MEGA- TO MICRO-SCALE CLASSIFICATION AND DESCRIPTION OF BOTTOMFISH ESSENTIAL FISH HABITAT ON FOUR BANKS IN THE NORTHWESTERN HAWAIIAN ISLANDS

BY

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ABSTRACT

We coupled multibeam sonar data with submersible and remotely operated vehicle (ROV) observations to classify and describe bottomfish essential fish habitat (EFH) on four banks in the Northwestern Hawaiian Islands Coral Reef Ecosystem Reserve (NWHICRER). From 2001 to 2003, a total of 22 *Pisces IV* and *V* dives along with 37 *RCV-150 ROV* dives were conducted on Raita Bank, W. St. Rogatien Bank, Brooks Bank, and Bank 66 to evaluate the impacts of bottomfishing on these banks. In the process of addressing that issue, extensive data were collected on the biological communities and substrate characteristics within the EFH depth range of 100 to 400 meters. Multibeam mapping was conducted between dives from the submersible support ship "*KOK*" as well as during a separate cruise on the RV *Kilo Moana*. All four banks had relatively flat featureless tops (i.e., <5 % slopes) which extended down to a depth of 120 m. ROV dives revealed that the area between 100-120 m was characterized by sediment interspersed with rhodoliths and carbonate outcrops. At this depth on Raita, W. St. Rogatien, and Brooks Bank, the slope increased to 25-60 degrees, which continued down to 300-400 m. The substrate on these slopes was carbonate bedrock interspersed with flats and channels. Ten sponge, 64 cnidarian, 1 ctenophore, 49 echinoderm, 15 mollusk, 30 crustacean, 3 tunicate, and 152 fish species were observed during the dives. A distinct transition occurred between shallow-water and deep-water fish families within this depth range that may be temperature related.

INTRODUCTION

The term EFH was defined by Congress as "those waters and substrate necessary to fish for spawning, breeding, feeding, or growth to maturity" (16 U.S.C. 1802(10). According to the EFH website maintained by the National Oceanic and Atmospheric Administration (NOAA), National Marine Fisheries Service (NMFS), "waters" in the definition refers to the "aquatic areas and their associated physical, chemical, and biological properties that are used by fish." "Substrate" refers to "sediment, hard bottom, structures underlying the waters, and associated biological communities," and "spawning,

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breeding, feeding, or growth to maturity" encompasses the full life cycle of the fish. EFH is therefore a term that blends together the more basic concepts of "habitat", which have traditionally been used to describe just the physical aspects of an environment, with "ecosystem", which has been used to describe the biological communities and their interactions, and the physical properties of an environment. The concept of EFH was created in an attempt to advance the application of ecosystem-based approaches to fishery management (Park, 2002). To develop an EFH definition for a managed fish species, the task is to describe not only substrate and hydrological features but also the other living organisms (e.g., fish, invertebrates, and algae) living in association with that species.

Hawaiian bottomfish are a group of federally managed species, most of which are commercially valuable deep-slope snappers. The NMFS is presently engaged in refining its EFH definition for this fishery, which for years has been simply the 100-400 m depth zone around each island and bank within the Hawaiian Archipelago. Studies on benthic habitats and their biological communities are typically approached by coupling seafloor mapping with direct observations and/or benthic sampling (Greene et al., 1999). The bottomfish EFH depth range precludes optical mapping techniques and SCUBA, requiring instead the use of acoustic mapping techniques coupled with manned and/or unmanned deepwater vehicles. The costs associated with these types of operations have prevented examination of all but a few specific sites. Furthermore, multibeam mapping and direct observations have been carried out opportunistically and usually in conjunction with other mission priorities. Even so, valuable data have been obtained for use in creating a more accurate and specific EFH definition for this fishery. In this paper we initiate the development of a mega- to micro-scale classification and description of bottomfish EFH by providing a summary of acoustic mapping data and submersible/ROV observations obtained on bottomfish habitats in the Northwestern Hawaiian Islands (NWHI).

MATERIALS AND METHODS

During September-November, 2001-2003, three cruises were conducted in NWHICRER on the Hawaii Undersea Research Laboratory's (HURL) submersible support ship, *Kaimikai-o-Kanaloa* (*KOK*). These cruises had two tasks: a) to map the 100-fathom contour around Raita Bank, W. St. Rogatien Bank, Brooks Bank, and Bank 66 to obtain a more accurate position for each bank, and b) to obtain *in situ* observations of bottomfish fishing sites for use in evaluating the impacts of bottomfishing on the banks. The first task was carried out with the *KOK*'s SeaBeam 210 multibeam sonar mapping system while the second was carried out with HURL's manned and unmanned deepwater vehicles.

