Mapping Bottom-contact Fishing Intensity in the Gulf of Mexico in Relation to Predicted Suitable Habitats for Deep Sea Corals

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About this Document

In 2013, NCCOS completed predictive habitat suitability models for 21 species and complexes of deep corals in the Gulf of Mexico, including framework-forming deep corals. In addition to internal cross-validation, these models were field-tested and validated during the Okeanos Explorer EC1402L3 mission in April 2014. These models are being used to advise the Gulf of Mexico Fishery Management Council on possible deep coral protection zones, and have also been used by BOEM, NOAA OR&R and academic partners. However, no effort to date has assessed the degree of overlap between fishing intensity with bottom-contact gear and predicted habitat suitability of key deep coral groups. NOAA's Deep Sea Coral Research and Technology Program has identified the need to know more about where bottom contact commercial fishing takes place and how it may impact deep coral communities. This report examines two bottom contact fishing gears, shrimp trawls and bottom longlines, and potential conflicts with specific predicted coral communities. For more information about this report, please contact Randy Clark at randy.clark@noaa.gov.

Acknowledgements

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Front cover image of *Lophelia* with a crab and urchin was provided in courtesy of *Lophelia II: Reefs, Rigs, and Wrecks 2009 Expedition*, NOAA OER/BOEM. The back cover photo of *Madrepora* coral in the Gulf of Mexico was provided in courtesy of Expedition to the Deep Slope 2007, NOAA OER.

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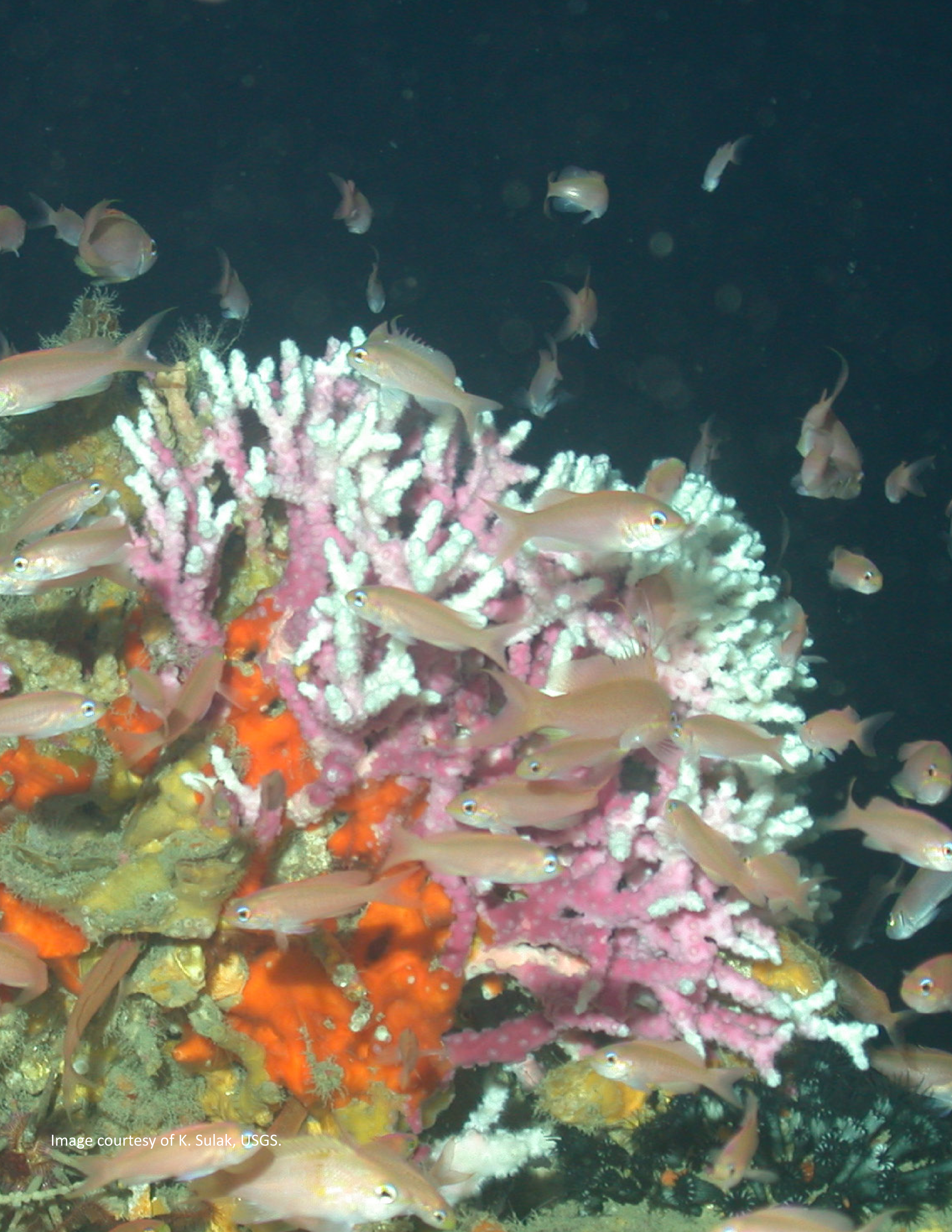

Image courtesy of K. Sulak, USGS.

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Image courtesy of Lophelia II 2010 Expedition, NOAA-OER/BOEM.

Chapter 1: Introduction

1.1 BACKGROUND

Deep sea corals are taxonomically and morphologically diverse and a valuable resource globally (NOAA, 2008). Corals and sponges form complex, three-dimensional biogenic structures that directly and indirectly influence the occurrence and abundance of many fish and invertebrate species. Globally, deep-sea fisheries that target stocks on outer continental shelves and slope habitats may remove or disturb benthic fauna (Roberts et al., 2009; Clark et al., 2016), particularly hard and soft corals that exhibit slow growth rates. Fishing activities compromise habitat infrastructure and often re-occur in the same area thus preventing recovery. In the Gulf of Mexico several gear types that may impact deep sea corals have been identified (Brooke and Schroeder, 2007; Etnoyer et al., 2016; Boland et al., 2017). Bottom trawling is identified as having the most significant impact to benthic habitats. Bottom long-line gear, while not as damaging, also has significant impacts. Clark et al. (2016) illustrated ecological effects of bottom long-line and other bottom fishing gears on Atlantic and Pacific hardbottom areas. Impacts include removal of habitat forming species, reduced species diversity and biomass decline, among others.

The Gulf of Mexico shrimp fishery accounts for 60% (197 million pounds) of the national total landings (NOAA NMFS, 2015). In estuaries and shelf habitats, the fishery predominantly targets brown (*Farfantepenaeus aztecus*) and white shrimp (*Litopenaeus setiferus*), but also targets pink shrimp (*Farfantepenaeus duorarum*). In 2005, the Gulf-wide commercial fleet was estimated to be in excess of 20,000 vessels (Condrey and Fuller, 1992). The royal red shrimp (*Pleoticus robustus*) fishery is a smaller fishery (26 vessels in 2011; Nance et al., 2011). This fishery primarily operates in deep waters (approximately 500 m) in areas east of the Mississippi River. The Gulf reef fish bottom longline fishery retains a diverse catch but typically targets snapper and grouper species, and the fishery's catch is dominated by red grouper (*Epinephelus morio*), which comprised 67% of the total catch onboard observer-monitored vessels from 2010-2011 (Scott-Denton and Williams, 2013). Among all other species caught by longline, each makes up <10% of the fishery's total catch on observer vessels. However, other commonly landed species include yellowedge grouper (*Epinephelus flavolimbatus*), red snapper (*Lutjanus campechanus*), golden tilefish (*Lopholatilus chamaeleonticeps*), blueline tilefish (*Caulolatilus microps*), and scamp (*Mycteroperca phenax*; Scott-Denton et al., 2011; Scott-Denton and Williams, 2013).

*Top species of targeted shrimp in Gulf of Mexico shrimp fishery (top-bottom, L-R): brown shrimp (*Farfantepenaeus aztecus*), white shrimp (*Litopenaeus setiferus*), pink shrimp (*Farfantepenaeus duorarum*) and royal red shrimp (*Pleoticus robustus*). Brown, white and pink shrimp images courtesy of NOAA Teacher at Sea David Walker; royal red shrimp image courtesy of Brandi Noble, NOAA NMFS/SEFSC Pascagoula Laboratory.*

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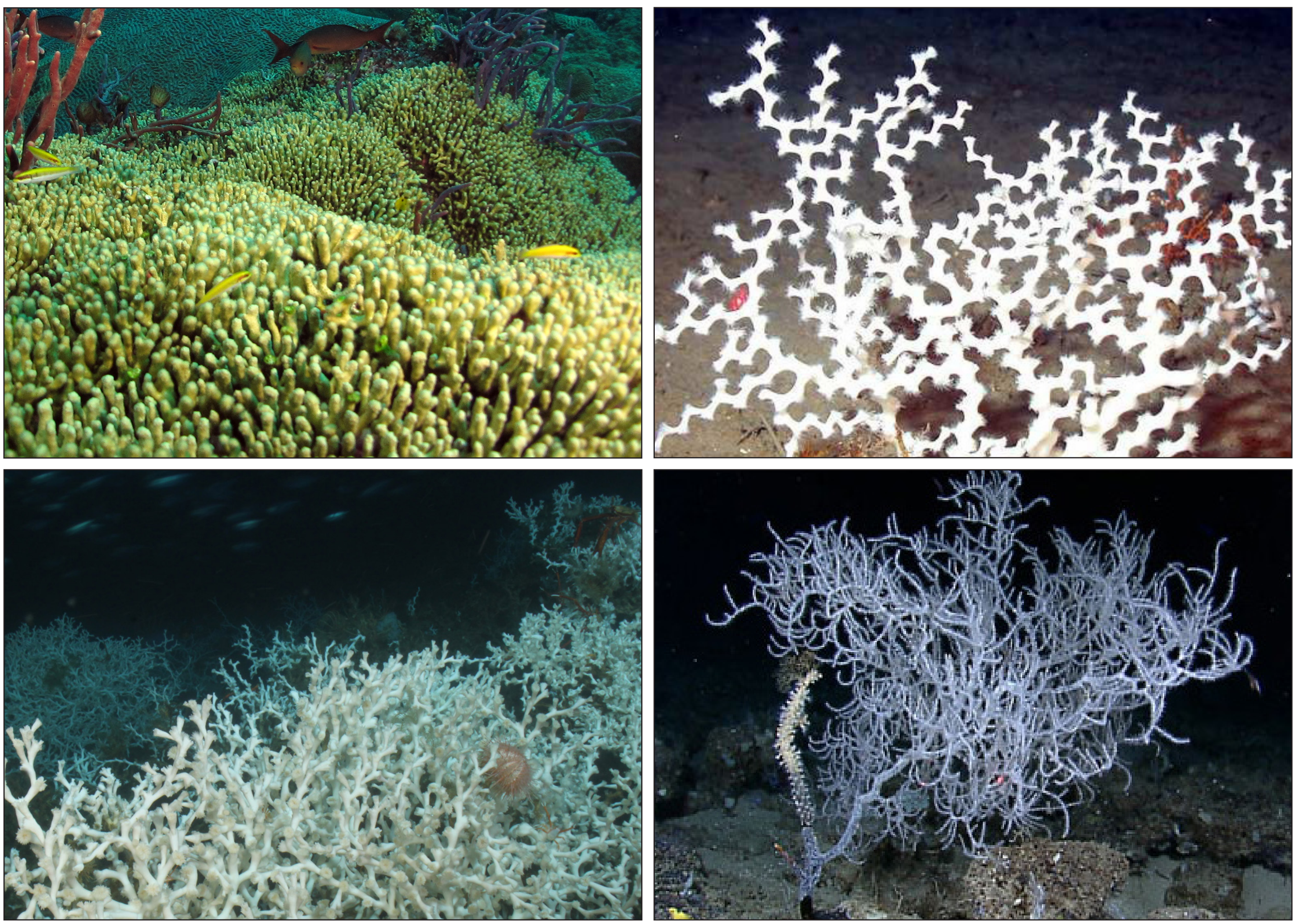
1.2 CORAL SPECIES COMPLEXES OF INTEREST

In general, the Gulf of Mexico has distinctive geospatial differences among shelf (<100 m), upper slope (100-300 m) and deep coral communities (>300 m). Corals from the genera *Madracis* and *Madrepora* typically occur on shallow and mesophotic shelf communities in the northern Gulf of Mexico to depths of 300 m or more (Etnoyer et al., 2017). Many deep coral communities on the lower slope areas are dominated by the stony coral *Lophelia pertusa*, while others are comprised of abundant octocoral and black coral species, such as the *Leiopathes* complex.

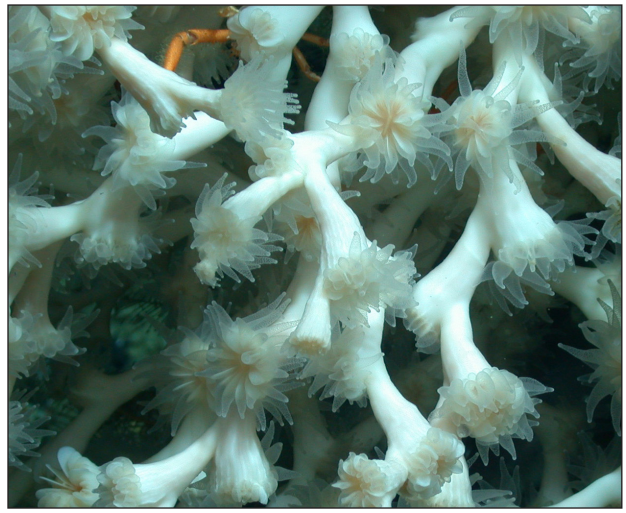
Lophelia pertusa is the dominant azooxanthellate colonial scleractinian coral in the Gulf of Mexico, typically occurring between 300-600 m (Cordes et al., 2008; Lunden et al., 2014; Boland et al., 2017). Extensive thicket development occurs in the northern Gulf of Mexico, the west Florida slope and on parts of the Pourtales and Miami Terraces (Schroeder, 2002; Reed et al., 2005; Reed et al., 2006). Another colonial genus of stony coral, *Madrepora*, forms large colonies on carbonate boulders in the northern and eastern Gulf. Branching *Madrepora* are found at depths between 100 and 1500 m, with *M. oculata* often co-occurring with *Lophelia*. Structure-forming corals of the genus *Madracis* are typically found in the photic and mesophotic regions of the Gulf often at depths less than 150 m (Brooke and Schroeder, 2007), but may be found as deep as 875 m (Cairns, 1978). Black corals (Order Antipatharia) are locally common in the northern Gulf of Mexico, west Florida slope and Florida Straits. *Leiopathes* is a common antipatharian genus found on the continental slope at depths between 300-1,500 m, and forms large bushy colonies that may provide substrate and refuge for other organisms (Hourigan et al., 2007).



Examples of four genera of corals: Madracis aurentenra *(E. Hickerson, NOAA OMNS/FGBNMS; top left),* Madrepora oculata *(NOAA/FGBNMS and UNCW/NURC; top right),* Lophelia pertusa *(NOAA OER and BOEM; bottom left), and* Leiopathes *complex (NOAA Okeanos Explorer Program; bottom right).*

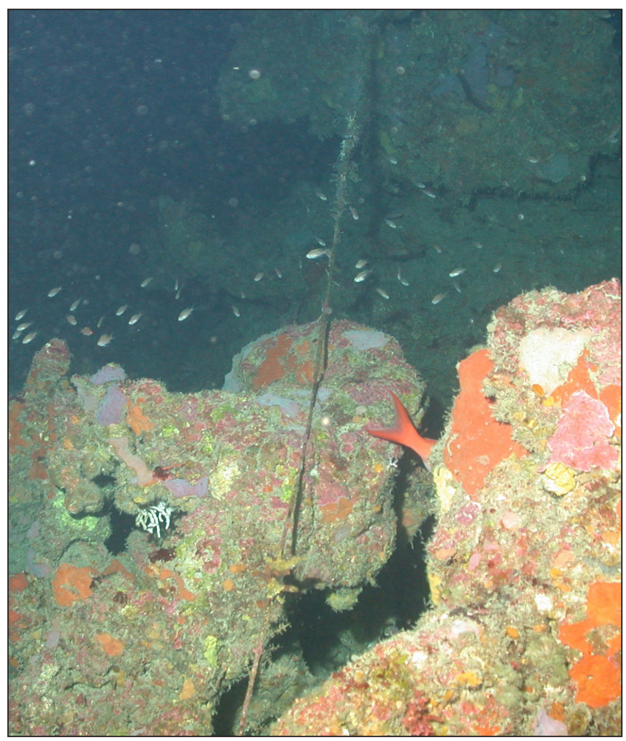
Introduction

NOAA's National Center for Coastal Ocean Science (NCCOS) has developed habitat suitability index (HSI) models for corals, such as the *Madracis* species complex, derived from observations of *M. asperula*, *M. aurentenra*, *M. brueggemanni*, *M. decactis*, *M. formosa*, *M. myriaster*, *M. pharensis,* and those identified as *Madracis* sp.; and the *Madrepora* species complex, derived from observations of *M. carolina* and *M. oculata* (Kinlan et al., 2016; https://coastalscience.noaa.gov/project/deep-coral-habitat-modeling-atlantic-gulf-mexico/; Figure 1). HSI maps were also generated for *Lophelia pertusa* (Kinlan et al., 2016; Figure 2) and the *Leiopathes* species complex, derived from observations of *L. glaberrima* and those identified as *Leiopathes* sp. (Etnoyer et al., 2017; Figure 2), as well as others, to address a variety of concerns regarding deep coral communities. These maps were developed using a suite of environmental parameters, such as bathymetry, seafloor complexity and composition, to provide estimates of where deep coral communities are most likely to occur based on known occurrences of coral observations that are housed in NOAA's Deep Sea Coral Research and Technology Program database (NOAA DSCRTP, 2017). The maps are currently used for environmental assessments for offshore activities, conservation and restoration planning, fisheries management, and planning for future exploration efforts and ecological studies.



Close up of Lophelia pertusa *polyps. Image courtesy of Lophelia II: Reefs, Rigs, and Wrecks 2009 Expedition, NOAA OER/BOEM.*

The effects of bottom fishing gears are well documented. Rooper et al. (2017) summarize effects of trawled and bottom tending gear in U.S. waters, and Etnoyer et al. (2016) describe effects from areas near the Deepwater Horizon wellhead. In order to fully assess how fishing gears interact with coral communities in the Gulf of Mexico scientists need to identify areas where these two activities occur and intersect. The objectives of this report are to examine the spatial overlap of two common Gulf of Mexico commercial fisheries gears, benthic bottom trawls and bottom set longline, with predictive models and actual observations of select structure-forming deep coral species. We stratify the gulf by region and depth zones to explore potential correlations of effort and coral distribution.



Longline gear marine debris on West Bank, Flower Garden Banks National Marine Sanctuary, Gulf of Mexico. Image courtesy of NURC/UNCW and NOAA ONMS/FGBNMS.

Additionally, spatial results will integrate with current and potential Habitat Areas of Particular Concern (HAPCs) areas to determine the amount of predicted coral habitat within HAPCs and highlight areas of potential conflict with commercial fishing effort. The Gulf of Mexico Fishery Management Council (GMFMC) initially identified 47 hard bottom habitat types and some specific sites in 1998, and adopted HAPC status for 17 areas in 2005. In 2014, the Council designated a Corals Expert Working Group to identify additional coral areas for potential protection, as recent research cruises had identified important, but unprotected coral hotspots around the Gulf. This group recommended additional areas as HAPCs based on certain criteria (MAFMC, 2016; Figures 3 and 4).

Introduction

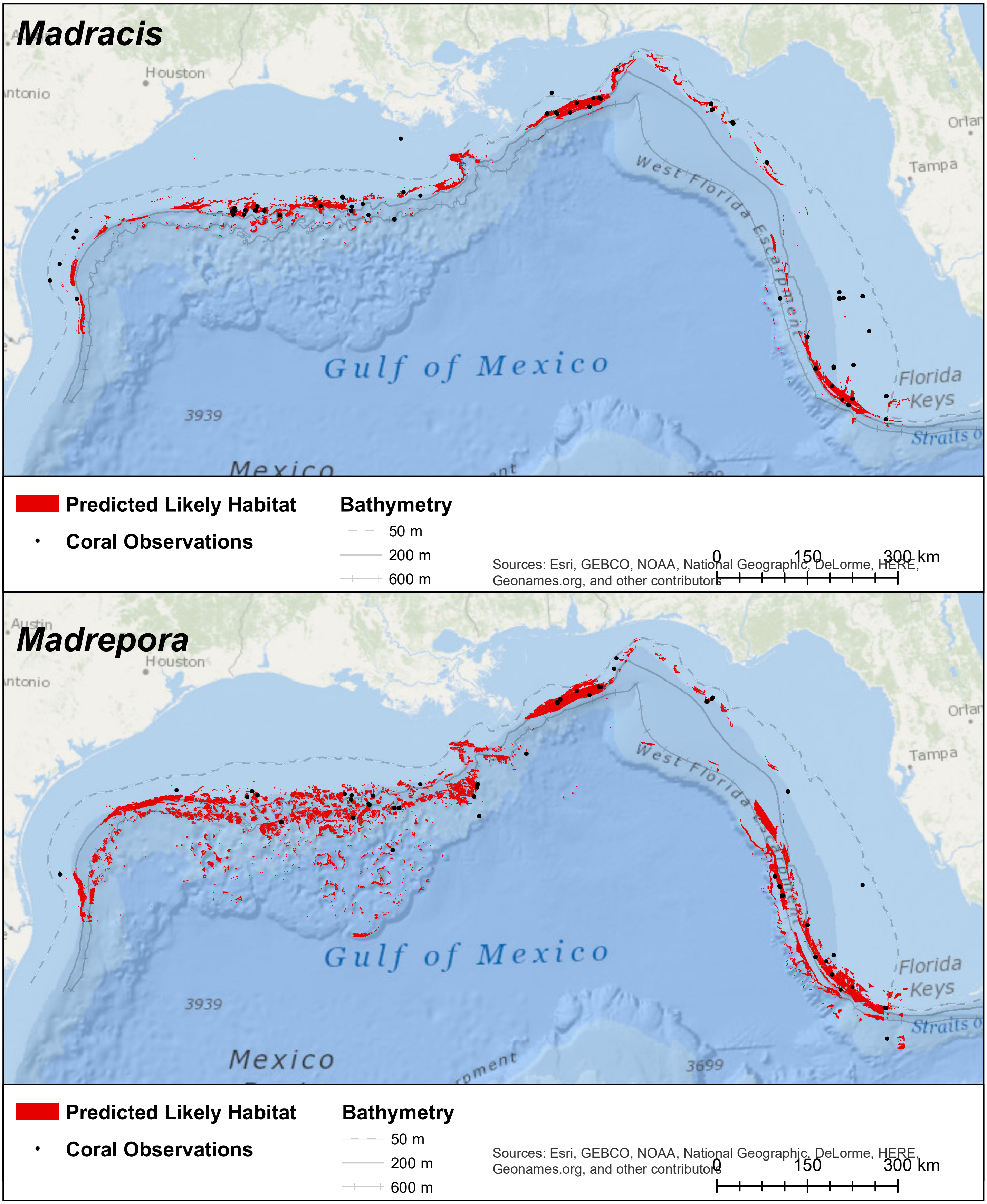


Figure 1. Predicted likely habitat and observational data for Madracis *and* Madrepora *complexes (Kinlan et al., 2016).*

