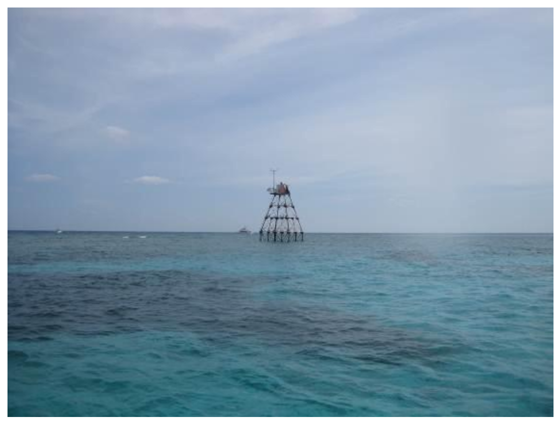
Abundance, Distribution and Condition of *Acropora* Corals, Other Benthic Coral Reef Organisms, and Marine Debris in the Upper Florida Keys National Marine Sanctuary

2011 Quick Look Report and Data Summary



December 2011

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Suggested Citation

Miller SL, Chiappone M, Rutten LM (2011) Abundance, distribution, and condition of *Acropora* corals, other benthic coral reef organisms, and marine debris in the upper Florida Keys National Marine Sanctuary – 2011 Quick look report and data summary. CMS/UNCW, Key Largo, FL. 262 pp

Acknowledgements

Funding was provided by NOAA's Coral Reef Conservation Program, The Department of Commerce's 1535 Endangered Species Act Projects, and NOAA's Aquarius Reef Base (ARB) through the University of North Carolina-Wilmington. Boat and diving support were provided by ARB (R/V *Research Diver,* R/V *George F. Bond*), the upper Keys office of the FKNMS, and Quiescence Diving Services, Inc. J. Delaney (NOAA/FKNMS) assisted with permitting and S.G. Smith of RSMAS-UM assisted with the sampling design. This effort would not have been possible without O. Rutten, T. Roberts, S. Donahue, D. Mooney, S. Morton, and B. Valley of the FKNMS. Research was conducted in the Florida Keys under National Marine Sanctuary Permit FKNMS-2010-077.

Cover photo. Examples of benthic coral reef organisms and marine debris sampled during 2011 in the upper Florida Keys National Marine Sanctuary. Upper left: *Acropora palmata* at Elbow Reef SPA, Upper right: Marine debris surveys, Lower left: *Condylactis gigantea* at Turtle Rocks, Lower right: Molasses Reef marker.

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2011 Executive Summary

During 29 days of fieldwork from May 5 to September 10, 2011, scientists from the Center for Marine Science, University of North Carolina at Wilmington, surveyed the density, size, and condition of *Acropora* corals, other benthic coral reef organisms, including urchins, anemones, corallimorpharians, and mollusks, as well as marine debris abundance and impacts to the benthos in the upper Florida Keys National Marine Sanctuary (FKNMS) (Figure 1). Benthic surveys using two replicate 15-m transects were conducted using a two-stage stratified design (Smith et al. 2011) that partitioned the sampling domain by habitat type (cross-shelf location and depth), geographic region (upper, middle and lower Keys), and management zone (inside and outside of FKNMS no-take zones). A total of 280 sites were surveyed to document the status and trends of benthic coral reef organisms, with a specific focus in 2011 on populations of *Acropora* corals. Funding was provided by NOAA's Coral Reef Conservation Program and The Department of Commerce's 1535 Endangered Species Act Projects. Dive support was provided by NOAA's Aquarius Reef Base and the upper Keys office of the Florida Keys National Marine Sanctuary. The survey team also included personnel from Gray's Reef National Marine Sanctuary and the FKNMS Damage Assessment and Response Research Program (DARRP). To support work with our expanding partner groups, a Field Protocol Manual was produced in 2011 (www.people.uncw.edu/millers) to help guide sampling in 2012 for a system-wide assessment of *Acropora* populations, including the Florida Keys, the US Virgin Islands and Puerto Rico.

Nine coral reef and hard-bottom habitat types were sampled from inshore of Hawk Channel to the deeper fore-reef from 0.9 to 15.8 m depth during 2011. The habitats sampled included inshore patch reefs, mid-channel patch reefs, offshore patch reefs, back-reef rubble, shallow (< 6 m) hard-bottom, inner line reef tract spur and groove, platform margin high-relief spur and groove, and the deeper fore-reef (6-15 m depth) encompassing continuous hard-bottom, patchy hard-bottom, and low-relief spur and groove habitats. Sites were further partitioned by management zone within the FKNMS to include areas inside and outside of no-take zones. All 12 no-take zones from northern Key Largo to Alligator Reef, designated as Sanctuary Preservation Areas and Research Only Areas, were sampled. For the 280 sites sampled, latitude/longitude points were randomly generated in a geographic information system (GIS) incorporating available benthic habitat and bathymetry data for the sampling domain. At each site, two 15-m transects were used to inventory benthic coral reef organisms and marine debris, including data on: depth and topographic complexity; *Acropora* coral density, size, and condition; density, size and condition of all other scleractinian coral species; urchin density and size; anemone and corallimorpharian density; density and size of mollusks; and marine debris.

This report summarizes results and provides descriptive data for the benthic variables measured during 2011. The report is divided by chapter for each of the major categories of variables measured and includes data tables, figures, underwater photographs, and maps. The data collection effort by the survey team required 762 SCUBA and just over 381 hours of underwater bottom time.

Population assessments of *Acropora* corals conducted in 2011 represent a continuation of our surveys that focus on the habitat distribution, density, size, and condition of these two corals conducted since 2006. The surveys are in addition to population assessments of all coral species, including *Acropora* spp., conducted by this program in 1999-2001, 2005, 2009, and 2011, as well as similar work in the Dry Tortugas region during 1999-2000, 2006, and 2008. Both species continue to show characteristic distribution patterns, with staghorn coral (*A. cervicornis*) more frequently encountered, in greater densities (up to 1.3 physiologic colonies per m^2), and larger colony sizes on offshore patch reefs, followed by mid-channel patch reefs and shallow (< 6 m) hard-bottom. Sparsely distributed staghorn corals were also found in back-reef rubble and high-relief spur and groove habitats. Population abundance estimates for the habitats surveyed indicate that there are approximately 2.59 million staghorn colonies (skeletal colonies) from the southern boundary of Biscayne National Park to Alligator Reef. However, most staghorn coral colonies are relatively small (< 250 cm^2 of live tissue surface area) and all thickets encountered were less than 1 m in maximum dimension. We estimate that approximately 66% of all staghorn corals in the upper FKNMS occur on mid-channel and offshore patch reefs, while the remaining 34% are distributed among shallow (< 6 m) hard-bottom and spur and groove reefs. Historically, staghorn coral occurred on some deeper fore-reef areas (especially low-relief spur and groove) in larger thickets of interlocking colonies, but no such thickets have been encountered during the past decade. In contrast to the pattern evident for *A. palmata*, it is estimated that nearly all (approximately 99%) of the staghorn corals present in the upper FKNMS occur outside of Sanctuary no-take zones. Of the condition categories assessed, bleaching (19 colonies, 7.4%) and predation (primarily damselfishes and snails) were the most common. Obvious signs of predation were found on 65 colonies, representing approximately 25% of the sampled staghorn corals. No disease-like symptoms or overgrowth by other organisms were encountered.

Relative to its congener, elkhorn coral (*Acropora palmata*) exhibited a narrower habitat distribution, with a few reefs supporting larger aggregations. The size range of skeletal colonies (n = 107) ranged from 3 to 268 cm, with an average of 66 ± 6 cm. Live tissue surface area of physiologic colonies ranged from 1 to 44,185 cm^2, with an average of 1,452 ± 217 cm^2. Among the habitat types sampled, elkhorn corals were only found on inner line reef tract and shallow spur and groove sites. In previous years, we encountered a few isolated colonies on offshore patch reefs, back-reef rubble, and shallow hard-bottom, but clearly most colonies are presently restricted to shallow fore-reef areas in the upper FKNMS. Similar to previous years, elkhorn corals were most common and characterized by larger colony sizes on several high-relief spur and groove reefs, especially within FKNMS no-take zones such as South Carysfort Reef, Elbow Reef, Grecian Rocks, and French Reef; a similar pattern was also evident for colony size. We estimate that more than 90% of elkhorn corals occur in these high-density thickets. In contrast to the size structure of staghorn corals, there is a greater range in size and a greater abundance of larger (> 1 m diameter) elkhorn corals. Several shallow spur and groove reefs continue to support reasonably large thickets, with most patches approximately 15-20-m in diameter. Reefs where stands (not just isolated colonies) of elkhorn coral occur in the upper Florida Keys include (from north to south): South Carysfort Reef, Elbow Reef, Horseshoe Reef, Grecian Rocks, French Reef, Sand Island, and Molasses Reef. In contrast to staghorn corals, most (87%) of the elkhorn coral colonies in the upper FKNMS occur within Sanctuary no-take zones. Of the condition categories assessed, bleaching (65 colonies, 21.7%) and predation (47 colonies, 15.7%) were the most common adverse conditions encountered. No disease-like symptoms or overgrowth by other organisms that was causing tissue loss were documented.

Surveys for all scleractinian coral species were conducted at all 280 sites, in which replicate 10-m x 1-m belt transects were used to survey the number, size (max. diameter), and condition (percent live tissue, bleaching, disease, overgrowth, and predation) of corals. These data were used, in turn, to compute abundance estimates, prevalence of different conditions, and size structure. A total of 19,716 corals representing 40 species were identified, counted, measured, and assessed for condition. Ten species accounted for approximately 93% of all of the corals encountered, with *Siderastrea siderea*, *Porites astreoides*, *Agaricia agaricites*, *P. porites porites* the most abundant. Coral species could be broadly grouped into those that are ubiquitous and abundant in most of the habitats surveyed, those that are less abundant overall, but common in certain habitats (e.g. *Montastraea faveolata*), and rarer species (e.g. *Dendrogyra cylindrus*). Prevalence of different adverse conditions such as disease and bleaching were generally low, with prevalence estimates of 0.8% and 1.5%, respectively. Bleaching and overgrowth were the most common conditions noted. Many of the most common corals exhibited differences in frequency of occurrence and density among the habitats surveyed. Inshore, mid-channel, and offshore patch reefs continue to support relatively high densities of many species, especially the larger reef-building corals. Comparisons between FKNMS no-take zones and reference areas indicated generally greater densities, sizes, and abundances for most species. Because of the relatively small area of FKNMS no-take zones in the upper Keys, it is therefore not surprising that most of the corals occur outside of the no-take zones.

Seven urchin species comprising 1,958 individuals were counted and measured for test diameter (TD) surveyed during 2011. Similar to previous years, most (~79%) urchins sampled were either *Echinometra viridis*, which was particularly abundant on many mid-channel and offshore patch reefs, or *Eucidaris tribuloides*, which was most abundant in back-reef rubble and high-relief spur and groove reefs. Densities of the long-spined sea urchin (*Diadema antillarum*) are still relatively low by historical (pre-1983) standards; the maximum site-level density recorded during 2010 was only 0.267 individuals per m^2. However, two temporal trends are apparent relative to similar surveys from a decade ago. First, densities of *D. antillarum* have slowly increased since 1999, and the greatest densities of larger (> 5 cm TD) individuals presently occur on mid-channel and offshore patch reefs, with abundant recently settled recruits in back-reef rubble. Second, there has been a notable increase in the average and maximum sizes of individuals encountered over the past 10 years. In 2011, individuals as large as 9.1 cm TD were recorded, which we never encountered in the Florida Keys prior to 2006. The average size of *D. antillarum* up until 2005 was < 3.0 cm TD, while 2011 yielded an average size of 4.2 cm TD (147 individuals); this average size includes 14 individuals measured in back-reef rubble sites where juveniles (< 2 cm TD) predominate. At sites where aggregations of urchins were found, there were clear and obvious impacts to the substratum. Thus, assuming these trends continue, and as more space becomes cleared of algae, it will be important to monitor potential changes to the benthos, for example, recruitment of corals and other invertebrates. For most of the species encountered, including *D. antillarum*, urchins tended to be more frequently encountered and occurred in greater densities on reference sites compared to no-take zones. Whether this result is due to greater urchin predation inside the no-take zones compared to reference areas is unknown.

Three anemone and three corallimorpharian species were encountered during 2011. Although more common in the lower Florida Keys region, which was not sampled this year, no individuals of *Bunodosoma granulifera*, *Epicystes crucifera*, the knobby anemone (*Heteractis lucida*), and the sun anemone (*Stichodactyla helianthus*) were encountered in the upper Keys during 2011. A total of 595 anemones were counted, mostly represented by *Bartholomea annulata* (81%) or *Condylactis gigantea* (14%). Anemones generally showed similar spatial patterns in abundance among habitats in 2011 compared to previous survey years, with *B. annulata* exhibiting the broadest habitat distribution and greatest frequency of occurrence and abundance. A total of 820 corallimorpharians were counted, of which approximately 96% were *Ricordea florida*, followed by *Discosoma sanctithomae* and *D. carlgreni*. Similar to previous years, *R. florida* was most abundant on mid-channel and offshore patch reefs, with mean densities as high as 9.8 individuals per m^2.

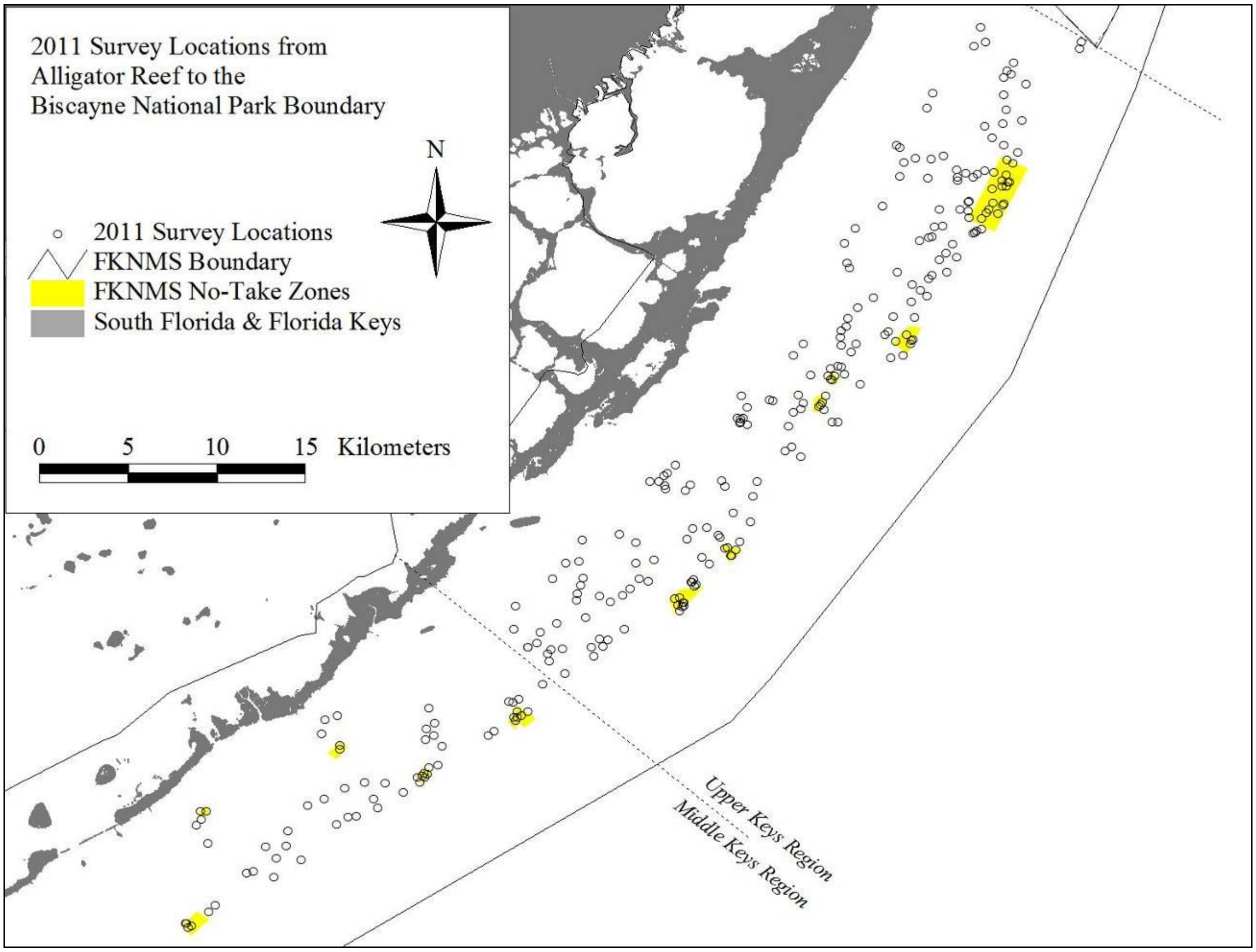
Surveys of the abundance, size, and substratum occupancy patterns of mollusks continued during 2011. All nudibranchs encountered, the sacoglossan *Elysia* (*Tridachia*) *crispata* (lettuce sea slug), and four gastropod species (*Coralliophila* sp., *Leucozonia nassa*, *Thais deltoidea*, and *Strombus gigas*) were enumerated and measured for shell length; in addition, the substratum occupied by a mollusk at the time of the survey was also noted. Seven nudibranch species were encountered, including several undescribed species. All but one of the 69 lettuce sea slugs (*E. crispata*) recorded were found on shallow, high-relief spur and groove reefs. Of the gastropods inventoried, the deltoid rock snail (*T. deltoidea*), an important micro-herbivore of turf algae, was the most abundant (221 individuals), with most individuals occurring on high-relief spur and groove reefs. Approximately 94% of the individuals encountered were found either occupying algal turf or crustose coralline algae. Of the 147 corallivorous snails (*Coralliophila* sp.) recorded, all but one individual were found on live coral tissue. Comparison to previous surveys suggests that *Coralliophila* snail abundance is increasing and that a greater diversity of coral species is experiencing snail predation. Particularly noteworthy was the diversity of coral species (13 species) encountered during 2011 with active snail predation, including species of *Acropora*, *Agaricia*, *Diploria*, and *Montastraea*.

Surveys of marine debris, including lost hook-and-line and lobster and crab trap fishing gear, carried out in 2011 represent a continuation of similar efforts conducted in the Florida Keys in 2000, 2001, 2008, and 2010. Data collected in 2011 included the type and frequency (density) of debris, the length of angling gear and lobster/crab trap rope, the total wet weight of debris recovered, as well as the frequency of benthic coral reef organisms impacted by tissue abrasion from debris entanglement. A total of 679 debris items were encountered. Marine debris was found at about 71% of sites (63%) and in all habitats, including the 12 no-take zones surveyed. Nearly 62% of the debris encountered consisted of lost hook-and-line fishing gear such as monofilament line, wire leaders, and lead sinkers. The remaining debris consisted of lobster and crab trap gear (25%) and other items such as glass, metals, and plastics. Just over 0.5 km of angling gear, mostly represented by monofilament and fishing wire, was recovered, along with 1.145 km of lobster/crab trap rope, and ~243 kg of debris (approximately 0.534 tons) was recovered from the seabed. A total of 363 sessile invertebrates represented by milleporid hydrocorals (44 colonies), scleractininian corals (89 colonies), gorgonians (195 colonies), sponges (32 individuals), and *Palythoa* (3 individuals) were recorded with abrasions from entanglement with marine debris, usually fishing gear.

Impacts to the benthos from the January 2010 cold-front event, perhaps the worst hypothermal event since the winter of 1976-77, continue to be apparent in particular areas of the upper Florida Keys. Large numbers of patch reefs in the Cannon Patch/Higdons Reef area, Mosquito Bank, Tavernier Rocks, and the

Cheeca Rocks area appear to have suffered the most mortality, especially larger *Montastraea* colonies, as well as gorgonians, as evidenced by the larger numbers of dead, upright gorgonian skeletons. However, areas further offshore of inshore patch reef and shallow bank areas appeared to have suffered little damage from the January 2010 event. Finally, we witnessed more lionfish in 2011 than ever before, as evidenced by greater site prevalence and more individuals (usually 3-6 in a 100-m^2 area). Lionfish were particularly common in habitats such as patch reefs with large coral heads or overhangs.

Figure 1. Sampling locations for *Acropora* corals, other benthic coral reef organisms, and marine debris in the upper Florida Keys National Marine Sanctuary during May-September 2011. A total of 280 sites were surveyed for coral density, size, and condition, including *Acropora* corals, as well as urchins, anemones, corallimorpharians, mollusks, and marine debris from the southern boundary of Biscayne National Park to Alligator Reef.



I. Introduction

Like many coral reef ecosystems, the Florida Keys have exhibited significant change in recent decades, including the loss of coral cover and urchins (*Diadema antillarum*) due to disease, as well as hypo- and hyperthermal events that have resulted in significant coral loss due to bleaching (Jaap 1984; Aronson and Precht 2001; Chiappone et al. 2002; Lirman et al. 2011). In addition, localized impacts to reefs are also evident from over-use such as from finfish fishing and harvesting ornamentals, coastal development, and a considerable array of larger-scale phenomena affecting Florida Keys reefs, such as continental influence (Biscayne Bay and Florida Bay exchange) and destructive tropical storms (Precht and Miller 2007). This array of stressors makes it challenging to discern the degree to which human activities have affected ecological integrity relative to natural system variability (Somerfield et al. 2008).

While understanding the causes of coral reef decline is a fundamental pursuit among coral reef ecologists, our sampling program was designed specifically to document the status and trends of no-take management zones throughout the Florida Keys National Marine Sanctuary (FKNMS). To evaluate potential changes in no-take management zones, it is necessary to also document changes caused by natural system variability, such as mortality events caused by disease or bleaching, coral recruitment events (especially related to *Acropora* corals), or recovery of the previously abundant sea urchin, *Diadema antillarum*. By broadly sampling populations among multiple habitat types across the south Florida shelf, inside and outside of the no-take management zones, and throughout the Florida Keys from south of Miami to the Dry Tortugas, over now a 13-year period, we have documented the distribution, abundance, and changes over time of coral reef organisms and communities in the region. Our data and results are unprecedented in spatial coverage and establish a baseline from which future comparisons can be made, related to further decline, recovery, or stasis. It is important to note that our program began in the late 1990s, long after major declines had already occurred in the region, specifically the loss of *D. antillarum* and *Acropora* corals.

In 2011, during 29 days of fieldwork in the upper Florida Keys, we sampled 280 sites stratified by cross-shelf habitat type, along-shelf position, and management zone from the southern boundary of Biscayne National Park to Alligator Reef within the upper region of the FKNMS. Surveys of *Acropora* corals included assessments of colony density at two different levels (skeletal colonies and physiologic colonies), as well as colony size, and condition. Surveys of all other scleractinian corals included assessments of density, size class, estimates of percent live tissue vs. dead skeleton, and condition assessments of bleaching disease, predation, and overgrowth. Other benthic coral reef organisms were surveyed for abundance and size, including urchins, anemones, corallimorpharians, and mollusks. Marine debris surveys continued in 2011 and consisted of measurements of the frequency, density, length, and weight of debris, as well as counts of benthic invertebrates exhibiting abrasion stress from debris entanglement. Our program team was joined by scientists from Grays Reef National Marine Sanctuary and the Damage Assessment and Restoration Research Program of the FKNMS. Funding was provided by NOAA's Coral Reef Conservation Program and the Department of Commerce's 1535 Endangered Species Act Projects, Boat and diving support were provided by NOAA's Aquarius Reef Base Program and the upper Keys office of the Florida Keys National Marine Sanctuary.

The 2011 surveys add to a growing temporal base of observations made by our program since 1998 (Chiappone et al. 2002a, b; Miller et al. 2002). Previous surveys aided in optimizing a sampling plan for obtaining estimates of abundance and size of benthic coral reef organisms, with a particular focus on *Acropora* corals (see previous Quick Look reports at http://people.uncw.edu/millers), which is part of a Florida and U.S. Caribbean effort to determine the population status of these species. In the Florida Keys, our sampling program is specifically designed to help resource managers evaluate the performance of smaller protected areas (no-take zones) relative to other factors that influence the larger ecosystem. This report is divided into several sections to summarize the observations and data collected for each of the major classes of variables measured during 2011. Accompanying summary tables, underwater images, and maps are included to illustrate some of the spatial patterns observed for the variables measured along a ~50 km stretch of the upper Florida Keys from northern Key Largo to Islamorada.

II. Study Area and Survey Methods

Study area and sampling objectives

The Florida Keys comprise an archipelago of limestone islands spanning more than 360 km from south of Miami to the Dry Tortugas. With the exception of isolated banks in the Flower Gardens area in the northwestern Gulf of Mexico, the Florida Keys ecosystem represents the only region of extensive coral reef development in the continental U.S. (Jaap 1984). The islands are part of the larger south Florida shelf, a submerged Pleistocene platform 6-35 km wide and generally < 12 m deep (Lidz et al. 2003). The primary influences on the distribution and development of Florida Keys reefs are paleotopography and fluctuating sea level (Shinn et al. 1989; Lidz et al. 2003). Bedrock throughout south Florida is Pleistocene limestone, either exposed on the seafloor or lying underneath Holocene reefs and sands (Shinn et al. 1989). Proceeding seaward from the shorelines of the Pleistocene islands, a nearshore rock ledge extends ~2.5 km from the shoreline, with the seabed consisting of hard-bottom, seagrass, and isolated inshore patch reefs (FMRI 1998). Seaward of the island platform is Hawk Channel, a broad trough-like depression dominated by mostly non-coralline, non-oolitic grainstone, dotted with several thousand patch reefs whose distribution is affected by the number and width of tidal passes connecting Florida Bay and the Atlantic Ocean (Marszalek et al. 1977; Shinn et al. 1989). Bands of rock ridges exist further offshore along the outer shelf and on the upper slope from 30-40 m depth before the shelf tapers off into the Straits of Florida. The semi-continuous offshore reef tract is emergent in places, in which Holocene reefs sit atop a ridge of Pleistocene corals (~86-78 ka), forming a shelf-margin ledge (Lidz et al. 2003), with a series of outlier reefs seaward of this main reef tract at 30-40 m depth (Lidz 2006). Like inner shelf margin patch reefs, the distribution of platform margin reefs reflects exchange processes between Florida Bay and the Atlantic Ocean (Marszalek et al. 1977; Shinn et al. 1989), which is related to the size and orientation of the Pleistocene islands and thus the presence and size of tidal passes, as well as the proximity of the Florida Current to the platform margin (Pitts 1994; Smith 1994).

The 2011 sampling of *Acropora* corals, other benthic coral reef organisms, and marine debris in the upper Florida Keys National Marine Sanctuary (FKNMS) was undertaken as a spatially intensive effort to document the population status of staghorn and elkhorn corals. The 2011 surveys conducted from May 5 to September 10 were an outgrowth of previous efforts conducted by our program dating back to 1998 to quantify the abundance and condition of coral reef benthos throughout the FKNMS, including the Tortugas region (Miller et al. 2002). Previous surveys in the FKNMS, excluding the Tortugas region, consisted of 80 sites sampled Keys-wide in 1999, 45 sites in the lower Keys region in 2000, 108 sites Keyswide in 2001, 195 sites Keys-wide in 2005, 107 sites in the upper Keys region in 2006, 235 sites Keyswide in 2007, 145 sites Keyswide in 2008, 160 sites Keyswide in 2009, and 120 sites in the upper

Keys region in 2010. Data obtained from these earlier efforts, together with existing habitat mapping information for the FKNMS, were used to guide the sampling of *Acropora* corals, other benthic coral reef organisms, and marine debris in 2011. The overall goals of the 2011 sampling effort were two-fold:

- Collect information on habitat distribution, colony abundance, size, and condition of *Acropora* corals to derive population abundance estimates for the upper FKNMS; and
- Continue the temporal data sets on the abundance and size of non-*Acropora* corals, urchins, anemones and corallimorpharians, and mollusks, as well as the density, length, weight, and impacts of marine debris in the upper FKNMS.