Multibeam Sonar Data

Mega- (1-10 km) and meso-scale (10 to 1000 m) features of the bottomfish EFH on the four banks were revealed from multibeam sonar data obtained in conjunction with submersible operations. The SeaBeam multibeam system on board the submersible support ship *KOK* was used to map the 100-fathom contour around Raita and W. St. Rogatien banks between submersible and ROV dives. During this process, a large portion of the bottomfish EFH was covered. These data, which include only bathymetry, were processed using the freeware multibeam sonar processing and plotting packages MB-System (Caress and Chayes, 1996) and the generic Mapping Tools [GMT] (Wessel and Smith, 1991). Manual and/or automatic bathymetric "ping" editing was carried out on the data to reduce outliers, followed by gridding of the swath data collected in various years. The optimum grid cell size was used for the target water depth, usually 10-20 meters, along with running a median filter of minimum width over the grids to further reduce noise while maintaining maximum resolution. The data were converted into ASCII grids and subsequently imported into ArcGIS where they were layered over digitized NOAA nautical charts. The charts provided a visual reference for understanding the multibeam coverage on each bank.

In Situ Submersible and ROV Data

In situ data within the 100-400 m depth range were obtained during 22 manned *Pisces IV* and *V* submersible dives and 37 unmanned *RCV-150 ROV* dives conducted on the four banks. All vehicles were deployed from the *KOK*. Each 8-hour submersible dive was conducted during the day between 0830-1630 hrs while each ROV dive was conducted at night between 1900-0200 hrs. During submersible dives, temperature, dissolved oxygen (DO), and salinity data were obtained from Seabird CTDs mounted on the vehicles. Macro- and micro-scale geological observations and biological data were obtained during 30-min transects (four per dive) designed to obtain quantitative data on potential bottomfishing impacts (see Kelley et al., submitted for this volume). Transects were conducted at different depths (i.e., T1: 190-210 m, T2: 240-260 m, T3: 290-310 m, and T4: 340-360 m) during which substrate observations as well as counts of fish and invertebrates were made. These data were recorded on the audio tracks of the *Pisces* digital video camera systems along with the submersible's GPS positions at 10-minute intervals. The average length of each transect was 1 km and the average visual range from each side of the sub was 10 m. Each transect therefore covered an area of approximately 2 hectares while each dive covered approximately 8 hectares.

The ROV was typically deployed to conduct 1.6-3.2 kilometer transects over selected survey sites. Two trained observers were present in the ROV control room and tasked with making substrate observations and identifications of fish and invertebrates encountered. The video along with the audio remarks from the observers were recorded throughout the dives on mini-DV video cassettes. After the dives, observer counts from the submersible transects were extracted from the videotapes. However, ROV transect videos were processed only by following HURL's standard ROV video-logging protocol that identifies species encountered during the dives with only rough quantification.

Light, an additional physical factor, changes considerably within the bottomfish EFH depth range. Since we are unaware of any actual light intensity measurements being made on these banks, theoretical values were derived from Wetzel's (2001)

attenuation equation: $I_z = I_0 e^{-kz}$, where
I_z = irradiance at depth z
I_0 = irradiance just below surface (i.e., z = 0)
e = natural logarithm
k = extinction coefficient (0.033 for clear seawater)

NWHICRER waters are known to be extremely clear, and therefore it was assumed that the k value used in this equation would be appropriate.

Bottomfish EFH Classification and Description

Sonar data coupled with substrate observations made from the submersibles and ROV were used to describe the geological aspects of the bottomfish EFH around the banks according to the mega- to micro-scale classification scheme designed by Greene et al. (1999) for deep-water benthic habitats. Hydrological data were analyzed for each 100 m interval. Biological data (i.e., algae, invertebrate, and fish observations) were grouped into taxonomic categories and by abundance.

RESULTS

Multibeam Sonar Data

The multibeam sonar coverage of the EFH around each bank is shown in Figure 1 between black lines. Multibeam data outside of the 100-400 m depth range from a 2002 Kilo Moana mapping cruise, as well as single-beam sonar data obtained on the top of Raita Bank (courtesy of J. Miller), were included in the Raita and W. St. Rogatien images (see Miller et al, 2004). No EFH boundaries are shown for Bank 66, which is located entirely within the 100-400 m depth range. For simplification, each map provides a slope analysis whereby green represents lower and red represents higher slope values. The tops of the banks were generally flat with slope values below 5°. With the exception of Bank 66, all were above 100-m depth. The "break" occurred at approximately 120 m where slope values increased rapidly to over 25°, and in some locations off Raita, over 60°. Steep slopes continued down to varying depths, however, in general, not below the lower 400-m boundary of the bottomfish EFH. Furthermore, the steepest slopes on Raita, W. St. Rogatien, and Brooks were found on the southwest sides of the banks while the lowest slope values were found on the northeast sides. The top of Bank 66 came up to approximately 120 m with the break generally beginning at 170 m. Slope values below the break to a depth of 250-270 m were for the most part between 10-20°. At that point, the slope flattened out to less than 5°, similar to the top.

