Supplementary Appendix 1 for

A Scientific Basis for Designation of the Northeast Canyons and Seamounts Marine National Monument

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METHODS FOR SPATIAL ANALYSES IMPLEMENTED TO PRODUCE THE MAP PRODUCTS

Details of study area inclusive of strawman, proposed and designated boundaries

The Canyons and Seamounts region had been advanced as a potential site for designation as a marine national monument by a coalition of environmental non-governmental organizations (NGOs; McMurray 2016, Skahill 2016). An official request to the President, from the Connecticut congressional delegation, subsequently modified the strawman boundaries (Blumenthal et al. 2016). In all cases the focus area was along the southern margin of Georges Bank and inclusive of four adjacent seamounts within the US EEZ (see Figure 1; references to figures in this supplement refer to those in the main paper). This region had been identified as ecologically important and sensitive to disturbance in multiple forums designed to identify priority areas of conservation concern (Jegalian 1999, Speer et al. 2001). In the current study our goal was to characterize the ecological setting of the proposed monument and surrounding region. We conducted an analysis of the spatial variability of multiple ecological attributes within a study area, determined a priori, in order to visualize and quantify the conservation potential for the proposed and any subsequent boundaries for protection within the larger marine landscape.

The study region bounding coordinates (in decimal degrees) are: 39.99772836, -65.00634557; 38.7682665, -67.06045951; 40.40018971, -68.90944345; 40.76667509, -68.91666647; 41.6666753, -67.71666612; 41.64305995, -66.2875258.

The strawman monument bounding coordinates from environmental NGOs are as follows: Northern Unit: 40.7580N, -66.7970W; 41.0660N, -66.4820W; 41.2326N, -66.3593W; 40.9945N, -66.1572W; 40.5959N, -66.5804W. Southern Unit: 39.8280, -66.0160W; 39.7660N, -66.0580W; 39.1810N, -67.1400W; 40.1220N, -68.2120W; 40.5270N, -68.2680W; 40.6000N, -67.6280W; 40.2070N, -67.5780W; 39.9600N, -66.2650W.

The proposed bounding coordinates from the Connecticut Congressional delegation are: Canyons Unit 41.1730N, -66.3086W; 41.1619N, -66.2992W; 40.9945N, -66.1572W; 40.5959N, -66.5804W; 40.2070N, -67.5780W; 40.1220N, -68.2120W; 40.2354N, -68.2276W; 40.5270N, -68.2680W; 40.6000N, -67.6280W; 40.3880N, -67.6010W; 40.4152N -67.4902W; 40.5248N, -67.4377W; 40.4770N, -67.3333W; 40.5375N, -67.1519W; 40.6589N, -67.0256W; 40.6264N, -66.9611W; 40.7540N, -66.7917W; 40.7580N, -66.7970W;

41.0660N, -66.4820W; 41.2326N, -66.3593W; 41.1730N, -66.3086W. Seamounts Unit 38.8661N, -66.9314W; 40.0439N, -67.7221W; 39.9399N, -65.9459W.

Final designated bounding coordinates from the monument proclamation are: Canyons Unit 40.122N, -68.212W; 40.527N, -68.268W; 40.600N, -67.628W; 40.207N, -67.578W. Seamounts Unit 38.865N, -66.931W; 39.939N, -65.943W; 40.044N, -67.722W. The U.S. EEZ limit forms the eastern boundary of the Seamount Unit.

Analysis of Seafloor Morphology and Benthic-Demersal Fauna

A topographic roughness index (TRI) was calculated for the study region as an indication of small-scale bathymetric roughness by measuring change in seafloor elevation from a central point to contiguous points (sensu Riley et al. 1999). To calculate TRI for the complete shelf margin around the CLC and CSM study areas, a 3 arc second digital elevation model was created in ArcGIS using the following data sets and projected into North American Datum 1983 UTM Zone 19 North: (1) 3 Arc Second Digital Elevation Model of the Gulf of Maine (U.S. Geological Survey Open-File Report 2011-1127), and (2) seafloor bathymetry with hillshade for the U.S. Atlantic Continental Margin (University of New Hampshire and its Center for Coastal and Ocean Mapping/Joint Hydrographic Center - (c) 2012).

