Deepwater reef fishes and multibeam bathymetry of the Tortugas South Ecological Reserve, Florida Keys National Marine Sanctuary, Florida

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Abstract—The Tortugas South Ecological Reserve, located along the margin of the southwest Florida carbonate platform, is part of the largest no-take marine reserve in the U.S. Established in July 2001, the reserve is approximately 206 km^2 in area, and ranges in depths from 30 m at Riley's Hump to over 600 m at the southern edge of the reserve. Geological and biological information for the Tortugas South Reserve is lacking, and critical for management of the area. Bathymetric surveys were conducted with a Simrad EM 3000 multibeam echosounder at Riley's Hump and Miller's Ledge, located in the northern and central part of the reserve. Resulting data were used to produce basemaps to obtain geological ground truth and visual surveys of biological communities, including reef fishes. Visual surveys were conducted using SCUBA and the Phantom S2 Remotely Operated Vehicle (ROV) at Riley's Hump. Visual surveys were conducted using the ROV and the Deepworker 2000 research submersible along Miller's Ledge, within and outside of the reserve. A total of 108 fishes were recorded during SCUBA, ROV, and submersible observations. Replicate survey transects resulted in over 50 fishes documented at Miller's Ledge, and eight of the top ten most abundant species were planktivores. Many species of groupers, including scamp (*Mycteroperca phenax*), red grouper (*Epinephelus morio*), snowy grouper (*E. niveatus*), speckled hind (*E. drummondhayi*), and Warsaw grouper (*E. nigritus*), are present in the sanctuary. Numerous aggregations of scamp and a bicolor phase of the Warsaw grouper were observed, indicating the importance of Miller's Ledge as a potential spawning location for both commercially important and rare deep reef species, and as a potential source of larval recruits for the Florida Keys and other deep reef ecosystems of Florida.

Introduction

The Tortugas Ecological Reserve is located 225 km west of Key West, Florida, at the western terminus of the Florida Keys island chain (Fig. 1). The reserve was implemented in July 2001, and consists of two sections: Tortugas North (312 km^2) and Tortugas South (206 km^2), with a total area of 518 km^2 (Cowie-Haskell and Delaney, 2003). Tortugas North protects relatively deep (30–50 m) coral reef banks known as Tortugas Bank, while Tortugas South protects Riley's Hump, a known spawning aggregation site for many species of snappers (family Lutjanidae), and a range of deepwater habitats (50–600 m) (Dahlgren et al., 2001; Cowie-Haskell and Delaney, 2003). The Tortugas South Preserve is part of the largest fully protected marine reserve in the United States (Cowie-Haskell and Delaney, 2003).

Despite the widespread distribution of deep reef ecosystems in the southeastern United States (Avent et al., 1977; Barans and Henry, 1984), our knowledge of deep reef fish diversity, distribution, and ecology is extremely limited. Numerous large predators, including commercially important scamp, gag, red snapper, snowy grouper, Warsaw grouper, and wreckfish, reach abundant population numbers at water depths between 100 and 500 m along the southeastern U.S. and Gulf of Mexico. Smaller species of western Atlantic deep reef fishes are taxonomically and ecologically diverse, and may reach great abundances in these deepwater ecosystems.

Hard bottom reef communities at the shelf-slope break, formed by the consolidation of post-glacial paleoshorelines and formation of relict reef communities following sea level lowstands some 18,000 years ago, provide extensive shelf edge fish habitat worldwide (Mallinson et al., 2003). Holocene reefs of the Dry Tortugas and Riley's Hump actively developed on Pleistocene reef rock between 6 and 10 kbp, but coral growth rates diminished at Riley's Hump at approximately 4 kbp due to rising sea levels, resulting in a "give up" condition of low reef growth (Mallinson et al., 2003). To the south of Riley's Hump, hard bottom habitats are formed from Pleistocene paleoshoreline rock and erosional features, forming a dramatic scarp known as "Miller's Ledge."

Water depths in TSER range from approximately 30 m at Riley's Hump to over 600 m at the southern edge. However, previous research has focused on the coral reef and reef fish assemblage of Riley's Hump, and few studies have been conducted below

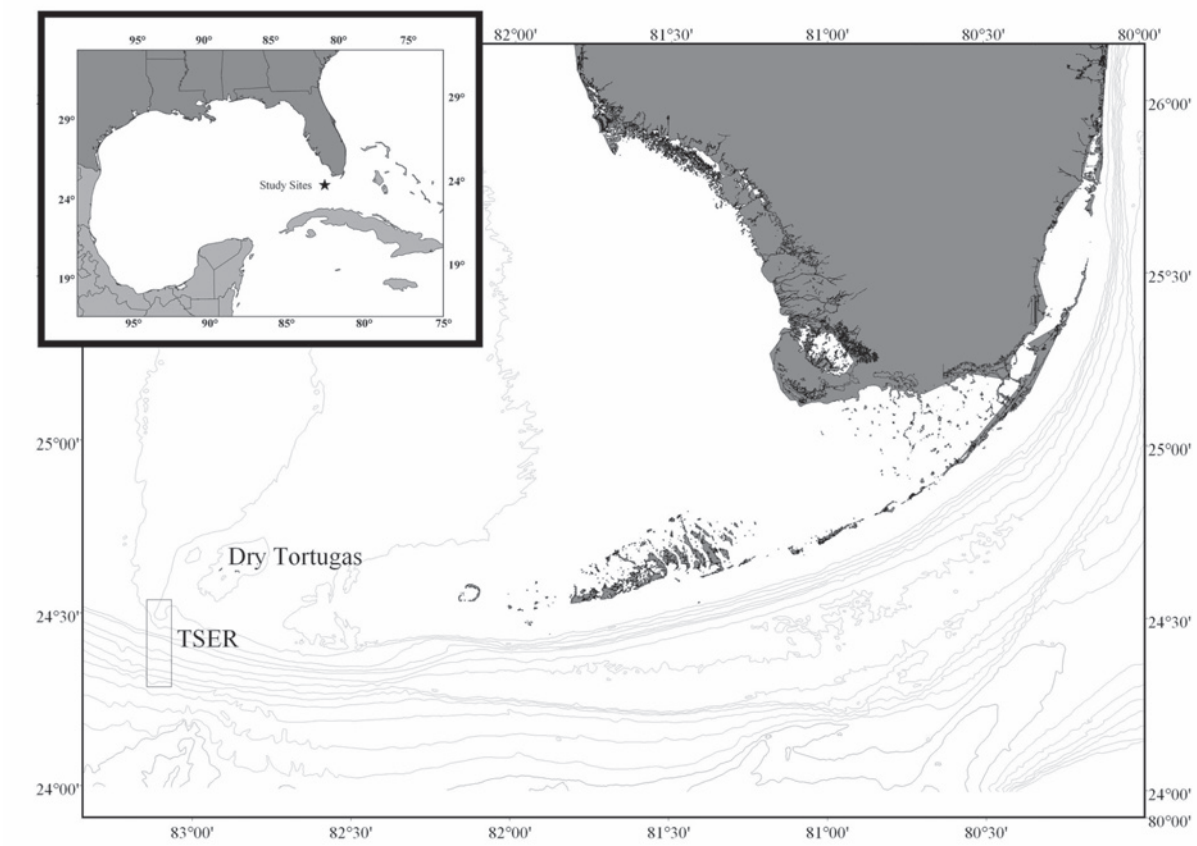

Figure 1

Location of Tortugas South Ecological Reserve, at the western terminus of the Florida Keys tract.

50 m in the reserve (Dahlgren et al., 2001, Franklin et al., 2003). To assist with biological characterization, geological characterization, and habitat mapping within the reserve, we provide bathymetry and information on surface geology between 40 and 150 m within the reserve. To provide comparative ecological data for other deep reef communities and assist with management decisions concerning the TSER, we provide a preliminary list of fishes occurring at the reserve as a representative shelf-edge reef community of the Gulf of Mexico and Caribbean.

Materials and methods

Two additional research cruises were conducted to document reef fish communities within the reserve using SCUBA, remotely operated vehicle (ROV), and manned submersibles. Multibeam bathymetric surveys were conducted using a pole mounted Kongsberg Simrad EM3000 multibeam echo sounder aboard the RV *Suncoaster* (operated by the Florida Institute of Oceanography). During data collection, survey speeds reached a maximum of 9 knots. Sound velocity casts were limited to twice a day because of the relative stability of sound velocity in this area. Sound velocity data were collected using a SBE-19 Seabird CTD, from which the speed of sound was calculated using the Chen-Millero equation. The largest change in sound velocity normally occurs at sea level, which was monitored using an AML sound velocity smart sensor sending data directly to the acquisition computer once per second. The data were post-processed using Neptune software (Kongsberg Maritime, Kongsberg, Norway). Navigation data were cleaned by flagging out positions where the distance between points was greater than 5 m and survey speed was above 9 knots. For data cleaning, the cell size was set to 4 m. Points were rejected if they exceeded a noise limit that was two times the standard deviation of the average mean value of the cell. Final processing was the correction for tidal variation, using a tidal estimating program developed by Ruoying He and Robert Weisberg at the University of South Florida (Ruoying He, pers. commun.). The data were then exported in an ASCII x,y,z

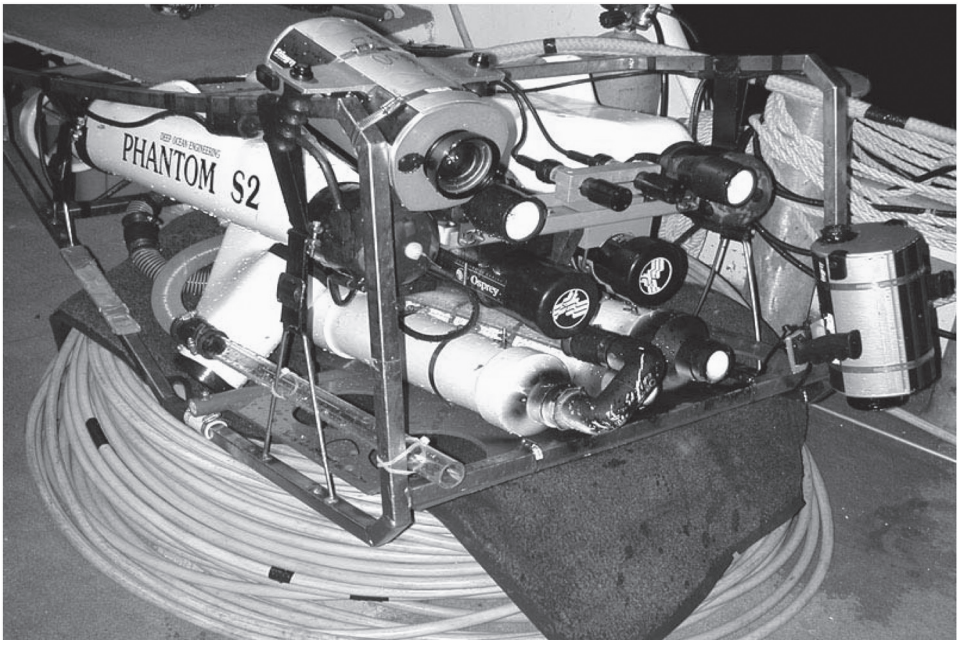

Figure 2

The Phantom S2 Remotely Operated Vehicle (ROV), provided by the National Undersea Research Center at the University of North Carolina, Wilmington. Surveys were conducted to characterize benthic habitat and reef fish communities of Tortugas South Ecological Reserve.

format and imported into Fledermaus software (Interactive Visualization Systems, Fredericton, NB, Canada). The Fledermaus software provided the base maps in this article and a guide to the subsequent fish surveys. Attitude and position of the sonar head were calculated using the Applanix PosMV 320 (previously called TSS POS/MV), which uses dual GPS antennas and an Inertial Motion Unit, which provided Roll and Pitch within 0.2 degrees accuracy and heading within 0.3 degrees accuracy. Positions accuracy is 1 m or better.