The multibeam data did not reveal any particularly surprising features on the banks. All four had a relatively homogenous structure consisting of a flat top with a moderately steep slope in the bottomfish EFH that generally flattened out before reaching a depth of 400 m. The one exception was the presence of several small pinnacles found within the northern boundary of the EFH off Raita. These features extended up from the seafloor approximately 40-60 m and it is likely that more will be found when the mapping of the EFH in this area is completed.

Submersible Data

The number of submersible and ROV dives conducted on each bank within the 100- to 400-m depth range are summarized in Table 1. Since more than one dive took place on some sites, the number of sites examined on each bank also is provided. Data from submersible, ROV, or both vehicles, were obtained during a total of 59 dives on 28 different sites.

Observations made during the dives revealed that the substrate within the EFH on all banks consisted of carbonate bedrock interspersed with sediment deposits. The latter were mostly composed of carbonate sand and pebbles with smaller amounts of gravel and cobbles. Not surprisingly, bedrock was predominant just below the break where the slope was the steepest, whereas sediment was predominant above the break as well as deeper, near the lower boundary of the EFH where the slope was flatter (Fig. 2). Low amplitude sediment waves were present even where the sand layer was relatively thin. In these cases, the underlying bedrock was clearly visible in the troughs.

Exposed carbonate bedrock clearly had different levels of complexity (i.e., rugosity + porosity). Bottomfish, as well as many other fish species observed, were typically found in association with high complexity bedrock rather than low complexity bedrock or sediment. Furthermore, porosity (i.e., the number of holes in the rock as the term is used here) was clearly a more important factor than rugosity, presumably because it offered more effective shelter against predators.

A summary of the CTD data obtained within the bottomfish EFH on the banks as well as the calculated theoretical light intensity values are presented in Table 2. Due to technical problems, temperature and salinity measurements were only available from 15 of the 16 submersible dives conducted in 2001 and 2002. Furthermore, only the DO measurements from 9 of the 10 submersible dives in 2002 were considered useable. Within the 100-400 m EFH depth range, both salinity and DO remained relatively constant at all sites, varying between 34-35 ppt and 5-6 ml/l, respectively. In contrast, temperature ranged from a high of 23°C at 100 m to a low of 10°C at 400 m, while the theoretical irradiance values ranged between a low of 0 to a high of 4,098 klux (4% of the light intensity just below the surface).

A summary of the biological organisms observed within the EFH depth range on these four banks is presented in Table 3. Of the invertebrates, a total of 64 cnidarian, 49 echinoderm, 30 crustacean, 15 mollusk, 10 sponge, 3 tunicate, and 1 ctenophore species were recorded during the dives. Examples of these are provided in Figure 3. Anemones (11 species), seastars (22 species), gastropods (10 species), and crabs (11 species) were the most diverse groups of cnidarians, echinoderms, mollusks, and crustaceans, respectively. Most urchins, seastars, and crustaceans were identified to species; however, many of the sponges and cnidarians were not, due to the difficulty in making accurate identifications of these organisms without close inspection of specimens. Clearly different types were noted, such as small white pennatulids vs. large orange ones, which were assumed to be different species. Small branching hydrozoans were not routinely recorded because in most cases, they could not be distinguished from small dead antipatharians. Furthermore, the seven different species of algae observed during the dives were not identified past major division. Those observed appeared to be primarily non-attached fragments which had originated from the tops of the banks and were subsequently carried down slope. Therefore, these were not considered to be part of the natural biota within the bottomfish EFH and were not carefully recorded, although that assumption should be more thoroughly investigated. Furthermore, the importance of algae to the bottomfish EFH may be understated in this study, because locations at or near the 100-m upper boundary where naturally growing algae occur were underrepresented.

One hundred and fifty-two different fish species were observed within the EFH on the banks representing fifty-nine families (Table 3). Of these, serranids (groupers) were the most specious (12) followed by lutjanids (snappers, 9), labrids (wrasses, 9), scorpaenids (scorpionfish, 7) and morids (cods, 7). Twenty-one families had only one representative and included a berycid (alfonsin), a mullid (goatfish), an apogonid (cardinal fish), an ammodytid (sandlance), and an argentinid (deep-sea smelt).

