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DISTRIBUTION AND HABITAT USE OF THE GOLDEN CRAB *CHACEON FENNERI* OFF EASTERN FLORIDA BASED ON *IN SITU* SUBMERSIBLE AND ROV OBSERVATIONS AND POTENTIAL FOR IMPACTS TO DEEPWATER CORAL/SPONGE HABITAT

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Abstract: This study documents the distribution and habitat use of the golden crab (*Chaceon fenneri*), a commercially fished species, in relation to deep–sea coral/sponge ecosystems (DSCEs) at 200–900 m depths off eastern Florida. A total of 386 h of videotapes from 94 submersible and remotely operated vehicle (ROV) dives from 1999 to 2009, covering a total distance of 376 km, were reviewed and characterized for habitat type and presence of crabs. The DSCEs surveyed included *Lophelia* coral mounds, Miami Terrace, Pourtalès Terrace, and Tortugas Valleys. Video transect data also included environmental surveys of proposed deepwater routes for Liquid Natural Gas (LNG) pipelines, LNG port, and telecommunications fiber–optic cable. A total of 351 golden crab was counted and observed on a wide variety of habitat types, including coral thickets, rock escarpments, rock pavement, boulders, and soft bottom. The mean density of golden crabs was greater on soft bottom than on hard bottom habitat (0.342±0.234 vs 0.190±0.121 crabs /1000 m^2); within the hard bottom regions, mean density was greater on rock substrate than coral substrate (0.206±0.120 and 0.040±0.035 crabs /1000 m^2). The current golden crab fishery operates off eastern Florida in Allowable Crab Fishing Areas (ACFAs) within the deepwater Coral Habitat Areas of Particular Concern (CHAPCs); however, we have documented at least 8 regions within the CHAPCs where the ACFAs overlap probable DSCE habitat. Resource managers should adjust the boundaries of the ACFAs to protect and preserve vulnerable DSCE habitat while allowing benthic fisheries to operate in areas of soft bottom habitat.

Keywords: deep–sea coral ecosystems, trawling, *Lophelia* coral, allowable crab fishing areas

Introduction

Fisheries along the southeastern U.S. from North Carolina to Florida are regulated by the South Atlantic Fishery Management Council (SAFMC). In 2010, the SAFMC designated 5 deepwater Coral Habitat Areas of Particular Concern (CHAPCs) covering 59,569 km^2 in order to protect deep–sea coral/sponge ecosystems (DSCE) from potential impacts of benthic fisheries (NOAA 2010). Deepwater bottom fisheries off the southeastern U.S. include the golden crab (*Chaceon fenneri* [Manning and Holthuis 1984]), royal red shrimp (*Pleoticus robustus* [Smith 1885]), Blueline Tilefish (*Caulolatilus microps* Goode and Beane 1878), and Golden Tilefish (*Lopholatilus chamaeleonticeps* Goode and Beane 1879). All have been observed in this region during surveys with manned submersibles and Remotely Operated Vehicles (ROVs). This study documents the distribution and habitat use of the golden crab in relation to DSCEs at 200–900 m depths off eastern and southern Florida, and also documents the potential overlap of Allowable Crab Fishing Areas (ACFAs) on DSCEs.

Deep–sea coral/sponge ecosystems exist off the southeastern U.S. at depths of 200 to >900 m and include a variety of hard–bottom habitats including *Lophelia* and *Enallopsammia* coral mounds, rocky mounds and terraces, rocky escarpments, and Miocene–age karst topographic features including giant sinkholes (Reed 2002, Reed et al. 2005, 2006, 2013, 2014). In our study area, these habitats occur along the Florida–Hatteras Slope, in the Straits of Florida, on the Miami Terrace and Pourtalès Terrace, and in the Agassiz and Tortugas Valleys. Hard bottom provides habitat for fish and benthic species, including deepwater stony corals, hydrocorals, octocorals, black corals, and sponges. The dominant habitat–forming deepwater corals in this region are the scleractinian corals *Lophelia pertusa* (Linnaeus 1758), *Enallopsammia profunda* (Pourtalès 1867), and *Madrepora oculata* Linnaeus 1758; various species of hydrocorals (family Stylasteridae); black corals (order Antipatharia); and diverse gorgonian octocorals.

The golden crab fishery has operated in the deepwaters off Florida since the early 1990s, and a fishery management plan was implemented in 1995 (SAFMC 2009). Here, golden crab fishers deploy long lines up to 8 km long with 20–50 baited traps, each weighing 11–22 kg, attached about 150 m apart; Erdman and Blake (1988) described the fishery techniques in detail. The trap lines are retrieved by dragging a heavy grappling hook to snag the main long–line on the bottom; once hooked the main line and traps are pulled up. The deepwater shrimp fishery originally fished for rock shrimp (*Sicyonia brevirostris* Stimpson 1871) on the shelf of Florida but then moved to deeper water in search of the royal red shrimp. The royal red shrimp fishery use trawls similar to the rock shrimp trawls which drag the bottom. In 2014, 8 permits were issued for golden crab fishers off eastern Florida, resulting in landings of 937,365 kg, and 7 permittees landed

914,831 kg of royal red shrimp in 2013 (Chip Collier, pers. comm., SAFMC). The annual catch limit for golden crab was updated in 2011 (909,090 kg whole weight) as an amendment to the Magnuson—Stevens Fishery Conservation and Management Act (SAFMC 2011). Currently, the SAFMC does not require Vessel Monitoring Systems (VMSs) for golden crab fisheries; however, VMSs are required for the deepwater shrimp fishers. In 2011, the Law Enforcement Advisory Panel (LEAP) recommended that the SAFMC consider a VMS requirement for the golden crab fishery, but the council decided against it because the vessel—mounted VMS would not reflect where the gear landed or how it had drifted.

The SAFMC has designated 5 ACFAs off eastern Florida (Northern; Middle A, B, C; and Southern) where golden crab traps are allowed within the CHAPCs; however, portions of these areas may overlap DSCEs. If the gear is fished in these areas, the potential exists for unintentional impacts to DSCE habitat. The golden crab long—line traps, which extend several km in length, drift in the strong Florida Current during deployment. In addition, during retrieval with grappling hooks, the gear may drag across the bottom, which could impact any DSCE habitat (Erdman and Blake 1988, SAFMC 2011). The SAFMC also has established Shrimp Fishery Access Areas (SFAAs) within the CHAPC in order to allow shrimp fishers to continue operating in traditional fishing grounds. Although the royal red shrimp fishery is not directly managed by the SAFMC, participants in the rock shrimp fishery occasionally target royal red shrimp. Bottom trawling for rock shrimp has demolished extensive areas of coral habitat dominated by the scleractinian *Oculina varicosa* Lesueur, 1821 off eastern Florida at depths of 70 to 100 m (Koenig et al. 2005, Reed et al. 2007). In deeper water, royal red shrimp fishers use similar bottom trawl gear where DSCE habitat could be impacted.

This study has 2 major objectives: 1) document the distribution and habitat use of golden crab (e.g., hard bottom habitat vs. soft bottom habitat, and coral substrate vs. rock substrate) off eastern and southern Florida based on our visual surveys using submersibles and ROVs, and 2) determine whether the ACFAs within the CHAPCs off Florida include areas of DSCE habitat that should be avoided. These data will permit fishers to focus on crab populations while avoiding critical DSCE habitat, and also will provide data that will allow the SAFMC to revise or modify ACFA boundaries in areas that overlap DSCEs. High—resolution surveys are critical for defining both DSCEs and areas devoid of these fragile habitats that could potentially be suitable for future bottom fisheries and energy development. This is the first detailed survey based on visual observation of the distribution and habitat use of golden crab in this region off Florida, and the results are compared with other areas fished off South Carolina and the eastern Gulf of Mexico.

Materials and Methods

The region of study was the deepwater benthos (200 to ~900 m) off eastern and southern Florida, within the jurisdiction of the SAFMC, from the northern border of Florida (31° N latitude) to the Dry Tortugas off south Florida (83°W longitude), and out to the boundary of the U.S. Exclusive Economic Zone (EEZ) between Florida and the Bahamas and Cuba (Figure 1). From 1999 to 2009, the authors have mapped and characterized extensive regions of DSCEs off the southeastern U.S. (Reed 2004, Reed et al. 2005, Messing et al. 2006 a,b, Reed 2006, Reed et al. 2006, 2008, 2013, 2014), and have ground—truthed these sites with submersibles, ROVs, or Autonomous Underwater Vehicles (AUVs). Videotapes and data from this archive were selected for this study and were analyzed to document the distribution of golden crab, including their relationships to DSCEs, their abundances, sizes and associated environmental factors. Other deepwater fisheries species, such as tilefish and royal red shrimp, were recorded in our surveys, but were relatively rare and were not analyzed in this study. In addition to the surveys that targeted DSCEs, we also analyzed several benthic envi-

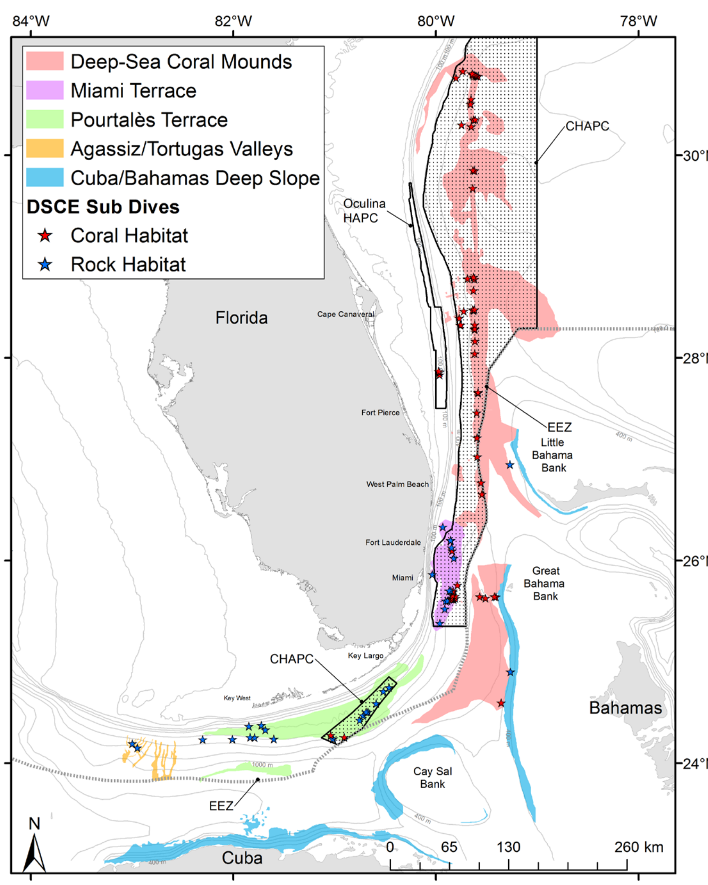

FIGURE 1. *Regions of deep—sea coral ecosystems (DSCE) off eastern Florida. Polygons (heavy black lines) = boundaries of deepwater Coral Habitat Areas of Particular Concern (CHAPC) and deepwater Oculina coral HAPC; colored polygons = DSCE habitats and major topographic features (see legend). Stars=DSCEs surveyed with ROV or submersible dives (red stars = coral habitat, blue stars = rock habitat). Depth contours in meters. (from Reed et al. 2013, 2014).*