Reef fish surveys were conducted using a Phantom S2 ROV provided by the National Undersea Research Center at the University of North Carolina, Wilmington (NURC-UNCW) to document geological formations and associated reef fish community structure throughout the reserve (Fig. 2). Digital video cameras in underwater housings were attached to the ROV to improve resolution of the digital videotapes for taxonomic identification of reef fishes. Fishes were identified to the lowest possible taxon following Humann and DeLoach (2002), based on the taxonomic nomenclature of Robins et al. (1991). Trophic categories were assigned based on dietary information from Randall (1967), Smith-Vaniz et al. (1999), or Bullock and Smith (1991) for individual species or closely related taxa.

Multiple transects were conducted along Miller's Ledge, both within the no-take reserve, and the unprotected areas to the west of the sanctuary. The third research cruise was conducted as part of the Sustainable Seas Expeditions (SSE) using the Deepworker 2000 research submersible, equipped with digital videocamera and sampling arm (Fig. 3). A single submersible transect, 5 km in length, was conducted on 19 July 2002 within the reserve to survey geological features identified in the multibeam basemap and further document reef fish community structure. The first author conducted an additional visual survey on 20 July 2002, using SCUBA and a housed video camera at Riley's Hump to document representative reef fishes occurring on the feature.

Results

Multibeam bathymetry surveys of Riley's Hump reveal a relatively flat crest with an elevated rim along the southwestern and SSE margins (Fig. 4, Fig. 5). A shallow depression is present in the center of the feature, with numerous regions of variable topography along the eastern-central half of the feature. The southern margin of the bank is characterized by a steep (~20 m

Figure 3

The first author in the Deepworker 2000 Research submersible. This one-person submarine is rated to a depth of 2000 fsw (610 m) and equipped with a digital video camera, manipulator arm, and sampling basket. The submersible was used to survey Miller's Ledge at Tortugas South Ecological Reserve. Photograph provided by Kip Evans, National Geographic Society, in association with the Sustainable Seas Expeditions, 2002 (Sylvia Earle, Chief Scientist).

in relief) escarpment, ranging in depth from 30 m at the top of the bank to 50+ m at the base, where a well-developed trough surrounds the southern margin and extends eastward. Reported aggregation sites of the mutton snapper (*Lutjanus analis)* are associated with this steep southern scarp (Fig. 5). The slope is less steep to the east of the bank, suggesting a debris field generated by the prominent easterly flow of the Gulf Loop/Florida Current in this region. A detailed review of geology of Riley's Hump is presented in Mallinson et al. (2003).

Hard bottom communities observed at Riley's Hump are dominated by scleractinian coral assemblages, gorgonians, assorted sponges, and leafy algae (Fig. 6). ROV surveys revealed isolated reef communities interspersed with sand channels and carbonate debris. Dominant scleractinians were *Montastraea cavernosa*, *M. annularis*, and *Siderastrea siderea*. Individual colonies of *Montastrea* sp. were typically small, ranging from 10 to 50 cm in diameter. Occasional large colonies were observed to 2 m in height. Massive sponges, including vase sponges (*Callyspongia* sp.) and giant barrel sponges (*Xestospongia muta*), were abundant on the reef surface. Sea plumes (*Pseudopterogorgia* sp.) and assorted octocorals were abundant on patch reef communities, and extended out onto the carbonate debris fields surrounding the reef platform. At deeper water depths, the benthic community was dominated by rope sponges (*Aplysina cauliformis*) and calcareous algae including *Halimeda* and *Penicillus* sp. Dense algal mats of *Dictyota* sp. and *Lobophora* were observed during SCUBA and ROV surveys on the shallower patch reef communities.

Multibeam bathymetry surveys at Miller's Ledge provide a detailed view of the ~40 m (in relief) escarpment occurring through the center of the TSER (Figs 7–9). Water depths at Miller's Ledge range from approximately 84 m at the crest to 124 m at the base of the feature, where a distinct trough and moat has formed (Fig. 7).

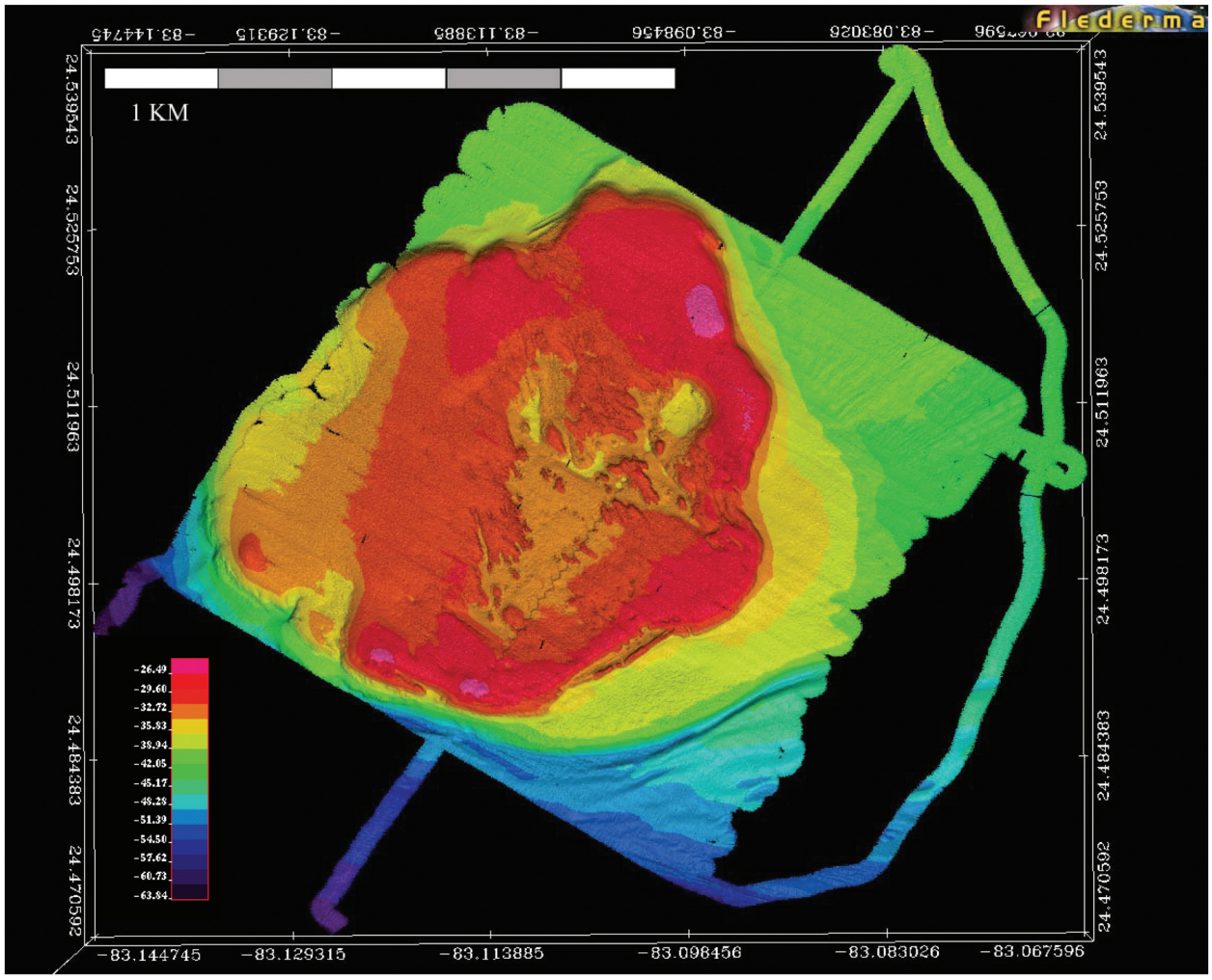

Figure 4

Plan view of color-shaded bathymetry of Riley's Hump. Vertical exaggeration=4X. Depth in meters.

The escarpment is steep, with an estimated rise of approximately 20–30 degrees. There are numerous areas of rock outcrops at the base of the feature (Fig 8A). The escarpment begins along the eastern boundary of TSER and extends 11 km to the western edge of the survey area. Bathymetric charts indicate that it may extend an additional 40 km to the southern extent of Pulley Ridge along the SW corner of the shelf. The western half of the study area is characterized by abrupt topography and many isolated mounds and peaks (Fig. 8A). In contrast, the eastern half of the survey area is characterized by a gradual decrease in the height of the scarp, a reduced number of solitary mounds at the base of the feature, and its eventual burial under shelf sediments (Fig 8C). North of the escarpment, distinct linear ridges are present parallel to the crest of the feature. These ridges most likely represent consolidated paleoshorelines formed during sea level lowstands, and were observed as linear belts of low profile rock outcrops during ROV and submersible dives.