Two clear patterns were evident from the fish identifications and count data. First, a diurnal-nocturnal shift in the fish communities on the banks was detected within the EFH depth range. The majority of the families shown in Table 3 appeared to be diurnal; however, there were a number of families that were only observed during ROV surveys at night. Most notable among these were the morids, carapids (pearlfish), myctophids (lantern fish), trachichthyids (slimeheads), and nettastomatids (duck-billed eels). Furthermore, most of the congrid (conger eels) observations were made at night as well. Three types of behaviors appeared to be responsible for this pattern. Morids and the congrid, *Conger oligoporus,* appeared to remain in the EFH during the day, hiding in holes in the rocks until night when they presumably emerged to feed. In contrast, other congrids, such as *Ariosoma marginatus*, also hid during the day but by digging burrows in the sediment instead. The nettastomatid, *Saurenchelys stylurus,* was enigmatic since these fish never were observed during the day and only observed on sediment substrates at night. Unlike the burrowing congrids, this species was not observed digging in response to the approach of the ROV, and, furthermore, it has a delicate caudal fin that does not appear to be well adapted for creating burrows. Third, it is well known that many myctophids undergo a daily vertical (i.e., from further down the slope) and/or lateral (i.e., from further offshore) migration at night. It is believed that these fish most likely leave the bottomfish EFH, or that portion close to the substrate, during the day and return each night.

The second pattern was a shift in the families observed between the upper and lower boundaries of the EFH, clearly indicating this depth range is the major transition zone between shallow and deep-water fish species. The depth ranges observed on the banks for 39 of the 59 families are shown in Figure 4. A complete change takes place between 100 and 400 meters with the upper end of the EFH dominated by shallow-water families such as acanthurids (surgeonfish), chaetodontids (butterflyfish), pomacentrids (damselfish), priacanthids (big-eyes), while the lower end was dominated by deep-water families such as epigonids (deepwater cardinal fishes), chlorophthalmids (green-eyes), bembrids (deep-water flat-heads), symphysanodontids (no common name), and others. While this pattern is not surprising given the changes in both water temperature and light, it is certainly worth noting in any update of the bottomfish EFH definition. Similarly, invertebrate communities showed a considerable change between 100 and 400 m, although not with such a clear pattern at the family level.

DISCUSSION

EFH definitions are designed to guide management decisions on the protection and sustainable exploitation of fishery resources and therefore need to be as complete and specific as possible. Similar to many other fisheries in the U.S., the EFH for the Hawaiian bottomfish fishery has been defined in general terms due to the lack of available information on their ecology (Park, 2002) and therefore does not provide the value it was intended to provide. This situation is changing, however, with several recent studies generating multibeam sonar data and *in situ* observations useful for creating a more specific definition. In the Main Hawaiian Islands (MHI), a bottomfish habitat geographic information system (GIS) that incorporates multibeam bathymetry and sidescan data with over 5,000 fishing survey records was submitted this past year to state and federal fishery management agencies (Kelley, unpublished). Additional ship days have been scheduled for 2005-2006 to complete the mapping of the entire MHI 100-400 m EFH depth zone. Recent submersible dives have been conducted on bottomfish grounds off the islands of Oahu, Molokai, and Kahoolawe (Kelley et al., unpublished report; Moffitt et al., unpublished) which provided macro- and micro-scale geological and biological data. In the NWHI, multibeam mapping and submersible/ROV dives have also been conducted on four banks, the data from which are summarized in this paper. In short, a more extensive archipelago-wide description of the EFH is forthcoming which will include multibeam and *in situ* data from both the NWHI and MHI.

With respect to the larger picture, this paper presents only a brief look at the EFH- relevant information obtained on a deep-water fishery during a study examining the impacts of fishing activities in the NWHI. Many studies are being conducted elsewhere, which are also accumulating large amounts of EFH-relevant data for other fisheries (see Benaka, 1999). However, a widely accepted data framework for creating EFH definitions has not been developed, and consequently these efforts are not being conducted in a coordinated manner. GIS is being commonly used to visualize habitat types and boundaries and may provide the means by which the process can be standardized. All of the various types of data summarized in this paper, including multibeam bathymetry, substrate observations, water quality parameters, and the various species present at different times of the day and at different depths, can be converted into GIS layers. One can imagine many other types of data layers, such as current vectors, catch data, and life stage distributions, which would be useful toward achieving more accurate and functional definitions. A consensus needs to be attained as to which layers to include and how each type of data are collected and coded. Once this occurs, the concept of EFH truly can begin to achieve its intended goal of ecosystem-based fishery management.

ACKNOWLEDGEMENTS

The authors are indebted to the following individuals and organizations for providing the funding for this study: Robert Smith, National Ocean Survey; Tom Hourigan, NOAA Fisheries; Kitty Simonds, Western Pacific Regional Fishery Management Council; and NURP. We would like to thank all of the observers who assisted us with the submersible operations: Sean Corson, Bruce Mundy, Frank Parrish, Ray Boland, Jane Culp, Terry Kerby, and Eric Conklin. Charles Holloway and T. Kerby piloted the *Pisces IV* and *V,* while Chris Taylor, Dan Greeson, Tym Catterson, Keith Tamburi, and Mark Drewry piloted the ROV. We would also like to thank the NWHI fishers who provided us with invaluable information on their fishing sites: Guy Ohara, Tim Timony, Dane Johnson and Bobby Gomes.