We were able to continue amassing temporal data sets on the population status of several additional groups of benthic invertebrates dating back to 1999 throughout the upper Keys area. The objectives of the 2011 sampling effort were to provide information on:

- Depth and physical structure (maximum vertical relief) of survey sites;
- Distribution, density, size, and condition (bleaching, disease, overgrowth, and predation) of *Acropora* corals;
- Density, size class, percent live tissue vs. dead skeleton, and condition of non-*Acropora* corals;
- Density and size (test diameter) of sea urchins, representing an ongoing effort to monitor recovery of the historically abundant long-spined sea urchin *Diadema antillarum*;
- Density of sea anemones and corallimorpharians, as well as density and size of mollusks such as sea slugs, nudibranchs, and other gastropods (*Coralliophila* sp., *Leucozonia nassa*, *Strombus gigas*, and *Thais deltoidea*); and
- Density, length, weight, and impacts of entangled marine debris, representing a continuation of efforts carried out in 2000-01, 2008, and 2010.

Sampling design and field methodology

The sampling design for assessing *Acropora* corals, other benthic coral reef organisms, and marine debris encompassed 280 sites visited during May-September 2011. Sites were distributed from the southern boundary of Biscayne National Park to Alligator Reef (Figure 2-1). The sampling design included nine habitat types, as well as all 12 no-take zones designated as Sanctuary Preservation Areas (SPA) or Research Only Areas (RO) between northern Key Largo and Alligator Reef (Table 2-2). Table 2-2 lists the sites sampled chronologically during May-September 2011.

The habitat strata sampled during 2011 incorporated most of the hard-bottom and coral reef habitat types from the island platform (e.g. inshore patch reefs such as Tavernier Rocks) inshore of Hawk Channel to ~15 m depth along the reef tract. However, the 2011 effort did not include nearshore hard-bottom, hard-bottom/seagrass matrix habitats, or deeper (> 15 m) fore reef areas, as these areas do not appear to support *Acropora* corals based upon previous surveys. The habitats sampled during 2011 were inshore and mid-channel patch reefs, offshore patch reefs, back reef rubble, shallow (< 6 m) hard-bottom, inner line reef tract spur and groove from Grecian Rocks northward to Turtle Reef, shallow (< 6 m) high-relief spur and groove along the platform margin, and deeper fore-reef habitats from 6-15 m depth. Deeper fore-reef habitats encompassed continuous, low-relief hard-bottom, patchy hard-bottom, and low-relief spur and groove. For the data presented in this report, inshore patch reefs and mid-channel patch reefs were combined, as were inner line reef tract and platform margin spur and groove habitats, as well as deeper (6-15 m) fore-reef habitats. Table 2-3 lists the sites by benthic habitat type and management zone, along with summaries of transect depth sampled and maximum vertical relief. Besides habitat type, sites were further categorized by along-shelf position and management zone (i.e. inside and outside of FKNMS no-take zones). Figures 2-2 to 2-4 show the spatial distribution of sampling locations by habitat type for the 280 sites, along with the boundaries of existing no-take zones in the upper FKNMS. Figures 2-5 to 2-8 illustrate examples of each of the hard-bottom and coral reef habitat types sampled during 2011.

A geographic information system (GIS) containing digital layers for benthic habitat (FMRI 1998), bathymetry, and FKNMS no-take zone boundaries was used to facilitate delineation of the sampling survey domain, strata, and sample units. Existing resolution of benthic habitats is such that the survey domain was divided into a grid of individual cells 200 m by 200 m (40,000 m^2) in area that that serve as primary sampling units. A two-stage sampling scheme we adapted (Smith et al 2011) following Cochran (1977) was employed to control for spatial variation in population metrics at scales smaller than the grid cell minimum mapping unit. Grid cells containing targeted reef and hard-bottom habitats were designated as primary sample units. A second-stage sample unit was defined as a belt transect of fixed area (15-m x 1-m in dimension) within a primary sample unit. The size of an individual primary sampling unit allowed divers to swim to the location of any given second-stage sampling unit from a moored or anchored vessel.

To control for spatial variation in the benthic variables assessed, the upper Florida Keys survey domain was partitioned into strata based upon: 1) habitat class, 2) geographic region (along-shelf position), and 3) management zones of the Florida Keys National Marine Sanctuary (FKNMS). A grid system constructed in a geographic information system (GIS) was used to overlay the existing habitat map of the Florida Keys. Cells or blocks 200 m x 200 m in dimension were used to randomly select sites from the combination of habitat type, regional sector, and management zone. Habitats were designated using regional benthic habitat maps (FMRI 1998). The habitat classification scheme accounted for features that correlate with benthic fauna distributions, including cross-shelf position, topographic complexity, and the proportion of sand interspersed among hard-bottom structures. A geographic regional stratification variable was used to account for oceanographic and geological features in the Florida Keys that may influence the distribution and community composition of hard-bottom and reef habitats (Marszalek et al. 1977; Shinn et al. 1989). We have previously defined regional sectors as follows: upper Florida Keys (BNP boundary south to Pickles Reef), middle Florida Keys (Conch Reef southwest to Moser Channel), and lower Florida Keys (Big Pine Shoal west to Satan Shoal). FKNMS no-take zones are incorporated as a third stratification variable that delineates areas open and closed to consumptive activities. Within each no-take zone, a minimum of two replicate sites are sampled in a given habitat type. The power of the stratified random sampling approach is essentially two-fold: 1) the habitats comprising the most area are initially allocated more sites than those with less area (i.e., a proportional design); and 2) habitats exhibiting more variability with respect to particular metrics (e.g. coral density) are allocated more sites than those with less variability. The ultimate power of this approach is derived more from the number of sites sampled rather than the effort expended per site.

The underwater surveys consisted first of locating randomly selected, pre-determined coordinates with a differential global positioning system. A Garmin® global positioning system receiver (model GPS76) was used to determine the position at each site. The original sampling list encompassed 300 sampling locations, with an additional 156 alternate sites between Alligator Light and the northern FKNMS boundary. If the original waypoint was not the intended habitat type, based on visual assessment by a snorkeler, the closest alternate site was sampled instead. Once on-site, usually a two-person diver team oriented two transect tapes 15-m in length, marked in 10-cm increments, along the bottom. A 1-m wide belt centered on each 15-m long transect tape was surveyed at each site for most of the benthic variables described below, with a total of 60-m^2 surveyed (Figure 2-10). At all 280 sites sampled during 2011, 15-m^2 belt transect areas were surveyed for:

- Minimum and maximum depth;
- Maximum vertical relief of the substratum such as ledges, spur edges, crevices, coral heads, and sponges;
- Number of colonies, skeletal unit size, live tissue surface area, and condition (bleaching, disease, predation, overgrowth) of *Acropora* corals;
- Numbers and test diameters of sea urchins;

- Numbers of anemones and corallimorpharians;
- Numbers and total lengths or shell lengths of nudibranchs, the lettuce sea slug (*Elysia crispata*), and the gastropods *Coralliophila* sp., *Leucozonia nassa*, and *Thais deltoidea*; and
- The frequency of marine debris and the numbers of benthic organisms exhibiting abrasion stress (partial mortality due to tissue loss).

Smaller belt transect areas (10-m x 1-m) were surveyed for the numbers of colonies, sizes (binned by size class), percent live tissue vs. dead skeleton, and condition of all other scleractinian corals greater than 4 cm in maximum diameter. Finally, 15-m x 2-m belt transect areas were surveyed for the density of marine debris, the length of all angling gear and lobster/crab trap rope encountered, the numbers of benthic organisms exhibiting abrasion stress (partial mortality due to tissue loss), and the wet weight of all debris collected per transect. Data were collected using pencils and pre-printed slates that facilitate efficient recording (Figure 2-10). At the end of the day, slates were scanned for archival purposes and then data were entered and checked using pre-formatted spreadsheets.

Training and Partnerships

The 2011 field effort was facilitated by participation of scientists from Grays Reef National Marine Sanctuary (Sarah Fangman) and the Florida Keys National Marine Sanctuary Damage Assessment Restoration and Research Program (DAARP) (Table 1). One day of in-water training on May 19 was used to review sampling protocols with five personnel in the Pickles Reef area. This represents the beginning of a partnership-effort with the FKNMS that we expect will continue in 2012. A Field Protocol Manual with drafted in June to assist with training. An updated version of the Field Protocol Manual was completed in December 2011 and was provided to colleagues in the U.S. Virgin Islands and Puerto Rico, who will sample *Acropora* populations in 2012.

Logistics Summary

Twenty-nine (29) field days were required to sample 280 sites from northern Key Largo to Alligator Reef. Fourteen days during May and August were supported by ARB-UNCW day-boat support out of Key Largo aboard the R/V *Research Diver* and R/V *George F. Bond* (captained by T. Roberts), in which 112 sites were sampled by a 2-person team. Six field days (6/13-6/18) were supported by a private vessel charter (R/V *Expedition II*, captained by B. Altmeier); 61 sites were sampled by either a 3- or 4-person team (Chiappone, Fangman and Rutten, with Anderson and Bailey alternating). Six days (6/19-6/23 and 9/10) were supported by a private vessel charter (Quiescence Q-1), in which 50 sites were sampled by a 3-person team (Bailey, Fangman, and Rutten). The upper Keys office of the FKNMS supported seven days (6/20-6/24 and 8/11-8/12) of fieldwork (Sea-Vee, captained by D. Mooney and J. Halas), in which a 2-person (Chiappone and Rutten) or a 3-person team (Anderson, Chiappone and Goodwin) sampled 57 sites.

A total of 762 dives were completed by participants during 29 days of fieldwork, in which divers logged a combined total of just over 381 hours of underwater bottom time (Table 2-4). The depth range of dives ranged from 5 feet to 53 feet. The sampling effort depended upon 6 to 7 hours in the water daily by a two- or three-person benthic team to complete an average of eight (8) sites per day. Typically 30-40 minutes per site were needed to sample the targeted benthic variables.

Figure 2-1. Sampling locations for *Acropora* corals, other benthic coral reef organisms, and marine debris in the upper Florida Keys National Marine Sanctuary from the southern boundary of Biscayne National Park to Alligator Reef during May-September 2011.

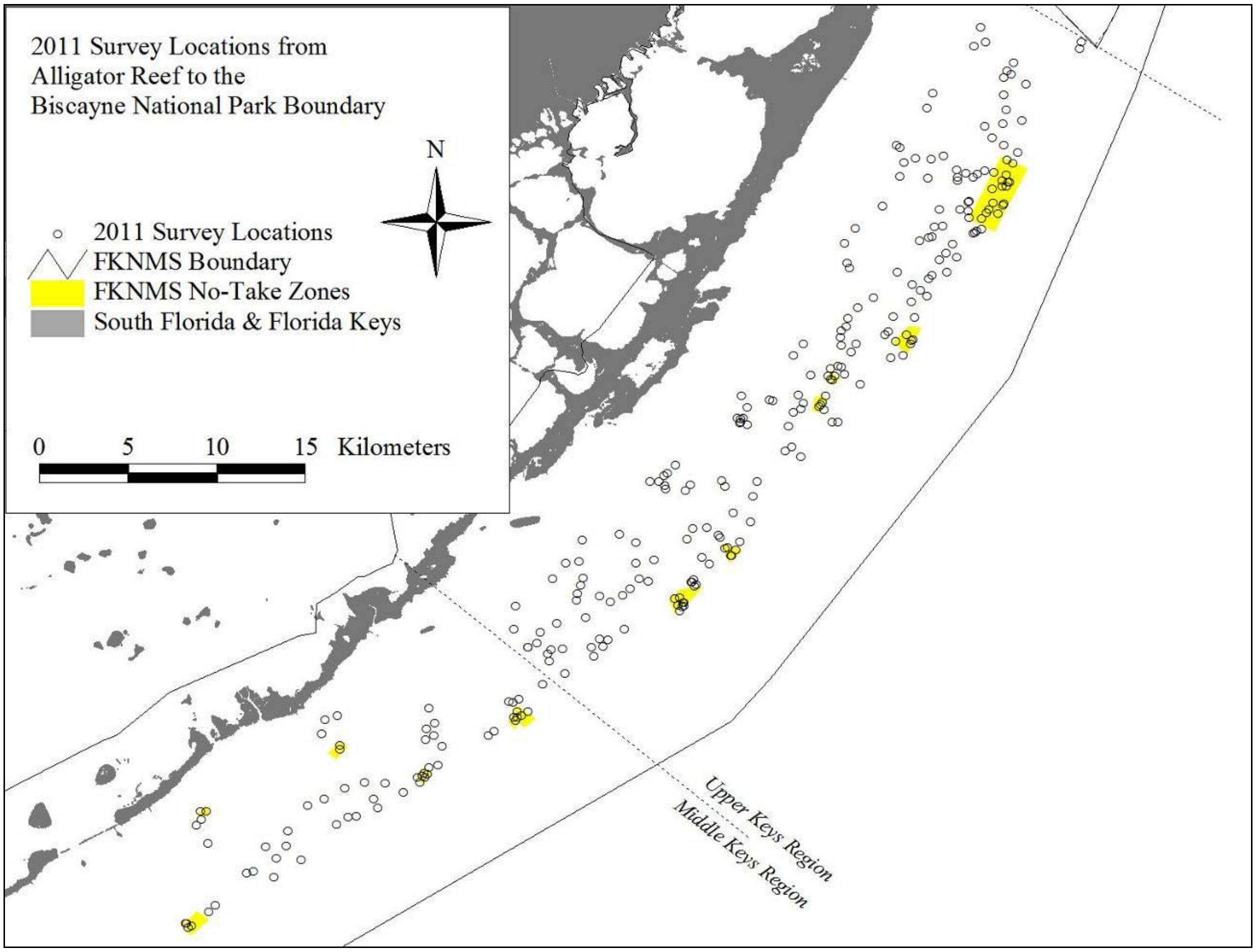


Figure 2-2. Upper Florida Keys sampling locations by benthic habitat type from the southern boundary of Biscayne National Park to the Watsons Reef area during May-September 2011.

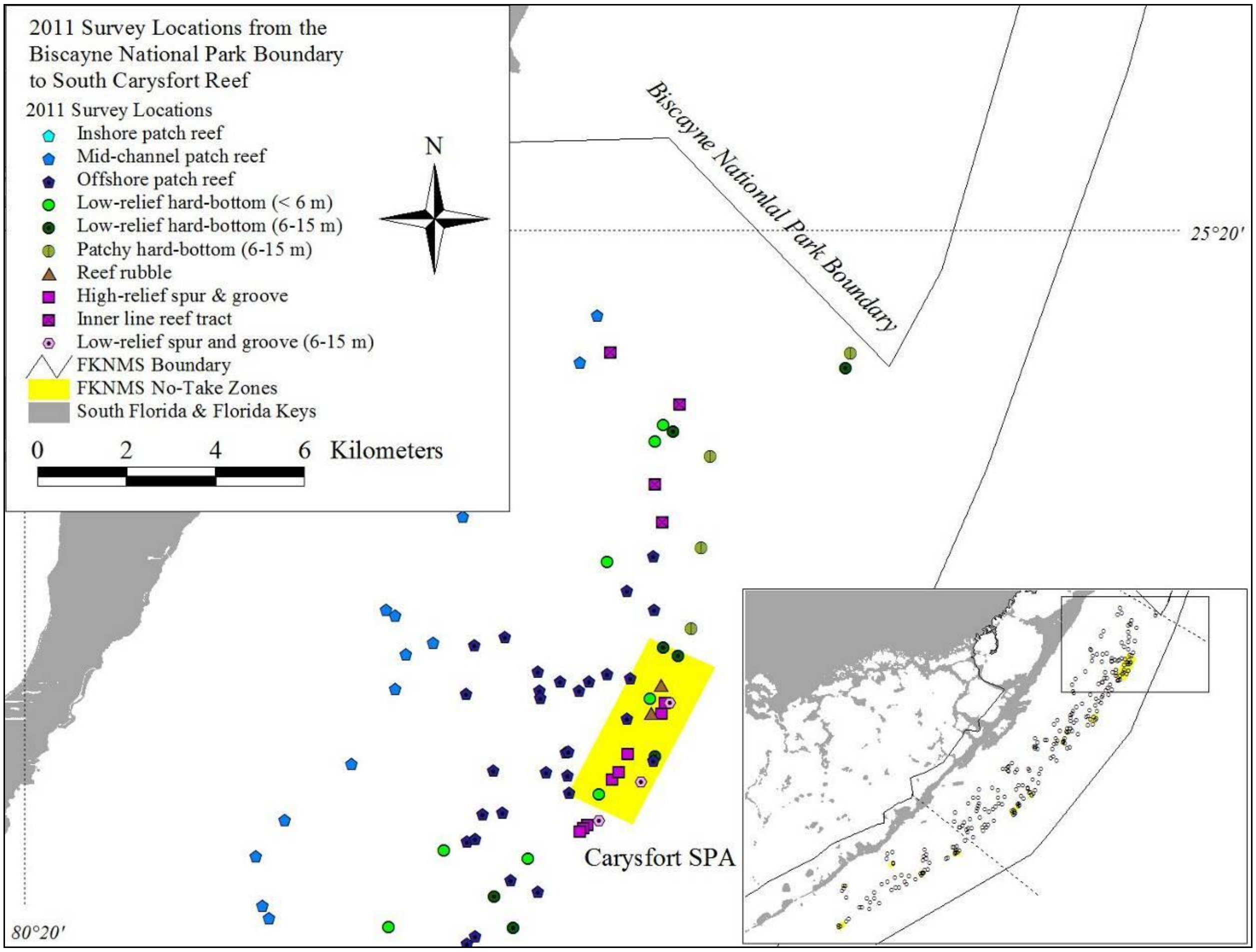


Figure 2-3. Upper Florida Keys sampling locations by benthic habitat type from Elbow Reef to the Pickles Reef area during May-September 2011.

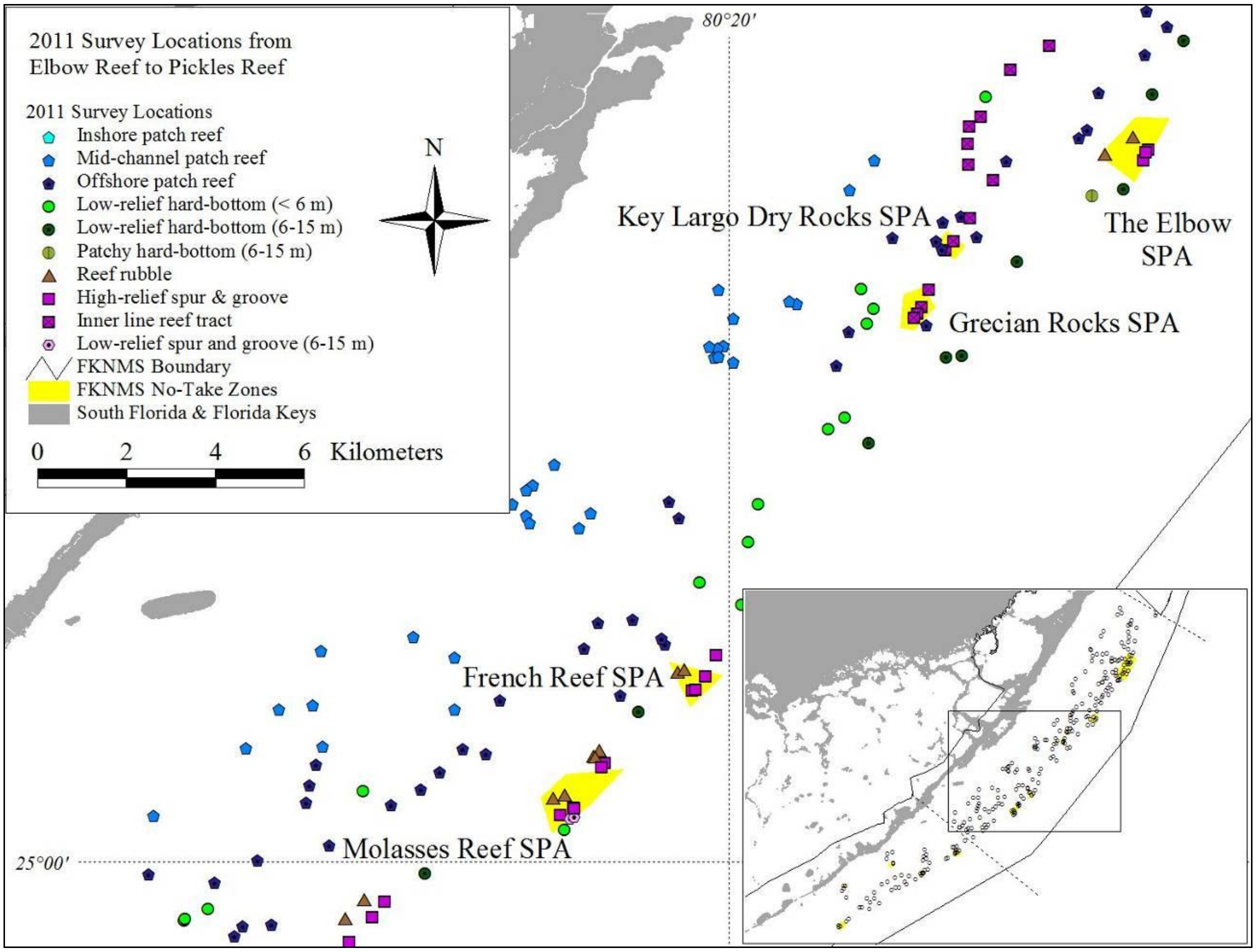


Figure 2-4. Upper Florida Keys sampling locations by benthic habitat type from Conch Reef to Alligator Reef during May-September 2011.

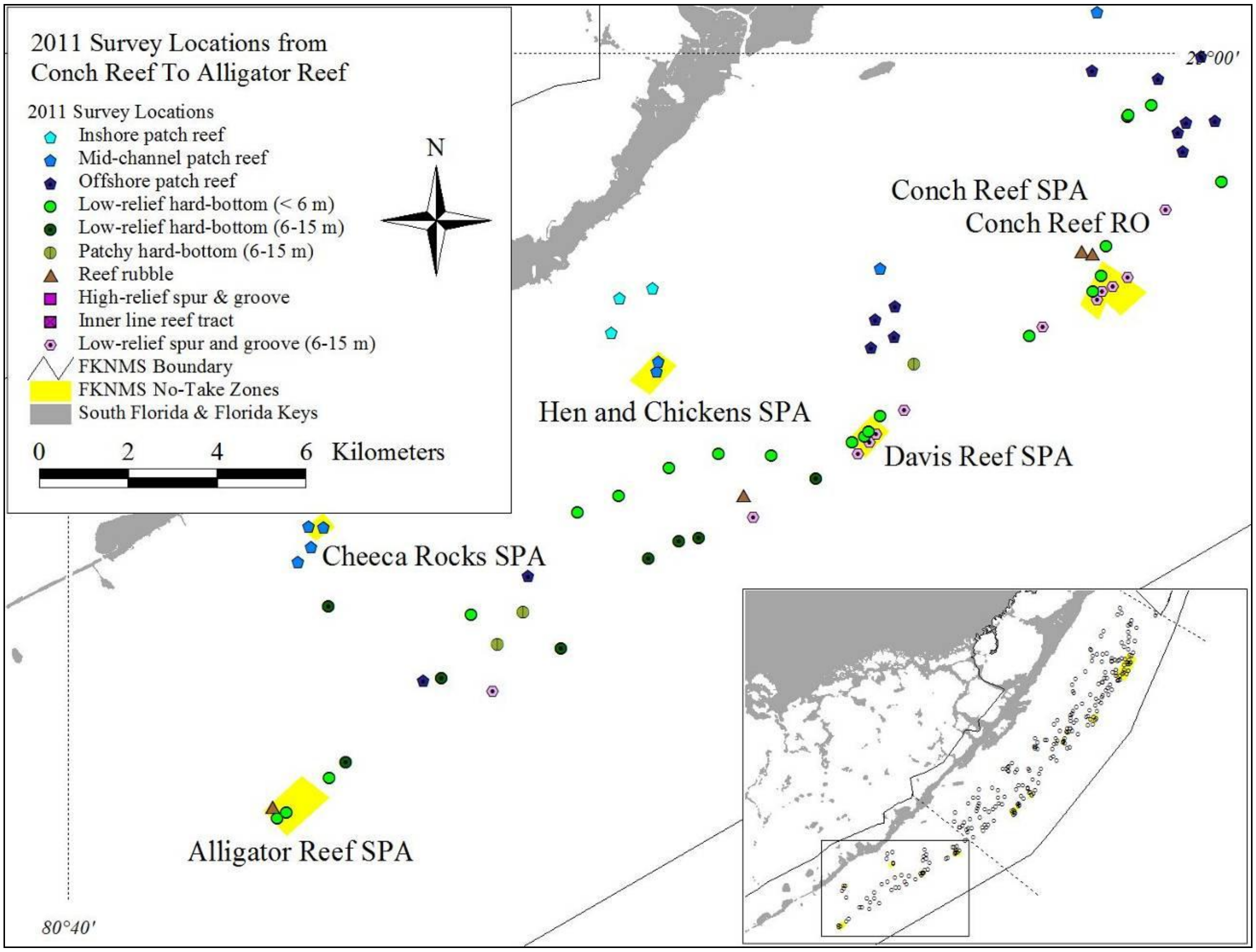
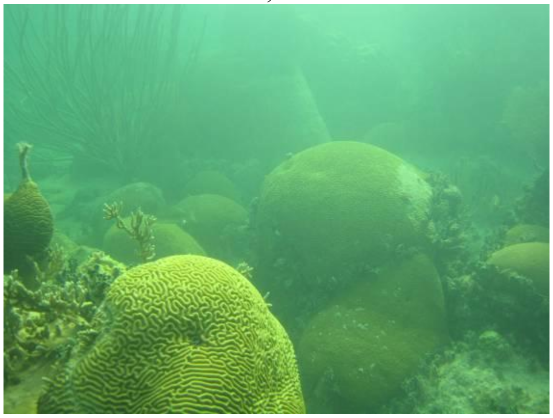


Figure 2-5. Examples of inshore, mid-channel and offshore patch reefs sampled in the upper Florida Keys National Marine Sanctuary during May-September 2011.

Inshore patch reef
Site #141, Cheeca Rocks SPA, 2.4-3.7 m
24^{o} 54.252'N, 80^{o} 36.896'W



Mid-channel patch reef
Site #90, Basin Hill Shoals, 2.4-4.3 m
25^{o} 14.412'N, 80^{o} 15.868'W

Offshore patch reef
Site #62, West of S. Carysfort Reef, 1.5-2.7 m
25^{o} 12.752'N, 80^{o} 13.797'W

Offshore patch reef
Site #106, Watsons Reef area, 11.0-12.2 m
25^{o} 10.067'N, 80^{o} 15.239'W

Figure 2-6. Examples of back-reef rubble and shallow (< 6 m) low-relief hard-bottom sites sampled in the upper Florida Keys National Marine Sanctuary during May-September 2011.