In contrast to the deep coral reef communities of Riley's Hump, benthic assemblages of Miller's Ledge are dominated by small sponges, bryozoans, small solitary corals, and the corkscrew sea whip, *Cirrhipathes* sp. Rocky outcrops associated with paleoshorelines and high profile outcrops at the crest of the ledge had relatively low levels of encrusting invertebrate growth. Consolidated rock cobbles, boulders, and larger blocks were scattered along the face of Miller's Ledge, and colonized by bryozoans, hydrozoans, and solitary corals. This encrusting assemblage was observed on all hard surfaces below 90 m. During submersible dive A20-

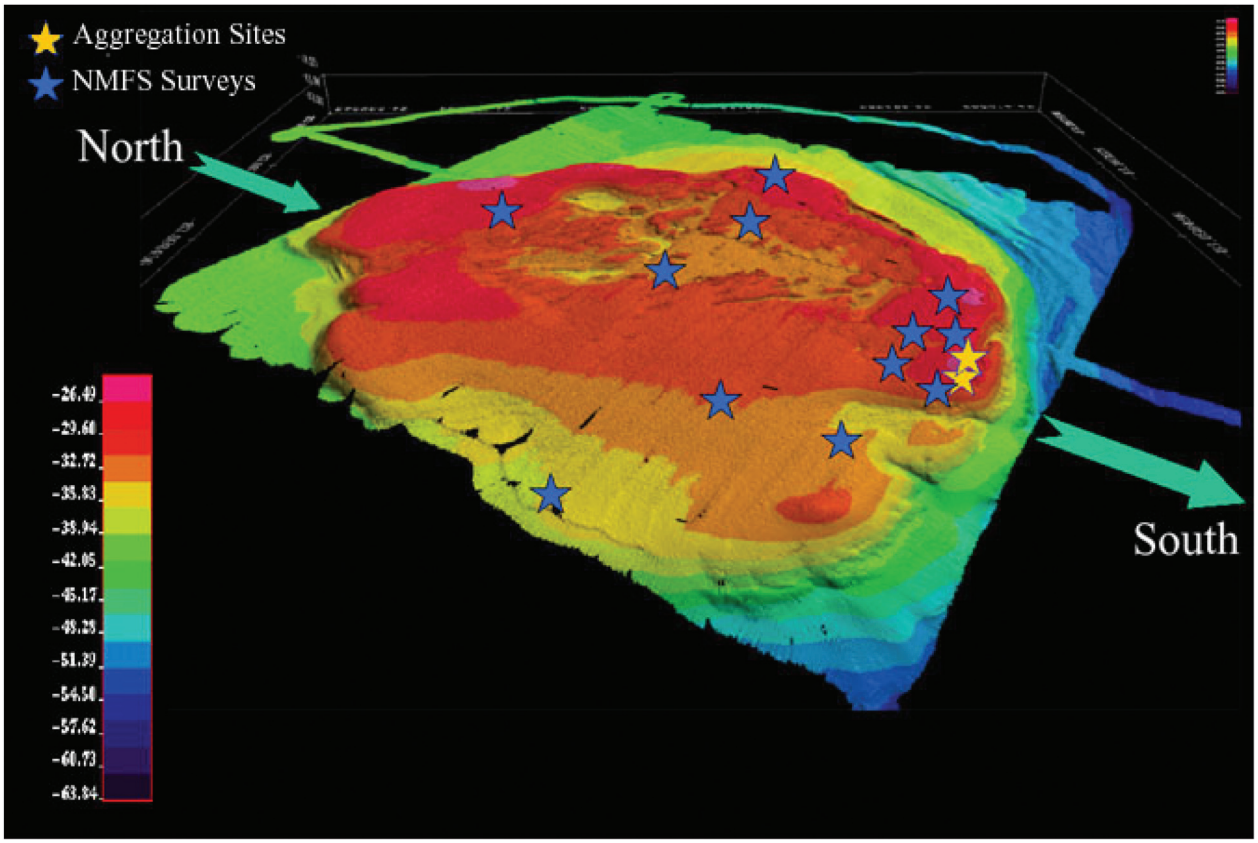

Figure 5

Oblique view of color-shaded bathymetry of Riley's Hump, looking east. Vertical exaggeration=4X. Depth in meters. National Marine Fisheries Service study locations depicted by blue stars, mutton snapper aggregation sites represented by yellow stars (locations courtesy M. Burton, NMFS Beaufort). See Figure 4 for scale.

164, extensive expanses of coarse sediments and fields of carbonate debris were observed along the eastern extent of the feature. This area appears to be buried by coarse sediments and carbonate material carried to the southeast from the shallower regions of the shelf, including Riley's Hump (Fig. 8B). Few hard bottom communities were observed in this area, with occasional low profile rock outcrops and scattered rock fragments. At three separate locations along the submersible track, large aggregations of pencil urchins, *Eucidaris* sp., were observed evenly distributed across the coarse sediment fields. These urchin aggregations were not observed during ROV operations.

Also during the submersible dive, an abandoned set of traps was observed to form an artificial reef (Figs. 10A–C). Seven individual traps were tightly bundled together by a length of trapline (Fig 10A). The surface of the trap mesh was covered with colonial oysters, forming a high profile oyster reef. This artificial reef was densely colonized by small reef fishes, primarily the red barbier (*Hemanthias vivanus*), and attracted numerous species of grouper and snapper, including a pair of speckled hind (*Epinephelus drummondhayi*) and a large aggregation of scamp (*Mycteroperca phenax*) (Fig 10B). A large hogfish (*Lachnolaimus maximus*) was observed foraging on the surface of the artificial reef (Fig 10C).

During ROV surveys at Miller's Ledge, we observed a large Warsaw grouper (*Epinephelus nigritus*) in a distinct bicolor phase, with dark brown grey dorsum, head and caudal fin coloration clearly demarcated from a bright white lateral surface. The black anal fin spot was clearly visible in this individual (Fig. 11).

During ROV surveys at the central and western portion of the survey area, extensive areas of deep rocky reefs were observed at the base of the feature (Fig. 12). The rectilinear fracture pattern observed on these blocks suggest transport of a large section from the rocky layers forming the crest of the escarpment. At other areas of the base of the scarp and trough, extensive regions of

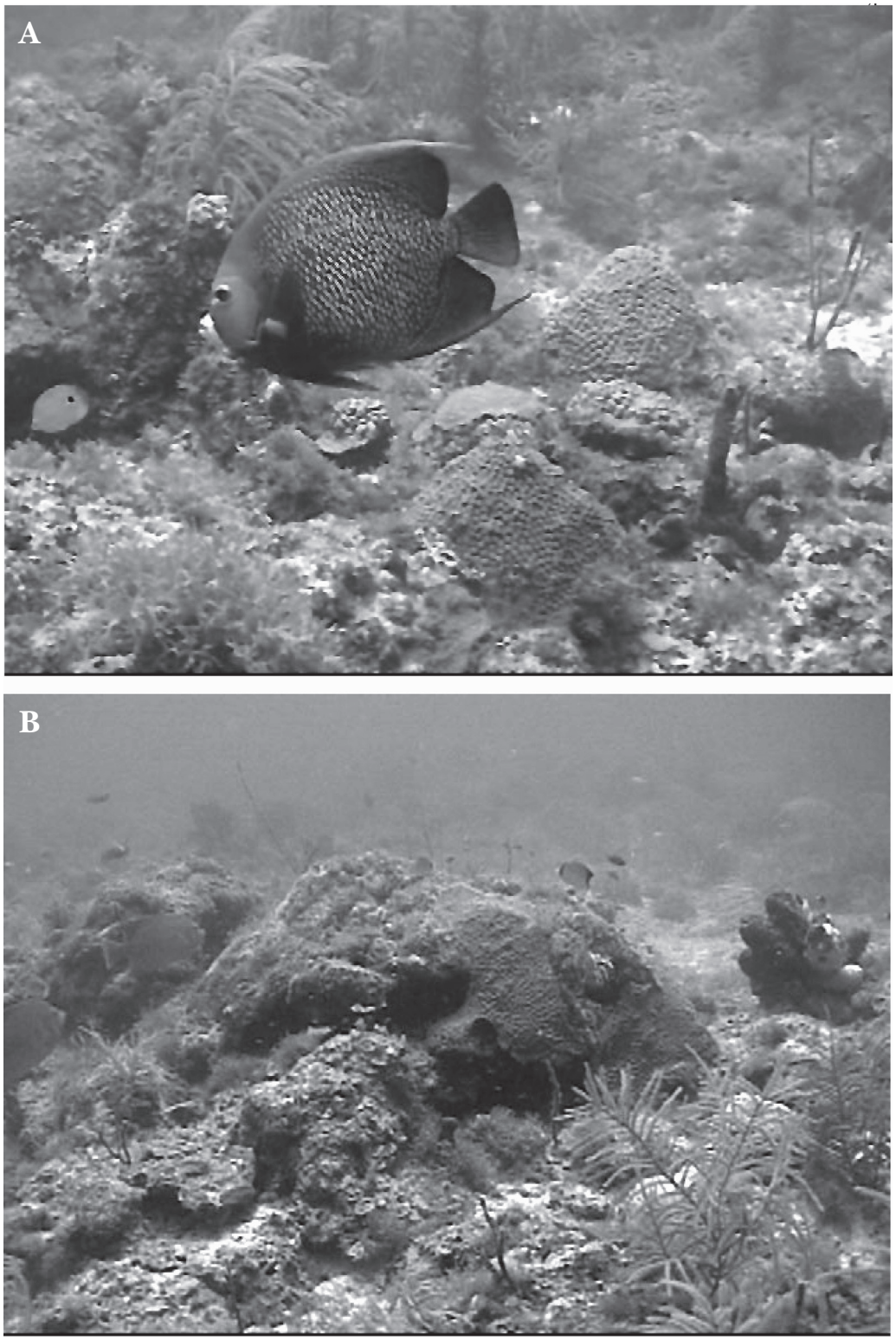

Figure 6

Biological communities of Riley's Hump. A) French angelfish (*Pomacanthus paru*) above scattered small hard coral heads and sea plumes. B) Larger colonies of *Montastrea cavernosa*, sea plumes, and sponges.

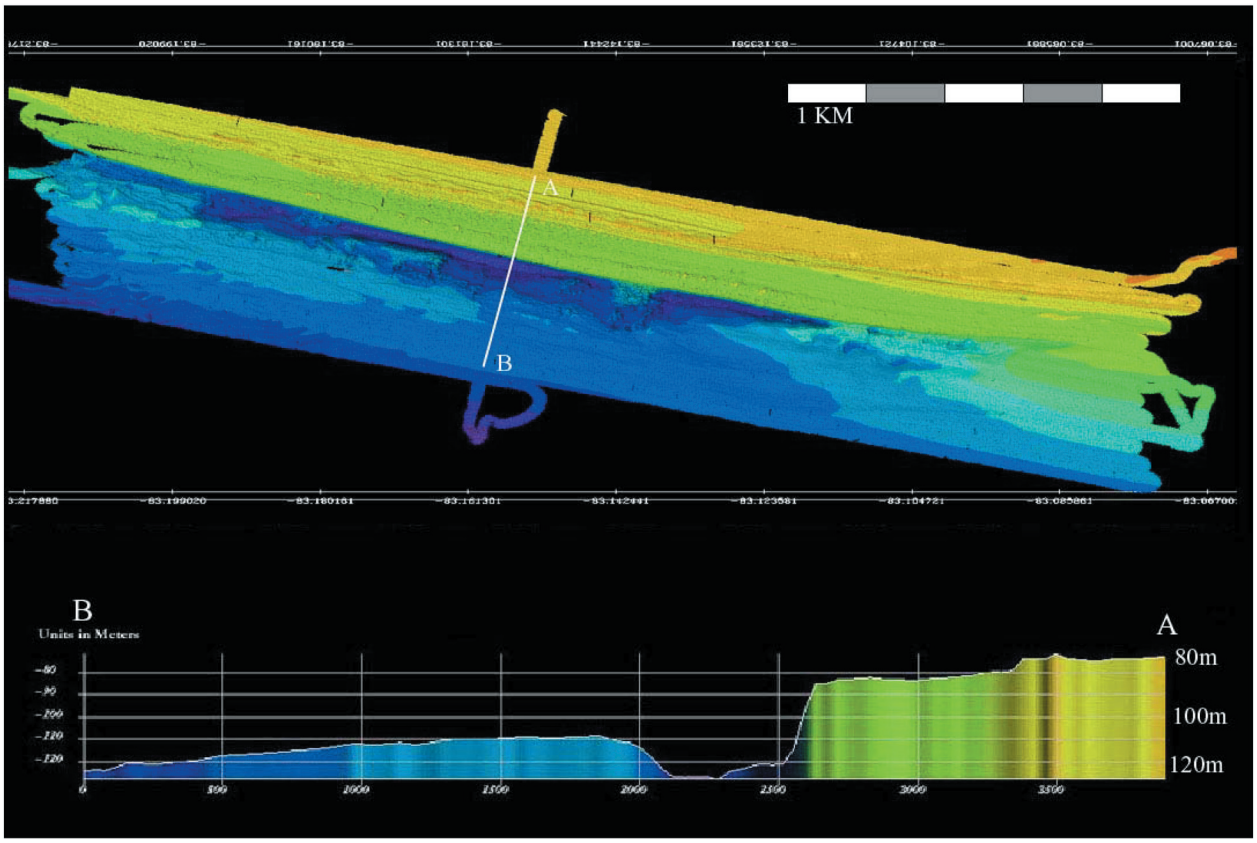

Figure 7

Top) Plan view of color-shaded bathymetry for Miller's Ledge of the Tortugas South Ecological Reserve. Bottom) Cross-section (A–B) of Miller's Ledge revealing steep escarpment. Depth range from 80 m (red) to 150 m (purple). This feature provides extensive habitat for a variety of groupers, including scamp, speckled hind, Warsaw, and snowy grouper.