Table 1: Number of submersible and ROV dives conducted on each bank.

Bank	**Sub Dives**	**ROV Dives**	**Total Dives**	**# Sites**
Raita	10	14	**24**	**9**
W. St. Rogatien	8	15	**23**	**12**
Brooks	3	5	**8**	**3**
Bank 66	1	3	**4**	**4**
Total	**22**	**37**	**59**	**28**

Table 2: Summary of CTD data and calculated light intensity.

Depth Range (m)	**Salinity (ppt)**	**DO (ml/l)**	**Temp (°C)**	**Light (klux)**
100-200	34-35	5-6	15-23	38-4098
200-300	34-35	5-6	12-21	1-151
300-400	34-35	5-6	10-17	0-6
100-400	**34-35**	**5-6**	**10-23**	**0-4098**

Table 3: Summary of the biological organisms observed within the 100-400 m EFH on the four banks.

CATEGORY	GROUP	#	CATEGORY	FAMILY	#	FAMILY	#
Algaes	chlorophyta	3	**Fish**	serranids	12	pinguipedids	2
	phaeophyta	3		labrids	9	pomacanthids	2
	rhodophyta	1		lutjanids	9	pomacentrids	2
Sponges	hexactinellids	4		morids	7	sternoptychids	2
	unidentified	6		scorpaenids	7	symphysanodontids	2
Cnidarians	anemones	11		congrids	6	synodontids	2
	gorgonians	9		chaetodontids	5	trachichthyids	2
	antipatharians	9		bothids	4	triglids	2
	pennatulids	9		carangids	4	acropomatids	1
	alcyonaceans	8		tetraodontids	4	ammodytids	1
	scleractinians	8		carcharhinids	3	apogonids	1
	cerianthids	7		emmelichthyids	3	argentinids	1
	hydrozoans	3		epigonids	3	ariomatids	1
Ctenophores	coeloplanids	1		holocentrids	3	berycids	1
Echinoderms	seastars	22		muraenids	3	callionymids	1
	urchins	16		ophidiids	3	caproids	1
	crinoids	7		percophids	3	chaunacids	1
	holothurians	3		priacanthids	3	chlorophthalmids	1
	gorgonocephalids	1		acanthurids	2	draconettids	1
Mollusks	gastropods	10		bembrids	2	gempylids	1
	bivalves	2		callanthiids	2	hoplichthyids	1
	octopuses	2		carapids	2	lophiids	1
	squids	1		macrourids	2	macroramphosids	1
Crustaceans	crabs	11		monacanthids	2	mullids	1
	shrimps	7		myctophids	2	myliobatids	1
	pagurids	4		nettastomatids	2	oplegnathids	1
	galatheids	3		ogcocephalids	2	plesiobatids	1
	lobsters	3		ophichthids	2	squalids	1
	stomatopods	2		ostraciids	2	zeids	1
Tunicates	pelagic tunicates	3		pentacerotids	2		