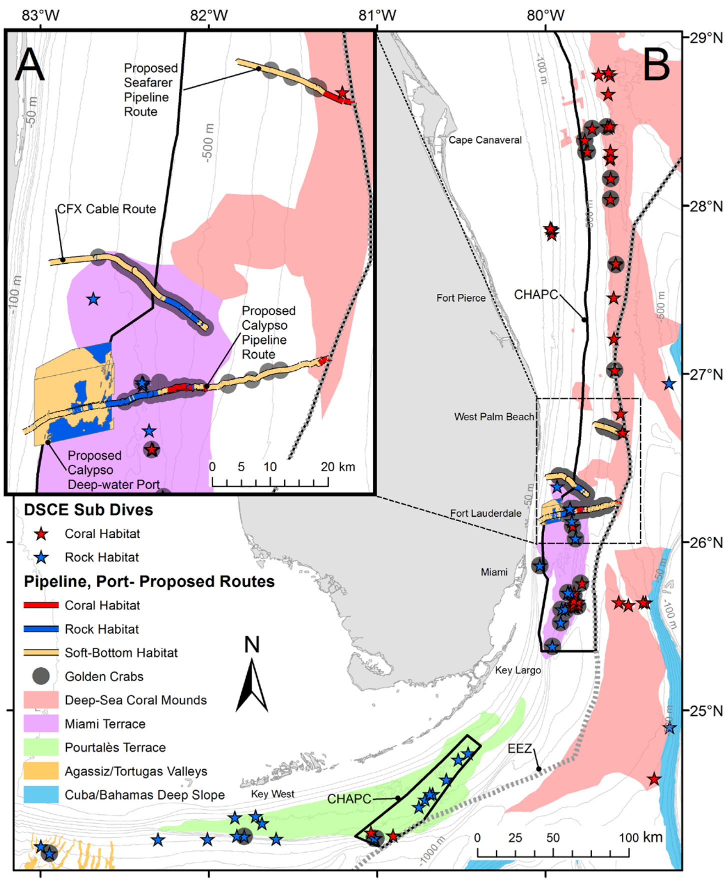

FIGURE 2. *Distribution of golden crab (*Chaceon fenneri*) at submersible and ROV survey sites off Florida. Dark gray circles = golden crabs observed. A. Inset showing environmental surveys for proposed liquid natural gas (LNG) pipeline routes, proposed deep-water LNG port, and fiber-optic cable route off south Florida. Color codes indicate habitat types of each survey. CHAPC boundaries indicated by thick black lines.*

ronmental surveys for proposed liquified natural gas (LNG) deepwater pipeline routes, for a proposed LNG deepwater port, and a telecommunications fiber–optic cable route (Figure 2A). These environmental surveys provided east–west transects from depths of 200 m out to the EEZ (~900 m) and included extensive soft bottom habitat for comparison with the DSCE sites. With respect to physical parameters, we used the annual mean bottom temperature (°C), salinity (ppt), and bottom current velocity (m/sec) from modeled data of Fiechter and Mooers (2003) which covers the area of study where we encountered golden crabs. We used these modeled annual mean parameters, since environmental data were collected only sporadically during some of the dives.

Source Data: Deepwater Submersible and ROV Surveys

A total of 94 submersible and ROV dives were selected as representative of the latitudinal and depth ranges of golden crab for this study (Table 1). The total distance surveyed was 376.8 km for a total bottom time of 386.2 h. Dives were categorized by survey type: 1) submersible dives to specifically investigate DSCEs; and 2) environmental surveys for proposed deepwater LNG pipelines, proposed LNG deepwater port, and telecommunication fiber–optic cable routes in the region.

Submersible DSCE Surveys

We used Harbor Branch Oceanographic Institute's (HBOI) extensive archives of *in situ* videotapes from *Johnson Sea Link* (*JSL*) and *Clelia* submersible dives that surveyed DSCEs off eastern and southern Florida from 1999 to 2009 (Reed 2004, Reed et al. 2005, 2006, 2013, 2014). The primary objectives of these dives were to map and characterize the habitat and associated benthic megafauna, including sponges, octocorals, black corals, scleractinian and stylasterid corals, decapod crustaceans, echinoderms, mollusks, and fish. As a result, these dives targeted and ground–truthed moderate to high–relief geological features that were evident from available bathymetric maps (Figures 1, 2), all of which documented DSCE habitat. Of these submersible dives, we selected 71 as representative of latitude, depth, and habitat type over the range of the study area, from the north Florida border to the Dry Tortugas, and within the jurisdiction of the SAFMC. These submersible dives covered 131.5 km;

TABLE 1. *Submersible and ROV dives analyzed for this study. Source Data: Deep–sea Coral Ecosystem (DSCE) surveys with* Johnson Sea Link *and* Clelia *submersibles; surveys of proposed liquified natural gas (LNG) pipeline routes; proposed deepwater LNG port; and fiber-optic cable route. Total number of dives, number of golden crab observations, distance in km, area surveyed by video (km²), and bottom time in hours for all dives of each survey. Percent (%) of each survey on soft-bottom habitat (SB) and hard-bottom habitat (HB). HB is further divided into % on coral substrate (Co) or rock substrate (Ro).*

Source Data	Survey Platform	Total No. Dives	Total No. Crabs	Bottom Distance (km)	Total Area (km2)	Total Bottom Time (h)	% on SB	%on HB	% on Co	% on Ro	Depth Range (m)
DSCE Sub Dives	Submersible	71	135	131.50	0.658	165.90	6.90	93.10	56.70	36.40	144-921
Calypso LNG Port	ROV	7	0	96.30	0.482	68.00	74.80	25.20	0.00	25.20	210-300
Calypso LNG Pipeline	ROV	7	40	92.60	0.463	87.00	46.20	53.80	19.20	34.60	189-782
CFX Fiber-optic Cable	ROV	3	167	29.80	0.149	39.30	77.30	22.70	0.00	22.70	189-532
Seafarer LNG Pipeline	Submersible	6	9	26.60	0.133	26.00	72.30	27.70	27.70	0.00	524-789
Total		94	351	376.80	1.884	386.20	44.10	55.90	26.46	29.44	144-921

each dive had up to four 60 min videotapes totaling 165.9 hours of bottom time (Table 1). Each tape was reviewed for habitat type and presence of golden crab. Submersible navigation used Ultrashort Baseline Sonar (USBL) technology, which calculated the submersible's real—time Differential Global Positioning System (DGPS) position throughout each dive. Analysis of USBL tracking accuracy estimated a maximum statistical positioning error of 9.6 m at a depth of 500 m (Opderbecke 1997). Color videotapes recorded each dive with an external pan and tilt video camera and parallel lasers for scale.

Environmental Surveys of Proposed Deepwater Pipelines, Port, and Cable Routes

Data was also collected from several benthic environmental surveys for proposed deepwater projects that we conducted in the region, including the following: proposed Seafarer deepwater LNG pipeline route (Reed 2006), proposed Calypso LNG port and pipeline routes (Messing et al. 2006 a,b), and the CFX telecommunications fiber—optic cable route (Reed et al. 2008). The Television Observed Nautical Grappling System (TONGS) ROV (U.S. Naval Surface Warfare Center, Carderock Division, South Florida Testing Facility, Dania Beach, FL) was used for the proposed Calypso port and Calypso pipeline route surveys. The *Nereus IV* ROV (Perry Tritech, Triton ST200 Series), owned and operated by Tyco Telecommunications, was used for the CFX fiber—optic cable route survey. The ROVs were equipped with video and digital still cameras and with parallel lasers. Underwater positions for the ROVs used an ultra—short baseline acoustic tracking system integrated into a DGPS. These pipeline and cable surveys were made in a general west to east direction along the proposed routes from the State of Florida boundary 4.8 km (3 miles) from shore, at ~200 m depth, to the U.S.—Bahamas EEZ, ~800 m depth. As such, these dives did not target hard bottom but followed the routes for the proposed cable and pipelines; however, the objectives for these environmental surveys were to document any hard bottom and sessile fauna with video and digital photographic transects. In addition, the proposed Calypso LNG port surveyed the top of the northern Miami Terrace, which included extensive hard— and soft—bottom habitats (Messing et al. 2006a). The videotape annotations from these surveys documented all benthic fauna larger than 5 cm; these annotations were used to find this study's target taxa. Where a golden crab was noted, the videotapes were then re—reviewed to verify the identification, and when possible, measured using the parallel lasers. These environmental surveys together compiled data from a total of 23 dives over a total transect distance of 245.3 km for 220.3 h of bottom time (Table 1, Figure 2A). The survey of the proposed Calypso LNG Port (Messing et al. 2006a) consisted of 96.3 km of ROV transects within the proposed 13.7 x 13.0—km boundaries of the proposed port on the Miami Terrace at depths of 210—300 m. The surveys of the proposed pipelines and fiber—optic cable covered 149 km for a bottom time of 152.3 h over a depth range of 189—789 m.