Back-reef rubble
Site #16, Molasses Reef SPA, 1.5-3.0 m
25° 00.708'N, 80° 22.691'W

Back-reef rubble
Site #63, Pickles Reef, 2.7-3.4 m
24° 59.480'N, 80° 24.978'W

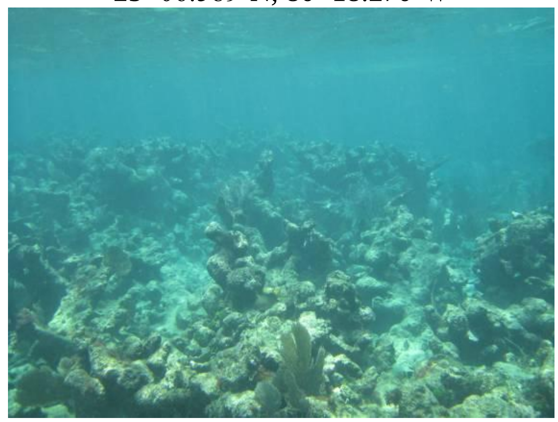
Low-relief hard-bottom
Site #43, Carysfort Reef SPA, 3.0-3.7 m
25° 13.399'N, 80° 12.772'W

Low-relief hard-bottom
Site #84, North of Watsons Reef, 4.0-5.5 m
25° 11.468'N, 80° 14.254'W

Figure 2-7. Examples of high-relief spur and groove reefs sampled in the upper Florida Keys National Marine Sanctuary during May-September during 2011.

Inner line reef tract spur and groove
Site #32, Turtle Rocks, 3.7-4.3 m
25^{o} 16.004'N, 80^{o} 12.713'W

Inner line reef tract spur and groove
Site #161, Grecian Rocks SPA, 1.8-3.7 m
25^{o} 06.589'N, 80^{o} 18.270'W



Platform margin high-relief spur and groove
Site #278, French Reef SPA, 4.9-8.5 m
25^{o} 02.026'N, 80^{o} 20.960'W

Platform margin high-relief spur and groove
Site #114, Elbow Reef SPA, 2.1-5.5 m
25^{o} 08.572'N, 80^{o} 15.475'W

Figure 2-8. Examples of deeper (6-15 m) fore-reef habitats sampled in the upper Florida Keys National Marine Sanctuary during 2011.

Low-relief hard-bottom
Site #27, Whistle Buoy, 6.7-8.5 m
25° 17.411'N, 80° 10.412'W

Low-relief spur and groove
Site #228, SW of Davis Reef, 10.7-11.3 m
24° 55.148'N, 80° 30.428'W

Patchy hard-bottom
Site #26, Whistle Buoy, 10.4-11.3 m
25° 17.596'N, 80° 10.351'W

Low-relief spur and groove
Site #220, Molasses Reef SPA, 12.2-13.4 m
25° 00.482'N, 80° 22.423'W

Figure 2.9. The two-stage stratification designed for the Florida Keys: (A) incorporates habitat type (cross-shelf position and depth), geographic region (along-shelf position), and management zone, utilizing a grid of 200-m x 200-m cells overlain onto existing habitat and bathymetry maps. (B) The example below shows an example of the two-stage stratification approach, where first- or primary-stage units shown as squares with a targeted habitat type are randomly selected based upon the three stratification variables. (C) An enlarged view of the sample grid with the arrow indicating a 200-m x 200-m cell containing a targeted benthic habitat type. (D) An enlarged view of one sample cell where second-stage units (transects) are deployed at random GPS points within a particular cell. Note that in 2011 we deployed two 15-m transects in each cell (site) surveyed.

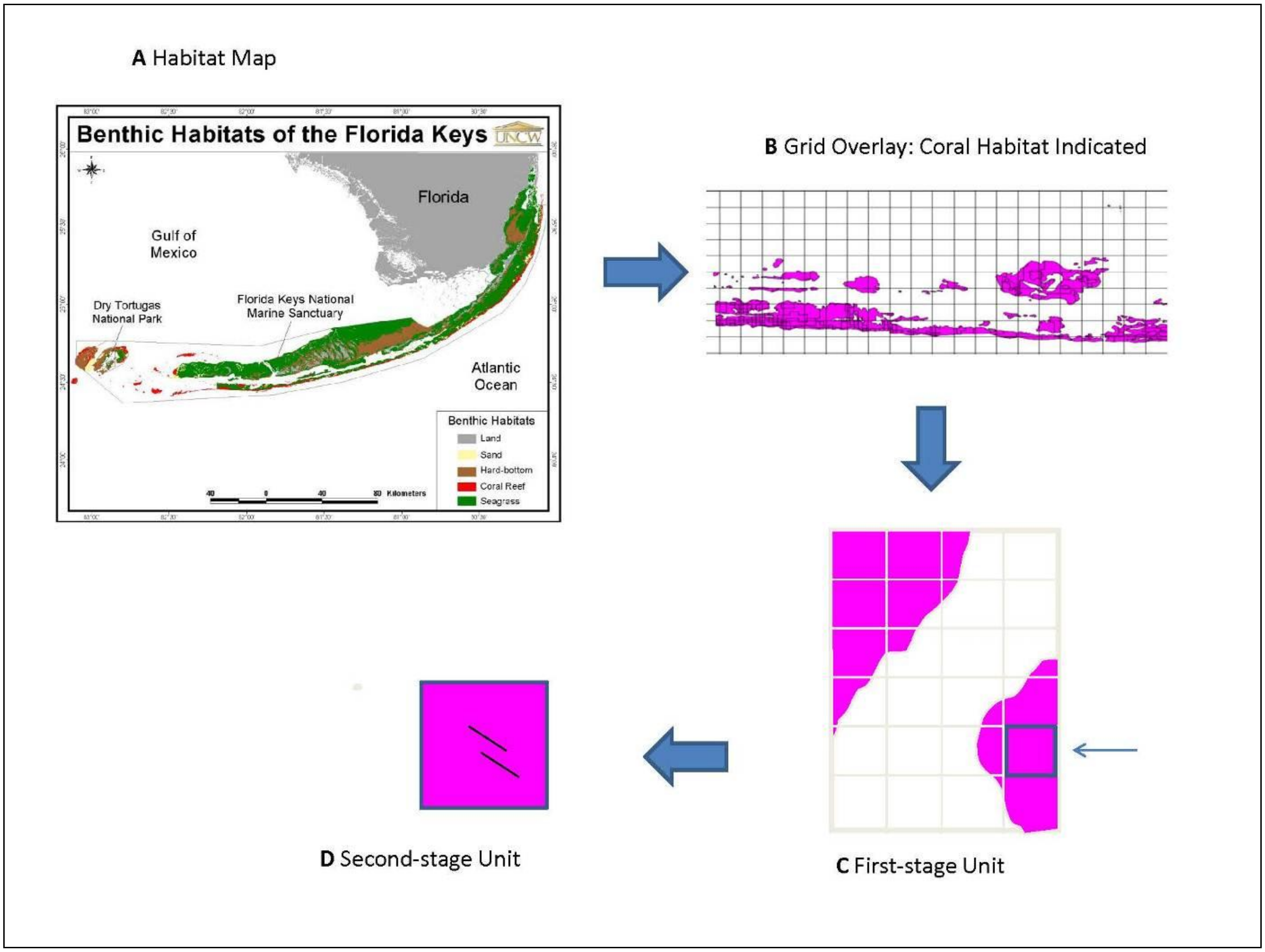


Figure 2-10. Examples of benthic survey methods used by this program.

Table 2-1. Sampling effort for *Acropora* corals, other benthic coral reef organisms, and marine debris in the upper Florida Keys National Marine Sanctuary during May-September 2011. At each site, replicate 15-m x 1-m transects were surveyed per site for all variables, except for non-*Acropora* corals (two 10-m x 1-m belt transect areas) and marine debris (two 15-m x 2-m belt transect areas). High-relief spur and groove sites include inner line reef tract (Grecian Rocks to Turtle Reef) and offshore spur and groove (Carysfort Reef to Pickles Reef) sites. Deeper fore-reef habitats included patchy hard-bottom, continuous low-relief hard-bottom, and low-relief spur and groove.

Habitat type/region/protection	**No. sites**	**Depth range (m)**	**% of Effort**	**No. transects**	**Area sampled (m^2)**
Inshore and mid-channel patch reefs					
Reference areas	50	0.9-8.2	17.86	100	1,500
No-take zones	4	1.8-6.7	1.43	8	120
Total	54	0.9-8.2	19.29	108	1,620
Offshore patch reefs					
Reference areas	73	1.5-12.8	26.07	146	2,190
No-take zones	4	3.7-7.0	1.43	8	120
Total	77	1.5-12.8	27.50	154	2,310
Back-reef rubble					
Reference areas	8	1.5-5.5	2.86	16	240
No-take zones	10	1.2-6.4	3.57	20	300
Total	18	1.2-6.4	6.43	36	540
Shallow (< 6 m) hard-bottom					
Reference areas	33	1.8-7.0	11.79	66	990
No-take zones	8	3.0-7.0	2.86	16	240
Total	41	1.8-7.0	14.64	82	1,230
High-relief spur and groove					
Reference areas	22	2.7-7.6	7.86	44	660
No-take zones	19	1.2-8.5	6.79	38	570
Total	41	1.2-8.5	14.64	82	1,230
Deeper fore reef					
Reference areas	36	5.8-11.6	12.86	72	1,080
No-take zones	13	5.5-15.8	4.64	26	390
Total	49	5.5-15.8	17.50	98	1,470
All habitat types					
Reference areas	222	0.9-12.8	79.29	444	6,660
No-take zones	58	1.2-15.8	20.71	116	1,740
Total	280	0.9-15.8	100.00	560	8,400

Table 2-2. Chronological list of the 280 sites surveyed for *Acropora* corals, other benthic coral reef organisms, and marine debris in the upper Florida Keys National Marine Sanctuary during May-September 2011. Asterisked sites (**) are within Sanctuary no-take zones (SPAs or ROs).

Site #	Date	Site location	Latitude (N)	Longitude (W)	Habitat type
1	5/5/2011	South of Cannon Patch	25º 06.522	80º 20.496	Mid-channel patch reef
2	5/5/2011	South of Cannon Patch	25º 06.193	80º 20.619	Mid-channel patch reef
3	5/5/2011	South of Cannon Patch	25º 06.168	80º 20.684	Mid-channel patch reef
4	5/5/2011	South of Cannon Patch	25º 06.052	80º 20.726	Mid-channel patch reef
5	5/5/2011	Mosquito Bank	25º 04.511	80º 22.926	Mid-channel patch reef
6	5/5/2011	Mosquito Bank	25º 04.443	80º 23.008	Mid-channel patch reef
7	5/5/2011	Mosquito Bank	25º 04.142	80º 23.007	Mid-channel patch reef
8	5/5/2011	Mosquito Bank	25º 04.048	80º 22.967	Mid-channel patch reef
9	5/5/2011	Mosquito Bank	25º 04.280	80º 23.172	Mid-channel patch reef
10	5/5/2011	Mosquito Bank	25º 04.265	80º 23.437	Mid-channel patch reef
11	5/6/2011	Inshore of Pickles Reef	24º 59.184	80º 26.096	Offshore patch reef
12	5/6/2011	Triangles area	25º 01.320	80º 26.400	Mid-channel patch reef
13	5/6/2011	Triangles area	25º 01.343	80º 25.480	Mid-channel patch reef
14	5/6/2011	Molasses Reef Channel	25º 01.028	80º 24.054	Offshore patch reef
15	5/6/2011	Wolf Reef	25º 01.311	80º 23.773	Offshore patch reef
16	5/6/2011	Molasses Reef**	25º 00.708	80º 22.691	Reef rubble
17	5/6/2011	Molasses Reef**	25º 00.753	80º 22.548	Reef rubble
18	5/6/2011	Sand Island	25º 01.219	80º 22.192	Reef rubble
19	5/6/2011	Sand Island	25º 01.284	80º 22.130	Reef rubble
20	5/8/2011	Turtle Harbor	25º 16.041	80º 14.857	Mid-channel patch reef
21	5/8/2011	Turtle Harbor	25º 15.611	80º 15.042	Mid-channel patch reef
22	5/8/2011	Turtle Rocks	25º 17.477	80º 13.624	Mid-channel patch reef
23	5/8/2011	Turtle Reef	25º 17.603	80º 13.258	Inner line reef tract
24	5/8/2011	Turtle Rocks	25º 18.055	80º 13.419	Mid-channel patch reef
25	5/8/2011	Turtle Reef	25º 16.973	80º 12.412	Inner line reef tract
26	5/8/2011	Whistle Buoy	25º 17.596	80º 10.351	Patchy hard-bottom (6-15 m)
27	5/8/2011	Whistle Buoy	25º 17.411	80º 10.412	Low-relief hard-bottom (6-15 m)
28	5/12/2011	Turtle Rocks	25º 16.718	80º 12.612	Low-relief hard-bottom (< 6 m)
29	5/12/2011	Turtle Rocks	25º 16.638	80º 12.496	Low-relief hard-bottom (6-15 m)
30	5/12/2011	Turtle Rocks	25º 16.521	80º 12.720	Low-relief hard-bottom (< 6 m)
31	5/12/2011	Turtle Rocks	25º 16.338	80º 12.051	Patchy hard-bottom (6-15 m)
32	5/12/2011	Turtle Rocks	25º 16.004	80º 12.713	Inner line reef tract
33	5/12/2011	Turtle Rocks	25º 15.545	80º 12.630	Inner line reef tract
34	5/12/2011	East of Turtle Rocks	25º 15.228	80º 12.153	Patchy hard-bottom (6-15 m)
35	5/13/2011	North of Carysfort Reef	25º 15.133	80º 12.740	Offshore patch reef
36	5/13/2011	North of Carysfort Reef	25º 15.059	80º 13.293	Low-relief hard-bottom (< 6 m)
37	5/13/2011	North of Carysfort Reef	25º 14.713	80º 13.053	Offshore patch reef
38	5/13/2011	North of Carysfort Reef	25º 14.487	80º 12.722	Offshore patch reef
39	5/13/2011	North of Carysfort Reef	25º 14.252	80º 12.280	Patchy hard-bottom (6-15 m)
40	5/13/2011	Carysfort Reef**	25º 14.027	80º 12.616	Low-relief hard-bottom (6-15 m)
41	5/13/2011	Carysfort Reef**	25º 13.919	80º 12.433	Low-relief hard-bottom (6-15 m)
42	5/13/2011	Carysfort Reef**	25º 13.568	80º 12.645	Reef rubble
43	5/13/2011	Carysfort Reef**	25º 13.399	80º 12.772	Low-relief hard-bottom (< 6 m)
44	5/13/2011	Carysfort Reef**	25º 13.350	80º 12.599	High-relief spur and groove
45	5/14/2011	Carysfort Reef**	25º 13.219	80º 12.632	High-relief spur and groove
46	5/14/2011	Carysfort Reef**	25º 13.651	80º 13.015	Offshore patch reef
47	5/14/2011	NW of Carysfort Lighthouse	25º 13.161	80º 13.056	Offshore patch reef
48	5/14/2011	West of Carysfort Lighthouse	25º 13.704	80º 13.293	Offshore patch reef
49	5/14/2011	West of Carysfort Lighthouse	25º 13.611	80º 13.517	Offshore patch reef
50	5/14/2011	West of Carysfort Lighthouse	25º 13.508	80º 13.635	Offshore patch reef
51	5/14/2011	West of Carysfort Lighthouse	25º 13.613	80º 13.862	Offshore patch reef
52	5/14/2011	West of Carysfort Lighthouse	25º 13.507	80º 14.117	Offshore patch reef
53	5/14/2011	West of Carysfort Lighthouse	25º 13.410	80º 14.103	Offshore patch reef
54	5/14/2011	West of Carysfort Lighthouse	25º 13.730	80º 14.138	Offshore patch reef

Site #	Date	Site location	Latitude (N)	Longitude (W)	Habitat type
55	5/15/2011	South Carysfort Reef**	25º 12.389	80º 12.885	Low-relief spur and groove (6-15 m)
56	5/15/2011	South Carysfort Reef**	25º 12.700	80º 12.717	Low-relief hard-bottom (6-15 m)
57	5/15/2011	South Carysfort Reef**	25º 12.734	80º 13.051	High-relief spur and groove
58	5/15/2011	South Carysfort Reef**	25º 12.421	80º 13.241	High-relief spur and groove
59	5/15/2011	South of South Carysfort Reef**	25º 12.244	80º 13.394	Low-relief hard-bottom (< 6 m)
60	5/15/2011	SW Carysfort Reef SPA**	25º 12.266	80º 13.761	Offshore patch reef
61	5/15/2011	West of South Carysfort Reef	25º 12.478	80º 13.781	Offshore patch reef
62	5/15/2011	West of South Carysfort Reef	25º 12.752	80º 13.797	Offshore patch reef
63	5/19/2011	Pickles Reef	24º 59.480	80º 24.978	Reef rubble
64	5/19/2011	Pickles Reef	24º 59.251	80º 25.210	Reef rubble
65	5/19/2011	Pickles Reef	24º 58.973	80º 25.158	High-relief spur and groove
66	5/19/2011	Pickles Reef	24º 59.271	80º 24.876	High-relief spur and groove
67	5/19/2011	Pickles Reef	24º 59.458	80º 24.724	High-relief spur and groove
68	5/19/2011	Pickles Reef	24º 59.796	80º 24.231	Low-relief hard-bottom (6-15 m)
69	5/20/2011	Carysfort Reef**	25º 13.357	80º 12.541	Low-relief spur and groove (6-15 m)
70	5/20/2011	Carysfort Reef**	25º 13.228	80º 12.766	Reef rubble
71	5/20/2011	West of South Carysfort Reef	25º 12.768	80º 13.766	Offshore patch reef
72	5/20/2011	West of South Carysfort Reef	25º 12.651	80º 12.736	Offshore patch reef
73	5/20/2011	West of South Carysfort Reef	25º 12.512	80º 14.040	Offshore patch reef
74	5/20/2011	West of South Carysfort Reef	25º 12.536	80º 14.672	Offshore patch reef
75	5/20/2011	South of South Carysfort Reef	25º 11.923	80º 13.395	Low-relief spur and groove (6-15 m)
76	5/20/2011	Maitland area	25º 11.878	80º 13.536	High-relief spur and groove
77	5/20/2011	Maitland area	25º 11.835	80º 13.589	High-relief spur and groove
78	5/21/2011	Maitland area	25º 11.796	80º 13.630	High-relief spur and groove
79	5/21/2011	North of Watsons Reef	25º 12.024	80º 14.563	Offshore patch reef
80	5/21/2011	North of Watsons Reef	25º 12.002	80º 14.804	Offshore patch reef
81	5/21/2011	North of Watsons Reef	25º 11.566	80º 15.277	Low-relief hard-bottom (< 6 m)
82	5/21/2011	North of Watsons Reef	25º 11.676	80º 14.995	Offshore patch reef
83	5/21/2011	North of Watsons Reef	25º 11.704	80º 14.891	Offshore patch reef
84	5/21/2011	North of Watsons Reef	25º 11.468	80º 14.254	Low-relief hard-bottom (< 6 m)
85	5/21/2011	Watsons Reef	25º 11.068	80º 14.133	Offshore patch reef
86	5/22/2011	Basin Hill Shoals	25º 14.156	80º 14.535	Offshore patch reef
87	5/22/2011	Basin Hill Shoals	25º 14.050	80º 14.905	Offshore patch reef
88	5/22/2011	Basin Hill Shoals	25º 13.465	80º 15.007	Offshore patch reef
89	5/22/2011	Basin Hill Shoals	25º 14.484	80º 15.975	Mid-channel patch reef
90	5/22/2011	Basin Hill Shoals	25º 14.412	80º 15.868	Mid-channel patch reef
91	5/22/2011	Basin Hill Shoals	25º 14.087	80º 15.401	Mid-channel patch reef
92	5/22/2011	Basin Hill Shoals	25º 13.940	80º 15.731	Mid-channel patch reef
93	5/22/2011	Basin Hill Shoals	25º 13.519	80º 15.861	Mid-channel patch reef
94	6/13/2011	Basin Hill Shoals	25º 12.617	80º 16.395	Mid-channel patch reef
95	6/13/2011	South of Basin Hill Shoals	25º 11.937	80º 17.205	Mid-channel patch reef
96	6/13/2011	South of Basin Hill Shoals	25º 11.496	80º 17.554	Mid-channel patch reef
97	6/13/2011	South of Basin Hill Shoals	25º 10.893	80º 17.472	Mid-channel patch reef
98	6/13/2011	South of Basin Hill Shoals	25º 10.740	80º 17.390	Mid-channel patch reef
99	6/13/2011	Inshore of Watsons Reef	25º 10.633	80º 15.943	Low-relief hard-bottom (< 6 m)
100	6/13/2011	Watsons Reef	25º 11.208	80º 14.462	Offshore patch reef
101	6/14/2011	Watsons Reef	25º 11.004	80º 14.663	Low-relief hard-bottom (6-15 m)
102	6/14/2011	Watsons Reef	25º 10.625	80º 14.433	Low-relief hard-bottom (6-15 m)
103	6/14/2011	Watsons Reef	25º 10.524	80º 14.894	Offshore patch reef
104	6/14/2011	Watsons Reef	25º 10.435	80º 14.994	Offshore patch reef
105	6/14/2011	Watsons Reef	25º 10.255	80º 15.491	Offshore patch reef
106	6/14/2011	Watsons Reef	25º 10.067	80º 15.239	Offshore patch reef
107	6/14/2011	Watsons Reef	25º 09.893	80º 15.043	Low-relief hard-bottom (6-15 m)
108	6/14/2011	Watsons Reef	25º 09.727	80º 15.512	Offshore patch reef
109	6/14/2011	North of Elbow Reef	25º 09.243	80º 15.417	Low-relief hard-bottom (6-15 m)
110	6/14/2011	NW of Elbow Reef	25º 09.269	80º 16.065	Offshore patch reef
111	6/15/2011	South of Elbow Reef	25º 08.014	80º 16.153	Patchy hard-bottom (6-15 m)
112	6/15/2011	South of Elbow Reef	25º 08.100	80º 15.769	Low-relief hard-bottom (6-15 m)
113	6/15/2011	Elbow Reef**	25º 08.449	80º 15.534	High-relief spur and groove
114	6/15/2011	Elbow Reef**	25º 08.572	80º 15.475	High-relief spur and groove

Site #	Date	Site location	Latitude (N)	Longitude (W)	Habitat type
115	6/15/2011	Elbow Reef**	25º 08.725	80º 15.657	Reef rubble
116	6/15/2011	Elbow Reef**	25º 08.513	80º 15.996	Reef rubble
117	6/15/2011	West of Elbow Reef	25º 08.714	80º 16.308	Offshore patch reef
118	6/15/2011	West of Elbow Reef	25º 08.817	80º 16.208	Offshore patch reef
119	6/15/2011	Inshore of Watsons Reef	25º 09.839	80º 16.667	Inner line reef tract
120	6/15/2011	Inshore of Watsons Reef	25º 09.547	80º 17.140	Inner line reef tract
121	6/16/2011	NW of Elbow Reef	25º 09.219	80º 17.444	Low-relief hard-bottom (< 6 m)
122	6/16/2011	North of Horseshoe Reef	25º 08.975	80º 17.501	Inner line reef tract
123	6/16/2011	North of Horseshoe Reef	25º 08.857	80º 17.643	Inner line reef tract
124	6/16/2011	North of Horseshoe Reef	25º 08.648	80º 17.657	Inner line reef tract
125	6/16/2011	North of North-North Dry Rocks	25º 08.437	80º 17.191	Offshore patch reef
126	6/16/2011	North-North Dry Rocks	25º 08.207	80º 17.349	Inner line reef tract
127	6/16/2011	Inshore of North Dry Rocks	25º 07.765	80º 17.742	Offshore patch reef
128	6/16/2011	Inshore of Dry Rocks	25º 07.696	80º 17.962	Offshore patch reef
129	6/16/2011	North Dry Rocks	25º 07.749	80º 17.632	Inner line reef tract
130	6/16/2011	East of Dry Rocks	25º 07.511	80º 17.547	Offshore patch reef
131	6/17/2011	NE of Alligator Reef	24º 52.785	80º 34.026	Low-relief hard-bottom (6-15 m)
132	6/17/2011	NE of Alligator Reef	24º 52.265	80º 34.854	Low-relief spur and groove (6-15 m)
133	6/17/2011	NE of Alligator Reef	24º 52.428	80º 35.476	Low-relief hard-bottom (6-15 m)
134	6/17/2011	NE of Alligator Reef	24º 52.398	80º 35.689	Offshore patch reef
135	6/17/2011	NE of Alligator Reef	24º 51.404	80º 36.633	Low-relief hard-bottom (6-15 m)
136	6/17/2011	NE of Alligator Reef	24º 51.212	80º 36.828	Low-relief hard-bottom (< 6 m)
137	6/17/2011	Alligator Reef**	24º 50.730	80º 37.460	Low-relief hard-bottom (< 6 m)
138	6/17/2011	Alligator Reef**	24º 50.797	80º 37.353	Low-relief hard-bottom (< 6 m)
139	6/17/2011	Alligator Reef**	24º 50.855	80º 37.519	Reef rubble
140	6/17/2011	Alligator Reef**	24º 50.852	80º 37.516	Reef rubble
141	6/17/2011	Cheeca Rocks**	24º 54.252	80º 36.896	Mid-channel patch reef
142	6/17/2011	Cheeca Rocks**	24º 54.260	80º 37.081	Mid-channel patch reef
143	6/18/2011	SW of Cheeca Rocks	24º 54.009	80º 37.055	Mid-channel patch reef
144	6/18/2011	SW of Cheeca Rocks	24º 53.833	80º 37.207	Mid-channel patch reef
145	6/18/2011	South of Cheeca Rocks	24º 53.298	80º 36.841	Low-relief hard-bottom (6-15 m)
146	6/18/2011	NE of Alligator Reef	24º 53.191	80º 35.114	Low-relief hard-bottom (< 6 m)
147	6/18/2011	NE of Alligator Reef	24º 52.830	80º 34.787	Patchy hard-bottom (6-15 m)
148	6/18/2011	NE of Alligator Reef	24º 53.223	80º 34.484	Patchy hard-bottom (6-15 m)
149	6/18/2011	NE of Alligator Reef	24º 53.666	80º 34.421	Offshore patch reef
150	6/18/2011	West of Crocker Reef	24º 54.431	80º 33.825	Low-relief hard-bottom (< 6 m)
151	6/18/2011	West of Crocker Reef	24º 54.634	80º 33.325	Low-relief hard-bottom (< 6 m)
152	6/18/2011	SW of Crocker Reef	24º 53.871	80º 32.963	Low-relief hard-bottom (6-15 m)
153	6/18/2011	SW of Crocker Reef	24º 54.082	80º 32.593	Low-relief hard-bottom (6-15 m)
154	6/18/2011	SW of Crocker Reef	24º 54.125	80º 32.357	Low-relief hard-bottom (6-15 m)
155	6/19/2011	Key Largo Dry Rocks**	25º 07.356	80º 17.927	Inner line reef tract
156	6/19/2011	Key Largo Dry Rocks**	25º 07.461	80º 17.833	Inner line reef tract
157	6/19/2011	Key Largo Dry Rocks**	25º 07.466	80º 18.038	Offshore patch reef
158	6/19/2011	Key Largo Dry Rocks**	25º 07.363	80º 17.973	Offshore patch reef
159	6/19/2011	North of Grecian Rocks	25º 06.880	80º 18.126	Inner line reef tract
160	6/19/2011	Grecian Rocks**	25º 06.665	80º 18.218	Inner line reef tract
161	6/19/2011	Grecian Rocks**	25º 06.589	80º 18.270	Inner line reef tract
162	6/19/2011	South of Three Heads Reef	25º 07.504	80º 18.564	Offshore patch reef
163	6/19/2011	Higdons Reef	25º 08.086	80º 19.090	Mid-channel patch reef
164	6/19/2011	Higdons Reef	25º 08.447	80º 18.784	Mid-channel patch reef
165	6/20/2011	East of Dry Rocks	25º 07.214	80º 17.060	Low-relief hard-bottom (6-15 m)
166	6/20/2011	East of Grecian Rocks	25º 06.445	80º 18.161	Offshore patch reef
167	6/20/2011	Southeast of Grecian Rocks	25º 06.073	80º 17.730	Low-relief hard-bottom (6-15 m)
168	6/20/2011	Southeast of Grecian Rocks	25º 06.060	80º 17.923	Low-relief hard-bottom (6-15 m)
169	6/20/2011	West of Grecian Rocks	25º 06.643	80º 18.800	Low-relief hard-bottom (< 6 m)
170	6/20/2011	West of Grecian Rocks	25º 06.889	80º 18.951	Low-relief hard-bottom (< 6 m)
171	6/20/2011	West of Grecian Rocks	25º 06.470	80º 18.879	Low-relief hard-bottom (< 6 m)
172	6/20/2011	West of Grecian Rocks	25º 06.370	80º 19.099	Offshore patch reef
173	6/20/2011	Southwest of Grecian Rocks	25º 05.954	80º 19.246	Offshore patch reef
174	6/20/2011	North of Cannon Patch	25º 06.872	80º 20.681	Mid-channel patch reef

