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OMNIBUS DEEP-SEA CORAL AMENDMENT

Appendix B: Coral Zone Boundary Development

Coral zone boundary development

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Introduction

This document describes the methods used to draw coral zone boundaries for the New England Fishery Management Council's deep-sea coral amendment. Four different approaches were used for four different zone types: depth-based broad zones, the empirically determined broad zone based on coral data and fishing effort, discrete canyon zones, and discrete Gulf of Maine zones. Maps at the end of this document depict selected coral zone boundaries overlaid on coral, slope, and depth data.

Broad zones based on depth

The depth-based broad zones (Options 1-6 in Section 4.2.1) cover large areas (over 60,000 km^2) of the continental slope and canyons within the New England region. The western boundary for each alternative is the same, the New England-Mid-Atlantic inter-council boundary. The eastern and seaward boundary for each zone is the U.S. EEZ. Development of the boundary that runs along the continental shelf break is discussed below.

Data sources

The boundary along the edge of the continental shelf for each of the size depth-based broad zones was drawn using a digital elevation model (DEM). The primary source of bathymetry data for the canyons comes 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. Data were collected at 25 m resolution. In a few locations at shallower depths of around 300-350 m, there are no data from this dataset. In these locations, a lower resolution 250 m DEM from The Nature Conservancy's Northwest Atlantic Marine Ecoregional Assessment (TNC DEM), which is largely based on the NOAA Coastal Relief Model, was used.

Approach

The boundaries along the edge of the shelf for Options 1-5 are simplified versions of the 300 m, 400 m, 500 m, 600 m, and 900 m depth contours. Each boundary consists of line segments connecting waypoints with specific latitude/longitude coordinates. The objective for each boundary was to define the simplest line possible that stays within 50 m depth on either side of the target depth. For example, the boundary of the 300 m zone has a minimum depth of 250 m and a maximum depth of 350 m.

ArcGIS for Desktop version 10.2 or 10.5 was used for all calculations. First, the Contour tool (Spatial Analyst toolbox) was used to generate depth contours from the DEM raster surface, at 25 m intervals. Then, the relevant contours were selected from the resulting vector dataset. In some cases, vertices were added manually to make shallower contours continuous, but comparing the ACUMEN contours to those generated based on the TNC DEM. This was only done when the ACUMEN data did not extend shallow enough, otherwise the ACUMEN data took priority over the TNC DEM.

Once a single line feature was available for each of the five depths (300, 400, 500, 600, and 900 m), simplified versions of these contours were generated using the Simplify Line tool (Cartography, Generalization toolbox). The bend simplify algorithm was specified, with a 0.5 km tolerance. This tolerance represents a horizontal distance at the sea surface, not a depth-based tolerance. Once this simpler contour was generated using the tool, vertices were adjusted manually to maintain the 50 m depth tolerance. This was required in steeper locations where the 0.5 km tolerance specified in the tool resulted in a boundary that was too deep or too shallow.

Overall, the objective was to minimize the number of waypoints and simplify the boundary as much as possible, given the 50 m depth tolerance around each target contour. Given the shape of the contours along the edge of the shelf, the 300 m zone is a somewhat smoother boundary, with the zones becoming increasingly complex (more vertices) as they go deeper.

The 600 m minimum depth broad zone (Option 6) was developed using similar methods, but instead of constraining the boundary line to fall between the 550 m and 650 m contours, the boundary was constrained on its shallow side by the 600 m contour. The purpose of the slightly deeper boundary vs. the zone at 550-650 m allows for additional room for fishing vessels to maneuver along the edge of the zone. Having a constraint on one side of the boundary only allows for somewhat fewer vertices in the 600 m minimum boundary as compared to Option 4, 600 m with a 50 m tolerance on either side. This is because in some areas the Option 6 boundary goes deeper than the 650 m contour.

Broad zone based on fishing effort and coral data (Option 7)

This zone was developed according to an approach suggested by a coalition of environmental non-governmental organizations, spearheaded by the Pew Charitable Trusts. Their original May 2017 submission was modified by the PDT, referencing additional sources of fishing effort data not publicly available. The overall approach was to consider evidence for fishing activity and coral habitat at each point along the boundary, moving the line deeper when necessary to avoid fishing activity, or shallower in the absence of local fishing effort and in the presence of known or putative coral habitats. The following decision criteria were used to define the boundary:

- Boundary follows the 550 m depth contour if: the area has evidence of MBTG fishing, but no evidence of coral habitat. This provides the mobile bottom fishing industry with an additional buffer beyond what was identified as the deepest current fishing during the New Bedford workshop.
- Boundary follows the 500 m depth contour if: the area has evidence of MBTG fishing and evidence of coral habitat or did not have evidence of MBTG fishing or evidence of coral habitat. This accommodates what the mobile bottom fishing industry identified as the maximum depth of current fishing.
- Boundary follows the spatial footprint of coral habitat, including areas as shallow as the 300 m depth contour if: the area did not have evidence of MBTG fishing, but did have evidence of coral habitat. This was done to protect corals where they are known or highly likely in areas where it is unlikely that fishing would be impacted.

The area was suggested as a closure to mobile bottom-tending gears, so fixed gear fishing effort distributions were not considered. Descriptions of the coral data, fishing effort data, and methods used to adjust the boundary for this option are provided below.

Coral data

Coral habitat was assessed based on coral presence records, areas identified as highly likely to be suitable soft coral habitat in a predictive model, or presence of steep slopes (> 30°).

Briefly, the coral database includes geo-referenced records from the late 1800s to present of all types of deep-sea corals: soft corals, sea pens, stony corals, and black corals. There are 704 records in the New England region between a depth of 100 m south of Georges Bank and the EEZ boundary. As noted in the environmental assessment, these data are not evenly distributed across the region, but rather are concentrated in specific areas of scientific study. Nonetheless, as a comparative metric, the number of records per zone is useful for understanding how different areas compare, particularly as the broad zones are generally nested, with Options 2-6 being nested subsets of the 300 m zone, Option 1. Locations of relatively recent camera transects and remotely operated vehicle dives were also considered when drawing the boundary.

The coral suitability model analysis pools three different soft coral model outputs together, and looks for areas estimated to be highly or very highly likely to contain habitats suitable for all types of soft corals combined, non-gorgonian soft corals only, or gorgonian soft corals only. While the broad zones extend to the outer edge of the Exclusive Economic Zone, the footprint of the suitability analysis described here is restricted to slope/canyon region south of Georges Bank: between 100 m depth, just shallower than the shelf break, and somewhere between 2,000-2,200 m depth, the spatial extent of the NOAA Coastal Relief Model in the NEFMC region. Thus, the suitability percentage for each zone option can be understood as the fraction of likely soft coral habitat in the slope/canyon region within that zone, relative to the total area of suitable habitat along the shelf break in New England. It is not a percentage of the whole zone area (i.e. a percentage of ~66,000 km^2). The total area of the NEFMC slope/canyon region is 21,629 km2, approximately 23% of which (4,973 km2) is highly or very highly likely to be suitable habitat for soft corals, based on the model results.