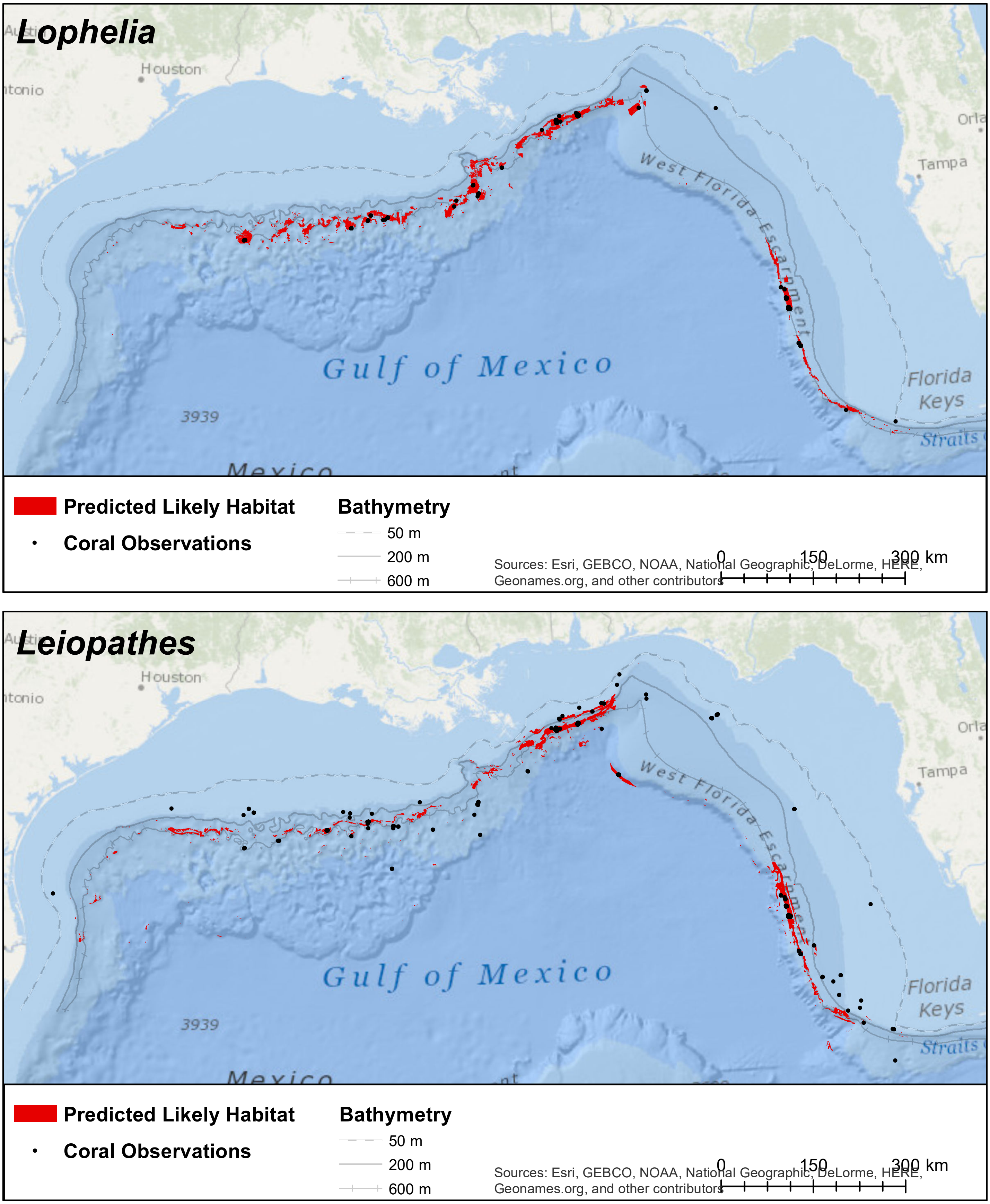
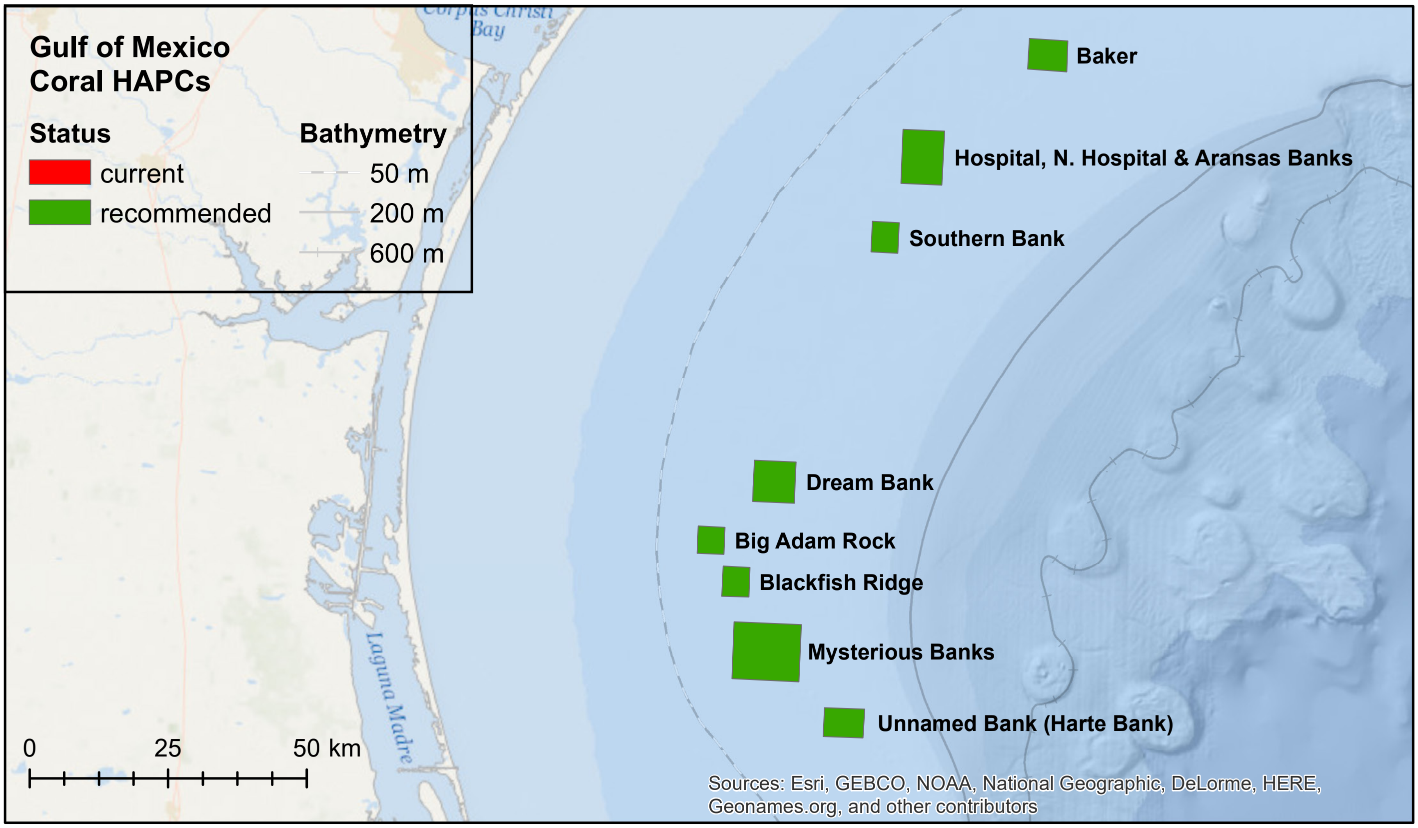


Figure 2. Predicted likely habitat and observational data for Lophelia pertusa *(Kinlan et al., 2016) and* Leiopathes *complex (Etnoyer et al., 2017).*

Introduction



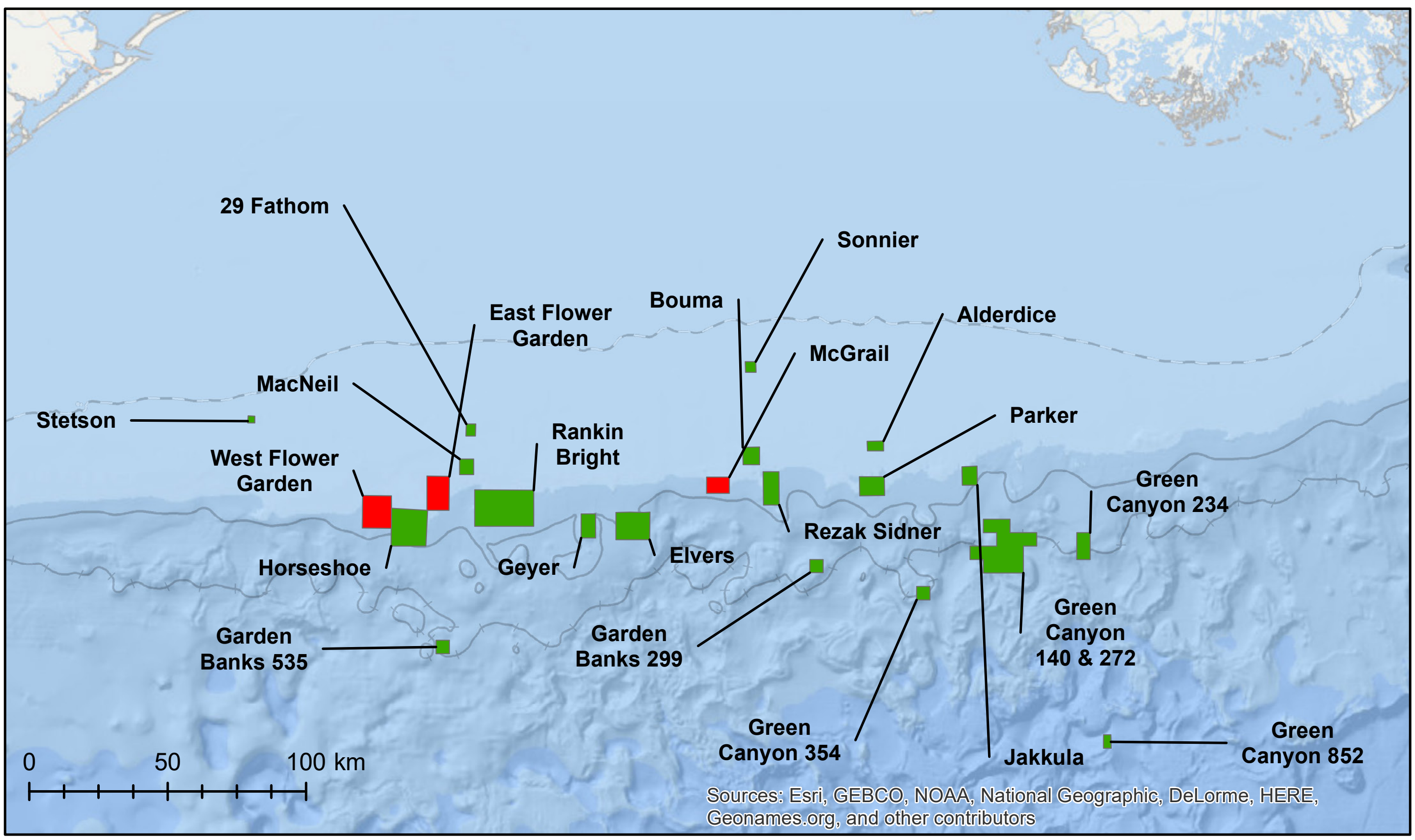


Figure 3. Location and status of existing and proposed coral habitat areas of particular concern (HAPC) in the west and central Gulf of Mexico.

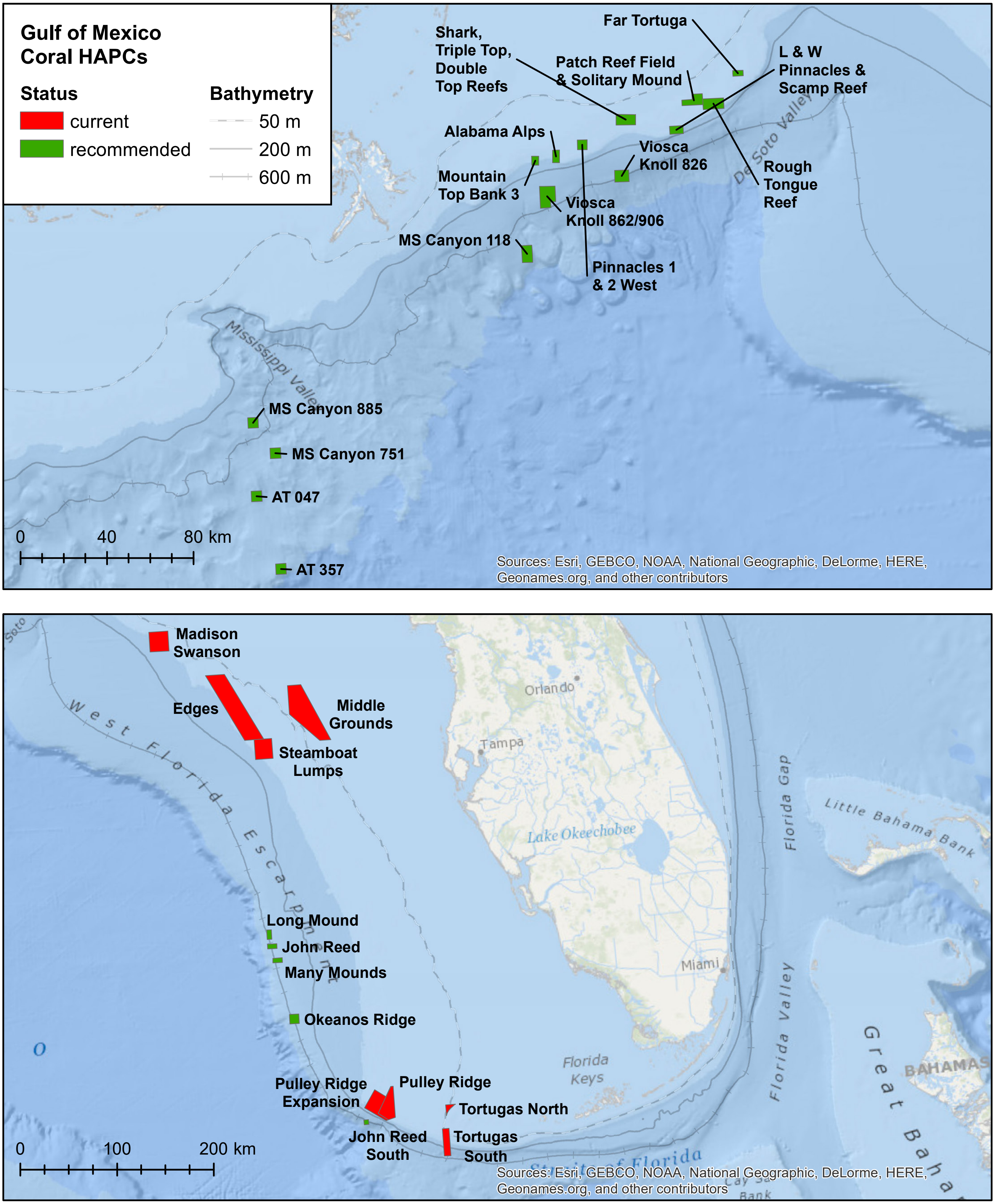


Figure 4. Location and status of existing and proposed coral habitat areas of particular concern (HAPC) in the northeastern Gulf of Mexico and west Florida shelf.

Chapter 2: METHODS

2.1 FISHERY DATA ANALYSIS

Several reporting tools are used by NOAA's National Marine Fisheries Service (NMFS) to estimate fisheries effort as part of the stock assessment process. The Electronic Log Book (ELB) program collects information on the amount and location of shrimp fishing effort. Current regulations require Gulf shrimp permit holders to participate in the program, if selected. Selection occurs randomly amongst the pool of active fishing vessels. The ELB is a global positioning system (GPS) that records a vessel's location at 10-minute time intervals. From these time-stamped locations, vessel speed between points can be estimated to determine if the vessel was stopped, towing or moving between towing points. With this information, effort can be calculated for each fishing trip. Approximately 500 vessels participate in the ELB program and represent about 50% of the commercial shrimp landings (James Nance, pers. comm.).

NMFS ELB data from 2006-2013 were used to evaluate spatial patterns relative to predicted coral habitat suitability. Algorithms to categorize ELB data as fishing or non-fishing were previously developed by LGL Ecological Associates (Gallaway et al., 2011), and the fishing data were provided to NCCOS for analysis. ELB data are described and analyzed as cumulative hours trawled.

Vessel Monitoring System (VMS) data from 2010-2015 were also obtained from NOAA's Office of Law Enforcement and Southeast Fisheries Science Center (SEFSC) and used to estimate fishing spatial patterns for reef bottom longline vessels. VMS instruments record GPS position and various directional and speed measurements, typically once per hour. Vessel fishing activity is not recorded but may be interpreted from vessel speed information. The VMS data package obtained from NMFS included the history of the vessel's movement, its permits and other background information (NOAA NMFS SEFSC, 2016). Actual gear used at a given point in time is not recorded, but permit information provides information on a vessel's allowable gear.

Commercial vessels in the Gulf targeting reef species such as grouper, snapper and tilefish require a Gulf of Mexico Reef Fish Commercial Permit and typically use bottom longline (BLL) or some type of vertical line gear (and occasionally fixed buoy gear in inshore areas where longlining is prohibited). Vessels also require an additional Eastern Gulf Reef Bottom Longline Endorsement to use BLL gear for reef fish east of Cape San Blas (85° 30' W longitude; GMFMC, 2017).

*Commonly targeted longline fishery species, red grouper (*Epinephelus morio*). Image courtesy of Don DeMaria.*

The VMS dataset was queried for vessels that possessed both the reef fish commercial permit and the BLL endorsement at the time of fishing. While the BLL endorsement is only required for fishing in the eastern Gulf, the presence of the annually renewed endorsement increased the likelihood that vessel was engaged in bottom longlining, and not just another fishing method encompassed by the commercial reef fish permit, such as handline or bandit reel fishing. The BLL endorsement was implemented in 2010 (GMFMC, 2010) and thus the time-period for the dataset was restricted to 2010-2015.

BLL gear is prohibited shallower than 50 fathoms (91 m) west of Cape San Blas. East of San Blas it is prohibited out to 20 fathoms (37 m) most of the year (September through May), and that closure extends out to 35 fathoms (64 m) from June through August (GMFMC, 2017). Given the restricted inshore effort and deep coral habitat focus of the analysis, the data were further restricted to those VMS points in waters deeper than 45 meters. These filters resulted in a preliminary dataset of 373,605 VMS points from 83 vessels. VMS data are described and analyzed as number of estimated fishing positions.

Vessel speed thresholds are a common means to separate likely fishing activity from non-fishing activity in VMS records (Witt and Godley, 2007; Bastardie et al., 2010; Jennings and Lee, 2012; Lambert et al., 2012; de Souza et al., 2016). Frequency distributions of individual vessel speed are typically bimodal, showing a slower peak indicative of fishing activity and a higher speed peak associated with steaming/transit (Mills et al., 2006; Palmer and Wigley, 2009).

Although VMS devices ostensibly collect instantaneous vessel speed, those measurements are missing or erroneous for many vessels in the Gulf of Mexico. As a result, SEFSC VMS managers calculated a derived speed for each VMS position using the straight-line distance and time interval between consecutive positions, a method used by other VMS managers (Mills et al., 2006; Palmer and Wigley, 2009; Gerritsen and Lordan, 2010). However, derived speeds skew slower than expected instantaneous fishing and steaming speeds (Gerritsen and Lordan, 2010). This is likely due to the assumption of straight line distance between points when actual movements are more circuitous, and because each value is an average over an approximately 1 hour period which may include highly variable speeds and occasional stops.

The 45 m depth minimum filter ensured that slow movements close to port areas were excluded from speed distributions. Many vessels show an additional peak where derived speed equaled zero, indicating no movement since the last position was taken. A stationary vessel is likely anchored and either not fishing or, given the reef fish permit these vessels possess, fishing with vertical line gear. Therefore, zero-speed points were excluded from analysis.

Speed distributions vary between vessels and were identified separately for each vessel in the R programming environment (R Core Team, 2016). The maximum fishing speed threshold was estimated by applying a segmented regression to the speed frequency distribution, which assigned breakpoints to divide the distribution into distinct segments (Palmer and Wigley, 2009; Bastardie et al., 2010; Hintzen et al., 2012). The first segment breakpoint falling on the downslope of the low ("fishing") speed peak was used as a conservative maximum fishing speed threshold V_{max} (Figure 5). Given the low speed peaks typically skewed close to zero, 0.1 kts/h was selected as the minimum fishing speed threshold V_{min} for all vessels. Relatively slow speeds across the entire frequency distribution can be attributed to the limitations of derived speed calculation.

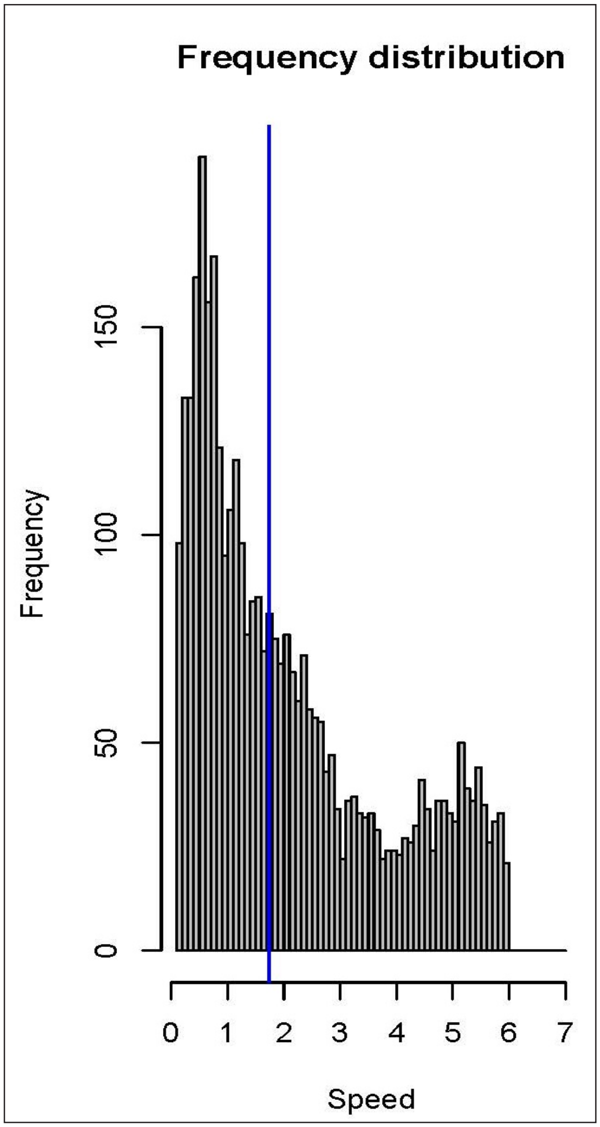
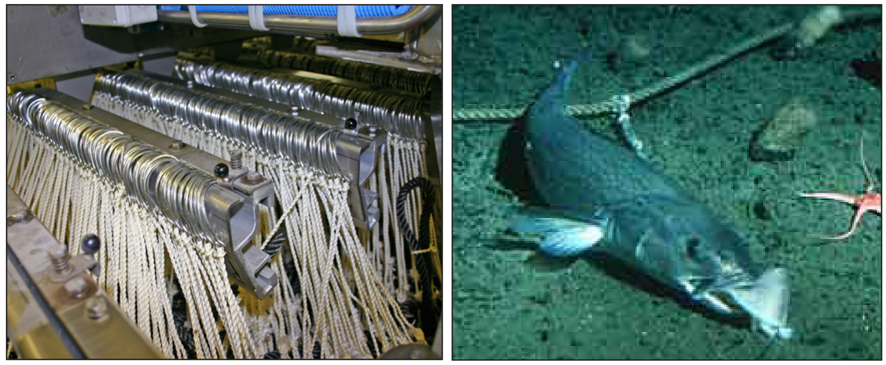


Figure 5. Example of vessel speed distribution and fishing speed identification. Cumulative frequency distribution of speeds (knots) from BLL vessel. Low speed peak associated with fishing speed; V_{min} set at 0.1 kts for all vessels, and V_{max} (blue line) set as the first breakpoint assigned by segmented regression.

Methods

All VMS points between V_{min} and the V_{max} identified for each vessel were considered to represent likely fishing activity. SEFSC observers report a fishing depth range of 35-388 m for the reef BLL fishery (Scott-Denton and Williams, 2013). Any fishing points deeper than 400 m were removed from the dataset, and were assumed to represent fishing associated with another permit (e.g., pelagic longlining). In total, these speed and depth filters reduced the original VMS point dataset by almost half, and 191,364 fishing activity points from 80 vessels were included in subsequent analyses.



Longline hooks (left; David Csepp, NOAA NMFS) and fish on hook of bottom longline (right; NOAA NMFS).

The spatial distribution of trawl and BLL fishing data (from ELB and VMS programs, respectively) were plotted in ArcGIS and aggregated into a grid of 10x10 km cells across the Gulf to visualize summary data and obscure individual vessel movement. NMFS adheres to strict confidentiality guidelines with regards to its various data collection programs, including the ELB and VMS programs. While no vessel information was included in the ELB (trawl) dataset, vessels were distinguished by numerical codes for the VMS (BLL) dataset allowing a number of fishing vessels to be quantified in a given area. In accordance with NOAA Fisheries' "Rule of Three," any grid cell with <3 vessels active within it was removed from figures and corresponding calculations to uphold the confidentiality requirements of The Magnuson-Stevens Fishery Conservation and Management Reauthorization Act of 2006. Smaller grid cells were explored as analytical units but resulted in too few cells with ≥3 vessels (e.g., 1 km^2 cells forced the exclusion of approximately 50% of the VMS dataset). ELB data does not contain specific vessel information and does not adhere to the "Rule of Three", but both data sets were summarized in the 10x10 km framework for standardization purposes.

