine Fisheries
- Bradley Harris, Alaska Pacific University
- Julia Livermore, Rhode Island Division of Marine Fisheries
- Dave Packer, NMFS/ Northeast Fisheries Science Center
- Chris Quartararo, NEFMC staff
- Felipe Restrepo, Alaska Pacific University
- T. Scott Smeltz, Alaska Pacific University
- David Stevenson, NMFS Greater Atlantic Regional Fisheries Office
- Page Valentine, U.S. Geological Survey
- Alison Verkade, NMFS Greater Atlantic Regional Fisheries Office

5 DATABASE DESIGN AND CONTENT

- Feature Class Name: Fishing Effects Sediment

[1] Polygons represent areas where the slope is greater than 30 degrees based on a 25 m resolution digital elevation model for the northeast U.S. canyon and slope region. Data come from a series of Atlantic Canyons Undersea Mapping Expeditions (ACUMEN) on NOAA's research vessels Hassler, Bigelow, and Okeanos Explorer. These mapping expeditions took place from February 2012 through August 2012.

- Total Number of Unique Features: 13,157
- Dataset Status: Complete
- Native storage format: ArcGIS feature class
- Feature Type: Polygon

Table 2. Data dictionary

Line	Name	Definition	Type	Size[1]
1	OBJECTID	Uniquely identifies a feature	OBJECTID	*
2	Shape	Geometric representation of the feature	geometry	*
3	GridID	Unique GridID field used to link across model datasets	Long	9
4	Mud	Proportion of grid cell classified as mud grain size	Double	18, 15
5	Sand	Proportion of grid cell classified as sand grain size	Double	18, 15
6	GrPe	Proportion of grid cell classified as granule or pebble grain size	Double	18, 15
7	Cobble	Proportion of grid cell classified as cobble grain size	Double	18, 15
8	Boulder	Proportion of grid cell classified as boulder grain size	Double	18, 15
9	StDeep	Proportion of grid cell classified as steep and deep	Double	18, 15
10	Diversity	Number of distinct sediment classes (mud-boulder)	Long	10
11	Density	Number of sediment points (does not account for polygon data inputs)	Long	10

[1] Size for type double fields refers to precision and scale

6 SPATIAL REPRESENTATION

- Geometry Type: vector polygon
- Projection
    - Reference System: GCS_North_American_1983
    - Horizontal Datum: North American Datum 1983
    - Ellipsoid: Geodetic Reference System 1980
- Geographic extent: -82.87 to -63.95, 22.14 to 47.13
- ISO 19115 Topic Category: environment, oceans, geoscientificInformation
- Place Names: Cape Cod Bay, Georges Bank, Gulf of Maine, Maine Inner Continental Shelf, Massachusetts Bay, New Jersey Continental Shelf, New York Bight, North Atlantic Ocean, Southern New England Shelf
- Recommended Cartographic Properties:
    - (Using ArcGIS ArcMap nomenclature)
    - Classified, Standard Deviation, with unique class for values = 0
        - Percent sediment type: Mud - 7 classes, color model R-G-B
            - 0 class: no color

        - 0 - 1%: 0-0-4
        - 1 - 15%: 59-15-112
        - 15 - 30%: 140-41-129
        - 30 - 44%: 222-73-104
        - 44 - 58%: 254-159-109
        - 58 - 100%: 252-253-191
    - Percent sediment type: Sand - 8 classes, color model R-G-B
        - 0 class: no color
        - 0 - 11%: 0-0-4
        - 11 - 27%: 59-15-112
        - 27 - 43%: 113-31-129
        - 43 - 59%: 182-54-121
        - 59 - 75%: 241-96-93
        - 75 - 91%: 254-175-119
        - 91 - 100%: 252-253-191
    - Percent sediment type: Granule and pebble - 6 classes, color model R-G-B
        - 0 class: no color
        - 0 - 4%: 0-0-4
        - 4 - 15%: 81-34-124
        - 15 - 25%: 182-54-121
        - 25 - 36%: 254-259-109
        - 36 - 100%: 252-253-191
    - Percent sediment type: Cobble - 5 classes, color model R-G-B
        - 0 class: no color
        - 0 - 2%: 0-0-4
        - 2 - 5%: 113-31-129
        - 5 - 9%: 241-96-93
        - 9 - 32%: 252-253-191
    - Percent sediment type: Boulder - 6 classes, color model R-G-B
        - 0 class: no color
        - 0 - 0.9%: 0-0-4
        - 0.9 - 6%: 81-34-124
        - 6 - 11%: 182-54-121
        - 11 - 16%: 251-136-97
        - 16 - 100%: 252-253-191
    - Percent sediment type: Steep/Deep - 4 classes, color model R-G-B
        - 0 class: no color
        - 0 - 0.5%: 0-0-4
        - 0.5 - 1%: 182-54-121
        - 1 - 20%: 252-253-191
- Scale range for optimal visualization:1,000,000 to 13,000,000

7 METHODS AND DATA PROCESSING

A map of sediment-based habitat categories was developed in order to apply habitat vulnerabilities across the Northeast region. Six habitat types were classified: mud, sand, gravel, cobble, boulder, and steep/deep. Except for steep/deep these habitat types were classified based on grain size. The steep/deep category was based on slope derived from a 25 m^2 resolution digital elevation model along the edge of the shelf and was included to account for corals found at depth that are highly susceptible to impact and require long recovery times. Steep/deep habitats classified according to these data likely indicate the presence of rock outcroppings in canyons and along the continental slope where organisms requiring hard substrates for attachment are likely to find suitable habitat.

A sediment profile was constructed for 5 km grid cells across the Northeast region that represented the proportional contribution of each sediment type found in the grid cell. The sediment profiles were produced from a compilation of six data sources listed in section 3. The table in that section provides metadata for each data source. Two were provided as GIS databases with point spatial geometry; four were provided with polygonal spatial geometry. The most substantial sediment database included in this analysis was optical assessments from camera surveys provided by the Marine Fisheries Field Research Group at the University of Massachusetts Dartmouth School for Marine Science and Technology, which included over 187,000 sediment points distributed primarily throughout Georges Bank and the Mid-Atlantic. To improve the spatial coverage of sediment data, additional sediment points were downloaded from U.S. Geological Survey databases (https://cmgds.marine.usgs.gov/publications/of2005-1001/htmldocs/datacatalog.htm). Polygonal sediment data was limited to coastal regions along Maine and Massachusetts, Narragansett Bay, and deep/rocky regions beyond 200 m depth.

Each of the data sources used a different sediment classification system. To standardize these classifications, the original sediment classifications were converted to a presence/absence representation of each of the six sediment types used in this analysis. Details are given in the table in section 3. A summary of the categories interpreted from each data source is provided below.

Table 3. Crosswalk between data source classification and Fishing Effects classification.