Finally, the high slope area is based on the ACUMEN bathymetry data. Slope is the rate of change in depth between two adjacent 25 m x 25 m grid cells, calculated in degrees. During 2013-2015 coral dives with ROVs and towed cameras, corals were almost always observed in locations with a slope of 30° or greater. Thus, the location of high slope habitats is a reliable indicator of the presence of deep-sea corals. The total area of very high slope is much smaller than the area of predicted suitable habitat. Within the NEFMC region, the ACUMEN data set covers 12,132 km2, only 164 km2 of which has a slope greater than 30° (1.4% high slope).

VMS data

Because the focus of this option is on mobile bottom-tending gears, and trawls are the only mobile gears used at coral habitat depths, the boundary was developed using bottom trawl vessel monitoring system (VMS) data. As described in the environmental assessment, bottom trawl vessels have high rates of VMS coverage. Two data types were used, model-based data from 2005-2012, and speed-filtered data from 2010-2016.

The foundation for the model-based maps was a database of VMS polls from 2005-2012. The data were assembled by Chad Demarest and David Records at the Northeast Fisheries Science Center and their methods are summarized in a draft working paper[1]. Some of these data were subsequently published[2].Each poll was matched with a trip-level vessel trip report (VTR) to identify gear and catch, and then matched to at sea fisheries observer data from the Northeast Fisheries Observer Program to estimate the probability that a poll represented fishing activity. The observer data identifies fishing events at the haul or set level, and includes haul start and end times that can be used to flag an individual VMS poll as fishing or non-fishing. Because observer data are not collected on all trips, generalized additive modeling was used to estimate fishing vs. non-fishing during unobserved trips. The time elapsed between adjacent polls, which is directly calculated from the VMS data, was multiplied by the probability of fishing at each poll location to generate a probability-weighted hours fished value for each point. Data were sorted into métiers (fisheries) and separate models were generated for each of two métiers and each year. Specifically, the bottom trawl and squid trawl data sets were used. The two data sets do not overlap with one another, i.e. a VTR trip was either classified as squid or other, and then matched to the VMS data. The universe of VMS polls included in the 'bottom trawl' data set is all bottom trawl polls, with three exceptions:

- Trips when gear code was 'bottom trawl fish' or 'bottom trawl other' AND > 74% of the quantity kept was squid. These trips are mapped separately in the coral zone analysis.
- Matching VTR data indicated a shrimp trawl was used. These are excluded from the coral zone analysis.
- When the vessel was likely participating in a raised footrope trawl whiting fishery. These are also excluded from the coral zone analysis.

In addition to this model, a speed-filtered dataset was developed by selecting all trawl-gear VTR trips that landed a range of species known to be caught in bottom trawls along the shelf break, and then matching those trips to their VMS polls. The species included were butterfish, silver hake, offshore hake, unclassified hake, red hake, longfin squid, *Illex* squid, summer flounder, scup, black seabass, and monkfish. The VTR data were filtered to reduce somewhat the number of trips and polls in the dataset, to improve processing time. Data were provided to the PDT by Mike Palmer, Northeast Fisheries Science Center.

Mapping method

For both model-based and speed-filtered data, VMS polls were converted to heatmaps using point density methods in Arc GIS 10.5. The approach was adapted from December 2015 methods used by the Northeast Regional Ocean Council to map VMS data (Rachel Shmookler, RPS Applied Science Associates). Annual data files for each métier were imported into ArcMap 10.5, and points were plotted using the Display XY Data function and assuming a WGS 1984 geographic coordinate system. Data were projected into WGS 1984 Zone 19N.

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[1] Records, D. and C. Demarest (2013). Producing high resolution spatial estimates of fishing effort using a VMS-based statistical model (draft working paper). Woods Hole, MA, Northeast Fisheries Science Center**:** 35p.

[2] Muench, A., G. S. DePiper and C. Demarest (2017). "On the precision of predicting fishing location using data from the Vessel Monitoring System (VMS)." Canadian Journal of Fisheries and Aquatic Sciences. Available online at http://www.nrcresearchpress.com/doi/10.1139/cjfas-2016-0446#.WjgimLpFwYA.

For the model-based data, polls representing a probability of fishing below 0.20 were removed from each annual dataset. The speed-filtered data were used as provided as they were already filtered to exclude polls unlikely to represent fishing.

Polls were then interpolated using the Point Density tool (Spatial Analyst). For the model-based data sets, the following settings were used: population field = hours fished, output cell = 100 m, neighborhood = 1000 m, and area units = square kilometers. This approach places a greater weighting on polls with higher hours fished values. For the speed filtered data, the settings were the same except that the population field was left blank, and all points were weighted equally. As specified here, the tool assesses the number (and for the model-based data, also the value) of VMS points within 1000 m radius circular neighborhood, and assigns a density based on this assessment to 100 m grid cells.

The resulting point density rasters were natural log transformed (Ln tool, Spatial Analyst), and the mean and standard deviation were read from the transformed data sets. Using the Raster Calculator tool (Spatial Analyst), each transformed data set was standardized by subtracting the mean and dividing by the standard deviation. All data sets were categorized in the same way, < -1 std dev, -1-0 std dev, 0-1 std dev, 1-2 std dev, > 2 std dev. The rasters were the permanently reclassified into these five categories (Reclassify tool, Spatial Analyst), and then converted to vector data (Raster to Polygon tool, Conversion toolbox).

Reclassified raster data were used for developing map products, but the polygons (vector data) were joined to the original point data to assign each point a standard deviation class from 1-5. The point data were then examined to ensure that at least three unique permit numbers were represented for each class. This ensures that the different colors represented in the maps are non-confidential. These criteria were easily met for all data sets and years, even when selecting just the subset of points falling along the shelf break in the New England region only.

Evaluate data with respect to boundary and edit points

The next step was to evaluate the initial boundary provided during May 2017 with respect to the coral and fishing effort data. This was done is a standardized fashion to improve objectivity of the assessment. Buffers were drawn around the draft boundary to indicate the distance 2 km from the boundary, and 5 km from the boundary (Buffer tool, Analysis toolbox). Within 2 km was assessed as being in close proximity of the boundary, within 5 km was assessed as being in proximity of the boundary, and beyond 5 km was assessed as being distant from the boundary. The shelf break was broken into 24 locations (canyons, groupings of adjacent canyons, or sections of the intercanyon slope). VMS data were grouped into low density (< -1 or -1-0 std dev), dense (0-1, 1-2 std dev), or very dense (> 2 std dev).

