MAPPING AND CHARACTERIZATION OF HABITATS ON THE CONTINENTAL SLOPE OFF THE SOUTHEASTERN UNITED STATES: CONTINUING AND EXPANDING THE SEADESC INITIATIVE

Final Report to the South Atlantic Fishery Management Council

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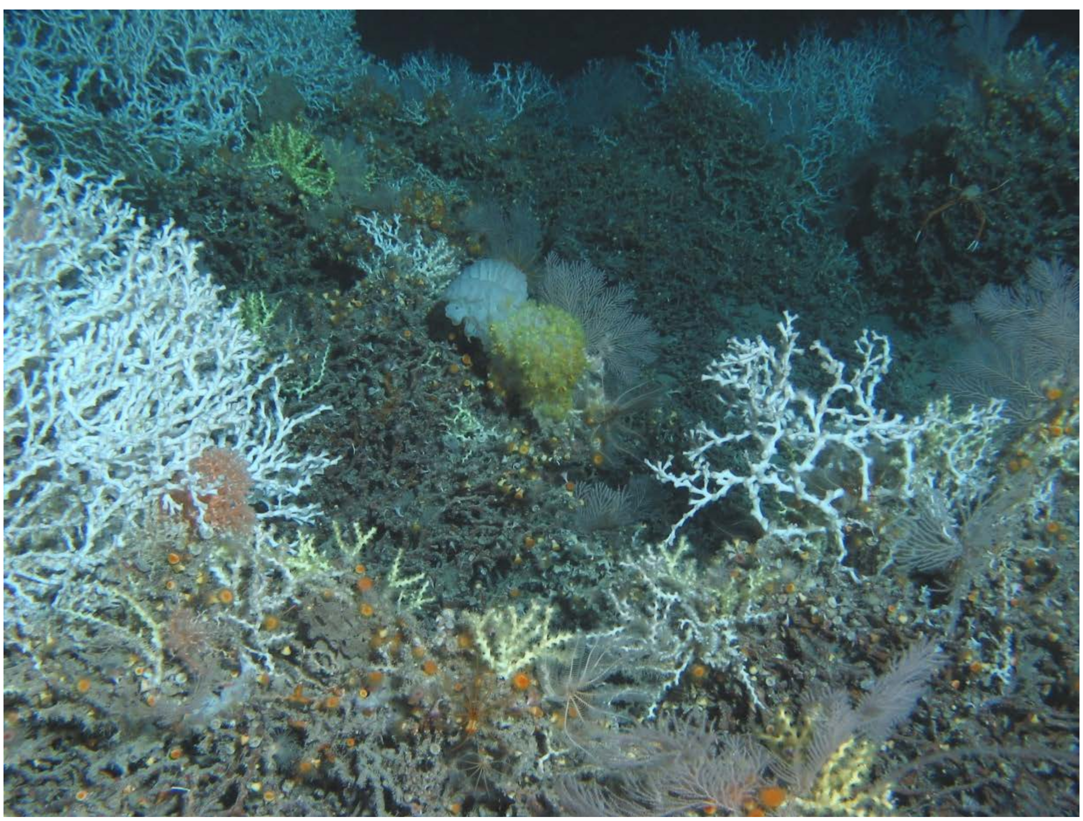

30 March 2012

PROJECT BACKGROUND

The Blake Plateau and surroundings off the southeastern US (SEUS) are rich in habitat diversity and biodiversity, including deep-sea corals (DSC). DSC habitats are abundant off the SEUS, perhaps more so than anywhere else in US waters, and have been under-appreciated for their roles in slope ecology. Hard substrata, potential bases for DSC, are abundant in the area, and gas hydrates and cold seeps also occur here. This combination of SEUS deep-sea habitat and faunal diversity, still poorly understood, provides the context for the habitat characterization project known as SEADESC. This project addressed NOAA and regional priorities of providing detailed habitat maps and characterizations of deep-water ecosystems and providing maps to facilitate exploration and research of important shelf and slope areas. In addition, this project supported the South Atlantic Fishery Management Council's (SAFMC) management objectives for deep water habitats by addressing priorities in the Council's Coral Fishery Management Plans (FMP), *Oculina* Experimental Closed Area Evaluation Plan, and the Deepwater Coral Research and Monitoring Plan (see http://www.safmc.net/), all of which identify habitat mapping and characterization as highly important. Results from SEADESC will improve the ability to define boundaries for recently established deep-reef Habitat Areas of Particular Concern.

Better habitat definition and description are essential components for developing state and federal FMPs, implementing the Essential Fish Habitat (EFH) initiative, and facilitating the habitat protection goals of state and federal programs. Our understanding of deep-sea habitat function is still incomplete, and central to this problem is the general lack of detailed, accurate habitat maps. Without better knowledge of habitat distribution and its temporal and spatial variability, it is difficult to assess habitat function or the status and trends in habitat quality and productivity. Assessment of habitat heterogeneity and extent, a major thrust of this project, is critical for evaluating an area's contributions to productivity, species conservation and population dynamics.

Fisheries and hydrocarbon exploitation are expanding rapidly into deeper frontier areas (> 200 m). But, information concerning continental slope habitats is either lacking or is very general (with a few isolated exceptions). One of the main reasons for this discrepancy has been a lack of affordable and/or readily available technology that could be applied to deeper waters. That situation is changing, and this project will capitalize on the availability of multibeam sonar mapping and visual observations to compile detailed structural data on important deep water habitats off the SEUS. Existing historical deep-sea data have also not been used to full effect to characterize habitats, and this project will acquire, evaluate and use such data. Combining available submersible and ROV habitat data with multibeam sonar will allow detailed mapping of large areas and needed ground truthing of the sonar data.

There has been significant progress in basic characterization of complex deep-sea ecosystems off the SEUS. Most of this research was focused on DSC and hardground habitats on the Blake Plateau and adjacent areas (e.g., see reviews in Ross and Nizinski 2007; Ross 2007). Even though previous investigations provided new habitat and biological data, for logistical and scientific reasons these studies usually repeatedly surveyed the same areas (Ross 2007). Because of the importance of DSC and their vulnerability to numerous threats (Guinotte et al. 2006; Roberts et al. 2006), the SAFMC proposed large Coral Habitat Areas of Particular Concern (CHAPC) to protect DSC in the SEUS, and these were enacted in July 2010. Boundaries for these areas were best estimates provided by J. Reed and S.W. Ross, but better data are needed for boundary definitions. This project added additional data to characterize unexplored areas, which can be incorporated by the SAFMC into current management strategies.

South East Area Deep-Sea Coral (SEADESC) project

The SEADESC initiative is a collaborative effort to characterize DSC and other hard ground shelf and slope habitats. Deep waters of the US EEZ off the SEUS were emphasized because of the concentration of recent direct observation data and the diversity of habitats. SEADESC was conceived because there are needs to better document and understand important continental slope ecosystems and to rapidly provide research data to a variety of users. See Partyka et al. (2007) for the initial objectives of SEADESC. SEADESC's primary focus is on direct observation data from which detailed georeferenced habitat data can be derived. Other data sets have been identified that would further enhance habitat interpretation in the region, but incorporation of these awaits additional funding. The SEADESC project was originally guided by an interagency committee (see Partyka et al. 2007), and the project currently is operating at Univ. of North Carolina-Wilmington (S.W. Ross laboratory). Funds provided by the SAFMC for the current effort allowed this project to continue through March 2012.

In the initial phase the SEADESC committee defined benthic habitats, video and data analysis protocols were developed, and the database was developed. The first data treatment task of the project involved obtaining and organizing selected data from ten NOAA Ocean Exploration cruises (2000-2004) and twelve *Oculina* Bank submersible dives. While the completed dive and site summaries (Partyka et al. 2007) are useful, they do not represent the end point for this effort. This project has the potential to be an evolving program to which data can be added (e.g., new dives, bathymetry) and for which protocols can continue to improve. Improving SEADESC protocols and adding new data to the SEADESC archive were major goals of the current project.

Partyka et al. (2007) made six recommendations for future work to continue the SEADESC effort. Addressing all six would require more resources than currently available. Therefore, the following SEADESC recommendations were addressed in this project: 2) Refine protocols: Analysis methods can be made more user friendly or automated. Additional software should be evaluated. Habitat definitions should be evaluated regularly by appropriate experts and adjusted as needed. 3) Add other data to SEADESC: A variety of high quality data are available to add to this project. Such additions would greatly expand the temporal and spatial coverage for the project as well as increase its utility. 6) Develop Web display of SEADESC.

PROJECT OBJECTIVES

1. Continue SEADESC project by addressing selected recommendations (see above).
2. Support the ongoing multibeam mapping of deep coral/reef habitats on the slope off the SEUS.
3. Explore depth and geographic boundaries of deep coral habitat, characterize previously uncharted habitats on the Blake Plateau.
4. Develop and test internet products related to deep water habitat mapping in the region, including displays of SEADESC results.

METHODS

Direct Observation Data and SEADESC logs

In general, these methods followed those described in Partyka et al. (2007) and were modified as needed. After acquiring raw submersible or ROV tracking data, video, and associated metadata, analysis involved a three step process of: 1) processing vehicle tracking data to produce an accurate, benthic track map of the vehicle's route along the bottom, 2) analyzing video data to classify benthic habitats along the vehicle's track, and 3) completing the two page SEADESC log per dive.

The original SEADESC process for producing accurate track maps (Partyka et al. 2007) was modified somewhat. ADELIE (v.1.8, IFREMER) software was purchased, tested with SEADESC data, and then used during video and track analysis as described below.

Raw (uncorrected) dive tracks were cleaned using a filter developed in MatLab, which considers direction and speed of the moving vehicle in order to remove location points that are impossible for it to achieve. The MatLab filter analyzes a dive track in Excel, with columns for "Time," "Change in Time," "Latitude," "Longitude," "Distance," and "Speed." Distance is calculated between track points from latitude and longitude. The speed is obtained from the distance and the change in time between two adjacent points. The filter scans the speed column and removes any data points that indicate the vehicle moved faster than 2.2 m sec-1. These deleted points are not considered in the analysis for the subsequent points. The analysis starts back at the beginning of the column and scans until it finds another point that exceeds the speed of 2.2 m sec-1, removes that point, and restarts. This continues until all erroneous points are removed from the dive track. After removal of outlier points, dive tracks are imported into ArcGIS and smoothed with ADELIE software using the simple moving average of every three points. This track is used while watching dive video. Video is coded as either good or bad (includes blurry video, vehicle too far from the bottom, moving too fast, or stopping to collect), and all bad video sections are removed from the dive track in ArcGIS. The above process varied somewhat from that used in Partyka et al. (2007) in being faster, more automated, and more accurate.

The same SEADESC habitat classifications as used in Partyka et al. (2007) were used for analysis of dive video in this project. Videos were examined, and two page SEADESC logs (Appendix I) were completed as described in Partyka et al. (2007), except that the ADELIE software facilitated integration of visual data with GIS. Multibeam sonar data were acquired from various sources and were used as underlying bathymetry for the dive habitat maps. Multibeam sonar coverage in this region is illustrated in Figure 1.

<u>Evaluation of Museum Records</u>

Since distributions of DSC are poorly known and detailed maps are generally lacking, many researchers have used museum records to enhance distribution maps. DSC museum data are usually acquired from online catalogues. However, lack of examination of specimens or interaction with museum personnel raises questions about the quality of the data, including the reliability of identifications, accuracy of positions, and completeness of data. Also, museum specimens are often unavailable through online sources because they are either uncatalogued or because catalogued specimens were not yet entered into electronic databases. Thus, in addition to the above listed data sources, museum data records were evaluated for four dominant DSC species (*Lophelia pertusa*, *Madrepora oculata*, *Enallopsammia profunda*, *E. rostrata*) in major US museums. This component of this project was published and it is included in Appendix II.

<u>Development of Internet Displays and Products</u>

This project to obtain detailed, accurate geomorphological data on deep reefs using multibeam technology and historical data is a cost effective approach for providing critical information to facilitate research and management. However, better presentations of data and resulting products are needed for a variety of users. All SEADESC data reside in digital data bases. A portion of the effort in this project was to be directed toward testing internet display options for SEADESC and mapping data. Unfortunately, the specialized personnel who were to work on this aspect of the project became unavailable, and we were unable to find suitable replacement. Therefore, effort that was to go into this component was redirected toward acquiring additional dive video, constructing additional SEADESC logs and constructing a photo guide to DSC associated fishes.

RESULTS

Several accomplishments were noted above and include: 1) Improvements to and automation of the dive track cleaning protocols, 2) acquisition and testing of ADELIE software and use of the software in video analysis, 3) evaluation of selected museum records and publication of that effort. An unanticipated effect of this project was that the NOAA Deep-Sea Coral Research and Technology Program (DSCRTP) met with personnel (Ross, Brooke) on this project to discuss using SEADESC or some modification of it to document dives and bottom habitat within their program. After several meetings, DSCRTP adopted SEADESC logs in the current form to document dives within the SEUS, and they are evaluating how this format will apply to other regions.

In total, 68 new dives were documented for SEADESC (Appendix I), more than doubling the number (n=66) from the original report (Partyka et al. 2007). These submersible and ROV dives ranged from North Carolina to the Florida Keys, with one dive from the West Florida slope (Gulf of Mexico) included (Fig. 2). Most of these data were from off the Florida east coast. The following sources provided dive data: 1) 2005 dives (n=19) under lead PI S.W. Ross, 2) 2005 dives (n=14) under lead PI S.D. Brooke, 3) 2007 dives (n=4) under lead PI C. Messing, 4) 2009 dives (n=22) under lead PI S.W. Ross, 5) 2010 dives (n=9) dives under co-PIs S.W. Ross and S.D. Brooke. Historical dive data and video tapes from off Jacksonville, FL were acquired from C. Paull. Most of these videos were digitized, but there was not enough time to incorporate them into this project.

As an additional and related activity, a pictorial guide to the common fishes associated with DSC in the region was compiled (Appendix III). Such guides are useful and even necessary when training inexperienced personnel to conduct SEADESC type analyses. Guides to the common corals and sponges were also started but are in draft stages, and there was insufficient time to include them as part of this project. Even the fishes guide requires some additional editing and polishing before it is ready for public distribution.

RECOMMENDATIONS

The SEADESC initiative was always intended as an ongoing, evolving program. The amount of relevant DSC data in the SEUS region is large, and it will take a number years to incorporate these data. We have made substantial contributions. The recommendations below for additional work will continue to add to an already impressive data base. Recommendations below are not prioritized and should be evaluated by the SAFMC and collaborators.

1. Develop a dynamic Web display (or at least begin a pilot internet display) of SEADESC
2. Continue adding historical and new SEADESC logs to the database
3. Publish a new revised SEADESC report (hard copy and electronic copy) (see # 8 below)
4. Evaluate museum holdings of other DSC in the region (as in Appendix II)
5. Continue improvements to SEADESC analysis methods
6. Incorporate 20 historical dives into SEADESC from C. Paull from off Jacksonville, FL
7. Incorporate various other data into SEADESC
8. Edit and improve the previous SEADESC logs from Partyka et al. (2007), incorporating new multibeam bathymetry data into the maps.
9. Complete guides to deep corals and sponges of the SEUS and improve the fishes guide (Appendix III).

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The South Atlantic Fishery Management Council provided most of the funding for this project, and their continued support of this work is appreciated. I especially thank Anna Martin and Myra Brower (both of SAFMC) for their interest in deep-sea habitats. The Friends of the NC Museum of Natural Sciences managed the grant funding, and I thank Angela Baker-James for help with grant administration. April Zilg (UNCW) and Maya Watts (OIMB) conducted the SEADESC data analysis and produced the dive logs. I thank Andrea Quattrini (Temple Univ.) for continuing to advise the project and provide help as needed. Dr. Sandra Brooke (Marine Conservation Inst.) contributed data to this project and provided valuable oversight and advise. Mike Rhode (UNCW) provided GIS support and helped produce maps. I thank Andy Shepard for initially helping to start this project and for his support throughout our deep coral work. The NOAA DSCRTP partially funded cruises in 2009 and 2010 and contributed some support to this project.

References

Guinotte, J.M., J. Orr, S. Cairns, A. Freiwald, L. Morgan and R. George. 2006. Will human-induced changes in seawater chemistry alter the distribution of deep-sea scleractinian corals? Frontiers in Ecol. Envir. 4: 141-146.

Partyka, M.L., S.W. Ross, A.M. Quattrini, G.R. Sedberry, T.W. Birdsong, J. Potter. 2007. Southeastern United States deep sea corals (SEADESC) initiative: a collaborative effort to characterize areas of habitat-forming deep-sea corals. NOAA Tech. Memo. OAR OER 1. Silver Spring, MD. 176 pp.

Roberts, J.M., A.J. Wheeler and A. Freiwald. 2006. Reefs of the Deep: the biology and geology of cold-water coral ecosystems. Science 312: 543-547.

Ross, S.W. 2007. Unique deep-water ecosystems off the southeastern United States. Oceanography 20(4): 130-139.

Ross, S.W. and M.S. Nizinski. 2007. State of Deep Coral Ecosystems in the U.S. Southeast Region: Cape Hatteras to southeastern Florida. p. 233-270, Ch 6 In: Lumsden, S.E., T.F. Hourigan, A.W. Bruckner and G. Dorr (eds.). The State of Deep Coral Ecosystems of the United States. NOAA Tech. Memo. CRCP-3. Silver Spring, MD. 365 pp.

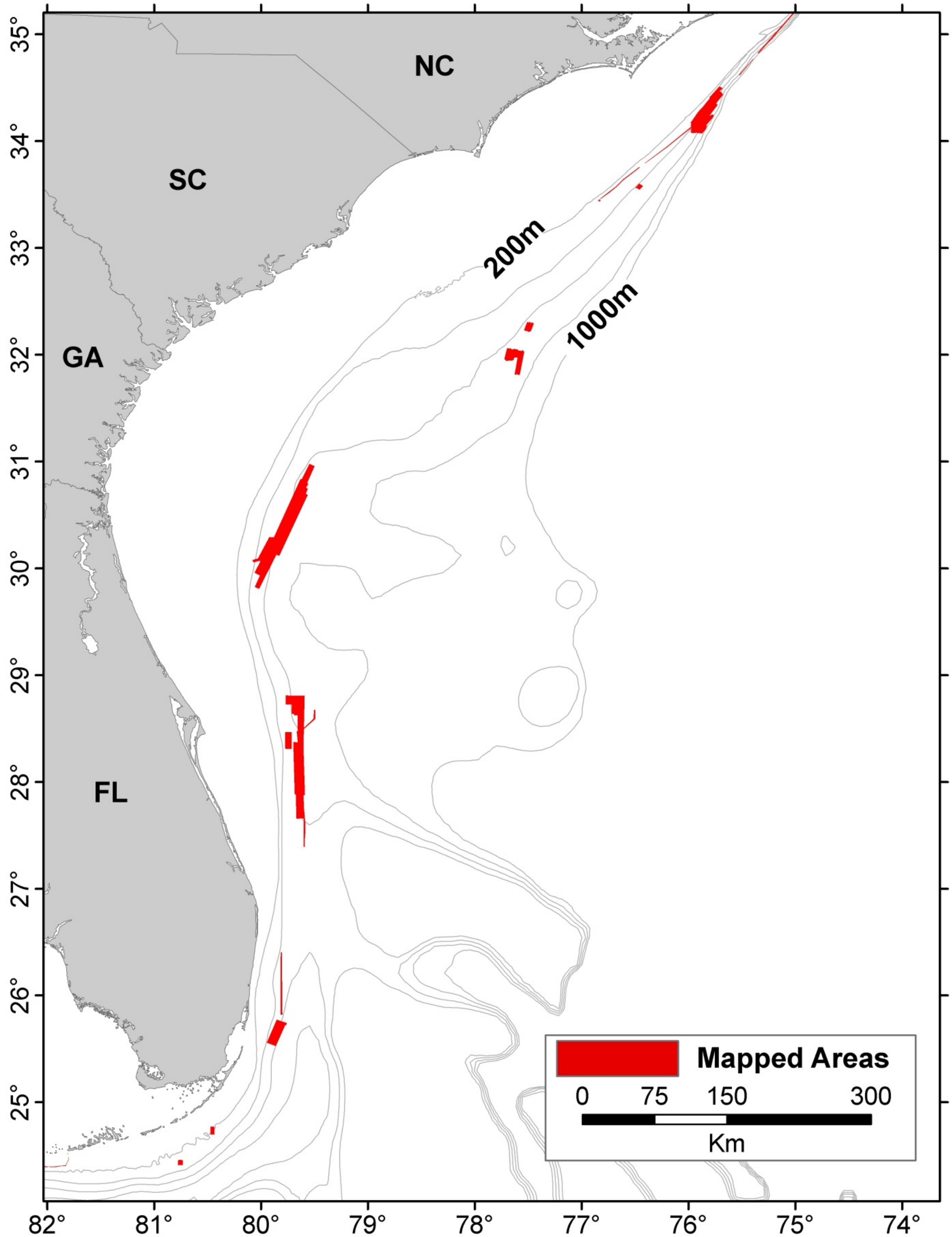

Figure 1. Areas where multibeam sonar data have been collected off the southeastern US deeper than 200 m since 2006. These data were incorporated into the habitat maps used in the SEADESC logs generated in this project. See Fig. 2 for dive sites.