Data source	Mud	Sand	Granule/ Pebble	Cobble	Boulder	Steep/Deep
Bethoney & Stokesbury 2018 (point)	**Mud**	**Sand**	**Granule/Pebble**	**Cobble**	**Boulder**	*Not mapped using these data*
USGS 2014 (point)	**Clay or silt**	**Sand**	**Gravel**	*Not mapped using these data*	*Not mapped using these data*	*Not mapped using these data*
Barnhardt et al 1998 (polygon)	**Mud**	**Sand**	**Gravel**	*Not mapped using these data*	**Rock**	*Not mapped using these data*
MA CZM 2014 (polygon)	**Mud**	**Sand**	**Gravel**	*Not mapped using these data*	**Rock**	*Not mapped using these data*
NBEP 2017 (polygon)	**Mud or muddy sand**	**Muddy sand or sand**	**Gravel**	*Not mapped using these data*	*Not mapped using these data*	*Not mapped using these data*
ACUMEN 2012 (polygon)	*Not mapped using these data*	*Not mapped using these data*	*Not mapped using these data*	*Not mapped using these data*	*Not mapped using these data*	**Entire dataset used to represent this category**

Despite a wide variability in the spatial distribution of sediment information support, sediment profiles were estimated on a consistent 5 km grid. The goal was to ensure the sediment data aligned with the resolution of the fishing data. To accommodate this varying spatial resolution of the sediment data, three different methods were used to convert presence/absence sediment data to sediment profiles depending on the geometry and/or density of points within a grid cell. In grid cells with polygonal sediment data, a modified area-weighted approach was used to calculate the proportion of each sediment within a grid cell:

$$\phi_{i,s} = \frac{\sum_{j=1}^{n} \pi_{i,s,j}}{\sum_{s=1}^{6} \sum_{j=1}^{n} \pi_{i,s,j}}$$

where $\phi_{i,s}$ is the proportion of sediment, s, in grid cell, i; and $\pi_{i,s,j}$ is the area of the jth polygon of n total polygons within a grid cell. Note that if no single polygon represented multiple sediments, the denominator would simply be equal to the area of the grid cell and be a straightforward area-weighted calculation.

In grid cells with eight or more sediment points, a similar method was used, except instead of using an area-weighted approach, a count of points with sediments present was used to calculate $\phi_{i,s}$. The equation above was still the basis for the calculation, where *j* was an index of *n* total sediment points, and $\pi_{i,s,j}$ takes the value of 0 or 1 if sediment is absent or present, respectively.

In grid cells with less than eight points, an Ordinary Kriging spatial interpolation was first applied to the full domain to estimate the probability that each sediment was present at the center of a 2.5 km grid cells nested within the 5 km grid. This approach produced four estimations of sediment probabilities within each 5 km grid cell. Again, the equation above was used to calculate $\phi_{i,s}$ in these grid cells, where $\pi_{i,s,j}$ was the estimated probability of presence for sediment s, and $n = 4$ was fixed, which corresponded to the four 2.5 km grid center points within each 5 km grid cell. The Kriging analysis was conducted in R (ver. 3.4.3) using the *gstat* package (Gräler *et al.*, 2016[2]).

8 QUALITY PROCESS

- Attribute Accuracy: Attribute values are derived from authoritative metadata sources.
- Logical Consistency: These data are believed to be logically consistent.
- Completeness: The completeness of the data reflects the feature content of the data sources, and their associated metadata.
- Positional Accuracy: Positional accuracy may vary according to positioning methodology in the underlying data sources. Results are aggregated by Fishing Effects Model grid cell, with each cell having a resolution of 5 kilometers.
- Timeliness: Based on samples collected between 1934 and 2018.
- Use restrictions: Data are presented as is. Users are responsible for understanding the metadata prior to use. The New England Fishery Management Council shall be acknowledged as data contributors to any reports or other products derived from these data.

[2] Gräler, B., Pebesma, E., & Heuvelink, G. 2016. Spatio-Temporal Interpolation using gstat. The R Journal 8(1), 204-218.

- Distribution Liability: All parties receiving these data must be informed of all caveats and limitations.

9 CAVEATS AND DISCUSSION

- Areas outside SMAST, MA CZM, and Barnhardt data will miss occurrence of rock/boulder, if it exists
- Rock outcrops and boulder-sized gravel are not the same but are mapped as boulder
- Areas outside SMAST will miss occurrence of cobble, if it exists
- The ledges in the GOM seem to be showing larger areas of cobble and boulder habitat than may exist in reality. This may be because nearby areas have low data density/numbers of points.
- The methods used to generate the sediment data compiled by USGS often do not have the ability to sample the largest grain sizes, cobble and boulder. Therefore, even in areas of high point data density, these larger grain sizes may be under-represented. This could be occurring in Long Island Sound, Buzzards Bay, and Massachusetts Bay. While in general sediments are finer in the Mid-Atlantic Bight as compared to New England, there are localized areas of high data density (>7 points) associated with data from the USGS database along the coast of NJ, DE, MD, and NC as well. Other than these areas, locations with greater than 7 points per grid were surveyed with drop camera, capable of detecting the larger grain sizes.

10 REFERENCES

NEFMC (2011). Omnibus Essential Fish Habitat Amendment 2 Final Environmental Impact Statement. Appendix D: The Swept Area Seabed Impact (SASI) approach: a tool for analyzing the effects of fishing on Essential Fish Habitat. Newburyport, MA, New England Fishery Management Council: 257p.

NEFMC (2019). Fishing Effects Model Northeast Region. Newburyport, MA, New England Fishery Management Council: 109p.

Smeltz, T. S., B. P. Harris, J. V. Olson and S. A. Sethi (2019). "A seascape-scale habitat model to support management of fishing impacts on benthic ecosystems." Canadian Journal of Fisheries and Aquatic Sciences: **76**(10): 1836-1844.

11 FIGURES

Figure 1. Massachusetts Coastal Zone Management sediment map domain overlaid with 5x5 km grid.