For each VMS dataset (data type/year combination), the heat map was studied to determine if there were no polls within 5 km of the boundary, if there were only low-density polls within 5 km of the boundary, if there were dense or very dense polls within 5 km of the boundary, or if there were dense or very dense polls within 2 km of the boundary. These findings were scored as follows:

Code	Description
x	*No data for that dataset and year*
1	No VMS polls near boundary
2	Only low density of polls near boundary (low is defined as <-1 std deviations or -1-0 std deviations from mean density). Near is within 5 km.
3	Dense, but inshore of the boundary (dense is defined as 0-1 or 1-2 standard deviations from mean density). Inshore of is within 2-5 km.
4	Very dense, but inshore of the boundary (very dense is defined as >2 standard deviations from mean density). Inshore of is 2-5 km.
5	Dense, and tight to the boundary (dense is defined as 0-1 or 1-2 standard deviations from mean density). Tight is within 2 km of boundary.
6	Very dense, and tight to the boundary (very dense is defined as > 2 standard deviations from the mean density). Tight is within 2 km of boundary.

This scoring gives priority to distance from the boundary, rather than density. Evidence of coral habitat was also summarized in the table.

Boundaries were reconsidered for each location, and in some cases drawn at different depths for the east or west walls of individual canyons according to the location of dense or very dense VMS polls. In many cases, a boundary of around 500 m was maintained from the May 2017 approach, since there was both evidence of coral habitat and evidence of fishing within 5 km of the boundary. In general, dense VMS polls were in closest proximity to the zone boundary along the edges of canyons, and dense VMS polls were often beyond 2 km or even beyond 5 km from the zone boundary in intercanyon areas. Once the boundary was redrawn, the 2k and 5k buffers were redrawn and the scoring was reassessed for each area/dataset combination with respect to the updated buffers.

In certain areas, the updated boundary was more than 2 km from the boundary for all, or nearly all, datasets and years. These included Dogbody/Clipper Canyons, Sharpshooter/Welker Canyons, Heel Tapper Canyon, Lydonia to Powell intercanyon, Powell to Munson intercanyon (except 2009 model-based bottom trawl), and Munson to Nygren intercanyon (except 2009 model-based bottom trawl).

In contrast, in a few areas, there were very high-density areas of VMS polls within 2 km of the boundary. This included the Veatch to Hydrographer intercanyon area (model-based squid trawl, during 2009 only), and Heezen Canyon (model-based squid trawl 2007, speed-filtered trawl 2015-2016). In Heezen canyon, except during 2005, at least one dataset showed dense (0-1 or 1-2 std dev) VMS polls within 2 km of the boundary during each year. This suggests that fishing occurs close to the edge of Heezen Canyon very consistently over the period examined. Alvin and Atlantis Canyons showed similar results, with fishing consistently occurring within 2 km of the 500 m (approximate depth) boundary in all years examined, except for Atlantis Canyon during 2012).

Near Nygren Canyon and east towards Heezen Canyon, very dense areas of VMS polled occurred within 5 km of the boundary in the speed-filtered dataset, very consistently. The model-based bottom trawl dataset showed dense VMS polls closer to the boundary. Squid trawl data were more variable on a year to year basis for these areas.

Discrete canyon zones

Data sources

ACUMEN DEM, Coral Habitat Suitability Model, Coral database, recent dive sites with corals, high slope data

Approach

Boundaries of these zones are based on the most up to date information on coral observations, high resolution terrain data, and habitat suitability model results. Coral zone boundaries are primarily based on bathymetry and slope and were designed to encompass the full extent of the canyon feature from the shelf break to the point where the slope begins to flatten out at the edge of continental rise. The 3° slope contour was used to identify the shelf break in previous PDT coral analyses, and this convention is adopted here as well. The 3° slope contour is typically lies somewhere between 200 and 300 meters depth off of New England. Because the shallow edge of the high-resolution ACUMEN bathymetry dataset overlaps these contours, this dataset was not suitable for defining a 3° slope contour. Therefore, the slope contour was developed using The Nature Conservancy Northwest Atlantic Marine Ecoregional Assessment digital elevation model. This slope contour roughly approximates the landward coral zone boundary in the shelf incising canyons, and in some of the slope confined canyons as well. The landward boundary of other slope confined canyons begins slightly deeper, which is consistent with the slope and habitat suitability model outputs (more on this below).

Corals have been observed most of the time in high-slope areas of the canyons (>30°) during recent ROV and towed camera surveys. Corals have been found in areas with very high slope (greater than 36°) during all recent dives. Thus, these high and very high slope areas, derived from ACUMEN bathymetry, were useful for defining the width of the canyon zones (west to east dimension), as well as the seaward boundaries of the zones.

The high and very high habitat suitability outputs for Gorgonian Alcyonacea, and Non-Gorgonian Alcyonacea were also considered when developing canyon zone boundaries. These high and very high suitability model outputs often align well with the high and very high slope areas described above. Like the slope outputs, the model results were used to help define the width of the canyon zones, and well as their landward and seaward extents. A buffer of 0.4 nautical miles around the high suitability outputs was generated to roughly reflect the degree of spatial uncertainty in the model results. As appropriate, the zones include these buffer areas as well. The PDT prioritized the high-resolution bathymetry and slope data over the model outputs when developing boundaries because these high-resolution data are best for accurately bounding the spatial extent of the canyon features. The suitability outputs are a useful guide but are based on a lower resolution dataset. This diverges slightly from the approach used by the MAFMC FMAT. In the MAFMC coral amendment, the FMAT included high and very high habitat suitability areas, plus the buffer, in their initial canyon zone boundary recommendations, but these areas were ultimately scaled back in the heads of the canyons by the time the boundary development process had concluded after their coral workshop. More tightly focused boundaries at this initial stage will hopefully result in the need for fewer changes as these areas make their way through the Council process.

The locations of historic and recent coral observations generally fall solidly within zones developed using bathymetry, slope, and suitability model results, so while they are confirmatory of the presence of coral habitats in a canyon zone, they are not really a driving factor behind the zone boundaries.

Discrete seamount zones

Data sources

For the deepest portions of the canyons, the abyssal plain, and the seamounts, 100 m resolution multibeam bathymetry data are available. These data were collected as part of a NOAA-initiated collaboration to fill data gaps identified during an inventory of data holdings to support potential claims under the United Nations Convention on the Law of the Sea (UNCLOS). Data are available for download from the University of New Hampshire Center for Coastal and Ocean Mapping Joint Hydrographic Center (http://ccom.unh.edu/theme/law-sea/law-of-the-sea-data/atlantic).

Approach

A bounding box was drawn around each seamount by visually inspecting the DEM to determine where the seamount rose from the abyssal plain.