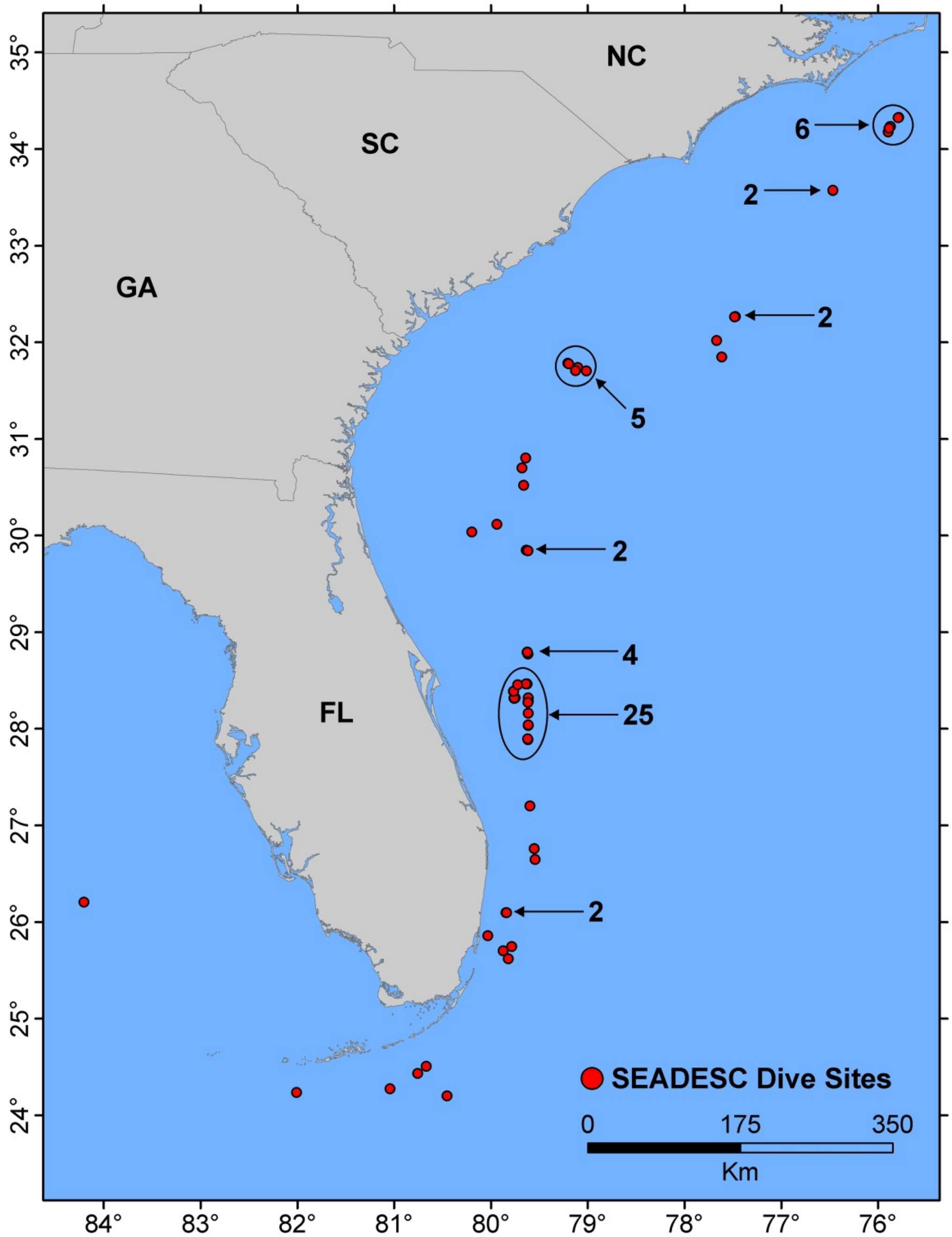

Figure 2. Southeastern US, illustrating 68 deep reef dive sites where submersible and ROV video and other data were obtained for SEADESC logs. Data were from 2005-2010, and numbers refer to the number of dives clustered in an area.

APPENDIX I

SEADESC LOGS

(see electronic files on CD)

APPENDIX II

EVALUATION OF MUSEUM DSC RECORDS PUBLICATION

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ORIGINAL ARTICLE

The utility of museum records for documenting distributions of deep-sea corals off the southeastern United States

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Abstract
Museum records can enhance distribution maps of deep-sea corals (DSC), but museum data usually acquired from online internet catalogues may be of uncertain quality. Also, many museum records are unavailable through online sources. Holdings of four structure-forming DSC species (*Lophelia pertusa*, *Madrepora oculata*, *Enallopsammia profunda*, *Enallopsammia rostrata*) collected from off the southeastern US were evaluated from the US National Museum of Natural History (NMNH), Harvard University's Museum of Comparative Zoology (MCZ), University of Miami's Marine Invertebrate Museum, and Yale University's Peabody Museum of Natural History. Data were gathered from online sources, selected publications, and personal visits to the MCZ and NMNH. Each record was located, if possible, specimens were photographed and additional data obtained, including whether the specimen was collected alive or dead. The resulting database was imported into ArcGIS to examine coral distributions. Museums yielded 304 records: 126 *L. pertusa*, 62 *M. oculata*, 113 *E. profunda*, 3 *E. rostrata*. Most (87%) records occurred between 400 and 900 m depths; some were <300 m (46–248 m) and >900 m (965–2195 m). Museum records confirmed geographic and bathymetric ranges of these corals and suggested areas for further exploration. Problems encountered in the museum data were varied but generally minor. Museum collections are useful for investigating DSC distributions; however, these data require more scrutiny than they usually receive. Visits to museums and/or interaction with museum staff are recommended to improve museum data utility.

Key words: *Deep-sea corals, cold-water corals,* Lophelia pertusa, Madrepora oculata, Enallopsammia profunda, Enallopsammia rostrata

Introduction

Despite significant recent attention toward deep-sea (or cold-water) coral habitats, distributions of deep-sea corals (DSC), in general, remain poorly known because they are based on patchy or opportunistic sampling. Thus, detailed maps of DSC distributions are often lacking. Except for a few relatively small study areas (e.g. Paull et al. 2000; Grasmueck et al. 2006; Partyka et al. 2007; S.W. Ross, unpubl. data), benthic habitat data gaps are particularly acute in US waters deeper than 200 m. Some countries, like Ireland, have produced detailed seafloor maps of their outer shelf and slope, including habitats such as DSC (Dorschel et al. 2010), but many DSC mapping efforts have relied on indirect data (e.g. trawl surveys, fishery observations; Gass & Willison 2005), including museum records. DSC are hard to collect because they are brittle (especially scleractinians), occur in deep water with fast currents, and usually occur on rough, hard substrata, which are difficult to sample with conventional ship-based gear. Also, fortuitous collections of DSC often were not recorded because they were considered unimportant by-catch in surveys targeting economically important fishery species. If noted during surveys, DSC were sometimes misidentified or only reported at higher taxonomic levels (Etnoyer & Morgan 2005; Watling & Auster 2005). Recently, the use of research submersibles and remotely operated vehicles (ROVs) have produced very high-quality DSC samples with more precise data about the local

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environment where they occurred and new information on a variety of corals and their associates (Reed et al. 2006; Henry et al. 2008; Kellogg et al. 2009). However, the great expense of manned and tethered vehicles and the limited area which they can cover has resulted in relatively small areas of the potential habitat available to DSC being surveyed. Using the basic environmental requirements known for DSC, predictive modelling of potential DSC distributions has revealed that the North Atlantic Ocean seems to have particularly favourable conditions for DSC (Bryan & Metaxas 2007; Davies et al. 2008; Roberts et al. 2009; Davies & Guinotte 2011). Such modelling efforts, however, suffer from a lack of in-situ verification and are limited by the quality and quantity of environmental and coral collection data available.

Well-curated museum collections play an important role in conservation and a variety of scientific endeavours (Suarez & Tsuitsui 2004). Mapping museum records has proved valuable in terrestrial ecology for evaluating biodiversity, species distribution patterns, and habitat–species relationships, particularly when documenting changes related to global climate change, invasive species introductions and habitat alterations. However, issues with such data sets include lack of accurate location data, lack of randomized specimen collecting (observational bias), inadequate collecting (i.e. undersampling), and inaccurate taxonomy (Kress et al. 1998; Funk et al. 1999). DSC museum specimens have been used in a variety of taxonomic and zoogeographic studies (e.g. Cairns 1979, 2000). They have also been used to mitigate for the lack of high-quality field data and detailed maps. For example, museum and literature records of DSC have enhanced large-scale distribution maps (e.g. Figure 1; Freiwald et al. 2004; Morgan et al. 2006; Roberts et al. 2006). At the large scale of these maps, errors are not apparent and are not as misleading as they are at smaller scales. The global *Lophelia pertusa* (Linnaeus, 1758) map (Figure 1) suggests that this coral occurs continuously throughout the southeastern US (SEUS) from the coastline to an unknown depth offshore, which at the regional scale is inaccurate. In many cases the most efficient way to acquire DSC museum data are from online (internet) museum catalogues. While such data can be valuable, they can also lead to misinterpretations and perpetuation of errors. The lack of examination of specimens, interaction with collectors, or interaction with museum personnel raises questions about the quality of remotely acquired museum records, including the reliability of identifications, accuracy of positions, and completeness of data. Also, many museum specimens may not be available through online sources because they are either uncatalogued (i.e. no numbered entries in museum records) or because catalogued specimens are not yet entered into electronic databases. The degree of record completeness is usually not apparent from the internet databases. A variety of similar problems can result from simply plotting data from published lists without examination of the original records or other relevant data (e.g. cruise reports).

The continental slope off the SEUS, including the Blake Plateau, may support more DSCs than any other region in US waters deeper than 300 m (Ross & Nizinski 2007). At least 110 species of Anthozoa occur off the SEUS, colonizing a variety of existing hard substrata as well as forming bioherms (Reed et al. 2006; Ross & Nizinski 2007). These deep-sea

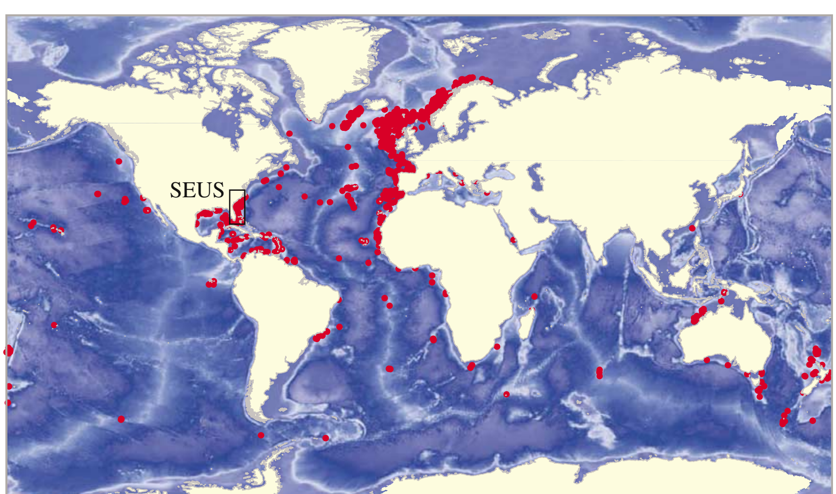

Figure 1. World-wide distribution of *Lophelia pertusa* (from Roberts et al. 2006), resulting from a variety of data, including museum records. At this scale individual locations and location errors cannot be resolved. Southeastern US (SEUS) study region denoted by black rectangle. Contrast with Figures 3–7.

reefs, in turn, support a diverse fauna that is unique from the surrounding soft substrata fauna (Ross & Nizinski 2007; Ross & Quattrini 2007). Accurately documenting the distributions of DSC off the SEUS is critical, since a large portion of the region was recently designated a Coral Habitat Area of Particular Concern (CHAPC; Federal Register 2010). During this investigation of DSC distributions off the SEUS, museum holdings of four prominent, structure-forming scleractinian species (*L. pertusa*, *Madrepora oculata* Linnaeus, 1758, *Enallopsammia profunda* (Pourtales, 1867), *Enallopsammia rostrata* (Pourtales, 1878)) were evaluated. The objectives of this study were to determine the quality, completeness, and utility of the museum records, while correcting and expanding a regional DSC database.

Materials and methods

The four prominent structure forming, deep-sea scleractinian coral species (*Lophelia pertusa*, *Madrepora oculata*, *Enallopsammia profunda* and *E. rostrata*) in the SEUS region were the focus of this study. The SEUS study area included the region from Cape Hatteras, NC through the Straits of Florida (approximately bordered at 82°W). Depth boundaries of the study area were not defined so as not to restrict discovery of specimens. Institutions likely to house major collections of these four species were contacted directly, and their collections were surveyed via examination of electronic Internet databases, if available. The Los Angeles County Museum of Natural History (Los Angeles, CA) and the Field Museum of Natural History (Chicago, IL) had no SEUS records of these corals. The American Museum of Natural History (New York, NY), Lamont-Doherty Earth Observatory (Columbia University, NY), and the Florida Museum of Natural History (Gainesville, FL) contained small collections of uncatalogued specimens from the SEUS in various conditions. Since the status of these minor holdings could only be ascertained by visiting these institutions, they were not included in the current database. Four museums (US National Museum of Natural History (NMNH), Smithsonian Institute, Washington, DC; Harvard Museum of Comparative Zoology (MCZ), Boston, MA; Marine Invertebrate Museum (UMML), University of Miami, Miami, FL; Yale Peabody Museum of Natural History (YPM), New Haven, CT) contained the majority of specimens, and the collections of the four coral species at these institutions were examined in detail. No data were added after March 2009, and there are likely new data available from the museums we examined and other museums that are not currently in our database.

First, electronic internet databases of three museums (NMNH, MCZ, YPM) were examined for SEUS records of the four scleractinian corals. All available data for each museum record from the electronic sources were imported into a MS Access database, consisting of 27 data fields per museum record (Table I). Data were not always available for all 27 fields. Lacking electronic access to the UMML collection, UMML data were acquired via direct contact with the curator. In addition, records for the four coral species were extracted from relevant taxonomic literature, added to the database and, where possible, the museum records were cross-referenced to published sources to identify and resolve data discrepancies. For example, different publications sometimes referenced the same museum number but provided contradictory data, like different locations. Literature was mainly accessed to clarify and search for museum specimens; therefore, literature records do not represent an exhaustive literature survey for these corals and will not be discussed or analysed extensively. In all searches, electronic or otherwise, we used the current taxonomic name of the coral as well as commonly used synonyms (e.g. *L. prolifera* for *L. pertusa*).

The existence and identifications of coral records were verified, and additional data were collected during visits to museums and interactions with museum staff. Data entered on original museum specimen labels were checked and compared with museum internet data and museum log book entries. Two museums housing the most records were visited in person (NMNH, 7–9 May 2008; MCZ, 13 May 2008), and each coral specimen was located (or not), photographed, its status (alive, dead, mixed, or unknown) at collection noted, and additional data not available from the Internet were added to the Access database. If not visited (UMML, YPM), the museum curators were contacted for additional collection data and to confirm data acquired from the Internet (YPM). The UMML and YPM curators located each known record as well as any other uncatalogued specimens or records not in Internet databases and provided photographs of specimens. The museum visits and personal contact (telephone, email) with the museum curators led to additional data about most records, which were gleaned from cruise reports or other unpublished sources. The status of specimens at collection was established as follows. When publications noted that specimens were alive at collection, this status was accepted, but the museum specimens were also examined. Museum specimens deemed likely to be alive at collection were generally bright white (*L. pertusa*, *Enallopsammia* spp.) or pinkish (*M. oculata*) with fairly clean skeletons and exhibited crisp calyx edges

Table I. MS Access database structure for museum specimens of scleractinian corals (*Lophelia pertusa*, *Madrepora oculata*, *Enallopsammia profunda*, *Enallopsammia rostrata*). Each column in the MS Access database was defined as noted below.

Museum Num: Museum catalog number (UNCAT if specimen not catalogued)
Photograph: Hyperlinked picture of specimen
Station: Collecting vessel and station number
Current State: Type of specimen storage (wet, dry) and specimen description (color, count, size)
Original State: Specimen status at time of collection (alive, dead, mixed, unknown)
Start Long: Longitude of point sample (or beginning of moving sample) in original format
Start Lat: Latitude of point sample (or beginning of moving sample) in original format
Start Depth: Starting depth in metres
End Long: Longitude at end of moving sample in original format
End Lat: Latitude at end of moving sample in original format
End Depth: Ending depth in metres
Location: General collection location description
Date: Day/Month/Year specimen or record was collected
Collection Method: gear type used
Notes: Additional notes about the specimen or the collection
Cruise Log: Name of cruise log, if one was located
Reference: Reference or person cited if associated with a coral record
Data Source: L = Literature, V = Visit to museum, O = internet online
At Museum Update: Notes on data added or modified in the database, if any, after a museum visit
Date Added: Date record was added to database
Start X: Starting longitude in decimal degrees converted from original as needed for GIS
Start Y: Starting latitude in decimal degrees converted from original as needed for GIS
End X: Ending longitude in decimal degrees converted from original as needed for GIS
End Y: Ending latitude in decimal degrees converted from original as needed for GIS
Photograph Q: Notes on quality issues with the specimen photographs
Photograph II: Hyperlinked second picture of specimen (if applicable)
Photograph III: Hyperlinked third picture of specimen (if applicable)

and little boring from other organisms (Figure 2a). Specimens judged to be dead at collection were generally brown to grey in colour, sometimes iron-stained, and were usually highly eroded (smooth calyx edges), pitted and bored (Figure 2b). In some cases coral specimens appeared to have a dead portion with outer branches living (also observed in situ, SWR, pers. obs.), and these were assigned a status of 'mixed'. To be conservative, if the colour or skeleton condition of specimens was equivocal, its collection status was categorized as unknown. The above criteria were based on the authors' extensive field experience with observing and collecting living and dead specimens of these species. Note that in situ, many deep-sea scleratinian corals have dead bases with living outer portions (mixed status per above), and the definitions above only apply to the fragments collected.

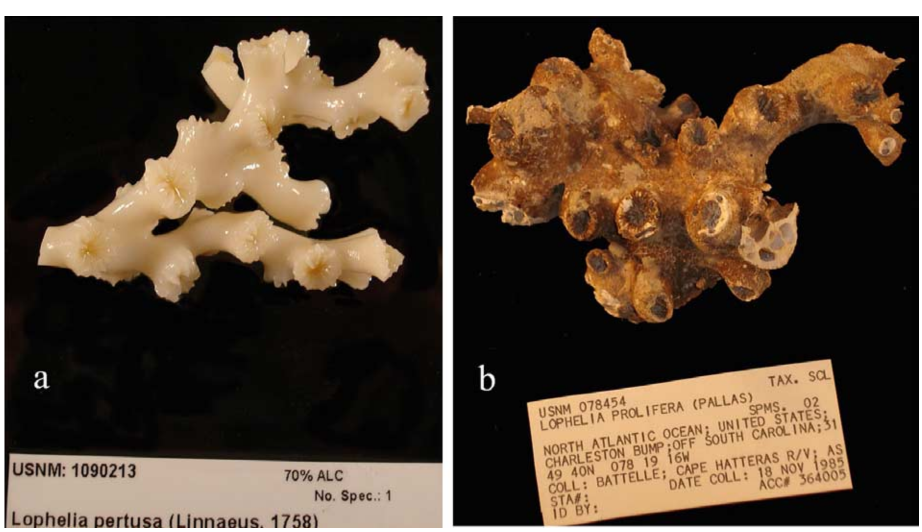

Figure 2. Examples of *Lophelia pertusa* museum specimens judged to be alive (2a, NMNH 1090213) and dead (2b, NMNH 078454) at time of capture.

The Access database was brought into a Geographic Information System (ArcGIS 9.2). Museum records were plotted on SEUS regional maps, and their accuracy and utility were evaluated in relation to bathymetry data and other published and unpublished location data for DSC of the region (see reviews in Partyka et al. 2007; Ross & Nizinski 2007). The status of specimens at collection (see above) was also mapped. Distribution maps were evaluated for their utility in documenting coral habitat and for guiding future exploration.