Site #	Date	Site location	Latitude (N)	Longitude (W)	Habitat type
175	6/20/2011	Northeast of Cannon Patch	25º 06.710	80º 19.724	Mid-channel patch reef
176	6/20/2011	Northeast of Cannon Patch	25º 06.741	80º 19.822	Mid-channel patch reef
177	6/20/2011	East of Cannon Patch	25º 06.001	80º 20.496	Mid-channel patch reef
178	6/20/2011	East of Cannon Patch	25º 06.066	80º 20.682	Mid-channel patch reef
179	6/20/2011	Cannon Patch	25º 06.189	80º 20.784	Mid-channel patch reef
180	6/20/2011	White Bank	25º 04.304	80º 21.273	Offshore patch reef
181	6/20/2011	White Bank	25º 04.108	80º 21.159	Offshore patch reef
182	6/21/2011	Southwest of Grecian Rocks	25º 05.012	80º 18.856	Low-relief hard-bottom (6-15 m)
183	6/21/2011	Southwest of Grecian Rocks	25º 05.326	80º 19.145	Low-relief hard-bottom (< 6 m)
184	6/21/2011	Southwest of Grecian Rocks	25º 05.183	80º 19.350	Low-relief hard-bottom (< 6 m)
185	6/21/2011	North of Dixie Shoal	25º 04.274	80º 20.198	Low-relief hard-bottom (< 6 m)
186	6/21/2011	North of Dixie Shoal	25º 03.817	80º 20.316	Low-relief hard-bottom (< 6 m)
187	6/21/2011	Dixie Shoal	25º 03.327	80º 20.912	Low-relief hard-bottom (< 6 m)
188	6/21/2011	Dixie Shoal	25º 03.056	80º 20.396	Low-relief hard-bottom (< 6 m)
189	6/21/2011	Northeast of French Reef	25º 02.450	80º 20.711	High-relief spur and groove
190	6/21/2011	Northeast of French Reef	25º 02.577	80º 21.331	Offshore patch reef
191	6/21/2011	Northeast of French Reef	25º 02.651	80º 21.365	Offshore patch reef
192	6/21/2011	Mosquito Bank	25º 04.168	80º 22.222	Mid-channel patch reef
193	6/21/2011	Mosquito Bank	25º 04.759	80º 22.668	Mid-channel patch reef
194	6/21/2011	Mosquito Bank	25º 03.988	80º 22.364	Mid-channel patch reef
195	6/21/2011	North of White Bank/Dry Rocks	25º 02.836	80º 22.134	Offshore patch reef
196	6/21/2011	White Bank/Dry Rocks	25º 02.875	80º 21.721	Offshore patch reef
197	6/21/2011	White Bank/Dry Rocks	25º 02.528	80º 22.309	Offshore patch reef
198	6/21/2011	Molasses Reef Channel	25º 01.899	80º 23.331	Offshore patch reef
199	6/21/2011	Three Sisters	25º 01.791	80º 23.873	Mid-channel patch reef
200	6/22/2011	French Reef**	25º 02.184	80º 20.837	High-relief spur and groove
201	6/22/2011	French Reef**	25º 02.015	80º 21.000	High-relief spur and groove
202	6/22/2011	French Reef**	25º 02.234	80º 21.179	Reef rubble
203	6/22/2011	French Reef**	25º 02.266	80º 21.097	Reef rubble
204	6/22/2011	SW of French Reef	25º 01.757	80º 21.649	Low-relief hard-bottom (6-15 m)
205	6/22/2011	Sand Island	25º 01.134	80º 22.057	High-relief spur and groove
206	6/22/2011	Sand Island	25º 01.213	80º 22.174	Reef rubble
207	6/22/2011	Molasses Reef**	25º 00.601	80º 22.439	High-relief spur and groove
208	6/22/2011	Crocker Reef	24º 54.374	80º 31.690	Low-relief spur and groove (6-15 m)
209	6/22/2011	Crocker Reef	24º 54.630	80º 31.816	Reef rubble
210	6/22/2011	Inshore of Crocker Reef	24º 54.975	80º 32.710	Low-relief hard-bottom (< 6 m)
211	6/22/2011	Inshore of Crocker Reef	24º 55.143	80º 32.113	Low-relief hard-bottom (< 6 m)
212	6/22/2011	Northeast of Crocker Reef	24º 55.126	80º 31.478	Low-relief hard-bottom (< 6 m)
213	6/22/2011	Northeast of Crocker Reef	24º 54.848	80º 30.929	Low-relief hard-bottom (6-15 m)
214	6/22/2011	Davis Reef**	24º 55.284	80º 30.287	Low-relief spur and groove (6-15 m)
215	6/22/2011	Davis Reef**	24º 55.378	80º 30.203	Low-relief spur and groove (6-15 m)
216	6/22/2011	Davis Reef**	24º 55.349	80º 30.349	Low-relief hard-bottom (< 6 m)
217	6/22/2011	Davis Reef**	24º 55.411	80º 30.298	Low-relief hard-bottom (< 6 m)
218	6/23/2011	Molasses Reef**	25º 00.511	80º 22.598	High-relief spur and groove
219	6/23/2011	Molasses Reef**	25º 00.455	80º 22.478	Low-relief spur and groove (6-15 m)
220	6/23/2011	Molasses Reef**	25º 00.482	80º 22.423	Low-relief spur and groove (6-15 m)
221	6/23/2011	Southwest of Molasses Reef	25º 00.333	80º 22.548	Low-relief hard-bottom (< 6 m)
222	6/23/2011	Molasses Reef Channel	25º 00.803	80º 24.982	Low-relief hard-bottom (< 6 m)
223	6/23/2011	Molasses Reef Channel	25º 00.625	80º 24.648	Offshore patch reef
224	6/23/2011	Molasses Reef Channel	25º 00.820	80º 24.281	Offshore patch reef
225	6/23/2011	Molasses Reef Channel	25º 01.251	80º 23.497	Offshore patch reef
226	6/23/2011	North of Davis Reef	25º 55.283	80º 30.490	Low-relief hard-bottom (< 6 m)
227	6/23/2011	North of Davis Reef	25º 55.600	80º 30.159	Low-relief hard-bottom (< 6 m)
228	6/23/2011	Southwest of Davis Reef	25º 55.148	80º 30.428	Low-relief spur and groove (6-15 m)
229	6/23/2011	Hen and Chickens Reef**	25º 56.139	80º 32.860	Mid-channel patch reef
230	6/23/2011	Hen and Chickens Reef**	25º 56.262	80º 32.847	Mid-channel patch reef
231	6/23/2011	Tavernier Rocks	25º 56.610	80º 33.411	Inshore patch reef
232	6/24/2011	Northeast of Davis Reef	25º 55.675	80º 29.866	Low-relief spur and groove (6-15 m)
233	6/24/2011	Northeast of Davis Reef	25º 56.229	80º 29.740	Patchy hard-bottom (6-15 m)
234	6/24/2011	North of Davis Reef	25º 56.563	80º 29.987	Offshore patch reef

Site #	Date	Site location	Latitude (N)	Longitude (W)	Habitat type
235	6/24/2011	North of Davis Reef	24º 56.433	80º 30.261	Offshore patch reef
236	6/24/2011	North of Davis Reef	24º 56.770	80º 30.219	Offshore patch reef
237	6/24/2011	North of Davis Reef	24º 56.937	80º 29.974	Offshore patch reef
238	6/24/2011	North of Davis Reef	24º 57.388	80º 30.151	Mid-channel patch reef
239	6/24/2011	Tavernier Rocks	24º 57.033	80º 33.308	Inshore patch reef
240	6/24/2011	Tavernier Rocks	24º 57.153	80º 32.914	Inshore patch reef
241	8/11/2011	Little Conch Reef	24º 56.572	80º 28.347	Low-relief hard-bottom (< 6 m)
242	8/11/2011	Little Conch Reef	24º 56.681	80º 28.185	Low-relief spur and groove (6-15 m)
243	8/11/2011	Conch Reef**	24º 57.176	80º 27.336	Low-relief spur and groove (6-15 m)
244	8/11/2011	Conch Reef**	24º 57.282	80º 27.156	Low-relief spur and groove (6-15 m)
245	8/11/2011	Conch Reef**	24º 57.014	80º 27.526	Low-relief spur and groove (6-15 m)
246	8/11/2011	Conch Reef**	24º 57.109	80º 27.470	Low-relief spur and groove (6-15 m)
247	8/11/2011	Conch Reef**	24º 57.114	80º 27.571	Low-relief hard-bottom (< 6 m)
248	8/11/2011	Conch Reef**	24º 57.302	80º 27.471	Low-relief hard-bottom (< 6 m)
249	8/12/2011	Conch Reef	24º 57.594	80º 27.718	Reef rubble
250	8/12/2011	Conch Reef	24º 57.663	80º 27.420	Low-relief hard-bottom (< 6 m)
251	8/12/2011	Conch Reef	24º 57.559	80º 27.586	Reef rubble
252	8/12/2011	NE of Conch Reef	24º 58.105	80º 26.697	Low-relief spur and groove (6-15 m)
253	8/12/2011	SW of Pickles Reef	24º 58.441	80º 26.016	Low-relief hard-bottom (< 6 m)
254	8/12/2011	West of Pickles Reef	24º 59.039	80º 26.541	Offshore patch reef
255	8/12/2011	West of Pickles Reef	24º 59.160	80º 26.444	Offshore patch reef
256	8/12/2011	West of Pickles Reef	24º 58.811	80º 26.485	Offshore patch reef
257	8/27/2011	Triangles area	25º 00.502	80º 27.525	Mid-channel patch reef
258	8/27/2011	West of Pickles Reef	24º 59.789	80º 27.583	Offshore patch reef
259	8/27/2011	West of Pickles Reef	24º 59.234	80º 27.157	Low-relief hard-bottom (< 6 m)
260	8/27/2011	West of Pickles Reef	24º 59.249	80º 27.145	Low-relief hard-bottom (< 6 m)
261	8/27/2011	West of Pickles Reef	24º 59.374	80º 26.869	Low-relief hard-bottom (< 6 m)
262	8/27/2011	West of Pickles Reef	24º 59.689	80º 26.781	Offshore patch reef
263	8/27/2011	NW of Pickles Reef	24º 59.961	80º 26.263	Offshore patch reef
264	8/27/2011	NW of Pickles Reef	25º 00.144	80º 25.391	Offshore patch reef
265	8/28/2011	Triangles area	25º 00.655	80º 25.676	Offshore patch reef
266	8/28/2011	Triangles area	25º 00.870	80º 25.639	Offshore patch reef
267	8/28/2011	Triangles area	25º 01.117	80º 25.559	Offshore patch reef
268	8/28/2011	South of Rodriguez Key	25º 01.785	80º 26.001	Mid-channel patch reef
269	8/28/2011	South of Rodriguez Key	25º 01.834	80º 25.598	Mid-channel patch reef
270	8/28/2011	Marker G37	25º 02.501	80º 25.491	Mid-channel patch reef
271	8/28/2011	Admiral's Reef	25º 02.422	80º 23.877	Mid-channel patch reef
272	9/05/2011	South Carysfort Reef**	25º 12.517	80º 13.158	High-relief spur and groove
273	9/05/2011	Elbow Reef**	25º 08.544	80º 15.504	High-relief spur and groove
274	9/05/2011	Horseshoe Reef	25º 08.394	80º 17.649	Inner line reef tract
275	9/05/2011	West of Mosquito Bank	25º 02.668	80º 24.371	Mid-channel patch reef
276	9/10/2011	Molasses Reef**	25º 00.591	80º 22.426	High-relief spur and groove
277	9/10/2011	Sand Island	25º 01.084	80º 22.097	High-relief spur and groove
278	9/10/2011	French Reef**	25º 02.026	80º 20.960	High-relief spur and groove
279	9/10/2011	West of French Reef	25º 01.961	80º 21.866	Offshore patch reef
280	9/10/2011	Grecian Rocks**	25º 06.536	80º 18.312	Inner line reef tract

Table 2-3. Physical data summary for sites surveyed in the upper Florida Keys National Marine Sanctuary during May-September 2011. Sites are arranged from NE to SW by habitat type and management zone. Asterisked sites (**) are Sanctuary no-take zones (SPAs or ROs). Mean ± 1 SE transect depth, maximum vertical relief, and mean maximum vertical relief are based upon two 15-m x 1-m transects per site.

Site number/site location (no. sites)	Latitude (N)	Longitude (W)	Mean depth (m)	Max. vertical relief (cm)	Mean max. vertical relief (cm)
Inshore and mid-channel patch reefs					
Reference areas					
24 - Turtle Rocks	25º 18.055	80º 13.419	3.2 ± 0.0	35	35 ± 1
22 - Turtle Rocks	25º 17.477	80º 13.624	3.7 ± 0.1	58	54 ± 4
20 - Turtle Harbor	25º 16.041	80º 14.857	3.6 ± 0.1	35	33 ± 3
21 - Turtle Harbor	25º 15.611	80º 15.042	3.9 ± 0.1	60	48 ± 13
89 - Basin Hill Shoals	25º 14.484	80º 15.975	3.2 ± 0.2	85	83 ± 3
90 - Basin Hill Shoals	25º 14.412	80º 15.868	3.2 ± 0.3	110	98 ± 13
91 - Basin Hill Shoals	25º 14.087	80º 15.401	3.8 ± 0.0	90	75 ± 15
92 - Basin Hill Shoals	25º 13.940	80º 15.731	1.9 ± 0.1	80	58 ± 23
93 - Basin Hill Shoals	25º 13.519	80º 15.861	2.7 ± 0.2	108	100 ± 8
94 - Basin Hill Shoals	25º 12.617	80º 16.395	3.4 ± 0.1	80	70 ± 10
95 - South of Basin Hill Shoals	25º 11.937	80º 17.205	3.9 ± 0.1	48	46 ± 3
96 - South of Basin Hill Shoals	25º 11.496	80º 17.554	4.1 ± 0.2	55	48 ± 8
97 - South of Basin Hill Shoals	25º 10.893	80º 17.472	3.9 ± 0.1	110	83 ± 28
98 - South of Basin Hill Shoals	25º 10.740	80º 17.390	2.0 ± 0.0	30	28 ± 3
164 - Higdons Reef	25º 08.447	80º 18.784	2.4 ± 0.2	140	130 ± 10
163 - Higdons Reef	25º 08.086	80º 19.090	2.1 ± 0.1	90	73 ± 18
174 - North of Cannon Patch	25º 06.872	80º 20.681	4.6 ± 0.2	150	120 ± 30
176 - Northeast of Cannon Patch	25º 06.741	80º 19.822	6.1 ± 0.0	200	163 ± 38
175 - Northeast of Cannon Patch	25º 06.710	80º 19.724	5.3 ± 0.2	150	135 ± 15
1 - South of Cannon Patch	25º 06.522	80º 20.496	3.4 ± 0.2	64	50 ± 15
2 - South of Cannon Patch	25º 06.193	80º 20.619	3.0 ± 0.2	65	60 ± 5
179 - Cannon Patch	25º 06.189	80º 20.784	4.0 ± 0.1	65	54 ± 11
3 - South of Cannon Patch	25º 06.168	80º 20.684	2.8 ± 0.1	60	52 ± 9
178 - East of Cannon Patch	25º 06.066	80º 20.682	2.4 ± 0.1	80	69 ± 12
4 - South of Cannon Patch	25º 06.052	80º 20.726	3.9 ± 0.1	65	60 ± 5
177 - East of Cannon Patch	25º 06.001	80º 20.496	7.3 ± 0.0	112	106 ± 6
193 - Mosquito Bank	25º 04.759	80º 22.668	2.7 ± 0.2	135	118 ± 18
5 - Mosquito Bank	25º 04.511	80º 22.926	1.9 ± 0.1	145	128 ± 18
6 - Mosquito Bank	25º 04.443	80º 23.008	1.9 ± 0.1	100	92 ± 9
9 - Mosquito Bank	25º 04.280	80º 23.172	1.4 ± 0.1	80	65 ± 15
10 - Mosquito Bank	25º 04.265	80º 23.437	1.9 ± 0.1	50	46 ± 4
192 - Mosquito Bank	25º 04.168	80º 22.222	2.4 ± 0.0	55	47 ± 9
7 - Mosquito Bank	25º 04.142	80º 23.007	1.3 ± 0.1	95	88 ± 8
8 - Mosquito Bank	25º 04.048	80º 22.967	1.6 ± 0.1	90	68 ± 23
194 - Mosquito Bank	25º 03.988	80º 22.364	2.4 ± 0.2	100	98 ± 3
275 - West of Mosquito Bank	25º 02.668	80º 24.371	3.1 ± 0.1	45	43 ± 3
270 - Marker G37	25º 02.501	80º 25.491	2.4 ± 0.1	75	59 ± 16
271 - Admiral's Reef	25º 02.422	80º 23.877	2.7 ± 0.1	40	38 ± 3
269 - South of Rodriguez Key	25º 01.834	80º 25.598	4.0 ± 0.0	50	49 ± 1
199 - Three Sisters	25º 01.791	80º 23.873	5.6 ± 0.1	115	105 ± 10
268 - South of Rodriguez Key	25º 01.785	80º 26.001	4.6 ± 0.0	55	48 ± 8
13 - Triangles area	25º 01.343	80º 25.480	2.8 ± 0.1	85	60 ± 25
12 - Triangles area	25º 01.320	80º 26.400	3.3 ± 0.2	65	58 ± 8
257 - Triangles area	25º 00.502	80º 27.525	4.4 ± 0.0	90	75 ± 15
238 - North of Davis Reef	24º 57.388	80º 30.151	3.6 ± 0.1	125	85 ± 40
240 - Tavernier Rocks	24º 57.153	80º 32.914	3.1 ± 0.1	195	185 ± 10
239 - Tavernier Rocks	24º 57.033	80º 33.308	2.7 ± 0.1	140	133 ± 8
231 - Tavernier Rocks	24º 56.610	80º 33.411	3.4 ± 0.1	160	138 ± 23
143 - SW of Cheeca Rocks	24º 54.009	80º 37.055	3.4 ± 0.1	185	168 ± 18
144 - SW of Cheeca Rocks	24º 53.833	80º 37.207	4.0 ± 0.0	220	160 ± 60
Reference area total (50)			3.3 ± 0.2	94 ± 6	81 ± 6

Site number/site location (no. sites)	Latitude (N)	Longitude (W)	Mean depth (m)	Max. vertical relief (cm)	Mean max. vertical relief (cm)
No-take zones					
230 - Hen and Chickens Reef**	24º 56.262	80º 56.262	5.3 ± 0.1	245	225 ± 20
229 - Hen and Chickens Reef**	24º 56.139	80º 56.139	5.6 ± 0.2	190	180 ± 10
142 - Cheeca Rocks**	24º 54.260	80º 54.260	3.5 ± 0.2	130	115 ± 15
141 - Cheeca Rocks**	24º 54.252	80º 54.252	2.9 ± 0.2	160	129 ± 32
No-take zone total (4)			4.3 ± 0.7	181 ± 25	162 ± 25
Mid-channel Patch Reef Total (54)			**3.4 ± 0.2**	**101 ± 7**	**87 ± 6**
Offshore patch reefs					
Reference areas					
35 - North of Carysfort Reef	25º 15.133	80º 12.740	5.0 ± 0.1	95	83 ± 13
37 - North of Carysfort Reef	25º 14.713	80º 13.053	3.4 ± 0.2	80	73 ± 8
38 - North of Carysfort Reef	25º 14.487	80º 12.722	6.5 ± 0.1	90	83 ± 8
86 - Basin Hill Shoals	25º 14.156	80º 14.535	2.6 ± 0.2	170	110 ±60
87 - Basin Hill Shoals	25º 14.050	80º 14.905	3.4 ± 0.0	70	59 ± 11
54 - West of Carysfort Lighthouse	25º 13.730	80º 14.138	2.5 ± 0.1	80	65 ± 15
48 - West of Carysfort Lighthouse	25º 13.704	80º 13.293	2.9 ± 0.2	110	88 ± 23
51 - West of Carysfort Lighthouse	25º 13.613	80º 13.862	2.4 ± 0.1	85	65 ± 20
49 - West of Carysfort Lighthouse	25º 13.611	80º 13.517	3.8 ± 0.0	90	75 ± 15
50 - West of Carysfort Lighthouse	25º 13.508	80º 13.635	2.4 ± 0.0	95	75 ± 20
52 - West of Carysfort Lighthouse	25º 13.507	80º 14.117	2.5 ± 0.1	100	86 ± 14
88 - Basin Hill Shoals	25º 13.465	80º 15.007	2.0 ± 0.0	60	43 ± 18
53 - West of Carysfort Lighthouse	25º 13.410	80º 14.103	3.1 ± 0.2	80	68 ± 13
47 - NW of Carysfort Lighthouse	25º 13.161	80º 13.056	3.7 ± 0.2	60	53 ± 7
71 - West of South Carysfort Reef	25º 12.768	80º 13.766	3.4 ± 0.0	50	48 ± 3
62 - West of South Carysfort Reef	25º 12.752	80º 13.797	2.1 ± 0.2	75	64 ± 11
72 - West of South Carysfort Reef	25º 12.651	80º 12.736	2.7 ± 0.2	50	49 ± 2
74 - West of South Carysfort Reef	25º 12.536	80º 14.672	2.9 ± 0.0	45	44 ± 1
73 - West of South Carysfort Reef	25º 12.512	80º 14.040	4.3 ± 0.2	80	60 ± 20
61 - West of South Carysfort Reef	25º 12.478	80º 13.781	3.4 ± 0.2	93	74 ± 19
79 - North of Watsons Reef	25º 12.024	80º 14.563	3.9 ± 0.1	120	107 ± 14
80 - North of Watsons Reef	25º 12.002	80º 14.804	3.1 ± 0.1	105	73 ± 33
83 - North of Watsons Reef	25º 11.704	80º 14.891	3.7 ± 0.1	95	72 ± 23
82 - North of Watsons Reef	25º 11.676	80º 14.995	3.6 ± 0.1	90	85 ± 5
100 - Watsons Reef	25º 11.208	80º 14.462	5.8 ± 0.2	55	45 ± 10
85 - Watsons Reef	25º 11.068	80º 14.133	7.6 ± 0.0	55	49 ± 7
103 - Watsons Reef	25º 10.524	80º 14.894	11.8 ± 0.2	85	80 ± 5
104 - Watsons Reef	25º 10.435	80º 14.994	11.3 ± 0.0	55	53 ± 3
105 - Watsons Reef	25º 10.255	80º 15.491	5.6 ± 0.4	85	73 ± 13
106 - Watsons Reef	25º 10.067	80º 15.239	11.7 ± 0.2	130	120 ± 10
108 - Watsons Reef	25º 09.727	80º 15.512	10.0 ± 0.1	60	58 ± 3
110 - NW of Elbow Reef	25º 09.269	80º 16.065	4.2 ± 0.2	190	140 ±50
118 - West of Elbow Reef	25º 08.817	80º 16.208	11.4 ± 0.1	62	56 ± 6
117 - West of Elbow Reef	25º 08.714	80º 16.308	9.4 ± 0.0	95	78 ± 18
125 – North of N-N Dry Rocks	25º 08.437	80º 17.191	8.4 ± 0.2	130	95 ± 35
127 - Inshore of North Dry Rocks	25º 07.765	80º 17.742	5.3 ± 0.2	70	59 ± 11
128 - Inshore of Dry Rocks	25º 07.696	80º 17.962	5.4 ± 0.1	120	90 ± 30
130 - East of Dry Rocks	25º 07.511	80º 17.547	9.1 ± 0.1	47	44 ± 4
162 - South of Three Heads Reef	25º 07.504	80º 18.564	3.8 ± 0.2	185	165 ±20
166 - East of Grecian Rocks	25º 06.445	80º 18.161	7.0 ± 0.2	75	50 ± 25
172 - West of Grecian Rocks	25º 06.370	80º 19.099	3.2 ± 0.0	150	133 ± 18
173 - Southwest of Grecian Rocks	25º 05.954	80º 19.246	3.0 ± 0.2	50	48 ± 3
180 - White Bank	25º 04.304	80º 21.273	3.6 ± 0.1	95	80 ± 15
181 - White Bank	25º 04.108	80º 21.159	2.8 ± 0.2	40	38 ± 3
196 - White Bank/Dry Rocks	25º 02.875	80º 21.721	3.7 ± 0.1	150	135 ±15
195 – N. of White Bank/Dry Rocks	25º 02.836	80º 22.134	3.4 ± 0.0	140	125 ± 15
191 - Northeast of French Reef	25º 02.651	80º 21.365	5.3 ± 0.2	55	45 ± 10
190 - Northeast of French Reef	25º 02.577	80º 21.331	8.5 ± 0.1	55	45 ± 10
197 - White Bank/Dry Rocks	25º 02.528	80º 22.309	3.9 ± 0.1	95	70 ± 25
279 - West of French Reef	25º 01.961	80º 21.866	8.2 ± 0.0	48	47 ± 2