Video Analysis

A Microsoft 2010 Access Database was used to record and annotate substrate type and targeted species data from these dives. The following data were recorded: data source, date, dive number, coordinates, depth (m), time (h), bottom type, time on hard bottom and soft bottom (h), bottom temperature (°C), and golden crab observations (number, habitat type, and size). Frame grabs were captured from video as JPEG images (720 x 480 pixel, ~1.0 MB files) to document each specific habitat type and to measure the carapace width (CW, mm) of the golden crabs. During the transects the submersibles and ROVs were kept <0.5 m off the bottom with the video cameras kept at a wide field of view and angled down ~30°. The field of view of the video used for identification of fauna was restricted to 5 m width, although in clear water the observer in the submersible could actually see >10 m. Parallel lasers mounted on the digital still and video cameras were used to determine the width of the field of view and size of golden crabs. To avoid inaccuracies associated with parallax, the carapace width of each golden crab was measured only when the crab appeared close to or on the same horizontal line as the lasers.

Deepwater Habitat Terminology

We used the following parameters to describe habitat and substrate types that were documented in the video annotations: soft—bottom (SB) habitat consisted of unconsolidated sediment (S) substrate (sand, mud); hard—bottom (HB) habitat was further subdivided into rock (Ro) substrate (pavement, rock slabs, boulders, cobble and rubble) and coral (Co) substrate (standing live/dead coral, coral rubble). These are the dominant habitats that we have documented elsewhere on the Florida shelf and Straits of Florida and have used in other deepwater benthic surveys in the region (Reed et al. 2005, 2006, Vinick et al. 2012, Reed et al. 2014). Coral is defined as hard, or stony, corals (Scleractinia) and other taxa with solid calcareous skeletons (e.g., Stylasteridae), as well as some non—accreting taxa: octocorals (Alcyonacea; chiefly "gorgonians"), and black corals (Antipatharia) (Lumsden et al. 2007). Hard bottom ranged from relatively flat (low relief) surfaces to high relief topography. The importance of hard bottom to fisheries stocks has been recognized, and the SAFMC has designated all hard bottoms in the region as essential fish habitat (EFH).

Data Analysis

We recognize the difficulty of using these various data sets to analyze the golden crab data. These crab data were analyzed *a posteriori*, and the cruises were not originally designed to document the crab distribution. The dives were made to characterize the habitat and benthic megafauna which happened to include the golden crab. We cannot provide seasonal data, nor provide replicate transects, nor night dive data. Also differences may exist between observations on rugged rock and coral bottom, where crabs may be hidden, versus transects over flat sand bottom, where the field of view is unobstructed. However, this is the first detailed survey of the distribution and habitat use of golden crab in this region and is based on the largest data set of video data collected to date.

Two data sets were analyzed: crab distribution and carapace width. First, crab distributions were analyzed to identify any use of habitat or substrate type. Previous studies off the Carolinas and Gulf of Mexico showed varying use of HB versus SB habitat, and these data will be useful for commercial fishers targeting the crab. Golden crab densities (# crabs/1000 m^2 ± se) were determined by enumerating the total number crabs for each survey divided by the total area surveyed (total distance of the dive multiplied by the 5 m width field of view) following the protocol previously used for video analysis of our submersible and ROV surveys (Reed et al. 2005, Harter et al. 2015). Each dive was then divided into segments that were on HB habitat and SB habitat, and the HB habitat was further subdivided into Co and Ro substrate, as described above. Crab densities on each substrate type were then calculated.

To assess habitat use of the golden crabs, normality assumptions and homogeneity of variances of crab distributions were tested. A Shapiro—Wilk test showed that crab density between SB and Co were statistically non—normal ($p < 0.5$) which could not be corrected by transformations. Therefore, non—parametric statistics were used to test for habitat use. A Chi—Square (χ^2) test was used to compare the actual distribution of crabs versus an expected even distribution on HB and SB habitats. Chi—Square was also used to test for differences between Ro and Co substrates.

The second test was used to determine whether crab size, based on CW, varied with depth. Previous studies indicated some evidence of crab migration up and down slope based on age (i.e., as identified by size). These data also may be useful for commercial fishers. Crab size was grouped into 100 m depth increments (e.g., 300—399, 400—499, etc.). The data were first analyzed for normality and homogeneity. The Shapiro—Wilk test showed that the data were normally distributed ($p>0.05$); therefore, an ANOVA was performed followed by pairwise comparisons using a post hoc Tukey Test to determine between—group differences. All analyses were performed using SPSS Version 24 and were considered significant if $p < 0.05$ unless stated otherwise.

ArcGIS Analyses

Data compiled from video analyses were entered into ArcGIS®, ArcMap® version 10.2. Separate Excel spreadsheets were created that summarized habitat type and counts and sizes of golden crabs. Data were recorded whenever habitat type changed or the target species was observed. The submersible and ROV dives were entered into ArcMap as a layer. The GIS map included layers for the various surveys: polylines (continuous lines) indicated routes of the proposed pipelines and cable surveys, the LNG deepwater port survey area was indicated as a polygon, and single points (stars) indicated the submersible DSCE dives. These layers were further classified by habitat and substrate type (HB, SB, Ro, Co), which were then measured for distance (km), resulting in a calculable distance for each bottom type. The map layers were then queried for occurrences of golden crabs and exported into new layers. Polygon shapefiles for the boundaries of the HAPCs and ACFAs were provided by the SAFMC.

To determine where the boundaries of the ACFAs overlapped potential DSCE habitat, ArcGIS was used to incorporate the following datasets: multibeam bathymetric surveys (including NOAA 2004, Grasmueck et al. 2006, Reed and Sherrell 2009, Reed 2011, NOAA 2014); U.S. Coastal Relief Models (CRM); NOAA—DEM (digital elevation models showing 3—D imagery of the Straits of Florida combining various NOAA bathymetry sources); NOAA regional bathymetric contour charts (NOAA 2001); and data from our submersible and ROV dives. NOAA National Centers for Environmental Information (NCEI; http://www.ngdc.noaa.gov/) provided recent bathymetric data (NOAA 2004, 2014) for the region, which were added to the ArcMap database. The Multibeam Bathymetry Database (MBBDB) at NCEI collects and archives multibeam sonar data acquired from a variety of government and academic sources, but the archive does not include all available data. We imported these files for our study region, which were chiefly relatively low resolution (10—50 m resolution) multibeam sonar maps (such as single swaths from NOAA Ship *Okeanos Explorer* [NOAA 2014]). We also incorporated high resolution multibeam maps (generally AUV multibeam sonar surveys at 1—5 m resolution), which were more useful in defining low to moderate relief habitats; these included surveys on Pourtalès Terrace (Reed 2011), Miami Terrace (Grasmueck et al. 2006, Correa et al. 2012), southeast Florida shelf (Vinick et al. 2012), and deepwater reefs off Cape Canaveral (Reed and Sherrell 2009). In addition to these recent multibeam maps, the older National Ocean Services (NOS) regional bathymetric maps are good for defining high—relief geological features, and in this region are at 10 m resolution. Reed et al. (2013) used these maps to discover and define both moderate and high relief DSCE habitat in this region. The following NOAA NOS bathymetric maps were imported and georeferenced into our GIS analyses: CRM—10—m—NAD83 (digital 10 m contour lines), NH17—6, NH17—9, NH17—12, NG17—3, NG17—6, NG17—9, NG17—12, L—184, and L—185 (NOAA 2001).

Results

Habitat Descriptions

The submersible DSCE surveys spanned 4 regions (Figure 1): 1) deepwater *Lophelia* and *Enallopsammia* coral mounds (depths 200–921 m), low to high relief (1–50 m) coral mounds and ridges that extend from north Florida to the Florida Keys; 2) Miami Terrace (depths 300–600 m), a flat topped Miocene age limestone terrace that extends from Fort Lauderdale to south Miami with low to high relief, karst–like pavement, rock ridges, rock mounds, steep escarpments, and large sinkholes; 3) Pourtalès Terrace (depths 200–460 m), a Miocene age limestone terrace that parallels the Florida Keys, with low to high relief rock mounds and massive, deepwater sinkholes; and 4) Tortugas and Agassiz Valleys (depths 500 to >900 m), a series of deepwater canyons with steep escarpments (up to 140 m relief), rock pavement, and boulders. For the DSCE submersible dives, 93.1% of the total transect length of all dives was on hard–bottom habitat and 6.9% was soft bottom (Table 1). Hard–bottom cover of the individual dives ranged from 67.3 to 100%. Hard–bottom habitat was primarily coral substrate (standing live/dead *Lophelia* and/or *Enallopsammia* coral, or coral rubble) associated with the coral mounds in the Straits of Florida (56.7%), and the remainder (36.4%) was rock substrates on the Miami Terrace and escarpment, Pourtalès Terrace, and Tortugas Valleys.

The environmental surveys for the proposed LNG pipelines and cable routes were primarily E–W linear transects and encountered 46.2–77.3% soft–bottom habitat, which typically was fine sand with varying amounts of silt and clay (Figure 2A, Table 1). The survey of the CFX fiber–optic cable route on the northern end of the Miami Terrace (Figure 2A) encountered low relief rock pavement and rubble substrate on top of the Terrace; however, the survey was cut short at a depth of 531 m on the Miami Terrace escarpment when the ROV was unable to operate in the strong Florida Current and did not extend to the EEZ as planned. Of the 29.8 km transect length, 22.7% was on rock habitat and 72.3% was on soft bottom (Table 1). Further south on the Miami Terrace and escarpment, the survey for the proposed Calypso pipeline route (Figure 2A) encountered extensive hard–bottom habitat consisting of rock pavement, rock slabs, and rubble/cobble, whereas only extensive soft–bottom habitat was encountered from the eastern base of the Terrace escarpment to the coral mounds near the EEZ. Of the total 92.6 km of transects, 53.8% was on hard bottom (19.2 % coral habitat, 34.6% rock habitat) and 46.2% on soft bottom. The survey of the proposed Calypso LNG port (Figure 2A) covered 96.3 km and was entirely on top of the northern Miami Terrace. These transects documented soft–bottom habitat (74.8% cover) mostly along the western half of the Terrace, with increasing amounts of hard bottom (25.2% cover) along the southern and eastern sides of the survey area (Table 1). The hard–bottom habitat consisted of rock pavement, rock rubble, and low–relief rock ledges, with large rock ledges and high relief escarpments near the eastern side of the survey area. The survey of the proposed Seafarer LNG pipeline route (26.6 km length) was north of the Miami Terrace and encountered coral mounds near the EEZ over a 5 km stretch (red portion of polyline in Figure 2A). Coral habitat was encountered on 27.7% of the transect (Table 1); the remainder (72.3%), to 523 m depth, was soft muddy sediment. The coral habitat consisted of low to moderate relief (1–3 m tall) mounds and ridges of *Lophelia* and *Enallopsammia* coral and coral rubble.