Results

The majority ($n = 260$, 75%) of the total 345 records of the 4 DSC species in the SEUS region were located without visiting the museums. Internet databases yielded 96 records of *Lopehlia pertusa* (76% of 126 total museum records), 43 records of *Madrepora oculata* (69% of 62 total museum records), 104 records of *Enallopsammia profunda* (92% of 113 total museum records), and 3 records (100%) of *E. rostrata* (Table II). Visits to the NMNH and MCZ produced additional records not otherwise available: 24 records of *L. pertusa* (19% total museum records), 17 of *M. oculata* (27% of total museum records), 3 of *E. profunda* (3% of total museum records) (Table II). The NMNH contained the most records ($n = 276$, 13% not available via internet) of the 4 species, followed by the MCZ ($n = 14$, 57% not available via internet), UMML ($n = 12$), and YPM ($n = 2$). A few specimens ($n = 8$) from all 4 species listed in museum catalogues could not be located and were assumed to be lost (not counted in our data). Some of the above museum holdings were also referenced in the literature and were not counted twice; however, the limited scientific literature examined provided an additional 24 (*L. pertusa*), 9 (*M. oculata*), 6 (*E. profunda*), and 2 (*E. rostrata*) non-museum records (Table II).

Although errors in museum collections were not extensive, the problems encountered included lost specimens, incorrect location data, missing, incomplete or vague collection data for cataloged lots, museum numbers associated with multiple stations, and same museum number for different taxa. As an example of confounding data, one large container of *E. profunda* from *Albatross* station 2415 (1 April 1885) was associated with eight NMNH catalogue numbers. In another case, a collection of *L. pertusa* apparently from one station was split between

Table II. Museum and literature (Lit) records of four scleractinian deep-water coral species collected off the southeastern US; USNM, US National Museum, Smithsonian Institution; MCZ, Museum of Comparative Zoology, Harvard University; YPM, Yale Peabody Museum, Yale University; UMML, University of Miami Marine Lab. Specimen status (A = alive; D = dead; M = mixed, alive + dead; U, unknown) refers to condition of coral specimen when collected as judged from the museum specimen; Lit only records were not catalogued in museums.

				Specimen status				
Species	Total n	n found w/o museum visit	n added w/ museum visit	A	D	M	U	n spec. lost
Lophelia pertusa								
USNM	110	93	17	19	54	8	29	2
MCZ	10	3	7	2	7	1	0	
UMML	5	5	0	0	1	0	4	
YPM	1	1	0	0	0	0	1	
Lit only	24	n/a	n/a	13	0	0	11	
Madrepora oculata								
USNM	59	43	16	14	14	12	19	
MCZ	1	0	1	0	1	0	0	2
UMML	2	2	0	0	0	0	2	
YPM	0	0	0	0	0	0	0	
Lit only	9	n/a	n/a	0	0	0	9	
Enallopsammia profunda								
USNM	105	102	3	20	50	26	9	
MCZ	2	2	0	0	2	0	0	2
UMML	5	5	0	0	3	1	1	
YPM	1	1	0	0	1	0	0	
Lit only	6	n/a	n/a	0	0	0	6	
Enallopsammia rostrata								
USNM	2	2	0	1	1	0	0	
MCZ	1	1	0	0	0	1	0	2
UMML	0	0	0	0	0	0	0	
YPM	0	0	0	0	0	0	0	
Lit only	2	n/a	n/a	0	0	0	2	

w/ with; w/o without; n/a not applicable.

the NMNH and UMML. The same cruise, station number and date were associated with the specimens, but two very different locations and depths were recorded for the two museum records. The correct location and depth data could not be determined. Missing station data was the most pervasive issue, the most difficult to address, and limited specimen utility. Data for each record available via internet searches of museum databases were generally restricted. Cruise reports and museum labels were helpful in adding data, but in many cases cruise reports could not be found or perhaps did not exist. Station data are still missing in many cases in the Access database compiled for this project and may never be found; however, a variety of data (e.g. collection depths, ending station locations for towed gear, station notes) that were not available online were added for nearly every record in the database, and this resulted from visits to museums and interactions with curators.

The original status for each of the four coral species at time of collection varied widely and did not exhibit obvious geographic patterns (Figures 4—7). Of the 126 *L. pertusa* museum records, 30 were collected alive or mixed, and 62 represented dead material (Table II). The status of 34 *L. pertusa* museum specimens was unclear, as was the status of most specimens from published records (Table II). Of the 62 *M. oculata* museum specimens, 26 were collected alive or mixed, 15 represented dead material, and the status of 21 specimens was unclear (Table II). Of the 113 *E. profunda* museum specimens, 47 were collected alive or mixed, 56 represented dead material and the status of 10 specimens was unclear (Table II). Of the three *E. rostrata* museum specimens, one was collected alive, one mixed, and one represented dead material (Table II). Collection methods (see below and Discussion) may account for why most specimens were collected dead.

Nine general gear types were used to collect the museum specimens of the four coral species from off the SEUS (Table III). These collections spanned a time period from 1867 to 2005, but most were collected after 1960. Various types of trawls (mostly beam and otter), towed in 70–2377 m depths, accounted for 34% of specimens, and these methods largely resulted from US government fishery surveys in the region. Other towed gear (e.g. various dredges) also accounted for a substantial number of specimens (Table III). The ending locations of towed gear were usually missing in original museum entries, but these were obtained for 50 trawls and dredges. Six dredge samples with start and end locations covered a mean distance of 0.89 km (SD = 0.89, range = 0.13–2.0 km). Forty-four trawls with start and end locations were towed over a range of distances from 2.5 to 42 km (mean = 11.73 km, SD = 7.9). While a 42-km tow distance seems improbable, there were several ($n = 8$) other very long tows (18–39 km). Collections by submersible accounted for about 7% of the total samples from a depth range of 282–871 m. Seventy-nine records could not be associated with any collection method (Table III) because such data were not recorded and sources of these data (e.g. cruise reports) could not be located. Additional metadata related to collection methods were difficult to impossible to find because such data were not provided with specimens and cruise reports were often not discovered. Although various reports and station logs were located and some additional data were added, a substantial amount of important data could not be found.

Geographic and bathymetric distribution of records

The utility of museum records was best displayed when plotted on regional maps. Sufficient data were available to plot the locations of 292 records of the four DSC species (Figure 3). These data are presented in three geographic subsets (Figures 4—6) to gain resolution and allow comparisons with other data. Well-known DSC sites confirmed with

Table III. Museum specimens listed by collection method. Depth (m) listed under each gear type. Trawls include otter, beam, balloon, semi-balloon, shrimp and benthic trawls. Submersibles (sub) include the *Alvin* and the *Johnson-Sea-Link*. Grabs include Campbell and VanVeen samplers. Dredges include tumbler, scallop, pipe, rock and day dredges; Unk = Unknown.

Species	Box core (495)	Piston core (790)	Isaac-Kidd Midwater Trawl (547–695)	Chain Bag & Pipe (475–1098)	Dredges (220–1097)	Grabs (46–871)	Trawls (70–2377)	Sub (282–871)	Tangles (507–512)	Unk (105–1337)
Lophelia pertusa		1		13	18	13	40	11	1	30
Madrepora oculata				5	2	3	32	6	1	13
Enallopsammia profunda	1		3	14	6	22	25	6	1	36
Enallopsammia rostrata							3			
Totals	1	1	3	32	26	38	100	23	3	79

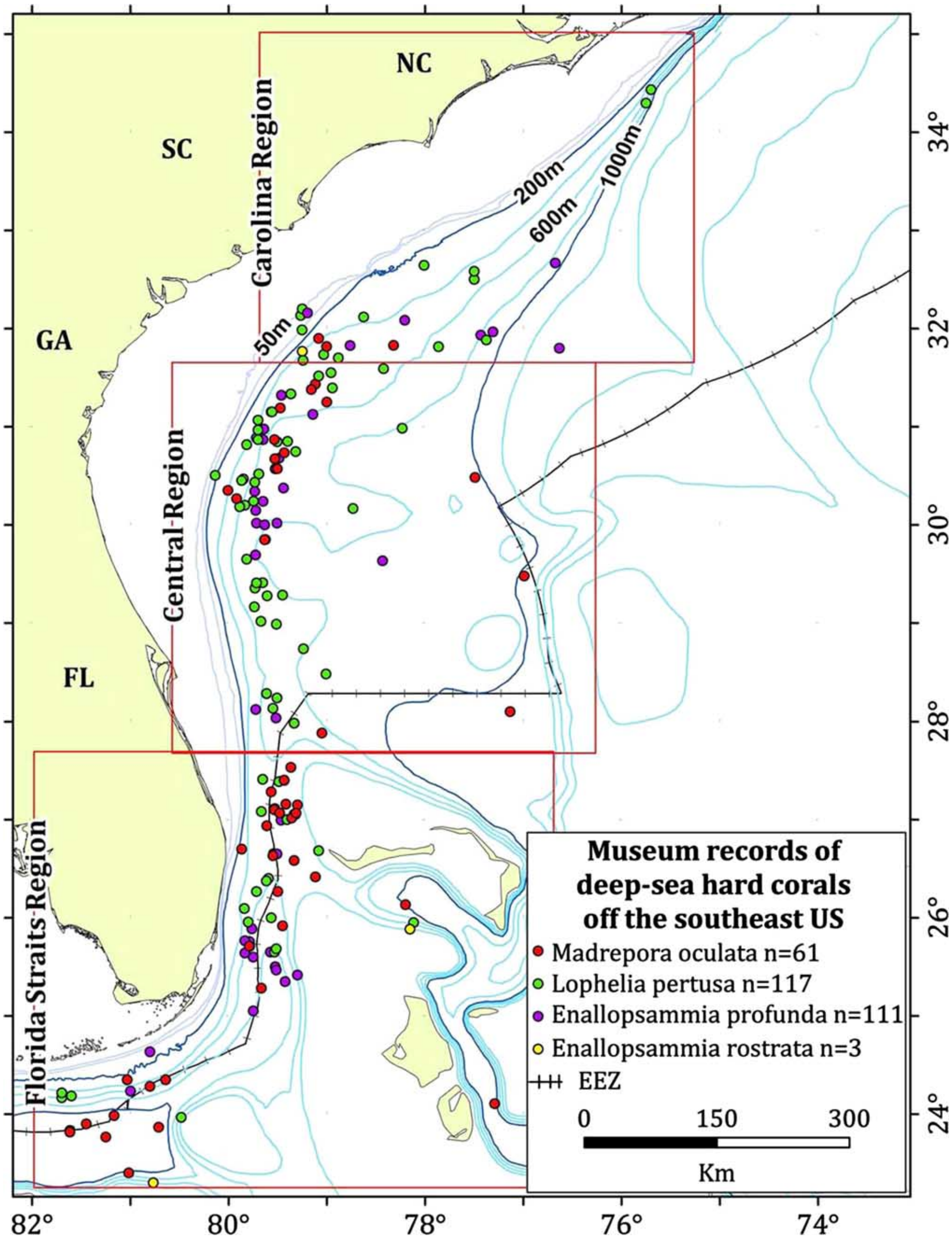

Figure 3. Locations of records ($n = 292$) of 4 species of scleractinian corals off the SEUS obtained from selected taxonomic literature and from four museum databases. All records obtained could not be plotted because of missing location information. See Figures 4–6 for more detail.

submersible and/or ROV observations and the recently established CHAPC boundaries were also included in these distribution maps. The northernmost locality records in the study area were of *Lophelia pertusa* off Cape Lookout, NC (Figure 4), but there was a large gap between these and the next museum record locations to the south off South Carolina (Figure 4). *Madrepora oculata* records were not common north of Georgia (about 32°N, Figure 4). South of about 32°15′N there were nearly continuous records of corals all the way through the Straits of Florida (Figures 4–6), many locations falling outside the US EEZ in the southern part of the study area (Figure 6). Except off southern Florida, few DSC records fell outside the CHAPC boundaries (Figures 4–6). Only a few museum records coincided with known, visually confirmed DSC sites (Figures 4–6). The majority (87%) of records of all 4 DSC species occurred between 400 and 900 m depths. Five records of *L. pertusa* were shallower than 300 m (46–248 m), nearly all collected dead. Two records of *Enallopsammia profunda* (46, 146 m) and one record of *E. rostrata* (220 m) occurred shallower than 300 m. Aside from 15 records of *M. oculata* deeper than

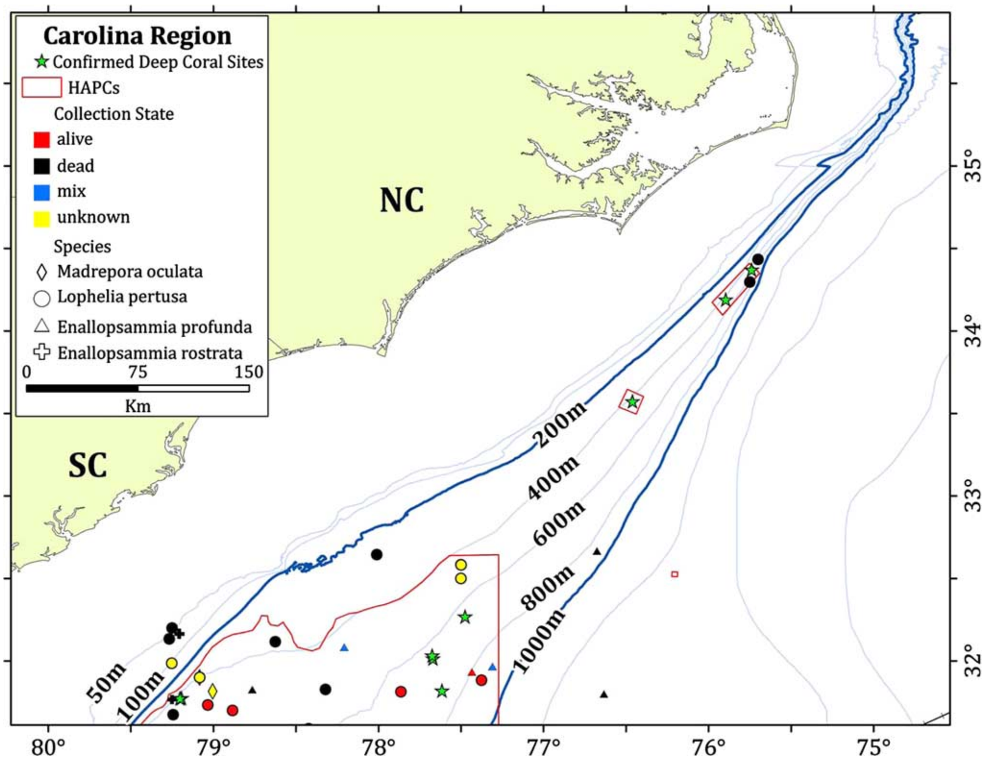

Figure 4. Carolina Region showing location and status of *Lophelia pertusa*, *Madrepora oculata*, *Enallopsammia profunda* and *E. rostrata* museum records when collected (see Methods). Coral Habitat Areas of Particular Concern (CHAPC) boundaries and DSC sites confirmed via submersible or ROV observations are also mapped. See Figure 7 for more data on the northernmost museum records.

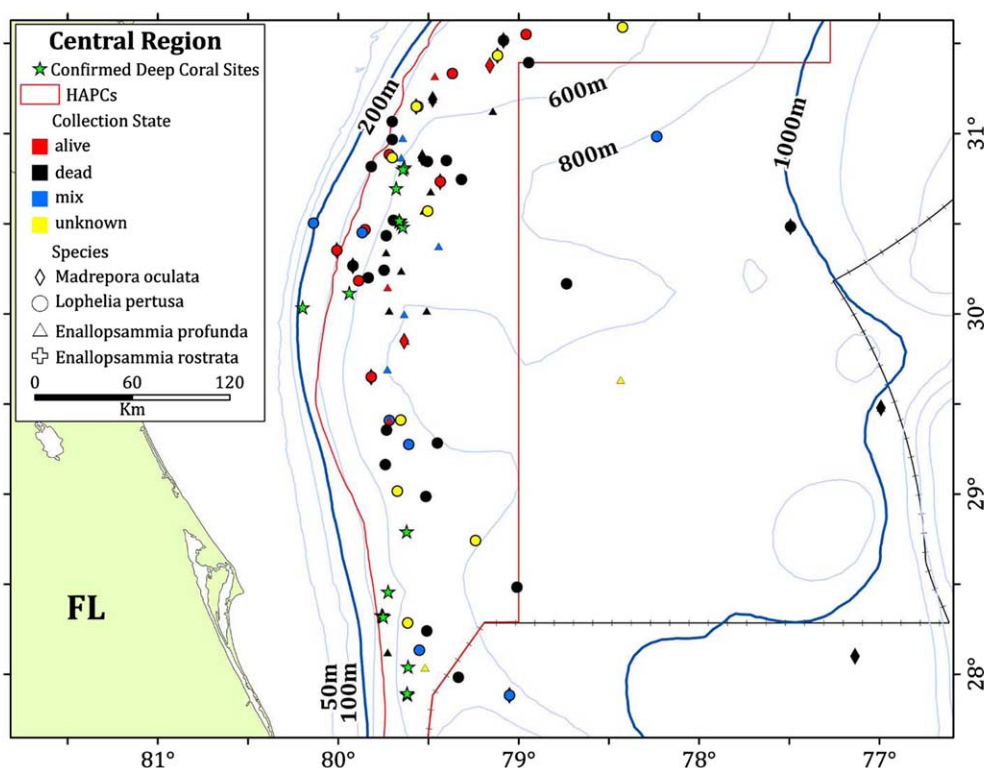

Figure 5. Central SEUS Region showing location and status of *Lophelia pertusa*, *Madrepora oculata*, *Enallopsammia profunda* and *E. rostrata* museum records when collected (see Methods). Coral Habitat Areas of Particular Concern (CHAPC) boundaries and DSC sites confirmed via submersible or ROV observations are also mapped.

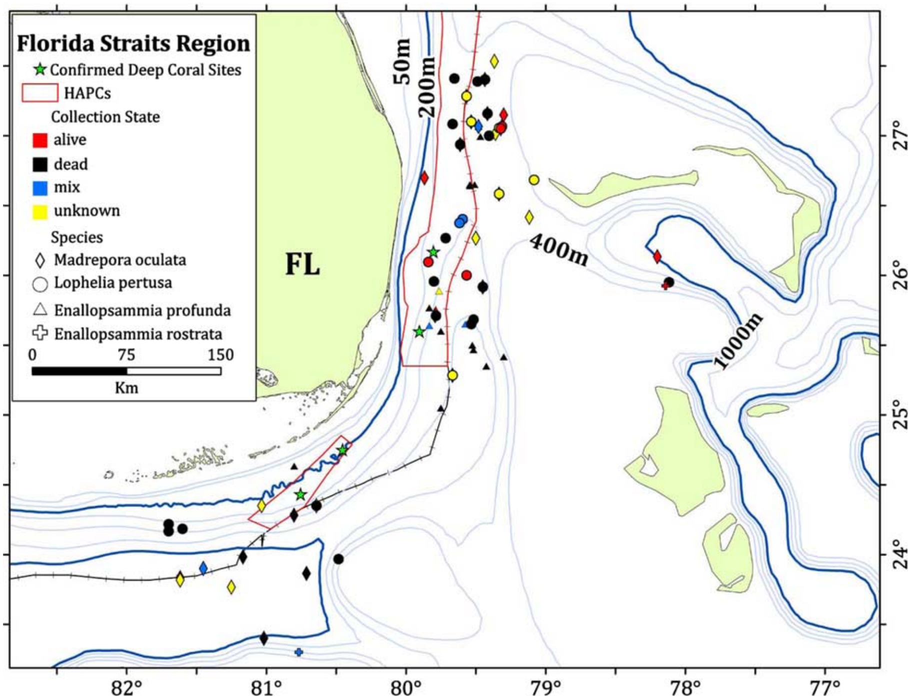

Figure 6. Straits of Florida Region showing location and status of *Lophelia pertusa*, *Madrepora oculata*, *Enallopsammia profunda* and *E. rostrata* museum records when collected (see Methods). Coral Habitat Areas of Particular Concern (CHAPC) boundaries and DSC sites confirmed via submersible or ROV observations are also mapped.

900 m (965–1464 m), records of any of the 4 species beyond 900 m were rare (*E. profunda*, $n = 3$; 1337, 1098, 2195 m).