Site number/site location (no. sites)	Latitude (N)	Longitude (W)	Mean depth (m)	Max. vertical relief (cm)	Mean max. vertical relief (cm)
198 - Molasses Reef Channel	25º 01.899	80º 23.331	3.6 ± 0.1	50	40 ± 10
15 - Wolf Reef	25º 01.311	80º 23.773	4.3 ± 0.2	96	71 ± 26
225 - Molasses Reef Channel	25º 01.251	80º 23.497	8.6 ± 0.1	95	95 ± 0
267 - Triangles area	25º 01.117	80º 25.559	3.4 ± 0.1	85	83 ± 3
14 - Molasses Reef Channel	25º 01.028	80º 24.054	4.8 ± 0.1	40	40 ± 0
266 - Triangles area	25º 00.870	80º 25.639	3.7 ± 0.1	70	68 ± 3
224 - Molasses Reef Channel	25º 00.820	80º 24.281	6.6 ± 0.1	150	140 ± 10
265 - Triangles area	25º 00.655	80º 25.676	4.1 ± 0.2	62	52 ± 11
223 - Molasses Reef Channel	25º 00.625	80º 24.648	5.9 ± 0.1	150	140 ±10
264 - NW of Pickles Reef	25º 00.144	80º 25.391	4.8 ± 0.1	40	35 ± 5
263 - NW of Pickles Reef	24º 59.961	80º 26.263	3.7 ± 0.1	55	52 ± 4
258 - West of Pickles Reef	24º 59.789	80º 27.583	3.8 ± 0.0	138	112 ± 27
262 - West of Pickles Reef	24º 59.689	80º 26.781	4.6 ± 0.1.	110	82 ± 29
11 - Inshore of Pickles Reef	24º 59.184	80º 26.096	7.8 ± 0.1	125	93 ± 33
255 - West of Pickles Reef	24º 59.160	80º 26.444	6.0 ± 0.1	60	49 ± 11
254 - West of Pickles Reef	24º 59.039	80º 26.541	6.6 ± 0.2	52	50 ± 2
256 - West of Pickles Reef	24º 58.811	80º 26.485	8.5 ± 0.0	60	51 ± 9
237 - North of Davis Reef	24º 56.937	80º 29.974	4.3 ± 0.0	74	54 ± 21
236 - North of Davis Reef	24º 56.770	80º 30.219	4.6 ± 0.0	45	43 ± 3
234 - North of Davis Reef	24º 56.563	80º 29.987	5.6 ± 0.2	52	48 ± 4
235 - North of Davis Reef	24º 56.433	80º 30.261	5.3 ± 0.1	55	54 ± 1
149 - NE of Alligator Reef	24º 53.666	80º 34.421	6.5 ± 0.1	90	90 ± 0
134 - NE of Alligator Reef	24º 52.398	80º 35.689	6.4 ± 0.2	33	33 ± 1
Reference area total (73)			5.2 ± 0.3	85 ± 4	72 ± 3
No-take zones					
46 - Carysfort Reef**	25º 13.651	80º 13.015	6.6 ± 0.1	95	93 ± 3
60 - SW Carysfort Reef SPA**	25º 12.266	80º 13.761	4.2 ± 0.1	95	78 ± 18
157 - Key Largo Dry Rocks**	25º 07.466	80º 18.038	5.3 ± 0.0	50	40 ± 10
158 - Key Largo Dry Rocks**	25º 07.363	80º 17.973	6.1 ± 0.0	70	60 ± 10
No-take zone total (4)			5.6 ± 0.5	78 ± 11	68 ± 11
Offshore Patch Reef Total (77)			**5.2 ± 0.3**	**85 ± 4**	**72 ± 4**
Back reef rubble					
Reference areas					
19 - Sand Island	25º 01.284	80º 22.130	2.1 ± 0.3	30	30 ± 0
18 - Sand Island	25º 01.219	80º 22.192	2.5 ± 0.2	14	12 ± 2
206 - Sand Island	25º 01.213	80º 22.174	2.6 ± 0.2	40	28 ± 13
63 - Pickles Reef	24º 59.480	80º 24.978	3.1 ± 0.2	20	20 ± 1
64 - Pickles Reef	24º 59.251	80º 25.210	3.4 ± 0.3	35	25 ± 10
249 - Conch Reef	24º 57.594	80º 27.718	1.7 ± 0.0	20	19 ± 1
251 - Conch Reef	24º 57.559	80º 27.586	2.0 ± 0.0	40	35 ± 5
209 - Crocker Reef	24º 54.630	80º 31.816	5.3 ± 0.0	25	20 ± 5
Reference area total (8)			2.8 ± 0.4	28 ± 3	24 ± 3
No-take zones					
42 - Carysfort Reef**	25º 13.568	80º 12.645	3.8 ± 0.0	50	37 ± 14
70 - Carysfort Reef**	25º 13.228	80º 12.766	6.0 ± 0.1	22	21 ± 1
115 - Elbow Reef**	25º 08.725	80º 15.657	2.3 ± 0.0	15	14 ± 2
116 - Elbow Reef**	25º 08.513	80º 15.996	3.9 ± 0.1	22	20 ± 2
203 - French Reef**	25º 02.266	80º 21.097	2.5 ± 0.1	10	8 ± 3
202 - French Reef**	25º 02.234	80º 21.179	2.7 ± 0.2	25	20 ±5
17 - Molasses Reef**	25º 00.753	80º 22.548	1.5 ± 0.2	16	13 ± 3
16 - Molasses Reef**	25º 00.708	80º 22.691	2.2 ± 0.2	20	8 ± 8
139 - Alligator Reef**	24º 50.855	80º 37.519	5.0 ± 0.0	30	28 ±3
140 - Alligator Reef**	24º 50.852	80º 37.516	2.6 ± 0.0	30	30 ± 0
No-take zone total (10)			3.3 ± 0.4	24 ± 4	20 ± 3
Back-reef rubble Total (18)			**3.1 ± 0.3**	**26 ± 2**	**21 ± 2**

Site number/site location (no. sites)	Latitude (N)	Longitude (W)	Mean depth (m)	Max. vertical relief (cm)	Mean max. vertical relief (cm)
Low-relief hard-bottom (< 6 m)					
Reference areas					
28 - Turtle Rocks	25º 16.718	80º 12.612	3.9 ± 0.1	35	28 ± 8
30 - Turtle Rocks	25º 16.521	80º 12.720	3.4 ± 0.1	48	37 ± 12
36 - North of Carysfort Reef	25º 15.059	80º 13.293	2.7 ± 0.1	45	36 ± 9
81 - North of Watsons Reef	25º 11.566	80º 15.277	3.1 ± 0.1	40	37 ± 4
84 - North of Watsons Reef	25º 11.468	80º 14.254	4.7 ± 0.0	40	38 ± 3
99 - Inshore of Watsons Reef	25º 10.633	80º 15.943	3.4 ± 0.2	70	55 ± 15
121 - Northwest of Elbow Reef	25º 09.219	80º 17.444	5.0 ± 0.0	95	72 ± 24
170 - West of Grecian Rocks	25º 06.889	80º 18.951	3.5 ± 0.2	60	55 ± 5
169 - West of Grecian Rocks	25º 06.643	80º 18.800	4.0 ± 0.1	35	28 ± 8
171 - West of Grecian Rocks	25º 06.470	80º 18.879	3.8 ± 0.2	80	78 ± 3
183 - Southwest of Grecian Rocks	25º 05.326	80º 19.145	5.9 ± 0.1	35	30 ± 5
184 - Southwest of Grecian Rocks	25º 05.183	80º 19.350	5.7 ± 0.1	20	20 ± 0
185 - North of Dixie Shoal	25º 04.274	80º 20.198	4.8 ± 0.1	20	18 ± 3
186 - North of Dixie Shoal	25º 03.817	80º 20.316	5.8 ± 0.0	35	35 ± 0
187 - Dixie Shoal	25º 03.327	80º 20.912	4.2 ± 0.1	40	38 ± 3
188 - Dixie Shoal	25º 03.056	80º 20.396	6.1 ± 0.2	30	28 ± 3
222 - Molasses Reef Channel	25º 00.803	80º 24.982	3.4 ± 0.0	50	33 ± 18
221 - Southwest of Molasses Reef	25º 00.333	80º 22.548	3.5 ± 0.2	45	45 ± 0
261 - West of Pickles Reef	24º 59.374	80º 26.869	4.1 ± 0.0	32	31 ± 1
260 - West of Pickles Reef	24º 59.249	80º 27.145	4.1 ± 0.2	50	40 ± 10
259 - West of Pickles Reef	24º 59.234	80º 27.157	4.1 ± 0.0	24	20 ± 4
253 - Southwest of Pickles Reef	24º 58.441	80º 26.016	6.2 ± 0.1	30	26 ± 4
250 - Conch Reef	24º 57.663	80º 27.420	2.2 ± 0.1	40	38 ± 3
241 - Little Conch Reef	24º 56.572	80º 28.347	5.8 ± 0.2	35	34 ± 2
227 - North of Davis Reef	24º 55.600	80º 30.159	2.9 ± 0.0	50	48 ± 3
226 - North of Davis Reef	24º 55.283	80º 30.490	6.6 ± 0.1	50	43 ± 8
211 - Inshore of Crocker Reef	24º 55.143	80º 32.113	5.6 ± 0.1	72	52 ± 20
212 - Northeast of Crocker Reef	24º 55.126	80º 31.478	6.5 ± 0.1	47	36 ± 11
210 - Inshore of Crocker Reef	24º 54.975	80º 32.710	6.2 ± 0.0	38	32 ± 7
151 - West of Crocker Reef	24º 54.634	80º 33.325	6.4 ± 0.2	40	33 ± 8
150 - West of Crocker Reef	24º 54.431	80º 33.825	6.6 ± 0.0	20	20 ± 0
146 - NE of Alligator Reef	24º 53.191	80º 35.114	5.6 ± 0.1	52	46 ± 6
136 - NE of Alligator Reef	24º 51.212	80º 36.828	5.9 ± 0.0	32	31 ± 1
Reference area total (33)			4.7 ± 0.2	43 ± 3	37 ± 2
No-take zones					
43 - Carysfort Reef**	25º 13.399	80º 12.772	3.4 ± 0.0	57	48 ± 9
59 - South of South Carysfort Reef**	25º 12.244	80º 13.394	4.0 ± 0.2	75	63 ± 13
248 - Conch Reef**	24º 57.302	80º 27.471	5.3 ± 0.2	70	60 ± 10
247 - Conch Reef**	24º 57.114	80º 27.571	4.4 ± 0.2	45	45 ± 0
217 - Davis Reef**	24º 55.411	80º 30.298	5.6 ± 0.2	50	49 ± 1
216 - Davis Reef**	24º 55.349	80º 30.349	6.6 ± 0.0	45	43 ± 2
138 - Alligator Reef**	24º 50.797	80º 37.353	4.4 ± 0.3	85	75 ± 10
137 - Alligator Reef**	24º 50.730	80º 37.460	6.2 ± 0.2	55	43 ± 13
No-take zone total (8)			5.0 ± 0.4	60 ± 5	53 ± 4
Shallow hard-bottom Total (41)			**4.8 ± 0.2**	**47 ± 3**	**40 ± 2**
High-relief spur and groove					
Reference areas					
23 - Turtle Reef	25º 17.603	80º 13.258	4.5 ± 0.2	110	90 ± 20
25 - Turtle Reef	25º 16.973	80º 12.412	4.0 ± 0.1	90	68 ± 23
32 - Turtle Rocks	25º 16.004	80º 12.713	3.8 ± 0.2	70	67 ± 4
33 - Turtle Rocks	25º 15.545	80º 12.630	3.4 ± 0.2	50	49 ± 1
76 - Maitland area	25º 11.878	80º 13.536	4.6 ± 0.2	105	99 ± 7
77 - Maitland area	25º 11.835	80º 13.589	3.5 ± 0.0	83	77 ± 7
78 - Maitland area	25º 11.796	80º 13.630	4.8 ± 0.1	110	105 ±5
119 - Inshore of Watsons Reef	25º 09.839	80º 16.667	3.4 ± 0.0	70	65 ± 5

Site number/site location (no. sites)	Latitude (N)	Longitude (W)	Mean depth (m)	Max. vertical relief (cm)	Mean max. vertical relief (cm)
120 - Inshore of Watsons Reef	25º 09.547	80º 17.140	4.6 ± 0.0	100	90 ± 10
122 - North of Horseshoe Reef	25º 08.975	80º 17.501	4.9 ± 0.2	120	105 ± 15
123 - North of Horseshoe Reef	25º 08.857	80º 17.643	4.6 ± 0.0	85	83 ± 3
124 - North of Horseshoe Reef	25º 08.648	80º 17.657	5.4 ± 0.2	105	95 ± 10
274 - Horseshoe Reef	25º 08.394	80º 17.649	4.2 ± 0.2	185	138 ± 48
126 - North-North Dry Rocks	25º 08.207	80º 17.349	5.3 ± 0.2	120	115 ± 5
129 - North Dry Rocks	25º 07.749	80º 17.632	4.1 ± 0.2	145	130 ± 15
159 - North of Grecian Rocks	25º 06.880	80º 18.126	6.9 ± 0.2	170	150 ± 20
189 - Northeast of French Reef	25º 02.450	80º 20.711	3.5 ± 0.0	50	48 ± 3
205 - Sand Island	25º 01.134	80º 22.057	4.3 ± 0.2	200	190 ±10
277 - Sand Island	25º 01.084	80º 22.097	4.0 ± 0.1	90	85 ± 5
67 - Pickles Reef	24º 59.458	80º 24.724	3.7 ± 0.2	70	53 ± 18
66 - Pickles Reef	24º 59.271	80º 24.876	3.4 ± 0.1	55	54 ± 1
65 - Pickles Reef	24º 58.973	80º 25.158	6.5 ± 0.1	52	51 ± 1
Reference area total (22)			4.4 ± 0.2	102 ± 9	91 ± 8
No-take zones					
44 - Carysfort Reef**	25º 13.350	80º 12.599	4.4 ± 0.0	180	160 ±20
45 - Carysfort Reef**	25º 13.219	80º 12.632	4.8 ± 0.1	145	128 ± 18
57 - South Carysfort Reef**	25º 12.734	80º 13.051	4.9 ± 0.2	230	210 ± 20
272 - South Carysfort Reef**	25º 12.517	80º 13.158	2.1 ± 0.0	155	133 ± 23
58 - South Carysfort Reef**	25º 12.421	80º 13.241	3.4 ± 0.4	95	88 ± 8
114 - Elbow Reef**	25º 08.572	80º 15.475	3.7 ± 0.7	190	160 ±30
273 - Elbow Reef**	25º 08.544	80º 15.504	4.3 ± 0..4	165	128 ± 38
113 - Elbow Reef**	25º 08.449	80º 15.534	5.7 ± 0.2	120	93 ± 28
156 - Key Largo Dry Rocks**	25º 07.461	80º 17.833	4.3 ± 0.1	95	78 ± 18
155 - Key Largo Dry Rocks**	25º 07.356	80º 17.927	3.4 ± 0.2	95	83 ± 13
160 - Grecian Rocks**	25º 06.665	80º 18.218	2.1 ± 0.0	110	108 ± 3
161 - Grecian Rocks**	25º 06.589	80º 18.270	2.9 ± 0.2	120	95 ± 25
280 - Grecian Rocks**	25º 06.536	80º 18.312	2.8 ± 0.2	110	105 ± 5
200 - French Reef**	25º 02.184	80º 20.837	5.9 ± 0.1	150	108 ± 43
278 - French Reef**	25º 02.026	80º 20.960	6.6 ± 0.1	290	220 ± 70
201 - French Reef**	25º 02.015	80º 21.000	5.9 ± 0.0	45	38 ± 8
207 - Molasses Reef**	25º 00.601	80º 22.439	5.7 ± 0.1	350	285 ±65
276 - Molasses Reef**	25º 00.591	80º 22.426	6.5 ± 0.2	210	173 ± 38
218 - Molasses Reef**	25º 00.511	80º 22.598	4.4 ± 0.0	70	65 ± 5
No-take zone total (19)			4.4 ± 0.3	154 ± 17	129 ± 14
High-relief spur & groove Total (41)			**4.4 ± 0.2**	**126 ± 10**	**109 ± 8**
Deeper fore-reef habitats (6-15 m)					
Reference areas					
26 - Whistle Buoy	25º 17.596	80º 10.351	10.7 ± 0.1	95	75 ± 20
27 - Whistle Buoy	25º 17.411	80º 10.412	7.9 ± 0.3	50	41 ± 10
29 - Turtle Rocks	25º 16.638	80º 12.496	6.3 ± 0.1	65	60 ± 5
31 - Turtle Rocks	25º 16.338	80º 12.051	10.4 ± 0.1	55	53 ± 3
34 - East of Turtle Rocks	25º 15.228	80º 12.153	8.3 ± 0.1	49	40 ± 10
39 - North of Carysfort Reef	25º 14.252	80º 12.280	10.3 ± 0.1	70	68 ± 3
75 - South of South Carysfort Reef	25º 11.923	80º 13.395	10.4 ± 0.1	40	39 ± 1
101 - Watsons Reef	25º 11.004	80º 14.663	7.6 ± 0.0	55	53 ± 3
102 - Watsons Reef	25º 10.625	80º 14.433	8.8 ± 0.3	60	58 ± 3
107 - Watsons Reef	25º 09.893	80º 15.043	10.4 ± 0.2	60	53 ± 8
109 - North of Elbow Reef	25º 09.243	80º 15.417	9.1 ± 0.4	68	54 ± 14
112 - South of Elbow Reef	25º 08.100	80º 15.769	8.6 ± 0.1	53	48 ± 6
111 - South of Elbow Reef	25º 08.014	80º 16.153	10.9 ± 0.1	50	50 ± 0
165 - East of Dry Rocks	25º 07.214	80º 17.060	7.8 ± 0.2	50	48 ± 3
167 - Southeast of Grecian Rocks	25º 06.073	80º 17.730	7.8 ± 0.1	55	40 ± 15
168 - Southeast of Grecian Rocks	25º 06.060	80º 17.923	9.4 ± 0.1	40	40 ± 0
182 - Southwest of Grecian Rocks	25º 05.012	80º 18.856	7.3 ± 0.0	35	30 ± 5
204 - Southwest of French Reef	25º 01.757	80º 21.649	10.4 ± 0.1	45	43 ± 3

Site number/site location (no. sites)	Latitude (N)	Longitude (W)	Mean depth (m)	Max. vertical relief (cm)	Mean max. vertical relief (cm)
68 - Pickles Reef	24º 59.796	80º 24.231	6.9 ± 0.2	48	47 ± 2
252 - NE of Conch Reef	24º 58.105	80º 26.697	8.5 ± 0.3	50	40 ± 10
242 - Little Conch Reef	24º 56.681	80º 28.185	7.8 ± 0.2	85	68 ± 18
233 - Northeast of Davis Reef	24º 56.229	80º 29.740	6.8 ± 0.1	45	40 ± 5
232 - Northeast of Davis Reef	24º 55.675	80º 29.866	7.8 ± 0.1	53	49 ± 4
228 - Southwest of Davis Reef	24º 55.148	80º 30.428	11.1 ± 0.2	50	50 ± 0
213 - Northeast of Crocker Reef	24º 54.848	80º 30.929	6.7 ± 0..5	90	60 ± 30
208 - Crocker Reef	24º 54.374	80º 31.690	8.2 ± 0.2	40	37 ± 3
154 - SW of Crocker Reef	24º 54.125	80º 32.357	9.1 ± 0.1	42	33 ± 10
153 - SW of Crocker Reef	24º 54.082	80º 32.593	7.5 ± 0.0	38	32 ± 7
152 - SW of Crocker Reef	24º 53.871	80º 32.963	9.6 ± 0.0	40	35 ± 5
145 - South of Cheeca Rocks	24º 53.298	80º 36.841	6.6 ± 0.0	42	41 ± 1
148 - NE of Alligator Reef	24º 53.223	80º 34.484	6.2 ± 0.1	45	33 ± 13
147 - NE of Alligator Reef	24º 52.830	80º 34.787	7.8 ± 0.1	40	36 ± 4
131 - NE of Alligator Reef	24º 52.785	80º 34.026	8.4 ± 0.0	23	22 ± 2
133 - NE of Alligator Reef	24º 52.428	80º 35.476	7.1 ± 0.2	50	44 ± 6
132 - NE of Alligator Reef	24º 52.265	80º 34.854	8.3 ± 0.1	34	31 ± 3
135 - NE of Alligator Reef	24º 51.404	80º 36.633	7.2 ± 0.1	20	17 ± 3
Reference area total (36)			8.5 ± 0.2	51 ± 3	44 ± 2
No-take zones					
40 - Carysfort Reef**	25º 14.027	80º 12.616	8.4 ± 0.3	80	65 ± 15
41 - Carysfort Reef**	25º 13.919	80º 12.433	8.5 ± 0.3	110	78 ± 33
69 - Carysfort Reef**	25º 13.357	80º 12.541	7.6 ± 0.0	42	39 ± 4
56 - South Carysfort Reef**	25º 12.700	80º 12.717	5.8 ± 0.2	52	35 ± 17
55 - South Carysfort Reef**	25º 12.389	80º 12.885	8.8 ± 0.2	43	33 ± 10
220 - Molasses Reef**	25º 00.482	80º 22.423	12.9 ± 0.1	75	53 ± 23
219 - Molasses Reef**	25º 00.455	80º 22.478	12.0 ± 0.2	50	48 ± 3
244 - Conch Reef**	24º 57.282	80º 27.156	15.0 ± 0.1	70	45 ± 25
243 - Conch Reef**	24º 57.176	80º 27.336	13.3 ± 0.1	50	45 ± 6
246 - Conch Reef**	24º 57.109	80º 27.470	9.7 ± 0.1	60	58 ± 3
245 - Conch Reef**	24º 57.014	80º 27.526	11.2 ± 0.2	31	26 ± 6
215 - Davis Reef**	24º 55.378	80º 30.203	10.7 ± 0.0	42	39 ± 4
214 - Davis Reef**	24º 55.284	80º 30.287	11.0 ± 0.0	30	30 ± 0
No-take zone total (13)			10.4 ± 0.7	57 ± 6	45 ± 4
Deeper Fore-reef Total (49)			**9.0 ± 0.3**	**52 ± 3**	**45 ± 2**

Table 2-4. SCUBA diving effort for benthic coral reef surveys in the upper Florida Keys National Marine Sanctuary during May-September 2011.

Scientific Diver	**Affiliation**	**No. of dives**	**Depth range (ft.)**	**Bottom time (hrs.)**
Mark Chiappone	CMS/UNCW	245	5-53	125.60
Leanne Rutten	CMS/UNCW	248	6-51	131.77
Lonny Anderson	FKNMS-DARRP	58	7-37	25.50
Hatsue Bailey	FKNMS-DARRP	58	7-44	30.00
Sarah Fangman	GRNMS	110	6-44	3.08
Alicia Farrer	FKNMS-DARRP	5	9-24	49.75
Bill Goodwin	FKNMS-DARRP	38	10-38	15.63
Total all divers		762	5-53	381.33

III. Distribution and Abundance of *Acropora* Corals

Background

The declines in abundance of two of the principal Caribbean reef-building corals, staghorn coral (*Acropora cervicornis*) and elkhorn coral (*A. palmata*), are often-cited examples of the changes that have occurred on wider Caribbean reefs, including the Florida Keys, during the past several decades (Bruckner 2002; Gardner et al. 2003). The causes of these declines, which began in the late 1970s, include regional phenomena such as coral bleaching and diseases, especially white band disease (Gladfelter 1982; Aronson and Precht 2001), as well as more localized effects from tropical storms, cold fronts, and predation by corallivorous snails, fireworms, and damselfishes (Miller et al. 2002). Both corals were under consideration for addition to the U.S. Endangered Species List (ESA) as of the early 1990s and were formally determined to be "threatened" on the ESA in 2005, based upon range-wide population declines and poor recovery (*Acropora* Biological Review Team 2005).

Populations of both species remain well-below historical levels, including those in the Florida Keys (Dustan and Halas 1987; Porter and Meier 1992). Moreover, localized and regional stressors remain a threat and are likely to inhibit population recovery (*Acropora* Biological Review Team 2005). Monitoring by our program addresses both the potential for further population decline, as well as the potential for recovery, should it occur. We specifically collect data on habitat distribution, colony size, and density, in order to calculate abundance estimates for both species. Using a stratified random sampling design, the goals of the 2011 surveys were to continue our long-term monitoring in the upper and a portion of the middle Florida Keys, but also to use the survey data to prepare for a Keys-wide assessment in 2012, and to help facilitate a regional population assessment effort in the U.S. Caribbean (Puerto Rico and the U.S. Virgin Islands). The 2011 data were used to update population abundance estimates by habitat, management zone, and size class and by habitat.

Acropora Survey Methods

An updated version of our field protocol manual was completed in December 2011 and provides further details on our benthic survey methods, including *Acropora* corals (Miller et al 2011). Briefly, the field methodology for assessing *Acropora* corals during 2011 consisted of the following:

- Two replicate 15-m x 1-m (15-m^2) belts transects were deployed per site for *Acropora* corals, which were sampled for presence-absence, colony numbers, colony sizes, and condition by species. The F1 hybrid, *Acropora prolifera*, was not encountered in the upper Keys during 2011.

- *Acropora* colonies were assessed at both the skeletal unit and physiologic unit levels, as described below, for numbers, size, and condition.

Each colony that was encountered was assessed in three ways: 1) dimensions (maximum branch diameter, secondary branch diameter, and maximum height), percent live tissue vs. dead skeleton, and condition of "skeletal" colonies, defined as continuous skeleton, regardless of whether or not the colony is partitioned into several individual patches of continuous live tissue; 2) overall dimensions (maximum branch diameter, secondary branch diameter, and maximum height) and condition of "physiologic" colonies, defined as individual patches of continuous live tissue that are contained within a skeletal unit; and 3) physiologic colony measurements of individual branches, patches, and bases to more accurately estimate the surface area of live tissue within each colony. For example, if an *Acropora cervicornis* colony was encountered and consisted of two patches of live tissue on one larger skeletal unit, the following measurements were made:

- One skeletal unit assessment of colony size , percent dead tissue, and colony condition;
- Two physiologic unit assessments of overall colony size, percent dead tissue, and colony condition;
- Two physiologic unit assessments of surface area based on all live tissue by measuring individual branches, patches, and bases).

The summary data reported below show density and abundance estimates of skeletal colonies, as well as density, size (surface area of live tissue patches), and condition of physiologic colonies based upon detailed measurements of live tissue surface area (branches, patches, and bases). The reason we take both skeletal and physiologic measurements is because they provide an estimate of population condition, related potentially to fragmentation and the relative proportion of ramets and genets.

2011 *Acropora* Survey Results

Staghorn coral (*Acropora cervicornis*)

A total of 280 sites (560 15-m x 1-m belt transects) were surveyed for *Acropora* corals. Staghorn coral (*A. cervicornis*) (Figure 3-1) was encountered at 8.2% of all sites and 5.5% of all sampled belt transects. Staghorn coral was found in most of the habitats sampled, except for back-reef rubble and the deeper fore reef. Table 3-1 summarizes the site presence, transect frequency, physiologic colony density (live tissue patches), total surface area, and mean colony size by habitat and management zone, while Figures 3-2 to 3-4 show the spatial distribution of presence-absence and physiologic colony density for the upper Keys study area. Evident from the spatial distribution of colonies is the importance of offshore patch reefs and shallow (< 6 m depth) platform margin habitats, specifically low-relief hard-bottom and high-relief spur and groove. Site presence and transect frequency were more or less similar in these three habitats (Table 3-1, Figure 3-5, top). Historically, staghorn coral occurred on some deeper fore-reef areas (especially low-relief spur and groove) in larger fingers of interlocking colonies, but no such thickets have been encountered during the past decade.