Golden Crab— Habitat Use

A total of 351 golden crabs were counted on all dives (Table 1, Figure 2). They were common on the soft bottom in the Straits of Florida between West Palm Beach and Miami, and also were associated with the following hard–bottom areas: East Florida *Lophelia–Enallopsammia* coral mounds, Miami Terrace and escarpment, Pourtalès Terrace, and Tortugas Valleys. On Pourtalès Terrace, no crabs were recorded from the *Lophelia* coral mounds, but they were observed around and on the rocky escarpments of the deepwater sinkholes. They were also found on vertical escarpments in the canyons of the Tortugas Valleys. Thus, golden crabs occur in a wide variety of habitat types in this region, including: dense live coral thickets, vertical rock escarpments, rock pavement, rock boulders and slabs, and flat mud/sand bottom (Figure 3).

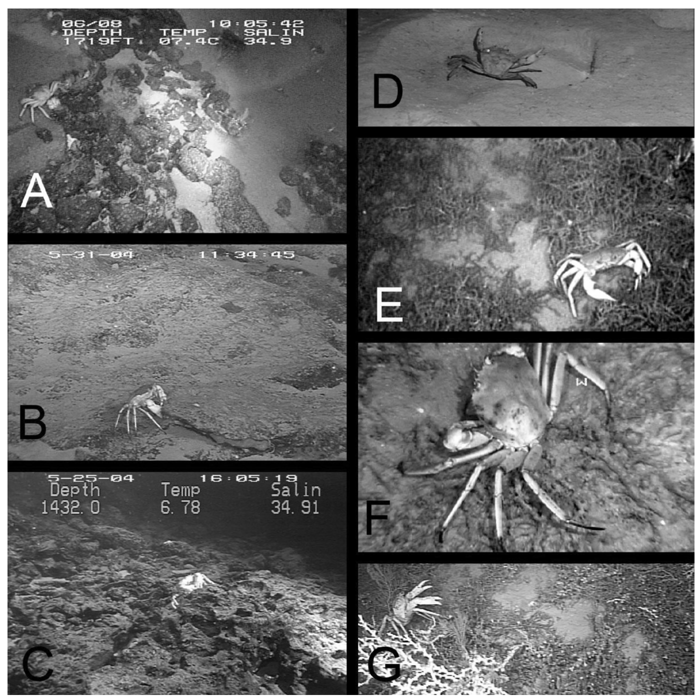

FIGURE 3. *Golden crabs (*Chaceon fenneri*) on a variety of hard– and soft–bottom habitats. A. Rock cobble and boulders on the Miami Terrace. B. Rock slabs and pavement on Miami Terrace. C. Rugged high-relief rock on the Miami Terrace escarpment. D. Flat muddy sand habitat in Straits of Florida. E. Standing dead coral on the slope of a* Lophelia *coral mound. F. Coral rubble habitat on coral mound. G. Live* Lophelia *coral habitat on the slope of coral mound. (from* Johnson-Sea-Link *submersible, Harbor Branch Oceanographic Institute).*

The mean density of crabs over all surveys was 0.296 ± 0.209 crabs/1000 m^2. The greatest crab density of any individual dive site was 1.121 crabs/1000 m^2 which occurred along the fiber–optic cable route on the northern Miami Terrace (Figure 2). Crab distribution was further analyzed for habitat use. Overall, mean density was greater on SB than on HB habitat (0.342 ± 0.234 vs 0.190 ± 0.121 crabs /1000 m^2, respectively, Figure 4A). A Chi–Square test showed a significant difference in the actual distribution of crabs on HB versus SB habitats compared to an expected even distribution (χ^2 = 8.550, df = 1, p < 0.01). Within the HB habitats, mean crab density was greater on Ro than on Co substrate (0.206 ± 0.120 and 0.040 ± 0.035 crabs /1000 m^2 respectively, Figure 4B). However, Chi–Square did not show a significant difference in distribution between Co and Ro substrate types (χ^2 = 3.418, df = 1, p > 0.05).

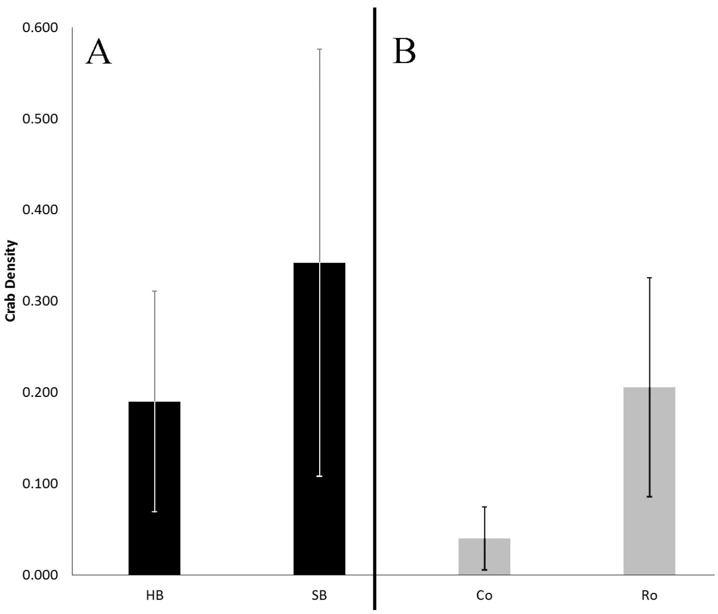

FIGURE 4. *Mean (± se) density of golden crabs (Chaceon fenneri) for each major habitat type for all surveys (# crabs/1000 m^2). A. Mean density on hard-bottom (HB) habitat and on soft-bottom (SB) habitat; significant difference (Chi–Square: p< 0.01). B. HB habitat was divided into coral (Co) and rock (Ro) substrata.*

Golden Crab Distribution, Physical Parameters, and Size

The surveys extended from ~24 to 31°N latitude. Crabs were observed over the entire region, although none were observed either off north Florida between 29°N to 31°N or on the western part of Miami Terrace in the region of the deepwater port (Figure 2). Actual bottom temperatures recorded during the submersible dives ranged from 5.6–16.7°C; however, annual mean temperatures of the modeled data for the golden crab observations was 7.3–11.8°C. Annual mean bottom salinities for the crab distribution ranged from 35.0–35.5. Annual mean bottom current velocities ranged from 0.06–0.20 m/sec; however, current velocities recorded during some submersible dives exceeded these values, especially on the Pourtalès Terrace bioherms and on the peaks of the coral mounds, where velocities at times exceeded 1.0 m/sec.

Overall, the golden crabs were observed from depths of 247–888 m. Greatest frequencies of occurrence were between 400 and 500 m but relatively few (36 individuals, 10% of total) were found at depths >600 m, which were primarily on the deepwater coral mounds. Of 74 golden crabs measured, CW ranged from 58–190 mm with peak frequencies between 80–130 mm CW (Figure 5A). There was a significant difference of carapace size by depth (ANOVA, $F_{4,70}$ = 3.209, p < 0.05). Crabs in the 300–400 m depth zone were, in general, smallest (96 ± 3.98 mm CW) and were significantly smaller than in the 400–500 m depth zone (121 ± 5.28 mm CW, p < 0.01). There were no significant differences in crab size among other depth zones. The sex of crabs could not be determined from visual observations.

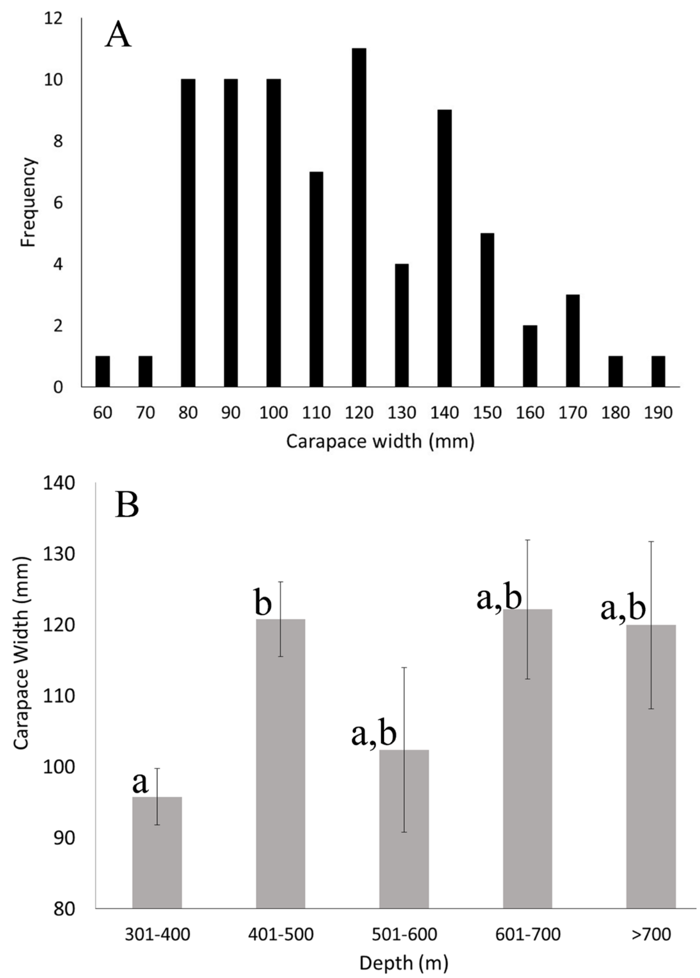

FIGURE 5. *A. Frequency of occurrence of distribution of carapace width (CW) of golden crabs (Chaceon fenneri). B. Mean (± se) golden crab CW by depth (mean ± se). Means that share the same letter are not significantly different from one another (Tukey HSD: p <0.01).*

Potential Overlap of Allowable Golden Crab Fishing Areas and DSCE Habitat

Over 350 of the areas that indicated high–relief bathymetry (see Figure 1) were ground–truthed with submersible and ROV dives, all of which proved to be DSCE habitat. Currently, detailed mapping of the distribution of deepwater coral and hard bottom habitats in this region remains inadequate and incomplete. For example, we have discovered several high relief, deepwater reef sites off Florida that appear only as small irregularities in the isobaths of the best currently available NOAA bathymetric charts. One example lies off Cape Canaveral, where NOAA bathymetry based on 10 m contour lines shows only a slight curvature of the bathymetric contour lines (inset of Figure 6A), whereas high–resolution AUV multibeam of the same feature (Figure 6B) revealed 5 individual mounds with up to 60 m relief and extending over 1 km. Ground–truthing the AUV maps with the *JSL* submersible revealed magnificent, pristine *Lophelia* coral reefs, with thickets of living coral up to 3 m tall covering the peaks and slopes (Figures 6C, D). Although these reefs do not lie within ACFAs, they point to the possibility that this important habitat type is likely in these designated areas.