The Geospatial Data Abstraction Library (GDAL) toolset was then used with the open source geospatial software OSGeo4W to implement TRI analysis of the bathymetric mosaic DEM of the Gulf of Maine. Specifically, the difference in elevation between each centroid and neighboring cell was calculated, summed and divided by 8 (the total number of cells). The resulting distribution of TRI values from the study region was assessed to identify natural breaks (Chen et al. 2013) and parsed into six bins (Figure 2A).

Benthic data used for species richness analysis and coral presence in this study were a summation of taxonomic observations of demersal and epifaunal communities (fish and invertebrates) from seven relevant datasets spanning the time period from 1881 to present in the Gulf of Maine, New England shelf, slope, canyon and seamounts areas[i.e., for deep sea coral taxa data inclusive of the late 1800s through recent cruise data to 2015 from the study area (described in NEFMC 2019), NOAA Northeast Fisheries Science Center Benthic Database 1953-1984 for infaunal and epifaunal benthic taxa (NEFSC 2010), East Coast of North America Strategic Assessment Program (ECNASAP) 1970-1995 trawl survey data (Brown et al. 2005), aggregate datasets from diverse sampling programs along continental margin region (Kelly et al. 2010), fish, coral and decapod taxa from 2013 ROV dives in canyons and seamounts region (Quatrini et al. 2015), NOAA Ship Okeanos Explorer 2014 dive logs from study region (NOAA Exploring Atlantic Canyons and Seamounts unpublished dive logs), and aggregate data from archived and recent submersible and ROV still and video imagery in study region for 1978-2013 (described in Kilgour et al. 2016)]. All datasets were combined into an aggregate spreadsheet and pivot table in .xlsx file format, maintaining much of the original metadata including sample date, geographic position (in decimal degrees), water depth, ancillary water quality measurements and taxonomic identifications in a consistent format and plotted in ArcGIS (v. 10.3.1. and projected into North American Datum 1983 UTM Zone 19 North). In some cases, relevant fields from original datasets were renamed accordingly for consistency across the spreadsheet and the data crosswalk. The level of taxonomic identification differed among and within datasets and thus, unique observations at each level were counted only once. Coral species were then identified using a Boolean numbering system. Overall, there were 25,940 taxonomic observations in the cumulative data set including 2,370 unique taxa, respectively.

Known Species Richness: Using the aggregate benthic dataset, all taxonomic observations were identified to the lowest possible taxon and plotted in ArcGIS v. 10.3.1. and projected into North American Datum 1983 UTM Zone 19 North. The study area was trimmed to 8 km X 8 km grid cells that contained the 100 m isobath to avoid comparisons with species and communities bounded by shallower depths that were outside the proposed monument region (Auster and Shackell 1997; see grid pattern in Figure 2b and c). Species richness was calculated with Arc Toolbox to extract the taxa per grid cell and recorded in a table to list unique observations within each cell. The numeric values of species richness were then used to produce a color ramp in ArcGIS (Figure 2B). For the CSM region, 255 grid cells contained species data. The remainder of cells in each study area were designated ND for no data.

Coldwater Corals Presence: Using the unique species occurrences per 8 km x 8 km grid cell from the larger benthic data set, individual taxonomic observations of corals were assigned a Boolean value of 1 accordingly, color coded and plotted as coral presence in ArcGIS (Figure 2C).

Marine Mammal Analyses

Marine mammal sightings data was acquired from the North Atlantic Right Whale Consortium (NARWC) database) from the years 1963 - 2014 and includes the 26 species or species groupings: Beaked Whale (*Mesoplodon*/*Ziphius* sp.), Blue Whale (*Balaenoptera musculus*), Bottlenose Dolphin (*Tursiops truncates*), Fin Whale (*Balaenoptera physalus*), False Killer Whale (*Pseudorca crassidens*), Risso's Dolphin (*Grampus griseus*), Harbor Porpoise (*Phocoena phocoena*), Humpback Whale (*Megaptera novaeangliae*), Killer Whale (*Orcinus orca*), Minke Whale (*Balaenoptera acutorostrata*), Northern Bottlenose Whale (*Hyperoodon ampullatus*), Pilot Whale (*Globicephala* sp.), Pygmy Killer Whale (*Feresa attenuat*), North Atlantic Right Whale (*Eubalaena glacialis*), Common Dolphin (*Delphinus delphis*), Sei Whale (*Balaenoptera borealis*), Spinner Dolphin (*Stenella longirostris*), Spotted Dolphin (*Stenella attenuata*/*frontalis*), Sperm Whale (*Physeter macrocephalus*), Striped Dolphin (*Stenella coeruleoalba*), Unidentified Blackfish, Pygmy or Dwarf Sperm Whale (*Kogia* sp.), White-Beaked Dolphin (*Lagenorhynchus albirostris*), Atlantic White-Sided Dolphin (*Lagenorhynchus acutus*), Unidentified Dolphin or Porpoise, Unidentified Whale. These data were collected during aerial and shipboard surveys, including both on and off survey lines, and opportunistic sightings.