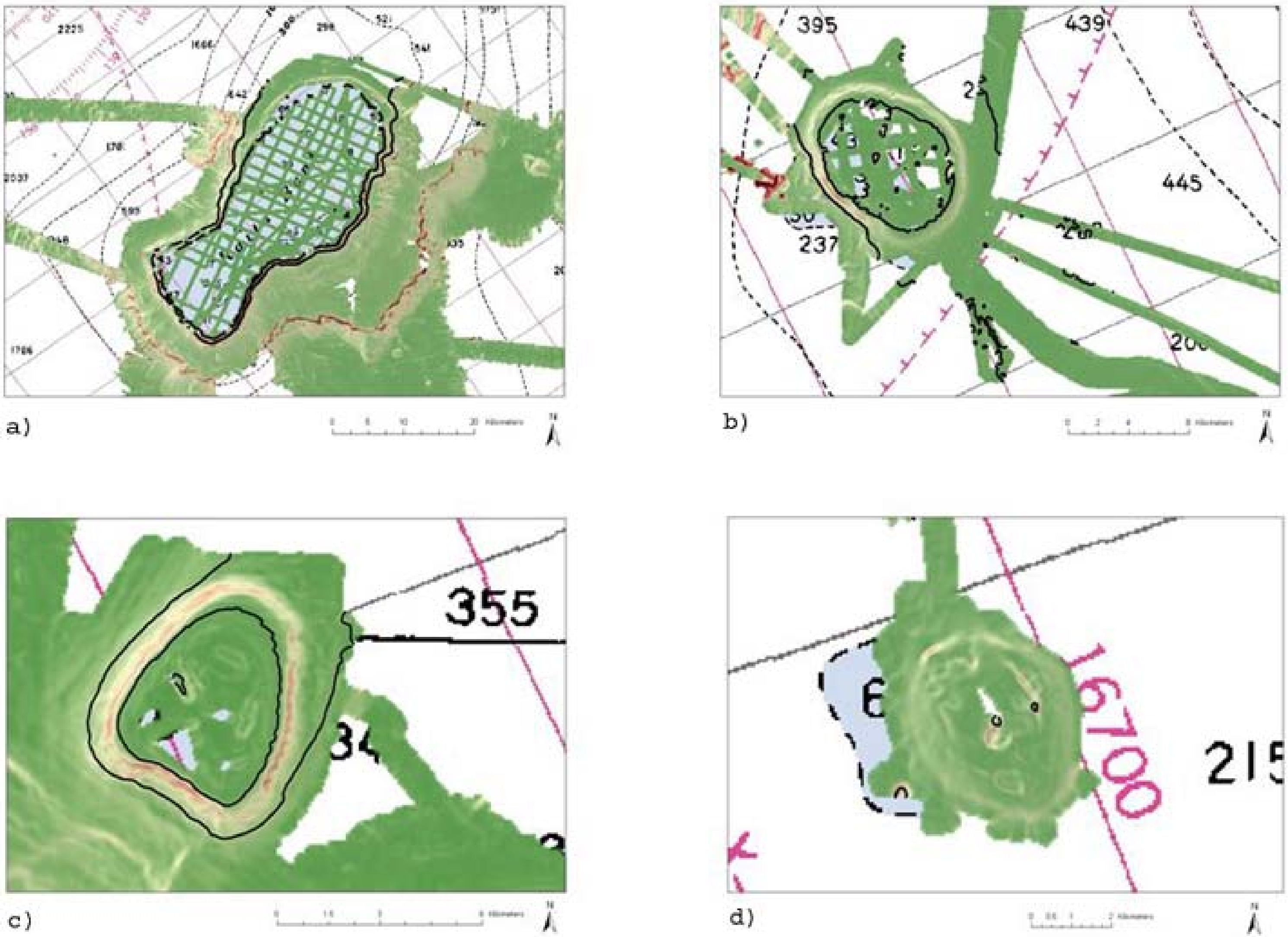

Figure 1: Multibeam sonar coverage of the 100-400 m EFH (area between the black lines) around a) Raita Bank, b) W. St. Rogatien Bank, c) Brooks Bank and, d) Bank 66.