We used these ArcGIS data plus more recent multibeam sonar surveys to draw additional polygons within the ACFAs, where there is evidence of high–relief features that indicate probable DSCE habitat. Figure 7 shows all the ACFAs in relation to the CHAPCs. The black polygons (numbered HB Sites 1–8) are areas containing high–relief bathymetry and therefore probable DSCE habitat.

From Cape Canaveral to West Palm Beach, the ACFAs within the CHAPC include the "Northern" and "A" ACFAs. In 4 regions, designated as HB Sites 1, 2, 3, and 4 (black polygons, Figure 7), these ACFAs abut fragile deepwater *Lophelia* coral reefs along their eastern borders (e.g., see HB Site 3 in Figure 8). The bathymetric features in 3 other areas, designated as HB Sites 5–7, are similar in shape and contour to known *Lophelia* coral reef sites ground–truthed elsewhere in this region (e.g., Figure 6). For example, HB Site 7 appears to have several high–

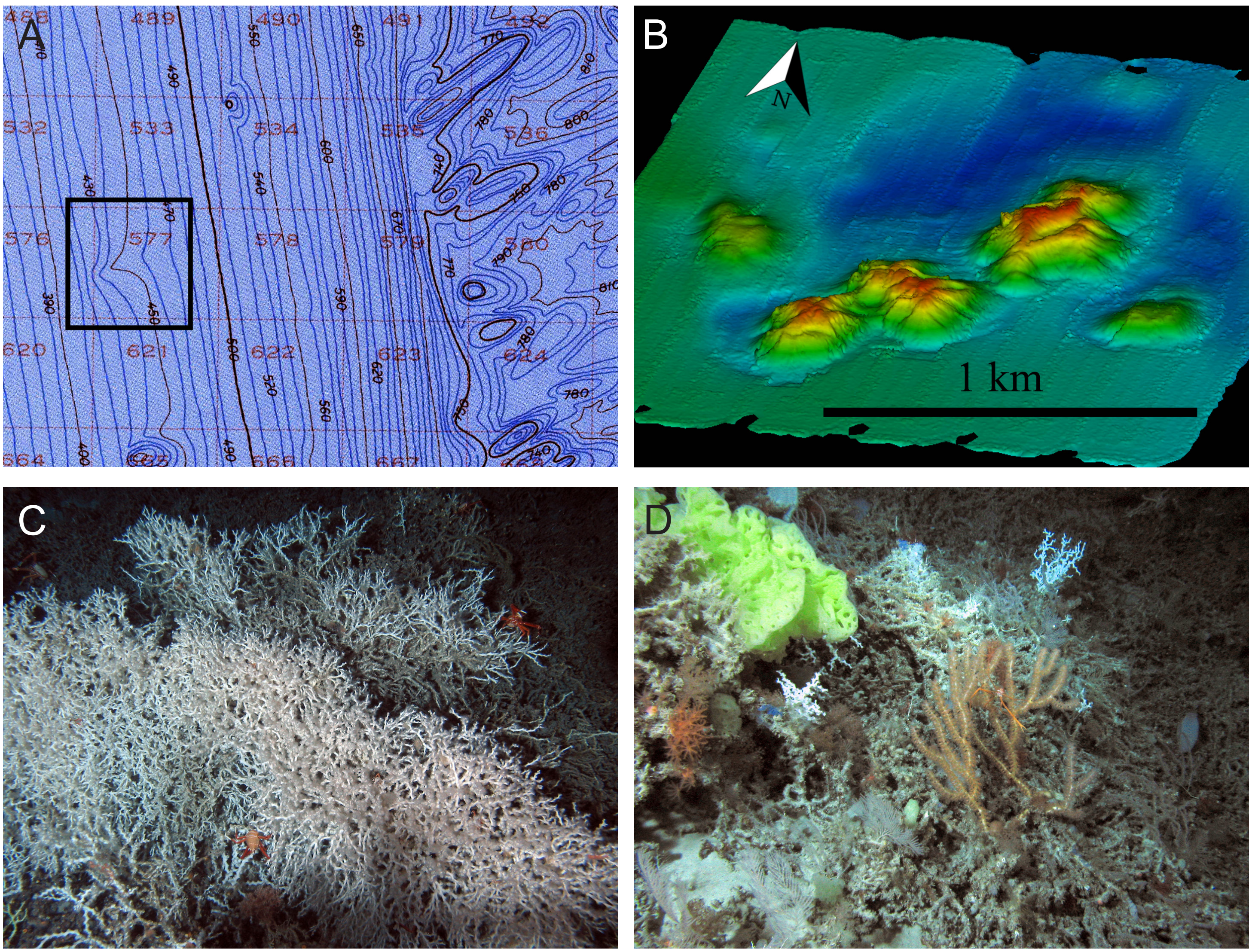

FIGURE 6. *Bathymetry and images of deepwater* Lophelia *coral mounds within the deepwater Coral Habitat Areas of Particular Concern (CHAPC) off Cape Canaveral, Florida. A. 10 m contour lines from NOAA regional bathymetric chart (Pillsbury NH 17-12), box inset region surveyed in panel B. B. AUV multibeam sonar of same area as inset of panel A, showing five 60 m tall mounds spanning distance of 1 km (from Reed and Sherrell 2009). C. Image from* Johnson Sea Link *submersible showing* Lophelia *coral thickets within CHAPC. D. Image from* Johnson Sea Link *submersible showing* Lophelia *coral thickets with crabs, sponges, octocorals, and fish within CHAPC (images courtesy of S. Brooke, FSU, 2005 NOAA-OE cruise).*

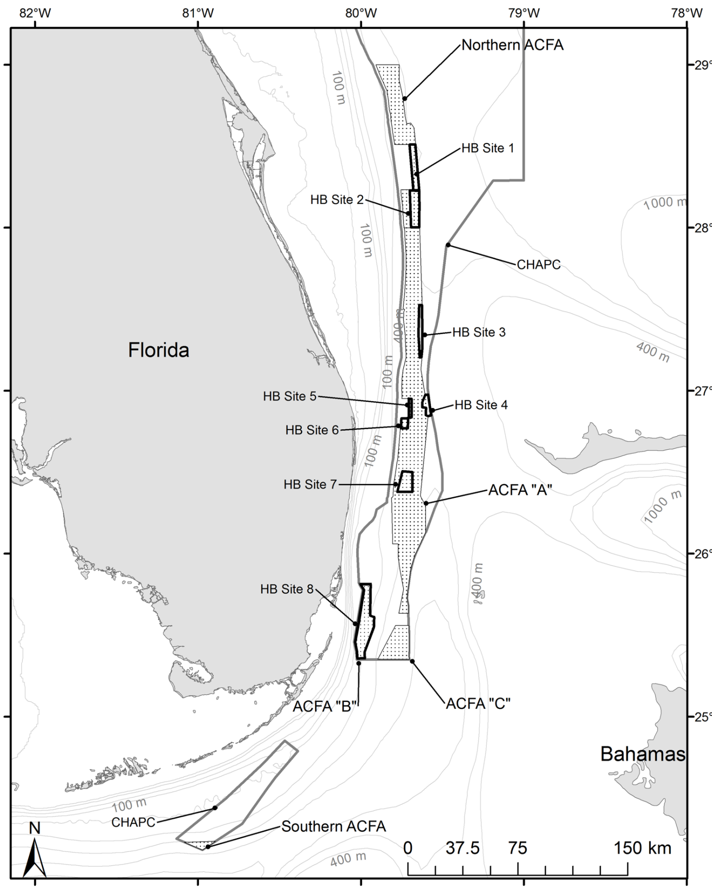

FIGURE 7. *Boundaries of deepwater Coral Habitat Areas of Particular Concern (CHAPCs; gray bordered polygons), and Allowable Crab Fishing Areas (ACFAs) for golden crab, Chaceon fenneri (stippled polygons). Black bordered polygons = probable deep–sea coral ecosystem habitat (HB Sites 1-8) within the ACFAs (refer to Figures 8-10 for details of these sites).*

relief features within ACFA "A" (Figure 9). The NOAA Digital Elevated Model (DEM; Figure 9B) confirms the high relief bathymetry apparent in Figure 9A, and is further confirmed by the more recent multibeam sonar image of Figure 9C.

The Allowable Crab Fishing Area "B" lies along the southwestern Miami Terrace (Figure 10). The NOAA DEM chart (Figure 10A) clearly shows high—relief bathymetry within this area. In one portion (Figure 10, red polygon inset), the NOAA Regional Bathymetric Bahamas Chart shows a high—relief mound, which has been confirmed by high—resolution multibeam (1—5 m) from an AUV survey (Figure 10C; top of mound 345 m, base 375 m, sinkholes in 382—480 m; Grasmueck et al. 2006). This was further confirmed by recent NOAA multibeam surveys (Figure 10 D, NOAA 2014). Several submersible dives adjacent to this area also documented high—relief, hard—bottom, rocky escarpment on the Terrace.

Discussion

We observed golden crabs over most of the deepwater regions off eastern Florida from Cape Canaveral to the Dry Tortugas. For unknown reasons, we observed none during our dives off northern Florida between 29 and 31°N latitude, even though the species occurs north to the Carolinas. We also documented their distribution within all of the ACFAs, except for ACFA "C" and the Southern ACFA where we had no dives, as well as in some areas outside of the ACFAs. Bottom temperatures recorded during submersible dives found the crabs over a temperature range of 5.6 to 16.7°C, similar to values noted off South Carolina (7°C; Wenner et al. 1987) and Georgia (15°C; Wenner and Barrans 1990). Also, golden crabs documented in our study ranged from depths of 247—888 m, with a peak in frequency of occurrence between 400 and 500 m. Previous trawl surveys in the Straits of Florida found golden crabs ranging from depths of 322—477 m (Soto 1985). These depths fall within the range reported for the species from 183 m off south Florida (Boone, 1938 in Manning and Holthuis 1984) to 1,462 m off Bermuda (Wenner and Barans 1990). Most fisheries records in the SE U.S occur between 350 and 500 m (Manning and Holthuis 1984).