white clay substratum and scattered rock cobbles and boulders were observed (Fig. 13). This formation was termed "cookie dough" reef due to the rough surface of the rock structures and the presence of small solitary coral colonies scattered about the surface. Dredge samples taken along the west-central region of the study area reveal these reef structures to be biogenic, formed by sessile molluscs, bryozoans, tube worms, and solitary corals (Fig 13, bottom). These small reef structures attracted numerous species of reef fishes, and a variety of groupers were observed on the larger rocky outcrops at the base of the feature.

One hundred and six (106) species of reef fishes and a total of 13,766 individuals were observed at both Riley's Hump and Miller's Ledge via all survey methods (Appendix A). Comparisons of reef fish assemblages at Riley's Hump and Miller's Ledge reveals distinct differences in the reef fish communities (Table 1). Reef fish surveys conducted at Riley's Hump revealed a diverse shallow water coral reef assemblage, dominated by labrids, pomacentrids, and scarids, making up over 70% of the fish population by number. The bluehead (*Thallasoma bifasciatum*), bicolor damsel (*Stegastes partitus*), yellowhead wrasse (*Halichoeres garnoti*), and greenblotch parrotfish (*Sparisoma atomarium*) were the dominant reef fish taxa observed by ROV surveys. In addition to these taxa, the masked goby (*Coryphopterus personatus*) and striped grunts (*Haemulon striatum*) were abundant during SCUBA surveys. Other families of fishes represented were serranids, tetraodontids, acanthurids, and chaetodontids. In contrast, fishes of Miller's Ledge are overwhelmingly dominated by schooling serranids, including the roughtongue bass (*Pronotogrammus martinicensis*), red barbier (*Hemanthias vivanus*), and creole-fish (*Paranthias furcifer*). Other serranids, including tattler (*Serranus phoebe*) and scamp (*Mycteroperca phenax*), are abundant along the ledge and associated habitats. Other dominant taxa at Miller's Ledge include the yellowtail reeffish (*Chromis enchrysura*) and striped grunts. Of the top 15 fish

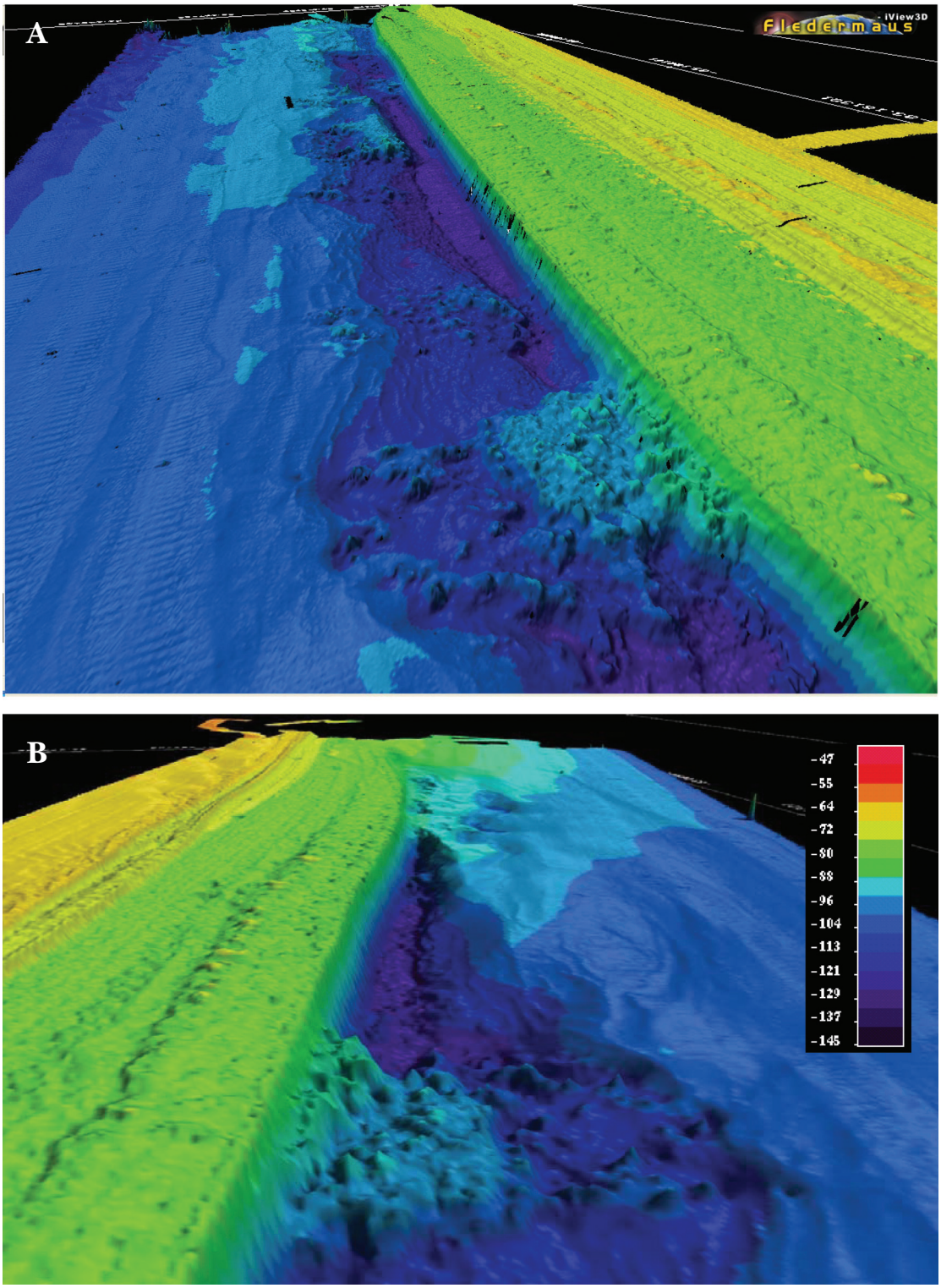

Figure 8

A) Oblique view of color-shaded bathymetry of Miller's Ledge, looking west. B) Oblique view of color-shaded bathymetry of Miller's Ledge, looking east. Vertical exaggeration=4X. Depth in meters. See Fig. 7 for scale.

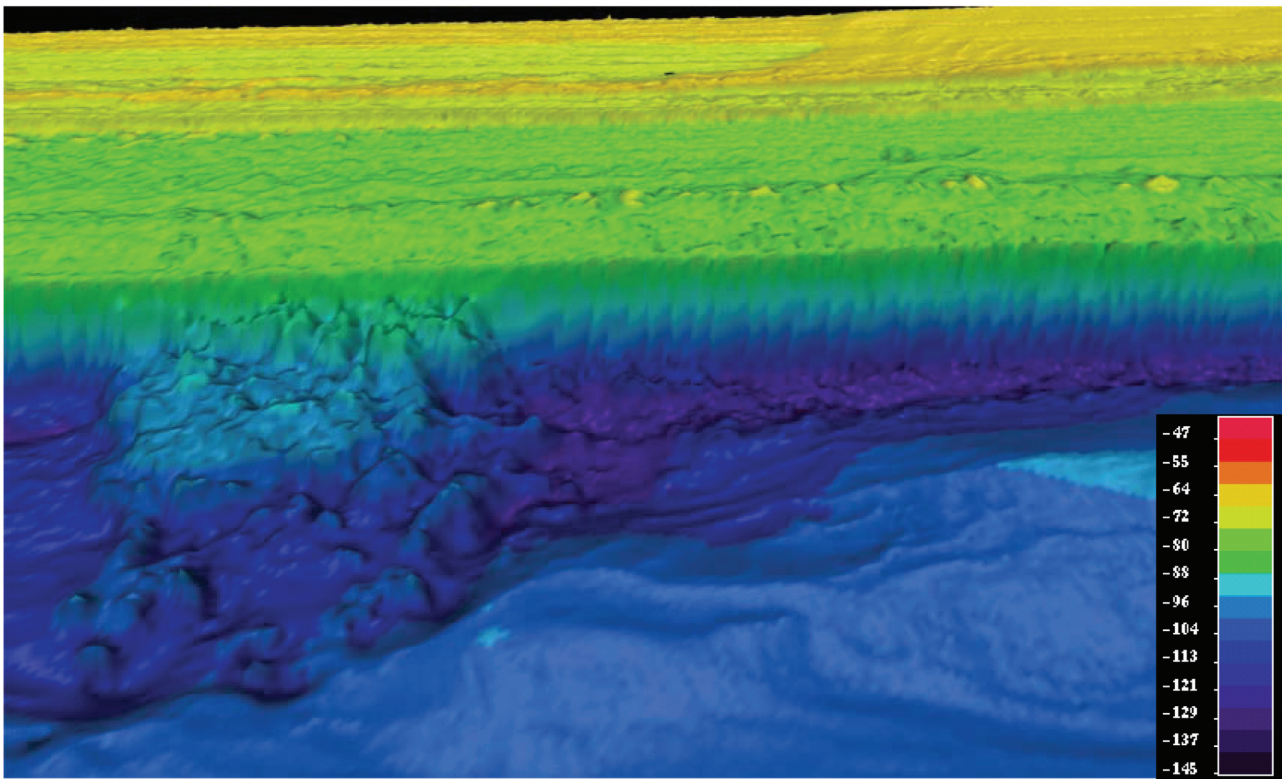

Figure 9

Oblique view of color-shaded bathymetry of Miller's Ledge, looking north. Vertical exaggeration=4X. Depth in meters. See Fig. 7 for scale.

taxa observed at each location, only sharpnose puffer (*Canthigaster rostrata*) and yellowtail reef fish were represented in the 15 most abundant fish taxa observed at both locations (Table 1).