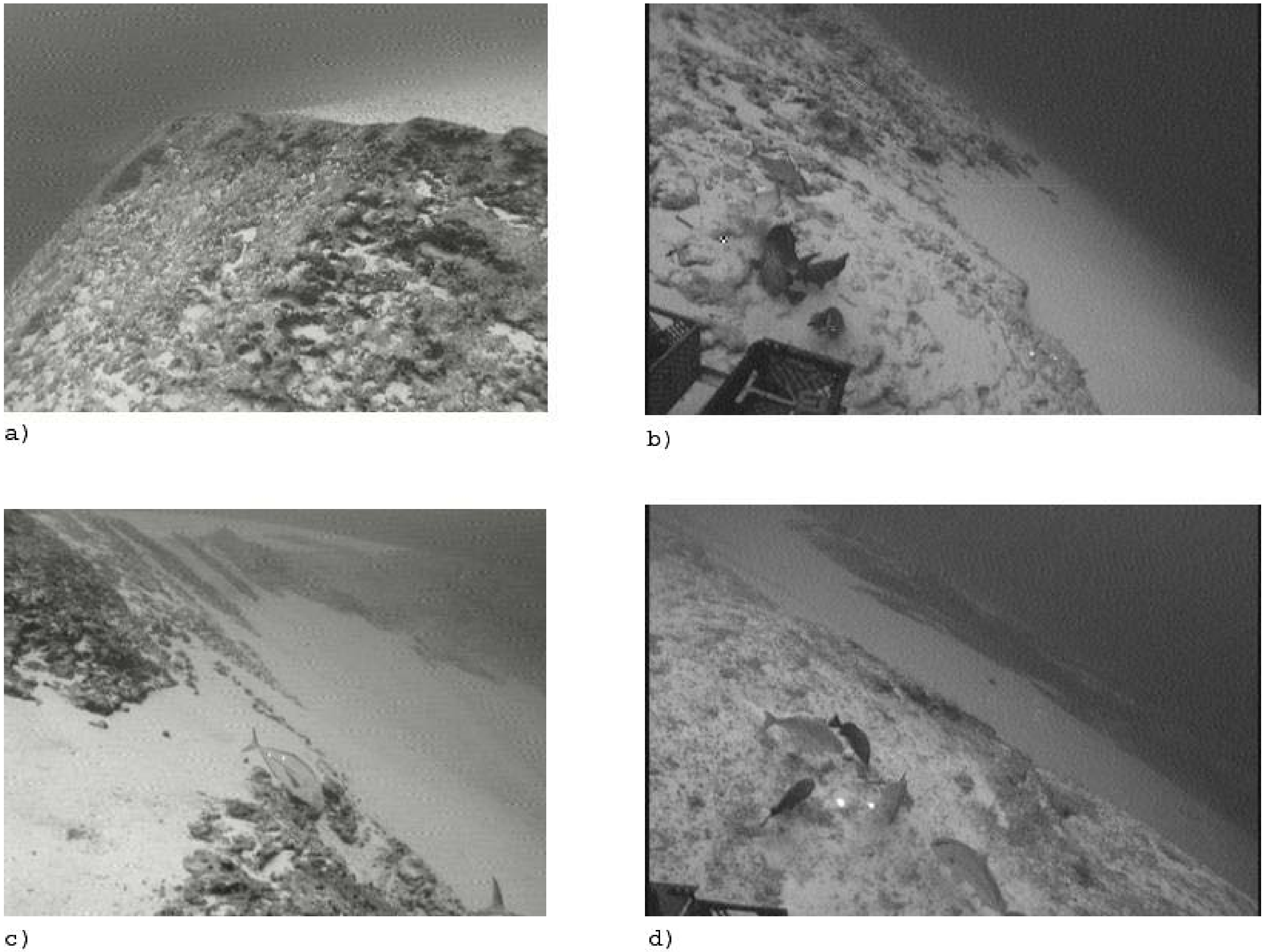

Figure 2: Low-light camera images of the break (a) and further down the slope (b,c,d) at Raita and W. St. Rogatien Banks.