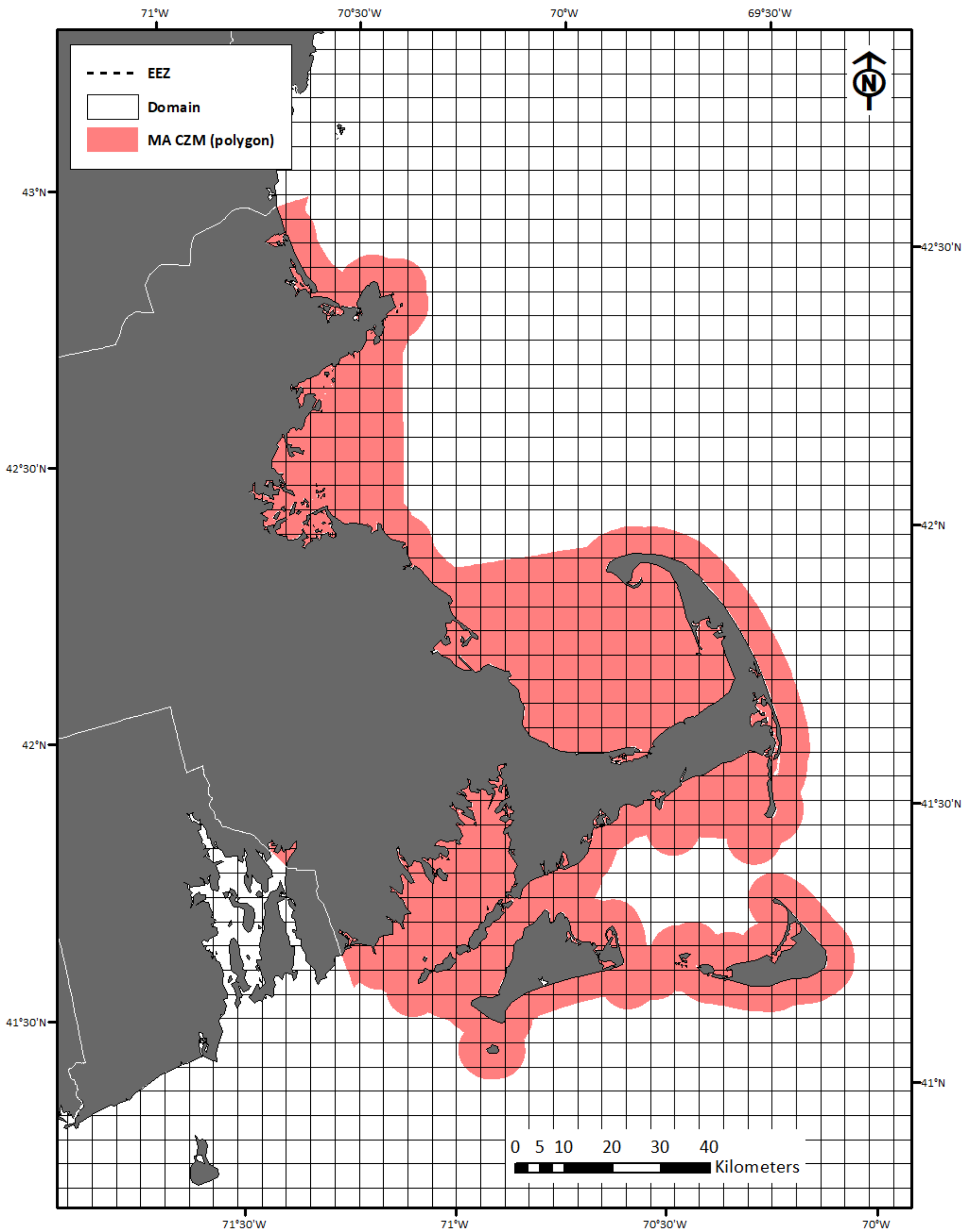

Figure 2. Maine Bottom Type Data sediment map domain overlaid with 5x5 km grid.

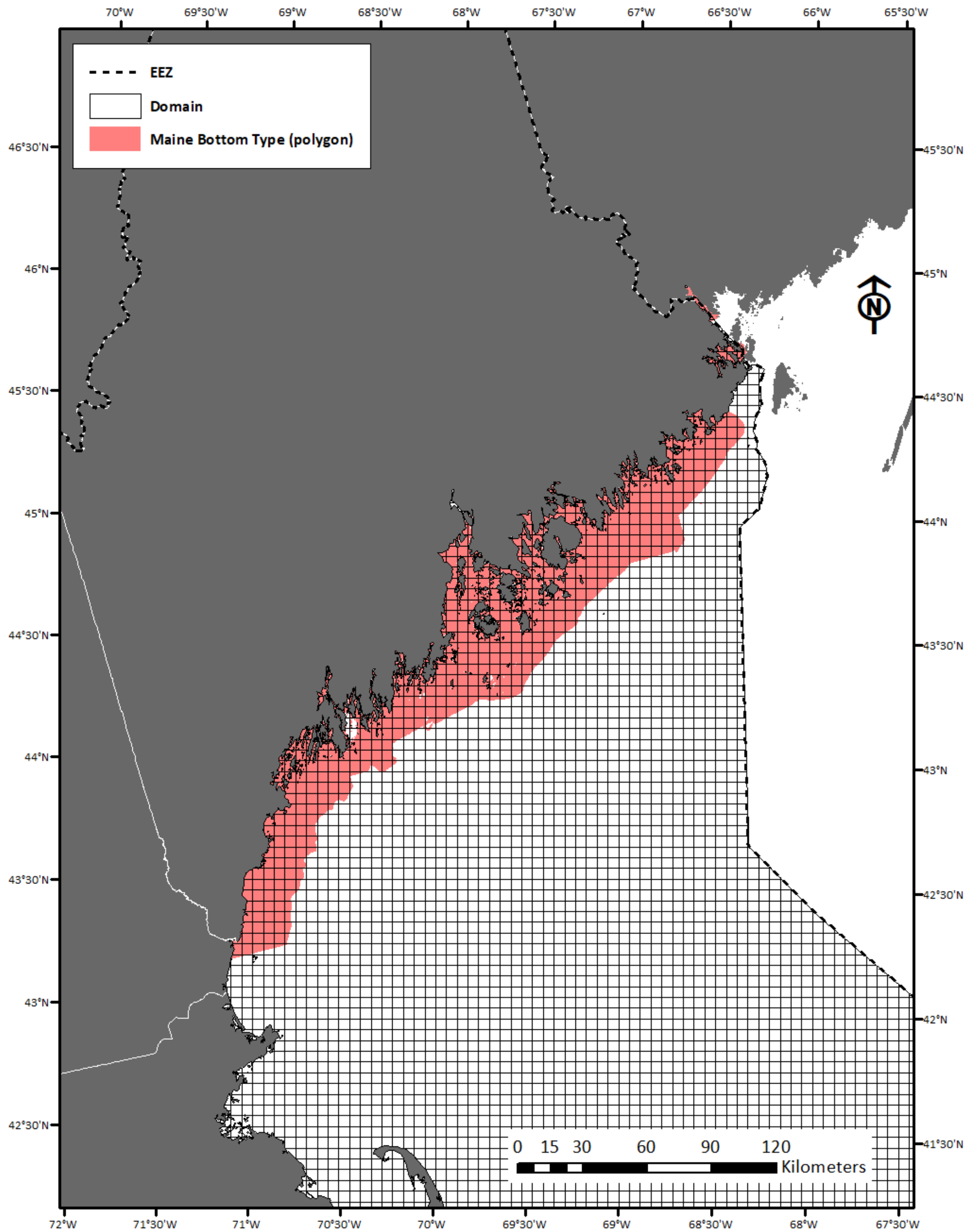

Figure 3. Narragansett Bay Estuary Program sediment map domain overlaid with 5x5 km grid.