Reef fishes documented at Riley's Hump were ecologically diverse, and dominated by planktivores (three of the top four most abundant species—Table 1). Herbivores, benthic carnivores, and epibenthic browsers were also common in the deep coral reef community. In contrast, the fish community at Miller's Ledge was overwhelmingly dominated by planktivores, with over 95% of the individuals observed by ROV and submersible belonging to this feeding guild. The top five most abundant species observed by ROV, and top four observed by submersible, were planktivores. Piscivores, represented primarily by scamp, and generalized carnivores, represented by tattler, were the next most abundant groups on the submersible transect and ROV transects, respectively. Other groups observed included benthic carnivores (greenband wrasse, *Halichoeres bathyphilus* and red hogfish, *Decodon puellaris*). Epibenthic browsers were represented by the reef butterflyfish (*Chaetodon sedentarius*) and the goldface toby (*Canthigaster jamestyleri*).

Discussion

Reef fish communities observed at the TSER are distinctly divided between the deep coral reef fish assemblage of Riley's Hump, and the outer shelf/upper slope deep reef assemblage associated with drowned/fossil reef formations at Miller's Ledge. Common reef fish taxa of the drowned reef assemblages also dominate hard bottom reefs and banks of the northwestern Gulf of Mexico (Rezak et al., 1985, 1990; Dennis and Bright, 1988). Reef fish assemblages follow similar patterns to benthic invertebrate assemblages, where distance from shore, water turbidity, seasonal temperatures, and water depth determines benthic assemblages and the associated reef fish assemblages (Dennis and Bright, 1988).

While the northwestern Gulf of Mexico is characterized by a diversity of deep reef habitats, including coralgal reefs (partly drowned reefs) and algal nodule-sponge communities, these communities, and many of their associated reef fishes, are absent at the crest of Miller's Ledge. Elevated turbidity levels and swift currents associated with the persistent flow of the Loop Current/Florida Current likely increases suspended sediment levels in this region, and lead to the burial of

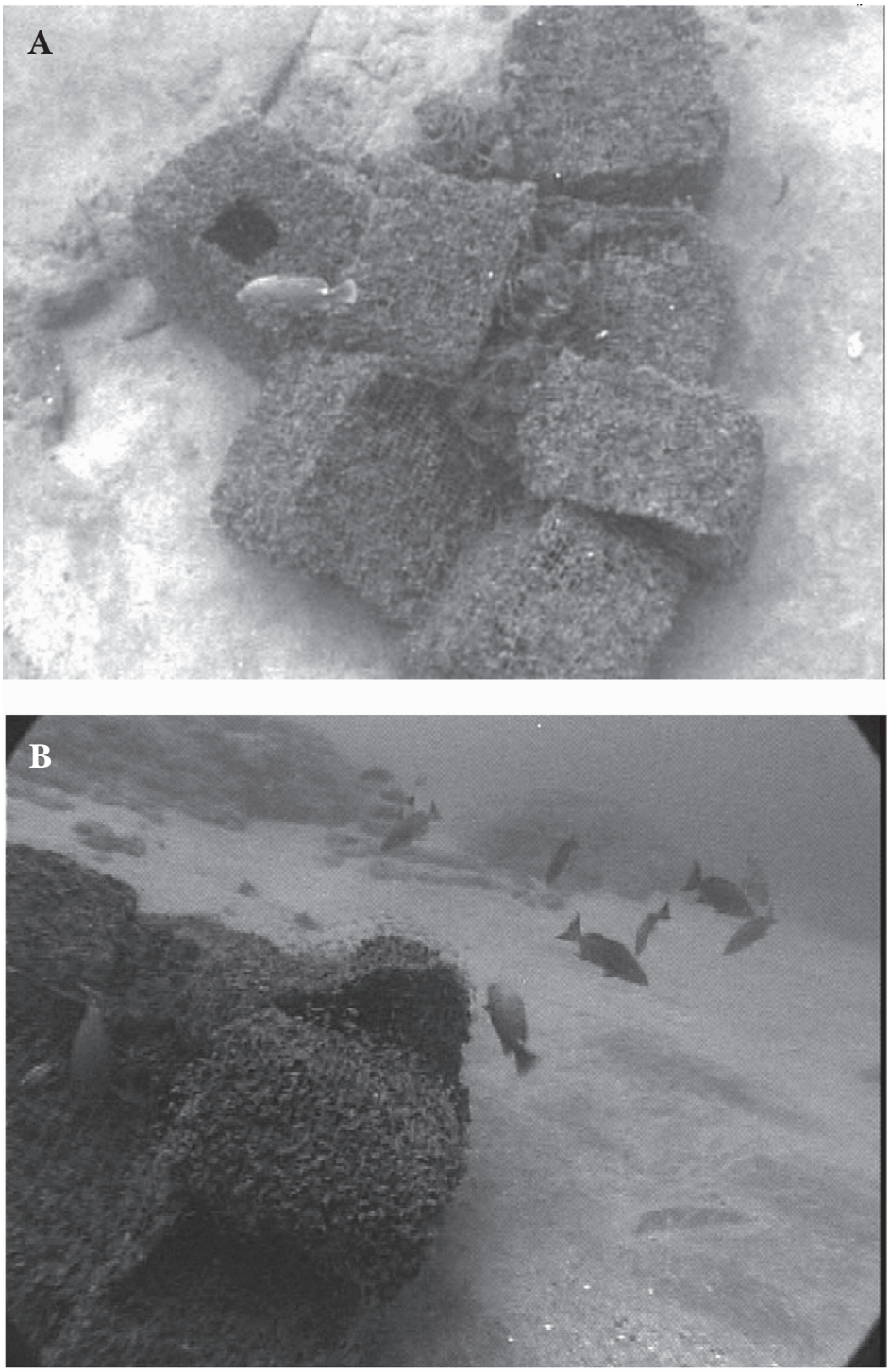

Figure 10

A) Seven ghost fish traps forming an artificial reef, colonized by oysters, at the eastern terminus of Miller's Ledge. A speckled hind (*Epinephelus drummondhayi*) swims above the reef. B) A large group of scamp (*Mycteroperca phenax*) aggregating around the artificial reef. Natural rock outcrops of Miller's Ledge visible in background. C) A large male hogfish (*Lachnolaimus maximus*) foraging on the reef surface. Stills taken from video footage courtesy the Sustainable Seas Expedition.

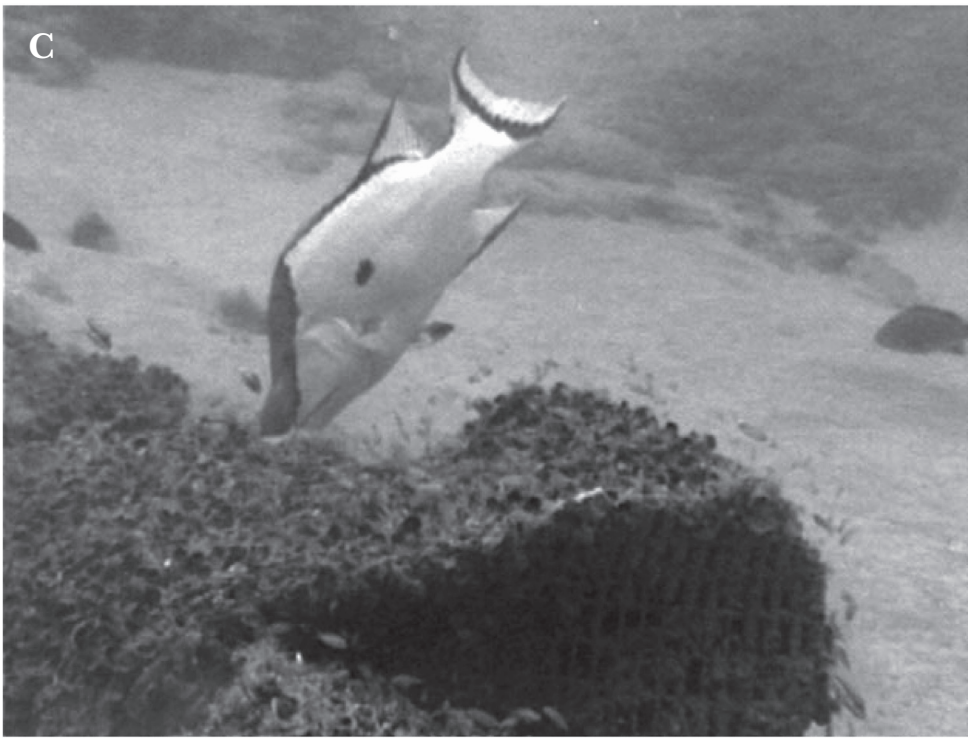

Figure 10 (continued)

the scarp at the eastern boundary of TSER. The formation of the steep vertical scarp of Miller's Ledge along its central and western portion, the associated trough and moat at the base of the formation, and the sweeping of sediments from Riley's Hump and the surrounding shelf eastward all appear to be linked to the prominent flow of the Florida Current. Turbulent water flow and upwelling was observed at the surface during our research cruises, and appear to be caused by the impact of this major current on this steep scarp.

The dominance of planktivores in deep reef fish assemblages has been observed in other studies of community structure in the Gulf of Mexico (Pattengill-Semmens et al., 1997) and the Pacific (Hamner et al., 1988; Thresher and Colin, 1986). Pettengill Semmens et al. (1997) and Hamner et al. (1988) consistently observed high numbers in the reef fish communities of the northwestern Gulf of Mexico (Flower Garden Banks and Stetson Banks) and the Great Barrier Reef, Australia, respectively. Results of the Riley's Hump reef fish surveys show parallel trends at assemblages, with over 50% of the individuals represented by planktivores. Plantivores and piscivores also appear to dominate deeper reef communities worldwide and form the primary trophic pathways between 90 and 300 m (Thresher and Colin, 1986). Roughtongue bass and red barbier were the dominant species observed at Miller's Ledge, and are the most abundant reef fish by number on most drowned reef areas throughout the southeastern U.S. and Gulf of Mexico. Roughtongue bass, red barbier, and threadnose bass form dense schools over high relief rocky structures throughout the Gulf of Mexico, and provide a forage base for many deep reef predators. The high profile rock face of Miller's Ledge provides feeding grounds for large groupers and snappers, and their prey. Numerous scamp were observed along the ledge, and the bicolor phase of the Warsaw grouper indicates a dominant male of the species and potential for spawning activity, as has been observed for other groupers (Gilmore and Jones, 1992).