Habitat suitability model results for *Madracis*, *Madrepora*, *Leiopathes* species complexes and *Lophelia pertusa* were used to evaluate their spatial distribution relative to the fishing effort information obtained from NMFS. Suitability maps for each species ranged from low (0) to high (10). Areas with suitability values greater than five reflect a stronger likelihood of potential habitat for each particular complex or species (Figures 1 and 2). Thus, areas with suitability less than five were excluded from analysis. Suitable area of each taxa was summarized within each grid cell.

2.2 FISHERY AND CORAL SPATIAL COINCIDENCE

Trawl and BLL data that overlapped with highly suitable coral habitat were extracted and incorporated into a GIS. Data were interpolated using kernel density in ArcMap 10.4 to highlight areas of spatial coincidence. Kernel density estimates were restricted to the spatial extent of each coral group's likely habitat for both trawl and BLL effort. These confined kernel estimates visualize the relative probability distribution of fishing effort across each habitat, and identify relative hotspots of activity.

Fishing effort was ranked for both kernel estimates and HAPC summaries. For trawl effort: 0 hrs/km^2 = rank of 0; 0-0.5 hrs/km^2 = 1; 0.5-3.0 = 2; and >3.0 hrs/km^2 = 3. For BLL effort: 0 positions/km^2 = rank of 0; 0-0.1 positions/km^2 = 1; 0.1-0.25 positions/km^2 = 2; and >0.25 positions/km^2 = 3. For ease of interpretation and comparison of priorities between HAPCs, the two effort ranks were summed to obtain a total fishing effort rank assigned to the HAPC: 0 = none; 1 = low; 2 = moderate and 3-6 = high impact level.

Coral habitat suitability was similarly ranked in HAPCs: for each coral taxon, 0% likely habitat = a rank of 0, 0-10% = 1; 10-50% = 2; and >50% = 3. Coral taxon ranks were then summed to obtain a final coral HSI rank for the HAPC: 0= none; 1-3 = low; 4-5= moderate and 6-12= high coral habitat coverage.

Chapter 3: RESULTS

3.1 SPATIAL DISTRIBUTION OF FISHING EFFORT

The study area for these analyses totaled 193,967 km² (Table 1). The eastern study area comprised 54% of the total study area while the western study area comprised 46%. Within both regions the 45-150 m strata was the largest. The 150-300 m strata in the west is the smallest western strata and the eastern counterpart is nearly twice as large. Deep strata (300-800 m) were similar in the west and east. Trawl effort was concentrated in the 45-150 m range in the western Gulf, while BLL effort was concentrated in the 45-150 m and 150-300 m strata in the Eastern Gulf.

Table 1. Area size, total fishing effort, and effort per unit area for the regional and depth strata of interest for deep coral habitat and fishery interactions.

Spatial Stratum	Area (km²)	BLL effort (positions)	BLL positions/km²	Trawl effort (hrs)	Trawl hrs/km²
East Gulf, 45-150 m	55,994	135,824	2.4	3,021	0.1
East Gulf, 150 – 300 m	25,255	39,916	1.6	89	0.0
East Gulf, 300 – 800 m	24,543	3,370	0.1	8,376	0.3
Total East Gulf, 45-800 m	**105,793**	**179,110**	**1.7**	**11,485**	**0.1**
West Gulf, 45-150 m	50,016	3,890	0.1	460,663	9.2
West Gulf, 150 – 300 m	10,879	4,135	0.4	91	0.0
West Gulf, 300 – 800 m	27,369	1,533	0.1	6,823	0.2
Total West Gulf, 45-800 m	**88,174**	**9,558**	**0.1**	**467,576**	**5.3**

Gulf trawl effort from 2006-2013 ELB data totaled 2.7 million hours. The majority (83%) of trawl effort occurred at depths less than 50 m throughout the Gulf of Mexico. Trawl effort within the study area was 479,059 hours or 17% of the total ELB data. Overall trawl effort by grid, ranged from zero to a maximum of 34,509 hours fished per 100 km² cell on shelf waters located between Lake Calcasieu and the Mississippi River (Figure 6). A broad band of high effort was observed over shallow shelf waters from southern Texas through the area south of Mobile Bay. Effort was overwhelmingly higher in the western Gulf, with only 2.4% of total ELB effort in the study area occurring in the area from Apalachicola Bay to the Florida Keys. In the eastern Gulf, effort was highest in the Dry Tortugas but still <5,000 hours per grid cell throughout the shelf.

BLL effort ranged from zero to a maximum 1,733 vessel positions per 100 km² (Figure 7) and a maximum of 46 vessels active per cell (Figure 8). Areas of highest effort and vessel number were all located in the eastern Gulf along the west Florida shelf, predominantly in mid-shelf waters <100 m in depth. The majority of cells with highest BLL effort (>500) occurred at depths less than 100 m. A broad band of peak effort and vessel number in the 45-100 m depth range extends from Tampa to Naples, with additional patches of high effort extending south inside the 100 m isobath to Pulley Ridge, inside the HAPCs and throughout the surrounding area. Following the same 50-100 m isobath range farther north, patches of high effort were found south of Apalachicola Bay, inside The Edges HAPC and between The Edges and Middle Grounds. Patches of high effort were also identified deeper on the West Florida Escarpment (WFE) between 200 m and 300 m isobaths, due west of Fort Myers and Naples. Little effort was observed in the western Gulf in this dataset, with many areas containing <3 positions per 100 km² grid cell, and none possessing more than 300 positions per cell.

Results

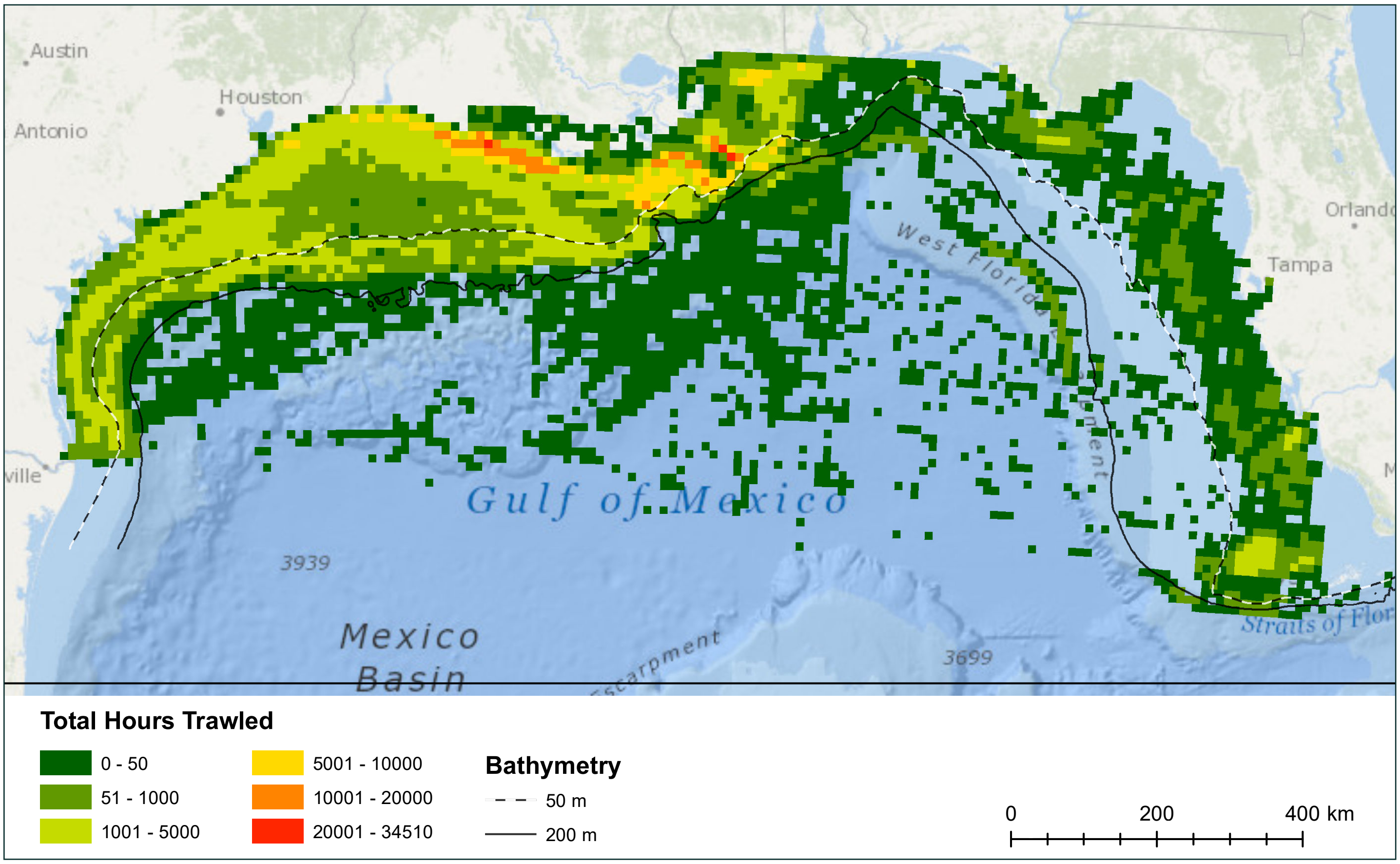


Figure 6. Shrimp electronic logbook trawl effort (hours trawled) summarized in 10 x 10 km² grid across all depths.

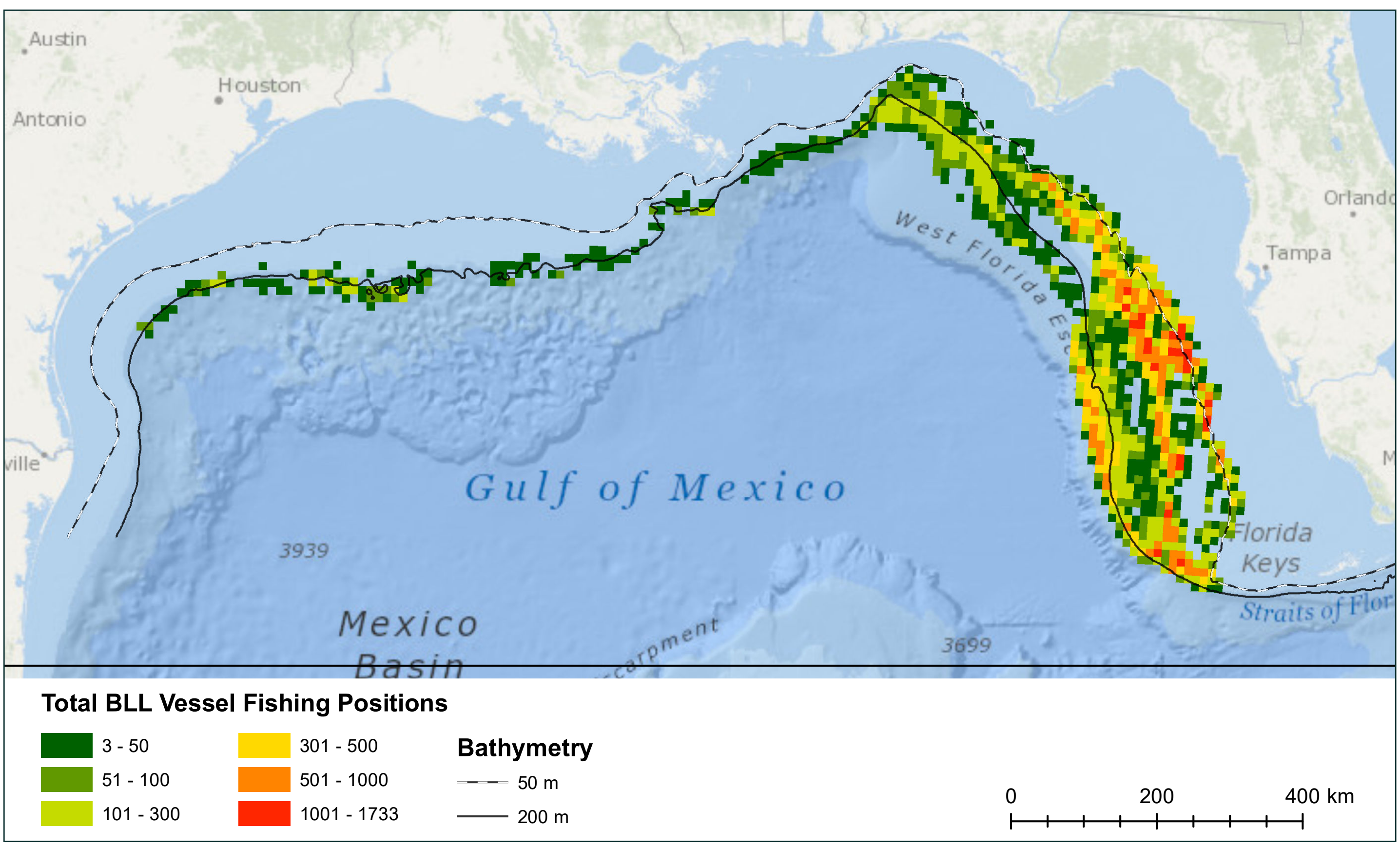


Figure 7. Bottom longline (BLL) fishing effort (positions) summarized in 10 x 10 km² grid. Only activity in waters deeper than 45 m is displayed here.

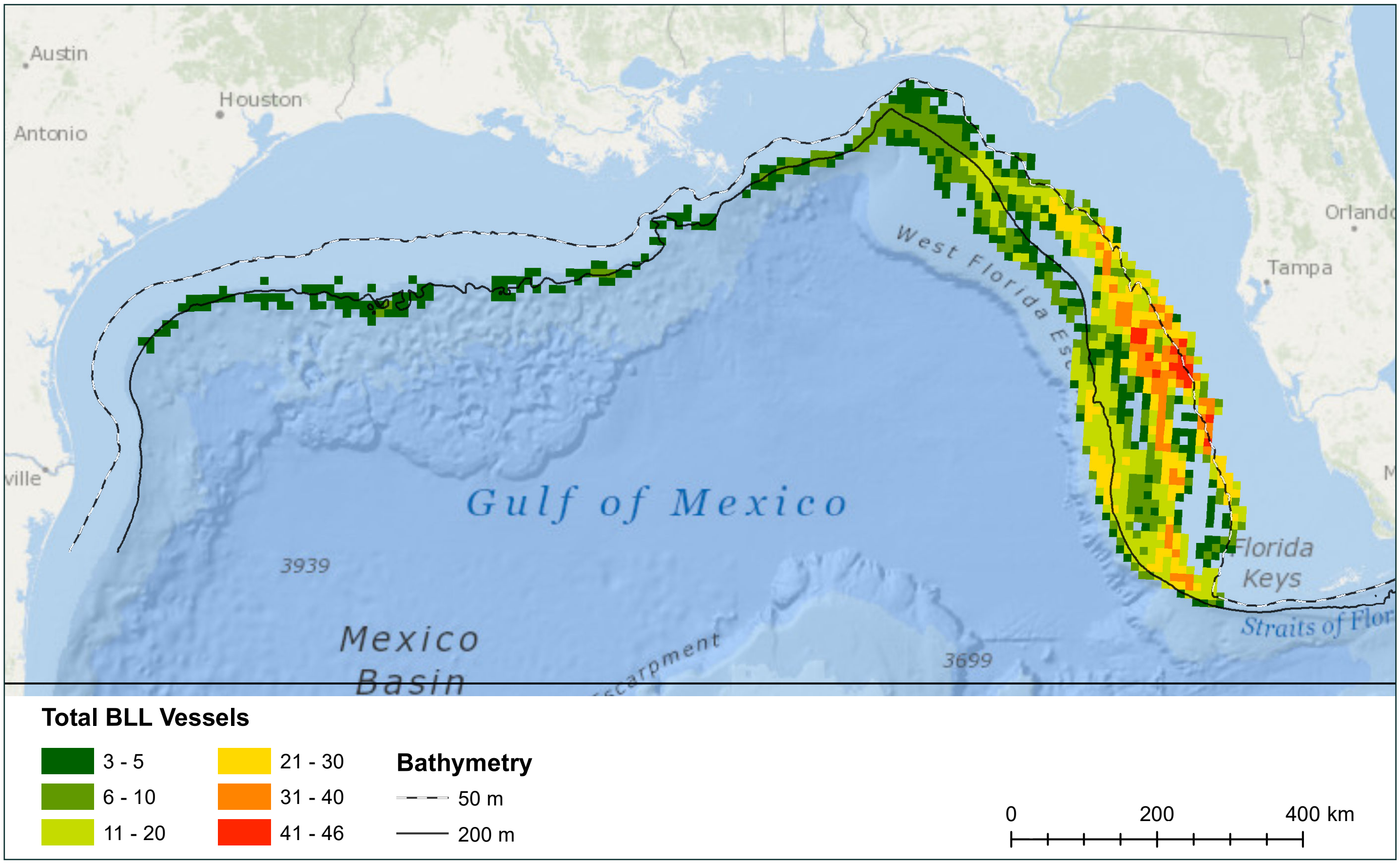


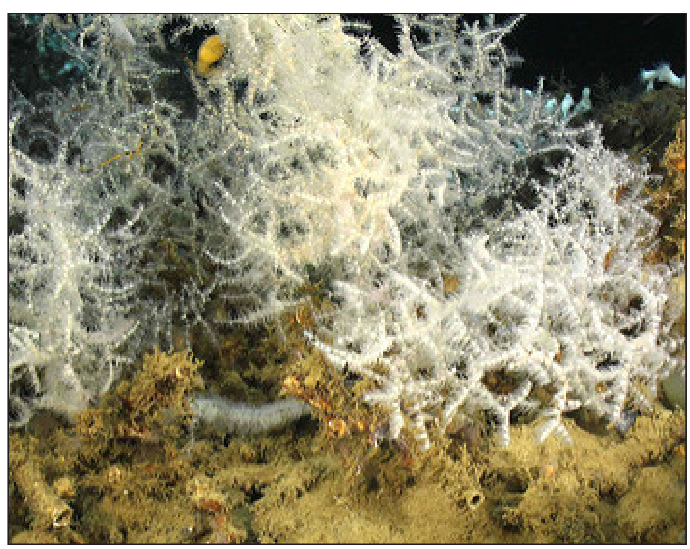
Figure 8. Bottom longline (BLL) fishing effort (vessels) summarized in 10 x 10 km² grid. Only activity in waters deeper than 45 m is displayed here.

3.2 SPATIAL RELATIONSHIPS OF LIKELY CORAL HABITAT TO FISHING EFFORT AND HAPCS

The spatial distribution of *Madracis*, *Madrepora*, *Leiopathes* and *Lophelia* HSI maps are shown in Figures 1 and 2. Table 2 provides summary statistics for each HAPC including predicted coral area, ELB trawl effort, VMS BLL effort, and actual coral observations. The spatial overlap of fishing effort kernel estimates and coral habitat on specific HAPCs is visualized in greater detail in Appendix Figures A1-A16.

Highly suitable habitat for *Madracis* is shallower than that for *Madrepora*, *Leiopathes* and *Lophelia*, occurring predominantly between the 50 and 200 m isobaths throughout the Gulf. The majority of habitat is closer to the 200 m isobaths, while a small proportion of habitat extends to depths of 800 m (Figure 1). Overall, suitable habitat for *Madracis* totals 11,301 km² or 5.8% of the study area.

Trawl effort was highly coincident (78%) with *Madracis* suitable habitat (Figure 9). Coincident hotspots occurred just east and west of the mouth of the Mississippi River, with smaller patches of high coincidence along the shelf edge heading west from eastern Louisiana to eastern Texas. No spatial overlap was observed from the Florida Panhandle to the shelf west of Charlotte Harbor.



Leiopathes *species. Image courtesy of Lophelia II 2010 Expedition, NOAA OER/BOEM.*

Results

*Table 2. Area and mean depth for current (regulated or non-regulated), recommended, and 'under consideration' HAPC areas. Other metrics include estimates of trawl effort (hours fished) and bottom longline effort (total positions). Each coral column (*Madracis, Madrepora, Lophelia, *and* Leiopathes*) indicates the percentage of HAPC area that contains suitable habitat for the given species complex, and the number of actual coral observations in that HAPC (collected by the Deep Sea Coral Research and Technology Program) is indicated in parentheses.*

Location Name	HAPC Status	Area (km²)	Mean Depth (m)	Trawl Effort (hours)	BLL Effort (positions)	*Madracis* % Habitat (Obs)	*Madrepora* % Habitat (Obs)	*Lophelia* % Habitat (Obs)	*Leiopathes* % Habitat (Obs)
29 Fathom Bank	current/no reg	14.8	65	23.4	7	55.3 (0)	9.3 (0)	0 (0)	0 (0)
Alabama Alps	under consideration	18.5	101	38.5	3	99.1 (10)	100 (3)	0 (0)	4.2 (0)
Alderdice Bank	current/no reg	20.7	88	1	0	69.9 (5)	59.7 (0)	0 (0)	0 (0)
AT 047	under consideration	23.3	866	0.5	0	0 (0)	76.9 (1)	0 (0)	0 (0)
AT 357	under consideration	23.3	1118	0	0	0 (0)	0 (2)	0 (0)	0 (0)
Baker Bank	recommended	38.7	72	633.6	0	10.3 (0)	0 (0)	0 (0)	0 (0)
Big Adam Rock	recommended	23.3	64	116.4	0	0 (0)	0 (0)	0 (0)	0 (0)
Blackfish Ridge	recommended	25.7	71	167.4	0	3.2 (0)	0 (0)	0 (0)	0 (0)
Bouma Bank	current/no reg	37.8	85	4	0	89.3 (2)	81.5 (0)	0 (0)	0 (0)
Dream Bank	recommended	55.1	81	561	0	8.5 (1)	0 (0)	0 (0)	0 (0)
East Flower Garden Bank	current/reg	98.7	100	0.8	0	83.6 (2)	53.2 (1)	0 (0)	0 (0)
Edges	current/reg	1337.7	87	0.3	4233	7.3 (4)	0.1 (0)	0 (0)	0 (0)
Elvers Bank	recommended	120.5	188	0	11	55.4 (0)	37.7 (0)	0 (0)	0 (0)
Far Tortuga	recommended	12.6	75	0.3	1	0 (0)	0 (0)	0 (0)	0 (0)
Garden Banks 299	under consideration	22.4	395	0	1	29.5 (0)	97.4 (0)	94.9 (0)	85.6 (57)
Garden Banks 535	under consideration	23.3	585	0	0	0 (0)	6.7 (0)	100 (55)	0.8 (3)
Geyer Bank	current/no reg	45.1	127	0.2	11	97 (8)	81 (0)	0 (0)	0 (0)
Green Canyon 140 & 272	under consideration	279.8	602	0.3	6	9.3 (1)	41	56.8 (9)	14.1 (59)
Green Canyon 234	under consideration	46.6	565	0.5	0	0 (0)	43.2 (0)	82 (107)	2.7 (0)
Green Canyon 354	under consideration	23.3	612	0	0	38.2 (0)	82.9 (1)	71.1 (39)	38.4 (1)
Green Canyon 852	under consideration	13.1	1588	0	0	0 (0)	32.1 (6)	0 (0)	0 (0)
Horseshoe Bank	recommended	170.9	151	0.8	125	60.1 (2)	23.7 (0)	0 (0)	0 (0)
Hospital, North Hospital & Aransas Banks	recommended	71.8	72	674.6	0	18 (3)	0.8 (0)	0 (0)	0 (0)
Jakkula Bank	current/no reg	36.6	144	0	8	32 (1)	25 (0)	0 (0)	0 (0)
John Reed North	under consideration	46.6	536	0	4	0 (1)	66.9 (2)	85.4 (37)	67.2 (12)
John Reed South	under consideration	23.3	700	0	0	0 (0)	51.7 (0)	52.5 (1)	51.9 (0)
L & W Pinnacles & Scamp Reef	under consideration	23	126	0.2	4	90.1 (6)	100	0 (0)	38 (0)
Long Mound	under consideration	46.6	488	0	0	0 (0)	99.9 (0)	100 (3)	100 (10)
MacNeil Bank	current/no reg	27.8	89	15.8	6	49.6 (0)	27.5 (4)	0 (0)	0 (0)

Table 2 ***continued****. Area and mean depth for current (regulated or non-regulated), recommended, and 'under consideration' HAPC areas. Other metrics include estimates of trawl effort (hours fished) and bottom longline effort (total positions). Each coral column (*Madracis, Madrepora, Lophelia, and Leiopathes*) indicates the percentage of HAPC area that contains suitable habitat for the given species complex, and the number of actual coral observations in that HAPC (collected by the Deep Sea Coral Research and Technology Program) is indicated in parentheses.*