Some species were grouped to the genus level due to the possibility of misidentification and/or the difficulty in identifying to the species level. For example Cuvier's Beaked Whale (*Ziphius cavirostris*), Sowerby's Beaked Whale (*Mesoplodon bidens*), True's Beaked Whale (*Mesoplodon mirus*), and Unidentified Beaked Whale were all grouped into the category Beaked Whale.

Data was provided in .xlsx file format and included sighting location latitude, longitude, species sighted, and number of animals present at that sighting. Provided data resulted in 7,422 sightings records (5,099 in the CSDAA; 2,323 from CLDAA).

Survey effort was relatively high and consistent along the shelf edge and over the top of Georges Bank, is inconsistent and sparse over the abyssal plain, and higher, but limited around the peaks of the seamounts. All systematically collected sightings data was supplemented with opportunistic sightings in the following analyses.

Species Richness analysis. Animal sightings latitude/longitude locations were plotted in ArcGIS v. 10.3.1. and projected into North American Datum 1983 UTM Zone 19 North. The Data Analysis Area was composed of 8 km X 8 km gridded cells resulting in 1,014 cells in the Canyons and Seamounts Data Analysis Area. For each species or species grouping, a presence/absence grid was created in which each grid cell was attributed a 0 (species not present in that grid cell) or 1 (species present in that grid cell). This resulted in a separate gridded dataset representing presence or absence for each species or species grouping. Unidentified Dolphin/Porpoise and Unidentified Whale categories were excluded in the species richness calculation to eliminate the possibility of double counting a species. All gridded datasets were summed resulting in the total number of species per grid cell (Figure 3A).

Abundance of marine mammals. The same sightings data and 8 km X 8 km grid as above was used to assess spatial patterns of abundance. For each species or species grouping, the number of animals located within each grid cell was summed and the respective grid cell was attributed with the value of that total number. If no sightings occurred in a grid cell, that grid cell was attributed a value of 0. This resulted in a separate gridded dataset for each species or species grouping in which grid values represent the total number of animals of that species found within that grid cell. All gridded datasets were summed, resulting in the total number of all animals (across all species and species groupings) per grid cell (Figure 3B).

Hot spot analysis: The 8 km X 8 km gridded dataset was converted to 8 km X 8 km polygons. One polygon on the northeast corner of the Data Analysis Boundary was excluded from the Hot Spot Analysis as it protruded past the level row of cells making up the northern boundary. This resulted in 1,013 polygons used in the analysis. Each polygon was attributed with (1) the total number of animals and (2) the total number of species within the respective 8 km X 8 km polygon. Two Hot Spot analyses were performed on; (1) the total number of animals and (2) the total number of species to test for statistically significant spatial clustering of hot spots (high values) and colds spots (low values) in the data using the Getis-Ord Gi* statistic at 99%, 95%, and 90% confidence intervals (Getis and Ord 1992) (Figure 3 C and D).

In the Getis-Ord Gi* statistic, the *contiguity edges/corners* spatial relationship between cells was used, where cells that share a boundary or corner influence the computations for the target cells. This option is best when polygons are similar in size and distribution, and when spatial interaction increases if the polygons share a boundary. This option is appropriate here, as polygons are of similar size and animals found in one 8 km X 8 km cell could easily move into an adjoining cell. The Euclidean Distance (straight line) method was used to calculate distances from each cell to neighboring cells.

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