While small prey fishes often reach great abundances at shelf edge reef structures, upper and middle slope regions are often food poor (Weaver and Sedberry, 2001). With greater depths (150–250 m), the main trophic pathways for dominant predators include benthic invertebrates (snowy grouper, *Epinephelus niveatus,* and tilefish, *Caulolatilus* spp.) and plankton for large schools of yellowtail bass (*Anthias nicholsi*) associated with isolated rock outcrops (Weaver and Sedberry, 2001). While few reef fishes were observed along the eastern (leeward) extent of Miller's Ledge, the persistent currents and abundant hard bottom structures observed along the scarp and base present high profile structures for reef fishes to aggregate. This abrupt change in topography

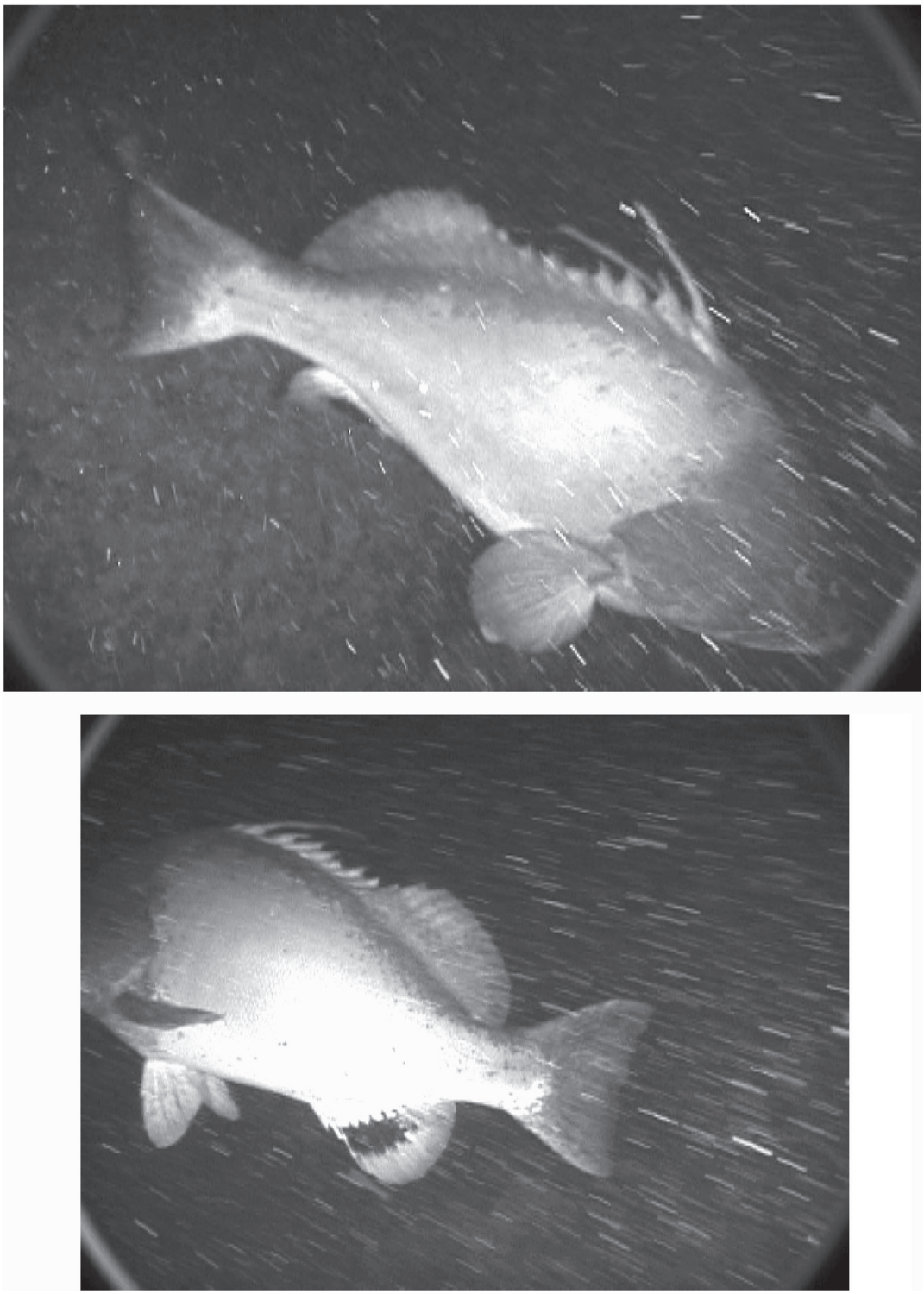

Figure 11

A large Warsaw grouper (*Epinephelus nigritus*) occurring at Tortugas South Ecological Reserve. This individual displays a "bicolor" phase typical of dominant males in spawning condition, and indicates a potential spawning area for this species. The Warsaw grouper is a rare species that is of management concern. Digital still frame provided by NURC-UNCW.

Table 1

Top 15 fishes observed at the Tortugas South Ecological Reserve via SCUBA, ROV, and submersible. Trophic categories follow Randall (1967) and Bullock and Smith (1991).

			TSER0801 Riley's ROV			SSE2002 Riley's SCUBA			TSER0801 Miller's ROV			SSE2002-164 Miller's submersible		
Species	Common name	Diet[1]	Rank	No.	Percent	Rank	No.	Percent	Rank	No.	Percent	Rank	No.	Percent
Thallasoma bifasciatum	bluehead	PL	1	424	25.48	3	127	11.27	—	—	—	—	—	—
Stegastes partitus	bicolor damselfish	PL	2	270	16.23	4	102	9.05	—	—	—	—	—	—
Halichoeres garnoti	yellowhead wrasse	BC	3	233	14.00	7	35	3.11	—	—	—	—	—	—
Chromis scotti	purple reeffish	PL	4	173	10.40	1	306	27.15	—	—	—	—	—	—
Sparisoma atomarium	greenblotch parrotfish	H	5	104	6.25	18	9	0.80	—	—	—	—	—	—
Inermia vittata	boga	PL	6	100	6.01	—	—	—	—	—	—	—	—	—
Clepticus parrae	creole wrasse	PL	7	44	2.64	15	13	1.15	—	—	—	—	—	—
Sparisoma aurofrenatum	redband parrotfish	H	8	26	1.56	14	14	1.24	—	—	—	—	—	—
Serranus tortugarum	chalk bass	PL	9	24	1.44	—	—	—	—	—	—	—	—	—
Canthigaster rostrata	sharpnose puffer	EB	10	21	1.26	21	4	0.35	25	3	0.04	—	—	—
Chromis cyanea	blue chromis	PL	11	19	1.14	6	45	3.99	—	—	—			
Acanthurus coeruleus	blue tang	H	12	17	1.02	17	11	0.98	—	—	—	—	—	—
Scarus iserti	striped parrotfish	H	13	16	0.96	8	25	2.22	—	—	—	—	—	—
Chromis enchrysura	yellowtail reeffish	PL	14	14	0.84	—	—	—	4	69	0.96	3	104	2.67
Coryphopterus personatus	masked goby	PL	15	12	0.72	2	201	17.83	—	—	—	—	—	—
Acanthurus chirurgus	doctorfish	H	18	11	0.66	9	22	1.95	—	—	—	—	—	—
Pseudopeneus maculatus	spotted goatfish	BC	20	9	0.54	12	16	1.42	45	1	0.01	—	—	—
Chaetodon sedentarius	reef butterflyfish	EB	21	8	0.48	13	14	1.24	9	36	0.50	11	12	0.31
Chromis insolata	sunshinefish	PL	23	7	0.42	11	16	1.42	—	—	—	—	—	—
Chaetodon capistrata	foureye butterflyfish	EB	28	4	0.24	10	19	1.69	—	—	—			
Priacanthus arenatus	bigeye	PL	30	4	0.24	—	—	—	15	16	0.22	28	1	0.03
Mycteroperca phenax	scamp	PI	62	1	0.06	—	—	—	7	44	0.61	5	33	0.85
Pronotogrammus martinicensis	roughtongue bass	PL	—	—	—	—	—	—	1	5663	79.03	2	804	20.66
Hemanthias vivanus	red barbier	PL	—	—	—	—	—	—	2	602	8.40	1	2709	69.62
Paranthias furcifer	creole-fish	PL	—	—	—	—	—	—	5	61	0.85	8	19	0.49
Serranus phoebe	tattler	GC	—	—	—	—	—	—	6	60	0.84	6	26	0.67
Halichoeres bathyphilus	greenband wrasse	BC	—	—	—	—	—	—	8	43	0.60	9	17	0.44
Sargocentron bullisi	deepwater squirrelfish	PL	—	—	—	—	—	—	10	24	0.33	12	7	0.18
Decodon puellaris	red hogfish	BC	—	—	—	—	—	—	11	23	0.32	14	4	0.10
Chaetodon aya	bank butterflyfish	PL	—	—	—	—	—	—	12	21	0.29	7	19	0.49
Seriola rivoliana	almaco jack	PI	—	—	—	—	—	—	13	20	0.28	—	—	—
Canthigaster jamestyleri	goldface toby	EB	—	—	—	—	—	—	14	19	0.27	13	6	0.15
Bodianus pulchellus	spotfin hogfish	GC	—	—	—	—	—	—	19	7	0.10	10	12	0.31
Haemulon striatum	striped grunts	PL	—	—	—	5	76	6.74	3	361	5.01	4	104	2.67
Epinephelus drummondhayi	speckled hind	GC	—	—	—	—	—	—	36	1	0.01	15	4	0.10

[1] BC=benthic carnivores (benthic crustaceans and infauna), EB=epibenthic browsers (sessile invertebrates), GC=general carnivore (mobile invertebrates and fishes), H=herbivore, PI=piscivore, PL=planktivore.