Location Name	HAPC Status	Area (km²)	Mean Depth (m)	Trawl Effort (hours)	BLL Effort (positions)	*Madracis* % Habitat (Obs)	*Madrepora* % Habitat (Obs)	*Lophelia* % Habitat (Obs)	*Leiopathes* % Habitat (Obs)
Madison Swanson	current/reg	395.3	108	0	48	20.1 (18)	19.9 (14)	0 (1)	0 (0)
Many Mounds	under consideration	44.7	449	0	6	0 (0)	81.6 (8)	79.2 (282)	81 (104)
McGrail Bank	current/reg	48.4	119	0.3	1	89 (0)	86.4 (0)	0 (0)	0 (0)
Middle Grounds	current/reg	1164.2	39	14.2	41	0 (0)	0 (0)	0 (0)	0 (0)
Mississippi Canyon 118	under consideration	37.9	949	3.8	0	0 (0)	0 (0)	37.5 (0)	0.2 (0)
Mississippi Canyon 751	under consideration	23.3	657	0.3	0	0 (0)	75.1 (4)	96.6 (12)	0 (0)
Mississippi Canyon 885	under consideration	23.3	465	0.3	0	0 (0)	44.1 (0)	89.4 (151)	0 (0)
Mountain Top Bank 3	recommended	13.4	122	86.2	6	96.1 (0)	100 (0)	0 (0)	0 (0)
Mysterious Banks	recommended	122.9	77	967.3	0	4.7 (0)	0.6 (0)	0 (0)	0 (0)
Okeanos Ridge	recommended	93.2	552	0.2	2	0 (0)	24.7 (0)	25.2 (39)	40.5 (13)
Parker Bank	recommended	61.8	103	0	4	97.4 (0)	88.5 (0)	0 (0)	0 (0)
Patch Reef Field & Solitary Mound	recommended	36.9	72	4.3	0	98.9 (1)	98.9 (0)	0 (0)	0 (0)
Pinnacle 1 Near West & West Pinnacle 2	recommended	20.2	92	2.8	0	100 (0)	100 (0)	0 (0)	13.9 (0)
Pulley Ridge	current/reg	345.1	70	0.2	154	65.2 (9)	76.5 (1)	0 (0)	0 (0)
Pulley Ridge Expansion	current/no reg	321.2	79	0.2	2556	76.7 (3)	85.5 (1)	0 (0)	0 (1)
Rankin Bright	current/no reg	278.2	117	1.3	21	66.1 (5)	47.2 (0)	0 (0)	0 (0)
Rezak Sidner	current/no reg	68.6	120	0	15	94.2 (2)	68.9 (0)	0 (0)	0 (0)
Rough Tongue Reef	under consideration	46.7	81	0.8	9	96.3 (8)	100 (10)	0 (0)	46.5 (0)
Shark, Triple Top, Double Top Reefs	recommended	43.3	81	4.7	1	89.7 (3)	87.7 (1)	0 (0)	0 (0)
Sonnier Bank	current/no reg	14.6	58	7.8	0	0 (0)	0	0 (0)	0 (0)
Southern Bank	under consideration	26.4	79	81.5	0	11.4 (1)	2.6 (0)	0 (0)	0 (0)
Steamboat Lumps	current/reg	365.9	87	0	8	19.4 (0)	13.9 (0)	0 (0)	0 (0)
Stetson Bank	recommended	6	55	1.5	7	15.9 (0)	0 (0)	0 (0)	0 (0)
Tortugas North	current/reg	41.4	52	2.6	1	13.6 (0)	1.7 (0)	0 (0)	0 (0)
Tortugas South	current/reg	187.2	164	1.2	22	9 (0)	31 (0)	1.4 (1)	1.3 (0)
Unnamed Bank (Harte Bank)	under consideration	37.2	94	1.5	3	8.1 (0)	0.4 (0)	0 (0)	0 (0)
Viosca Knoll 826	under consideration	35.4	584	2	0	0 (0)	0 (0)	100 (7170)	95 (1475)
Viosca Knoll 862/906	under consideration	64.5	426	279.9	7	0 (0)	27 (0)	99.7 (943)	89.4 (685)
West Flower Garden Bank	current/reg	122.7	115	0.5	8	96.7 (13)	74.9 (0)	0 (0)	0 (0)

Results

BLL effort overlapped 99% of highly suitable *Madracis* habitat (Figure 9). Areas of coincidence were located across the western and central Gulf primarily in the 50-200 m range, and there were hotspots in the eastern Gulf between 100-600 m from the Dry Tortugas region northward through the middle region of the WFE.

Madracis *at Stetson Bank, FGBNMS. Images courtesy of E. Hickerson, NOAA ONMS/FGBNMS.*

Thirty-nine HAPCs (18 current, 21 recommended or 'under consideration') contain suitable *Madracis* habitat (Table 2; Figures A1-A4). Twenty-two HAPCs (11 current and 11 recommended/considered) have 50% or more of their area comprised of *Madracis* habitat. Those with 100% or near 100% coverage are Pinnacle 1 Near West & West Pinnacle 2, Alabama Alps, Patch Reef Field and Solitary Mound. Observations of *Madracis* colonies occurred in 22 HAPCs (11 current and 11 recommended/considered), but most were recorded at Madison Swanson (18) and West Flower Garden Banks (13).

Madrepora highly suitable habitat (Figure 1) occurs extensively throughout the Gulf and accounts for 28,147 km² or 14.5% of shelf and slope habitat. High suitability areas range in depth between 50 and over 1000 m with most occurring at depths greater than 200 m. A conspicuous low abundance of suitable habitat exists from the Florida Panhandle to midway down the WFE in waters deeper than 200 m.

Trawl effort overlapped with 64% of suitable *Madrepora* habitat (Figure 10). Similar to *Madracis*, coincident trawl effort was found east and west of the mouth of the Mississippi River. Another area was located on the mid-region of the WFE.

Madrepora *species. Image courtesy of Expedition to the Deep Slope 2007, NOAA-OE.*

BLL effort data coincident with *Madrepora* suitability (Figure 10) exhibited similar patterns with that for *Madracis*. Overall 75% of suitable *Madrepora* habitat was coincident with BLL effort. Effort hotspots were distributed similarly to *Madracis* and observed throughout the entire Gulf, with especially broad swaths south of Mississippi and Alabama, and from the mid-region of the WFE extending south through the Dry Tortugas.

Forty-seven HAPCs (17 current, 30 recommended/considered) contain highly suitable *Madrepora* habitat (Table 2; Figures A5-A8). Twenty-five of these (8 current, 17 recommended/considered) have at least 50% suitable habitat and six HAPCs are comprised entirely of suitable *Madrepora* habitat (Pinnacle 1 Near West & West Pinnacle 2, Mountain Top Bank 3, L & W Pinnacles and Scamp Reef, Rough Tongue Reef, Alabama Alps, and Long Mound). Sixteen HAPCs (four current and 12 recommended/considered) contain actual *Madrepora* observations. The most observations were recorded on Madison Swanson (14) and Rough Tongue Reef (10).

Highly suitable habitat for *Lophelia* amounts to 6,966 km², or 3.5% of the study area, and occurs at depths between 150-800 m (Figure 2). The majority is evident in the northern Gulf from the western edge of the Florida Panhandle to south Texas. Like other taxa, there is a large gap in likely habitat in the eastern Gulf from the Panhandle running south to the midpoint of the WFE. Trawl effort overlap amounted to 39% of the total habitat area (Figure 11). Most trawl effort that coincided with suitable *Lophelia* habitat was considered low. Effort hotspots were restricted to an area concentrated in an east-west band off the mouth of the Mississippi River.

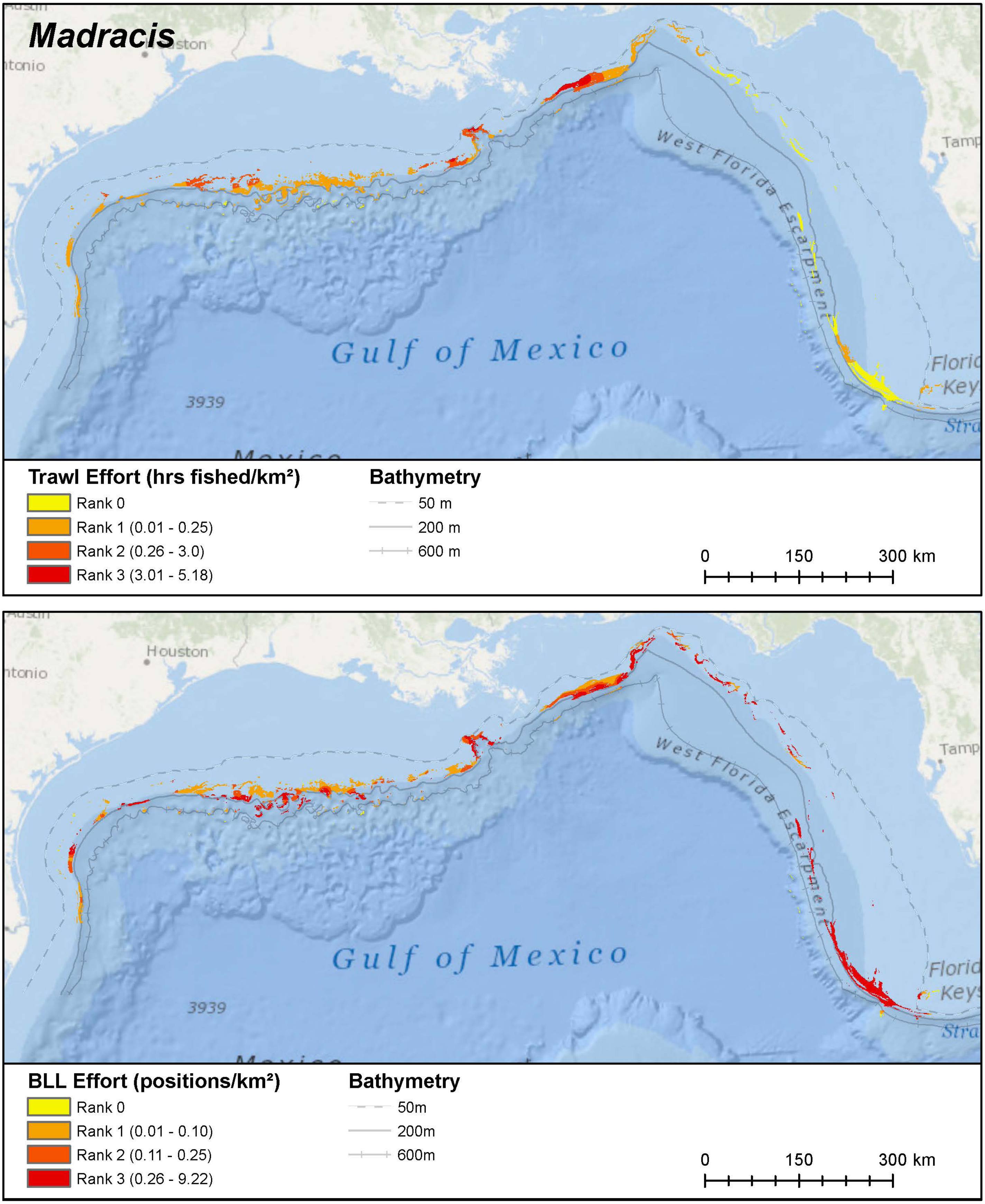
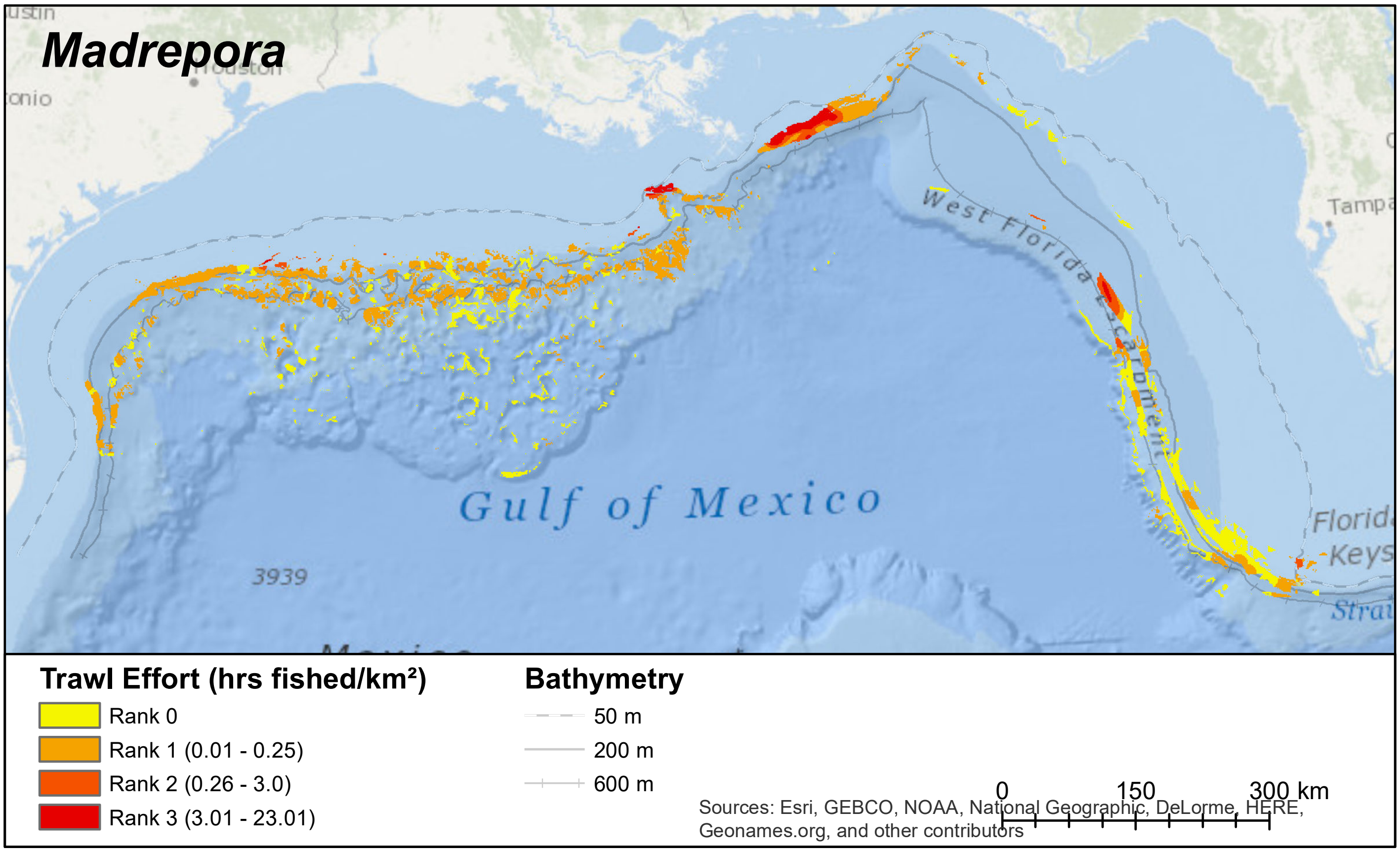


Figure 9. Kernel density estimates for trawl and bottom long line effort in areas predicted to be likely habitat for Madracis *complex.*

Results



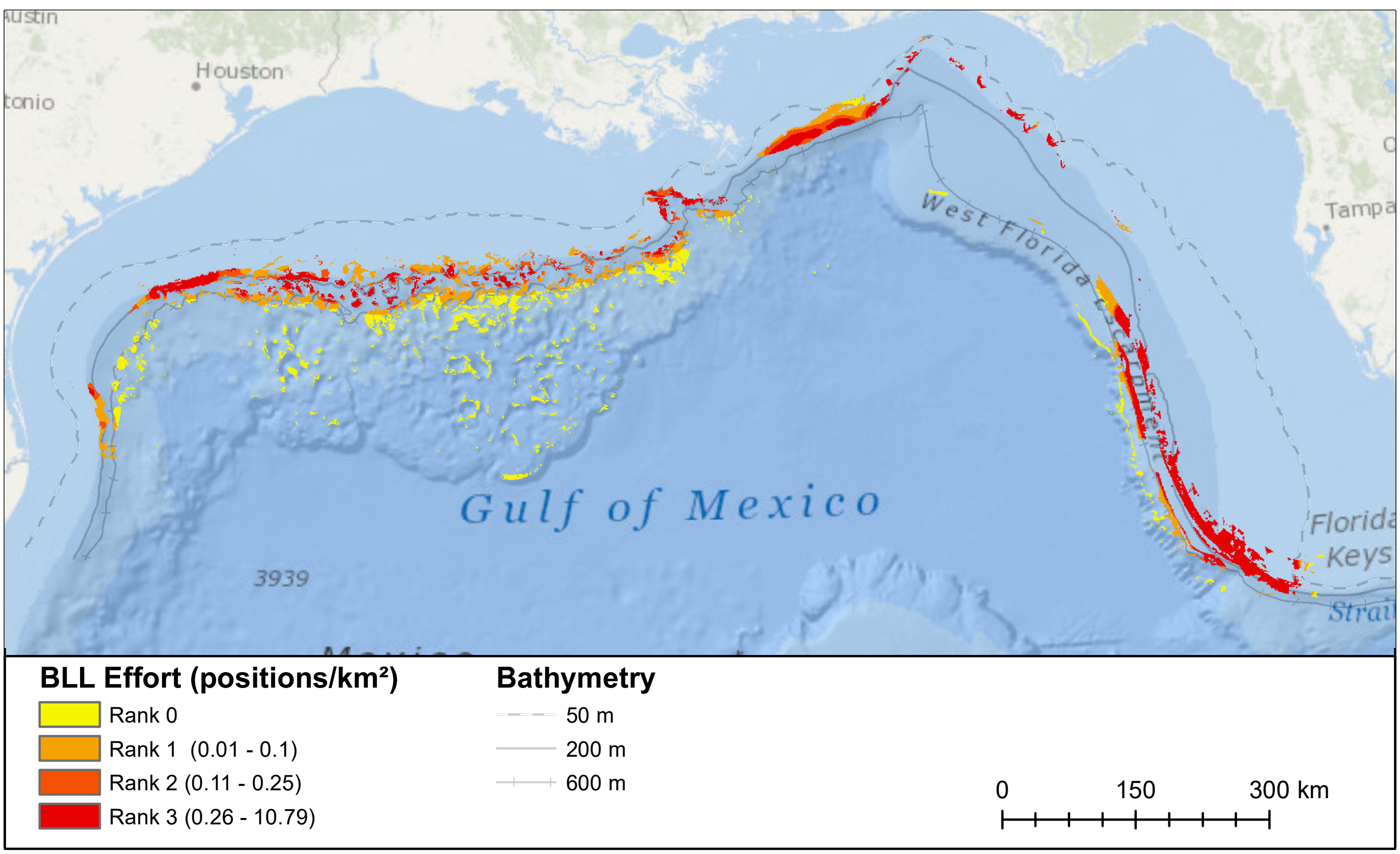
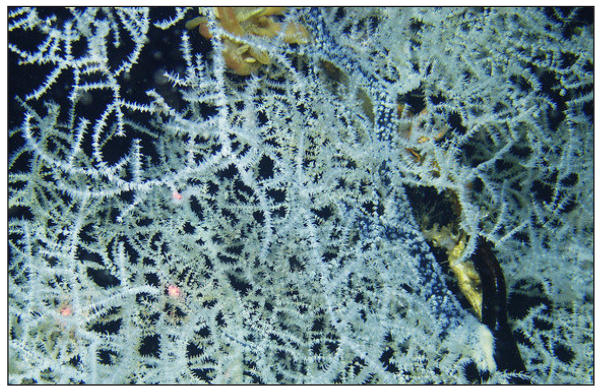


Figure 10. Kernel density estimates for trawl and bottom long line effort in areas predicted to be likely habitat for Madrepora *complex.*

BLL effort overlapped with 70% of suitable *Lophelia* habitat (Figure 11). Small hotspots of BLL effort were scattered across the central Gulf shelf, and the middle and southern end of the WFE.

Lophelia *species. Image courtesy of Ian McDonald, Lophelia II Reefs, Rigs, and Wrecks 2009 Expedition, NOAA OER/BOEM.*

Sixteen HAPCs (1 current, 15 recommended/considered) contain suitable *Lophelia* habitat. Thirteen have the majority of their areas comprised of suitable habitat, with Garden Banks 535, Long Mound, and both Viosca Knoll HAPCs having complete coverage (Table 2; Figures A9-A12). Fourteen areas had actual *Lophelia* observations, most notably those around the slope/canyon area south of the Mississippi River (Viosca Knoll 826, Viosca Knoll 862/906 and Mississippi Canyon 885).



Leiopathes *species. Image courtesy of Lophelia II Reefs, Rigs, and Wrecks 2009 Expedition, NOAA OER/BOEM.*

Highly suitable habitat for *Leiopathes* totals 6,042 km², or 3.1% of the study area, and is distributed between 300 and 800 m (Figure 2). Suitable habitat is most prevalent on offshore slope waters from central Texas to Pensacola Bay, Florida. As in *Lophelia* and others, a large gap in habitat extends from the Florida Panhandle midway down the WFE followed by a long broad area of suitable habitat extending through the Dry Tortugas region. Trawl effort overlapped 33% of *Leiopathes* suitable habitat (Figure 12). Like *Lophelia*, there was a band of high activity running east-west off the mouth of the Mississippi, encompassing approximately 100 km² (Figure 12). A smaller hotspot occurred on the WFE 50 km north of the Long Mound recommended HAPC.

BLL effort was coincident with 88% of *Leiopathes* habitat (Figure 12). As with trawl effort, hotspots of high effort were evident on the continental shelf edge south of Mississippi, and in the same region as *Lophelia*/BLL overlap. In the eastern Gulf, effort hotspots were most notable on the slope waters of the mid and southern WFE.

Eighteen HAPCs (all recommended or under consideration) have *Leiopathes* habitat included (Table 2; Figures A13-A16). Seven contain *Leiopathes* habitat for the majority of their area, with Long Mound having complete coverage.

Results

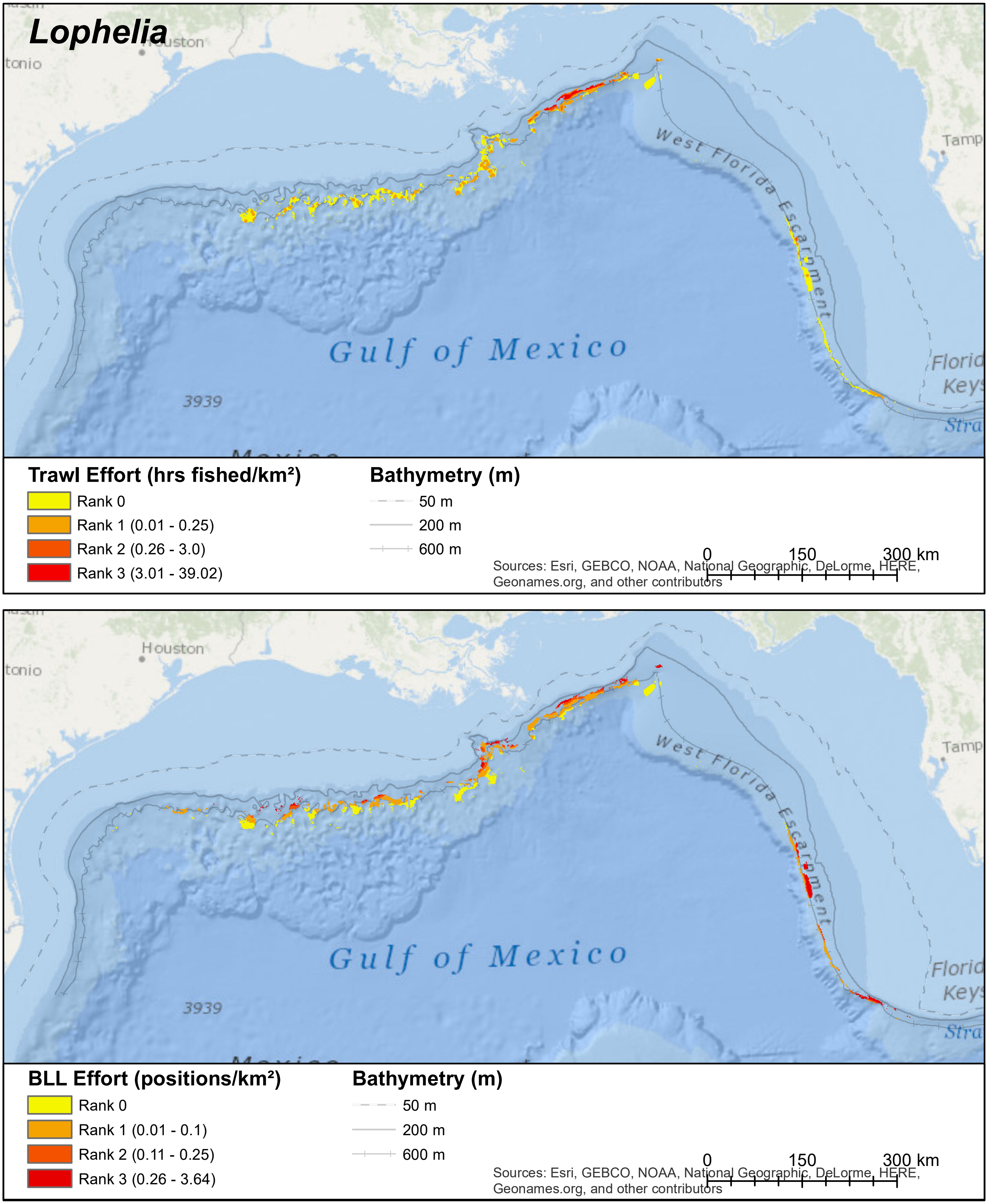


Figure 11. Kernel density estimates for trawl and bottom long line effort in areas predicted to be likely habitat for Lophelia pertusa.

