Fishing Effects Model
Intrinsic Seabed Habitat Vulnerability to Fishing
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Prepared for:
Northeast Regional Ocean Council (NROC)
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1 INTRODUCTION

These datasets constitute a secondary set of outputs from the Northeast Fishing Effects Model (Fishing Effects). The 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. The model differentiates six types of bottom-tending fishing gears: trawl, scallop dredge, clam dredge, longline, gillnet, and trap. Data inputs and outputs to Fishing Effects are gridded at a 5 km by 5 km resolution, except for cells along the edge of the domain which are clipped to the coastline or Exclusive Economic Zone boundary and are therefore smaller. The model outputs are monthly estimates of percent seabed habitat disturbance for each of these six gear types, by grid cell, from 1996-2017.

Generally, the model domain extends north to south from the U.S./Canadian border to the N.C./S.C. border. While the base grid extends inshore to offshore from the coastline to the Exclusive Economic Zone boundary, the intrinsic vulnerability outputs extend only to the shelf break because this is the limit of fishing activity with bottom-tending gears in the northeast region. This is important because disturbance metrics summarized at the scale of the region rely on the total model footprint as the denominator, and these estimates are not meaningful percentages if total disturbance is reported over large areas that are not fished.

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 Magnuson-Stevens Fishery Conservation and Management Act requires regional fishery management councils to designate essential fish habitats (EFH) for all species managed. EFH means those waters and substrate necessary for spawning, breeding, feeding, and growth to maturity. The primary purpose of the fishing disturbance products is to inform spatial and gear-specific fishery management strategies related to minimization of adverse fishery impacts to essential fish habitats.

While the primary percent disturbance outputs from Fishing Effects rely on realized distributions of fishing effort between 1996 and 2017, the intrinsic seabed habitat vulnerability products apply a constant level of fishing disturbance across all grid cells of the model, at each monthly timestep. This type of product is of value to managers because fishing effort is influenced by numerous factors which are subject to change, including spatial closures that prohibit certain types of gear in specific locations. The intrinsic vulnerability products allow the Council to predict which areas would be vulnerable to impact, even in the absence of existing fishing pressure.

3 SOURCES AND AUTHORITIES

The data inputs of the Fishing Effects model include a benthic sediment/energy map and fishing effort as swept area. Metadata for the sediment map are described in a separate document. Energy classification is based on depth or benthic boundary shear stress data (see NEFMC 2011 for methods). Fishing effort data were obtained from the Northeast Fisheries Science Center, either from Vessel Trip Reports or Clam Logbooks (see summary below). Model parameters defining how fishing effort data are modified initially upon entering the model at a given time step, and how fishing effort decays over time, are described in NEFMC 2011, NEFMC 2019, and Smeltz et al 2019.

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: HabVuln_BottomTrawl_Median, HabVuln_Gillnet_Median, HabVuln_Hydrualic_Median, HabVuln_Longline_Median, HabVuln_Scallop_Median, HabVuln_Trap_Median
- Total Number of Unique Features: 10,871
- Dataset Status: Complete
- Native storage format: ArcGIS feature class

- Feature Type: Polygon

Table 1. Data dictionary

Line	Name	Definition	Type	Size[1]
1	FID	Uniquely identifies a feature	OBJECTID	*
2	Shape	Geometric representation of the feature	geometry	*
3	SP_ID	Sequential unique identifier	String	5
4	GridID	Unique GridID field used to link across model datasets	Long	9
5	Jan1996	Proportion of cell disturbed by all gears or an individual gear type at the end of January 1996	Double	23, 15
6	Feb1996	Proportion of cell disturbed by all gears or an individual gear type at the end of February 1996	Double	23, 15
Analogous format for months between Feb 1996-Dec 2017				
256	Dec2017	Proportion of cell disturbed by all gears or an individual gear type at the end of December 2017	Double	23, 15

[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
- IS0 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, Manual classification, 10 classes, color model: R-G-B
        - < 3%: 69-117-181
        - 3 - 6%: 110-143-184
        - 6 - 9%: 153-174-189
        - 9 - 12%: 192-204-190
        - 12 - 15%: 233-237-190
        - 15 - 18%: 255-233-173
        - 18 - 21%: 250-185-132
        - 21 - 24%: 242-141-97
        - 24 - 27%: 230-96-67

    - 27 - 30%: 214-47-39
- Scale range for optimal visualization:1,000,000 to 13,000,000