Discussion

Museum collections are useful for investigating general DSC distributions; however, museum data require more scrutiny than they usually receive in order to achieve this utility. Museum data available via remote access (internet, literature) for the four species of DSC reviewed here were at times misleading and limited in utility and quality without further interactions with the museums. Plotting unverified locations with unknown characteristics, which may represent point collections, lengthy transects (trawls, dredges), live or dead specimens, has questionable value. For example, mapping the location (particularly if only a point somewhere along a tow track) of a small piece of dead coral rubble collected by gear which may have covered many kilometres of sea bottom reveals little about benthic habitats or about the coral, especially with no other information about the specimen or the overall collection. This type of record does not have the same value or data quality compared with a more precise collection made by submersible or ROV (which often also includes video documentation), yet specimen records are often mapped with little or no other documentation (Schroeder et al. 2005; Morgan et al. 2006; Scanlon et al. 2010). In fairness, such maps served a purpose the authors intended, but more complete information would have made these maps and data more valuable. Using poorly documented collections as input for distribution modelling (Davies & Guinotte 2011) may lead to inaccurate results. Predicted habitat suitability modelling for three DSC species (*Lophelia pertusa*, *Madrepora oculata*, *Enallopsammia rostrata*) common to the present study resulted in an overprediction of these corals' potential distributions off the US east coast (Davies & Guinotte 2011). Davies & Guinotte (2011) noted that overprediction could be due to limited coral location data and lack of fine-scale bathymetric or current data. Inaccurate or erroneous coral location data input into the model (e.g. Scanlon et al. 2010, see below) could contribute to inaccurate modelling for the SEUS. Also, it was not reported whether all coral records used in the model were of specimens collected alive (Davies & Guinotte 2011), and apparently both live and dead specimens were used (A.J. Davies & J.M. Guinotte, pers. comm.). Including distributional records of corals that have been dead for a very long (potentially thousands to tens of thousands of years) or unknown length of time may confound modelling results, particularly when such records are correlated with

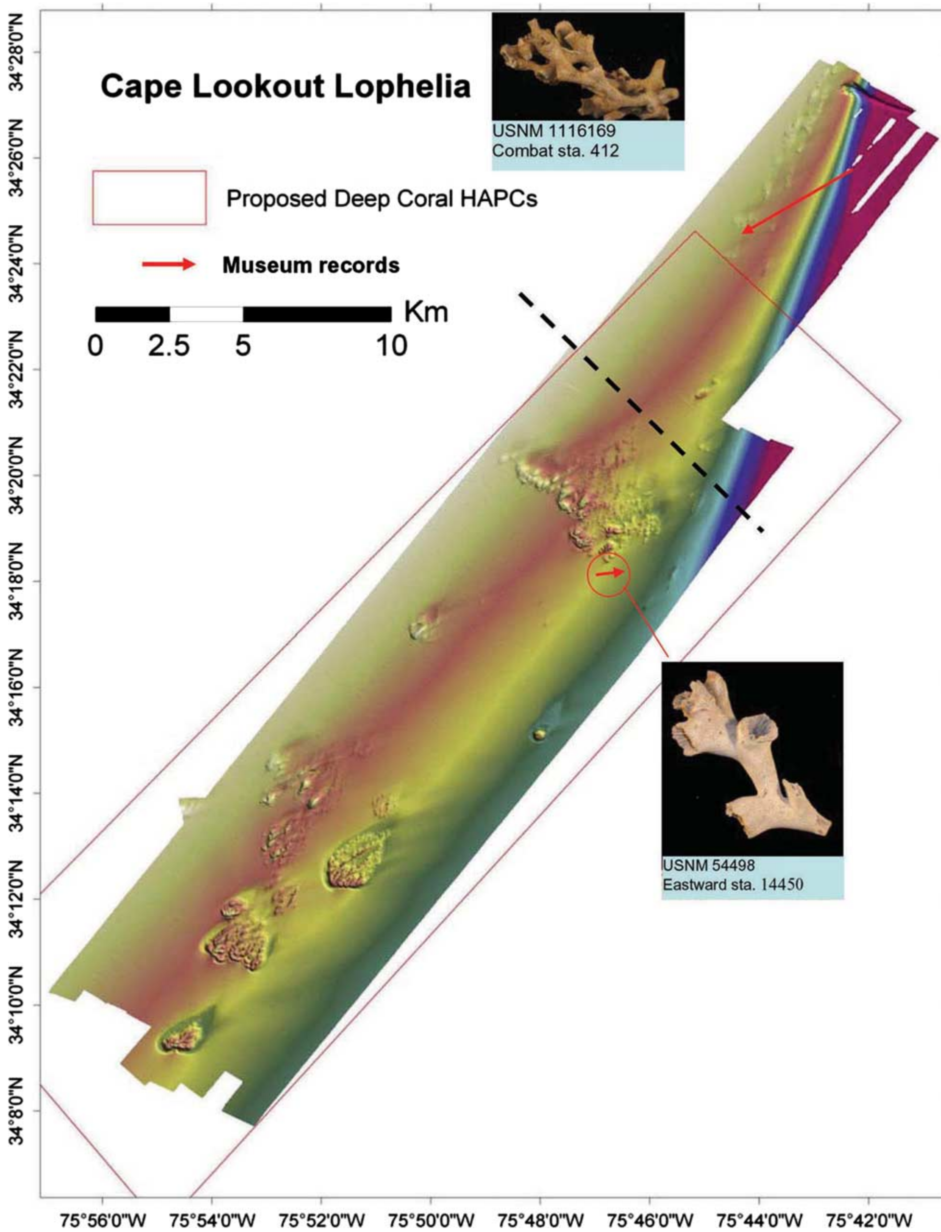

Figure 7. Multibeam sonar (10 m resolution) shaded bathymetry image of massive, living and dead coral bioherms off Cape Lookout, NC, also confirmed with numerous submersible dives. Two museum records of dead *Lophelia pertusa* rubble occurred in this area, neither of which were from the main mound systems (clearly apparent in the shaded bathymetry map). The black dotted line is the limit of the multibeam data collected in 2006. The northernmost museum record prompted additional multibeam mapping in 2008 (area above the line), revealing numerous low profile mounds that are likely coral bioherms.

recent environmental data to predict DSC habitat suitability.

Visiting relevant museums is often impractical; however, efforts should be made to access the reliability, completeness, and status of museum records before they are used. Internet databases are often in a state of flux, as limited museum staff continue to catalogue a vast amount of material. In fact, the NMNH includes a disclaimer on their website (http://www.mnh.si.edu/rc/db/2data_access_policy.html) stating that their electronic database does not represent the full collection nor does it include all data. Therefore, museum data should not be used without better explanations of data quality and limitations, and anyone tempted to take the easy route of remote data mining should consider that this labour saving step may lead to erroneous results, a pitfall noted by Graves et al. (2000). Nevertheless, online databases could be improved to include more information (if available) that would help reduce perpetuating errors, including additional metadata, additional specimens, original station logs, cruise reports and field notes. However, as with this study, by visiting the museums or at least interacting with curators, considerable data can be added that are otherwise unavailable. Using this approach, significant new records were added in this study, and many problems related to data contradictions or errors were solved. This significantly improved the functionality of our database, and new information was provided to the museums so that their records could be updated as well.

Taxonomic accuracy is an issue in accessing museum records or any records for that matter and is especially problematic if investigators do not know the taxonomic history of their study organisms. For example, *L. pertusa* and *M. oculata* have been known under nine and seven different names, respectively, since their descriptions (Cairns 1979, 2000). Because museums may maintain specimens under their original or other names, records could be missed if a search were conducted using only one name. However, one advantage of using museum material, especially from large, well-curated collections, is that such specimens are more likely to be correctly identified, regardless of whether an outdated name was assigned, than those from some literature or electronic sources (e.g. http://iobis.org/home). Literature and electronic sources do not always document the origins of records, who identified the specimens, or provide associated collection data; thus, taxonomic validity cannot be evaluated.

Although this exercise was not intended to document all coral locations known off the SEUS or to be an exhaustive review of the distributions of these four scleractinian species, these museum records were valuable in several ways and represented an impressive geographic and bathymetric spread of data. Most museum records fell within the geographic and bathymetric (>200 m) boundaries expected and agreed well with published literature (e.g. Cairns 1979, 2000), thus reinforcing what is known of their general distributions off the SEUS. However, as noted by Etnoyer & Morgan (2005), such records may represent the distribution of collecting effort as much as the distributions of corals. Although it is accepted that these DSC species are most common shallower than 1000 m (Roberts et al. 2009; this study), the lack of records ≥ 1000 m may also be related to a lack of scientific sampling below 500 m off the SEUS. In relation to this, maps of stations that did not yield corals (negative data) would be a useful addition to the positive occurrence data. Even though the two museum records (NMNH 1116169, 54498) of dead *L. pertusa* from off Cape Lookout, NC (Figure 7) misrepresent the DSC habitat in that area (see Partyka et al. 2007; Ross & Nizinski 2007), the northernmost specimen provided a target location for additional multibeam sonar mapping. This resulted in the discovery of numerous small mounds that were previously unknown (Figure 7), and the CHAPC should be extended northward to include these mounds. Although generally too shallow for living *L. pertusa* habitats off the SEUS (Ross & Nizinski 2007), the cluster of DSC museum records just inshore of the 200 m contour off South Carolina (Figure 4) suggest another area that should be explored in more detail, mainly because these records are very near a known DSC area (Savannah Banks, Reed et al. 2006; Partyka et al. 2007) and near other, deeper DSC museum records. Likewise, the validity of the *L. pertusa* (NMNH 99226) collected in 146 m off northern Florida (Figure 5) normally would be questioned; however, recent discovery of unusually shallow living *L. pertusa* near that area (S.W. Ross, S.D. Brooke, A.M. Quattrini, unpubl. data) make this record more viable and indicates that location is worth further investigation. The best correlation between known DSC sites and museum records was for an area off Jacksonville, Florida, where historical (Paull et al. 2000; Reed et al. 2006; Partyka et al. 2007) and current (S.W. Ross et al., upubl. data) studies have documented extensive hardgrounds and DSC habitats (Figure 5). As long as it is understood that historical museum record data have limited and often unknown navigational precision and if errors are corrected, the data are valuable for general distributional information and for suggesting areas to explore.

Sampling methods that produced most of these DSC records likely explain why few museum records coincided with DSC sites documented with submersible or ROV and why most records were of dead specimens. The known, visually documented DSC sites were usually the most topographically rugged and were likely avoided by mobile gear, such as trawls. Living coral is generally more common on the tops of these rugged, hard to sample features (Dolan et al. 2008; pers. obs.). Furthermore, dead coral rubble can be abundant on the flatter bottoms far away from the main mounds and ridges, representing areas more likely to be sampled by mobile gear. The ability to map the tracks of most towed gear was limited by the lack of station ending location data, and these data would have been useful in evaluating the area from which specimens were collected (for example, see trawl tracks in Figure 7). The most useful records in terms of specimen quality and precision and detail of collection data were those collected with submersible or ROV, but as of March 2009 such collections off the SEUS were not well represented in the museums. This will change as collections from recent deep reef expeditions using submersibles and ROVs off the SEUS (e.g. Reed et al. 2006; Partyka et al. 2007) are processed.

Unlike many non-fossil museum specimens, scleractinian corals can be collected in both dead and live conditions. Since the dead material can persist for thousands of years (Ayers & Pilkey 1981; Paull et al. 2000), it is important to distinguish between these two states as they convey different information. Overlaying the live and dead DSC records onto detailed bathymetric maps generated from multibeam sonar (e.g. Figure 7) may facilitate further coral habitat identification; however, to date, only a small part of the SEUS slope has been mapped with multibeam sonar, and many of these museum records were not within the mapped areas.

A recent attempt was made to compile a database of DSC records for the Gulf of Mexico and the Western North Atlantic Ocean (Scanlon et al. 2010, only available electronically). Within the same SEUS geographic boundaries as this project, Scanlon et al. (2010) documented 99 total records of *L. pertusa* (noting 17 of these as NMNH museum records), 30 records of *M. oculata*, and 36 and 1 records of *E. profunda* and *E. rostrata*, respectively. At least 4 records of *L. pertusa* were listed twice, thus the actual total number of records was 95. In general, these DSC records agreed with the depth and geographic ranges reported here. The Scanlon et al. (2010) records for the SEUS relied on five literature sources (Moore & Bullis 1960; Cairns 1976, 1979; Messing et al. 1990; Reed et al. 2006). As with the museum records, location data from some of the above references are misleading as some locations were for starting points of stations or submersible dives and are not necessarily the actual locations of corals (e.g. Reed et al. 2006), which is also a potential issue for modelling (see above). Although Scanlon et al. (2010) had a database field for the status of coral specimens upon collection provided by the references used, as noted above, these data are generally unattainable without locating the specimens. As noted here, lack of such data may lead to a variety of problems for modelling and general distribution mapping. It is unfortunate that the large number of museum specimens available and other relevant literature (e.g. Stetson et al. 1962; Paull et al. 2000; Popenoe & Manheim 2001; Partyka et al. 2007; Ross & Nizinski 2007) were not included or documented by Scanlon et al. (2010). Many records in the Scanlon et al. (2010) database, besides the 17 noted *L. pertusa*, were actually deposited and catalogued in museums and overlap with museum records reported here, but it is difficult to assess the degree of overlap as museum numbers were usually not noted in Scanlon et al. (2010). It is important that such databases are as accurate and complete as possible, especially because they may be used by management agencies and the science community. Direct interactions with museums and inclusion of as much literature as possible are recommended when compiling these regional databases.

Despite poor funding, most museums are gradually improving and expanding online internet data access. Networks of multiple museum holdings can even be searched simultaneously (Graham et al. 2004). Likewise, records and specimen data (e.g. photographs, improved station locations, collection notes) are being added to our database from a variety of sources, including non-museum data of known coral locations. Assuming data quality issues noted above are addressed, museum DSC collections will be important in the future for genetics studies (depending on preservation) and analysis of present and past species distributions. Just as museum collections are important in measuring terrestrial biodiversity (Ponder et al. 2001), repositories of DSC data will be similarly useful. Museum data can also help guide future GIS analysis to locate potential coral hotspots and habitats off the SEUS. For example, a potential functional relationship between the Gulf Stream and DSC distributions is suggested by the majority of SEUS DSC scleractinian museum records being located roughly under the present path of the Florida Current and Gulf Stream (Atkinson et al. 1985; Bane et al. 2001). However, the nature of this relationship is not clear from the museum data alone, in part because of unknown bias in sampling locations, lack of negative occurrence sampling data, lack of detailed bottom bathymetry, lack of bottom current data, and missing data from museum records about the nature of the habitat sampled. Museum data should be supplemented with other data, such as multibeam sonar maps, seismic surveys (e.g. Popenoe et al. 2001), and visual bottom surveys (Partyka et al. 2007) to evaluate distributions and explore the potential interactions between the Gulf Stream and coral mound development. Despite issues concerning data accuracy or completeness, museum records are valuable for guiding where to conduct additional surveys (Graham et al. 2004). It is also important to remember that museums serve other valuable functions (taxonomic, vouchers for other studies) besides the distributional facet described here.

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References

Atkinson LP, Menzel DW, Bush KA, editors. 1985. Oceanography of the Southeastern U.S. Continental Shelf. Coastal and Estuarine Sciences 2. Washington, DC: American Geophysical Union. 156 pages.

Ayers MW, Pilkey OH. 1981. Piston cores and surficial sediment investigations of the Florida Hatteras slope and inner Blake Plateau. In: Popenoe P, editor. Environmental Geologic Studies on the Southeastern Atlantic Outer Continental Shelf. USGS Open File Report 81-582-A, p 5–89.

Bane JM Jr, Attkinson LP, Brooks DA. 2001. Gulf Stream physical oceanography at the Charleston Bump: Deflection, bimodality, meanders, and upwelling. In Sedberry GR, editors. Island in the Stream: Oceanography and Fisheries of the Charleston Bump (pp. 25–36). Bethesda, MD: American Fisheries Society Symposium 25.

Bryan TL, Metaxas A. 2007. Predicting suitable habitat for Paragorgiidae and Primnoidae on the Atlantic and Pacific continental margins of North America. Marine Ecology Progress Series 330:113–26.

Cairns SD. 1976. Review of the deep-water ahermatypic corals (Scleractinia) of the tropical western Atlantic. PhD Dissertation, University of Miami. 228 pages.

Cairns S. 1979. The deep-water Scleractinia of the Caribbean Sea and adjacent waters. Studies on the Fauna of Curacao and Other Caribbean Islands 56:1–341.

Cairns S. 2000. A revision of the shallow-water azooxanthellate scleractinia of the western Atlantic. Studies of the Natural History of the Caribbean Region 75:1–231.

Davies AJ, Wisshak M, Orr JC, Roberts JM. 2008. Predicting suitable habitat for the cold-water reef framework-forming coral *Lophelia pertusa* (Scleractinia). Deep Sea Research (I) 55:1048–62.

Davies AJ, Guinotte JM. 2011. Global habitat suitability for framework-forming cold-water corals. PLoS ONE 6(4):e18483, 15 pages.

Dolan MFJ, Grehan AJ, Guinan JC, Brown C. 2008. Modelling the local distribution of cold-water corals in relation to bathymetric variables: adding spatial context to deep-sea video data. Deep Sea Research (I) 55:1564–79.

Dorschel B, Wheeler AJ, Monteys X, Verbruggen K. 2010. Atlas of the Deep-Water Seabed Ireland. London: Springer. 164 pages.

Etnoyer P, Morgan LE. 2005. Habitat-forming deep-sea corals in the northeast Pacific Ocean. In Freiwald A, Roberts JM, editors. Cold-Water Corals and Ecosystems. Berlin, Heidelberg: Springer-Verlag, p 331–43.

Federal Register. 2010. Department of Commerce, National Oceanic and Atmospheric Administration, 50 CFR Part 622, Fisheries of the Caribbean, Gulf of Mexico, and South Atlantic. Comprehensive Ecosystem-Based Amendment for the South Atlantic Region 75 (119):35330–35335.

Freiwald A, Fossa JH, Grehan A, Koslow T, Roberts JM. 2004. Cold-Water Coral Reefs. Cambridge: UN Environmental Programme, UK. 4 pages.

Funk VA, Zermoglio MF, Nasir N. 1999. Testing the use of specimen collection data and GIS in biodiversity exploration and conservation decision making in Guyana. Biodiversity Conservation 8:727–51.

Gass SE, Willison JHM. 2005. An assessment of the distribution of deep-sea corals in Atlantic Canada by using both scientific and local forms of knowledge. In Freiwald A, Roberts JM, editors. *Cold-Water Corals and Ecosystems*. Berlin, Heidelberg: Springer-Verlag, p 223–45.

Graham CH, Ferrier S, Huettman F, Moritz C, Peterson AT. 2004. New developments in museum-based informatics and applications in biodiversity analysis. Trends in Ecology and Evolution 19:497–503.

Grasmueck M, Eberli GP, Viggiano DA, Correa T, Rathwell G, Luo J. 2006. Autonomous underwater vehicle (AUV) mapping reveals coral mound distribution, morphology, and oceanography in deep water of the Straits of Florida. Geophysical Research Letters 33:L23616, 6 pages.

Graves GR, Scoble MJ, Wirtz P. 2000. Costs and benefits of web access to museum data. Trends in Ecology and Evolution 15:374–75.

Henry L-A, Nizinski MS, Ross SW. 2008. Occurrence and biogeography of hydroids (Cnidaria: Hydrozoa) from deep-water coral habitats off the southeastern United States. Deep Sea Research (I) 55:788–800.

Kellogg CA, Lisle JT, Galkiewicz JP. 2009. Culture-independent characterization of bacterial communities associated with the cold-water coral *Lophelia pertusa* in the northeastern Gulf of Mexico. Applied Environmental Microbiology 75:2294–303.

Kress WJ, Heyer WR, Acevedo P, Coddington J, Cole D, Erwin TL, et al. 1998. Amazonian biodiversity: Assessing conservation priorities with taxonomic data. Biodiversity Conservation 7:1577–87.

Messing CG, Neuman AC, Lang JC. 1990. Biozonation of deep-water lithotherms and associated hardgrounds in the north-eastern Straits of Florida. Palaios 5:15–33.

Moore DR, Bullis HR Jr. 1960. A deep-water coral reef in the Gulf of Mexico. Bulletin of Marine Science 10:125–28.

Morgan LE, Tsao C-F, Guinotte JM. 2006. Status of Deep Sea Corals in US Waters, with Recommendations for their Conservation and Management. Bellevue, WA: Marine Conservation Biology Institute. 64 pages.

Partyka ML, Ross SW, Quattrini AM, Sedberry GR, Birdsong TW, Potter J. 2007. Southeastern United States deep-sea corals (SEADESC) initiative: A collaboration to characterize areas of habitat-forming deep-sea corals. Silver Spring, MD: NOAA Technical Memorandum OAR OER 1. 176 pages.