The golden crab EFH (NOAA, 2010) includes soft—bottom habitat (flat foraminiferan ooze, rippled sediment, black pebble bottom, and soft bioturbated substrates) and hard—

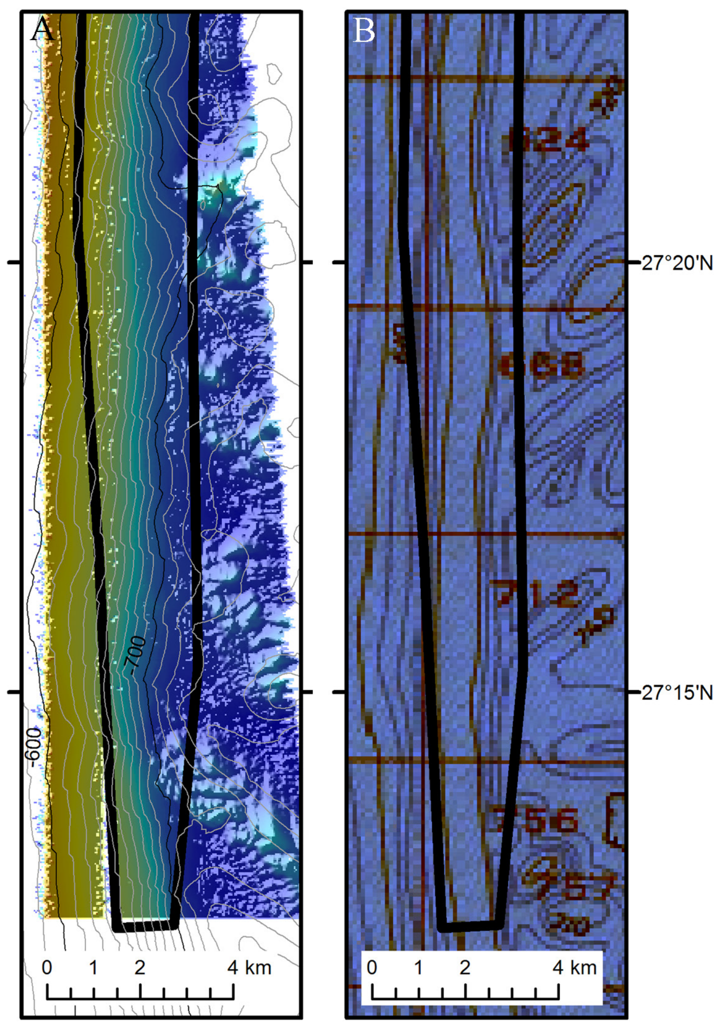

FIGURE 8. *HB Site 3 (black bordered polygon) within the Allowable Crab Fishing Area "A" showing high-relief topography along the eastern edge that indicates probable DSCE habitat. (See Figure 7 for location). A. Multibeam sonar map from EX1403 and NF-07-09-GRNMS (resolution = 35 m; NOAA 2004). B. NOAA Regional Bathymetric Chart- NG 17-3.*

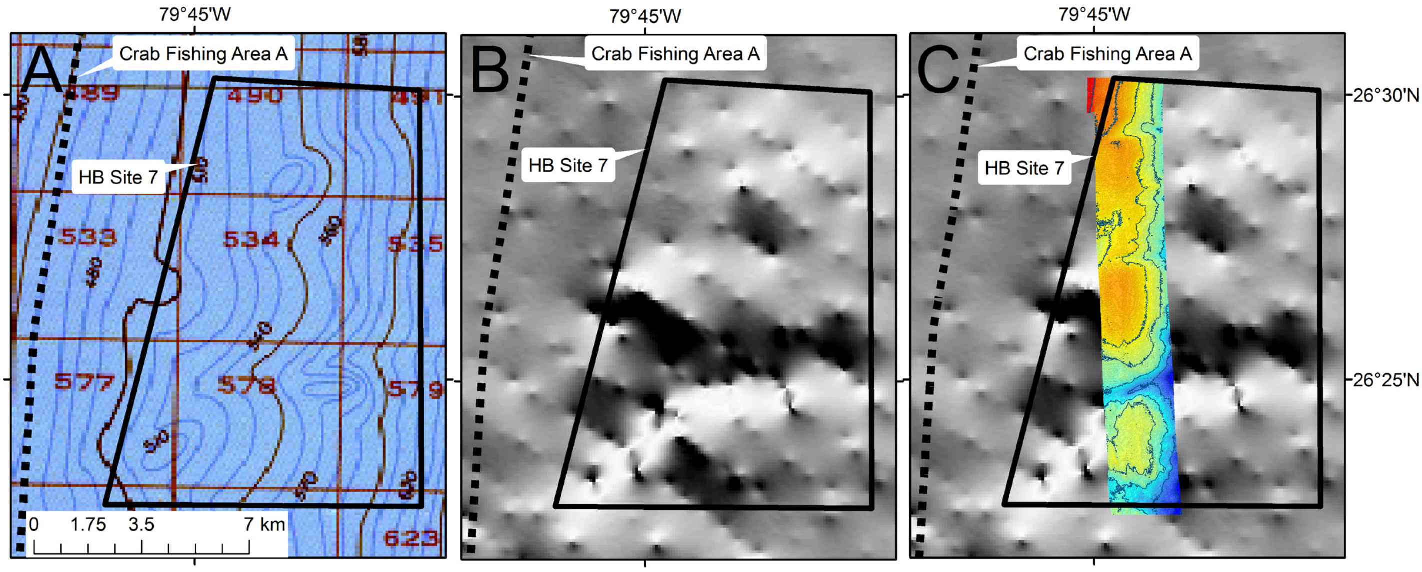

FIGURE 9. *HB Site 7 (black bordered polygon) within the Allowable Crab Fishing Area "A" (western boundary indicated by black dotted line) showing high relief topography that indicates probable DSCE habitat. (See Figure 7 for location). A. Bathymetry from NOAA Bahamas NG 17-6 chart. B. Bathymetry from NOAA-DEM chart. C. Multibeam sonar map from MGL1304 and NF-07-09-GRNM superimposed on map in B (10 m resolution; NOAA 2004).*

bottom habitat (dead coral mounds, and low rock outcrops). Visual counts conducted via submersible off the Carolinas recorded higher densities of golden crabs on low–relief rock outcrops than on other substrates (Wenner and Barans 1990, Wenner 1990). However, in exploratory trapping off South Carolina and Georgia, Wenner et al. (1987) found the highest numbers on soft–bottom habitat and none on rock and coral rubble. They suggested that if golden crab preferentially inhabited soft bottom then their zone of maximum abundance would be limited in the South Atlantic Bight. In trawl surveys in the Straits of Florida, Soto (1985) also reported that golden crab occurred primarily on mud bottom but was not restrictive in its substrate requirements and also occurred on Pourtalès Terrace. In contrast, Lindberg and Lockhart (1993) observed golden crab in the Gulf of Mexico on both hard and soft bottom habitats; however, the largest trap catches were on hard bottom (i.e., cobble, vertical rock walls and rock outcroppings). It appears that golden crab distribution may be more related to substrate type than to depth. Unlike red crabs (*Chaceon quinquedens* [Smith, 1879]), golden crabs do not bury in soft sediment and appear to prefer to take refuge against ledges, and crevices of canyon features (Lindberg and Lockhart 1993). In comparison, we found that golden crabs occurred off eastern and southern Florida on a wide variety of habitats, including dense live coral thickets, vertical rock walls, rock pavements, boulders, rock slabs, and flat mud–sand bottoms.

The mean density of golden crabs for all our dives was 0.296 ± 0.209 crabs/1000 m^2, and the mean density was greater on SB than on HB habitat. These densities are comparable to areas off South Carolina (0.1–0.7 crabs /1000 m^2; Wenner and Barans 1990). They also found that lower densities were ob-

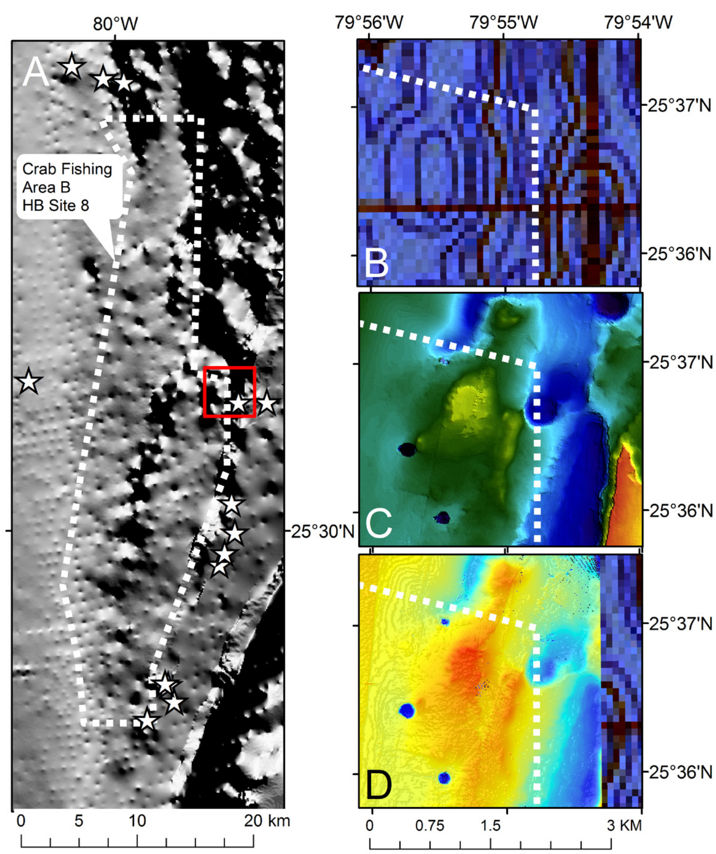

FIGURE 10. *Allowable Fishing Area "B" and HB Site 8 (white dotted polygon) showing high–relief topography that indicates probable DSCE habitat; high relief bathymetry is evident throughout this area. White stars = DSCE habitat ground-truthed by submersible dives. (See Figure 7 for location). A. Bathymetry from NOAA-DEM chart; red polygon inset enlarged in Figures 10B-D. B. Bathymetry from NOAA Regional Bathymetric Bahamas Chart. C. AUV high resolution multibeam map (5 m resolution; Grasmueck et al. 2006). D. Multibeam sonar map from AT29-03, EX1106, LCE2010, NF-07-09-GRNMS, and EW9609 (10 m resolution; NOAA 2004).*