7 METHODS AND DATA PROCESSING

Overall Fishing Effects Model Approach

The Fishing Effects model disaggregates fishing effort by gear type and classifies habitat into six types based on five substrate types (mud, sand, granule-pebble, cobble, boulder), plus steep and deep habitats that are expected to contain deep-sea corals and other associated species (see other data available on the data portal to describe percent sediment composition of each grid cell, sediment data density, and sediment diversity). Geological and biological features are inferred to each of these habitat types (see NEFMC 2011, 2019 for details). With respect to a feature-gear-substrate-energy combination, 'vulnerability' represents the extent to which the effects of fishing gear on a feature are adverse. 'Vulnerability' is defined as the combination of how susceptible the feature is to a gear effect and how quickly it can recover following the fishing impact.

Specifically, susceptibility is defined as the percentage of total habitat features encountered by fishing gear during a hypothetical single pass fishing event that have their functional value reduced, and recovery is defined as the time in years that would be required for the functional value of that unit of habitat to be restored. However, because functional value is difficult to assess directly, and will vary for each managed species using the feature for shelter, feature removal or damage was used as a proxy for reduction in functional value. In order to make the susceptibility and recovery information work as a set of model parameters, the susceptibility and recovery of each feature-gear-substrate-energy combination were scored on a 0-4 scale as summarized in Table 2. Quantitative susceptibility percentages in the table indicate the proportion of features in the path of the gear likely to be modified to the point that they no longer provide the same functional value. Recovery does not necessarily mean a restoration of the exact same features, but that after recovery the habitat would have the same functional value.

Table 2. Susceptibility and recovery values. The score of 4 is only used in specific steep and deep habitat areas.

Code	Quantitative definition of susceptibility	Quantitative definition of recovery
0	0–10%	< 1 year
1	>10%-25%	1-2 years
2	25-50%	2 – 5 years
3	>50%	> 5 years
4	n/a	10-50 years

Susceptibility and recovery were scored based on information found in the scientific literature, to the extent possible, combined with professional judgment where research results are lacking or inconsistent. The approach is detailed in NEFMC 2011, including "rules" for matrix evaluation. Each matrix listed in Table 3 includes the features present in that particular substrate and energy environment, gear effects related to that gear type and feature combination, susceptibility and recovery for each feature, and the literature deemed relevant to assigning susceptibility "S" and recovery "R" for a particular feature and gear combination. A complete set of S-R matrices by gear type (otter trawl, scallop dredge, hydraulic dredge, longline, gillnet, and trap) can be found in NEFMC 2019. These were updated slightly from the versions used in the original SASI model (NEFMC 2011).

Table 3. Matrices evaluated. Each substrate-type matrix included both energy environments and all associated features.

Gear type	Mud	Sand	Granule-pebble	Cobble	Boulder	Deep-sea coral
All trawl gears	X	X	x	X	X	X (New)
Scallop dredge	X	X	X	X	X	
Hydraulic dredge	-	X	X	X (New)	X (New)	
Longline	X	X	X	X	X	X (New)
Gillnet	X	X	X	X	X	X (New)
Trap	X	X	X	X	X	X (New)

In order to quantify fishing effort in like terms and compare the relative effects of different fishing gears, fishing effort inputs to the Fishing Effects model (e.g. number of trips, tows, sets) are converted to area swept in km^2, regardless of gear type. Simple quantitative models convert fishing effort data to area swept. These models provide an estimate of contact-adjusted area swept, measured in km^2 and are unchanged from the original SASI model. They are documented in NEFMC 2011 and NEFMC 2019 Appendix A. Regardless of gear type, the area swept models have three requirements:

- Total distance towed, or, in the case of fixed gears, total length of the gear;
- Width of the individual gear components; and
- Contact indices for the various gear components.

Fishing activity in the northeast region is documented using various methods, including vessel trip reports (often referred to as logbooks), satellite-based vessel monitoring systems, and at-sea observations by scientific personnel. The trip footprints used for Fishing Effects rely on positions (roughly one per trip) in vessel trip reports, or for clam trips, clam logbooks, with the estimated spread of fishing activity from that point estimated using other spatial data on fishing activity, including at-sea observer and vessel monitoring system. These trip-level footprints were developed using modeling approach that is routinely used for various fisheries management applications in the northeast region (DePiper 2014, Benjamin et al. 2018). Once tables of area swept values from individual trips were generated, they were joined with spatial data products that estimate the footprint of each trip, and area swept was distributed over this footprint.