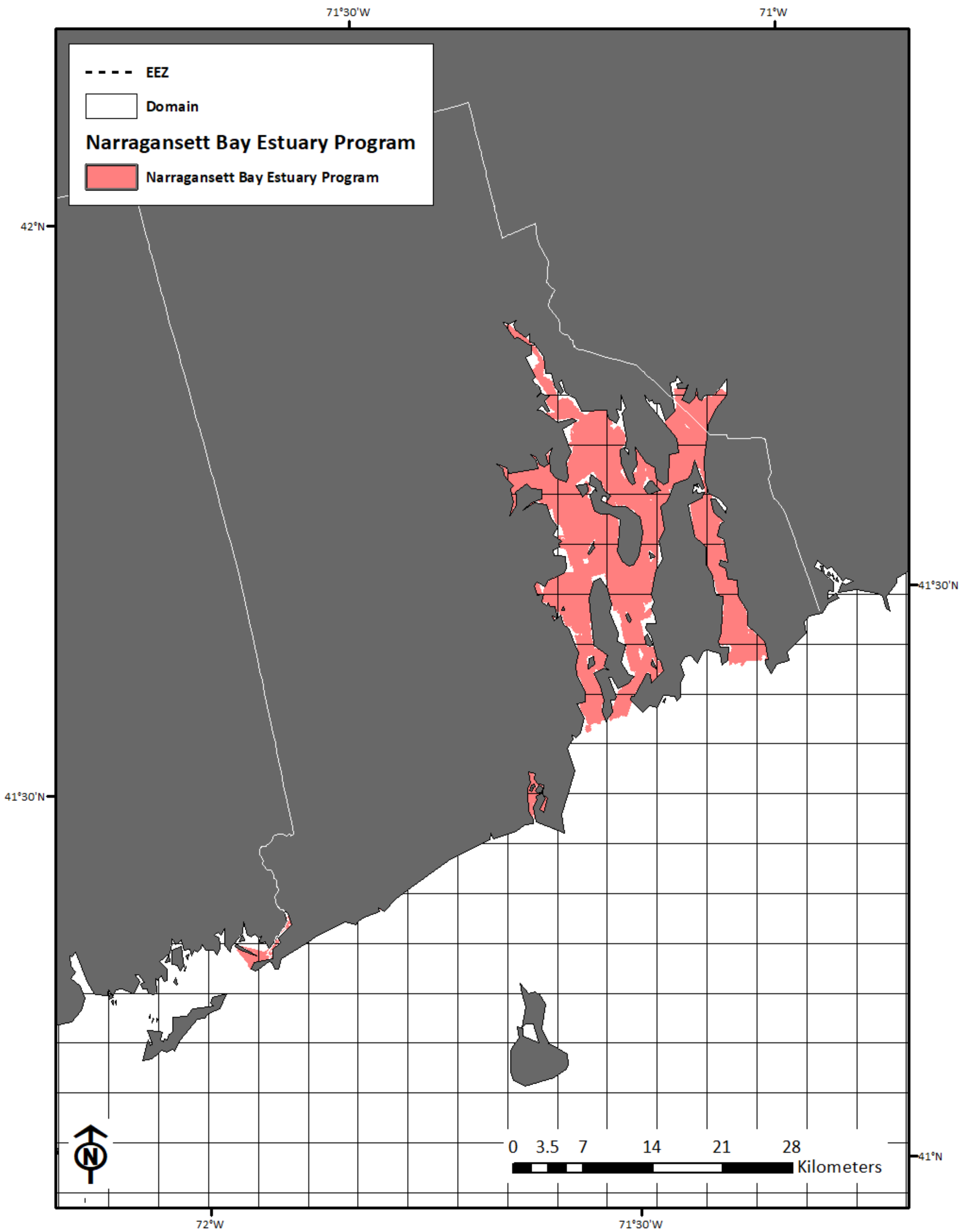

Figure 4. ACUMEN data overlaid with 5x5 km grid. Includes a 1 point border around the data to render them visible at this scale.

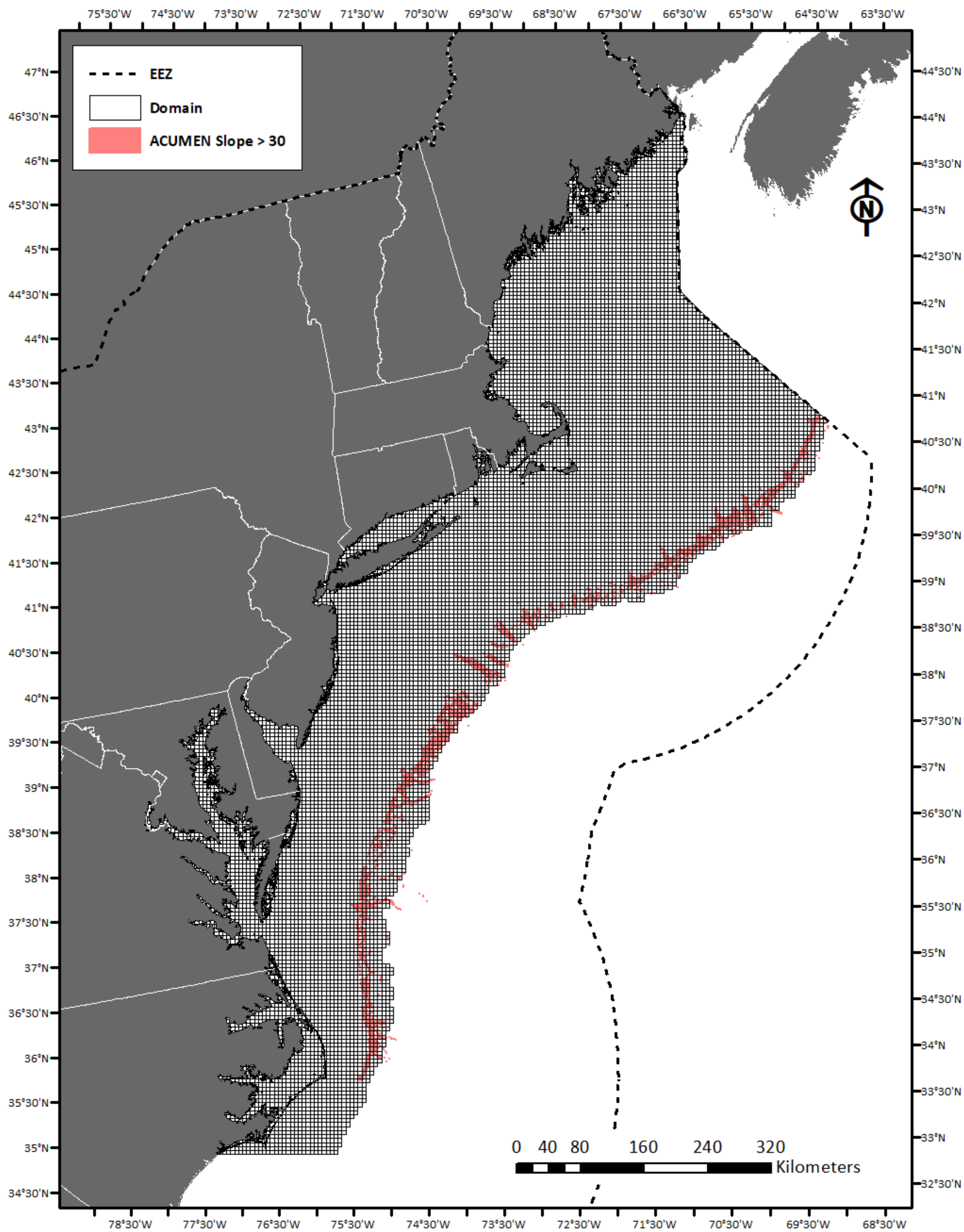

Figure 5. Data points from Bethoney and Stokesbury 2018.