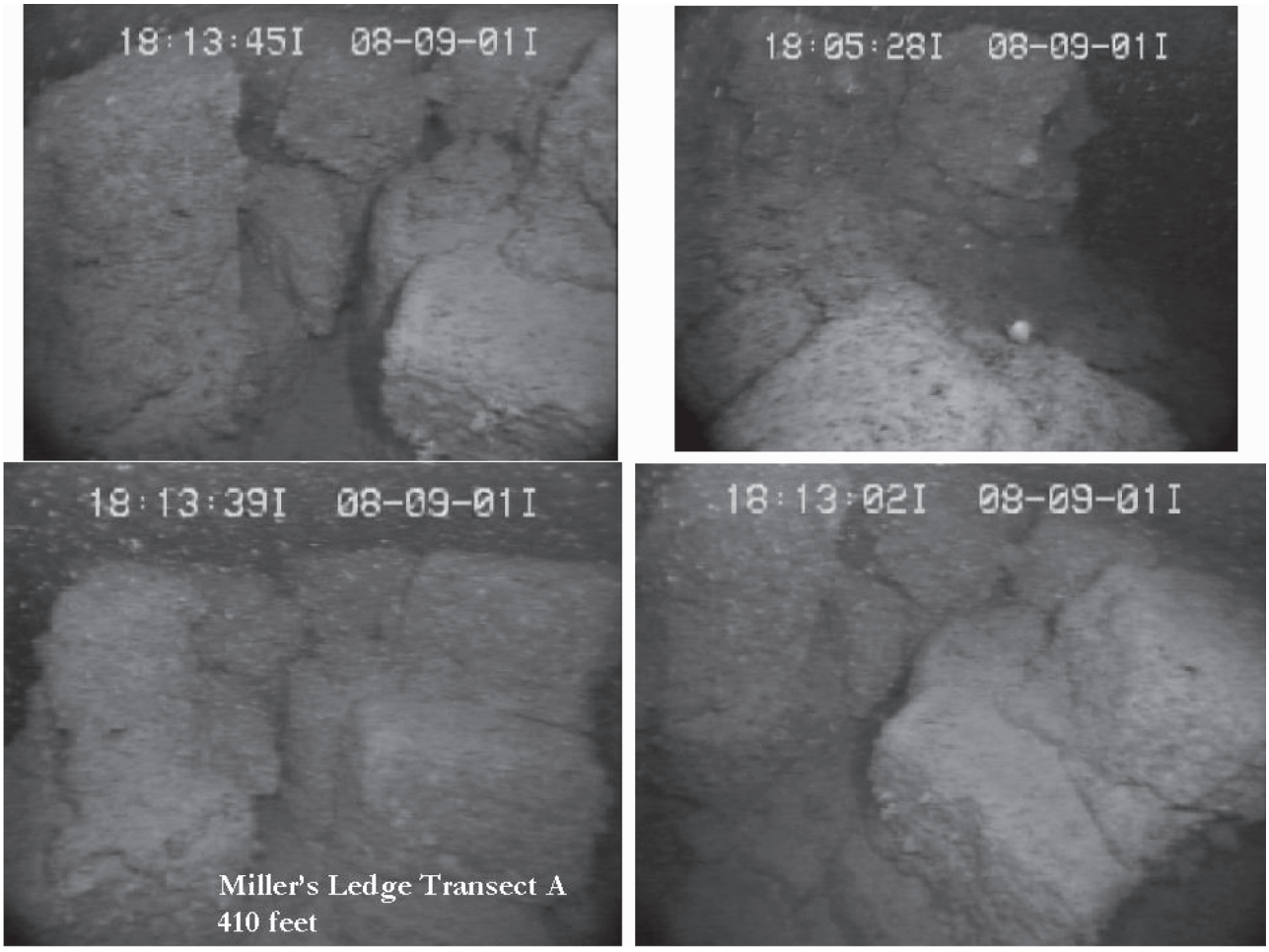

Figure 12

Large natural reef blocks located at the base of Miller's Ledge. Extensive areas of reef at the base of the ledge offer shelter for speckled hind, snowy grouper, scamp, and Warsaw grouper.

associated with rocky outcrops has been shown to support high numbers of fishes in other oceans (Yoklavich et al., 2000). Elevated structures provide shelter and access to plankton brought by impinging water currents (Hamner et al., 1988; Weaver and Sedberry, 2001). In addition to increases in local productivity and prey availability, reef fishes also appear to select areas of elevated topography based on behavioral preferences (Bohnsack, 1989). Further submersible and ROV operations within the reserve should target hard bottom communities in deeper waters to identify additional shifts in fish assemblages.

While the deep coral reef assemblage and underlying geology at Riley's Hump has been well documented (Franklin et al., 2003; Mallinson et al., 2003), the underlying processes leading to the formation of Miller's Ledge remain unresolved. The benthic assemblage leading to the formation of biogenic hard bottom reef structures, and the geologic processes that form rocky outcrops along the northern margin and crest of the scarp, are unknown. Further studies should be conducted to determine the origin and structure of the feature, the interaction between the Loop/Florida Current and the abrupt change in reef topography, and the transport and suspension of sediments from Riley's Hump and the surrounding shelf, so that impacts on the benthic invertebrate assemblages and associated reef fishes can be determined.

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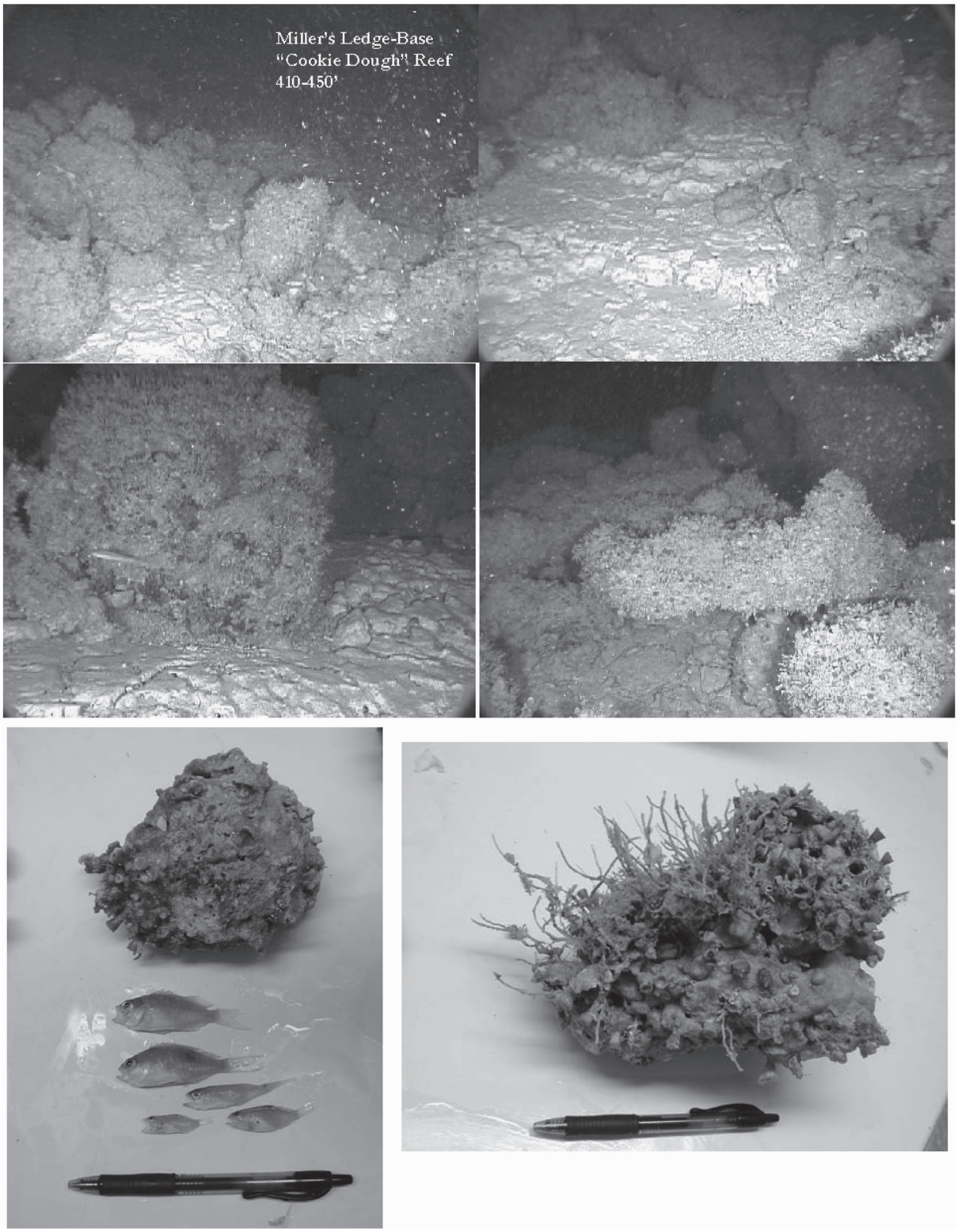

Figure 13

Top) "Cookie dough" reef cobbles and boulders located on a clay substratum along the base of Miller's Ledge. Bottom) These bioherms are built from oysters, bryozoans, and solitary corals, and form extensive hard bottom habitat for small reef fishes along the base of Miller's Ledge.

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Appendix A

Fishes observed at the Tortugas South Ecological Reserve via SCUBA, ROV, and submersible.

Family / Species	Common name	Diet[1]	TSER0801 Riley's ROV			SSE2002 Riley's SCUBA			TSER0801 Miller's ROV			SSE2002-164 Miller's submersible		
			Rank	No.	Percent	Rank	No.	Percent	Rank	No.	Percent	Rank	No.	Percent
Acanthuridae														
Acanthurus bahianus	ocean surgeonfish	H	19	10	0.60	—	—	—	—	—	—	—	—	—
Acanthurus chirurgus	doctorfish	H	18	11	0.66	9	22	1.95	—	—	—	—	—	—
Acanthurus coeruleus	blue tang	H	12	17	1.02	17	11	0.98	—	—	—	—	—	—
Apogonidae														
Apogon pseudomaculatus	twospot cardinalfish	PL	44	1	0.06	—	—	—	—	—	—	—	—	—
Blenniidae														
Parablennius marmoreus	seaweed blenny	H	—	—	—	—	—	—	—	—	—	19	3	0.08
Carangidae														
Caranx ruber	bar jack	PI	46	1	0.06	—	—	—	—	—	—	—	—	—
Seriola dumerili	greater amberjack	PI	17	12	0.72	—	—	—	—	—	—	24	2	0.05
Seriola rivoliana	almaco jack	PI	—	—	—	—	—	—	13	20	0.28	—	—	—
Carcharhinidae														
Carcharhinus sp.		PI	47	1	0.06	—	—	—	—	—	—	—	—	—
Negaprion brevirostis	lemon shark	PI	63	1	0.06	—	—	—	—	—	—	—	—	—
Chaetodontidae														
Chaetodon aya	bank butterflyfish	PL	12	21	0.29	7	19	0.49	—	—	—	—	—	—
Chaetodon capistrata	foureye butterflyfish	EB	28	4	0.24	10	19	1.69	—	—	—	—	—	—
Chaetodon ocellatus	spotfin butterflyfish	EB	27	5	0.30	22	4	0.35	23	4	0.06	—	—	—
Chaetodon sedentarius	reef butterflyfish	EB	21	8	0.48	13	14	1.24	9	36	0.50	11	12	0.31
Chaetodon striata	banded butterflyfish	EB	51	1	0.06	27	2	0.18		—	—	—		
Cirrhitidae														
Ambylocirrhus pinos	redspotted hawkfish	GC	—	—	—	34	1	0.09	—	—	—	—	—	—
Diodontidae														
Diodon holocanthus	balloonfish	GC	52	1	0.06	—	—	—	—	—	—	—	—	—
Echeneidae														
Echineus naucrates	sharksucker	GC	53	1	0.06	28	2	0.18	35	1	0.01	—	—	—
Gobiidae														
Coryphopterus personatus	masked goby	PL	15	12	0.72	2	201	17.83	—	—	—	—	—	—
Gnatholepis thompsoni	goldspot goby	EB	—	—	—	41	1	0.09	32	2	0.03	—	—	—
Ptereleotris calliurus	blue goby	PL	34	3	0.18	—	—	—	—	—	—	—	—	—
Haemulidae														
Haemulon plumieri	white grunt	BC	57	1	0.06	23	4	0.35	—	—	—	—	—	—
Haemulon striatum	striped grunt	PL	—	—	—	5	76	6.74	33	361	5.01	4	104	2.67
Holocentridae														
Corniger spinosus	spinycheek soldierfish	GC	—	—	—	—	—	—	17	12	0.17	—	—	—
Holocentrus adscensionus	squirrelfish	PL	24	9	0.54	—	—	—	21	5	0.07	—	—	—
Holocentrus rufus	longspine squirrelfish	P	16	12	0.72	16	12	1.06	—	—	—	—	—	—
Sargocentron bullisi	deepwater squirrelfish	PL	—	—	—	—	—	—	10	24	0.33	12	7	0.18

continued

Appendix A (continued)