Spatial datasets in raster format were prepared by overlaying the swept area footprints for a specific gear type and month, based on the date sailed of each trip. Finally, these monthly gear-specific rasters were joined to the 5x5 grid in order to serve as inputs to the Fishing Effects model.

Intrinsic Seabed Habitat Vulnerability to Fishing products

In order to select the level of disturbance to apply as the default, real fishing effort data were examined to understand typical swept area values associated with each gear type. Two model runs were completed for each gear type, one based on the median value of swept area ratio and one based on the 95% quantile. The swept area ratios for each gear, as well as the resulting mean and standard deviation habitat disturbance values, are shown in Table 4. A swept area ratio of 1 means that 100% of the grid cell is contacted each year, a value of 0.50 means half the grid is contacted, and a value of 2 means that the grid is swept twice, or 200%. Results are only generated for full grid cells (25 km^2). Putting the same amount of swept area into smaller partial/edge grids inflates the disturbance estimates for these grids. The results for median values in the terminal month of the model (December 2017) are shown on the data portal. All data sets are shown using the same color ramp, to allow for a comparison between gears.

Table 4. Intrinsic habitat vulnerability analysis effort inputs and summary statistics

Gear type	Effort calculation	Swept Area Ratio (year^{-1} grid^{-1})	Mean habitat disturbance	Standard deviation habitat disturbance
Bottom Trawls	Median	0.17	26%	13%
	95% quantile	4.7	88%	2.4%
Scallop dredge	Median	0.015	4.5%	9.9%
	95% quantile	1.06	68%	7.6%
Hydraulic dredge	Median	0.0022	1.2%	6.1%
	95% quantile	0.090	18%	13%
Traps	Median	3.0e-4	0.2%	2.8%
	95% quantile	0.047	6.5%	11%
Longlines	Median	2.8e-4	0.2%	2.7%
	95% quantile	0.021	3.5%	8.9%
Gillnets	Median	7.7e-5	0.1%	2.8%
	95% quantile	0.0051	1.3%	6.4%

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. Note that Vessel Trip Reports often represent each fishing trip by a single latitude/longitude. Results are aggregated by Fishing Effects Model grid cell, with each cell having a resolution of 5 kilometers.
- Timeliness: Based on sediment samples collected between 1934 and 2018 and fishing activity occurring between 1996 and 2017.
- 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.
- Distribution Liability: All parties receiving these data must be informed of all caveats and limitations.

9 CAVEATS AND DISCUSSION

The intrinsic habitat vulnerability model outputs indicate locations within the region that are relatively more or less vulnerable to impact from a particular type of fishing gear. Larger values indicate that a greater percentage of the seafloor in a given grid cell is estimated to be impacted by a median level of impact based on swept area for that gear type. Similarly, smaller percentages indicate a lower area of impact. On the data portal, all gear types are shown using the same color scale. While this does not show the fine spatial differences in vulnerability between grid cells, this visualization was chosen to facilitate comparison among gears. The first bin in the data is for values of less than 3% disturbance, such that the domain appears uniformly vulnerable for four of the six gear types. While there are modeled differences below a 3% level, those differences are not thought to be especially meaningful from a management perspective; therefore, they are not shown. That being said, there is no formally established threshold percentage indicating severe or significant vulnerability in a management context. During development of the New England Fishery Management Council's Omnibus Habitat Amendment 2, similar outputs of the Swept Area Seabed Impact model were used in a relative sense, to highlight gears and locations to consider for impact minimization efforts.

In considering how these model outputs relate to real-world fishing activity, it is important to recognize that while fishing is distributed broadly across the Northeast-shelf region, activity with specific gear types is typically concentrated spatially. The intrinsic vulnerability results can be contrasted with the percent disturbance results to get a sense of the difference between the expected effects from moderate, uniform levels of fishing as compared to the percentages of disturbance that result from real-world concentrations of effort. Because the Fishing Effects model allows for recovery from disturbance, the percent disturbance will eventually trend toward zero in the absence of fishing effort. Since the intrinsic vulnerability analysis continually adds fishing activity to each grid cell, habitat disturbance is never entirely eliminated and these model outputs indicate at least low levels of disturbance throughout the domain.