Discrete Gulf of Maine zones

Data sources

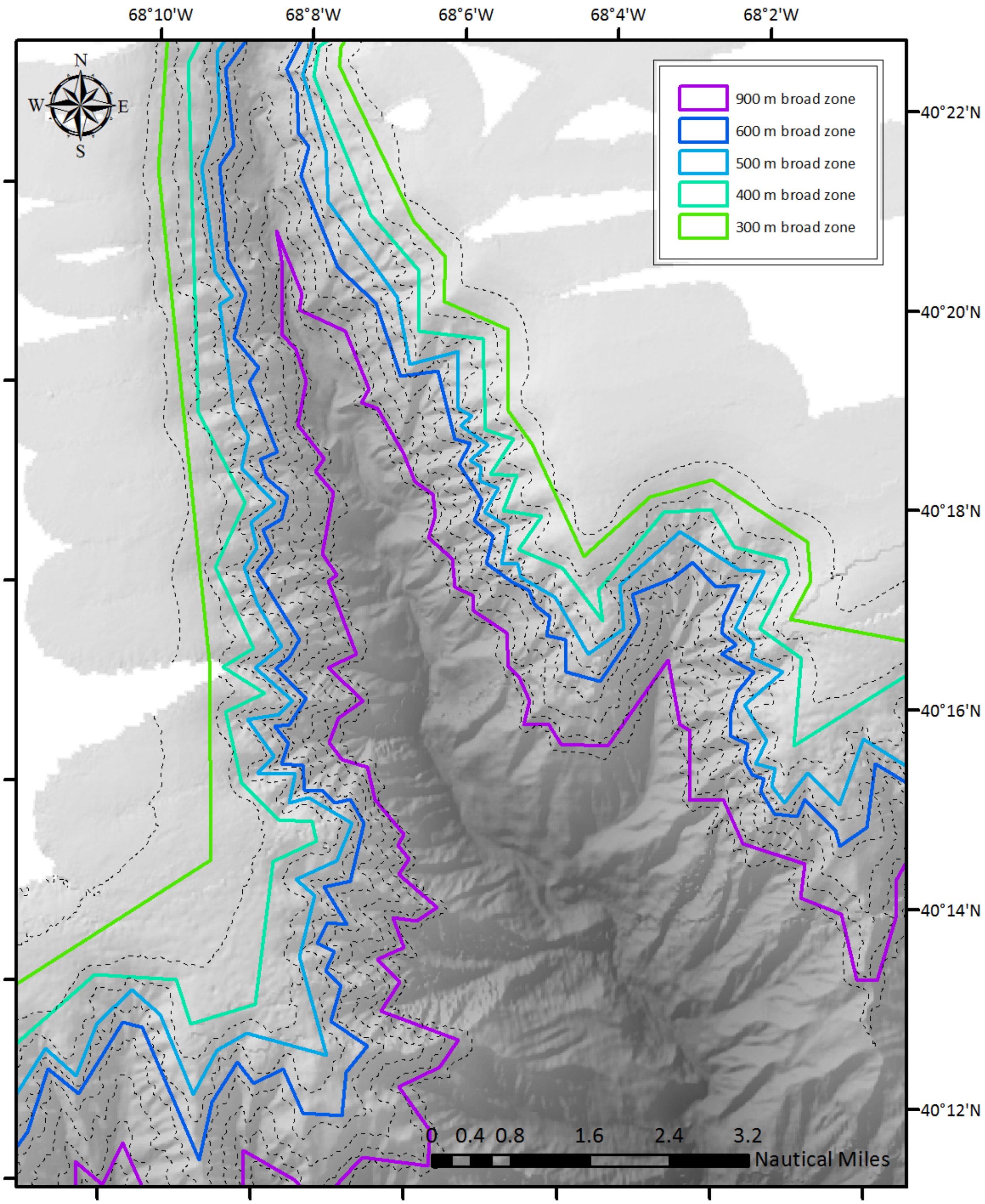
Recent dive sites with and without corals were used as the primary basis for defining coral zones. In addition, various DEMs were used to refine the boundaries. A 10 m resolution multibeam bathymetric dataset was used for Outer Schoodic Ridge, a 20 m resolution multibeam bathymetric dataset was used in Western Jordan Basin, and a 1/3 arc-second (about 10 m) bathymetric dataset (the Bar Harbor DEM) was used in the Mount Desert Rock area and surrounds. The Outer Schoodic Ridge and Western Jordan Basin data were collected during a fall 2013 ECOMON cruise aboard the *Okeanos Explorer* (Auster et al. 2014). The Bar Harbor DEM is described in Friday et al. 2011.

Approach

In general, the boundaries of the coral zones were drawn to encompass dive sites where corals were positively identified. These boundaries were refined using bathymetric data to indicate areas of high slope or relief relative to the surrounding seafloor. For Mt. Desert Rock, central and western Jordan Basin, and Lindenkohl Knoll, smaller and more targeted options were developed in addition to larger zones. The smaller zones are referred to as Option 2 in the amendment document, and the larger zones are referred to as Option 1. Only a single option was developed for the Outer Schoodic Ridge boundary.

Because the spatial extent of high-resolution bathymetric data is limited, it is not possible to delineate zone boundaries based on full spatial extent of specific terrain features, as is the case with the canyon and seamount sites. In some cases, coral presence and observations of the seafloor terrain in video and photos collected on dives confirms high-relief terrain that is not depicted with low-resolution bathymetric data. In other cases, bathymetric data show high relief terrain and corals are inferred to the location in the absence of dive observations. These high-resolution DEMs allowed the PDT to extend the coral zone boundaries out beyond the coral dive sites, which only cover a small area. In the absence of high-resolution bathymetry, the coral zones were drawn as regular rectangles, referencing lower-resolution DEMs to the extent possible.