Family / Species	Common name	Diet[1]	TSER0801 Riley's ROV Rank	TSER0801 Riley's ROV No.	TSER0801 Riley's ROV Percent	SSE2002 Riley's SCUBA Rank	SSE2002 Riley's SCUBA No.	SSE2002 Riley's SCUBA Percent	TSER0801 Miller's ROV Rank	TSER0801 Miller's ROV No.	TSER0801 Miller's ROV Percent	SSE2002-164 Miller's submersible Rank	SSE2002-164 Miller's submersible No.	SSE2002-164 Miller's submersible Percent
Inermiidae														
Inermia vittata	boga	PL	6	100	6.01	—	—	—	—	—	—	—	—	—
Labridae														
Bodianus pulchellus	spotfin hogfish	GC	—	—	—	19	7	0.10	10	12	0.31	—	—	—
Clepticus parrae	creole wrasse	PL	7	44	2.64	15	13	1.15	—	—	—	—	—	—
Decodon puellaris	red hogfish	BC	—	—	—	—	—	—	11	23	0.32	14	4	0.10
Halichoeres bathyphilus	greenband wrasse	BC	—	—	—	—	—	—	8	43	0.60	—	—	—
Halichoeres bivittatum	slippery dick	BC	32	3	0.18	29	2	0.18	—	—	—	9	17	0.44
Halichoeres cyanocephalus	yellowcheek wrasse	BC	58	1	0.06	—	—	—	—	—	—	—	—	—
Halichoeres garnoti	yellowhead wrasse	BC	3	233	14.00	7	35	3.11	—	—	—	—	—	—
Halichoeres maculipinna	clown wrasse	BC	25	6	0.36	19	7	0.62	—	—	—	—	—	—
Halichoeres radiatus	puddingwife	BC	—	—	—	42	1	0.09	—	—	—	—	—	—
Lachnolaimus maximus	hogfish	BC	39	2	0.12	24	4	0.35	—	—	—	26	1	0.03
Thallasoma bifasciatum	bluehead	PL	1	424	25.48	3	127	11.27	—	—	—	—	—	—
Lutjanidae														
Lutjanus analis	mutton snapper	GC	40	2	0.12	—	—	—	21	2	0.05	—	—	—
Lutjanus campechanus	red snapper	GC	61	1	0.06	—	—	—	40	1	0.01	27	1	0.03
Lutjanus griseus	gray snapper	GC	33	3	0.18	—	—	—	—	—	—	—	—	—
Lutjanus synagris	lane snapper	GC	—	—	—	—	—	—	—	—	—	17	4	0.10
Ocyurus chrysurus	yellowtail snapper	PL	64	1	0.06	—	—	—	—	—	—	—	—	—
Monacanthidae														
Cantherhines macroceros	whitespotted filefish	EB	45	1	0.06	—	—	—	—	—	—	—	—	—
Canthidermis sufflamen	ocean triggerfish	PL	22	7	0.42	36	1	0.09	—	—	—	—	—	—
Mullidae														
Psuedopeneus maculatus	spotted goatfish	BC	20	9	0.54	12	16	1.42	45	1	0.01	—	—	—
Muraenidae														
Gymnothorax moringa	spotted moray	GC	—	—	—	—	—	—	38	1	0.01	—	—	—
Gymnothorax sp.		GC	—	—	—	—	—	—	39	1	0.01	—	—	—
Opistognathidae														
Opstognathus aurifrons	yellowhead jawfish	PL	41	2	0.12	—	—	—	—	—	—	—	—	—
Ostraciidae														
Acanthostacion polygonia	honeycomb cowfish	EB	35	2	0.12	—	—	—	—	—	—	—	—	—
Lactophrys triqueter	smooth trunkfish	EB	60	1	0.06	—	—	—	—	—	—	—	—	—
Pomacanthidae														
Centropyge argi	cherubfish	EB	48	1	0.06	—	—	—	—	—	—	—	—	—
Holacanthus bermudensis	blue angelfish	EB	29	4	0.24	20	7	0.62	27	3	0.04	—	—	—
Holacanthus ciliaris	queen angelfish	EB	—	—	—	43	1	0.09	—	—	—	—	—	—
Holacanthus tricolor	rock beauty	EB	36	2	0.12	44	1	0.09	28	3	0.04	—	—	—
Pomacanthus paru	French angelfish	EB	65	1	0.06	45	1	0.09	—	—	—	—	—	—
Chromis cyanea	blue chromis	PL	11	19	1.14	6	45	3.99	—	—	—	—	—	—

continued

Appendix A (continued)

Family Species	Common name	Diet1	TSER0801 Riley's ROV			SSE2002 Riley's SCUBA			TSER0801 Miller's ROV			SSE2002-164 Miller's submersible		
			Rank	No.	Percent	Rank	No.	Percent	Rank	No.	Percent	Rank	No.	Percent
Chromis enchrysura	yellowtail reeffish	PL	14	14	0.84	—	—	—	4	69	0.96	3	104	2.67
Chromis insolata	sunshinefish	PL	23	7	0.42	11	16	1.42	—	—	—	—	—	—
Chromis multilineata	brown chromis	PL	—	—	—	26	3	0.27	—	—	—	—	—	—
Chromis scotti	purple reeffish	PL	4	173	10.40	1	306	27.15	—	—	—	—	—	—
Stegastes partitus	bicolor damselfish	PL	2	270	16.23	4	102	9.05	—	—	—	—	—	—
Stegastes variabilis	cocoa damselfish	H	68	1	0.06	33	2	0.18	—	—	—	—	—	—
Priacanthus arenatus	bigeye	PL	30	4	0.24	—	—	—	15	16	0.22	28	1	0.03
Pristigenys alta	short bigeye	PL	—	—	—	—	—	—	44	1	0.01	—	—	—
Rhincodontidae														
Ginglyostoma cirratum	nurse shark	GC	56	1	0.06	40	1	0.09	—	—	—	—	—	—
Scaridae														
Scarus iserti	striped parrotfish	H	13	16	0.96	8	25	2.22	—	—	—	—	—	—
Scarus taeniopterus	princess parrotfish	H	66	1	0.06	—	—	—	—	—	—	—	—	—
Sparisoma atomarium	greenblotch parrotfish	H	5	104	6.25	18	9	0.80	—	—	—	—	—	—
Sparisoma aurofrenatum	redband parrotfish	H	8	26	1.56	14	14	1.24	—	—	—	—	—	—
Sparisoma viride	stoplight parrotfish	H	43	2	0.12	46	1	0.09	—	—	—	—	—	—
Sciaenidae														
Equetus lanceolatus	high-hat	BC	—	—	—	—	—	—	—	—	—	20	2	0.05
Pareques iwamotoi	blackbar drum	BC	—	—	—	—	—	—	16	15	0.21	—	—	—
Scorpaenidae														
Scorpaena dispar	hunchback scorpionfish	GC	—	—	—	—	—	—	46	1	0.01	—	—	—
Scorpaena sp.		GC	—	—	—	—	—	—	20	12	0.17	—	—	—
Serranidae														
Centropristis fuscula	twospot seabass	GC	34	1	0.01	—	—	—	—	—	—	—	—	—
Cephalopholis cruentata	graysby	GC	49	1	0.06	37	1	0.09	22	4	0.06	25	1	0.03
Cephalopholis fulva	coney	GC	50	1	0.06	—	—	—	—	—	—	—	—	—
Epinephelus drummondhayi	speckled hind	GC	—	—	—	—	—	—	36	1	0.01	15	4	0.10
Epinephelus guttatus	red hind	GC	54	1	0.06	—	—	—	—	—	—	—	—	—
Epinephelus morio	red grouper	GC	55	1	0.06	39	1	0.09	30	2	0.03	18	3	0.08
Epinephelus nigritus	Warsaw grouper	GC	—	—	—	—	—	—	31	2	0.03	—	—	—
Epinephelus niveatus	snowy grouper	GC	—	—	—	—	—	—	37	1	0.01	—	—	—
Gonioplectrus hispanus	Spanish flag	GC	—	—	—	—	—	—	26	3	0.04	—	—	—
Hemanthias vivanus	red barbier	PL	—	—	—	—	—	—	2	602	8.40	1	2709	69.62
Hypoplectrus gemma	blue hamlet	GC	59	1	0.06	30	2	0.18	—	—	—	—	—	—
Hypoplectrus unicolor	butter hamlet	GC	38	2	0.12	31	2	0.18	—	—	—	—	—	—
Liopropoma eukrines	wrasse bass	GC	—	—	—	—	—	—	18	12	0.17	16	4	0.10
Mycteroperca bonaci	black grouper	PI	—	—	—	—	—	—	41	1	0.01	22	2	0.05
Mycteroperca phenax	scamp	PI	62	1	0.06	—	—	—	7	44	0.61	5	33	0.85
Paranthias furcifer	creole-fish	PL	—	—	—	—	—	—	5	61	0.85	8	19	0.49
Plectranthias garrupellus	apricot bass	GC	—	—	—	—	—	—	43	1	0.01	—	—	—

continued

Appendix A (continued)

Family / Species	Common name	Diet[1]	TSER0801 Riley's ROV			SSE2002 Riley's SCUBA			TSER0801 Miller's ROV			SSE2002-164 Miller's submersible		
			Rank	No.	Percent	Rank	No.	Percent	Rank	No.	Percent	Rank	No.	Percent
Pronotogrammus martinicensis	roughtongue bass	PL	—	—	—	—	—	—	1	5663	79.03	2	804	20.66
Serranus annularis	orangeback bass	GC	42	2	0.12	—	—	—	—	—	—	—	—	—
Serranus phoebe	tattler	GC	—	—	—	—	—	—	6	60	0.84	6	26	0.67
Serranus tabacarius	tabaccofish	GC	—	—	—	25	4	0.35	—	—	—	—	—	—
Serranus tigrinus	harlequin bass	GC	31	4	0.24	32	2	0.18	—	—	—	—	—	—
Serranus tortugarum	chalk bass	PL	9	24	1.44	—	—	—	—	—	—	—	—	—
Sparidae														
Calamus nodosus	knobbed porgy	BC	26	5	0.30	35	1	0.09	—	—	—	—	—	—
Pagrus pagrus	red porgy	BC	—	—	—	—	—	—	42	1	0.01	23	2	0.05
Sphyraenidae														
Sphyraena barracuda	great barracuda	PI	67	1	0.06	—	—	—	—	—	—	—	—	—
Synodontidae														
Synodus intermedius	sand diver	PI	—	—	—	—	—	—	24	4	0.06	—	—	—
Synodus synodus	red lizardfish	PI	—	—	—	—	—	—	47	1	0.01	—	—	—
Tetraodontidae														
Canthigaster rostrata	sharpnose puffer	EB	10	21	1.26	21	4	0.35	25	3	0.04	—	—	—
Canthigaster jamestyleri	goldface toby	EB	14	19	0.27	13	6	0.15	—	—	—	—	—	—
Total				1664			1145			7169			3888	

[1] BC=benthic carnivores (benthic crustaceans and infauna), EB=epibenthic browsers (sessile invertebrates), GC=general carnivore (mobile invertebrates and fishes), H=herbivore, PI=piscivore, PL=planktivore.