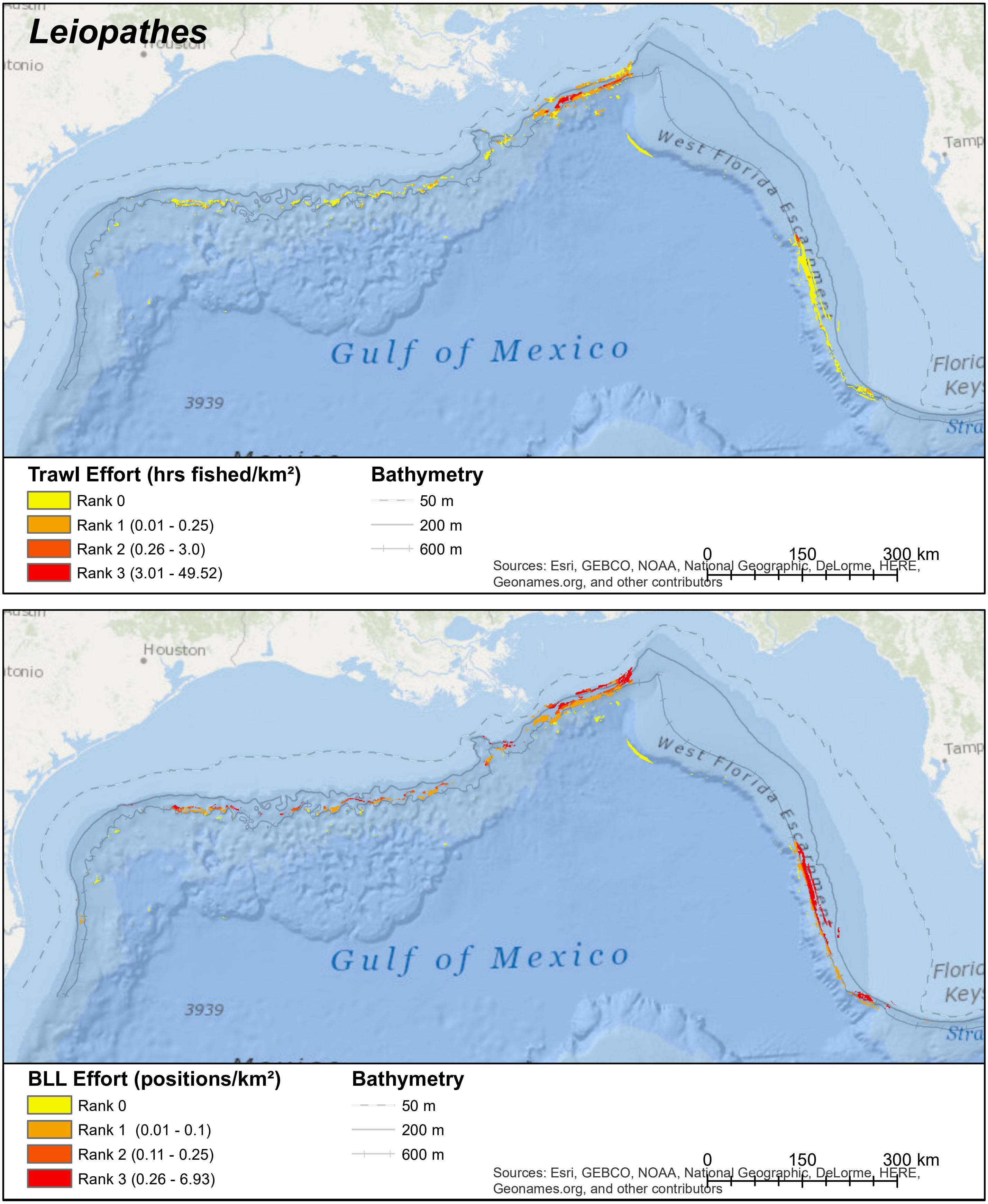


Figure 12. Kernel density estimates for trawl and bottom long line effort in areas predicted to be likely habitat for Leiopathes.

Results

3.3 HAPC SUMMARY DATA AND PRIORITIZATION

Figures 3 and 4 display the spatial distribution of existing and proposed coral HAPCs in the Gulf of Mexico. Refer to Table 2 for summary statistics for predicted coral habitat distribution, coral observations and fishing effort. Table 3 presents the summed fishing effort ranks and summed coral HSI ranks for each existing, proposed or recommended HAPC.

Table 3. Impact assessment for ranked fishing effort and habitat suitability area within current and proposed HAPCs and those areas recommended for HAPC consideration. Locations with most significant impacts are highlighted in red.

Location Name	Coral HSI Area Sum Ranks	Fishing Effort Sum Ranks	Coral/Effort Impacts
Mountain Top Bank 3	6	6	high/high
29 Fathom Bank	4	5	mod/high
Viosca Knoll 862/906	8	5	high/high
Alabama Alps	7	4	high/mod
MacNeil Bank	4	4	mod/mod
Stetson Bank	2	4	low/high
Baker Bank	2	3	low/high
Big Adam Rock	0	3	none/high
Blackfish Ridge	1	3	low/high
Dream Bank	1	3	low/high
Edges	2	3	low/high
Horseshoe Bank	5	3	mod/high
Hospital, North Hospital & Aransas Banks	3	3	low/high
L & W Pinnacles & Scamp Reef	8	3	high/mod
Mysterious Banks	2	3	low/high
Pulley Ridge Expansion	6	3	high/high
Pulley Ridge	6	3	high/high
Rough Tongue Reef	8	3	high/mod
Southern Bank	3	3	low/high
Tortugas South	5	3	mod/mod
Far Tortuga	0	2	none/mod
Geyer Bank	6	2	high/mod
Jakkula Bank	4	2	mod/mod
Madison Swanson	4	2	mod/mod
Many Mounds	9	2	high/mod
McGrail Bank	6	2	high/mod
Middle Grounds	0	2	none/mod
Rezak Sidner	6	2	high/mod
Shark, Triple Top, Double Top Reefs	6	2	high/mod
Sonnier Bank	0	2	none/mod

Location Name	Coral HSI Area Sum Ranks	Fishing Effort Sum Ranks	Coral/Effort Impacts
Tortugas North	3	2	low/mod
Unnamed Bank (Harte Bank)	2	2	low/mod
Alderdice	6	1	high/low
AT 047	3	1	low/low
Bouma Bank	6	1	high/low
East Flower Garden	6	1	high/low
Elvers Bank	5	1	mod/low
Garden Banks 299	11	1	high/low
Green Canyon 140 & 272	8	1	high/low
Green Canyon 234	6	1	high/low
John Reed North	9	1	high/low
Mississippi Canyon 118	3	1	low/low
Mississippi Canyon 751	6	1	high/low
Mississippi Canyon 885	5	1	mod/low
Okeanos Ridge	6	1	high/low
Parker Bank	6	1	high/low
Patch Reef Field & Solitary Mound	6	1	high/low
Pinnacle 1 Near West & West Pinnacle 2	8	1	high/low
Rankin Bright	5	1	mod/low
Steamboat Lumps	4	1	mod/low
Viosca Knoll 826	6	1	high/low
West Flower Garden	6	1	high/low
AT 357	0	0	none/none
Garden Banks 535	5	0	mod/none
Green Canyon 354	10	0	high/none
Green Canyon 852	2	0	low/none
John Reed South	9	0	high/none
Long Mound	9	0	high/none

Most HAPCs (whether current or recommended/considered) are between the 50 and 200 m isobaths. Sixteen are at depths between 200 and 1200 m (Table 2). Fourteen banks have trawl effort of more than 10 hours and seven banks have trawl effort greater than 100 hours (Big Adam Rock, Blackfish Ridge, Viosca Knoll 862/906, Dream, Baker, Hospital/North Hospital and Aransas, and Mysterious Banks).

Eleven HAPCs (current and recommended/considered) had >10 BLL fishing positions (Table 2). Only four had >50 BLL positions (Horseshoe Bank, existing Pulley Ridge closure, Pulley Ridge Expansion under consideration, and The Edges). Five HAPCs had >5 BLL vessels active within them (Middle Grounds, Madison Swanson, Pulley Ridge, Pulley Ridge Expansion and The Edges). The Middle Grounds is the only HAPC that extends into waters shallower than 45 m, our minimum depth for analysis. Thus, VMS data in Tables 2 and 3 for the Middle Grounds are incomplete and not representative for this HAPC.

The ranking scheme portrayed in Table 3 identifies six HAPCs that have potential significant conflicts between fishing and benthic communities. Four HAPCs (Mountain Top Bank 3, Pulley Ridge, Pulley Ridge Expansion, and Viosca Knoll 862/906) ranked highest for potential impacts. Horseshoe Bank and 29 Fathom Bank ranked high as well, with high potential impact from fishing and moderate coral ranking.

3.4 STATISTICAL CORRELATION RESULTS

Spatial correlations by depth strata revealed that predicted suitability for *Madrepora* and *Madracis* were highly correlated at depths between 45-300 m (Table 4). The correlation was significant for the 300-800 m depth strata but the rho (ρ) value was not as strong. Similar correlations, although not as strong, were observed for *Madrepora* and *Lophelia*; a stronger correlation was observed in the 300-800 m depth strata. *Leiopathes* and *Lophelia* were correlated moderately at 150-300 m (although only a handful of either genus have been observed shallower than 300 m in the Gulf of Mexico) and stronger in the 300-800 m depth strata. *Leiopathes* was moderately correlated with *Madracis* and *Madrepora* at all depth zones.

No strong positive or negative correlations were observed for any coral taxa and either trawl or long line fishing effort. A strong negative correlation was observed between trawl effort and BLL effort in the 45-150 m depth strata.

Geographically, most taxa correlations exhibited statistically significant positive correlations, but strength of the correlations varied (Table 5). *Madracis* was strongly correlated with *Madrepora* in the western (ρ = 0.48) and eastern Gulf (0.57). *Madracis* showed weak correlation with *Leiopathes* and no correlation with *Lophelia*. *Leiopathes* and *Lophelia* were also strongly correlated in the western (0.47) and eastern Gulf (0.58). *Leiopathes* was weakly correlated with *Madrepora* in the western Gulf (0.27) but stronger correlation was evident in the eastern Gulf (0.44). *Madrepora* was weakly correlated with *Lophelia* in the western Gulf (0.19) and more strongly in the east (0.35).

Table 4. Spearman results for correlations between coral habitat suitability, fishing effort, and depth in the Gulf of Mexico. Statistically significant rho (ρ) values are in bold.

Variable 1	Variable 2	45-150 m	150-300 m	300-800 m
Madracis	*Lophelia*		**0.1888**	**0.1917**
Madrepora	*Lophelia*		**0.1797**	**0.3973**
Madrepora	*Madracis*	**0.7916**	**0.6132**	**0.2813**
Leiopathes	*Lophelia*		**0.3212**	**0.5467**
Leiopathes	*Madracis*	**0.2785**	**0.2538**	**0.3587**
Leiopathes	*Madrepora*	0.319	**0.2778**	**0.3934**
BLL	*Lophelia*		-0.0202	**-0.082**
BLL	*Madracis*	0.0521	-0.0037	**0.1183**
BLL	*Madrepora*	**0.0799**	-0.0571	-0.0644
BLL	*Leiopathes*		0.0502	**0.0972**
Trawl	*Lophelia*		**0.1448**	**0.1854**
Trawl	*Madracis*	-0.0111	**0.1904**	**0.1295**
Trawl	*Madrepora*	-0.0342	**0.188**	0.049
Trawl	*Leiopathes*	0.0414	**0.1103**	**0.154**
Trawl	BLL	**-0.5979**	-0.0056	**0.1028**

Results

Weak but statistically significant negative correlation was observed between BLL effort and *Lophelia* in the western (-0.10) and eastern Gulf (-0.14). Positive correlation was observed between BLL and *Madracis*, with stronger correlation in the western Gulf. Correlation was significant, positive but weak between BLL and *Madrepora*. Trawl data were negatively correlated with coral taxa in the western Gulf. The strongest correlation was observed for *Madrepora* (-0.48) while others were weakly significant. Weak or non-significant correlations were observed in the eastern Gulf.

Trawl and BLL effort data were significant and negatively correlated for both eastern (-0.11) and western Gulf (-0.20).

Table 5. Spearman results for correlations between coral habitat suitability, fishing effort, and region in the Gulf of Mexico. Statistically significant rho (ρ) values are in bold.

Variable 1	Variable 2	Western Gulf	Eastern Gulf	All Gulf
Madracis	*Lophelia*	**-0.0658**	-0.0519	-0.005
Madrepora	*Lophelia*	**0.1975**	**0.3543**	**0.304**
Madrepora	*Madracis*	**0.4876**	**0.5711**	**0.5554**
Leiopathes	*Lophelia*	**0.4728**	**0.587**	**0.5244**
Leiopathes	*Madracis*	**0.1249**	**0.1275**	**0.1678**
Leiopathes	*Madrepora*	**0.2714**	**0.4476**	**0.3775**
VMS	*Lophelia*	**-0.1052**	**-0.1494**	**-0.187**
VMS	*Madracis*	**0.3635**	**0.229**	**0.135**
VMS	*Madrepora*	**0.2792**	**0.1177**	-0.0023
VMS	*Leiopathes*	**0.1129**	-0.005	**-0.0465**
ELB	*Lophelia*	**-0.2005**	**0.0626**	0.0046
ELB	*Madracis*	**-0.1403**	0.0341	**0.0658**
ELB	*Madrepora*	**-0.4816**	**0.0717**	**-0.0438**
ELB	*Leiopathes*	**-0.1569**	-0.019	0.0113
ELB	VMS	**-0.2045**	**-0.1139**	**-0.3207**

Chapter 4: DISCUSSION AND CONCLUSIONS

The current definition of coral essential fish habitat (EFH) states that wherever corals occur is considered EFH for corals (GMFMC, 2004). The Gulf Council is investigating new areas of deep coral (>50 m) habitat that warrant HAPC status. An area qualifies if it is determined to be an ecologically important habitat that is sensitive to human induced degradation, located in an environmentally stressed area, or is considered rare (GMFMC, 2016). Corals are sensitive to human induced habitat degradation by fishing and non-fishing activities and, coupled with slow growth rates of deep coral taxa, their recovery from damage would be slow or may not occur. Detailed knowledge of habitat requirements is essential for biodiversity conservation and fisheries management (Lauria et al., 2015), but ecological information for species that live in habitats >150 m are typically rare. Characterizing deep water community structure is difficult and costly but available information from targeted explorations with remotely operated vehicles (ROV) and submersibles, and anecdotal information from commercial or research fishing vessels, allow the opportunity to predict species distribution with the best information available. The coral habitat suitability predictive model data provide valuable insight into a probabilistic understanding of where ecologically sensitive deep coral communities occur. It is necessary to continue ground-truthing these maps to improve our understanding of these complex habitats.

While the majority of bottom fishing effort occurs <100 m (Figures 6, 7 and 8) and the majority of likely coral habitat is >200 m (Figures 1 and 2) for three of the four taxa examined, there is still substantial spatial overlap between the two. Effort from both trawl and BLL fisheries has occurred on >90% of predicted *Madracis* habitat, the shallowest coral examined. Effort from both fisheries occurred on >50% of suitable habitat for the other three taxa, with the exception of a negligible overlap between trawling and *Lophelia* habitat. The majority of these overlaps are areas of low fishing effort, yet even occasional contact between bottom gear and deep coral can have lasting impacts on the benthic community (Rooper et al., 2017), especially for trawling gear that have shown to have significant impacts to low mobility, long-lived species (NRC, 2002).

A double-rigged shrimp trawler, one net on board and the other deployed, off the coast of Galveston, TX (top; NOAA, Robert K. Brigham); brown shrimp on the seafloor (middle; NOAA NMFS); white shrimp among mussels (bottom left; NOAA NMFS); and close up of pink shrimp (bottom right; NOAA NMFS).

The footprint of shrimp trawling shows that fishing effort occurs predominantly west of Mobile Bay, with the heaviest concentration between Calcasieu, Louisiana and the Mississippi Sound. The footprint is heavily skewed to the penaeid fishery, which primarily operates <50 m deep, but ELB data also indicate effort in deep waters that conflict with predicted coral habitat. Hotspots of trawl activity

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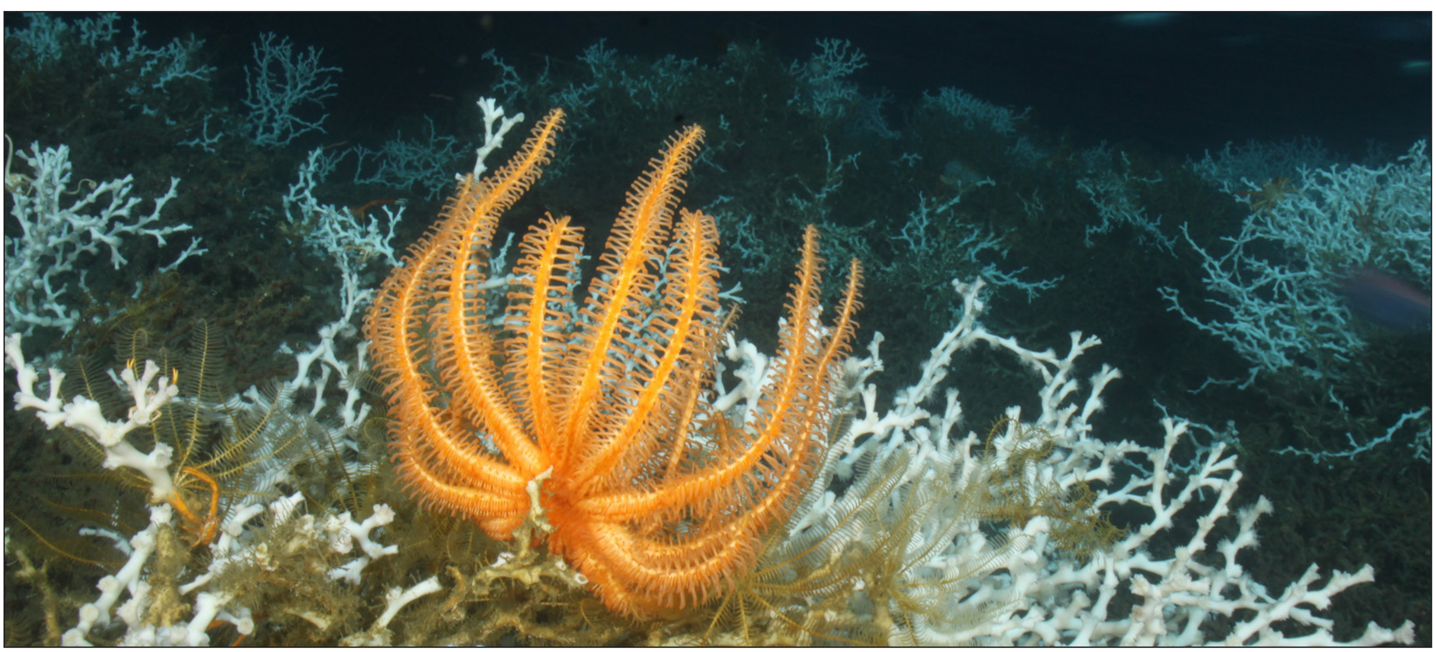
scattered along the shelf and slope of the northern Gulf are most likely effort targeting royal red shrimp, but may target penaeids as well. Effort coincides with all four coral habitats, particularly south of the Mississippi Sound and Mobile Bay. High trawl effort also exists within several existing and proposed/recommended HAPCs. These areas may be targets for further exploration. Despite lower trawl effort in general at depths greater than 50 m, benthic communities are ecologically sensitive and only one pass through with a commercial trawl could devastate ancient communities. Furthermore, ELB data are only a portion of the total Gulf of Mexico penaeid fishery. The complete footprint may have a greater spatial impact, which should also be considered.

The majority of reef fish BLL effort is inshore of deep coral habitat. Nevertheless, there is considerable effort along the WFE where *Madracis* and *Madrepora* habitat occur, and patches of effort south of the Mississippi Sound on the shelf edge where *Leiopathes* and *Lophelia* habitat occur. The largest concentration of fishing activity on deep coral habitat is on the southwest Florida shelf in and around Pulley Ridge where large areas of suitable habitat exist for multiple corals (see Appendix figures). There may be a seasonal component to this pattern as a response to the summer BLL closure on the west Florida shelf's inshore waters. This coastal closure may direct fishing effort deeper to shelf edge habitats such as Pulley Ridge.

Analysis of VMS data found the majority of BLL effort concentrated in the eastern Gulf along the west Florida shelf. NMFS fishery observer coverage studies spanning 2006-2011 illustrate the same spatial distribution of BLL effort found in this study, and reported the majority of observed sampling effort to be concentrated on the west Florida shelf and slope (Scott-Denton et al., 2011; Scott-Denton and Williams, 2013). However, it is important to note the caveat that only vessels with both a Commercial Reef Fish permit and an Eastern Gulf Bottom Longline Endorsement were included in analysis, and there are likely some vessels that longline only in the western Gulf and do not require the eastern endorsement. Permit summary data obtained from the NMFS Southeast Regional Office (SERO) Permit Office show that depending on the specific year from 2010-2015, 900-1000 vessels possessed a Commercial Reef Fish permit for at least part of the year, yet only 68-79 of these vessels (depending on year) also possessed an Eastern BLL Endorsement (NOAA NMFS SERO, unpublished data). A primary reason is that many vessels with a reef fish permit rely on vertical line gear (handlines or bandit reels) and do not use longlines. In addition, not all of these permitted vessels necessarily fished, and permit totals may be inflated by the transfer of permits between multiple vessels over the course of the year. Nevertheless, while focusing on vessels with the endorsement increased the odds that BLL fishing was occurring among analyzed vessels, this bias means that effort in the western Gulf may be underrepresented.



Basket star on a Lophelia *reef. Image courtesy of Lophelia II: Reefs, Rigs, and Wrecks 2009 Expedition, NOAA OER/BOEM.*

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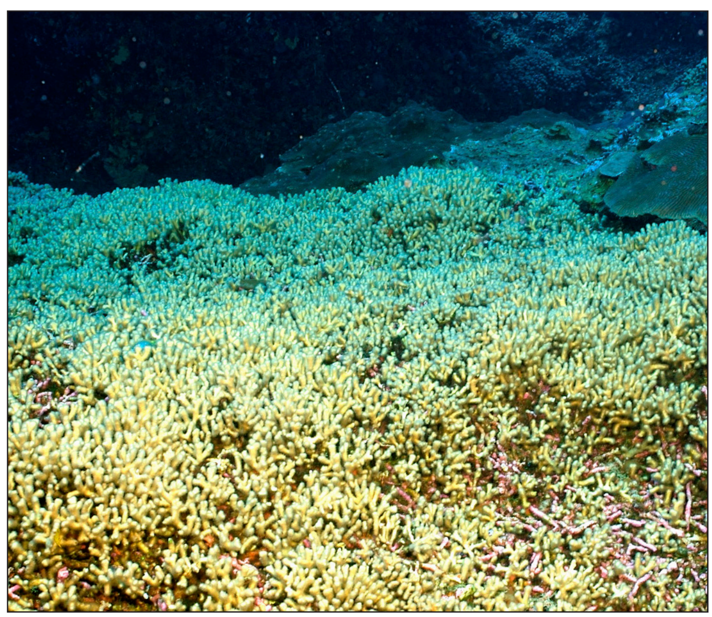
Another caveat to BLL analysis is the possibility that some vessels in this study engaged in pelagic longlining as well as bottom longlining. NMFS SERO Permit Office data show that of the 68-79 total vessels possessing an Eastern BLL endorsement during the study period, 8-14 of those vessels (depending on the year) also possessed an Atlantic Tuna Longline permit required for pelagic longlining (NOAA NMFS/SERO, unpublished data). Thus, some activity may represent pelagic sets that did not touch the seafloor, although the 400 m maximum depth considered for analysis may also have removed some offshore pelagic activity.