Habitat types are heterogeneously distributed in space (see related sediment data products). The vulnerability assessment conducted to support the precursor to Fishing Effects, the Swept Area Seabed Impact model, indicates that the living and nonliving features that occur in these different habitats have varying levels of susceptibility to fishing, and varying rates of recovery. Absent spatial variation in fishing effort, these underlying habitat distributions and assumed susceptibility and recovery rates drive spatial differences in percent disturbance. Thus, uncertainty and errors in the spatial distribution of habitats, the magnitude of susceptibility, and the duration of recovery will all affect the outputs of the model. During model development, sensitivity analyses were conducted to explore the influence of changing susceptibility and recovery parameters on model outputs (see section 7.2 of the model report, NEFMC 2019). Given the various data inputs, and the resolution of the grid, the results of the model are best considered at a regional scale, for areas of hundreds to thousands of square kilometers in size.

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

Additional related figures are available in the model report.

Figure 1. Intrinsic seabed habitat vulnerability to bottom trawls, based on a median level of impact evenly distributed across all areas.

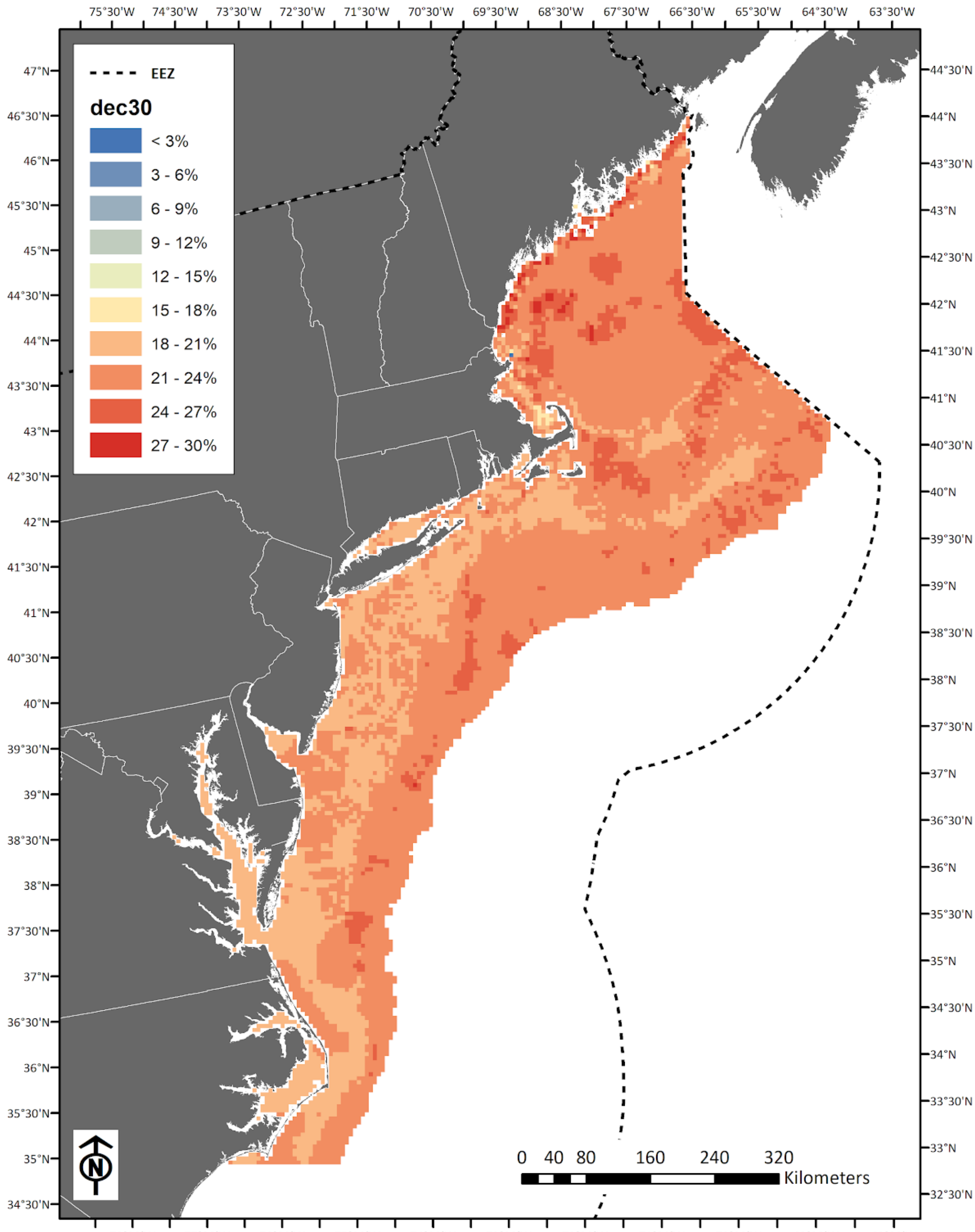

Figure 2. Intrinsic seabed habitat vulnerability to scallop dredges, based on a median level of impact evenly distributed across all areas.