served in their submersible studies relative to trap data which suggests that crabs are drawn to traps from a wider area than can be observed via submersible visual surveys (Wenner and Barans 1990, Kendall 1990). The antennule chemoreceptors of decapod crustaceans confer an extremely sensitive sense of smell (Ache 1982), so the crabs are likely able to detect trap bait from relatively long distances, which may generate the higher densities in trap data. It also may be possible, in part, that the crabs are avoiding the lights, sounds and electromagnetic field of the vehicles; however, we did not observe avoidance behavior until the submersible was within meters of a crab. Another consideration of visual surveys is that it may be easier to see crabs on open flat soft—bottom habitat compared to rugose hard—bottom features such as rocky escarpments and coral facies where the crabs could hide. However, our observations typically found the crabs fully exposed, standing erect or walking on the hard bottom. At least during the daytime hours of our surveys, they did not appear to be hiding or sleeping in crevices.

Golden crab CW measured from videotape screen grabs ranged from 58—190 mm with peak frequencies from 80—120 mm. The largest previously reported CW are 195 mm for males (Kendall 1990) and 147 mm for females (Manning and Holthuis 1984), with males generally larger than females. Although we could not determine the sex of the crabs, our surveys found that the smallest crabs (96 ± 3.98 mm CW) were at the shallowest depths (300—400 m), while the 400—500 m depth zone had significantly larger crabs (121 ± 5.28 mm CW). Erdman et al. (1990) suggested that golden crabs migrate up—slope for reproduction, and Lindberg and Lockhart (1993) reported that the largest members of both sexes were caught at the shallowest depths at which they appeared. However, Wenner et al. (1987) reported that mean CW and weight of females were greatest at the deeper depths sampled (733—823 m).

Potential Overlap of Allowable Golden Crab Fishing Areas and DSCE Habitat

The golden crab fishery off eastern Florida has been granted allowable fishing areas by the SAFMC within the CHAPCs, which were implemented in 2010. However, as our data has shown, some of these zones abut and overlap DSCE habitat on the East Florida *Lophelia* coral mounds, Miami Terrace, and Pourtalès Terrace. We have mapped 8 regions within the Northern ACFA, ACFA "A" and "B" where the bathymetry indicates probable DSCE habitat. Therefore, resource managers should reevaluate whether to allow golden crab fishing in these areas until further visual surveys are completed. By contrast, ACFA "C" appears to be relatively flat and presumably soft mud bottom based on available NOAA bathymetry, and our dive data in this area does not show otherwise. Therefore, no data support reevaluation of fishing regulations in this area. Also, the corridor between Area "A" and "C" has been documented to support high—relief coral habitat, even though it is not apparent from low resolution bathymetry.

The "Southern" ACFA is a small triangular tip of the CHAPC off Pourtalès Terrace that lies in an area containing numerous deepwater sinkholes and high—relief mounds with exposed hard bottom (Reed et al. 2005, 2013, 2014). Although we have no multibeam maps or *in situ* observations inside this ACFA, submersible dives immediately to the north revealed high relief, coral habitat. This is also an area where numerous golden crab traps are known to have been lost or discarded; it is estimated that several hundred traps plus >22,000 kg of associated debris and tens of nautical miles of associated rope occur here (J. Karazsia, pers. comm., NOAA Fisheries). A proposal to allow fishers to use grappling hooks to recover the traps and gear was denied given that the project could impact DSCE habitat. For example, if the grappling hook caught the crab trap long—line, the string of attached traps could be dragged over hard—bottom habitat, sweeping it largely clean of attached organisms including corals and sponges. Also, the fact that the gear was lost may indicate it had snagged on some type of hard—bottom such as low—relief ledges or outcrops, which do not appear on fathometers at such depths.

Golden crabs are fished using long lines of traps that are deployed over several km. Due to the velocity of the Florida Current/Gulf Stream (1—2 m/sec) and the depths fished (200—800 m), the gear certainly drifts before reaching the seafloor (Erdman and Blake 1988, SAFMC 2011), so it is uncertain where the traps end up on the bottom. In addition, the gear is retrieved with a grappling hook which is also likely to drag the gear across the bottom, and which could cause impact if fished in DSCE habitat. Therefore, we suggest that a wide corridor should exist between known DSCE habitat and the allowable fishing areas.

In addition, we have observed low to moderate relief (< 1—5 m) DSCE habitats that are not visible on a fathometer or in low—resolution multibeam sonar. Unfortunately, detailed bathymetric and habitat maps for these deepwater regions are inadequate, and very few areas of the South Atlantic Bight and Straits of Florida have been mapped with the high resolution (1—5 m) multibeam sonar required to identify low to moderate relief DSCE. Without adequate maps, the potential exists for impacts to DSCEs (SAFMC 2009).

Summary and Conclusions

Using visual data from previous submersible and ROV dives, we document for the first time the distribution and habitat use of golden crabs in U.S. waters off eastern and southern Florida. Golden crabs were associated with the following DSCEs: East Florida *Lophelia/Enallopsammia* coral mounds, Miami Terrace, Pourtalès Terrace, and Tortugas Valleys. They also were common on the soft mud bottom in the Straits of Florida between West Palm Beach and Miami. Golden crabs in this region occur on a wide variety of habitat types, including dense live coral thickets, vertical rock escarpments, rock pavements, boulders, rock slabs, and flat mud—sand bottoms. However the distribution of the crabs was significantly greater on SB than on HB habitat.

By analyzing previous submersible, ROV, and bathymetric surveys in the region, we also provide data indicating overlap of allowable crab fishing areas and DSCEs in some areas. The greatest concern for any bottom fishery in this region is potential impact to DSCEs. Impact from bottom—tending gear, such as crab traps, longlines, deep—drop weights, and shrimp bottom trawls, could damage sessile, habitat—forming species such as hard corals, octocorals, black corals, and sponges. The devastating impact of shrimp trawling on Florida's deepwater *Oculina* coral reefs, which form mounds similar to the *Lophelia* coral reefs (Reed 2002), is well documented (Koenig et al. 2005, George et al. 2007, Reed et al. 2007). Unprotected *Oculina* coral reefs lost nearly 100% of their live coral, whereas some reefs within the boundaries of the original *Oculina* Habitat Area of Particular Concern (created in 1984) survived and were not affected by trawling. The potential for impact of bottom—tending gear on DSCE habitat, such as deepwater *Oculina* and *Lophelia* coral reefs, is sufficiently high that the SAFMC requires some fisheries, such as deepwater shrimp trawls, to use vessel monitoring systems to track the vessels. Currently, the penalties for illegal trawling are relatively light (i.e., confiscated catch and moderate fines). Elsewhere, such as in the Florida Keys National Marine Sanctuary, those guilty of destroying coral habitat—for whatever reason—are subject to fines substantial enough (up to $250,000 per occurrence) to cover the costs of habitat restoration or mitigation (Koenig et al. 2005). However, the great depth and inaccessibility of Florida's deepwater reefs rule out any consideration of restoration or direct mitigation. These slow growing, deepwater reefs, once destroyed, may require centuries to recover (if ever); thus implementation of preventative regulations and enforcement is even more critical than for shallow reefs.

It is imperative that high—resolution seafloor habitat maps be developed prior to opening areas for bottom—tending gear. Within the Florida CHAPCs, areas open for golden crab fishing cover 4,981 km^2 (11% of the total protected area). As we have shown, some of this area supports coral/sponge habitat and should be removed from the ACFAs. In addition, Reed et al. (2013) estimated that nearly 30% (6,554 km^2) of the DSCE habitat that occurs in U.S. waters off Florida remains unprotected and outside the boundaries of the CHAPCs. These areas are currently open to all types of bottom gear including bottom trawling. The recent multibeam sonar surveys in this region are mostly relatively low resolution (>10—50 m) and are insufficient to reveal DSCEs. Management and conservation plans for deep—sea coral reef ecosystems in the U.S. must be flexible enough to protect newly discovered DSCE habitat as new technology enables discovery of unprotected sites. In fact, the SAFMC recently revised the deep CHAPC boundary when a *Lophelia* reef was discovered in much shallower water of 200 m off Jacksonville. The results reported here will enable fishers to focus on golden crab populations while avoiding critical DSCE habitat, as well as provide data that will allow SAFMC to revise or modify ACFA boundaries in areas that abut or overlap DSCEs. High—resolution surveys are critical for defining both DSCEs and areas devoid of these fragile habitats that potentially may be suitable for future bottom fisheries and energy development.

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Literature Cited

Ache, B.W. 1982. Chemoreception and thermoreception. In: H.L. Atwood and D.C. Sandeman, eds. The Biology of Crustacea. Academic Press, New York, NY, USA, p. 369—398. https://doi.org/10.1016/B978—0—12—106403—7.50017—3.

Correa, T.B.S., G.P. Eberli, M. Grasmueck, J.K. Reed, and A.M.S. Correa. 2012. Genesis and morphology of cold—water coral ridges in a unidirectional current regime. Marine Geology 326:14—27. http://doi.org/10.1016/j.margeo.2012.06.008.

Erdman, R., N. Blake, H. Perry, R. Waller, W. Lindberg and F. Lockhart. 1990. Annual reproduction in deep—sea brachyuran crabs (*Chaceon* spp.) from the southeastern United States. In: W.J. Lindberg and E.L. Wenner, eds. Geryonid crabs and associated continental slope fauna. NOAA National Undersea Research Center, University of North Carolina, Wilmington, NC, USA, p. 14—15.