Staghorn coral colonies were measured at the both skeletal (continuous skeleton) and physiologic levels (live tissue patches). Examples of live tissue patches include branches separated from the larger colony by dead tissue, or patches surrounded by dead tissue that could represent either remnant survival or recruitment of a new colony (genet) onto previously dead skeleton. A total of 88 skeletal colonies and 256 physiologic colonies were counted, measured, and assessed for condition; these values indicate that, on average, a given staghorn skeletal colony consisted of three physiologic fragments or patches of contiguous tissue. Mean density (no. per m^2) of staghorn corals at both of these levels showed similar patterns among habitat types (Figure 3-5), with offshore patch reefs, shallow hard-bottom, and high-relief spur and groove yielding the greatest colony densities. Mean tissue surface area of physiologic colonies was nearly two times greater on shallow hard-bottom compared to offshore patch reefs and high-relief spur and groove (Table 3-1). Comparisons of staghorn coral distribution and abundance between FKNMS no-take zones and reference areas are summarized for both skeletal and physiologic colonies in Table 3-1 and Figure 3-6. Transect frequency, density of skeleton colonies, density of physiologic colonies, and mean size were all consistently greater in reference areas compared to no-take zones for all habitats where staghorn coral was encountered. The only no-take zone where we recorded staghorn corals was Dry Rocks SPA.

Population abundance estimates (total numbers of colonies) of staghorn coral were derived for both skeletal and physiologic colonies by habitat, colony size, and management zone (Figures 3-7 to 3-9). These estimates take into consideration the density of colonies and the areas of the habitat types and management zones sampled. Population abundance estimates (± 95% confidence intervals) for skeletal colonies by habitat type (Figure 3-7, top) indicate that there are 2.7 million ± 2.9 million skeletal colonies in the upper Florida Keys. Note that there are relatively similar abundance values for mid-channel and offshore patch reefs, as well as shallow hard-bottom. The high degree of variability in these estimates, at both the skeletal and physiologic colony levels, reflects the patchy distribution of staghorn coral (Figures

3-2 to 3-4). We are investigating potential changes to our sampling protocols to help reduce variance in our 2012 surveys. Sampling more sites is one approach, as is modifying protocols in our second stage design (area or numbers of belt transects). Abundance estimates by habitat for physiologic colonies indicate 8.3 million ± 9.8 million colonies in the upper Keys, which is approximately three times the number of skeletal colonies. Staghorn coral abundance estimates for skeletal colonies by maximum diameter (Figure 3-8, top) and for physiologic colonies by tissue area size class (Figure 3-8, bottom) show a predominance of smaller colonies, a pattern that we have continued to document for over a decade. No thickets larger than about 1 m in maximum dimension (length or diameter) were encountered during 2011. Staghorn coral abundance estimates by habitat and management zone are shown in Figure 3-9 for both skeletal and physiologic colonies. In stark contrast to the pattern evident for *Acropora palmata* (see below), all or nearly all of the staghorn corals present in the upper FKNMS occur outside of Sanctuary no-take zones for mid-channel patch reefs (100%), offshore patch reefs (100%), shallow hard-bottom (100%), and high-relief spur and groove (93%).

Of the condition categories assessed on staghorn coral, bleaching (19 colonies, 7.4%) and predation (primarily damselfishes and snails) were the most common. Obvious signs of predation were found on 65 physiologic colonies or approximately 25% of the sampled staghorn corals. No disease-like symptoms or overgrowth by other organisms were documented. In summary, staghorn corals exhibit a broader habitat distribution than elkhorn corals, yet are also characterized by generally smaller colonies. In addition, most colonies occur outside of FKNMS no-take zones, especially in the patch reef environment.

Elkhorn coral (*Acropora palmata*)

Elkhorn coral (*A. palmata*) (Figure 3-10) was encountered at 3.2% of all sites and 3.0% of all sampled belt transects. Elkhorn coral was only found on high-relief spur and groove reefs. In previous years, we have encountered a few isolated colonies on offshore patch reefs, back-reef rubble, and shallow hard-bottom, but clearly most colonies are restricted to the shallow fore-reef area in the upper FKNMS. Table 3-2 summarizes the site presence, transect frequency, physiologic colony density (live tissue patches), total surface area, and mean colony size by habitat and management zone, while Figures 3-11 to 3-13 illustrate the spatial distribution of presence-absence and physiologic colony density for the upper Keys study area. Evident from the spatial distribution of elkhorn coral is the importance of the shallow platform margin, as well as the concentration of colonies in FKNMS no-take zones. In the high-relief spur and groove habitat, elkhorn coral was present at 22% of all sites and 21% of all transects (Table 3-2, Figure 3-14, top). Several shallow spur and groove reefs continue to support thickets of elkhorn corals, with most patches approximately 15-m to 20-m in diameter. Reefs where stands (not just isolated colonies) of elkhorn coral occur in the upper Florida Keys include (from north to south):

- South Carysfort Reef,
- Elbow Reef,
- Horseshoe Reef,
- Grecian Rocks,
- French Reef,
- Sand Island, and
- Molasses Reef.

Elkhorn coral colonies were also measured at the both skeletal (continuous skeleton) and physiologic levels (live tissue patches). A total of 109 skeletal colonies and 300 physiologic colonies were counted, measured, and assessed for condition. Like staghorn coral, these values indicate that, on average, a given elkhorn skeletal colony consisted of three physiologic colonies or patches of contiguous tissue. Mean density (no. per m^2) of elkhorn corals at both of these levels is shown in Figure 3-14. Comparisons of elkhorn coral distribution and abundance between FKNMS no-take zones and reference areas are summarized for both skeletal and physiologic colonies in Table 3-2 and Figure 3-15. Transect frequency, density of skeleton colonies, density of physiologic colonies, and mean size were all consistently greater in no-take zones. Most, but not all (e.g. Horseshoe Reef and Sand Island), of the reefs listed above with extant thickets of elkhorn coral are located in FKNMS no-take zones.

The overall size distribution of elkhorn corals encountered in the high-relief spur and groove habitat at the skeletal (maximum diameter) and physiologic (live tissue surface area) levels is illustrated in Figure 3-16. The 107 skeletal colonies ranged in maximum diameter from 3 to 268 cm and averaged (± 1 SE) 268 ± 66 cm. The size distribution of skeletal colonies reflected a mixture of various size classes (Figure 3-16, top), including both small (< 20 cm) and larger colonies (> 90 cm). Approximately 36% of the colonies were less than 20 cm in maximum diameter. However, approximately 24% were larger than 90 cm. The size distribution of elkhorn coral physiologic colonies based upon live tissue surface area also illustrated a large range of colony sizes and essentially a U-shaped size distribution, with large numbers of both smaller (< 100 cm^2) and larger (> 1,000 cm^2) colonies (Figure 3-16, bottom). The 289 physiologic colonies ranged in tissue surface area from 1 to 44,185 cm^2, averaging 1,452 ± 217 cm^2. Although nearly 32% of elkhorn corals encountered were less than 100 cm2 in surface area, approximately 29% were larger (> 1,000 cm^2).

Of the condition categories assessed for elkhorn coral, bleaching (65 colonies, 21.7%) and predation (47 colonies, 15.7%) were the most common adverse conditions encountered. No disease-like symptoms or overgrowth by other organisms that was causing tissue loss were documented.

Calculating population abundance estimates (total numbers of colonies) for *Acropora palmata* presents several challenges: 1) the species has a limited distribution, with nearly 90% of the population present in the high-relief spur and groove habitat and specifically within Sanctuary no-take zones with this habitat type; 2) within these spur and groove habitats in the no-take zones, when the species is present, it is primarily found at the shallower end of the depth range for the habitat type; and 3) when present, it often grows in relatively well-defined thickets or stands in sufficient abundance that it is difficult to identify individual colonies. Therefore, extrapolating density measurements to obtain population estimates is not straight forward and results typically include large variance terms. Therefore, we are evaluating refinements to how we calculate population estimates for *A. palmata*. The refinements include adding additional stratification to our habitat designations based on depth and *a priori* knowledge about the limited distribution of the species in the upper Keys. The practical result of the refinements will be to reduce the amount of habitat used to scale up the density measurements, which will improve precision. Further, we are considering whether or not to reduce our primary sample units to cell sizes from 200 m x 200 m (40,000 m^2) to something smaller, perhaps as small as 100 m x 100 m (10,000 m^2), which would allow us to locate more of the primary sample units into the zones. More primary sample units per habitat type will significantly reduce variance.

An additional element that impacts population estimates for a species with patchy distribution, such as *A palmata*, is the random assignment of primary sample units. For example, within the 280 sites we randomly sampled in 2011 were six sites considered to be “hotspots” for *A. palmata*, or “remnant” patches of high density. Including or excluding these six sites, impacts the population estimate by more than an order of magnitude. Obviously, picking and choosing what sites to include in the analysis is not appropriate. Therefore, we are currently assessing how best to refine our population estimates for *A. palmata*.

Discussion

Results from the 2011 sampling effort add to a growing spatial and temporal data set on the status and trends in Florida Keys *Acropora palmata* and *A. cervicornis* populations. Our earlier Keys-wide sampling in previous years was not optimized for *Acropora* corals, but was instead optimized for a few of the most abundant species (e.g. *Montastraea cavernosa*, *Porites astreoides*, and *Siderastrea siderea*, see Smith et al. 2011). However, the benthic data still provide important opportunities to compare populations across multiple habitat types, including managed areas in the FKNMS. What is apparent from the *Acropora* surveys is that the distribution and abundance patterns of these two species are significantly different. Although most, if not all, of the high-relief spur and groove reefs in the upper Keys were sampled during 2011, results for elkhorn coral indicate that significant stands remain at only a handful of sites. Although many of these reefs are already within existing FKNMS no-take zones, predation by snails and damselfishes is still prevalent. In contrast, the distribution pattern of *A. cervicornis* reflects the importance of patch reefs and shallow hard-bottom to the possible recovery of this species. The absence of staghorn corals in fore-reef habitats, where they were previously abundant, suggests that recovery in the upper Florida Keys has not started. Still, it is reasonable to suggest that for staghorn corals the remaining population appears relatively stable, at least for the last ten years. The large number of small colonies compared to large colonies and the absence of these corals in fore-reef habitats is a concern. Further, their abundance on patch reefs, with over 5000 in the Florida Keys, is both good news and bad news. The good news is that patch reefs are abundant. The bad news is that many of them are located close to shore and are susceptible to stress caused by cold-water, such as the 2010 event. The situation for elkhorn coral is more problematic, since population numbers are much smaller and aggregations are confined mostly to one habitat. Finally, the mismatch between the distribution and abundance of staghorn corals and the location of no-take-zones in the upper Keys is noteworthy. Whether or not no-take-zones might provide meaningful protection to *A. cervicornis* is uncertain, and remains a major topic of ongoing research and management interest.

Figure 3-1. Examples of staghorn coral (*Acropora cervicornis*) observed in hard-bottom and coral reef habitats in the upper Florida Keys National Marine Sanctuary observed during May-September 2011.

Mid-channel patch reef, 3.0-4.3 m
Site #22, Turtle Rocks
25° 17.477 N, 80° 13.624 W

Offshore patch reef, 2.7-3.4 m
Site #80, North of Watsons Reef
25° 12.002 N, 80° 14.804 W

Offshore patch reef, 9.8-10.4 m
Site #108, Watsons Reef
25° 09.727 N, 80° 15.512 W

Inner line reef tract, 3.4-5.8 m
Site #23, Turtle Reef
25° 17.603 N, 80° 13.258 W

Inner line reef tract, 4.6-6.1 m
Site #124, North of Horseshoe Reef
25° 08.648 N, 80° 17.657 W

Low-relief hard-bottom, 1.8-2.4 m
Site #250, Conch Reef
24° 57.663 N, 80° 27.420 W

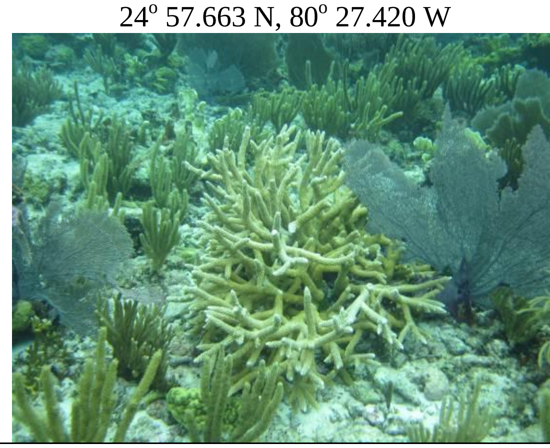


Figure 3-2. Densities (no. per m^2) of physiologic colonies of staghorn coral (*Acropora cervicornis*) in the upper Florida Keys National Marine Sanctuary from the southern boundary of Biscayne National Park to Carysfort/S. Carysfort Reef surveyed during May-September 2011. A physiologic colony is defined as a patch of contiguous live tissue.

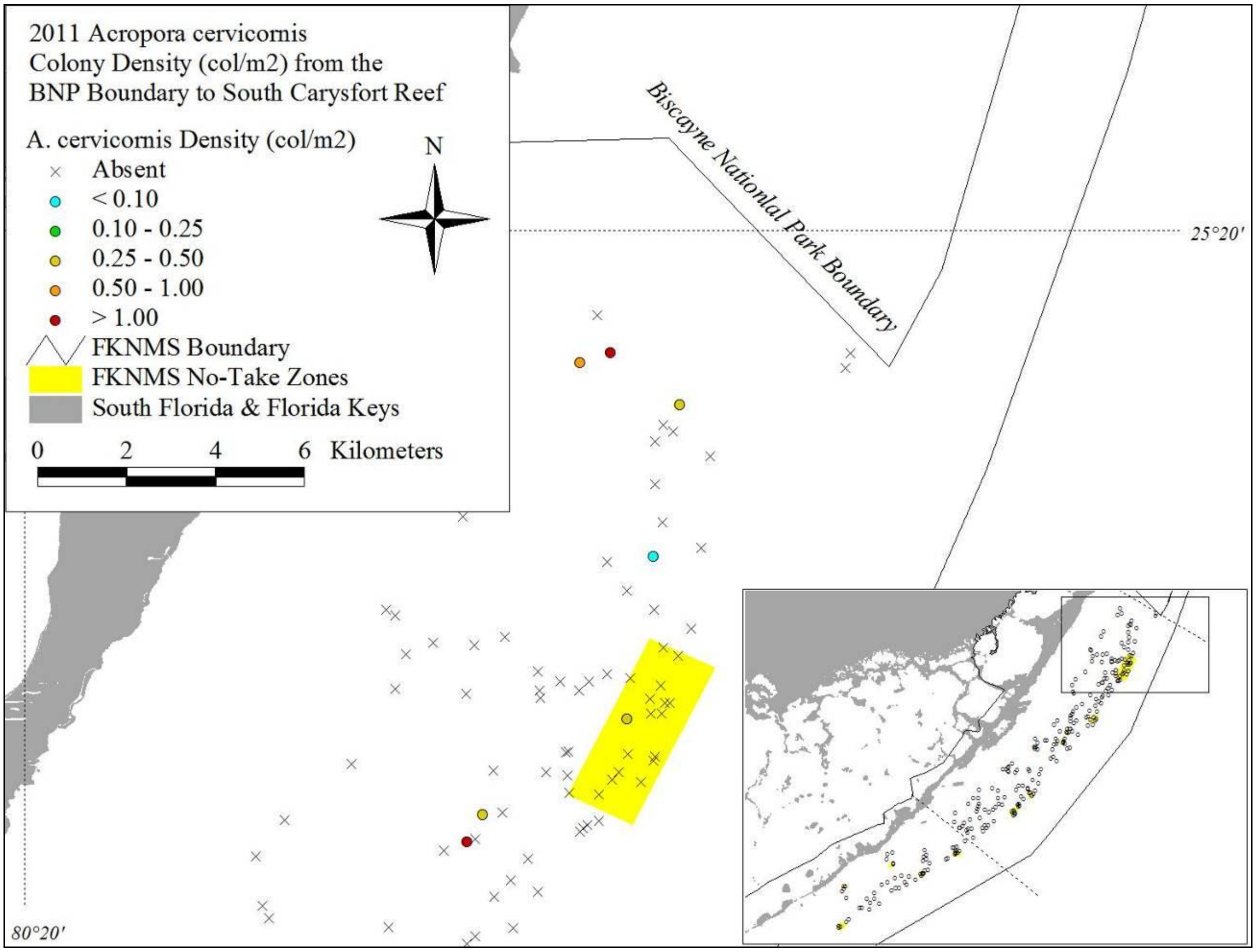


Figure 3-3. Densities (no. per m^2) of physiologic colonies of staghorn coral (*Acropora cervicornis*) in the upper Florida Keys National Marine Sanctuary from Elbow Reef to Pickles Reef surveyed during May-September 2011. A physiologic colony is defined as a patch of contiguous live tissue.

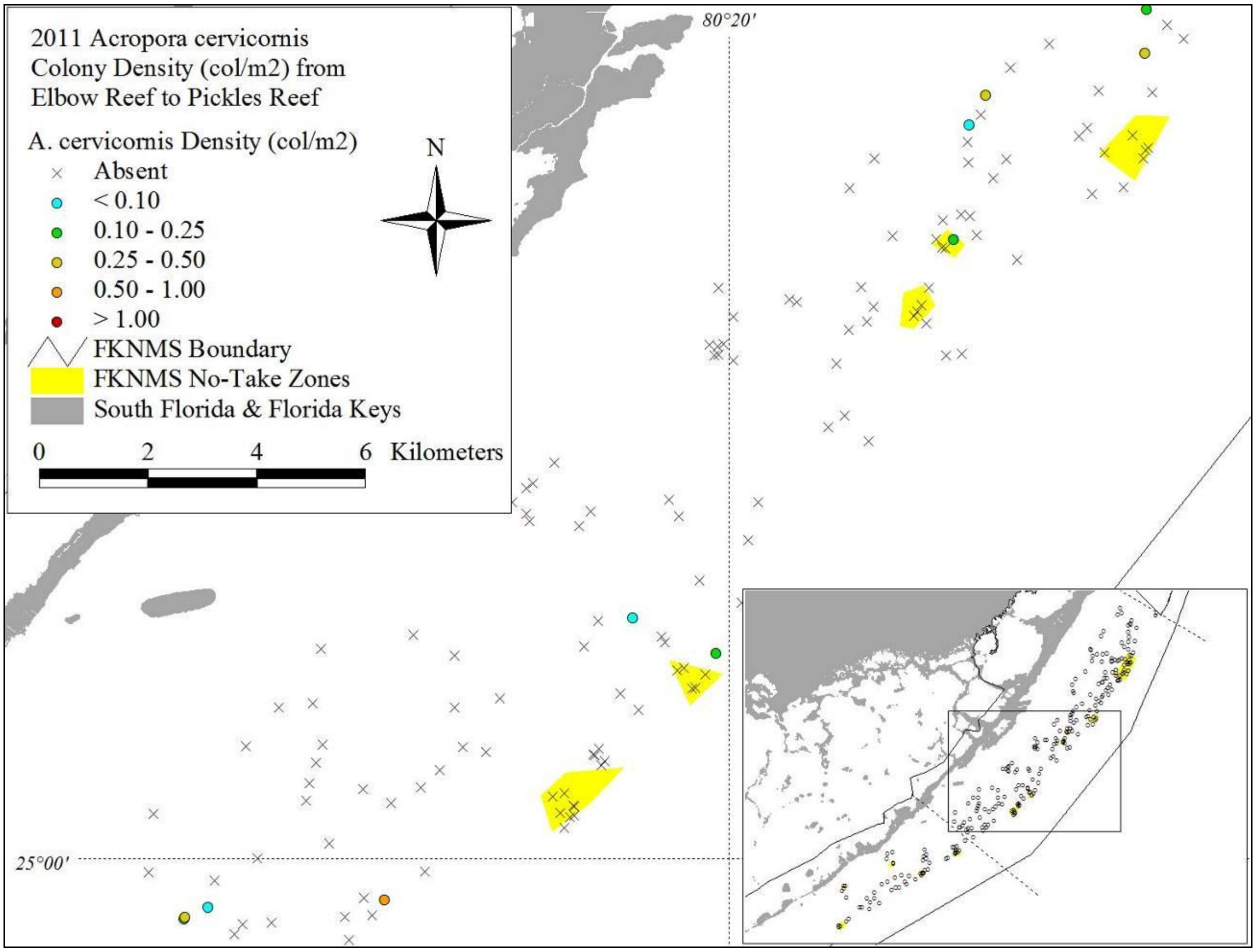


Figure 3-4. Densities (no. per m^2) of physiologic colonies of staghorn coral (*Acropora cervicornis*) in the upper Florida Keys National Marine Sanctuary from Conch Reef to Alligator Reef surveyed during May-September 2011. A physiologic colony is defined as a patch of contiguous live tissue.

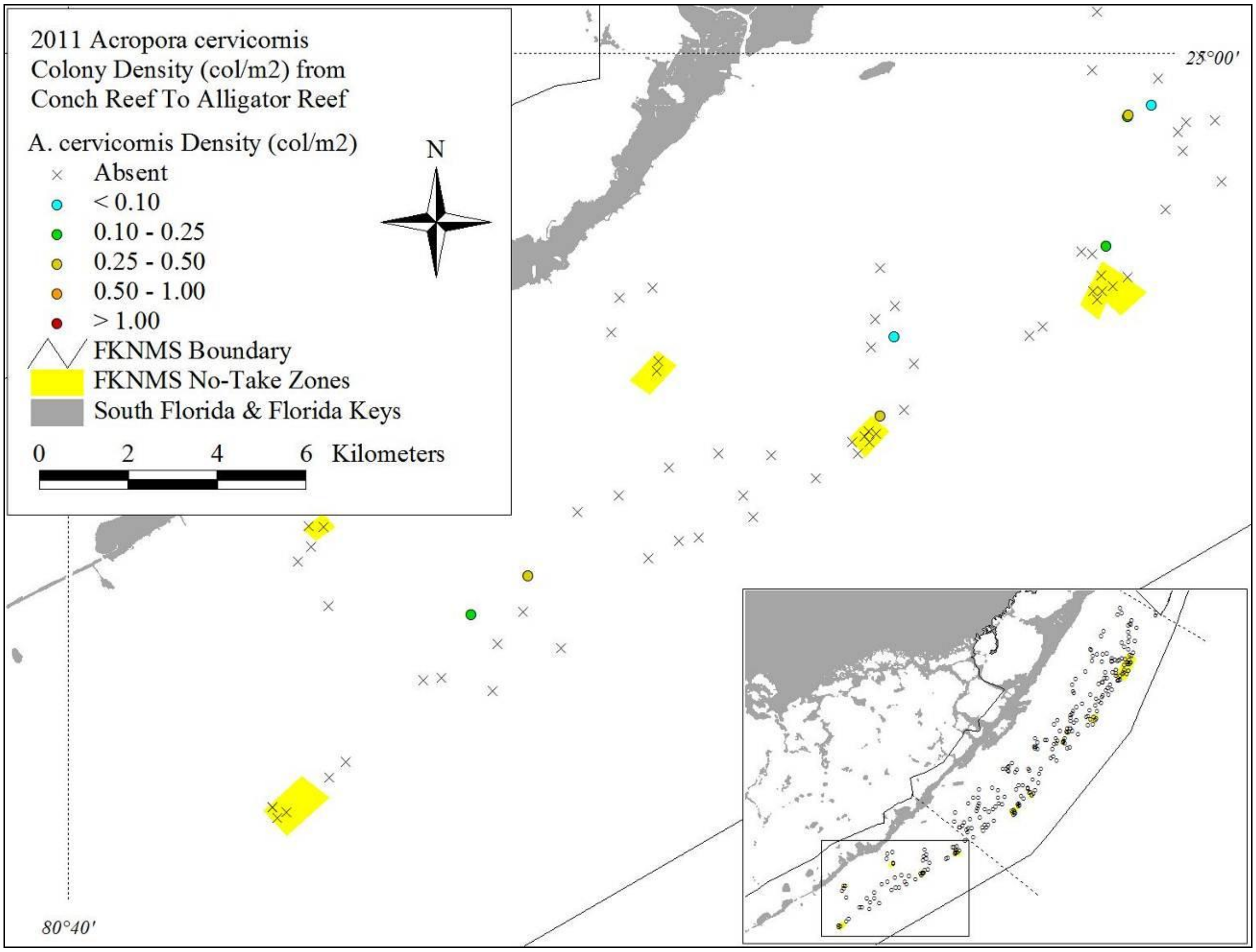


Figure 3-5. Mean (+ 1 SE) transect frequency (top), density (no. per m^2) of skeletal colonies (middle), and density (no. per m^2) of physiologic colonies of staghorn coral (*Acropora cervicornis*) by habitat type in the upper Florida Keys, as determined from surveys of replicate 15-m x 1-m belt transects per site at 280 sites. Domain-wide (upper Keys) values are weighted averages and standard errors. Values on the x-axis in parentheses are the number of sites surveyed in each habitat type. A physiologic colony is defined as a patch of contiguous live tissue, while a skeletal colony is defined as contiguous skeleton that may contain one or more physiologic colonies.