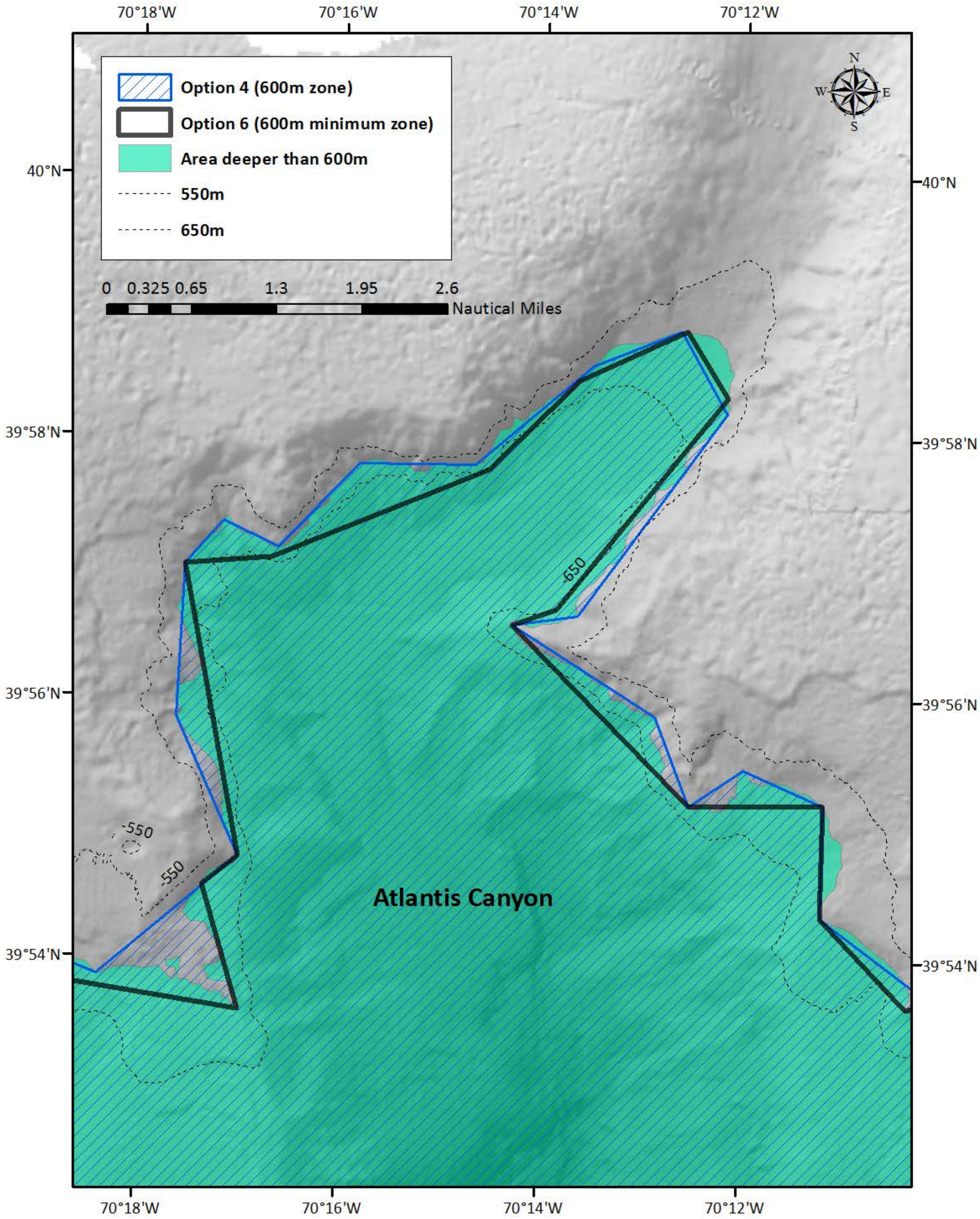
Map 1 – Broad zones Options 1-5 at the shoulder of Oceanographer Canyon showing the relationship between depth contours and zone boundaries. Options 6 and 7 are not shown.



Map created November 16, 2016 NEFMC Habitat Plan Development Team

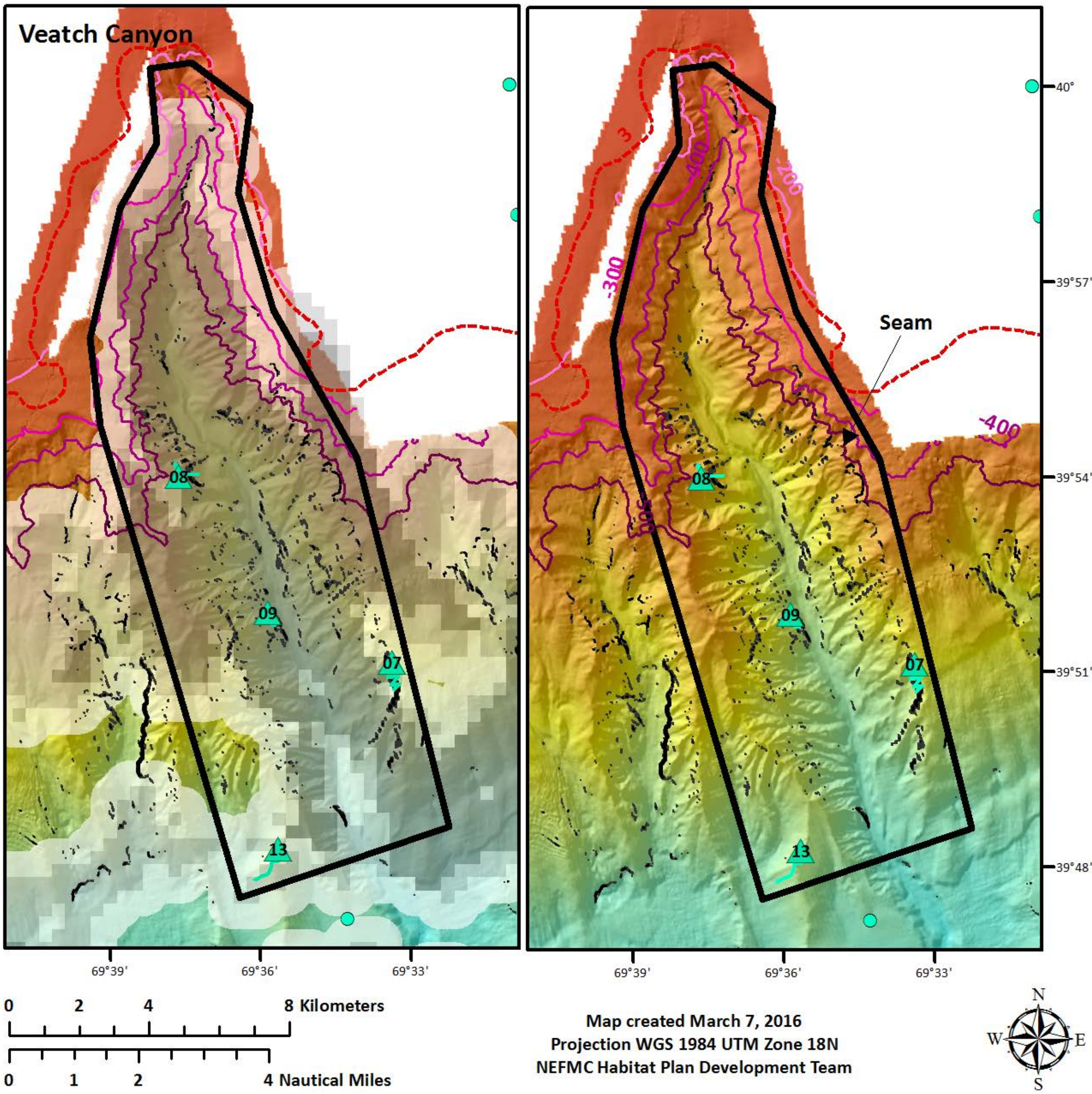
Notes: Heavy straight lines indicate the broad zone boundaries. The black dotted lines indicate the adjacent contours (50 m depth intervals) that serve as upper and lower depth bounds for the broad zones. Grey shading shows the underlying ACUMEN bathymetry surface from which the contours were derived.