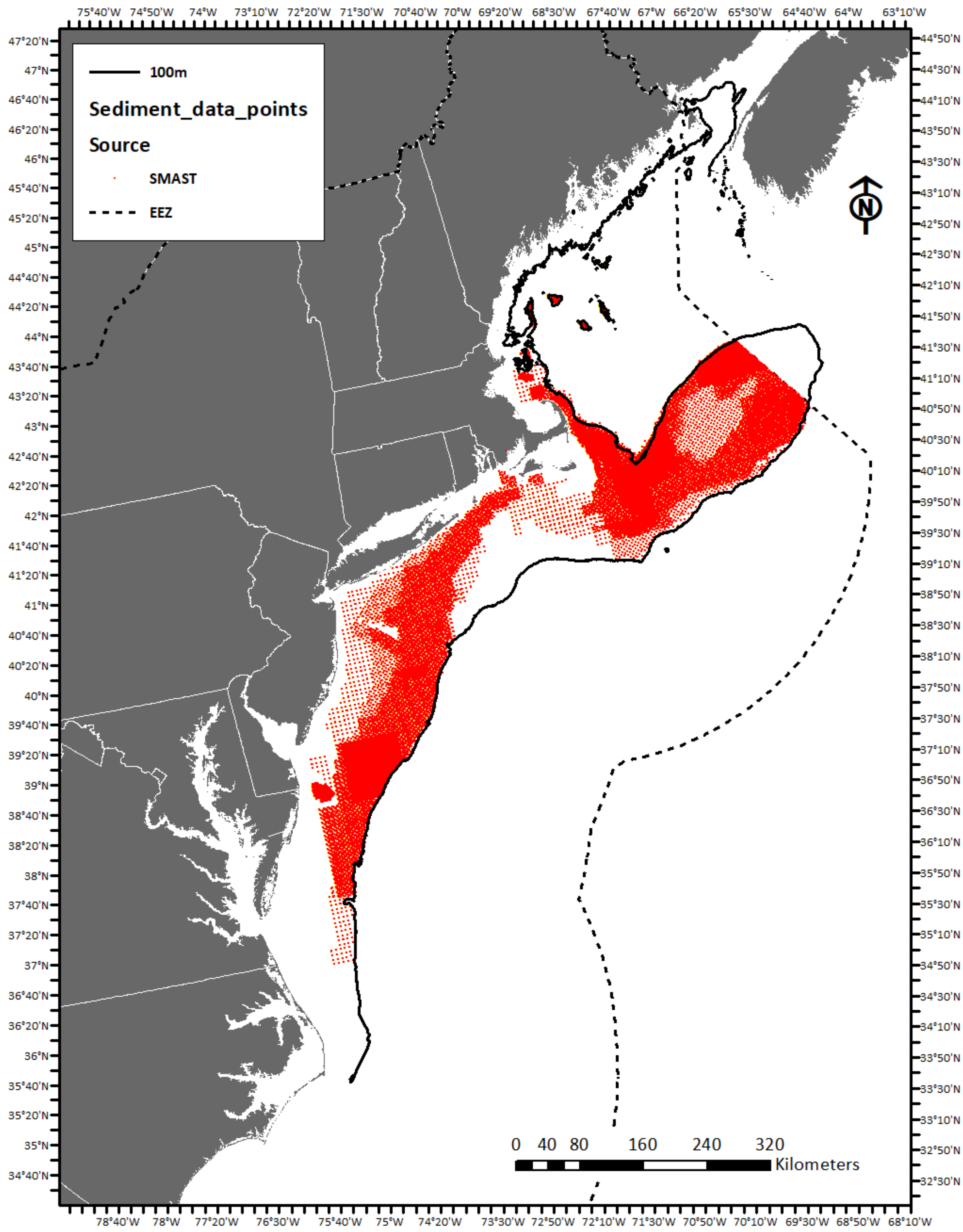

Figure 6. Data points from USGS 2014.