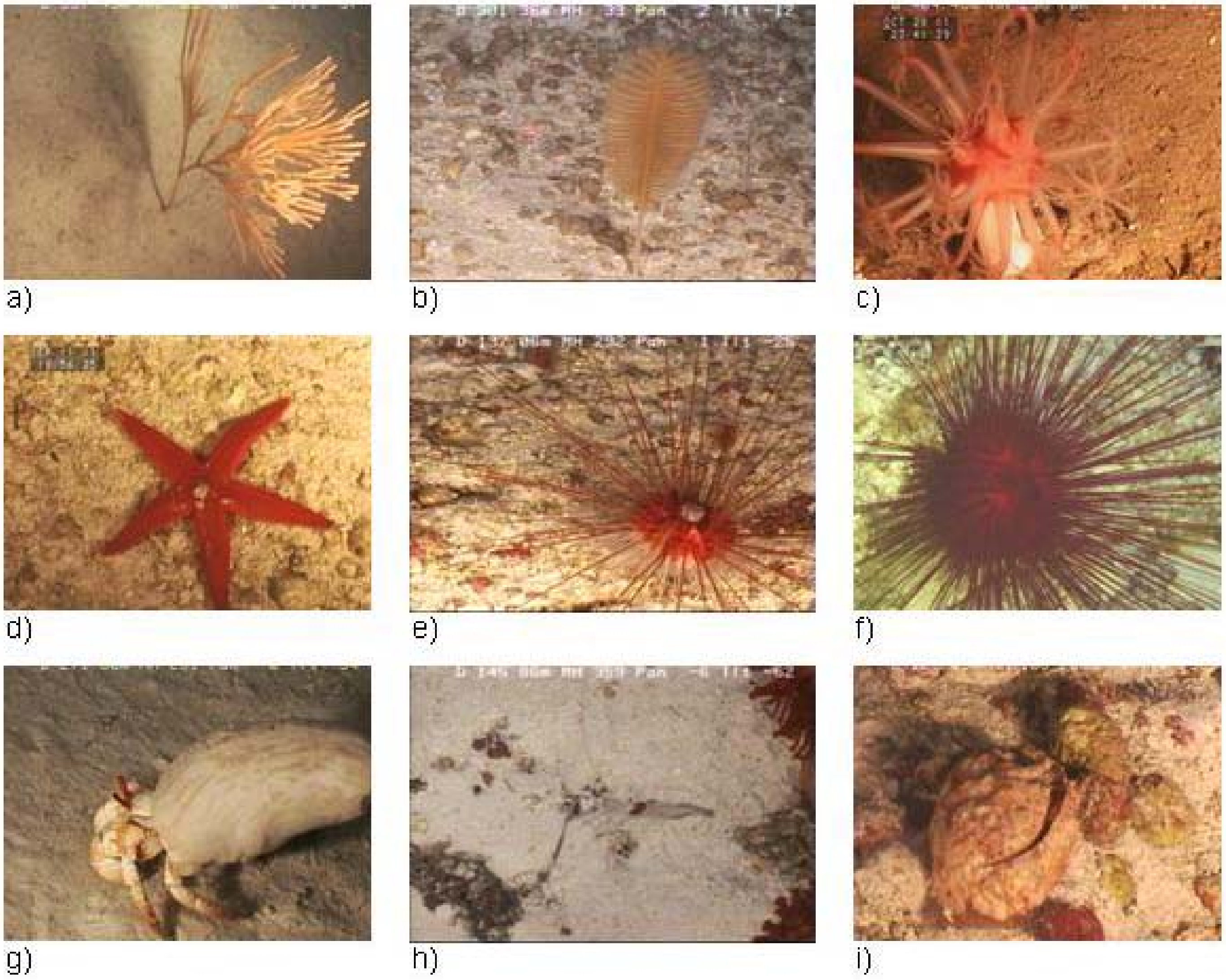

Figure 3: Examples of invertebrates recorded during the dives (a:*Fanellia eurytheia*, b:*Pennatula perci*, c:*Anthomastus sp*, d: *Ctenophoraster hawaiiensis*, e:*Diadema savignyi*, f:*Diadema sp*, g:*Dardanus sp*, h:*Plesionika sp*, i: *Calappa pokipoki*).

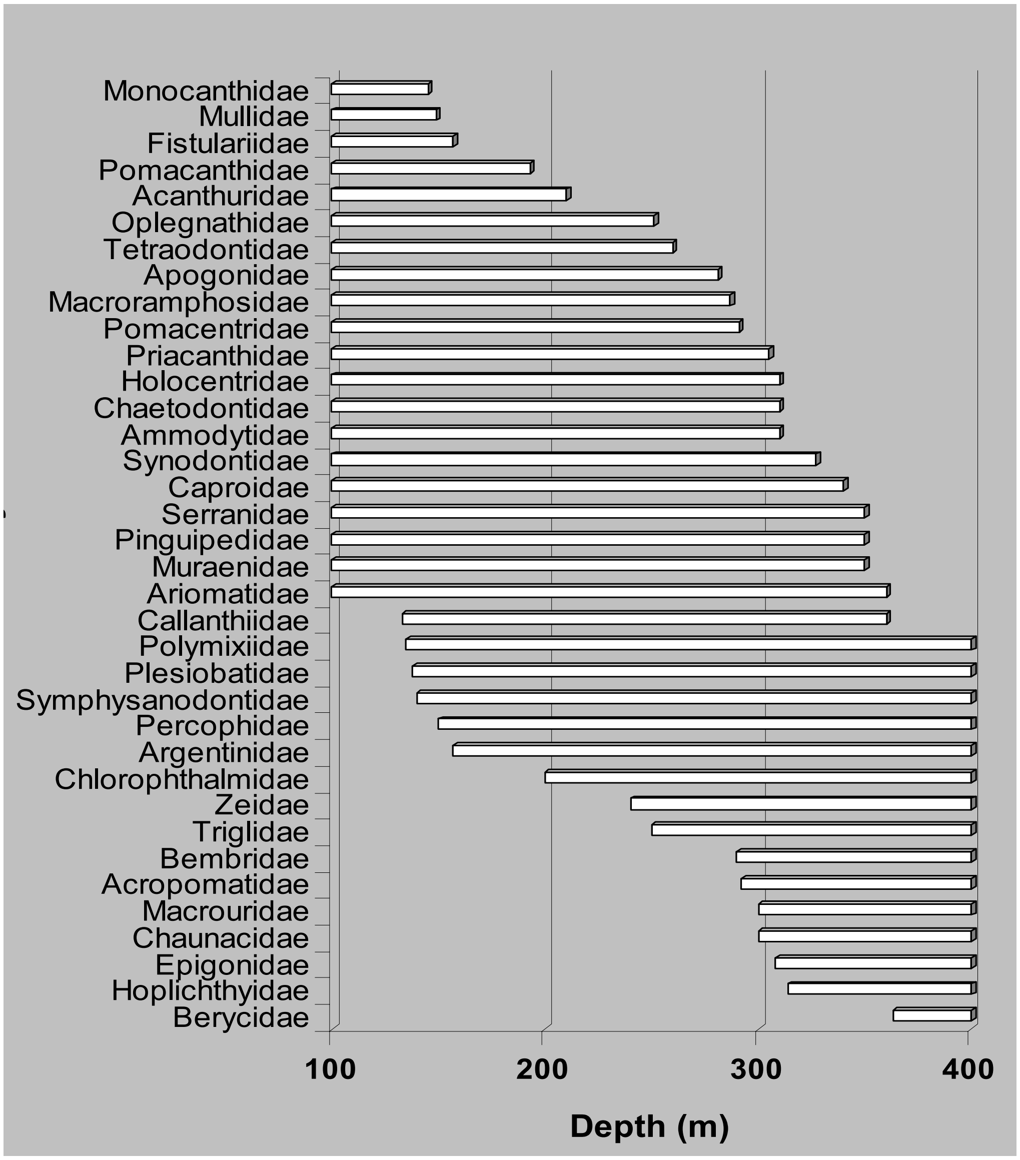

Figure 4: Depth ranges for 39 of the 59 fish families recorded during the dives.

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