Due to differences in ecology and benthic habitat preferences between shrimp and reef fish, it is not surprising that fishing activity rarely occurs for both at the same location, and effort is never high for both fisheries in the same HAPC (Table 2). Numerous proposed and recommended HAPCs exhibit high levels of habitat coverage for multiple taxa but relatively low fishing effort. However, even occasional bottom gear contact can inflict lasting damage on reefs, and if these HAPCs do encompass thriving deep reef communities, protection may be worthwhile against even low levels of fishing. It could also serve as a precautionary measure in the event that fishing pressure increases in the future.

Although many recommended or considered HAPCs in the western Gulf are areas of relatively high trawl effort, from Baker to Southern to Mysterious Banks, they contain little predicted coral habitat for the species of interest. However, other coral species observations have been recorded in these areas. Etnoyer (2009) documented many species of gorgonians in the western Gulf, and other observations of gorgonians and black corals are present in the Deep Coral Database. Limitations of the coral data and modeling techniques may play a role in the lack of predicted habitat in this region of the Gulf. Grouping species observations into a genera-based model may underestimate model results and not truly reflect distribution at the species level. For example, *Madrepora carolina* has a shallower distribution than its congener *M. oculata* (Etnoyer and Cairns, 2017), and grouping them in the model may not truly reflect each species' distribution. However, the conundrum is that observations at the species level are not sufficient for species-level modeling.

All HAPCs In the northwestern Gulf neighboring the Flower Garden Banks National Marine Sanctuary contained high quantities of predicted habitat suitability for *Madracis* and *Madrepora*. Several existing but unregulated HAPCs also contain moderate to high levels of predicted coral habitat and fishing effort, including Geyer, Rezak Sidner, 29 Fathom and MacNeil Banks, and it may be beneficial to review the management strategies for these areas. These banks are under consideration to be included in sanctuary expansion. The highest BLL effort among Western Gulf HAPCs was detected within the recommended Horseshoe Banks HAPC, which also possesses a high degree of predicted *Madracis* habitat. The fishing effort was attributed to just three vessels, but there may be additional vessels targeting this area that do not possess an eastern Gulf BLL endorsement and were not included in analyses.



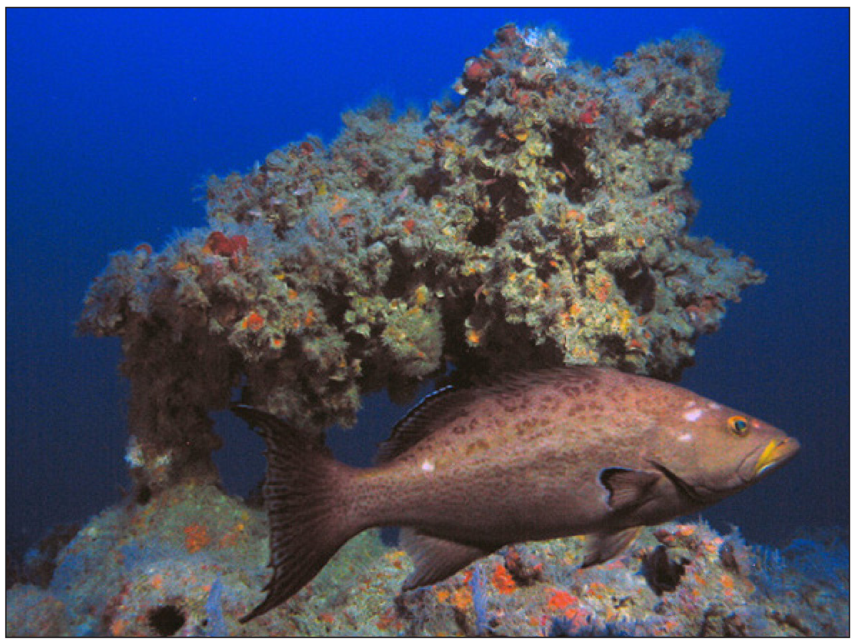
Madracis *species at Flower Garden Banks National Marine Sanctuary. Image courtesy of NOAA OMNS/FGBNMS.*

In the central Gulf between Louisiana and the Florida Panhandle, proposed and recommended HAPCs including Viosca Knoll 862/906, Mountain Top Bank 3, Alabama Alps, Rough Tongue Reef, L & W Pinnacles and Scamp Reef. These all contain moderate to high levels of both suitable coral habitat and fishing effort. More information is needed here to better determine coral habitat as ELB data indicate targeted effort in this region.

Discussion

On the WFE and Florida shelf, few HAPCs have both high levels of effort and predicted coral habitat. Although The Edges and Middle Grounds are seasonal closures and receive notable longline effort when open, predicted deep coral habitat is scarce. In addition, while coral observations are documented, surveys in this region (Panhandle and northern WFE and shelf) have been limited to date. Survey scarcity may be a driver for the small amount of predicted suitable habitat. More surveys around these HAPCs should improve model output. Smaller proposed HAPCs along the WFE provide high habitat levels for multiple corals, but have little fishing activity and are offset from longline activity along the shelf edge. The standout exception is the Pulley Ridge Expansion, an unregulated HAPC under consideration for fishing restrictions, which receives not only a large amount of longline effort but contains high quantities of predicted *Madracis* and *Madrepora* habitat.

High BLL effort in the existing Pulley Ridge closure was initially surprising, but inspection of the raw spatial data revealed a high volume of vessel positions concentrated along the closure's border on all sides. A fraction of those points fell just inside the closure. Given their close proximity to the border, this may not reflect an enforcement issue and instead be attributed to VMS positional error, minor spatial inconsistencies in GIS features used for analysis or vessels not actively fishing. A similar pattern was observed in the Madison-Swanson closed area, which contained 48 fishing positions. This dense effort stacked on the Pulley Ridge closure's border and the associated spillover into it, along with the high relative effort in the expansion area under review (33 vessels and >2,000 positions), illustrate the intense level of pressure in and around Pulley Ridge relative to other HAPCs, and the significance of this area to the reef fish fishery. Moreover, there is a high spatial coincidence of longline effort on habitat for all four species of coral in this area. The overlap between deep coral reefs and bottom longlines is potential cause for concern and close review not only of the Pulley Ridge Expansion, but the surrounding area on the southwest Florida shelf edge. These patterns of fishing effort suggest that more information is needed to better understand the impacts to the areas that are being protected. Without further knowledge, careful consideration should be given to future boundary delineations.



*Scamp grouper (*Mycteroperca phenax*), a commonly targeted longline fishery species, off the Dry Tortugas, southeast of Pulley Ridge. Image courtesy of the Cooperative Institute for Exploration, Research & Technology.*

While no significant correlations were found between the locations of fishing activity and coral habitat, this may be due to the coarse resolution of analysis (100 km² blocks). We recommend further analyses using smaller grid cells and no fishing data exclusion. While those data and potential spatial distributions could not be visualized in order to protect VMS confidentiality, the results of statistical analysis could still be reported.

Lastly, continued mapping, characterization and monitoring of deep coral ecosystems is necessary to provide greater understanding about these communities. Further analysis of different taxa that dominate shallow banks is needed. For example, *Swiftia exserta*, *Hypnogorgia* complex and other black corals may be valuable in future HAPC analyses. In addition to commercial and recreational fishing, there are other industries competing for space with deep coral communities, such as the oil and gas industry and deep sea mining. It would benefit all stakeholders in the Gulf of Mexico to know where deep coral communities are located and to obtain greater information about their ecology.

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Appendix

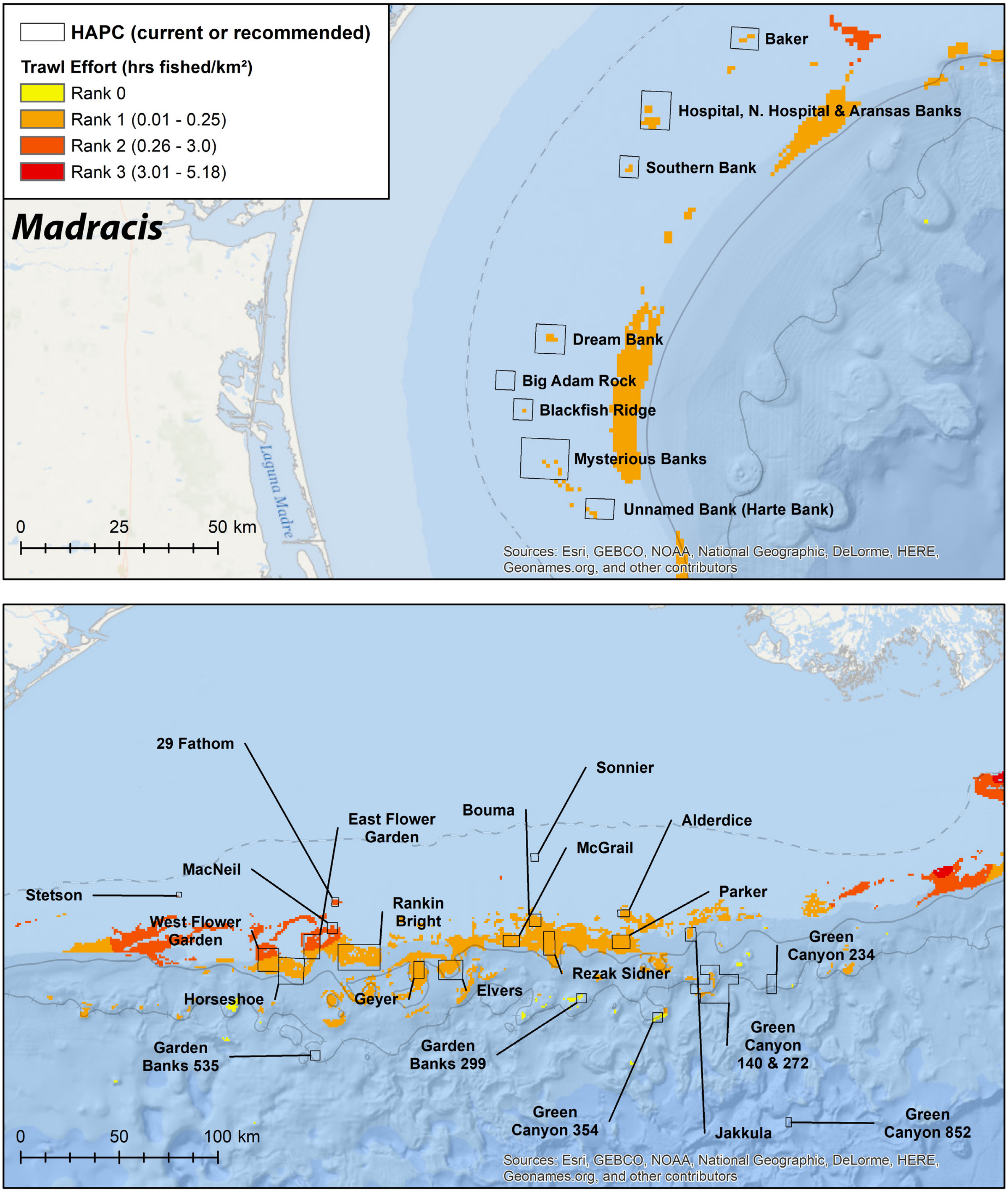


Figure A1. Location of habitat areas of particular concern (HAPC) in relation to trawl effort kernel density estimates on likely Madracis *habitat in west and central Gulf of Mexico.*

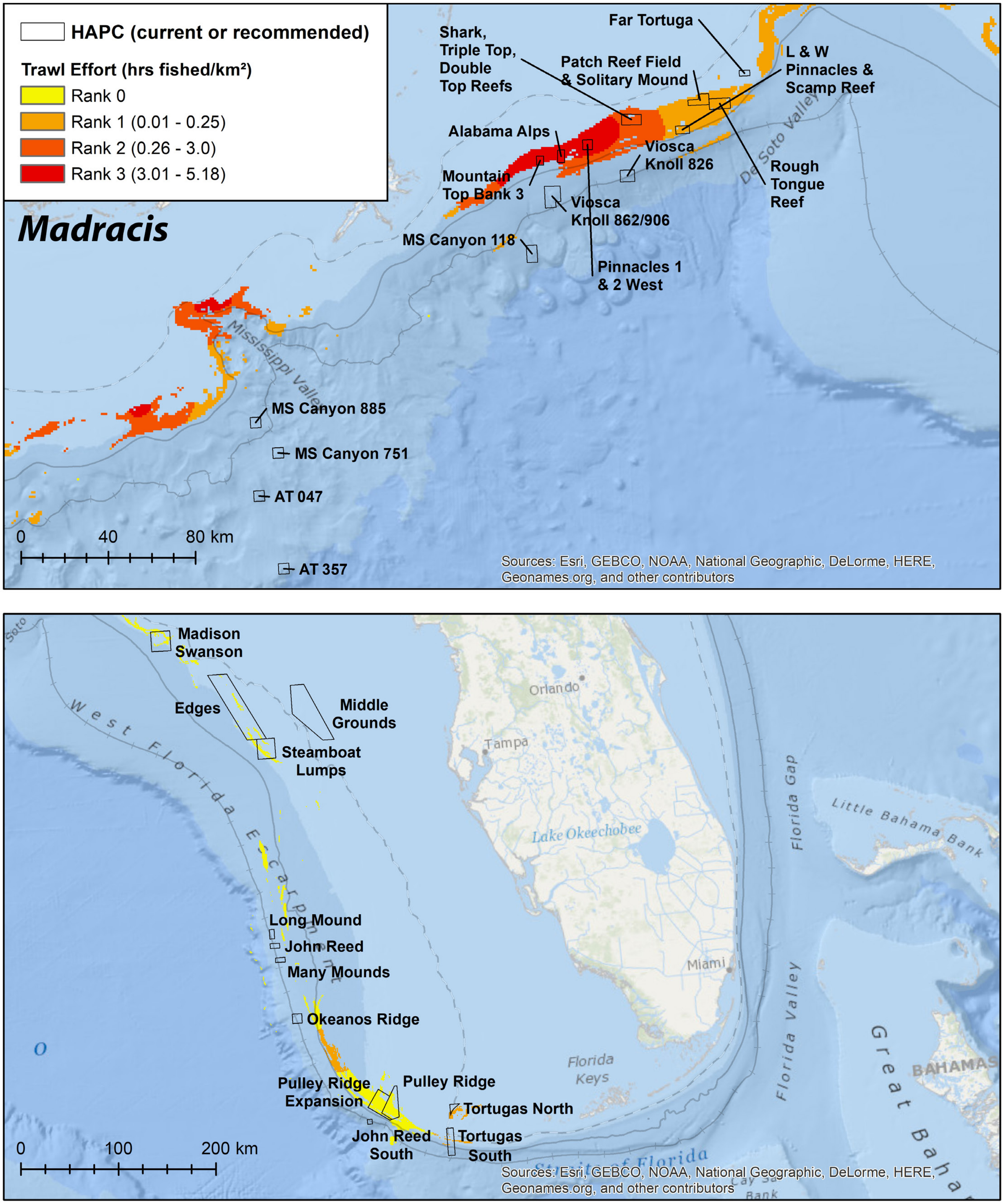


Figure A2. Location of habitat areas of particular concern (HAPC) in relation to trawl effort kernel density estimates on likely Madracis *habitat in the northeastern Gulf of Mexico and west Florida shelf.*

Appendix

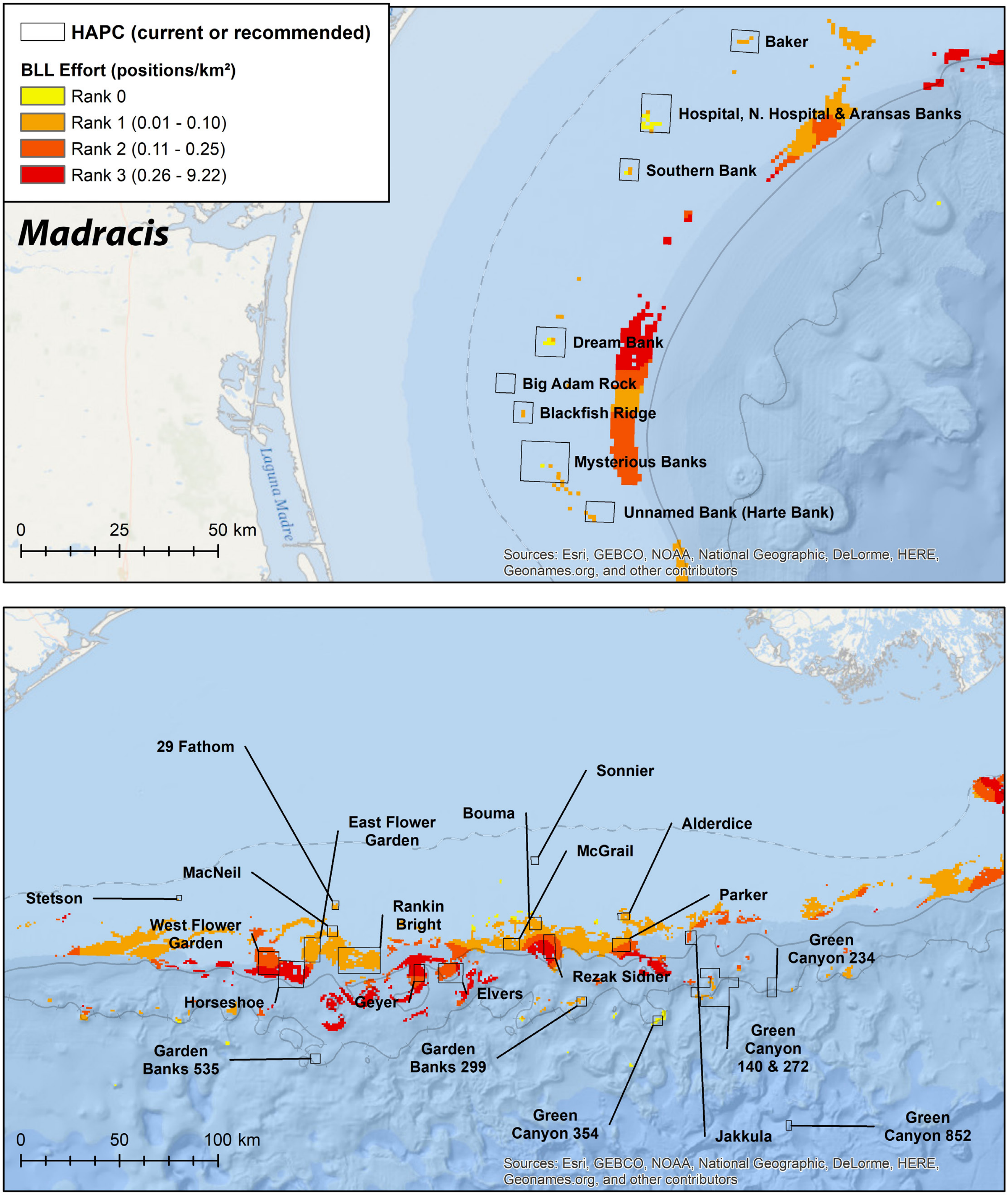


Figure A3. Location of habitat areas of particular concern (HAPC) in relation to bottom longline effort kernel density estimates on likely Madracis *habitat in west and central Gulf of Mexico.*

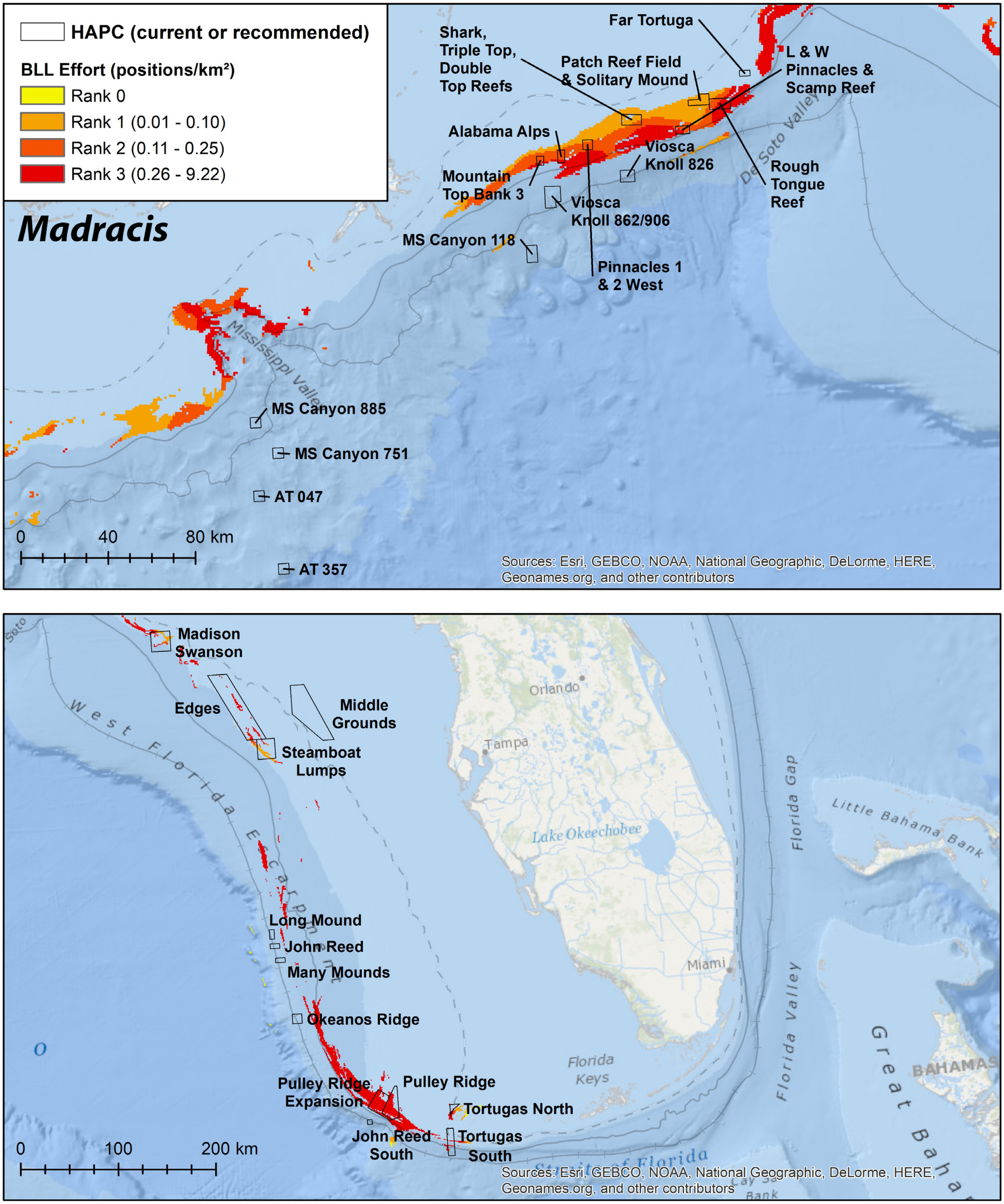


Figure A4. Location of habitat areas of particular concern (HAPC) in relation to bottom longline effort kernel density estimates on likely Madracis *habitat in the northeastern Gulf of Mexico and west Florida shelf*