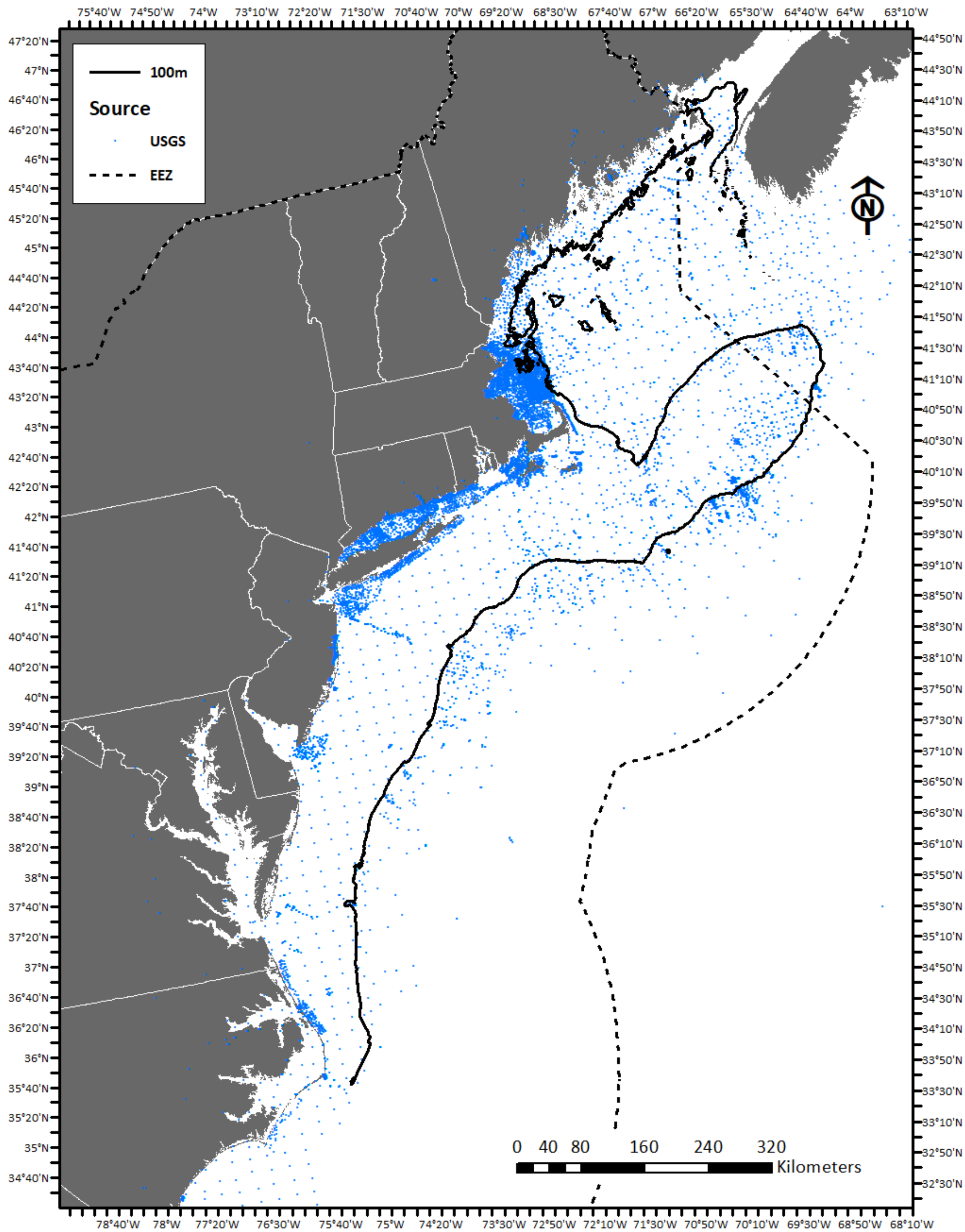

Figure 7. Percent mud by grid cell overlaid with 5x5 km grid. Zero values are not mapped.

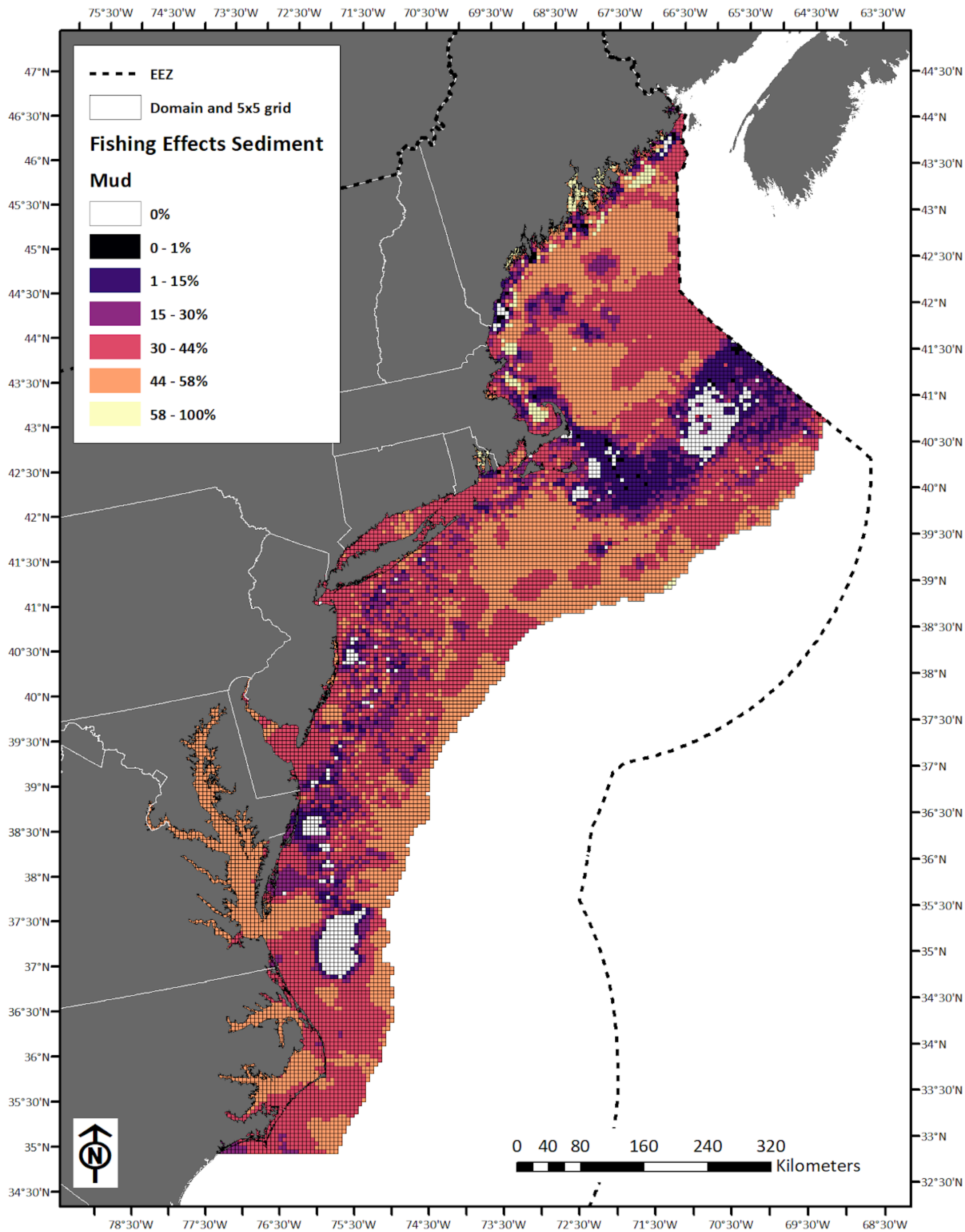

Figure 8. Percent sand by grid cell overlaid with 5x5 km grid. Zero values are not mapped.