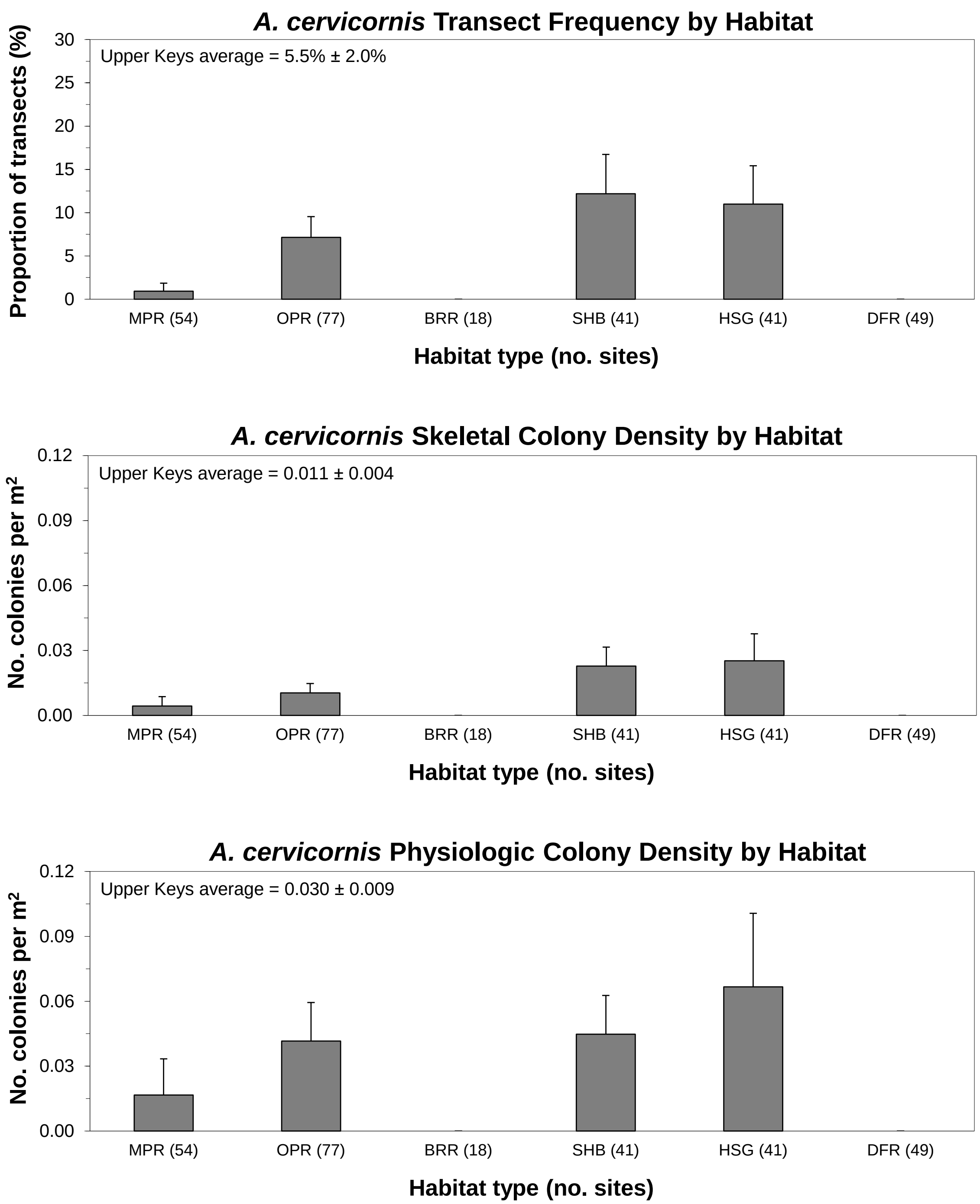
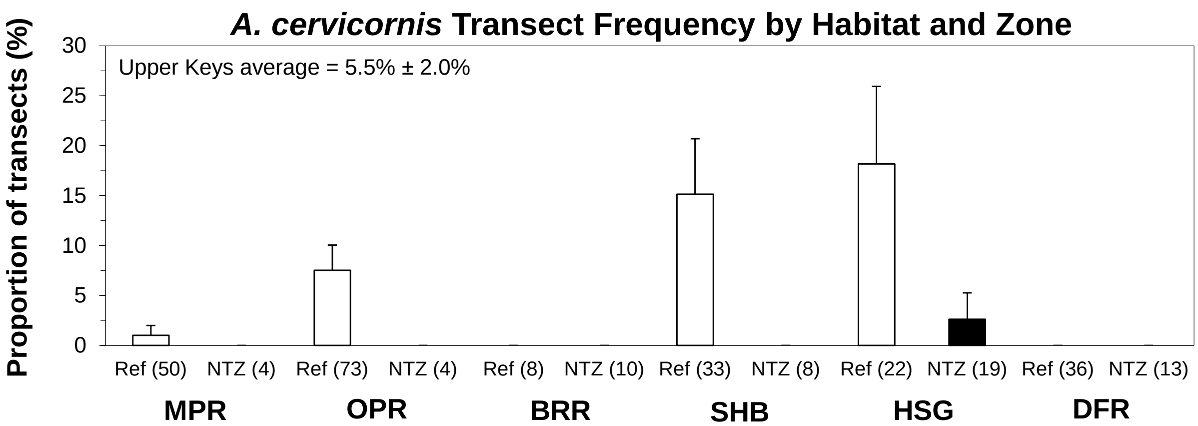
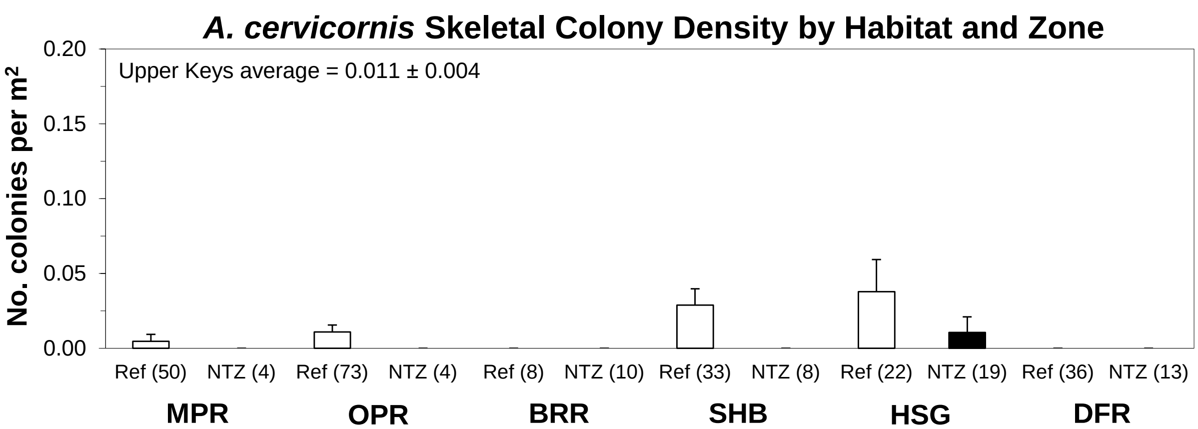


Figure 3-6. Mean (+ 1 SE) transect frequency (top), density (no. per m^2) of skeletal colonies (middle), and density (no. per m^2) of physiologic colonies of staghorn coral (*Acropora cervicornis*) by habitat type and management zone in the upper Florida Keys. Open bars = reference areas (Ref), filled bars = no-take zones (NTZ). Domain-wide (upper Keys) values are weighted averages and standard errors. Habitat abbreviations are: MPR = inshore and mid-channel patch reefs, OPR = offshore patch reefs, BRR = back-reef rubble, SHB = shallow (< 6 m) hard-bottom, HSG = high-relief and groove, and DFR = deeper (6-15 m) fore-reef habitats. Numbers in parentheses on the x-axis are the number of sites surveyed.





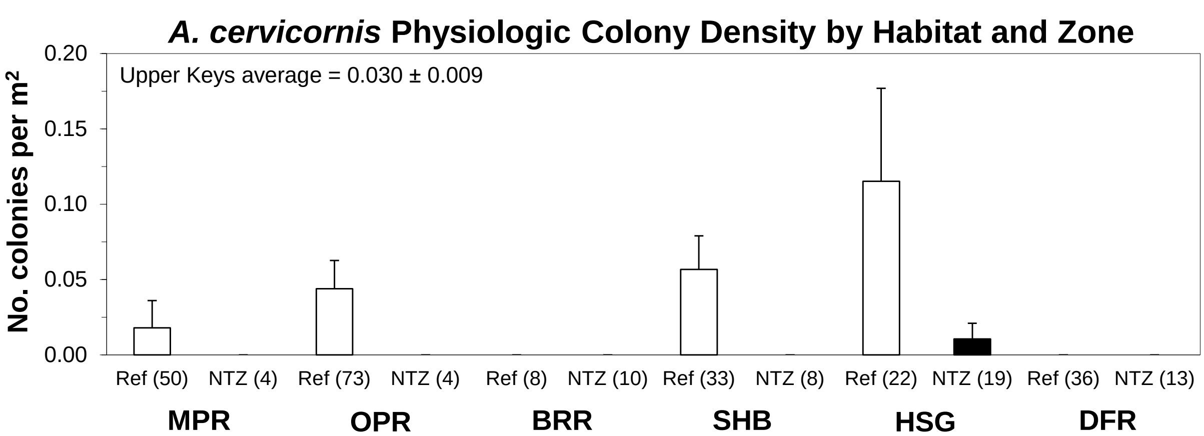
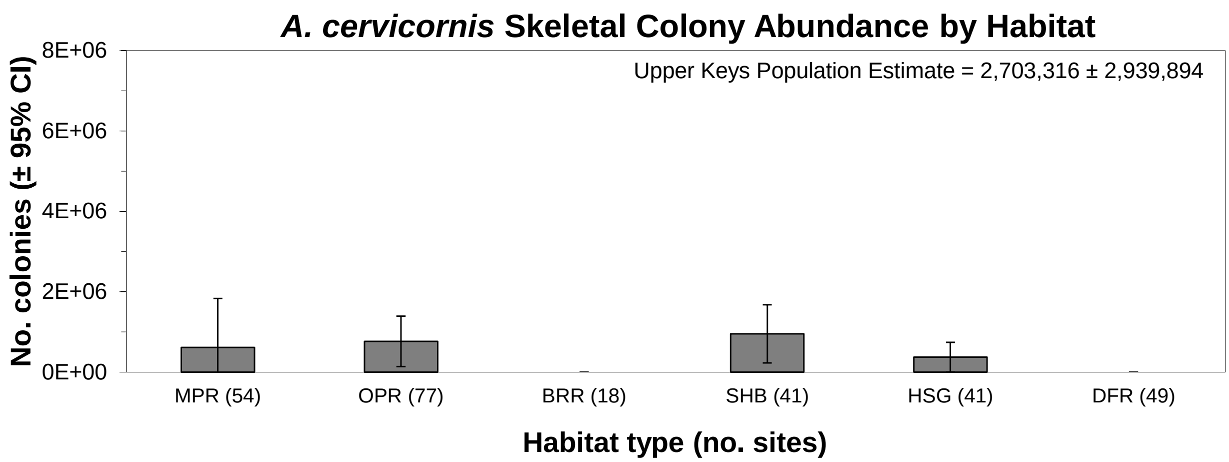


Figure 3-7. Abundance estimates (± 95% CI) of staghorn coral colonies (*Acropora cervicornis*) by habitat type for both skeletal (top) and physiologic colonies (bottom) in the upper Florida Keys (northern Key Largo to Alligator Reef). A physiologic colony is defined as a patch of contiguous live tissue, while a skeletal colony is defined as contiguous skeleton that may contain one or more physiologic colonies.



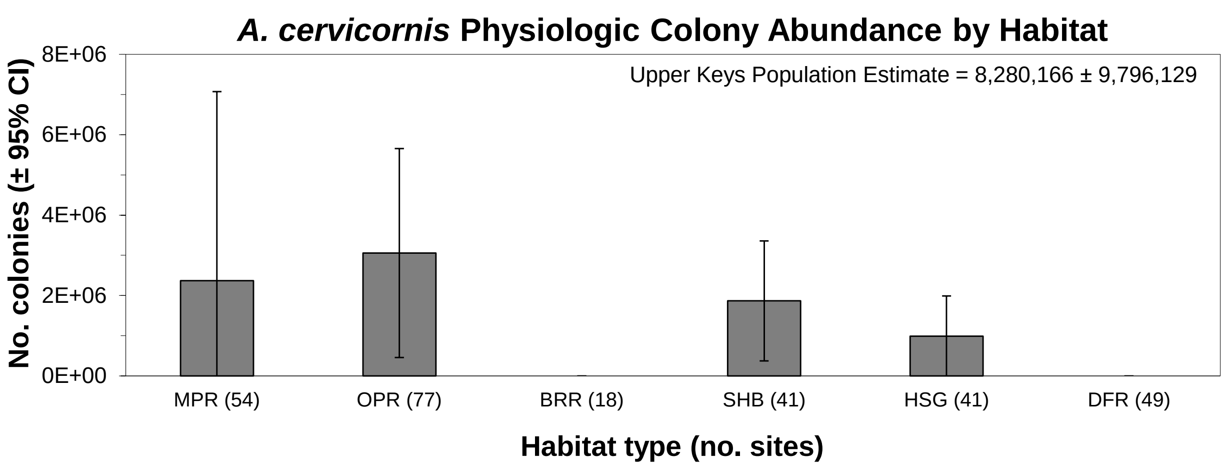
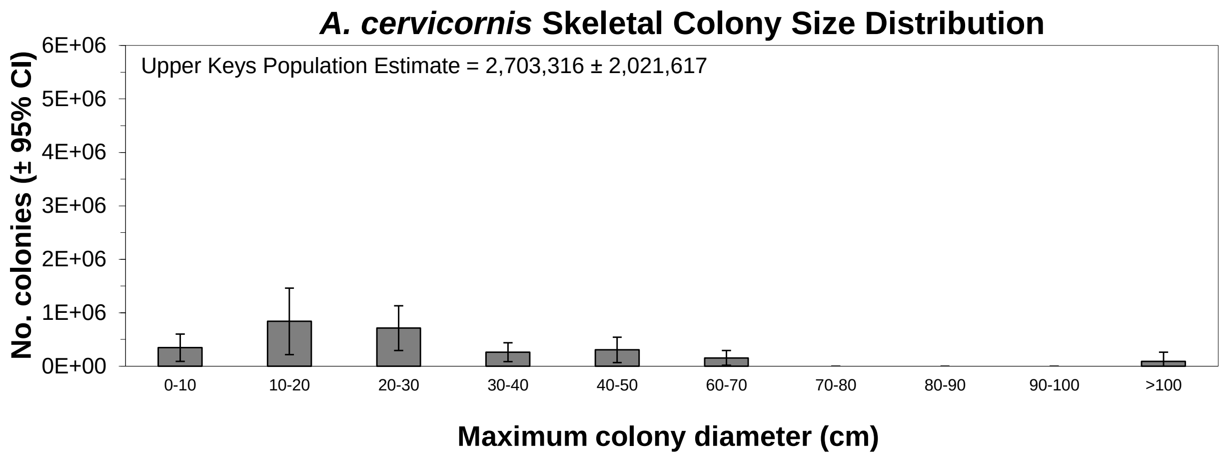


Figure 3-8. Abundance estimates (± 95% CI) of staghorn coral colonies (*Acropora cervicornis*) by maximum diameter of skeletal colonies (top) and by tissue surface area of physiologic colonies (bottom) in the upper Florida Keys (northern Key Largo to Alligator Reef). A physiologic colony is defined as a patch of contiguous live tissue, while a skeletal colony is defined as contiguous skeleton that may contain one or more physiologic colonies.



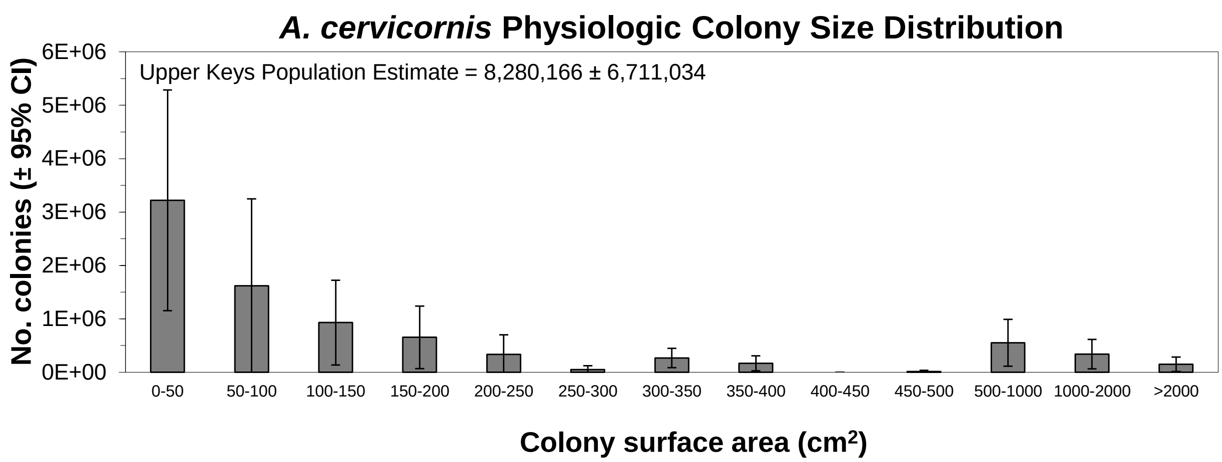
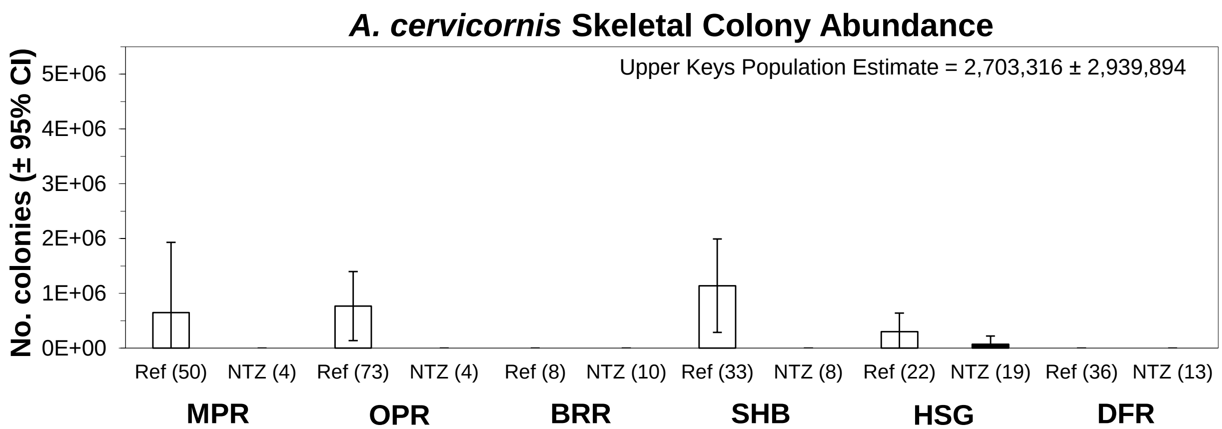


Figure 3-9. Abundance estimates (± 95% CI) of staghorn coral colonies (*Acropora cervicornis*) by habitat type and management zone for skeletal colonies (top) and physiologic colonies (bottom) in the upper Florida Keys (northern Key Largo to Alligator Reef). A physiologic colony is defined as a patch of contiguous live tissue, while a skeletal colony is defined as contiguous skeleton that may contain one or more physiologic colonies. Open bars = reference areas (Ref), filled bars = no-take zones (NTZ). Domain-wide (upper Keys) values are weighted averages and standard errors. Habitat abbreviations are: MPR = inshore and mid-channel patch reefs, OPR = offshore patch reefs, BRR = back-reef rubble, SHB = shallow (< 6 m) hard-bottom, HSG = high-relief and groove, and DFR = deeper (6-15 m) fore-reef habitats. Numbers in parentheses on the x-axis are the number of sites surveyed.



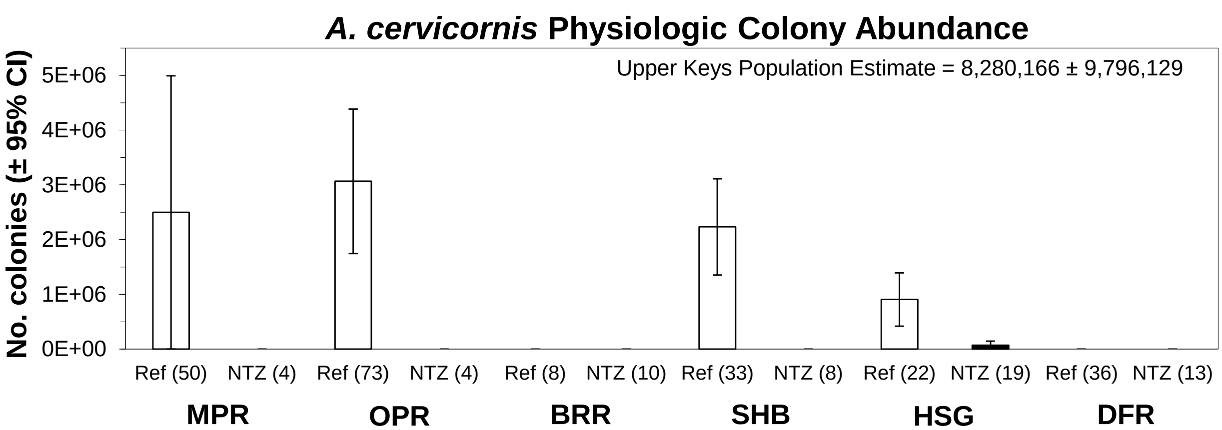


Figure 3-10. Examples of *Acropora palmata* in hard-bottom and coral reef habitats in the upper Florida Keys National Marine Sanctuary observed during May-September 2011.

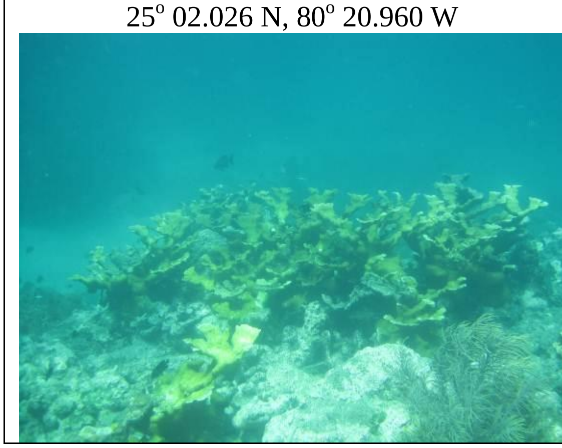
High-relief spur and groove, 1.2-3.0 m
Site #272, South Carysfort Reef
25° 12.517 N, 80° 13.158 W

High-relief spur and groove, 3.4-6.1 m
Site #273, Elbow Reef
25° 08.544 N, 80° 15.540 W

High-relief spur and groove, 5.2-7.0 m
Site #276, Molasses Reef
25° 00.591 N, 80° 22.426 W

High-relief spur and groove, 3.0-4.9 m
Site #277, Sand Island
25° 01.804 N, 80° 22.097 W

High-relief spur and groove, 4.9-8.5 m
Site #278, French Reef
25° 02.026 N, 80° 20.960 W



High-relief spur and groove, 1.8-4.0 m
Site #280, Grecian Rocks
25° 06.536 N, 80° 18.312 W

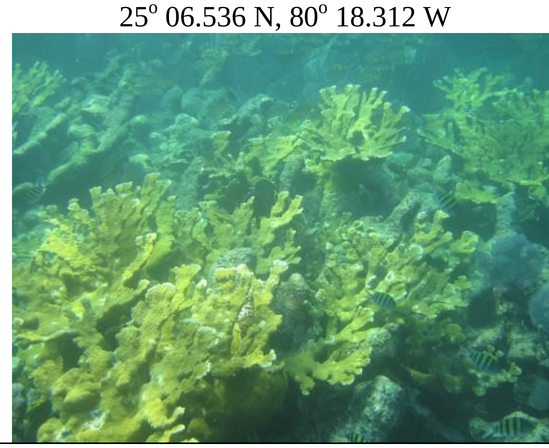


Figure 3-11. Densities (no. per m^2) of physiologic colonies of elkhorn coral (*Acropora palmata*) in the upper Florida Keys National Marine Sanctuary from the southern boundary of Biscayne National Park to Carysfort/S. Carysfort Reef surveyed during May-September 2011. A physiologic colony is defined as a patch of contiguous live tissue.

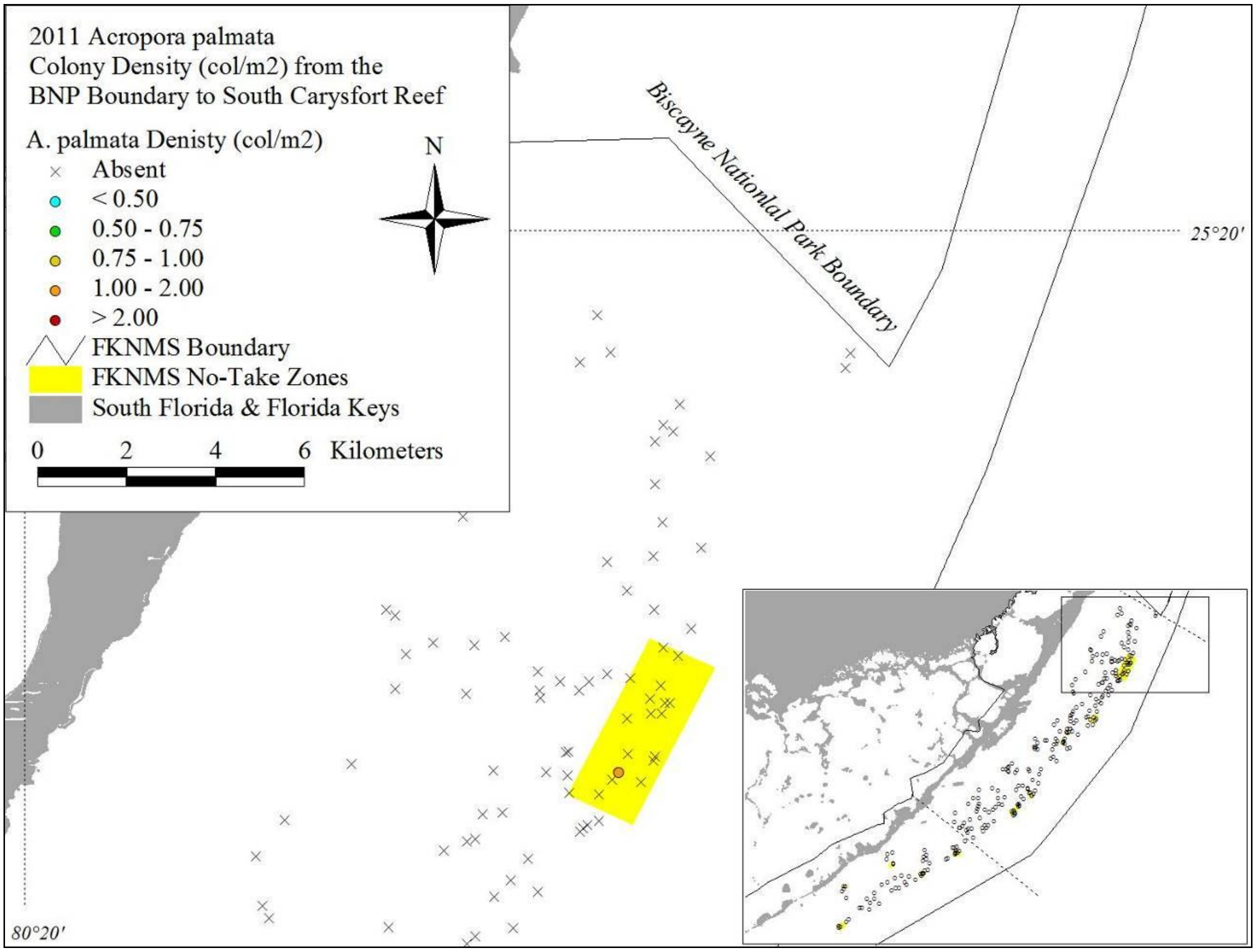


Figure 3-12. Densities (no. per m^2) of physiologic colonies of elkhorn coral (*Acropora palmata*) in the upper Florida Keys National Marine Sanctuary from Elbow Reef to Pickles Reef surveyed during May-September 2011. A physiologic colony is defined as a patch of contiguous live tissue.