Appendix

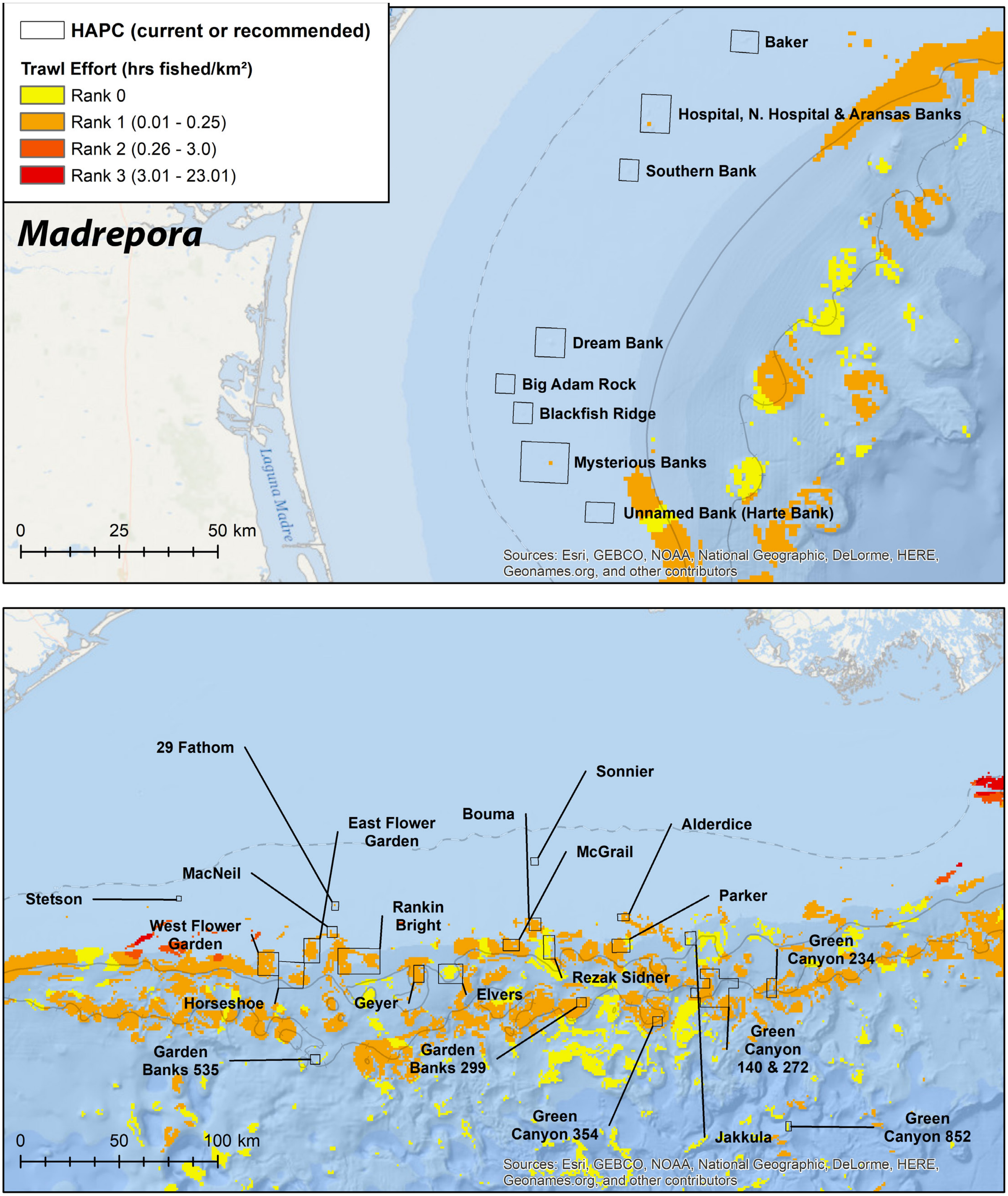
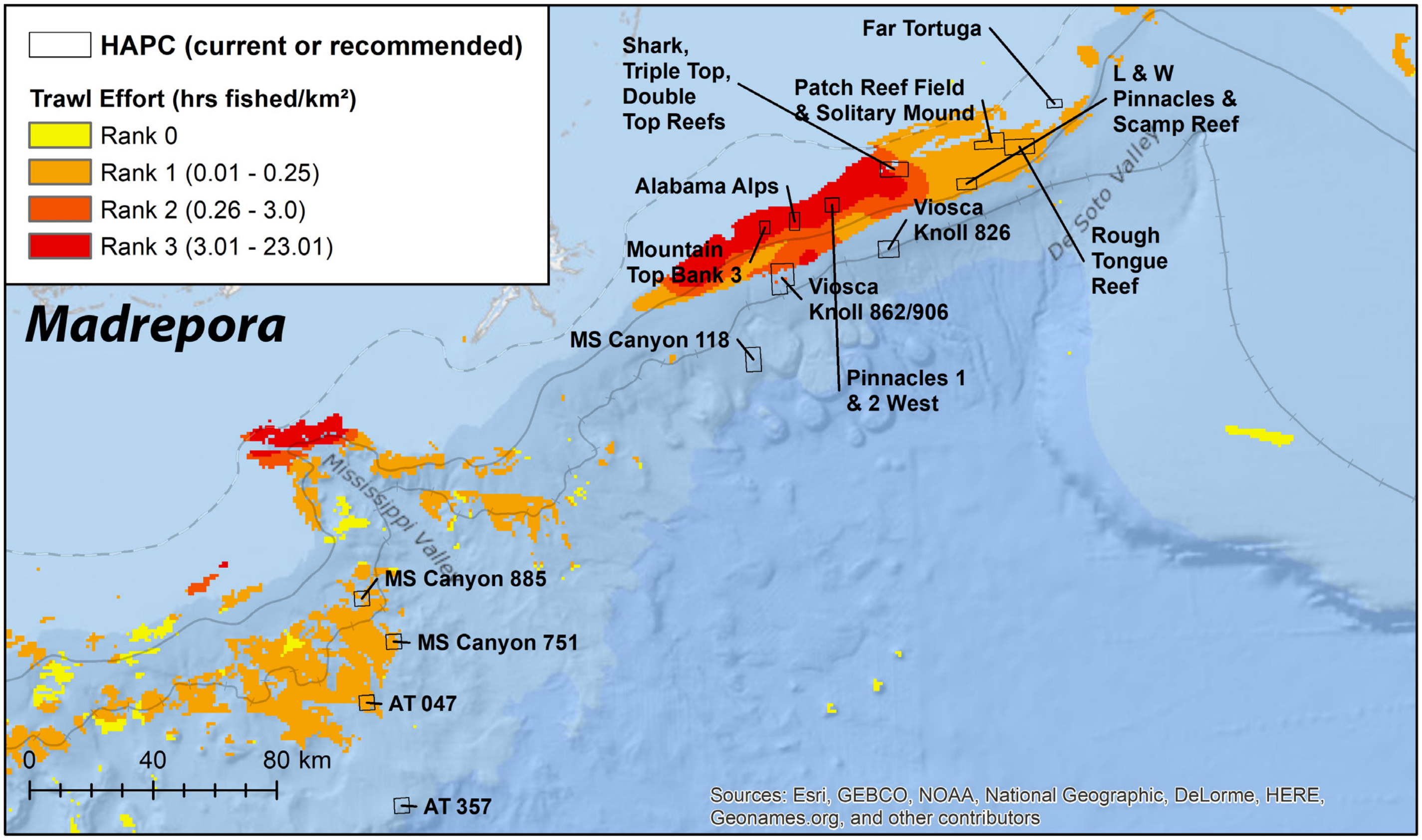


Figure A5. Location of habitat areas of particular concern (HAPC) in relation to trawl effort kernel density estimates on likely Madrepora *habitat in west and central Gulf of Mexico.*



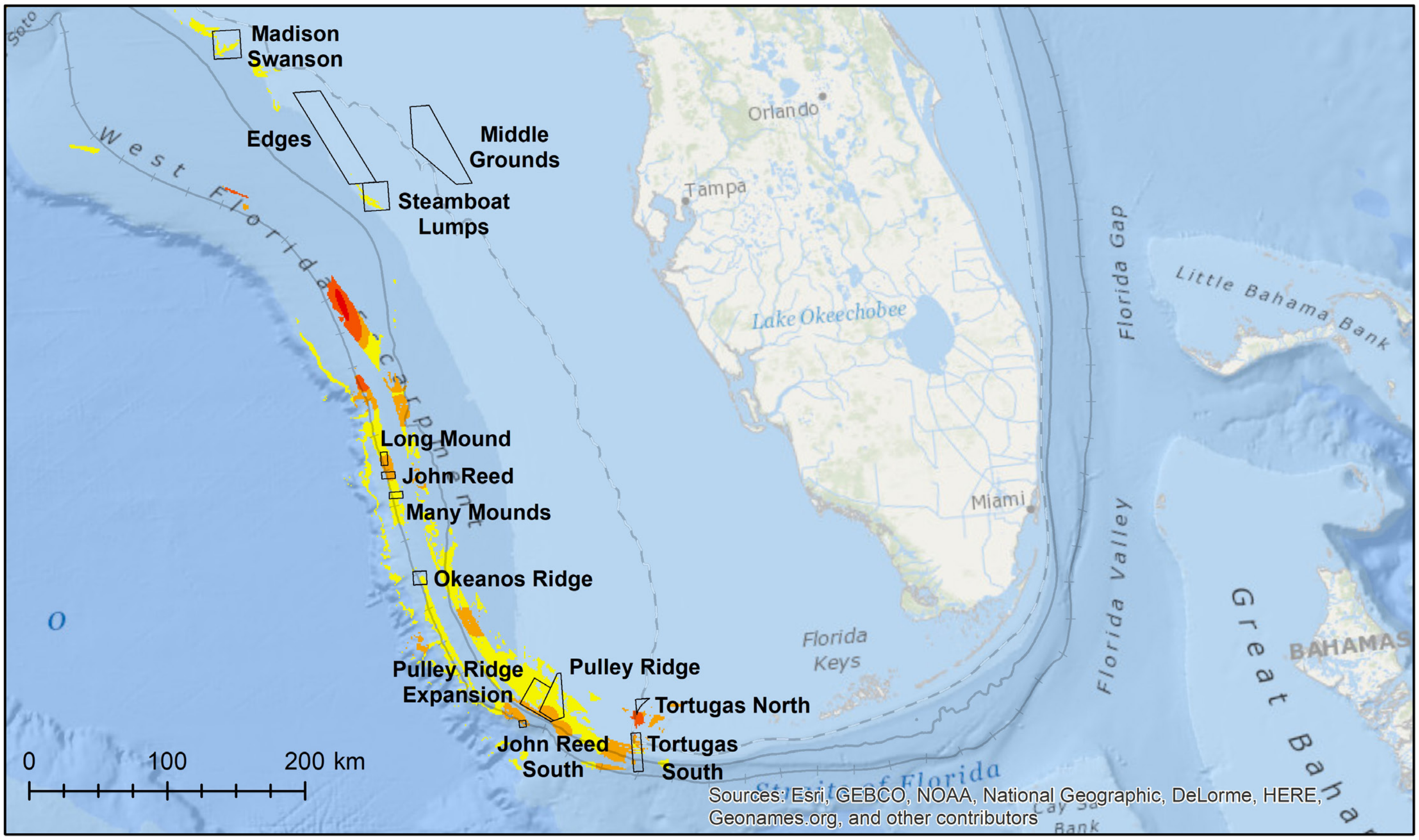


Figure A6. Location of habitat areas of particular concern (HAPC) in relation to trawl effort kernel density estimates on likely Madrepora *habitat in the northeastern Gulf of Mexico and west Florida shelf.*

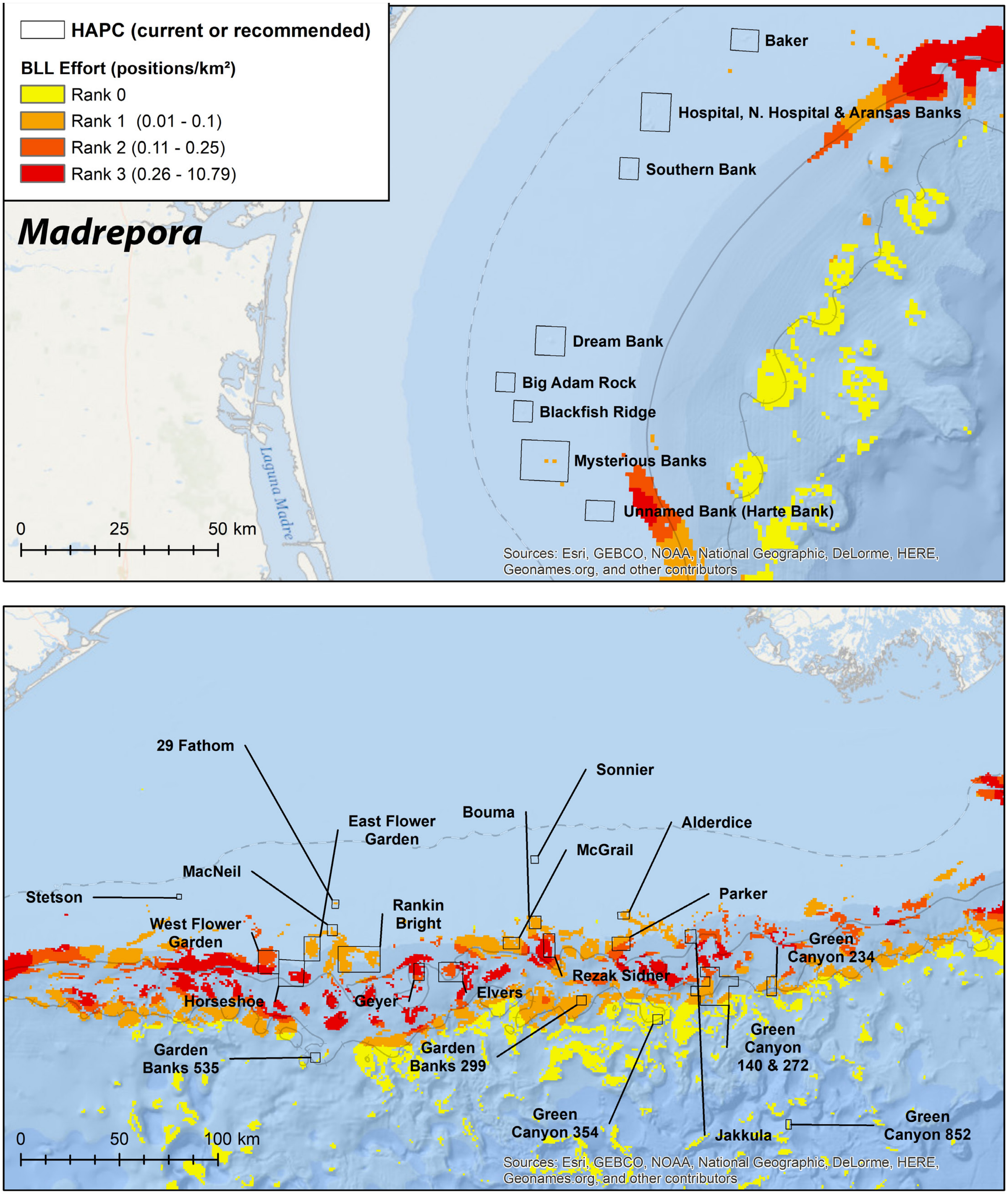


Figure A7. Location of habitat areas of particular concern (HAPC) in relation to bottom longline effort kernel density estimates on likely Madrepora *habitat in west and central Gulf of Mexico.*

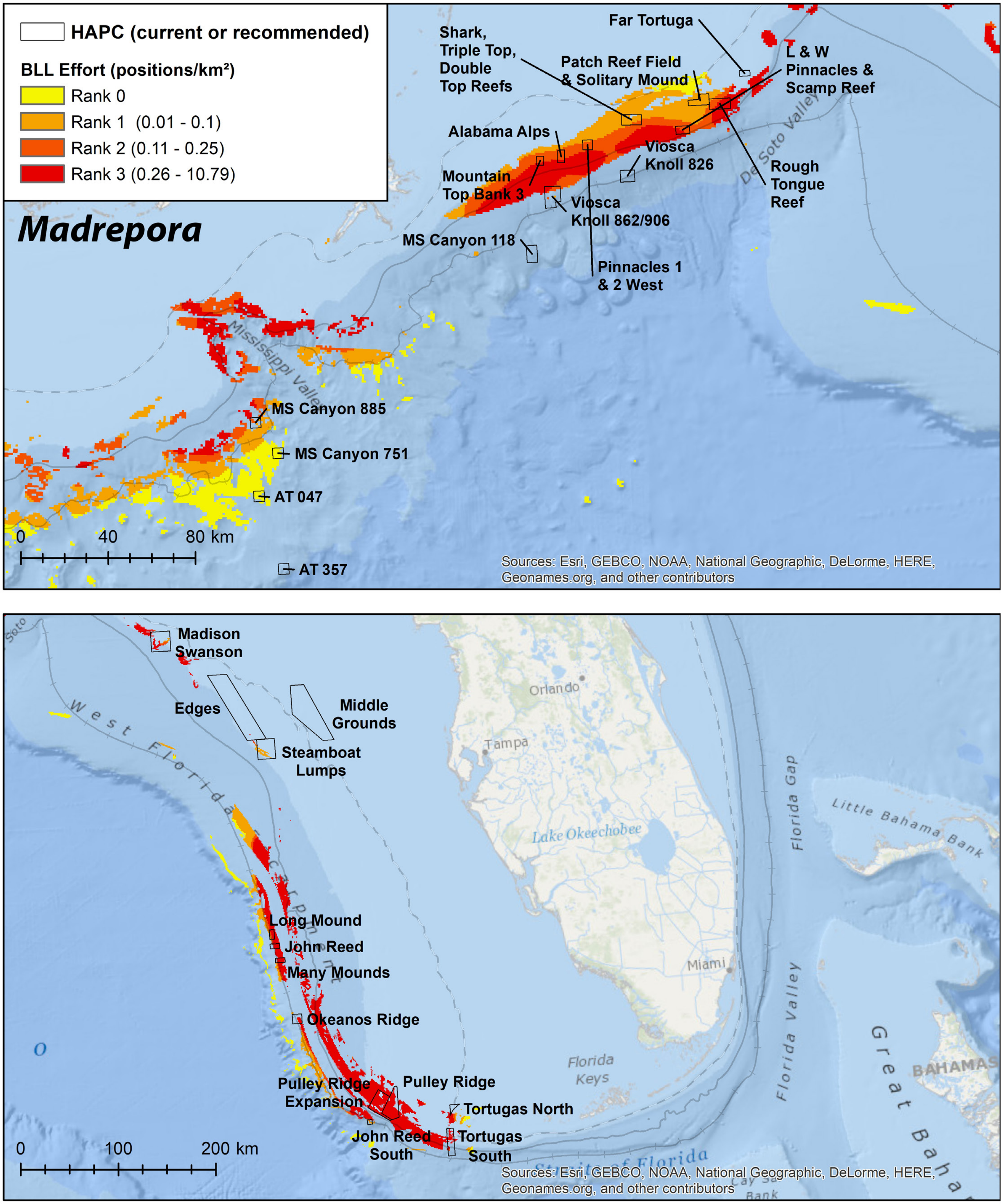


Figure A8. Location of habitat areas of particular concern (HAPC) in relation to bottom longline effort kernel density estimates on likely Madrepora *habitat in the northeastern Gulf of Mexico and west Florida shelf.*

Appendix

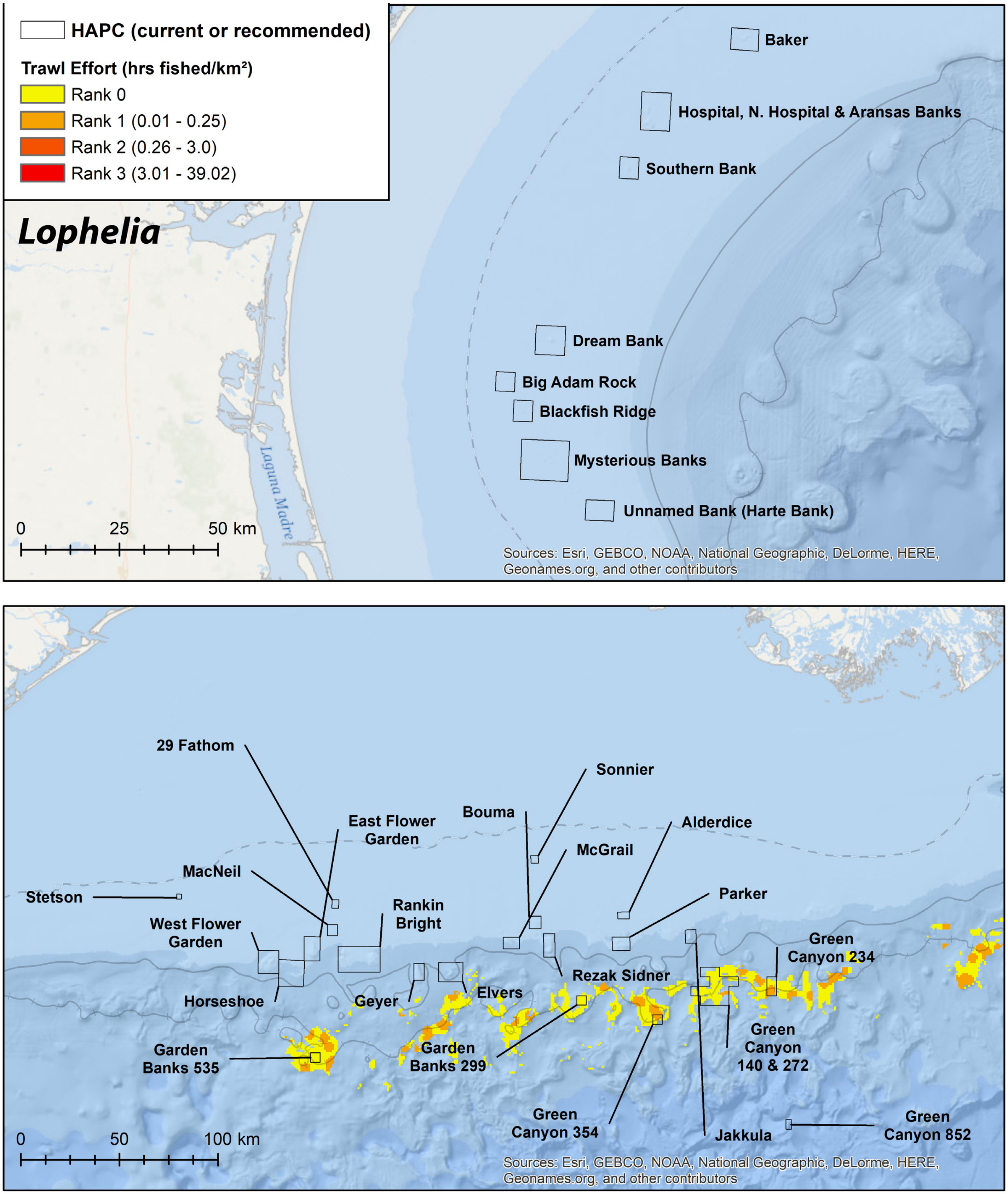


Figure A9. Location of habitat areas of particular concern (HAPC) in relation to trawl effort kernel density estimates on likely Lophelia *habitat in west and central Gulf of Mexico. Note: there is no* Lophelia *habitat in the vicinity of HAPCs in the western Gulf.*

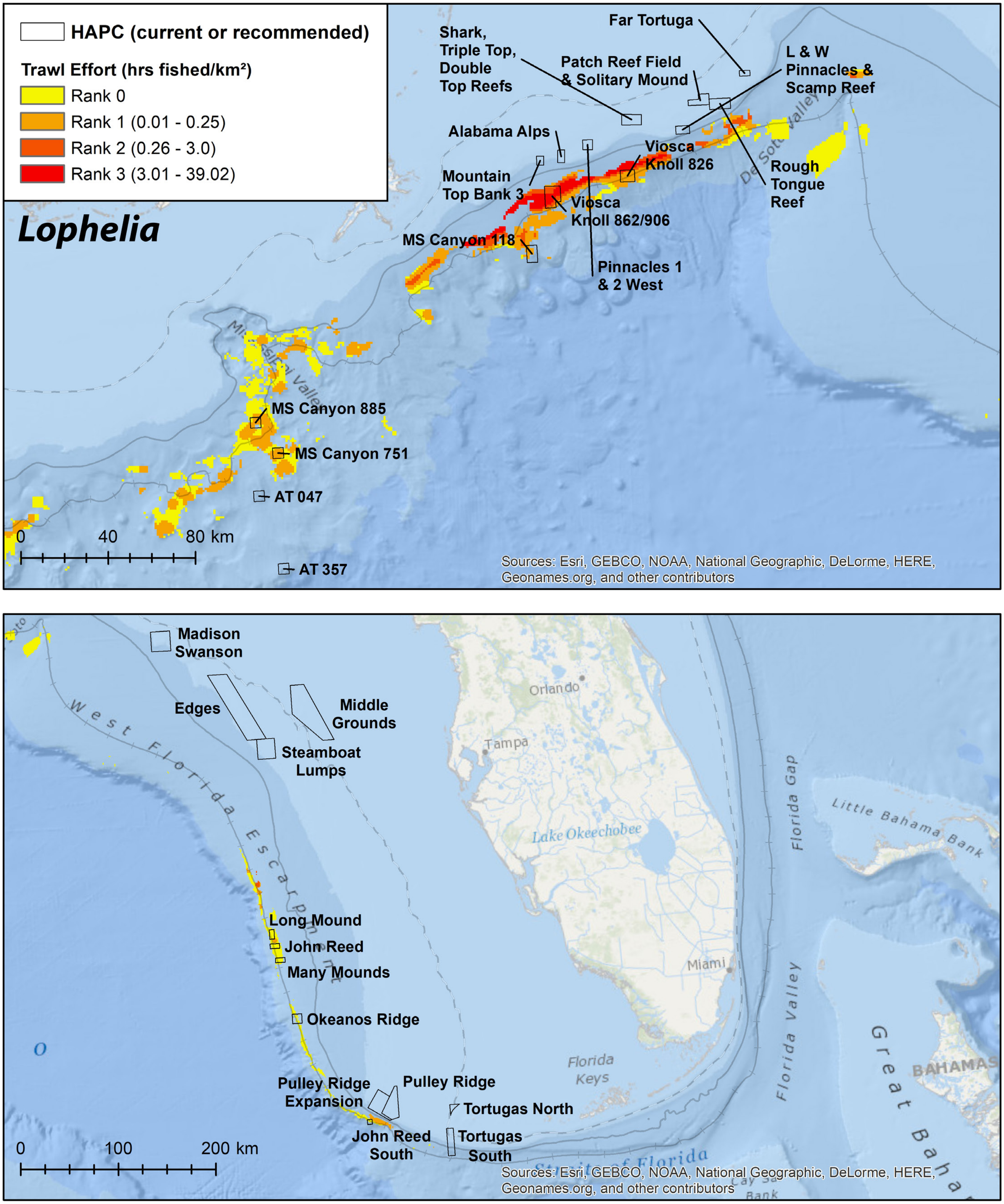


Figure A10. Location of habitat areas of particular concern (HAPC) in relation to trawl effort kernel density estimates on likely Lophelia *habitat in the northeastern Gulf of Mexico and west Florida shelf.*