Map 2 – Comparison of broad zone Options 4 and 6 within Atlantis Canyon to show difference between boundary constrained by 550 m and 650 m contours (Option 4) and minimum depth approach (Option 6).

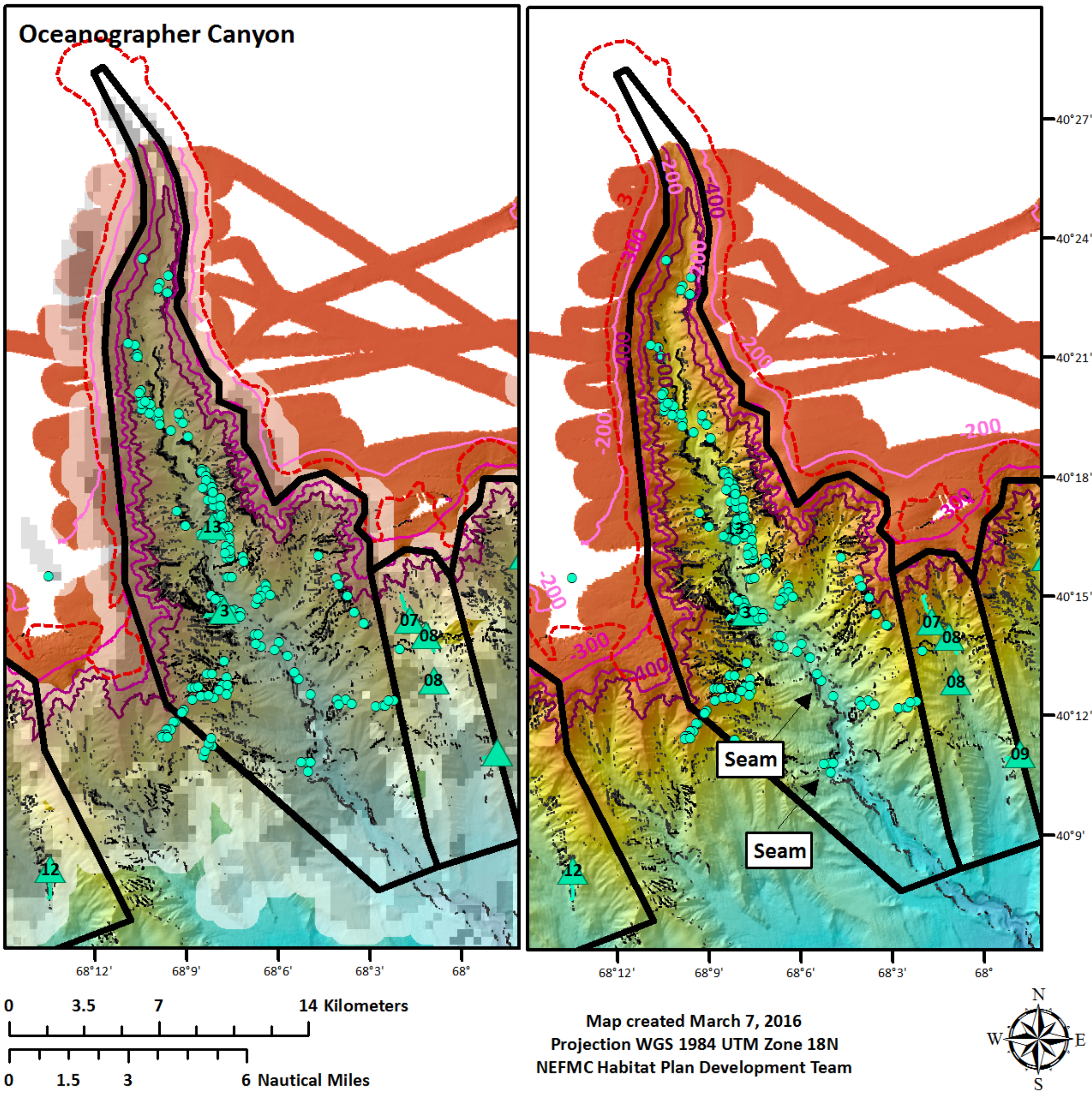


Notes: Option 4 is shown in blue hatching, and Option 6 is shown in bold black outline. The shaded area underneath indicate portions of the canyon deeper than 600 m, based on the high resolution depth contour. Option 6 is within this shaded area, but option 4 may extend outside it, to a depth as shallow as 550 m (dotted line). The deeper 650 m contour is also shown.