Paull CK, Neumann AC, am Ende BQ, Ussler W III, Rodriguez NM. 2000. Lithotherms on the Florida-Hatteras slope. Marine Geology 166:83–101.

Ponder WF, Carter GA, Flemons P, Chapman R. 2001. Evaluation of museum collection data for use in biodiversity assessment. Conservation Biology 15:648–57.

Popenoe P, Manheim FT. 2001. Origin and history of the Charleston Bump – Geological formations, currents, bottom conditions, and their relationship to wreckfish habitats on the Blake Plateau. In Sedberry GR, editors. Island in the Stream: Oceanography and Fisheries of the Charleston Bump. Bethesda, MD: American Fisheries Society Symposium 25, p 43–93.

Reed JK, Weaver DC, Pomponi SA. 2006. Habitat and fauna of deep-water *Lophelia pertusa* coral reefs off the southeastern U.S.: Blake Plateau, Straits of Florida, and Gulf of Mexico. Bulletin of Marine Science 78:343–75.

Roberts JM, Wheeler AJ, Freiwald A. 2006. Reefs of the deep: The biology and geology of cold-water coral ecosystems. Science 312:543–47.

Roberts JM, Wheeler AJ, Freiwald A, Cairns SD. 2009. Cold-water Corals: The Biology and Geology of Deep-sea Coral Habitats. Cambridge: Cambridge University Press. 352 pages.

Ross SW, Nizinski MS. 2007. State of deep coral ecosystems in the U.S. southeast region: Cape Hatteras to southeastern Florida. In Lumsden SE, Hourigan TF, Bruckner AW, Dorr G, editors. The State of Deep Coral Ecosystems of the United States. Silver Spring, MD: NOAA Technical Memorandum CRCP-3, p 233–70.

Ross SW, Quattrini AM. 2007. The fish fauna associated with deep coral banks off the southeastern United States. Deep Sea Research (I) 54:975–1007.

Scanlon KM, Waller RG, Sirotek AR, Knisel JM, O'Malley JJ, Alesandrini S. 2010. USGS cold-water coral geographic database – Gulf of Mexico and western North Atlantic Ocean, version 1.0. U.S. Geological Survey Open-File Report 2008–1351, CD-ROM. http://pubs.usgs.gov/of/2008/1351/.

Schroeder WW, Brooke SD, Olson JB, Phaneuf B, McDonough JJ III, Etnoyer P. 2005. Occurrence of deep-water *Lophelia pertusa* and *Madrepora oculata* in the Gulf of Mexico. In Freiwald A, Roberts JM, editors. Cold-Water Corals and Ecosystems. Berlin, Heidelberg: Springer-Verlag, p 297–307.

Stetson TR, Squires DF, Pratt RM. 1962. Coral banks occurring in deep water on the Blake Plateau. American Museum Novitates 2114:1–39.

Suarez AV, Tsutsui ND. 2004. The value of museum collections for research and society. BioScience 54:66–74.

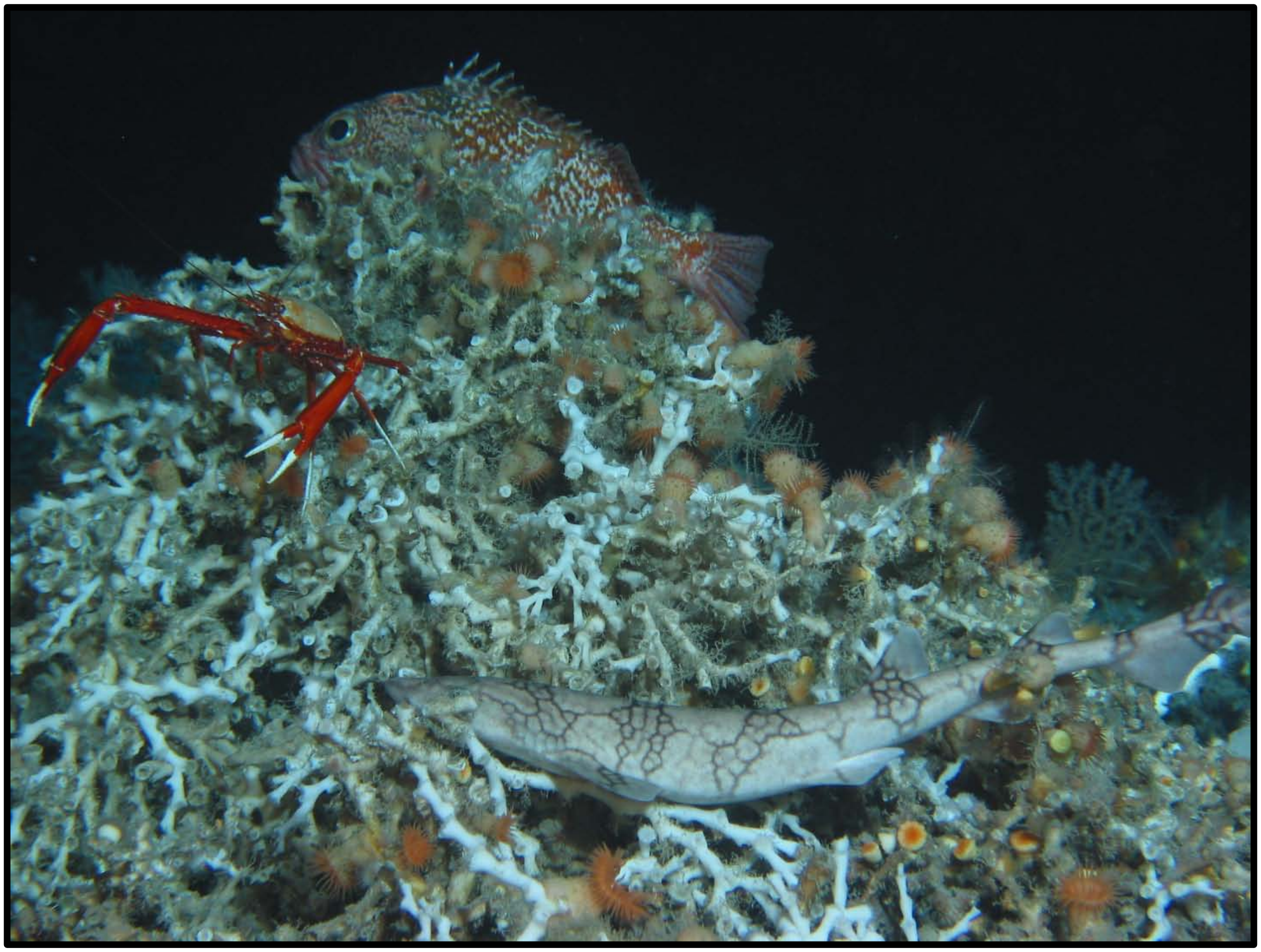
Watling L, Auster PJ. 2005. Distribution of deep-water Alcyonacea off the northeast coast of the United States. In Freiwald A, Roberts JM, editors. Cold-Water Corals and Ecosystems. Berlin, Heidelberg: Springer-Verlag, p 279–96.

Editorial responsibility: Ole S. Tendal

APPENDIX III

PICTORAL GUIDE TO FISHES ASSOCIATED WITH DSC OFF THE SEUS

A Photo Guide to
Common Deep-Sea Fishes of the SEUS Deep Reefs



Tara L. Casazza and Steve W. Ross
UNC W, Center for Marine Science
5600 Marvin Moss Lane
Wilmington, NC 28409

11 July 2011

UNCW
CENTER FOR MARINE SCIENCE

Common Deep-Sea Fishes of the SEUS Deep Reefs

Table of Contents **Page**

Myxinidae (hagfishes)

Eyes reduced; no paired fins; eel-shaped body

Eptatretus lopheliae

Bright pink to orange in color

Myxine glutinosa

Pale pink in color

Squalidae (dogfish sharks)

2 dorsal fins with spines; large spiracles; no anal fin

Cirrhigaleus asper **(roughskin dogfish)**

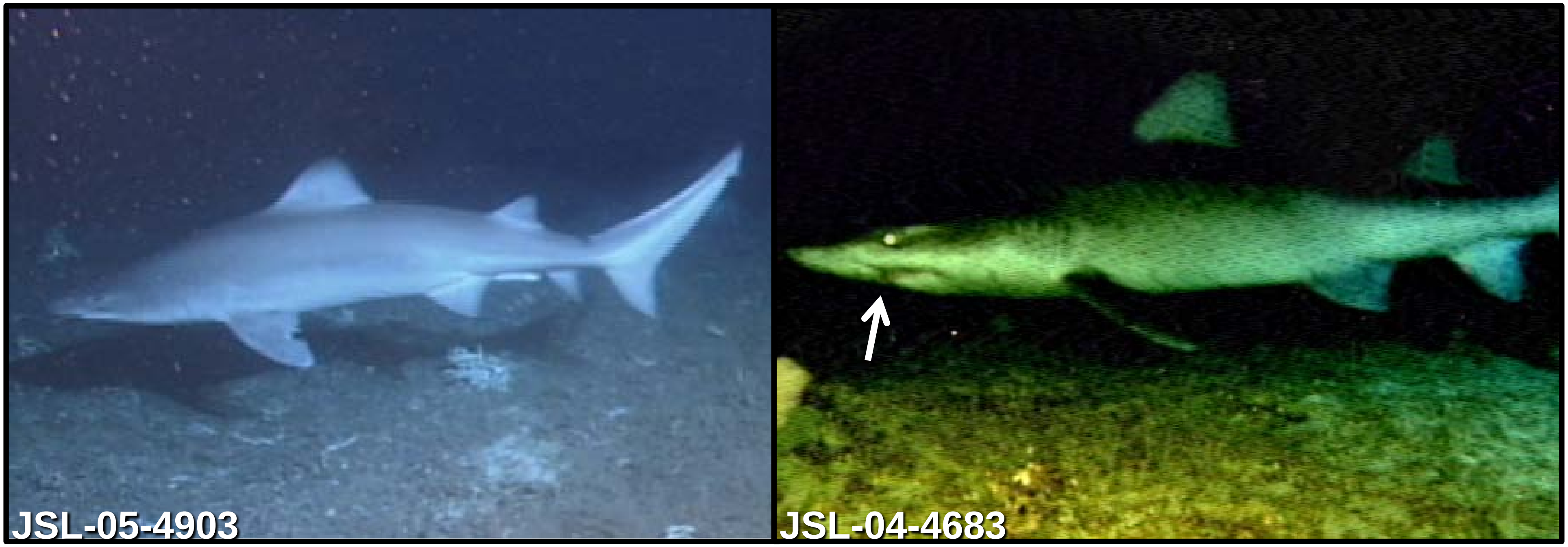
Snout & head very broad; 1st & 2nd dorsal fins equal in size; posterior margins of dorsal fins white

Squalus cubensis **(Cuban dogfish)**

Snout & head narrow; 2nd dorsal fin smaller than 1st; upper portion of dorsal fins black

Odontaspididae (sand tigers)

Large sharks; high dorsal fins; anal fin present



Odontaspis ferox (ragged-tooth shark)

Snout bulbous; protruding spike-like teeth; 1^{st} dorsal fin larger than 2^{nd}; 1^{st} dorsal closer to pectoral-fin than to pelvic-fin bases; color grey to grey brown above, lighter below

Scyliorhinidae (cat sharks)

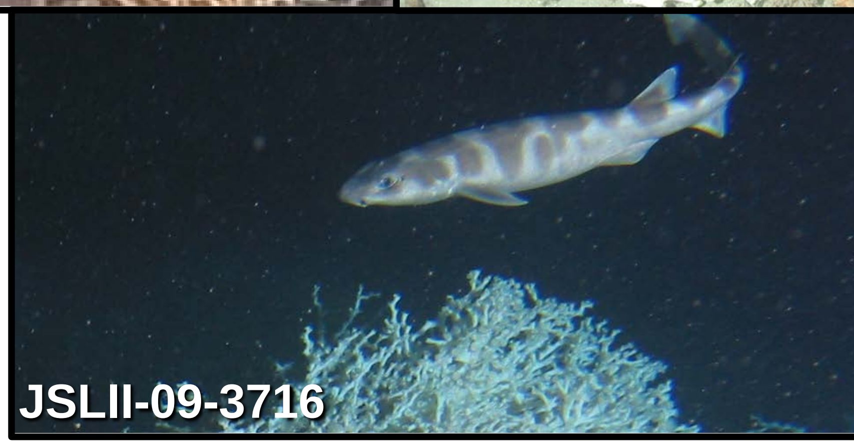
Small sharks; 1st dorsal originates over pelvic fin; usually with dark spots, blotches, bars or saddles

Scyliorhinus hesperius **(whitesaddled catshark)**

2nd dorsal fin smaller than 1st; numerous white spots on back; dark saddle marks conspicuous

Scyliorhinidae (cat sharks)

Small sharks; 1st dorsal originates over pelvic fin; usually with dark spots, blotches, bars or saddles

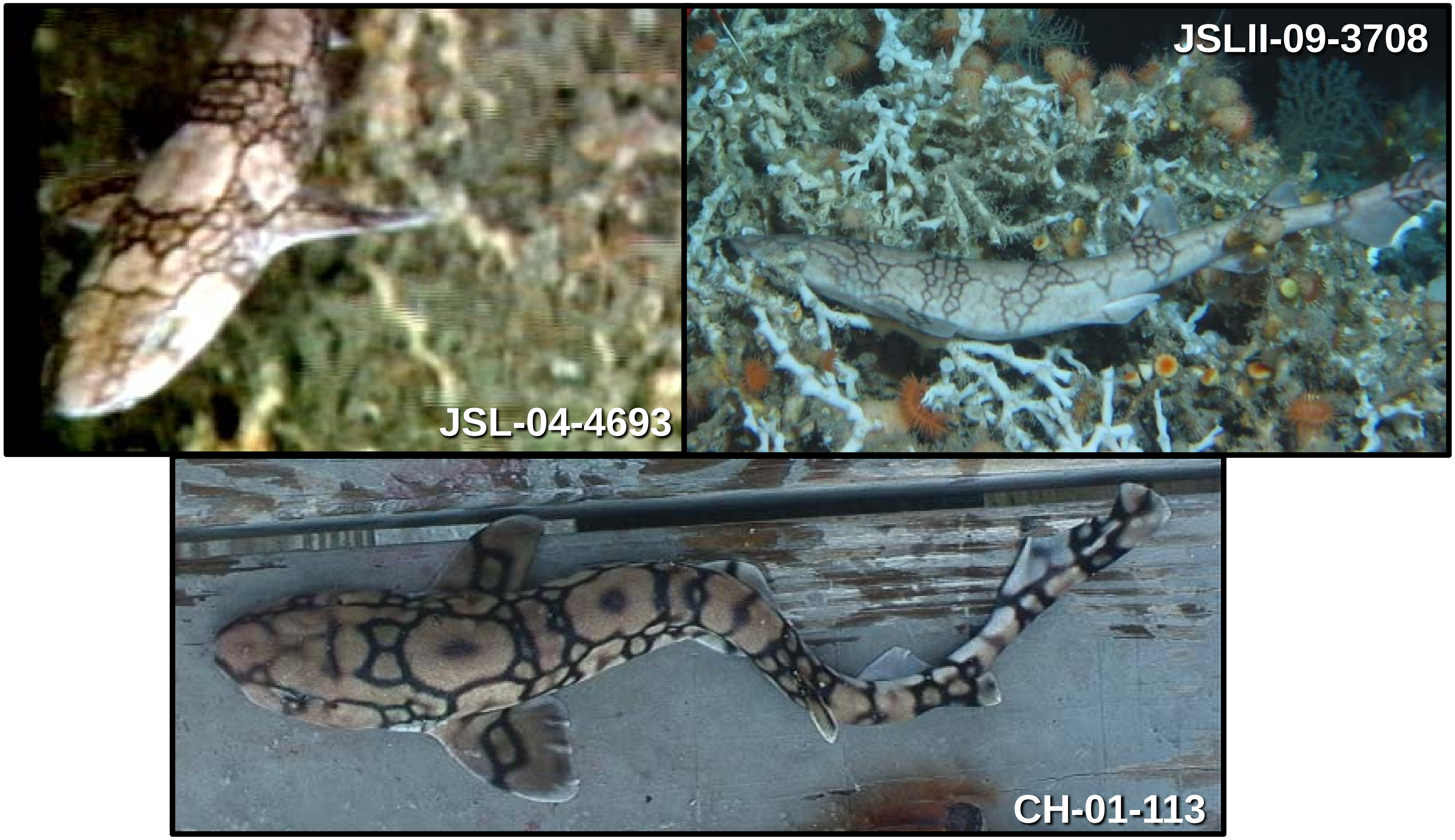


Scyliorhinus meadi (blotched catshark)

2nd dorsal fin smaller than 1st; ground color brown with darker saddles

Scyliorhinidae (cat sharks)

Small sharks; 1st dorsal originates over pelvic fin; usually with dark spots, blotches, bars or saddles

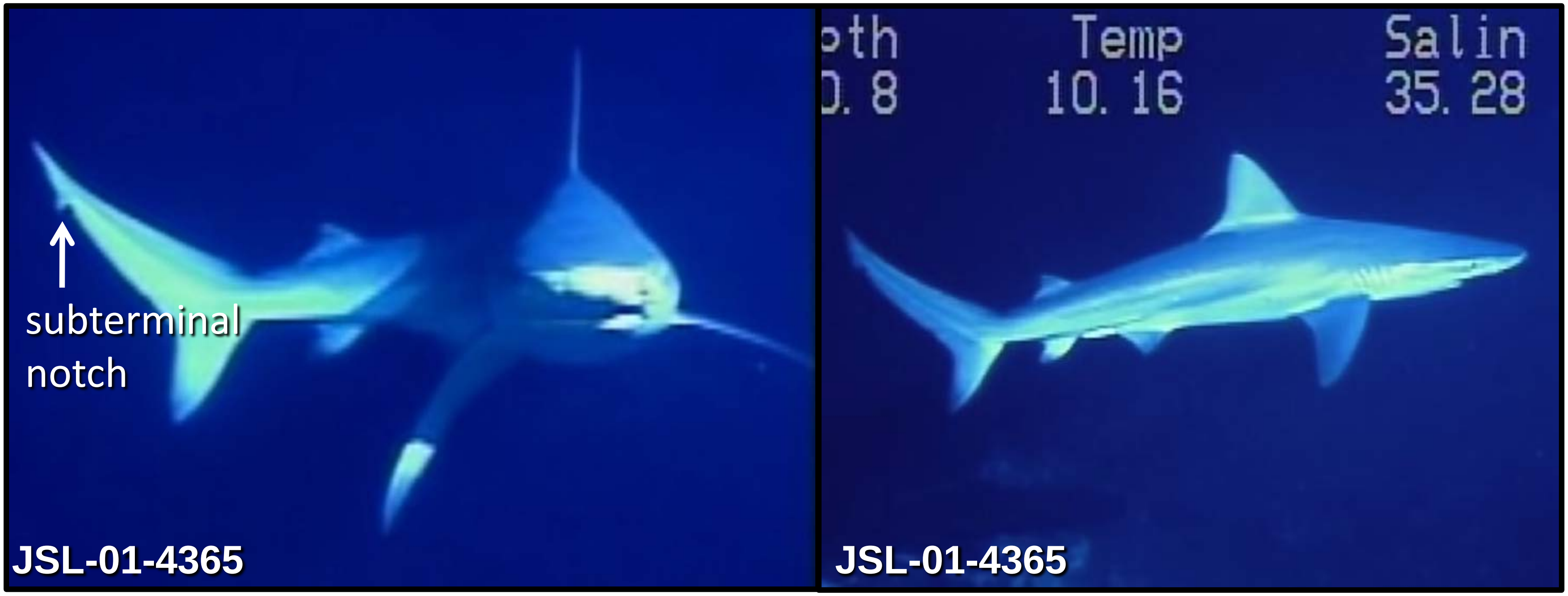


***Scyliorhinus retifer* (chain catshark)**

Color pattern of dark lines in reticular pattern

Carcharhinidae (requiem sharks)

Mouth extends beyond eyes; 1st dorsal high, 2nd dorsal small; subterminal notch present; anal fin present