Erdman, R.B. and N.J. Blake. 1988. The golden crab (*Geryon fenneri*) fishery of southeast Florida. Proceedings, The 12th Annual Tropical and Subtropical Fisheries Technological Conference of the Americas. Orlando, FL, USA, 9—11 November 1987, p. 95—106.

Fiechter, J. and C.N.K. Mooers. 2003. Simulation of frontal eddies on the East Florida Shelf. Geophysical Research Letters 30:1—4. http://doi.org/10.1029/2003gl018307.

George, R.Y., T.A. Okey, J.K. Reed, and R.P. Stone. 2007. Ecosystem—based fisheries management of seamount and deep—sea coral reefs in US waters: conceptual models for proactive decisions. Bulletin of Marine Science 81:9—30.

Grasmueck, M., G.P. Eberli, D.A. Viggiano, T. Correa, G. Rathwell, and J.G. Luo. 2006. Autonomous underwater vehicle (AUV) mapping reveals coral mound distribution, morphology, and oceanography in deepwater of the Straits of Florida. Geophysical Research Letters 33:L23616. http://doi.org/10.1029/2006gl027734.

Harter, S., J. Reed, S. Farrington, and A. David. 2015. South Atlantic MPAs and deepwater coral HAPCs: Characterization of fish communities, benthic habitat, and benthic macrobiota. Final Report. HBOI Technical Report Number 160. Harbor Branch Oceanographic Institute, Florida Atlantic University, Ft. Pierce, FL, USA. 75 p.

Kendall, D. 1990. An assessment of the Georgia golden crab fishery. In: W.J. Lindberg and E.L. Wenner, eds. Geryonid crabs and associated continental slope fauna: A research workshop report. SC Sea Grant Consortium and FL Sea Grant College Program, Gainesville, FL USA, p. 18—19.

Koenig, C., A. Shepard, J. Reed, F. Coleman, S. Brooke, J. Brusher and K. Scanlon. 2005. Habitat and fish populations in the deep—sea *Oculina* coral ecosystem of the western Atlantic. In: P.W. Barnes and J.P. Thomas, eds. American Fisheries Society Symposium 41:795—805.

Lindberg, W.J. and F.D. Lockhart. 1993. Depth—stratified population—structure of Geryonid crabs in the eastern Gulf of Mexico. Journal of Crustacean Biology 13:713—722. http://doi.org/10.2307/1549102.

Lumsden, S.E., T. Hourigan, A. Bruckner, G. Dorr (eds.) 2007. The state of deep coral ecosystems of the United States. NOAA Technical Memorandum CRCP—3. National Oceanic and Atmospheric Administration, Silver Spring MD, USA. 60 p.

Manning, R.B. and L.B. Holthuis. 1984. *Geryon fenneri*, a new deep—water crab from Florida (Crustacea, Decapoda, Geryonidae). Proceedings of the Biological Society of Washington 97:666—673.

Messing, C.G., J. Reed, B. Walker, and R. Dodge. 2006a. Calypso U.S. pipeline LLC, Mile Post (MP) 31–MP 0. Deepwater marine benthic video survey. Final Report. Calypso U.S. Pipeline, LLC, Houston, TX, USA. 64 p.

Messing, C.G., J. Reed, S. Brooke, B. Walker, and R. Dodge. 2006b. Calypso LNG deepwater port project, Florida marine benthic video survey. Final Report. Ecology and Environment, Inc. and Suez Inc., Pompano Beach, FL, USA. 60 p.

NOAA (National Oceanic and Atmospheric Adminiatration). 2001. National Geophysical Data Center, NESDIS, NOAA, U.S. Department of Commerce. Scanned NOS Bathymetric Maps. (Data CD: bathymetry). https://www.ngdc.noaa.gov/mgg/fliers/olmggol.html (viewed on 04/10/2017).

NOAA (National Oceanic and Atmospheric Adminiatration). 2004. NOAA National Centers for Environmental Information. Multibeam Bathymetry Database (MBBDB), [Multiple Cruises, AutoGrid]. (multibeam). http://doi.org/10.7289/V56T0JNC (viewed on 02/23/2015).

NOAA (National Oceanic and Atmospheric Adminiatration). 2010. Fisheries of the Caribbean, Gulf of Mexico, and South Atlantic; comprehensive ecosystem—based amendment for the South Atlantic region. Department of Commerce, 50 CFR, Part 633. Federal Register: 75(119):35330-35335.

NOAA (National Oceanic and Atmospheric Adminiatration). 2014. NOAA National Centers for Environmental Information; Multibeam Bathymetry Database (MBBDB), [EX1403]. NOAA National Centers for Environmental Information. (multibeam). http://doi.org/10.7289/V56T0JNC. (viewed on 02/23/2015).

Opderbecke, J. 1997. At—sea calibration of a USBL underwater vehicle positioning system. Proceedings, 1997 IEEE International Conference on Robotics and Automation. Halifax, NS, Canada. 6—9 October 1997. p. 721—726. http:/doi.org/10.1109/OCEANS.1997.634455

Reed, J.K. 2002. Comparison of deep—water coral reefs and lithoherms off southeastern USA. Hydrobiologia 471:57—69. http://doi.org/10.1023/A:1016593018389.

Reed, J.K. 2004. General description of deep—water coral reefs of Florida, Georgia and South Carolina: A summary of current knowledge of the distribution, habitat, and associated fauna. National Oceanic and Atmospheric Administration, National Marine Fisheries Service, South Atlantic Fishery Management Council. Charleston, SC, USA. 71 p.

Reed, J.K. 2006. Results of the deep—water submersible survey of the proposed Seafarer natural gas pipeline route from Mile Post 0 (U.S.—Bahamas EEZ) to Mile Post 12. Characterization of benthic habitat and biota with documentation of hard/live bottom habitat. February 28 – March 7, 2006, R/V *Seward Johnson*, *Johnson–Sea–Link* I Manned Submersible. Final Report, ENSR Corporation for Seafarer Inc., Westford, MA, USA. 257 p.

Reed, J.K. 2011. NOAA National Centers for Environmental Information; Multibeam Bathymetry Database (MBBDB), [NF—11—09—CIOERT]. (multibeam). http://doi.org/10.7289/V56T0JNC. (viewed on 02/23/2015).

Reed, J.K. and A. Sherrell. 2009. Analysis of AUV sonar data from deepwater *Lophelia* coral reef habitats off Eastern Florida. Final Report. National Oceanic and Atmospheric Administration National Marine Fisheries Service, Coral Reef Conservation Program (CRCP). Silver Spring, MD, USA. 17 p.

Reed, J.K., D.C. Weaver, and S.A. Pomponi. 2006. Habitat and fauna of deep—water *Lophelia pertusa* coral reefs off the southeastern US: Blake Plateau, Straits of Florida, and Gulf of Mexico. Bulletin of Marine Science 78:343—375.

Reed, J.K., C.C. Koenig, and A.N. Shepard. 2007. Impacts of bottom trawling on a deep—water *Oculina* coral ecosystem off Florida. Bulletin of Marine Science 81:481—496.

Reed, J.K., L. Duncan, and B. Furman. 2008. Results of the deep—water benthic video survey of the Colombia—Florida Express 1 (CFX—1 BC—1) Telecom Cable Route. Characterization of benthic habitat and biota with documentation of hard/live bottom habitat along the CFX 1 cable route within U.S. Federal waters from the Florida State 3—nm boundary to the U.S.—Bahamas EEZ boundary off eastern Florida. Final Report. Harbor Branch Oceanographic Insitute, Fort Pierce, FL, USA. 102 p.

Reed, J.K., S. Harter, S. Farrington, and A. David. 2014. Characterization and interrelationships of deepwater coral/sponge habitats and fish communities off Florida, USA. In: S.A. Bortone, ed. Coral Habitat and Fish Interrelationships, CRC Press, Boca Raton, Fl, USA, p 49—80.

Reed, J.K., S.A. Pomponi, D. Weaver, C.K. Paull, and A.E. Wright. 2005. Deep—water sinkholes and bioherms of south Florida and the Pourtalès Terrace — habitat and fauna. Bulletin of Marine Science 77:267—296.

Reed, J.K., C. Messing, B.K. Walker, S. Brooke, T.B.S. Correa, M. Brouwer, T. Udouj, and S. Farrington. 2013. Habitat characterization, distribution, and areal extent of deep—sea coral ecosystems off Florida, Southeastern U.S.A. Caribbean Journal of Science 47:13—30. https://doi.org/10.18475/cjos.v47i1.a3.

SAFMC (South Atlantic Fisheries Management Council). 2009. Amendment 5 to the golden crab fishery management plan of the South Atlantic region. South Atlantic Fisheries Management Council, North Charleston, SC, USA. 80 p.

SAFMC (South Atlantic Fisheries Management Council). 2011. Comprehensive annual catch limit (ACL) amdedment for the South Atlantic region; Amendment 5 to the fishery management plan for the golden crab fishery of the South Atlantic region. South Atlantic Fisheries Management Council, North Charleston, SC, USA. 775 p.

Soto, L.A. 1985. Distributional patterns of deep—water brachyuran crabs in the Straits of Florida. Journal of Crustacean Biology 5:480—499. https://doi.org/10.2307/1547920.

Vinick C., A. Riccobono, C.G. Messing, B.K. Walker, J.K. Reed, and S. Farrington. 2012. Siting study for a hydrokinetic energy project located offshore southeastern Florida: Protocols for survey methodology for offshore marine hydrokinetic energy projects, U. S. Department of Energy, Golden, CO, USA. 93 pp. https://doi.org/10.2172/1035555.

Wenner, E. 1990. Distribution and abundance of golden crab, *Chaceon fenneri*, in the South Atlantic Bight. Proceedings, Geryonid crabs and associated continental slope fauna: A research workshop report. South Carolina Sea Grant Consortium, Florida Sea Grant College Program Technical Paper. Gainesville, FL, USA. 19—20 January 1989. p. 6—7.

Wenner, E. and C. Barans. 1990. *In situ* estimates of density of golden crab, *Chaceon fenneri*, from habitats on the continental slope, southeastern US. Bulletin of Marine Science 46:723—734.

Wenner, E.L., G.F. Ulrich, and J.B. Wise. 1987. Exploration for golden crab, *Geryon fenneri*, in the South Atlantic Bight: Distribution, population structure, and gear assessment. Fishery Bulletin 85:547—560.