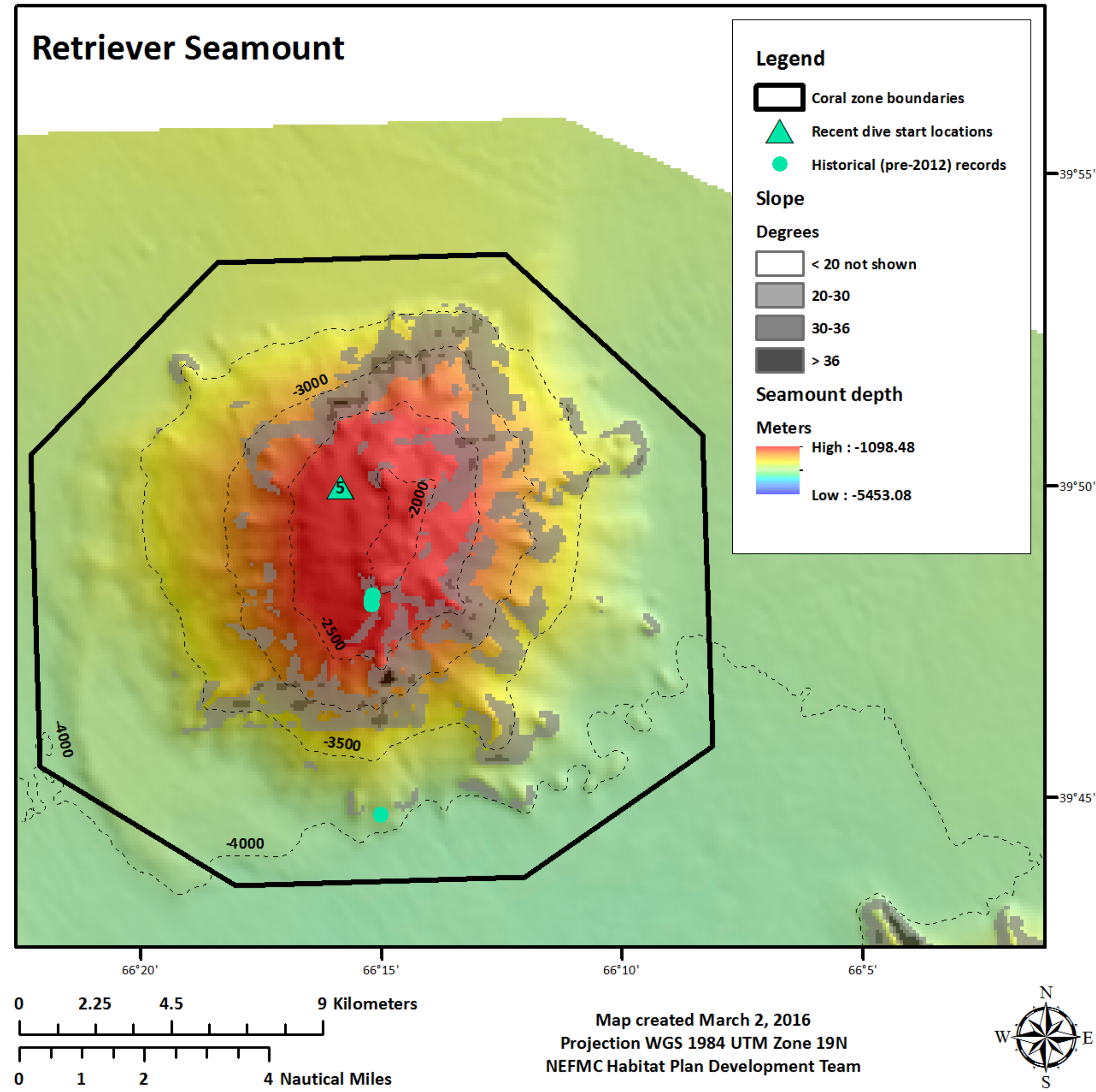
Map 3 – Veatch Canyon discrete zone



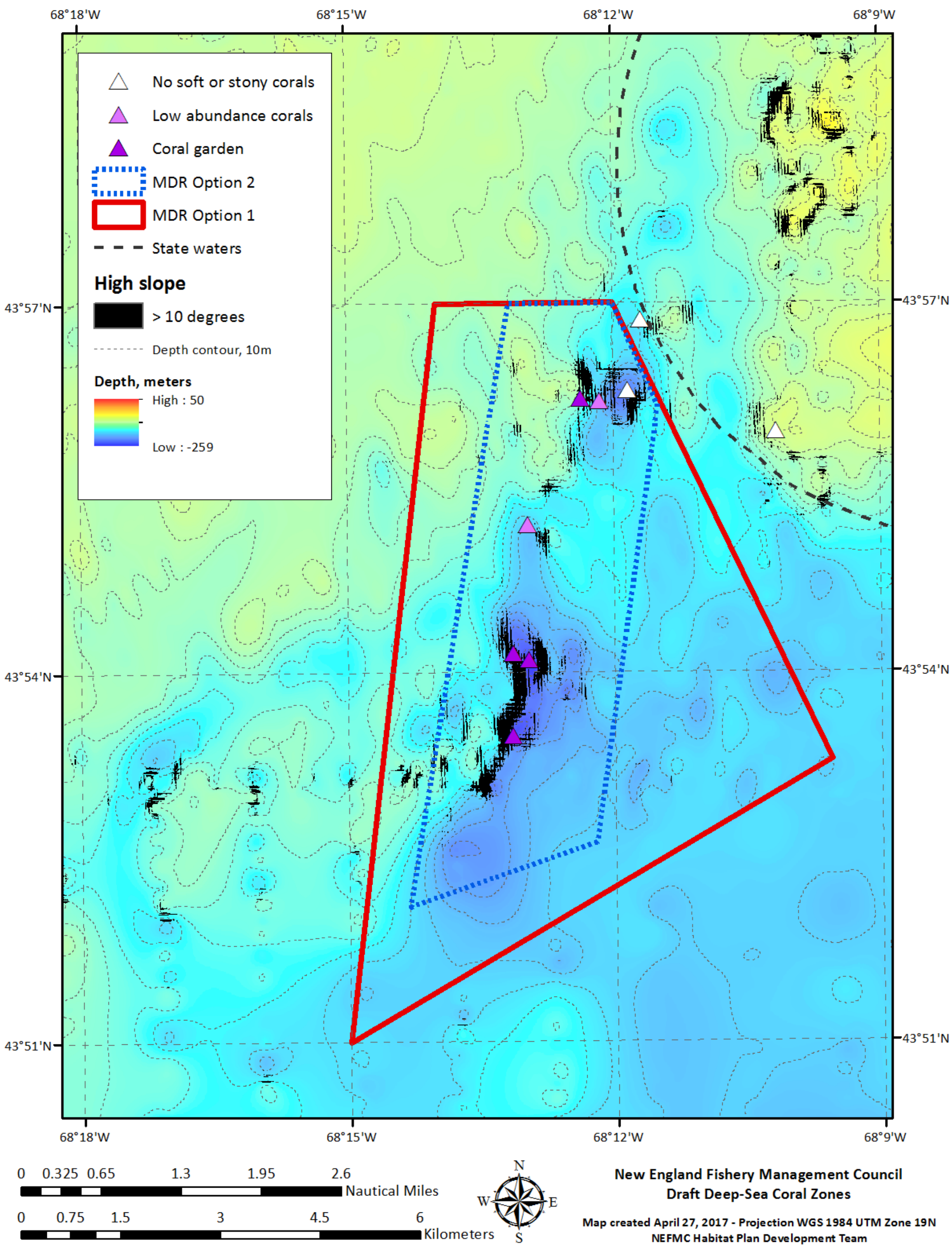
Map 4 – Oceanographer Canyon discrete zone