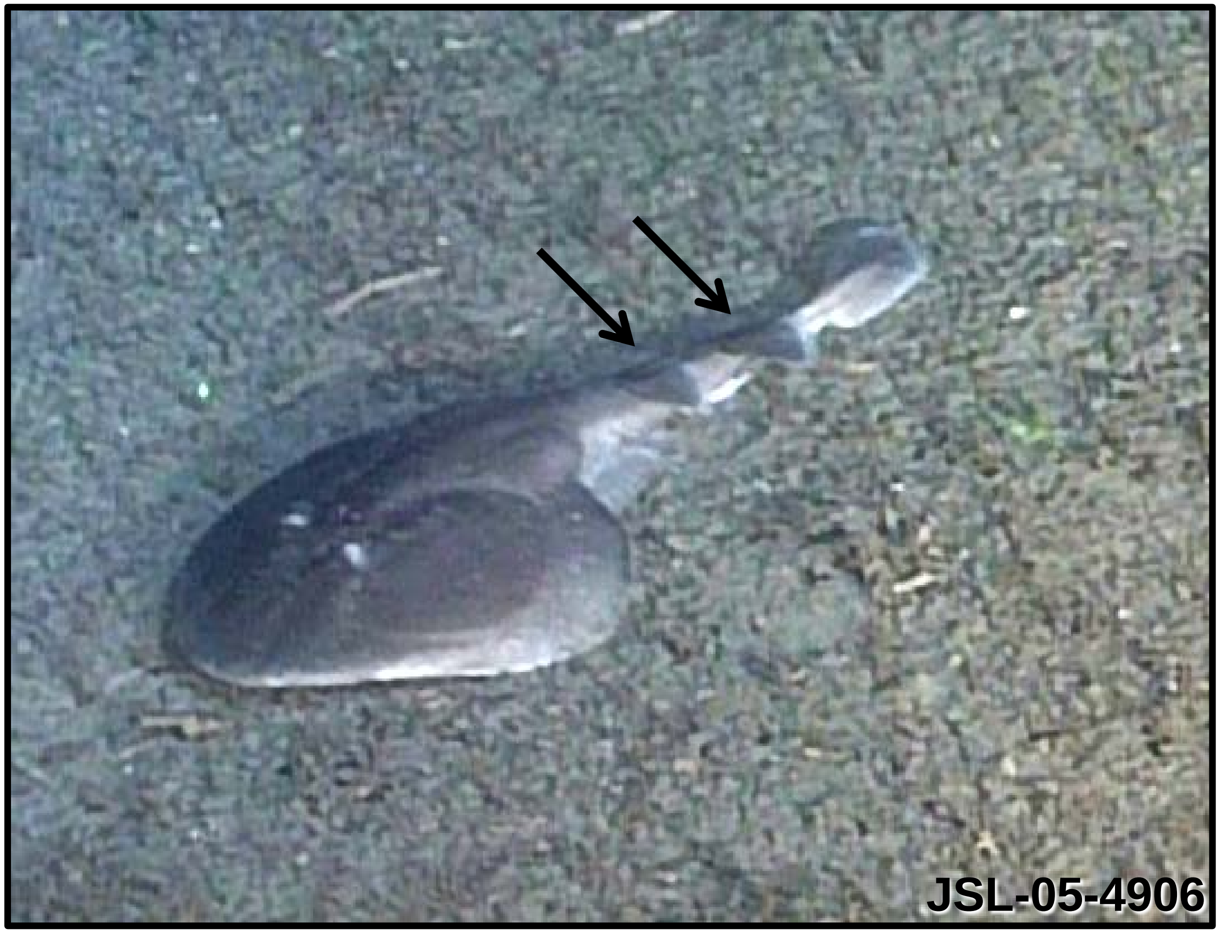


Carcharhinus altimus (bignose shark)

1st dorsal moderately high; pectoral fins long; back is grey, belly white, inner corners of pectoral fins black

Narcinidae (electric rays)

Disc moderately thick; 2 equal sized dorsal fins; anterior contour of disc rounded



Benthobatis marcida **(blind torpedo)**

Eyes minute, almost entirely concealed by skin; uniform in color

Rajidae (skates)

Rhombic or heart-shaped disc; tail slender; pelvic fins bilobed; 2 small dorsal fins

Breviraja claramaculata
(brightspot skate)

Dorsal surface of disc tan with 4-8 symmetrically arranged circular white spots

Dactylobatus armatus
(skilletskate)

Dorsal surface of disc brownish grey with black blotches

Rajidae (skates)

Rhombic or heart-shaped disc; tail slender; pelvic fins bilobed; 2 small dorsal fins

Fenestraja plutonia (Pluto skate)

Dorsal surface pale brown to purplish brown with irregular dark blotches over disc and cross-bands on tail

Unidentified Skate

Rhombic or heart-shaped disc; tail slender; pelvic fins bilobed; 2 small dorsal fins

Rajidae

Chimaeridae (chimaeras)

Large head; blunt snout; tail tapering to elongate filament; large eyes; large pectoral fins

Chimaera monstrosa **(rabbit fish)**

Mottled brown with white; 1st dorsal fin short-based with strong spine; caudal fin present

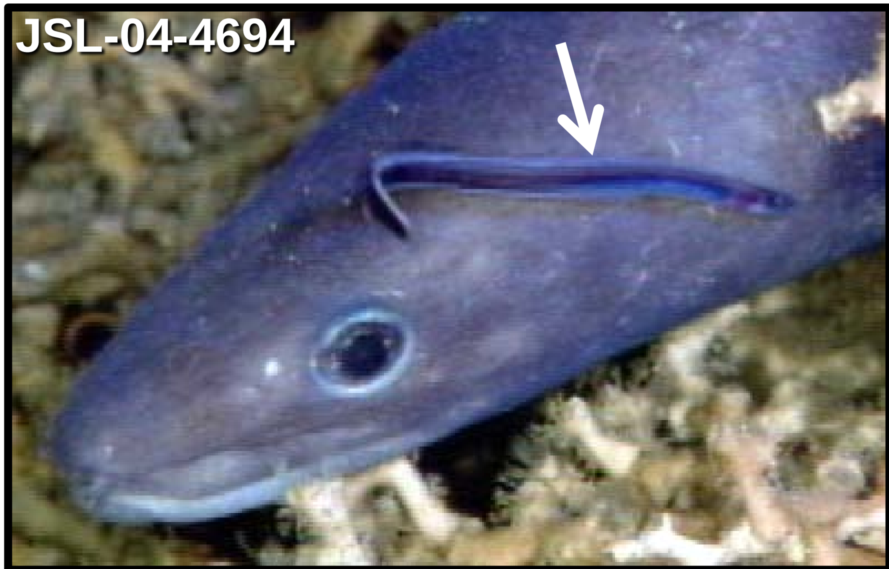
Synaphobranchidae (cutthroat eels)

Small to medium size; mouth extends beyond eyes; dorsal and anal fins well developed; eyes well developed

Note: Species of *Synaphobranchus* can’t be distinguished visually, leave at *Synaphobranchus* sp.

Synaphobranchidae (cutthroat eels)

Small to medium size; mouth extends beyond eyes; dorsal and anal fins well developed; eyes well developed

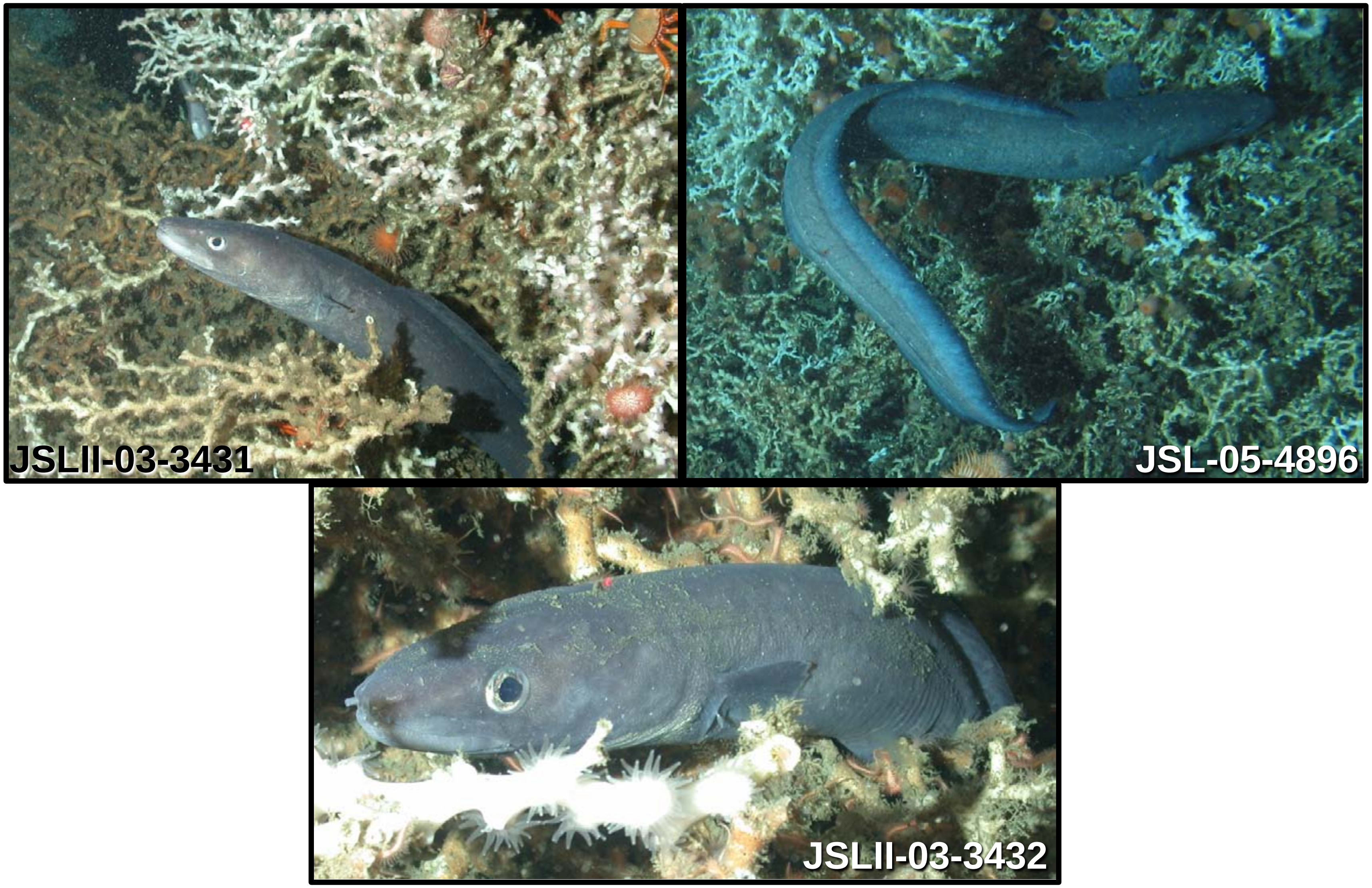


Dysommina rugosa

Body black or dark in color; dorsal, anal & caudal fins white in color

Congridae (conger eels)

Medium to large size; round in cross-section; eyes well developed; dorsal, anal & caudal fins present



Conger oceanicus **(conger eel)**

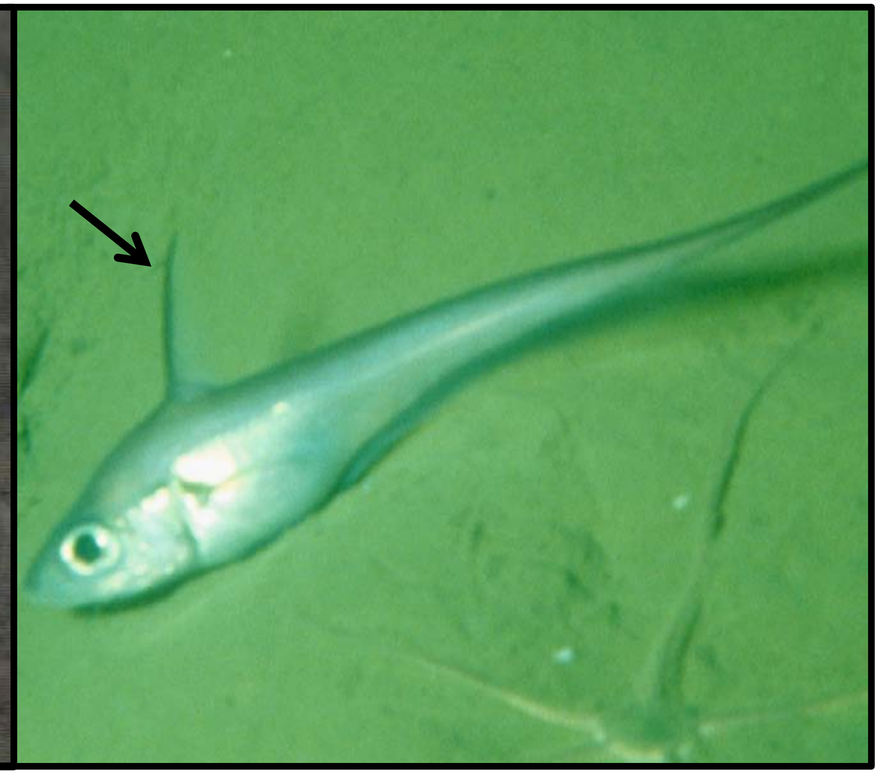
Nettastomatidae (duckbill eels)

Small to medium size; head slender; snout elongate; eyes well developed; tail slender, attenuate; dorsal & anal fins edged in black especially posteriorly

Nettenchelys exoria

Macrouridae (grenadiers)

Tail tapers to slender point; eyes large;1st dorsal high, 2nd dorsal long-based; silvery along sides of head and body

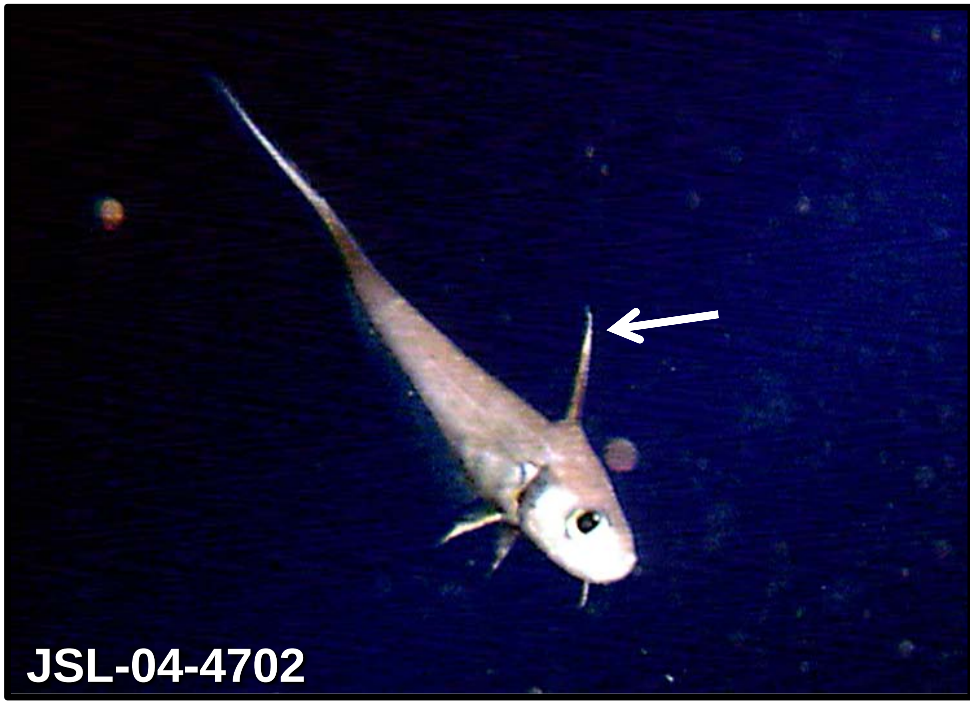


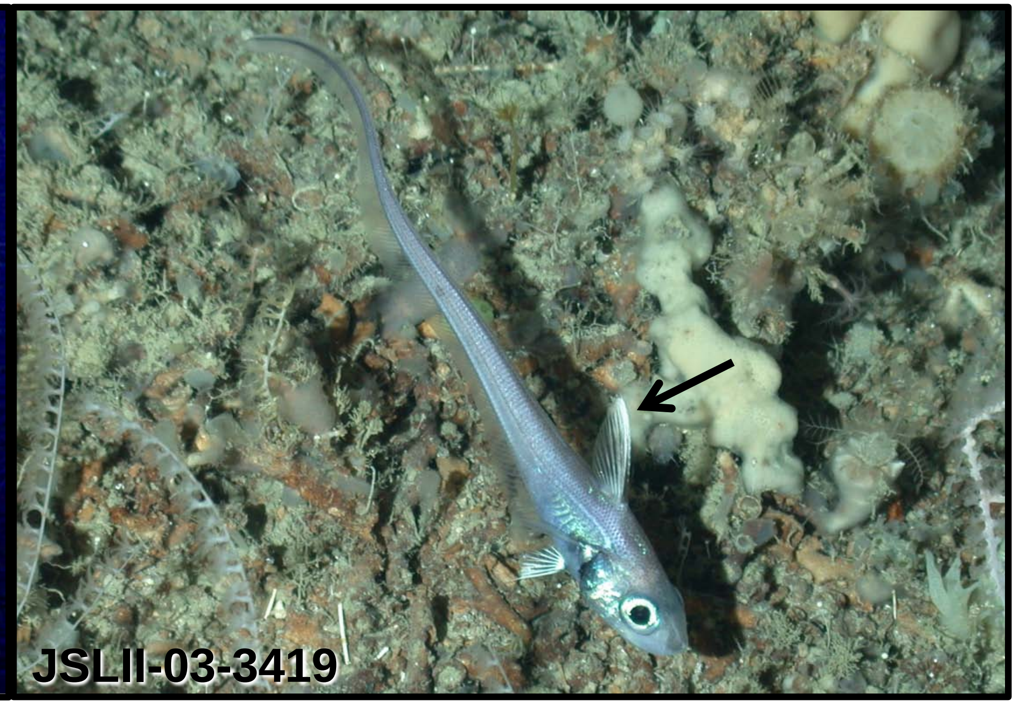
Nezumia aequalis
(common Atlantic grenadier)
1st dorsal fin with prominent black tip

Nezumia bardii
(marlin-spike grenadier)
1st dorsal fin with black membrane between 1st dorsal spine and 1st dorsal ray

Macrouridae (grenadiers)

Tail tapers to slender point; eyes large;1st dorsal high, 2nd dorsal long-based; silvery along sides of head and body





Nezumia sclerorhynchus (bluntsnout grenadier)

Tip of 1st dorsal spine white

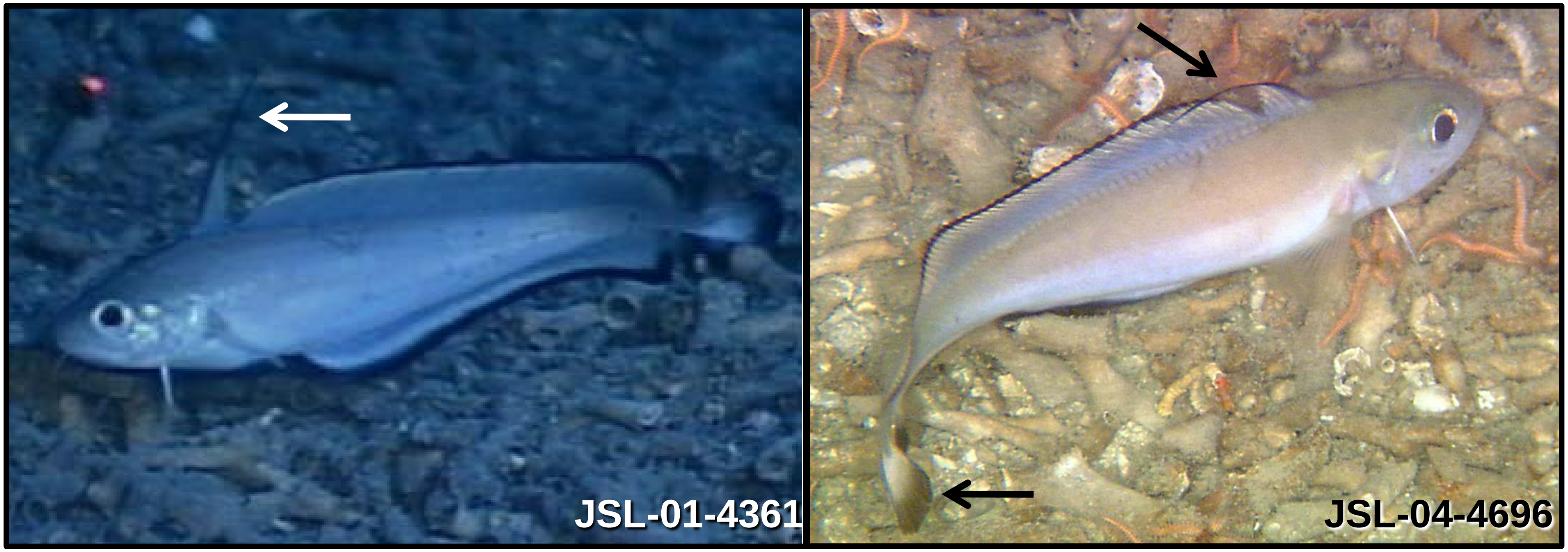
Macrouridae (grenadiers)