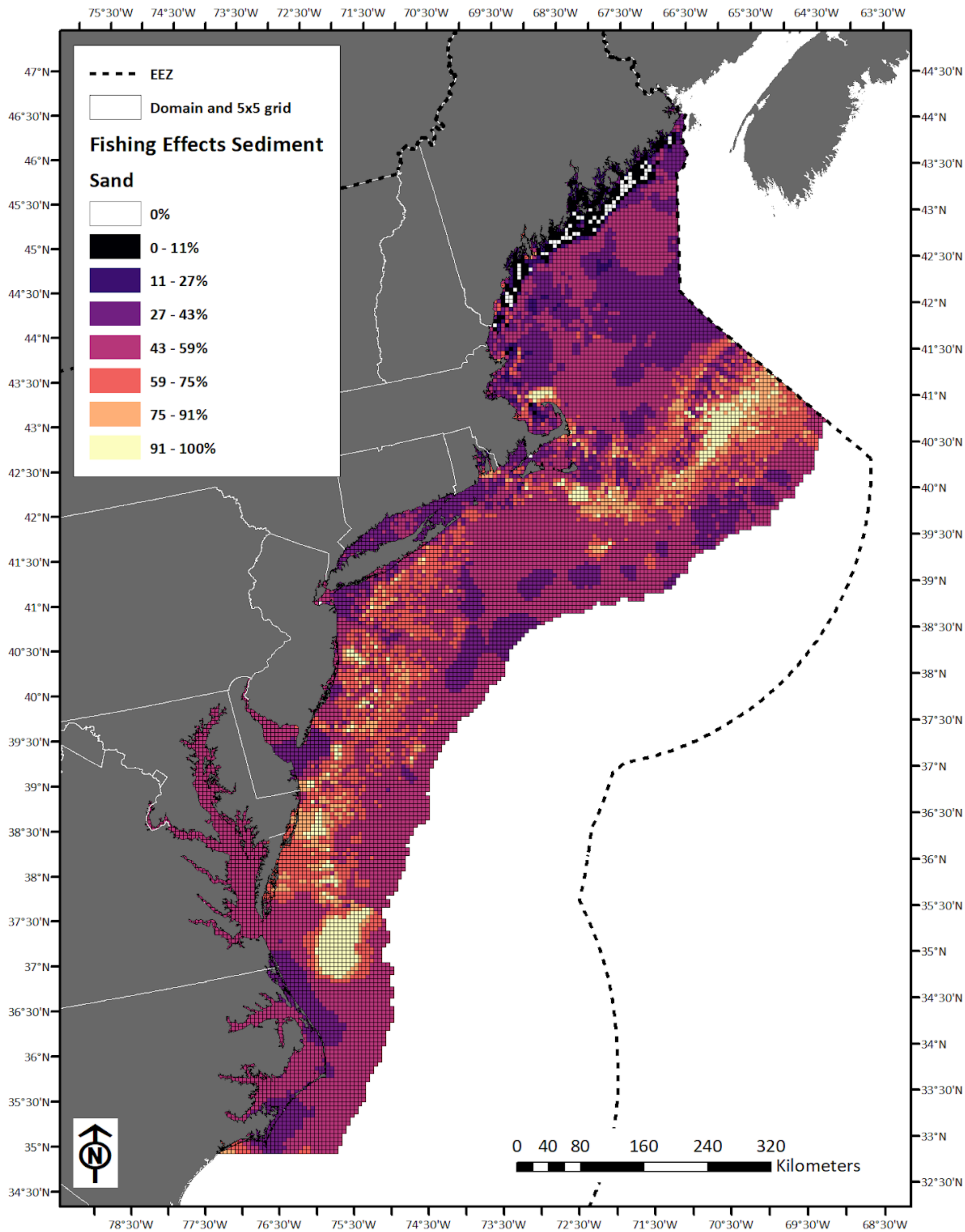

Figure 9. Percent granule/pebble by grid cell overlaid with 5x5 km grid. Zero values are not mapped.

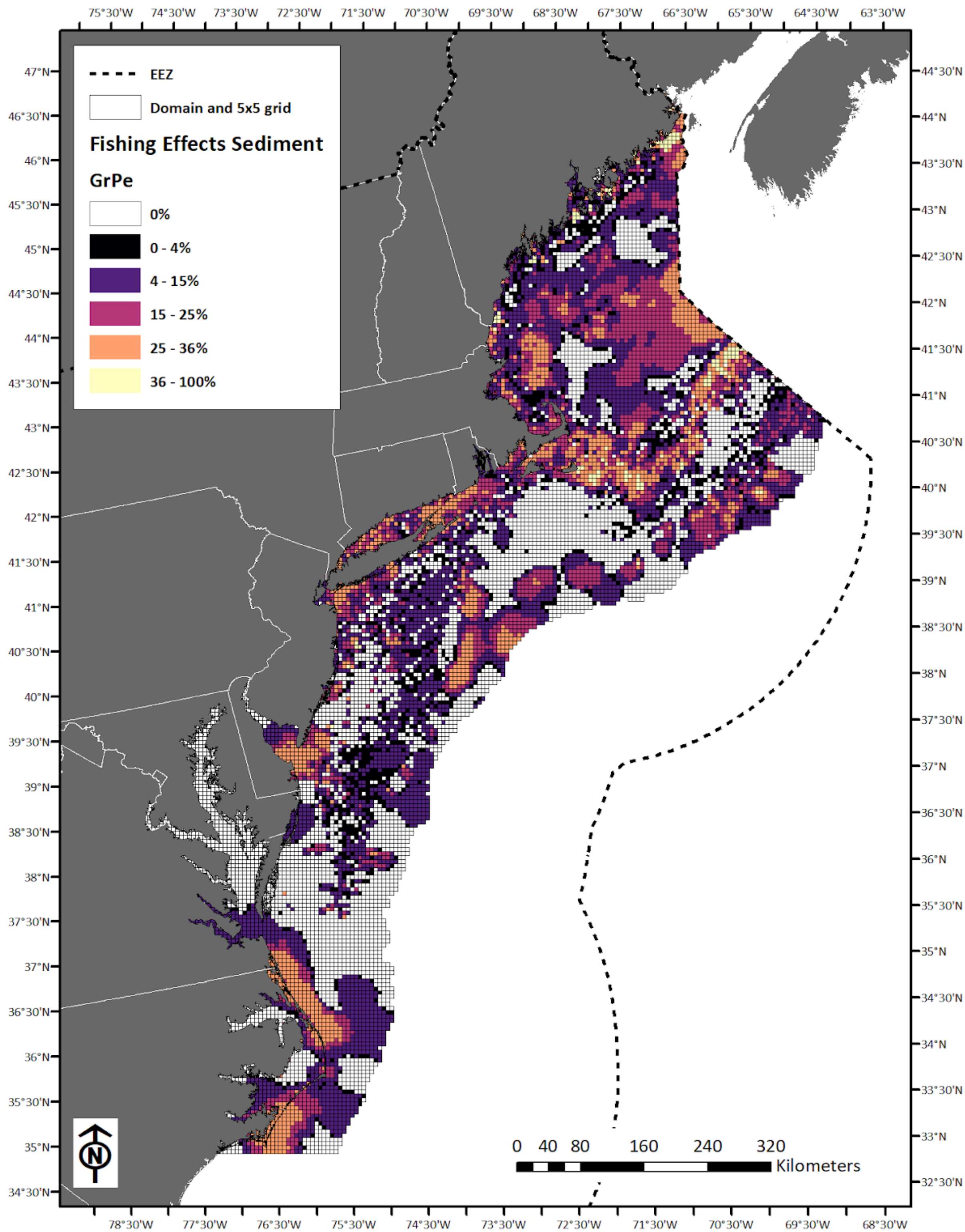

Figure 10. Percent cobble by grid cell overlaid with 5x5 km grid. Zero values are not mapped.