Appendix

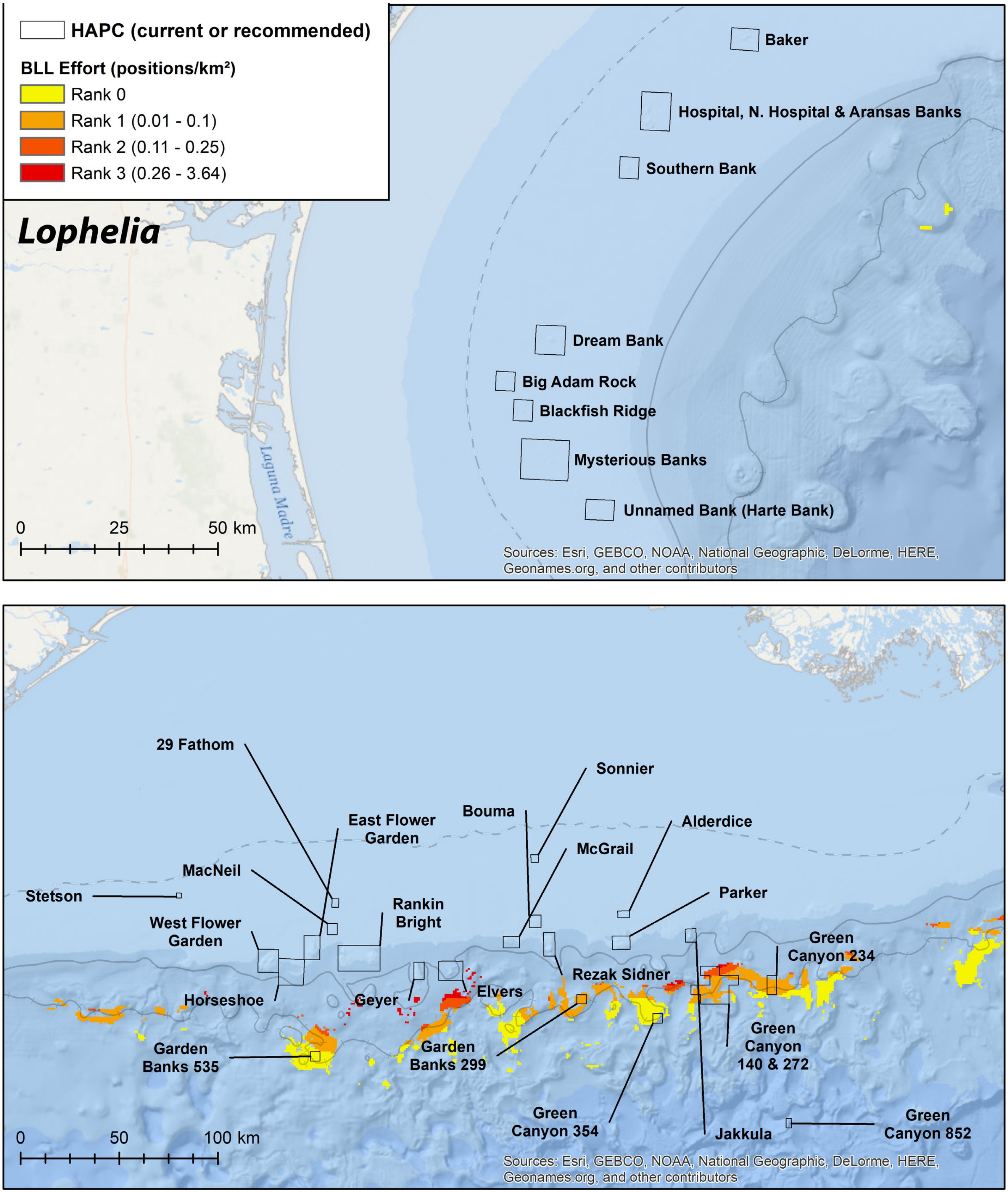


Figure A11. Location of habitat areas of particular concern (HAPC) in relation to bottom longline effort kernel density estimates on likely Lophelia *habitat in west and central Gulf of Mexico. Note: there is no Lophelia habitat in the vicinity of HAPCs in the western Gulf.*

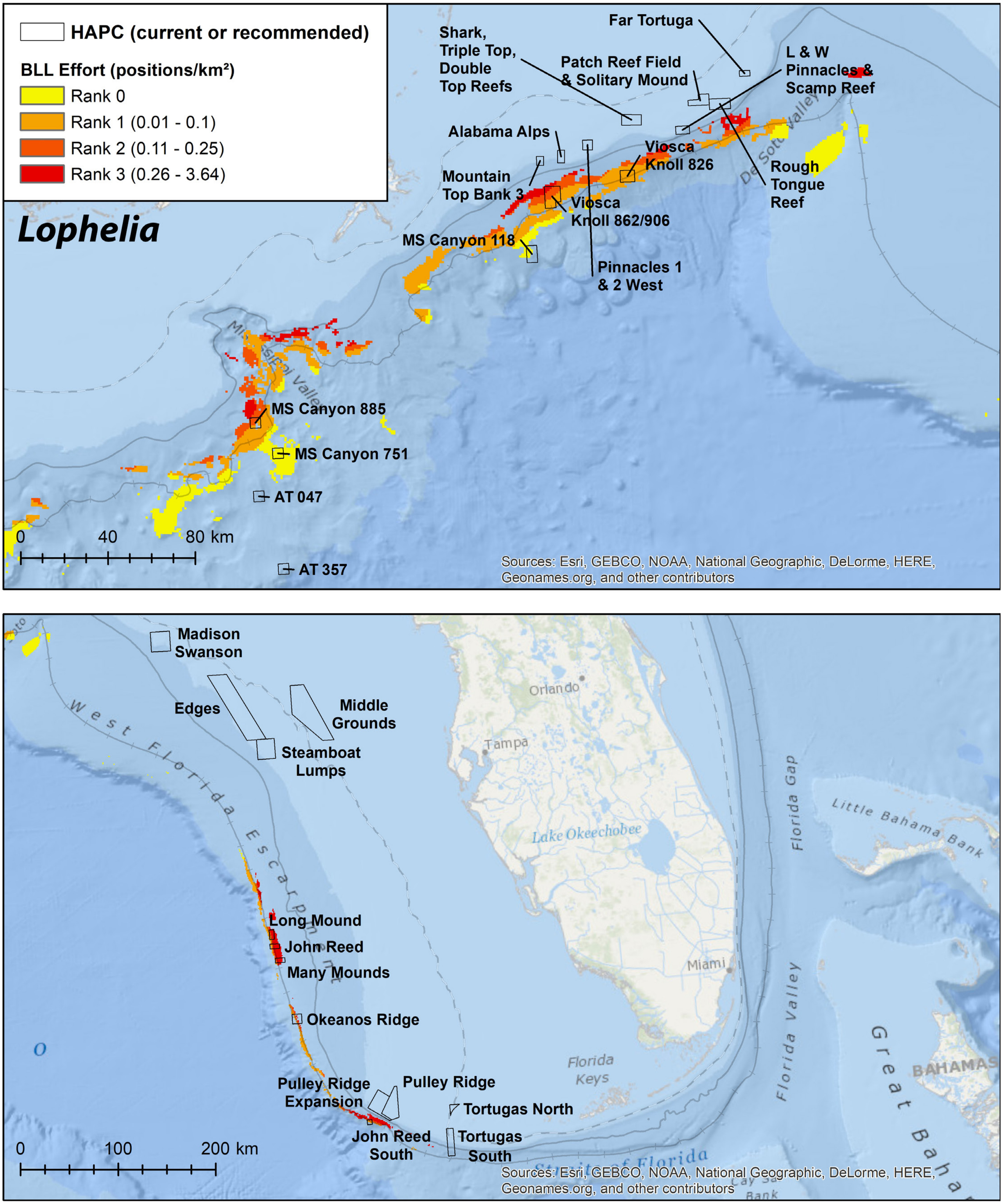


Figure A12. Location of habitat areas of particular concern (HAPC) in relation to bottom longline effort kernel density estimates on likely Lophelia *habitat in the northeastern Gulf of Mexico and west Florida shelf.*

Appendix

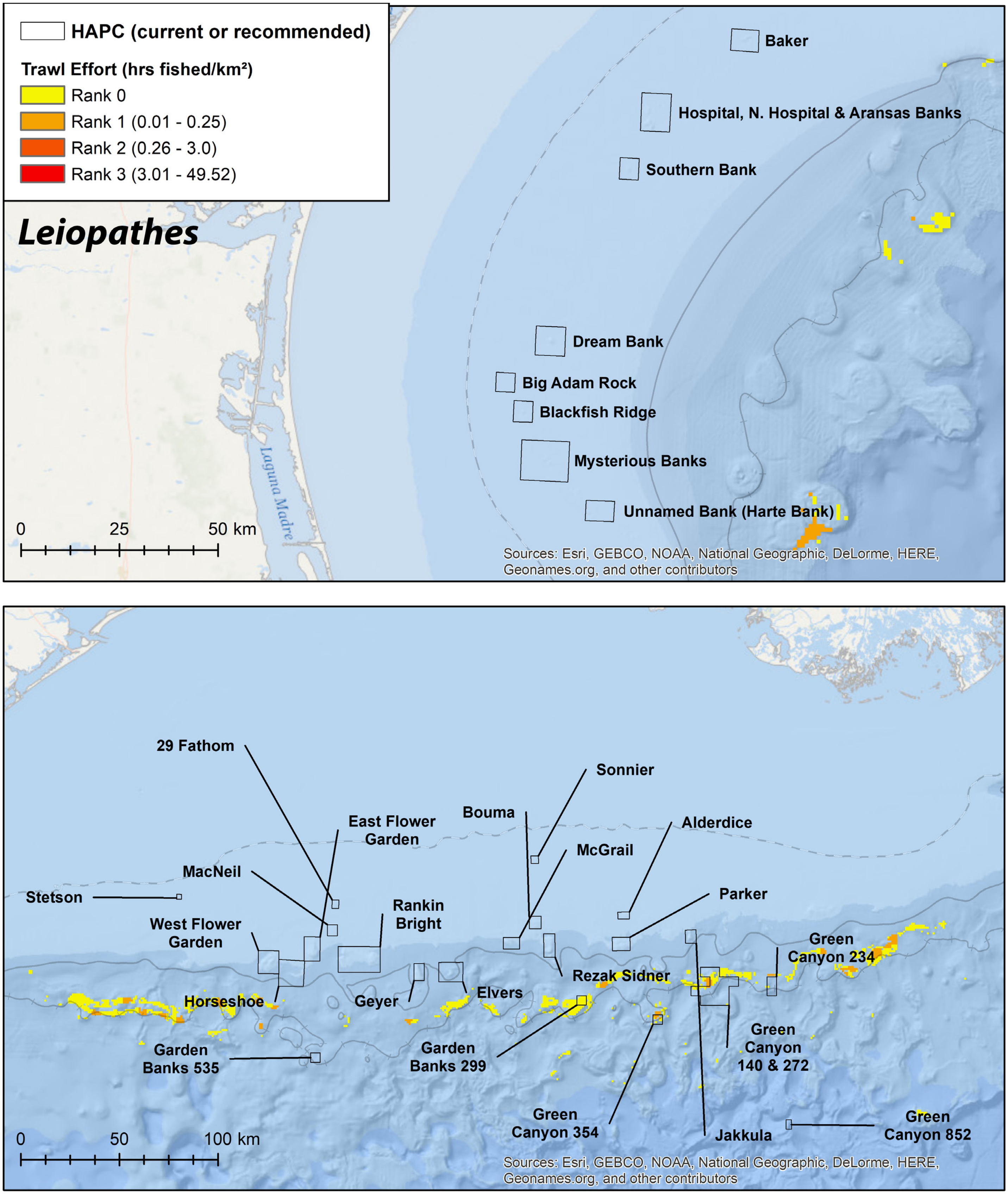


Figure A13. Location of habitat areas of particular concern (HAPC) in relation to trawl effort kernel density estimates on likely Leiopathes *habitat in west and central Gulf of Mexico.*

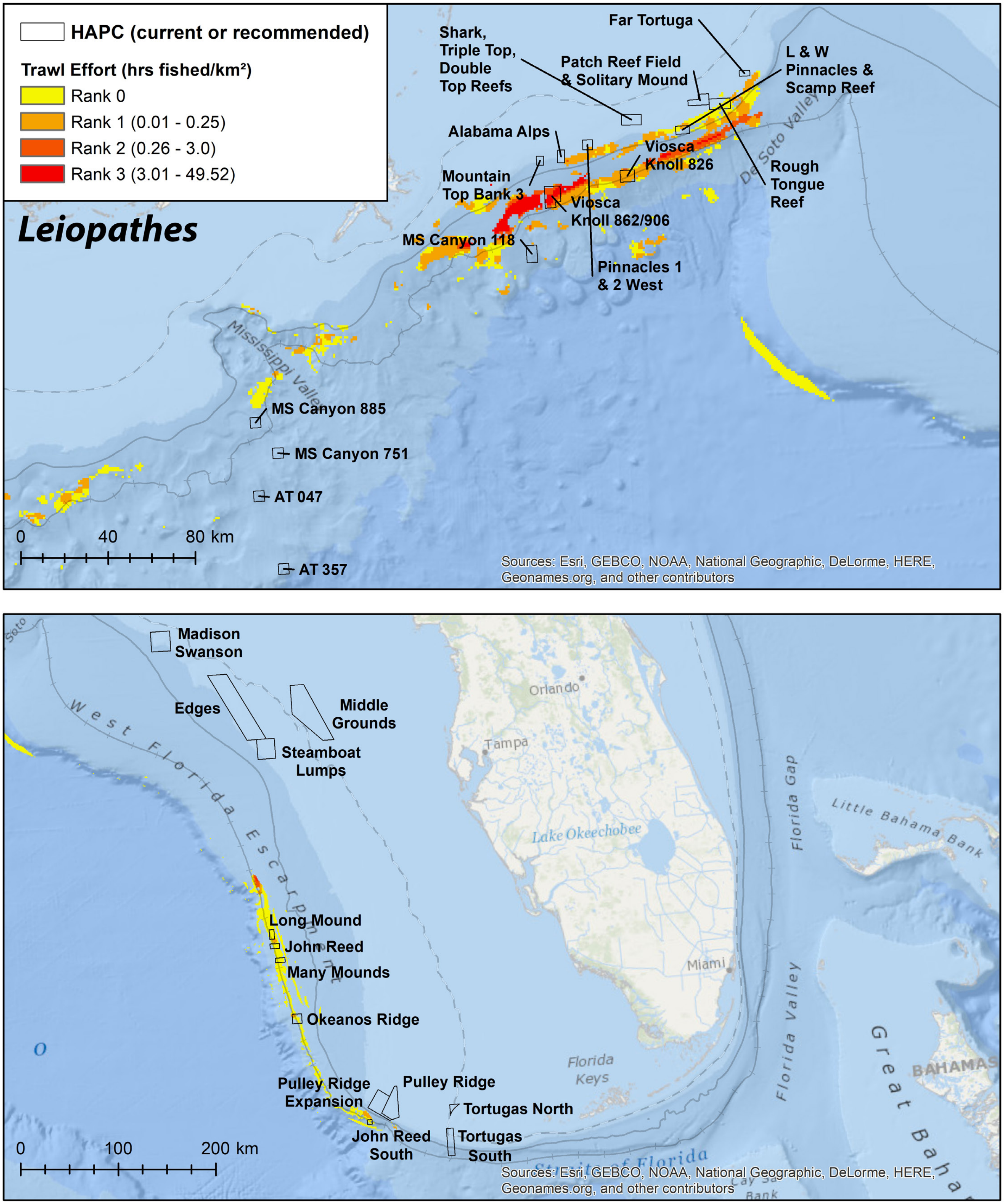


Figure A14. Location of habitat areas of particular concern (HAPC) in relation to trawl effort kernel density estimates on likely Leiopathes *habitat in the northeastern Gulf of Mexico and west Florida shelf.*

Appendix

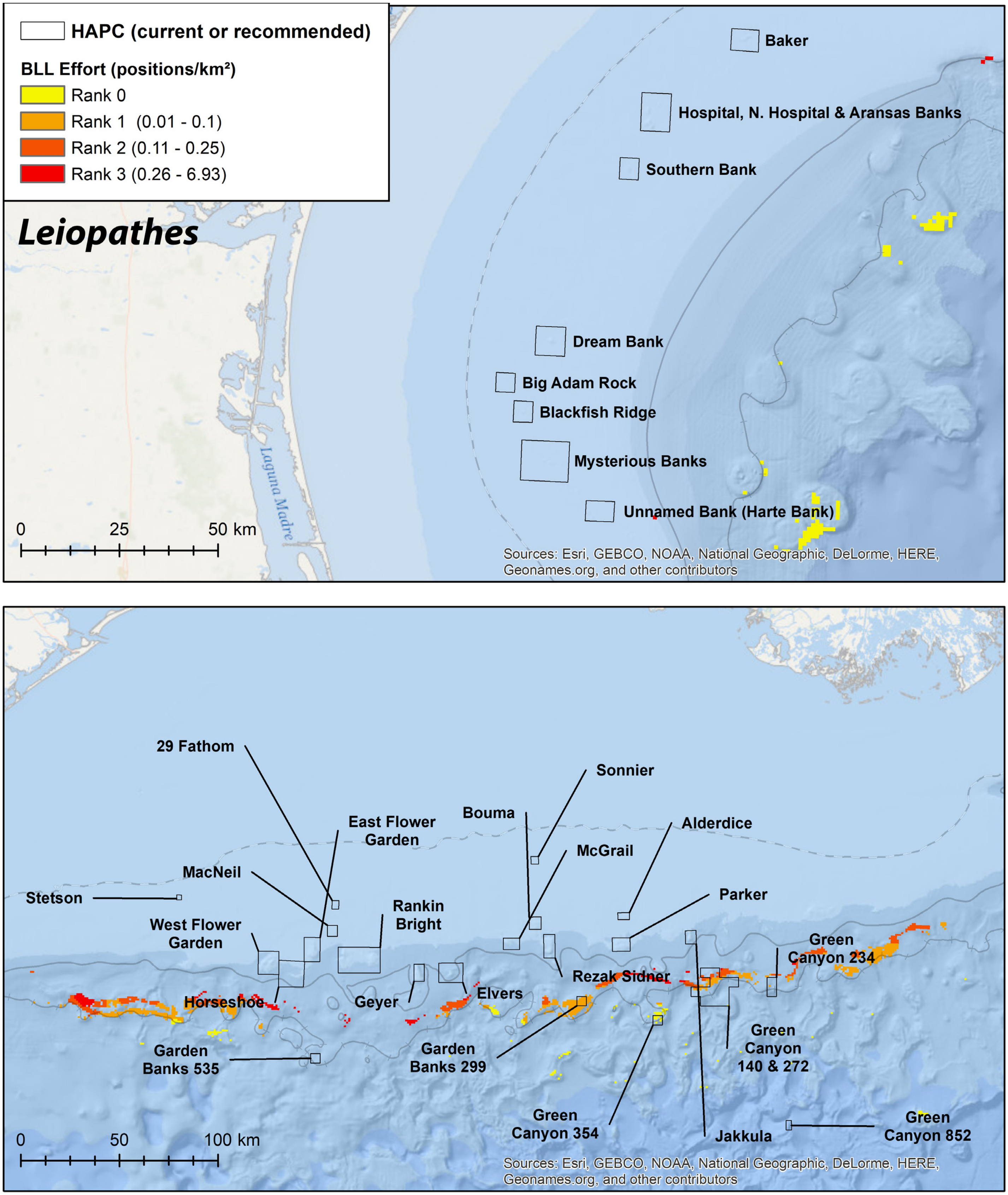


Figure A15. Location of habitat areas of particular concern (HAPC) in relation to bottom longline effort kernel density estimates on likely Leiopathes *habitat in west and central Gulf of Mexico.*

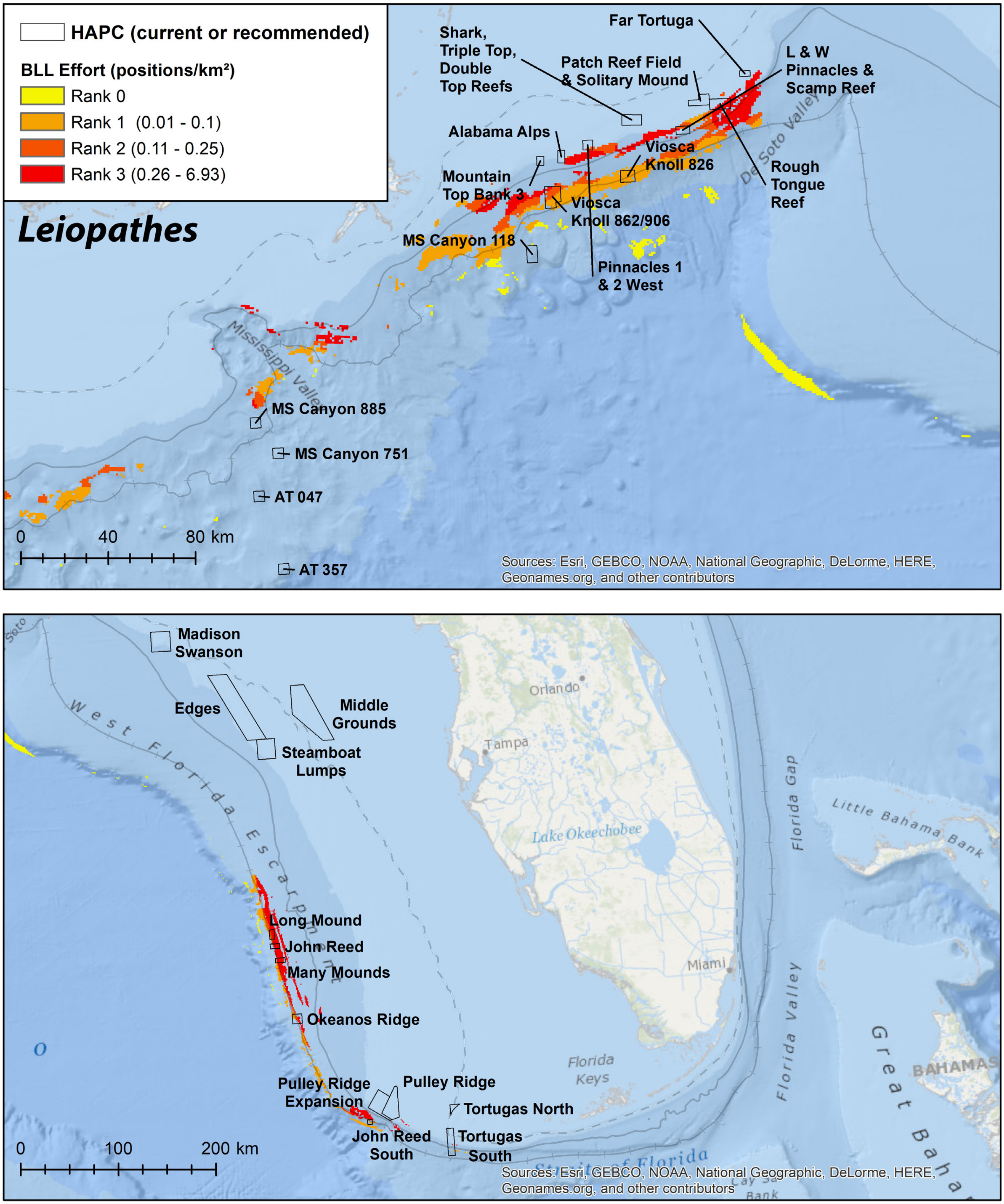


Figure A16. Location of habitat areas of particular concern (HAPC) in relation to bottom longline effort kernel density estimates on likely Leiopathes *habitat in the northeastern Gulf of Mexico and west Florida shelf.*

U.S. Department of Commerce

Wilbur L. Ross, Jr., *Secretary*

National Oceanic and Atmospheric Administration

RDML Tim Gallaudet, *Assistant Secretary of Commerce for Oceans and Atmosphere*

National Ocean Service

Russell Callender, *Assistant Administrator for National Ocean Service*

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