Tail tapers to slender point; eyes large;1st dorsal high, 2nd dorsal long-based; silvery along sides of head and body

***Nezumia* sp.**

Moridae (codlings)

Large eyes; 1st dorsal triangular, 2nd dorsal long-based; anal fin long-based; pelvic fins thoracic; narrow caudal peduncle; small caudal fin

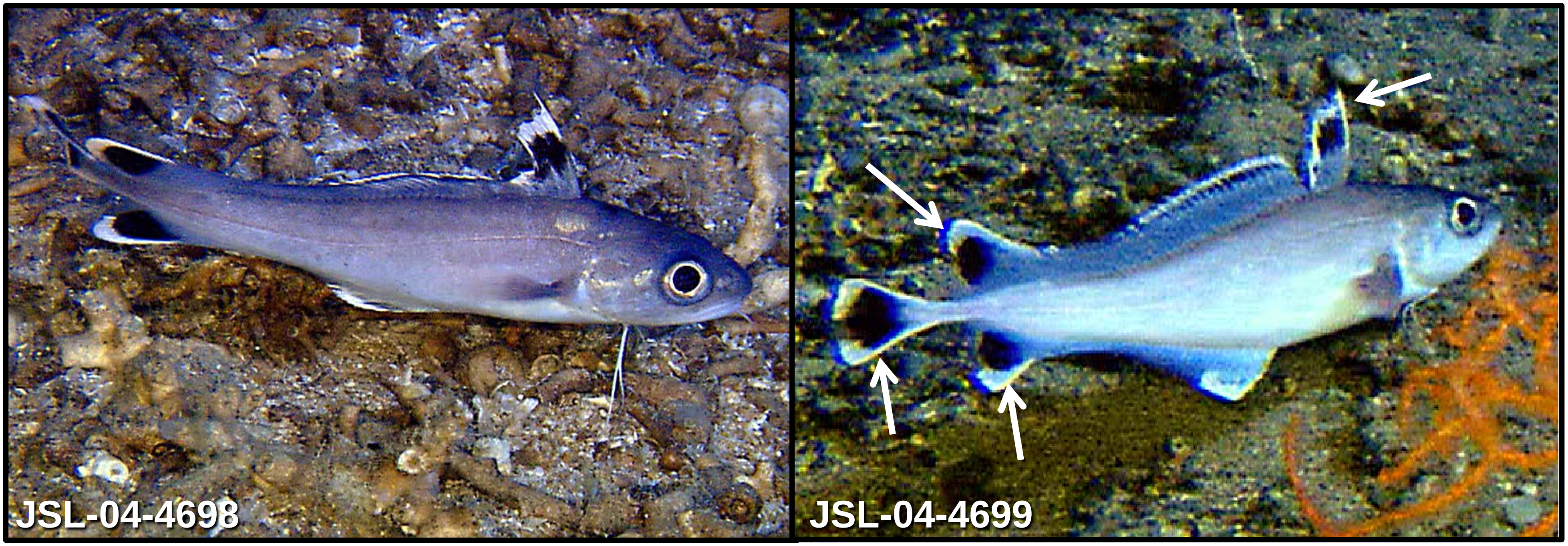


***Laemonema barbatulum* (shortbeard codling)**

Distal end of caudal fin black; prolonged black spine on 1st dorsal fin

Moridae (codlings)

Large eyes; 1st dorsal triangular, 2nd dorsal long-based; anal fin long-based; pelvic fins thoracic; narrow caudal peduncle; small caudal fin



Laemonema melanurum (coral hake)

Distal 2/3 of caudal fin & triangular shaped areas at posterior end of 2nd dorsal & anal fins black with white margins

Moridae (codlings)

Large eyes; 1st dorsal triangular, 2nd dorsal long-based; anal fin long-based; pelvic fins thoracic; narrow caudal peduncle; small caudal fin

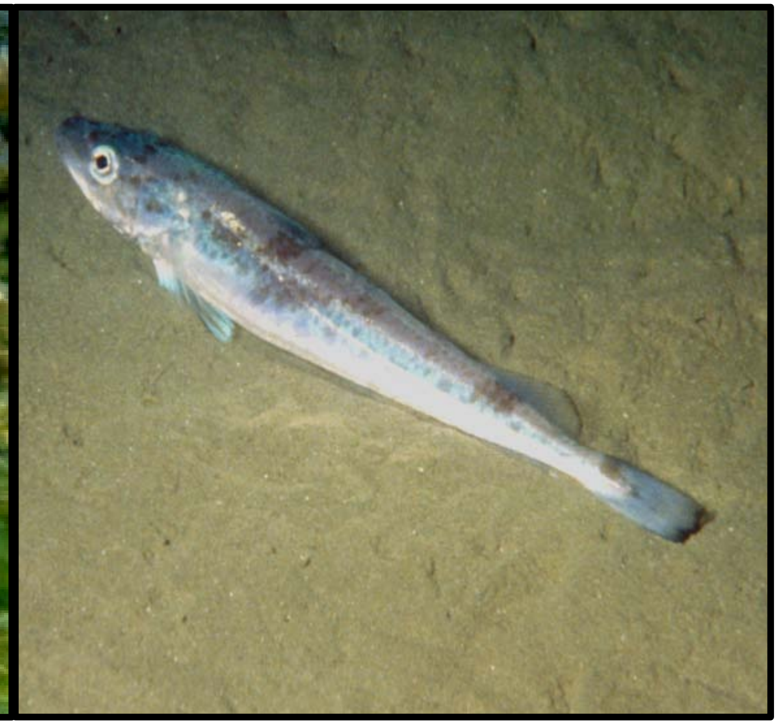
Physiculus fulvus
(metallic codling)

Physiculus karrerae

Note: Species of *Physiculus* can't be distinguished visually, leave at *Physiculus* sp.

Merlucciidae (merlucciid hakes)

Mouth large; 1st dorsal short, triangular; 2nd dorsal & anal fin long-based & notched near midlength; caudal fin well developed, weakly forked; silver in color with dark blotches



Merluccius albidus **(offshore hake)**

Often seen lying straight and stiff on habitat

Lophiidae (goosefishes)

Mouth very large & wide; lower jaw projecting, numerous sharp teeth; head & anterior part of body depressed & very broad; skin often with fleshy flaps on head &/or body; pelvic fins on ventral surface of head anterior to pectoral fins; 1st cephalic spine modified into angling apparatus with esca

Lophiodes beroe

Reddish to reddish brown background pigmentation with pale or white blotches; black illicium with pale esca

Chaunacidae (gapers)

Body rounded with very loose, flaccid skin; head very large & bearing open lateral-line canals; single short spine modified as angling apparatus located just behind snout; mouth large; generally pink, reddish, orange or rose-colored

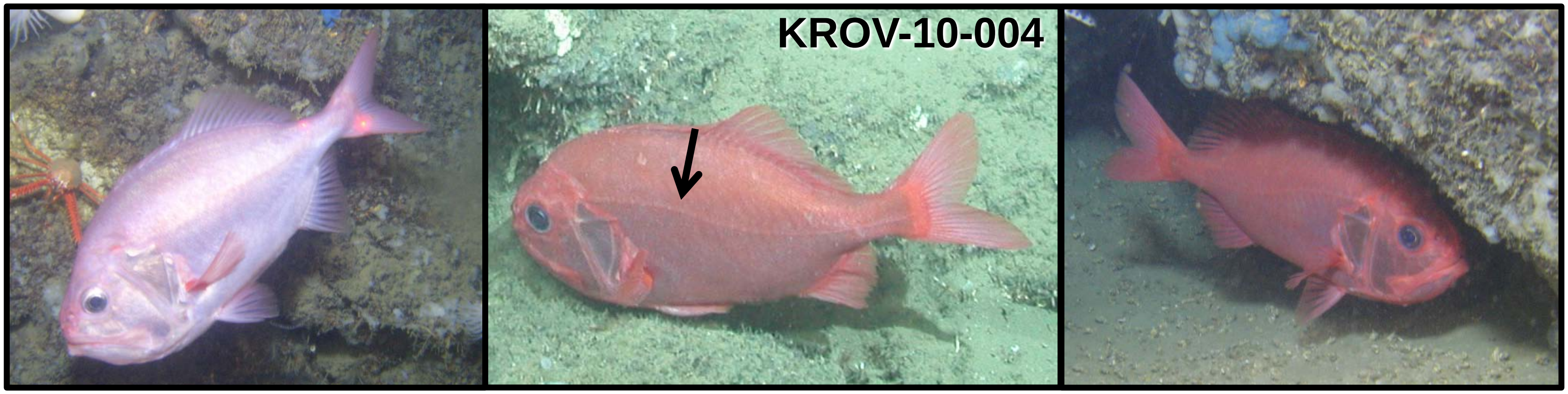
Chaunax stigmaeus **(redeye gaper)**

Rose or reddish-orange pigment; found on coral rubble or hard substrate

Note: Species of *Chaunax* can't be distinguished visually

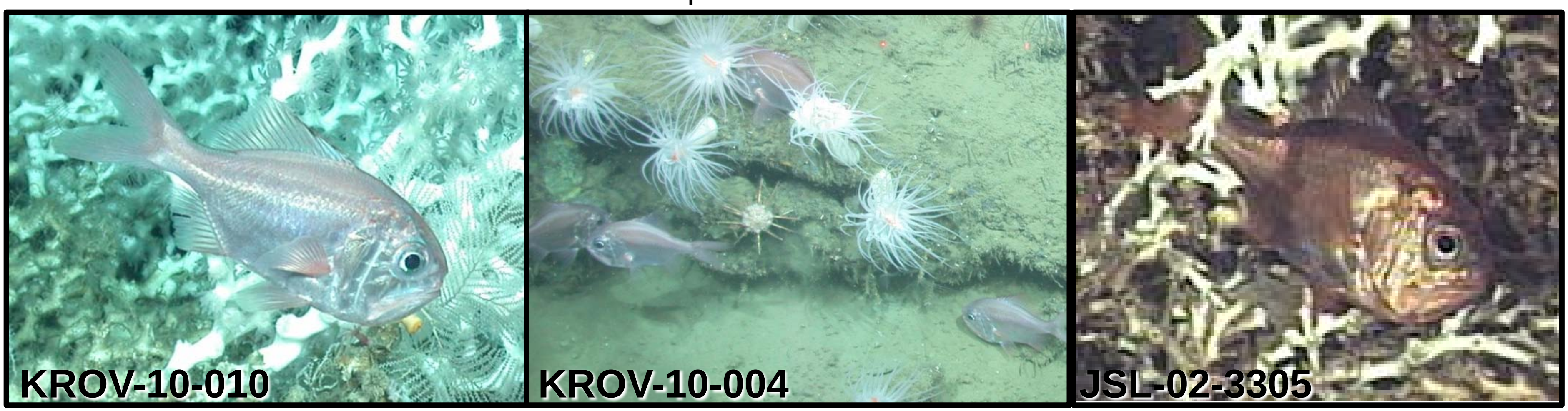
Trachichthyidae (roughies)

Body oval, laterally compressed; head, eyes & mouth large; extensive sensory canals; flat, triangular spine on preopercle; reddish orange, pinkish or dusky silver in color



Gephyroberyx darwinii **(big roughy)**

Lateral line scales slightly larger than body scales; prominent spine on opercle; dark spot at base of pectoral fins



Hoplostethus occidentalis **(western roughy)**

Lateral line scales much larger than body scales; no prominent spine on opercle; pinkish in color

Berycidae (alfonsinos)

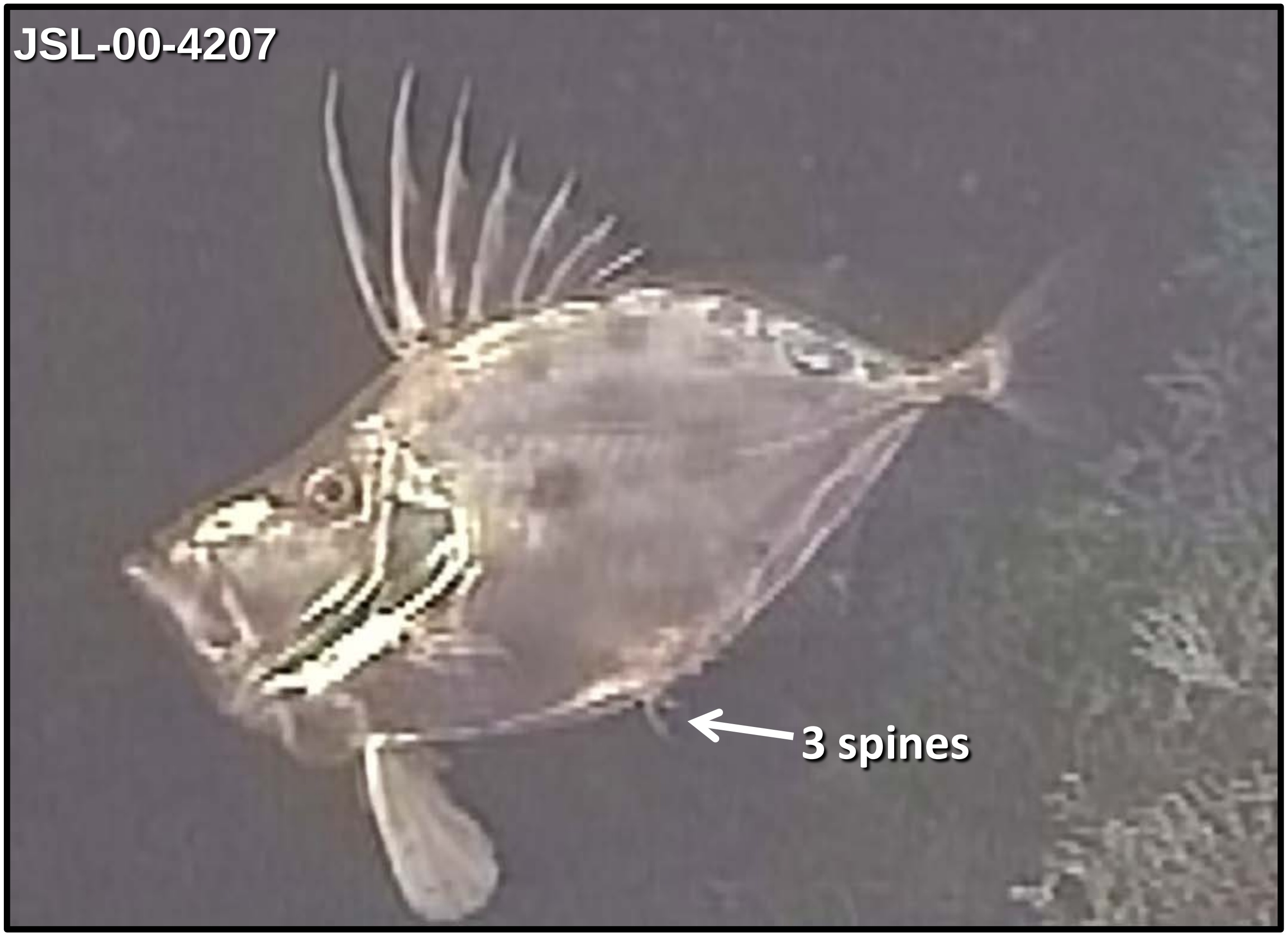
Body oval, laterally compressed; head, eyes & mouth large; no spines on preopercle; bright red on head, back & fins, silvery pink on lower sides & belly

Beryx decadactylus **(red bream)**

Bright red in color & deeper body than *B. splendens*

Zeidae (dories)

Body oval, greatly compressed; caudal fin convex; mouth large, oblique

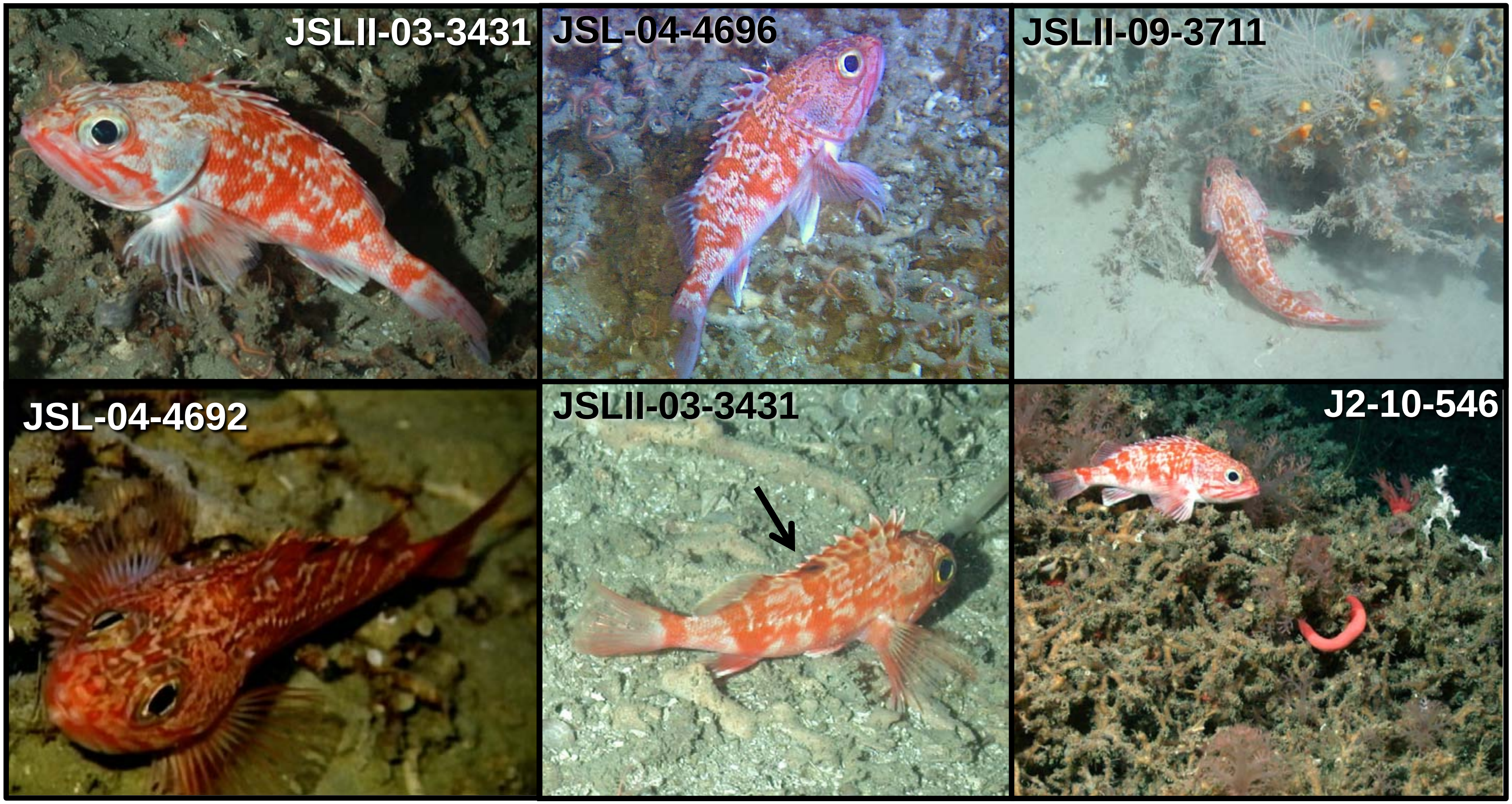


Zenopsis conchifera (**buckler dory)**

Body silvery; 3 anal spines

Scorpaenidae (scorpionfishes)

Mouth large; numerous head spines; dorsal fin with strong spines; large pectoral fins; strongly camouflaged, red or reddish brown in color with mottled color patterns



Helicolenus dactylopterus **(blackbelly rosefish)**

Dark red and white bars on body; small specimens have black spot on dorsal fin

Scorpaenidae (scorpionfishes)