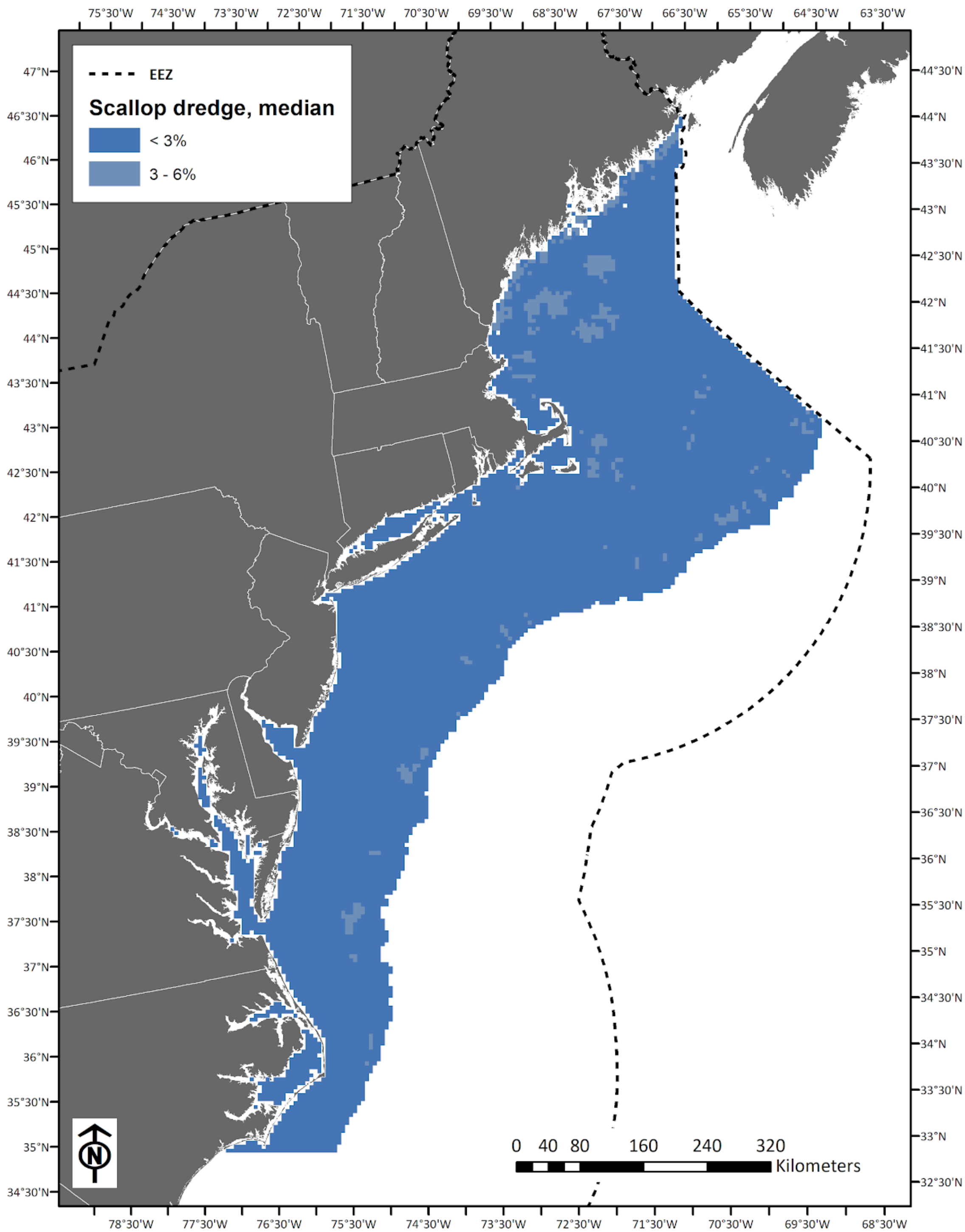

Figure 3. Intrinsic seabed habitat vulnerability to all other gear types, based on a median level of impact evenly distributed across all areas.