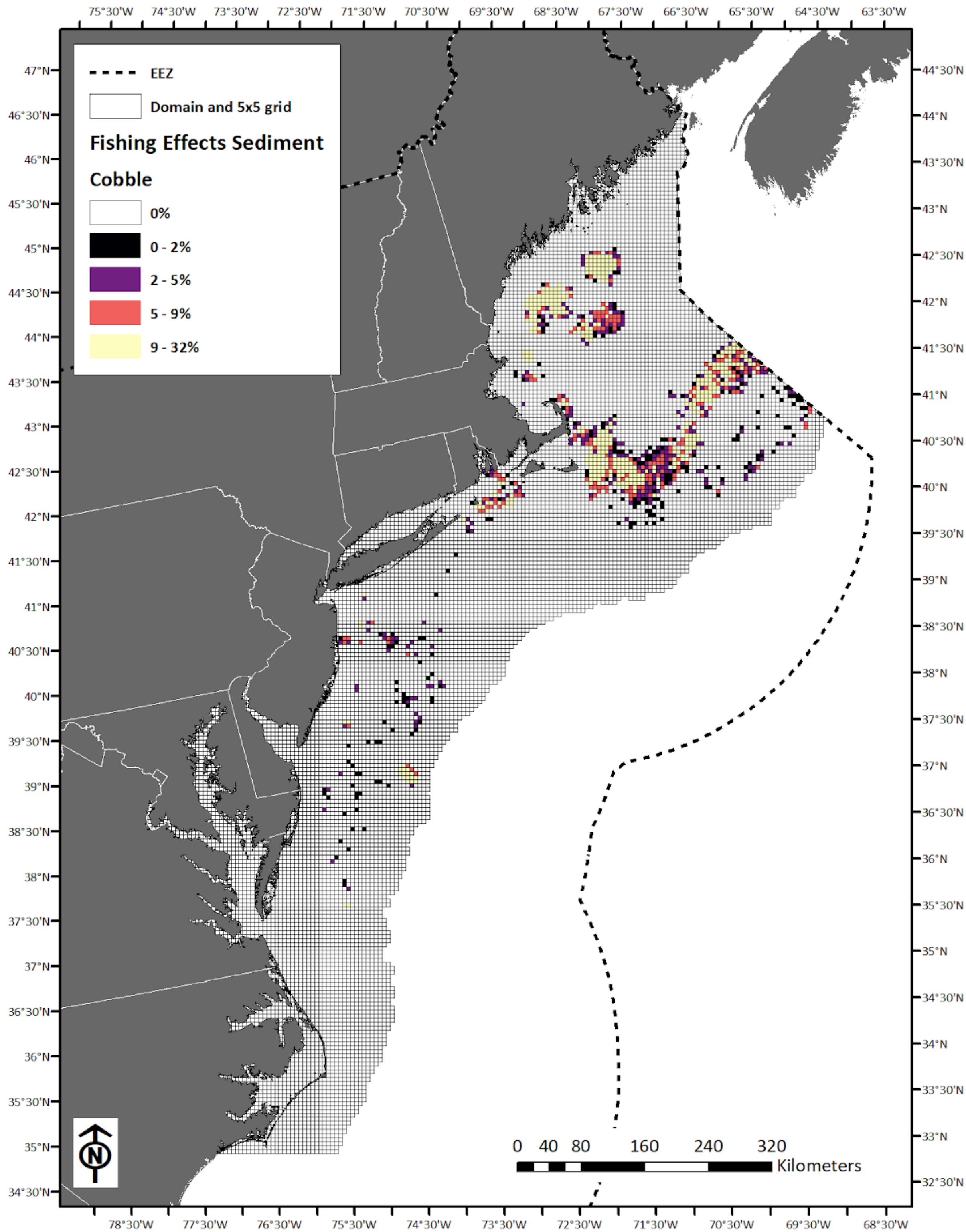

Figure 11. Percent boulder by grid cell overlaid with 5x5 km grid. Zero values are not mapped.

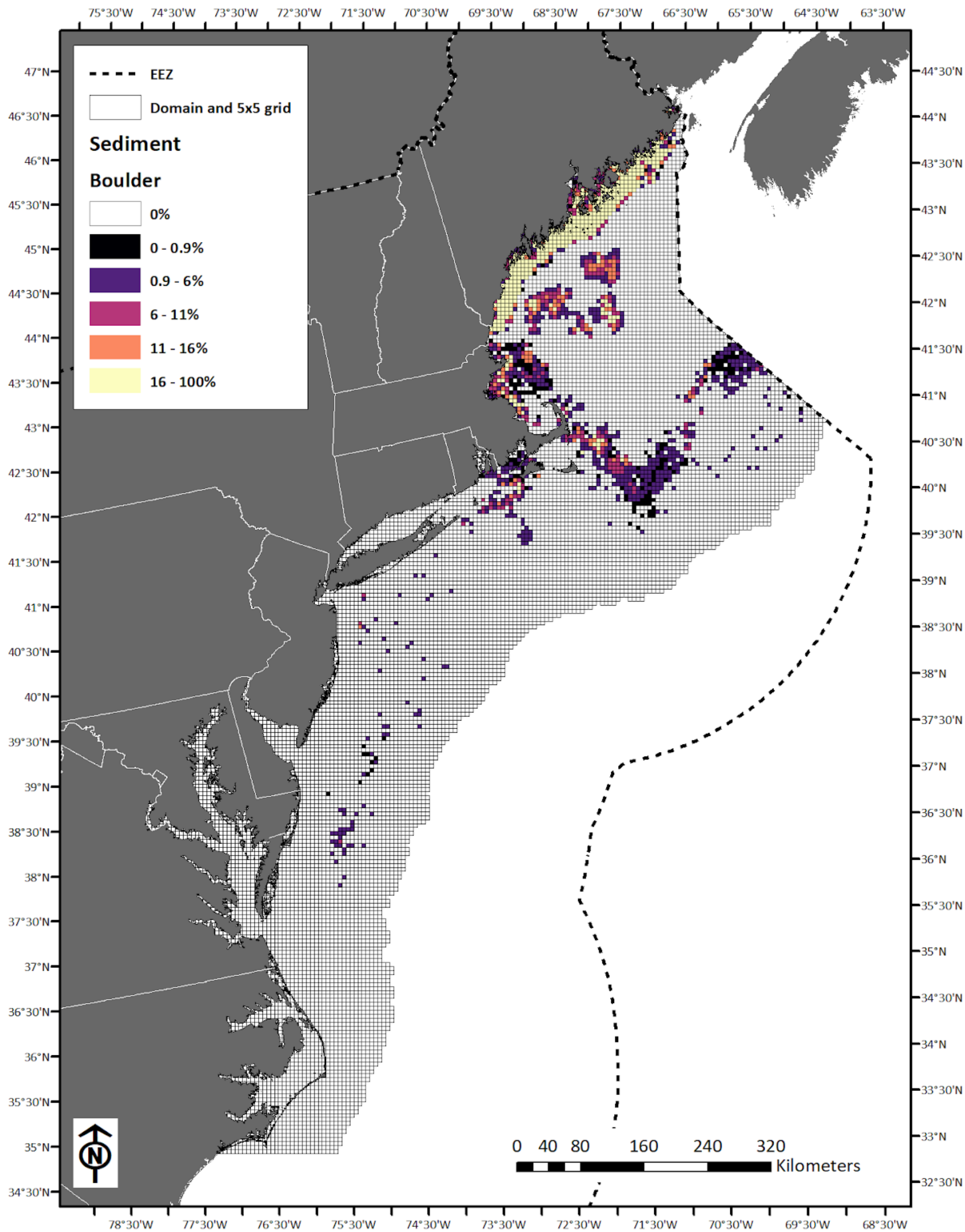

Figure 12. Percent steep and deep habitat by grid cell overlaid with 5x5 km grid. Zero values are not mapped.