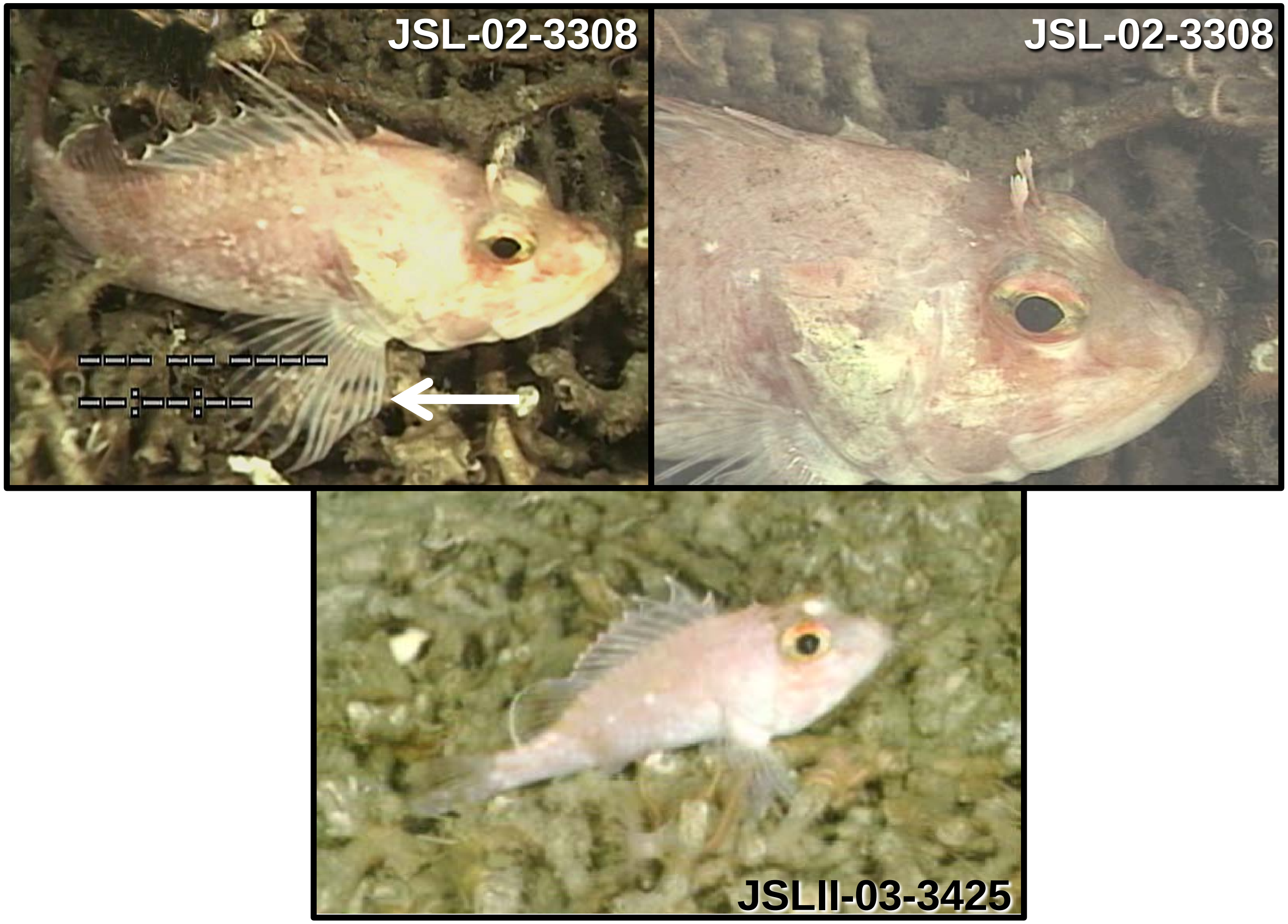
Mouth large; numerous head spines; dorsal fin with strong spines; large pectoral fins; strongly camouflaged, red or reddish brown in color with mottled color patterns

Idiastion kyphos

Mostly red; strong head spines; juveniles have white blotch on upper back & caudal peduncle

Scorpaenidae (scorpionfishes)

Mouth large; numerous head spines; dorsal fin with strong spines; large pectoral fins; strongly camouflaged, red or reddish brown in color with mottled color patterns

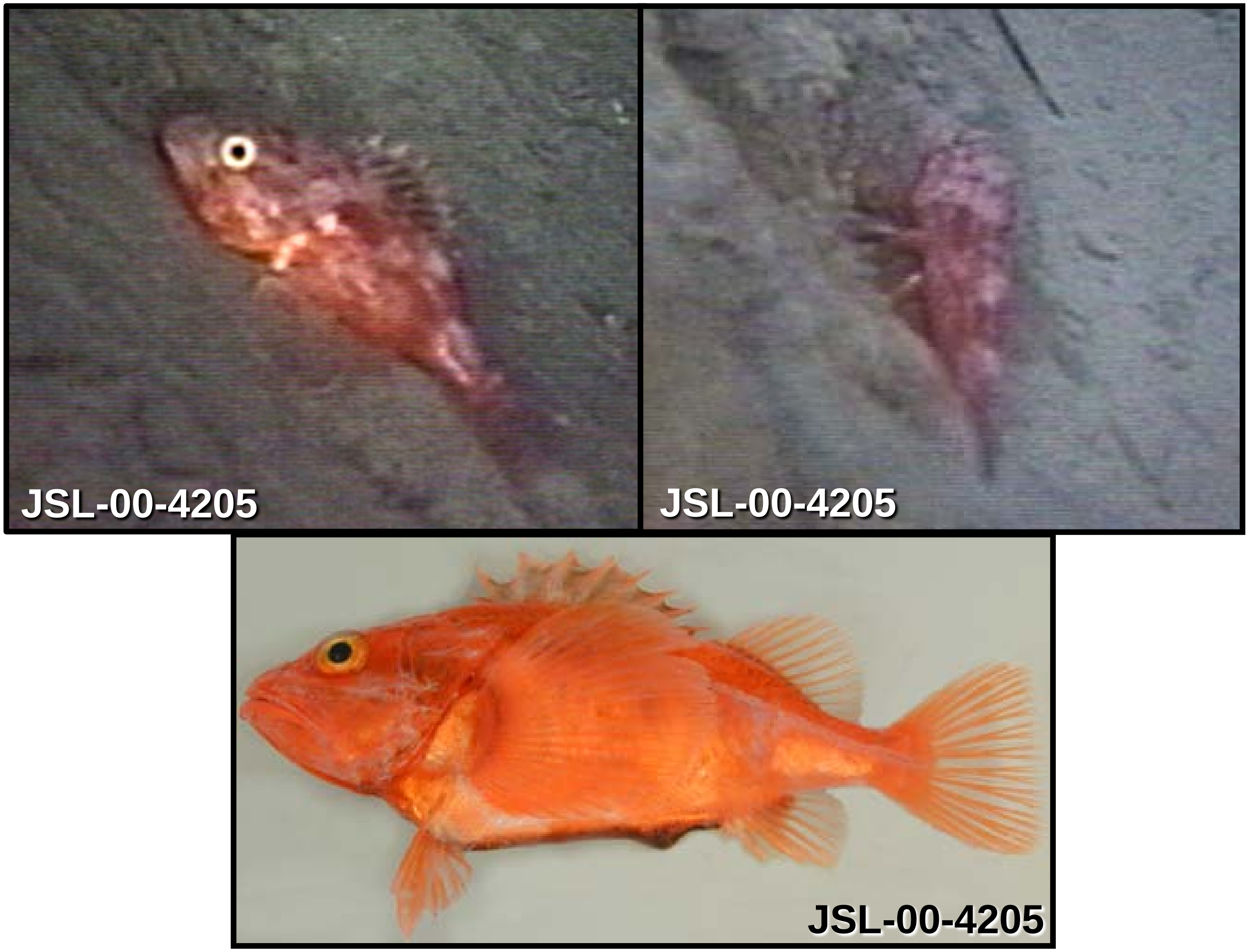


Pontinus rathbuni **(highfin scorpionfish)**

All pectoral-fin rays unbranched

Scorpaenidae (scorpionfishes)

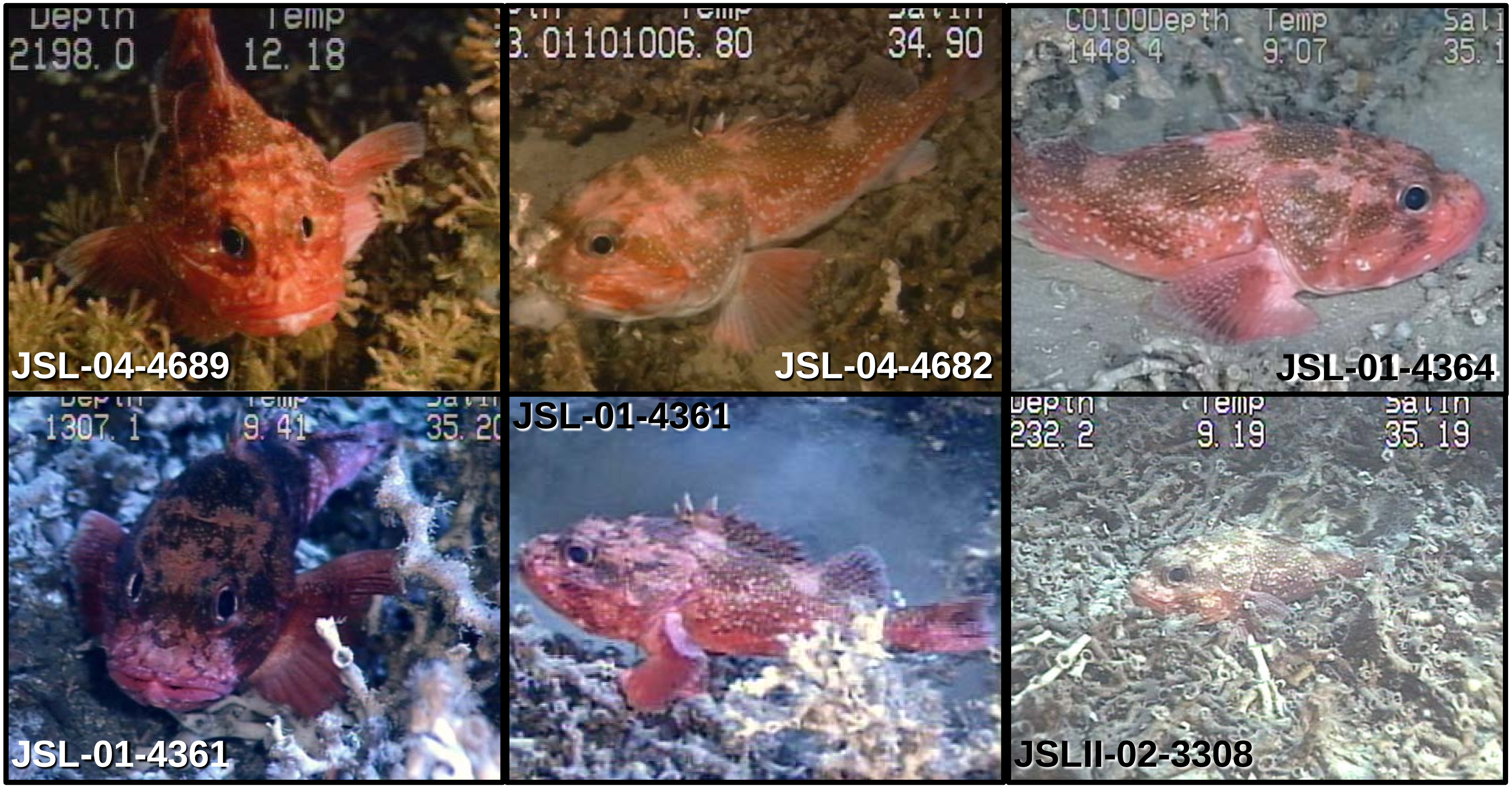
Mouth large; numerous head spines; dorsal fin with strong spines; large pectoral fins; strongly camouflaged, red or reddish brown in color with mottled color patterns



Setarches guentheri **(channeled rockfish)**

Scorpaenidae (scorpionfishes)

Mouth large; numerous head spines; dorsal fin with strong spines; large pectoral fins; strongly camouflaged, red or reddish brown in color with mottled color patterns

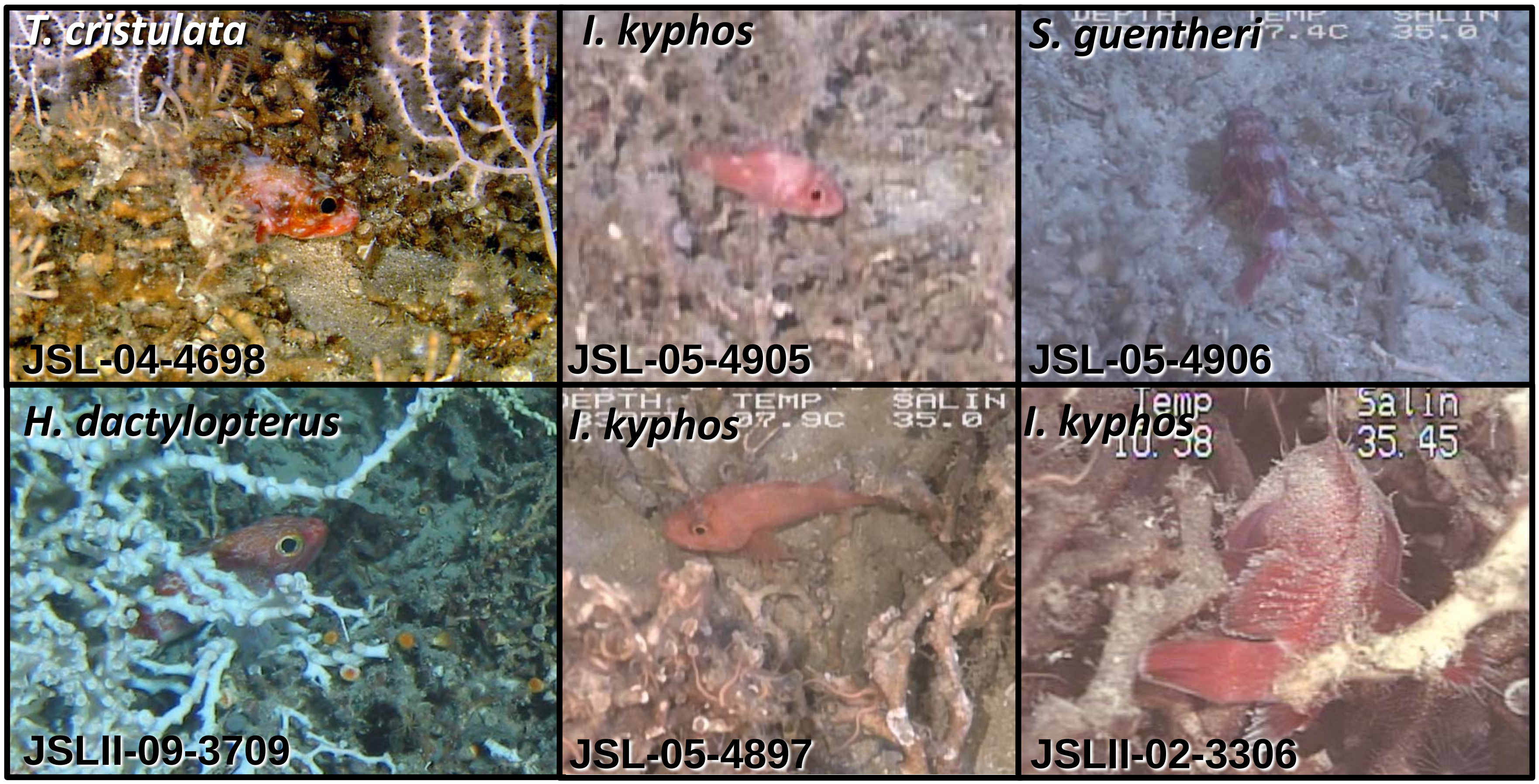


Trachyscorpia cristulata (Atlantic thornyhead)

Pectoral fin square-cut with longest rays near upper edge of fin; head large; reddish with brown blotches & small white spots

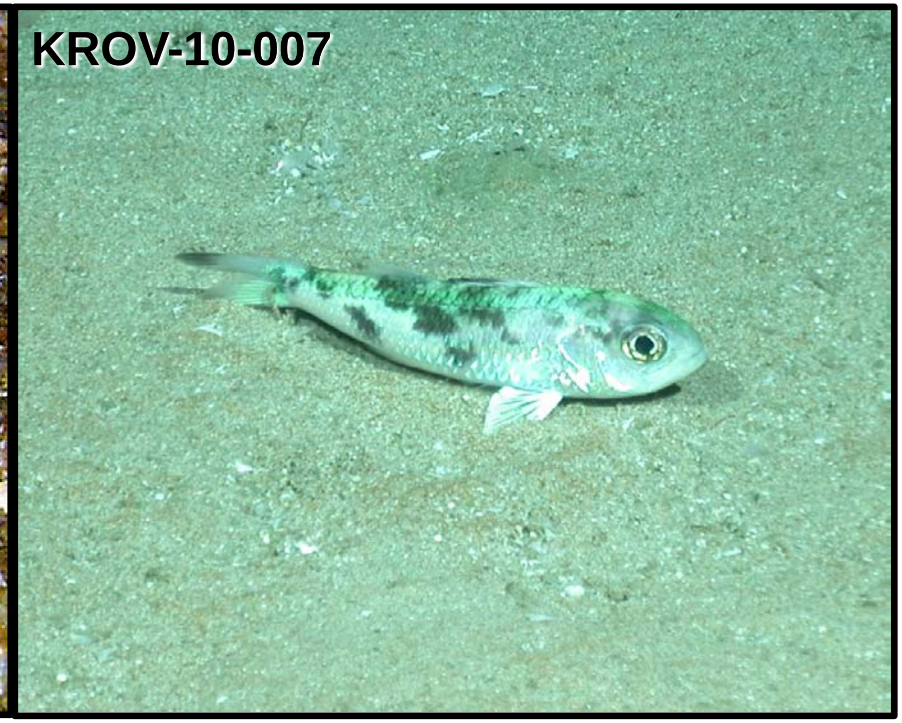
Scorpaenidae

Mouth large; numerous head spines; dorsal fin with strong spines; large pectoral fins; strongly camouflaged, red or reddish brown in color with mottled color patterns



Acropomatidae (lanternbellies)

Oblong body; mouth large; caudal fin forked; dusky silver with black blotches



***Synagrops* sp.**

Note: Species of *Synagrops* can't be distinguished visually

Polyprionidae (wreckfishes)

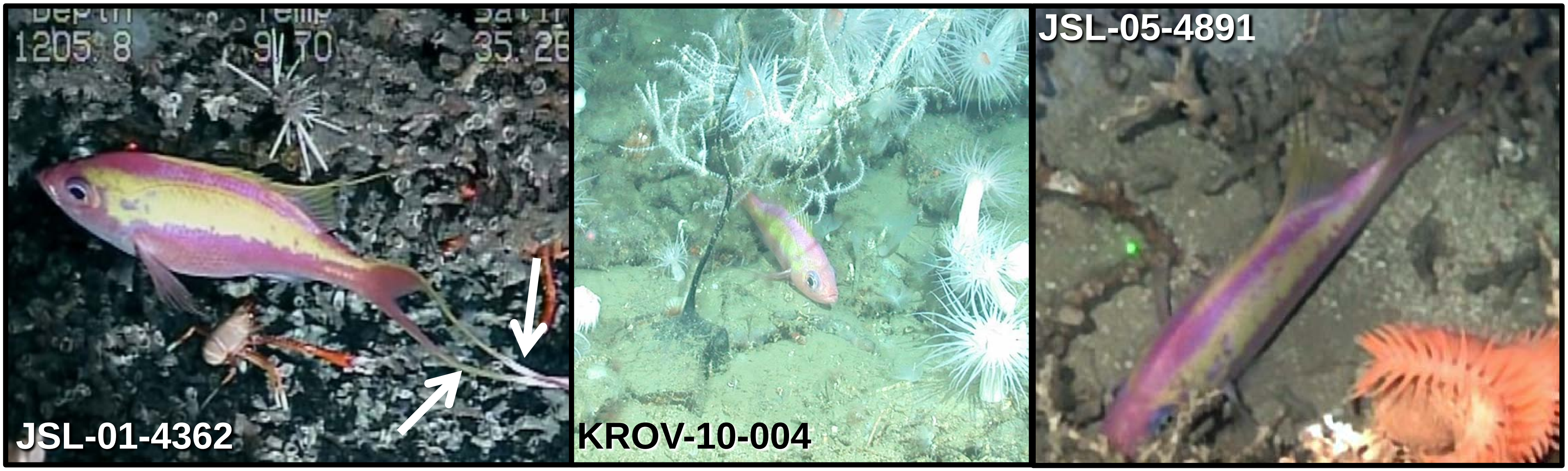
Large, fairly deep-bodied and grouper-like; mouth terminal, lower jaw projecting; dorsal with strong spines

Polyprion americanus **(wreckfish)**

Adults dark grey above, lighter below; juveniles mottled light & dark grey

Serranidae (sea basses & groupers)

Caudal fin forked, lunate, emarginate, truncate, or rounded; mouth moderate to large, terminal; dorsal fin single; color is variable; many species capable of rapid color changes



Anthias woodsi (swallowtail bass)

Caudal fin deeply forked, upper and lower lobes filamentous & long; mostly rose with broad yellow band originating on opercle; dorsal fin yellow in color