Map 5 – Retriever Seamount coral zone boundary

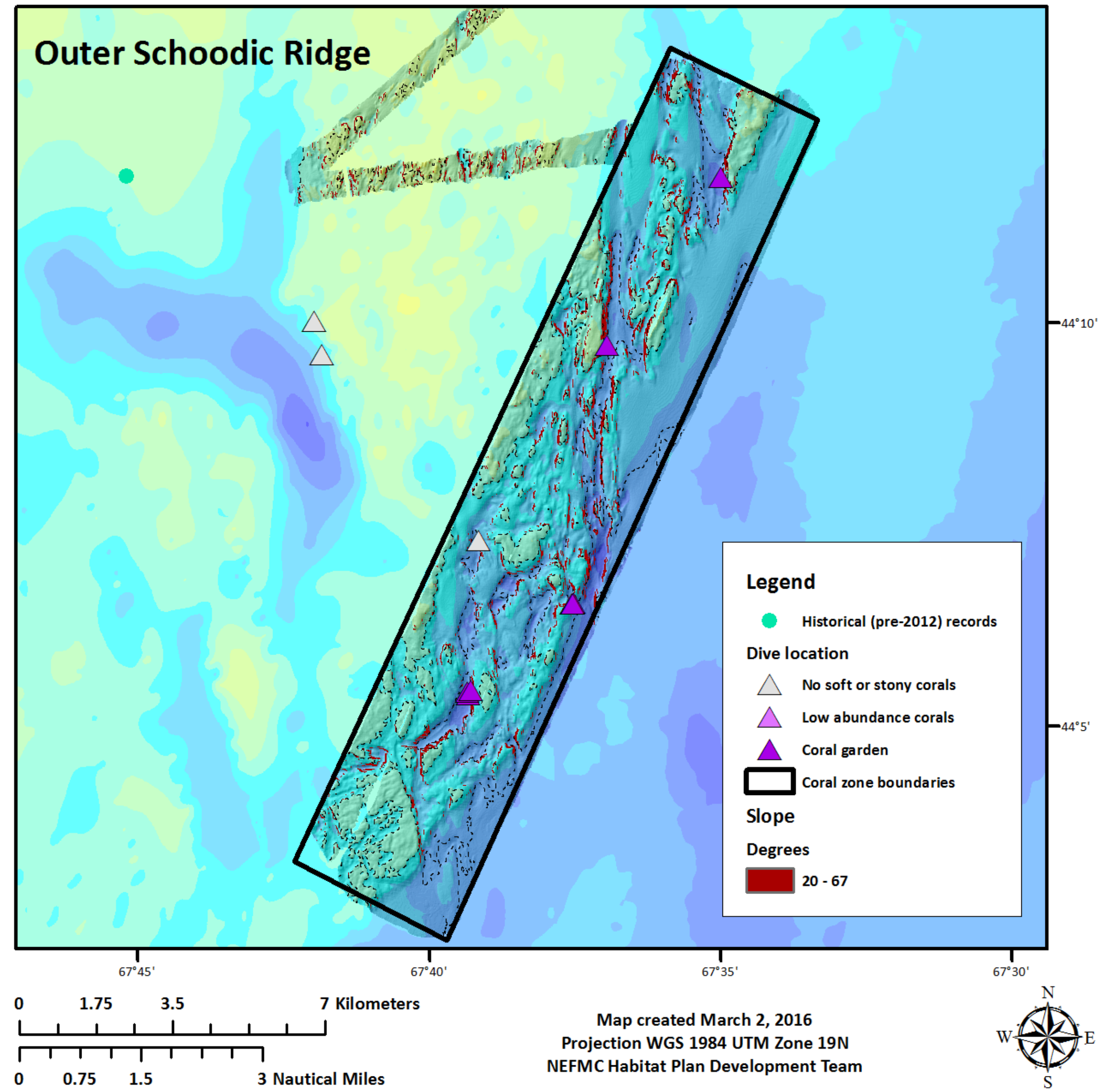


Map 6 – Mount Desert Rock Coral Zone options



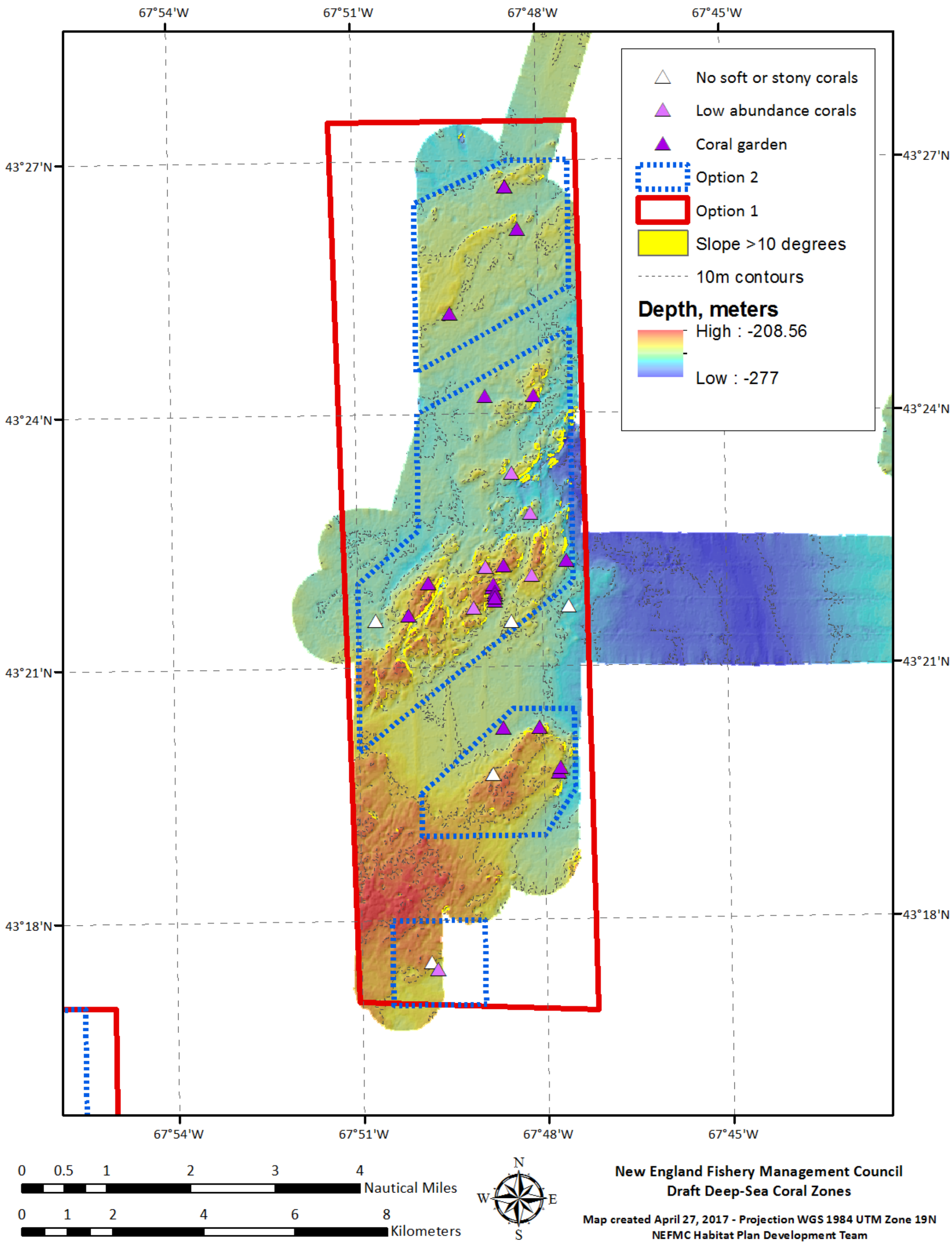
Map includes recent dive locations and relative abundance of corals. Contours are in 10 m intervals and areas of high slope are shown in black.

Map 7 – Outer Schoodic Ridge Coral Zone and high resolution bathymetry



Areas of high slope are shown in red. Relative coral densities during recent dives (triangles) are shown in purple shading.

Map 8 – Larger scale image of the high-resolution bathymetry at 114 fathom bump



Map 9 – Discrete coral zone options at Lindenkohl Knoll.