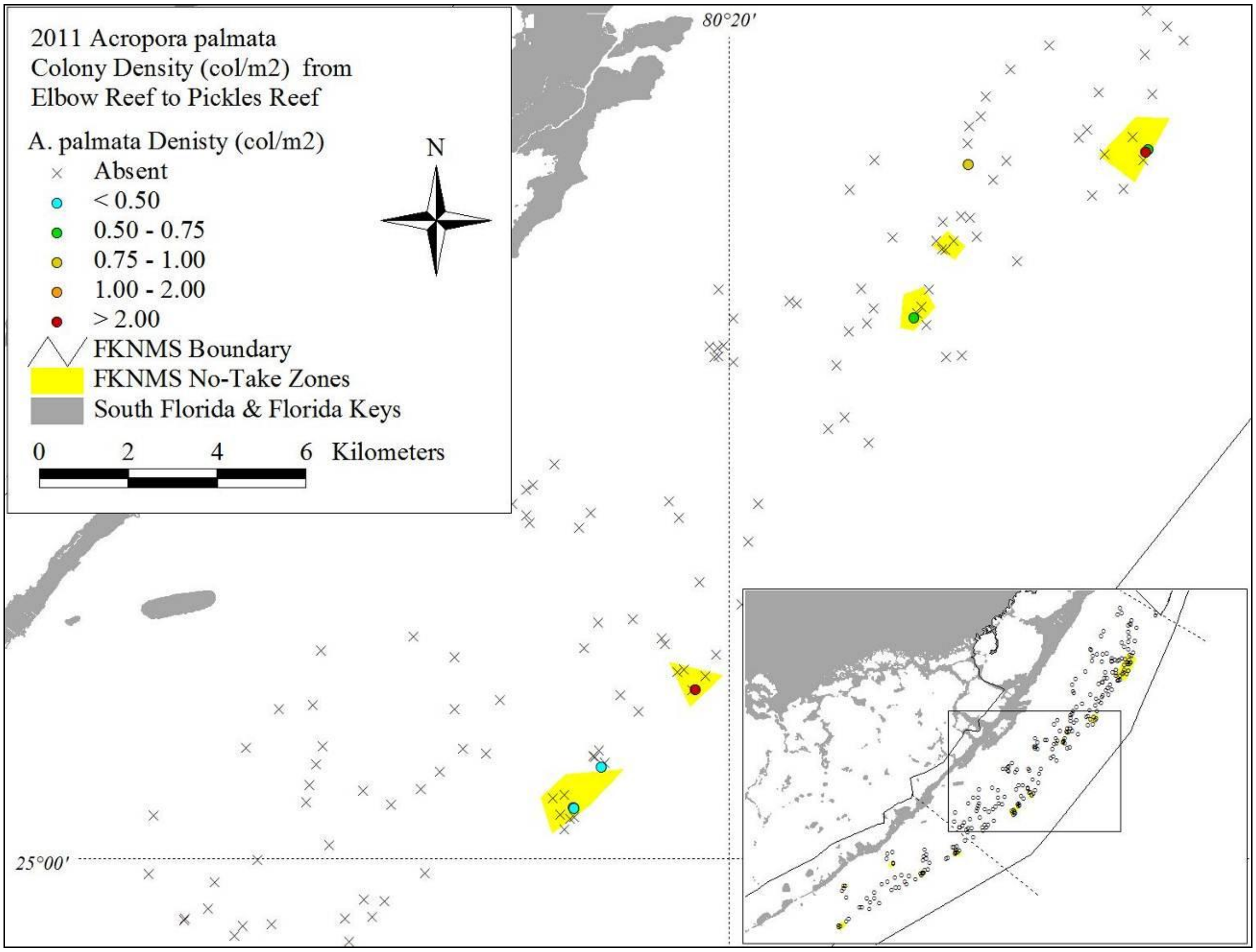


Figure 3-13. Densities (no. per m^2) of physiologic colonies of elkhorn coral (*Acropora palmata*) in the upper Florida Keys National Marine Sanctuary from Conch Reef to Alligator Reef surveyed during May-September 2011. A physiologic colony is defined as a patch of contiguous live tissue.

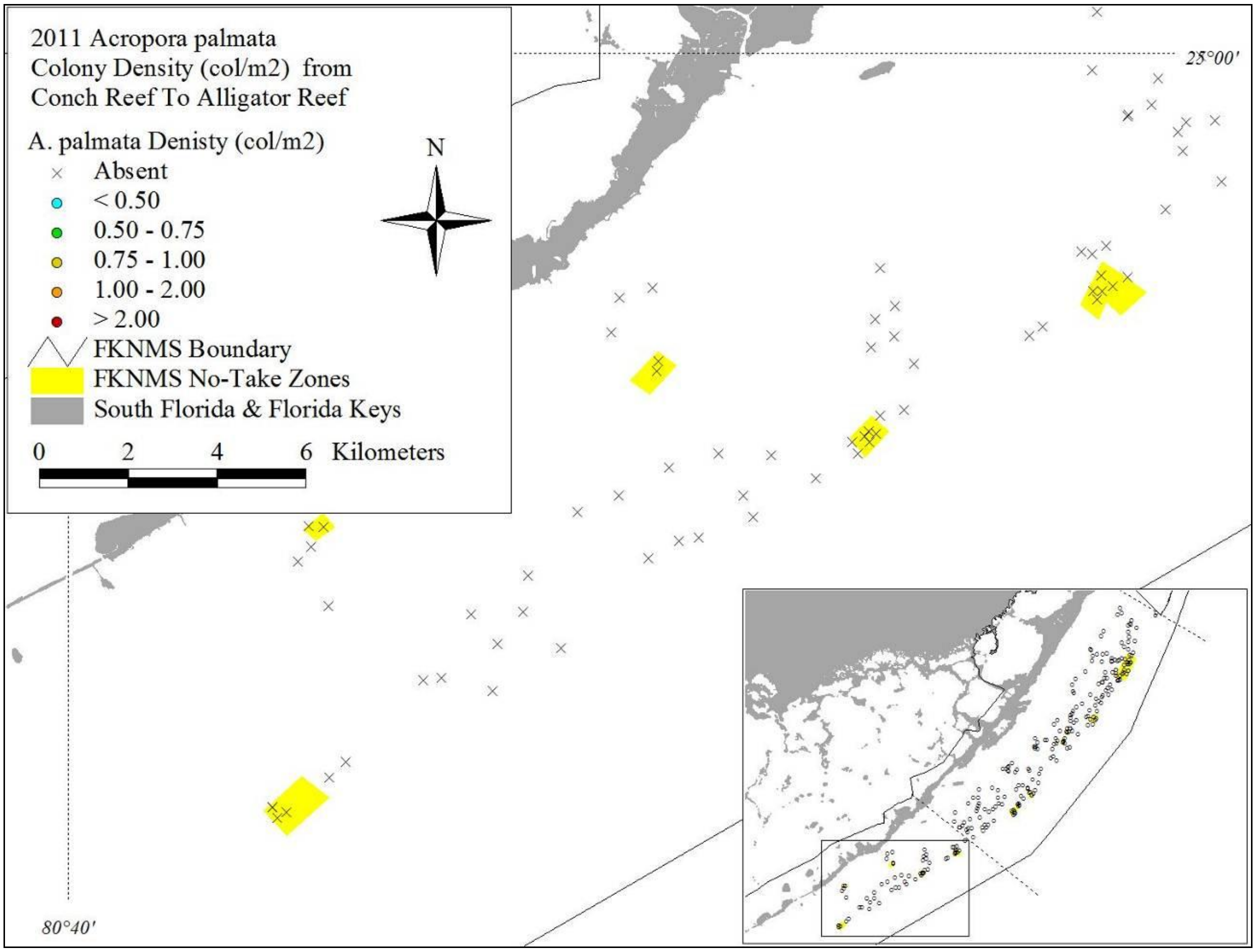
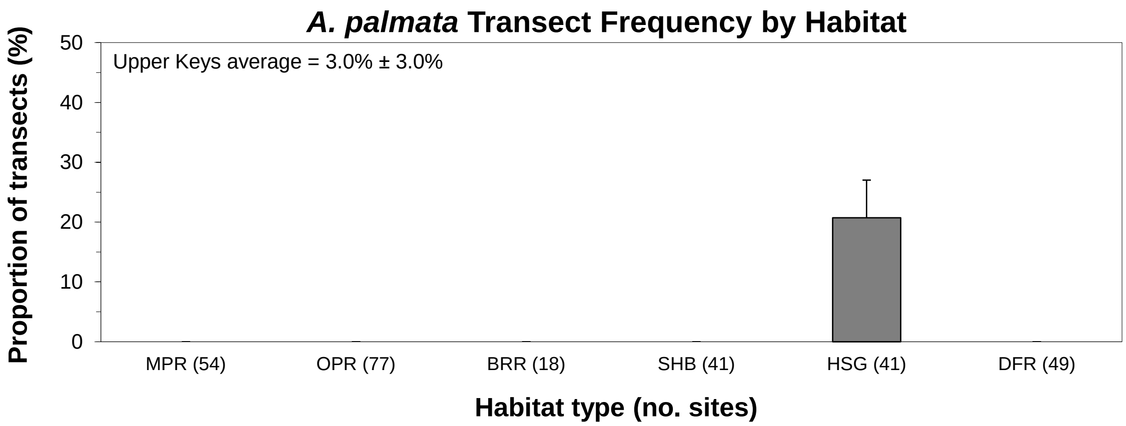
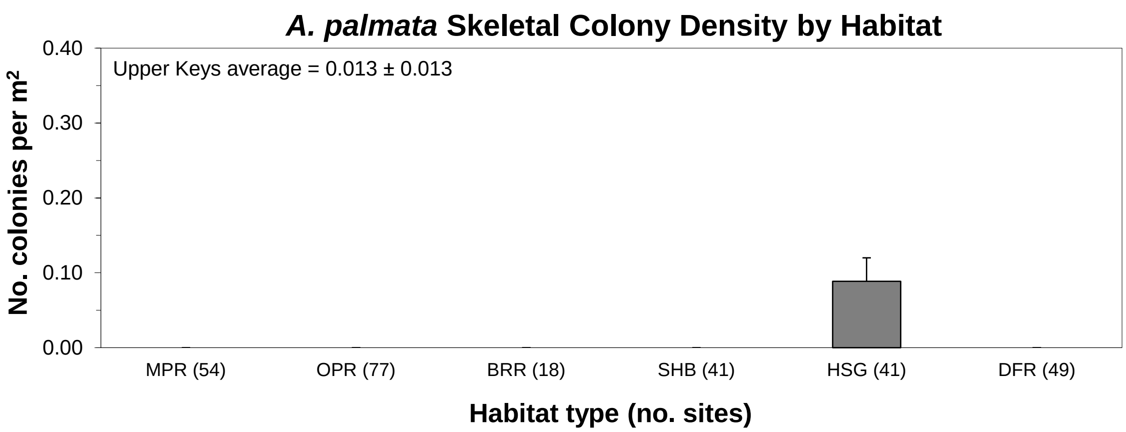


Figure 3-14. Mean (+ 1 SE) transect frequency (top), density (no. per m^2) of skeletal colonies (middle), and density (no. per m^2) of physiologic colonies of elkhorn coral (*Acropora palmata*) by habitat type in the upper Florida Keys, as determined from surveys of replicate 15-m x 1-m belt transects per site at 280 sites. Domain-wide (upper Keys) values are weighted averages and standard errors. Values on the x-axis in parentheses are the number of sites surveyed in each habitat type. A physiologic colony is defined as a patch of contiguous live tissue, while a skeletal colony is defined as contiguous skeleton that may contain one or more physiologic colonies.





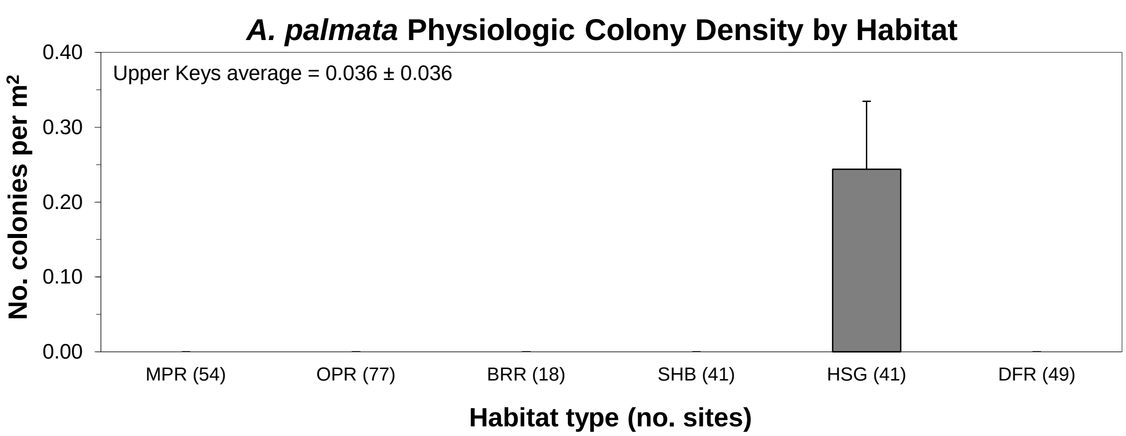
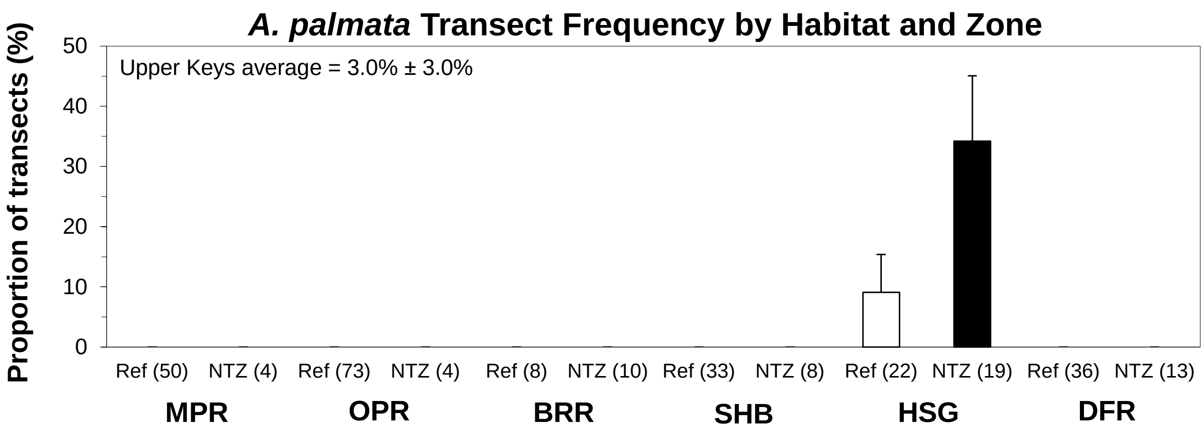
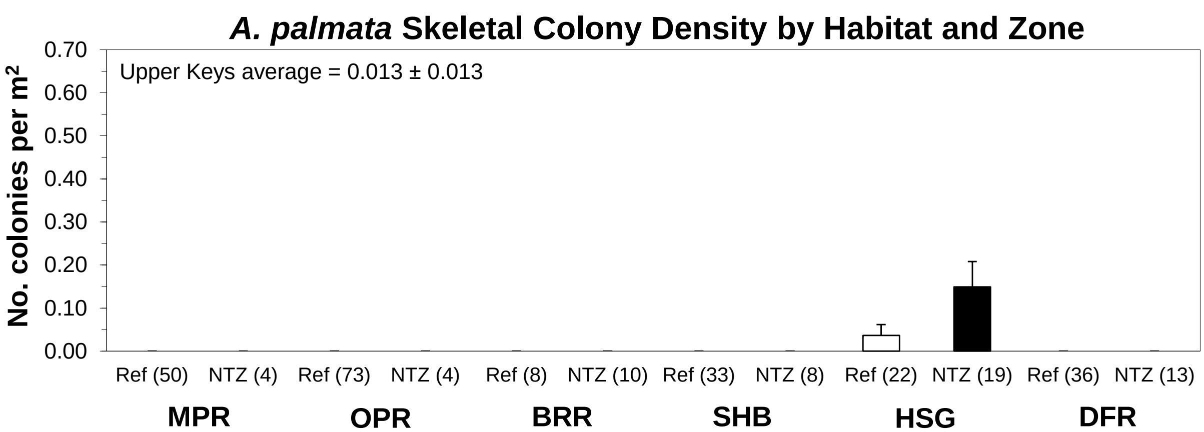


Figure 3-15. Mean (+ 1 SE) transect frequency (top), density (no. per m^2) of skeletal colonies (middle), and density (no. per m^2) of physiologic colonies of elkhorn coral (*Acropora palmata*) by habitat type and management zone in the upper Florida Keys. Open bars = reference areas (Ref), filled bars = no-take zones (NTZ). Domain-wide (upper Keys) values are weighted averages and standard errors. Habitat abbreviations are: MPR = inshore and mid-channel patch reefs, OPR = offshore patch reefs, BRR = back-reef rubble, SHB = shallow (< 6 m) hard-bottom, HSG = high-relief and groove, and DFR = deeper (6-15 m) fore-reef habitats. Numbers in parentheses on the x-axis are the number of sites surveyed.





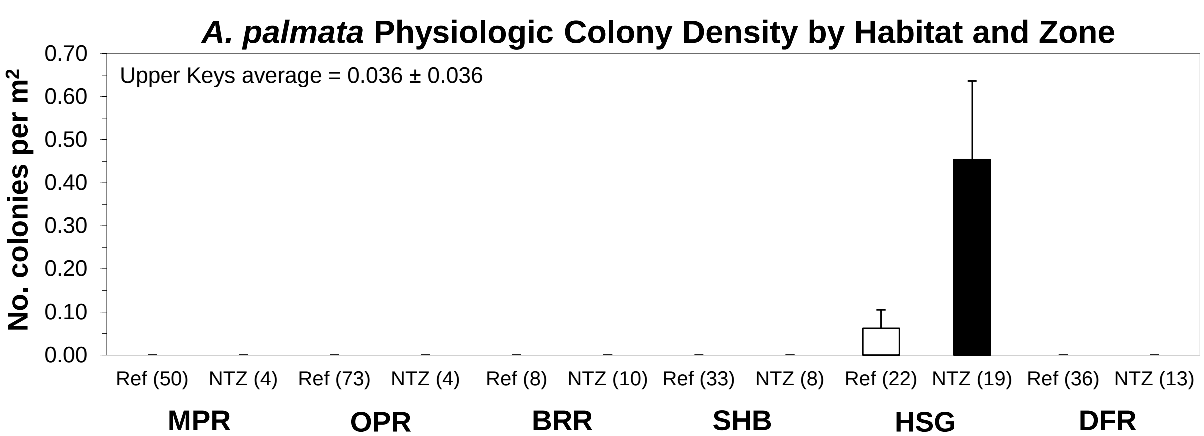
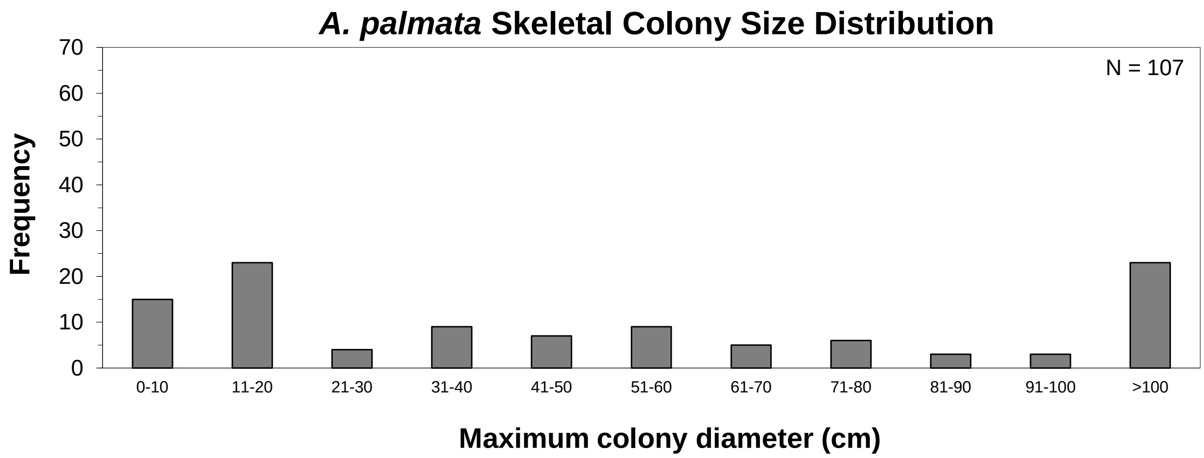


Figure 3-16. Size distribution of elkhorn coral (*Acropora palmata*) by maximum diameter of skeletal colonies (top) and by tissue surface area of physiologic colonies (bottom) in the upper Florida Keys (northern Key Largo to Alligator Reef). A physiologic colony was defined as a patch of contiguous live tissue, while a skeletal colony was defined as contiguous skeleton that may have contained one or more physiologic colonies. N = number of colonies measured.



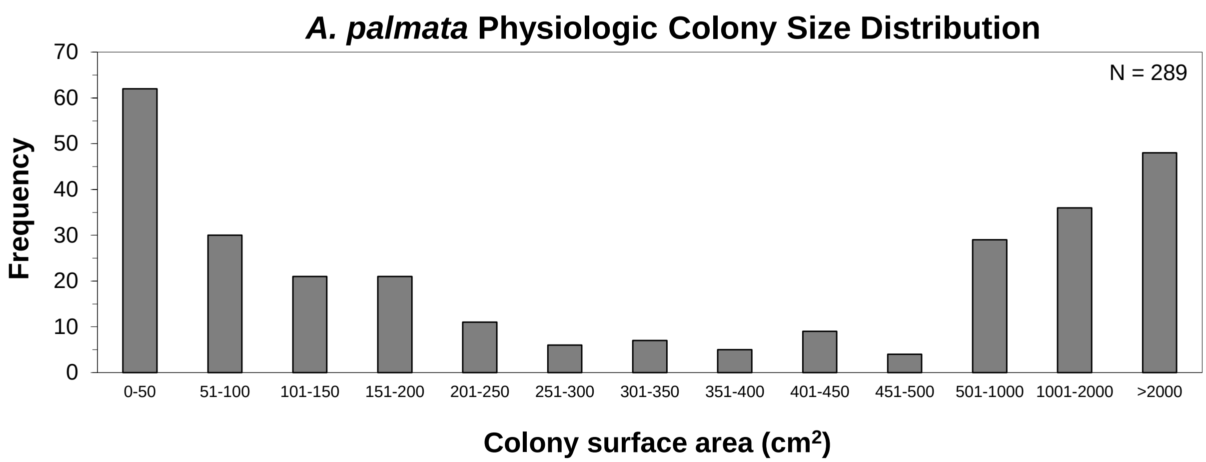


Table 3-1. Summary of habitat distribution, density, and size of *Acropora cervicornis* colonies (physiologic colonies) among habitat types and management zones in the upper Florida Keys, as determined from surveys of two replicate 15-m x 1-m belt transect surveys per site at 280 sites from northern Key Largo to Alligator Reef during May-September 2011. Physiologic colonies are patches of contiguous tissue. Habitat types are arranged from inshore to offshore and no-take zones represent Sanctuary Preservation Areas and Research Only areas. Values represent mean ± 1 SE, except for total surface area, which represent the combined live tissue area of all colonies (number of colonies measured in parentheses).

Habitat/management zone (no. sites)	**Site presence (%)**	**Transect frequency (%)**	**Colony density (no. per m^2)**	**Total surface area (cm^2)**	**Mean size (cm^2)**
Inshore and mid-channel patch reefs					
Reference areas (50)	2.0 ± 2.0	1.0 ± 1.0	0.018 ± 0.018	5,259 (27)	195
No-take zones (4)	0 ± 0	0 ± 0	0 ± 0	0 (0)	0 ± 0
Habitat total (54)	1.9 ± 1.9	0.9 ± 0.9	0.017 ± 0.017	5,259 (27)	195
Offshore patch reefs					
Reference areas (73)	12.3 ± 3.9	7.5 ± 2.5	0.044 ± 0.019	17,548 (96)	205 ± 53
No-take zones (4)	0 ± 0	0 ± 0	0 ± 0	0 (0)	0 ± 0
Habitat total (77)	11.7 ± 3.7	7.1 ± 2.4	0.042 ± 0.018	17,548 (96)	205 ± 53
Back-reef rubble					
Reference areas (8)	0 ± 0	0 ± 0	0 ± 0	0 (0)	0 ± 0
No-take zones (10)	0 ± 0	0 ± 0	0 ± 0	0 (0)	0 ± 0
Habitat total (18)	0 ± 0	0 ± 0	0 ± 0	0 (0)	0 ± 0
Shallow (< 6 m) hard-bottom					
Reference areas (33)	21.2 ± 7.2	15.2 ± 5.5	0.052 ± 0.021	17,238 (51)	410 ± 95
No-take zones (8)	0 ± 0	0 ± 0	0 ± 0	0 (0)	0 ± 0
Habitat total (41)	17.1 ± 5.9	12.2 ± 4.5	0.041 ± 0.017	17,238 (51)	410 ± 95
High-relief spur and groove					
Reference areas (22)	22.7 ± 9.1	18.2 ± 7.7	0.115 ± 0.065	9,716 (76)	115 ± 28
No-take zones (19)	5.3 ± 5.3	2.6 ± 2.6	0.011 ± 0.011	6,162 (6)	1,027
Habitat total (41)	14.6 ± 5.6	11.0 ± 4.5	0.067 ± 0.036	15,878 (82)	267 ± 154
Deeper fore reef					
Reference areas (36)	0 ± 0	0 ± 0	0 ± 0	0 (0)	0 ± 0
No-take zones (13)	0 ± 0	0 ± 0	0 ± 0	0 (0)	0 ± 0
Habitat total (49)	0 ± 0	0 ± 0	0 ± 0	0 (0)	0 ± 0

Table 3-2. Summary of habitat distribution, density, and size of *Acropora palmata* colonies (physiologic colonies) among habitat types and management zones in the upper Florida Keys, as determined from surveys of two replicate 15-m x 1-m belt transect surveys per site at 280 sites from northern Key Largo to Alligator Reef during May-September 2011. Physiologic colonies are patches of contiguous tissue. Habitat types are arranged from inshore to offshore and no-take zones represent Sanctuary Preservation Areas and Research Only areas. Values represent mean ± 1 SE, except for total surface area, which represent the combined live tissue area of all colonies (number of colonies measured in parentheses).

Habitat/management zone (no. sites)	**Site presence (%)**	**Transect frequency (%)**	**Colony density (no. per m^2)**	**Total surface area (cm^2)**	**Mean size (cm^2)**
Inshore and mid-channel patch reefs					
Reference areas (50)	0 ± 0	0 ± 0	0 ± 0	0 (0)	0 ± 0
No-take zones (4)	0 ± 0	0 ± 0	0 ± 0	0 (0)	0 ± 0
Habitat total (54)	0 ± 0	0 ± 0	0 ± 0	0 (0)	0 ± 0
Offshore patch reefs					
Reference areas (73)	0 ± 0	0 ± 0	0 ± 0	0 (0)	0 ± 0
No-take zones (4)	0 ± 0	0 ± 0	0 ± 0	0 (0)	0 ± 0
Habitat total (77)	0 ± 0	0 ± 0	0 ± 0	0 (0)	0 ± 0
Back-reef rubble					
Reference areas (8)	0 ± 0	0 ± 0	0 ± 0	0 (0)	0 ± 0
No-take zones (10)	0 ± 0	0 ± 0	0 ± 0	0 (0)	0 ± 0
Habitat total (18)	0 ± 0	0 ± 0	0 ± 0	0 (0)	0 ± 0
Shallow (< 6 m) hard-bottom					
Reference areas (33)	0 ± 0	0 ± 0	0 ± 0	0 (0)	0 ± 0
No-take zones (8)	0 ± 0	0 ± 0	0 ± 0	0 (0)	0 ± 0
Habitat total (41)	0 ± 0	0 ± 0	0 ± 0	0 (0)	0 ± 0
High-relief spur and groove					
Reference areas (22)	9.1 ± 6.3	9.1 ± 6.3	0.061 ± 0.045	40,335 (40)	1,371 ± 522
No-take zones (19)	36.8 ± 11.4	34.2 ± 10.9	0.454 ± 0.192	400,548 (259)	3,275 ± 1,630
Habitat total (41)	22.0 ± 6.5	20.7 ± 6.3	0.243 ± 0.096	440,883 (299)	2,852 ± 1,279
Deeper fore reef					
Reference areas (36)	0 ± 0	0 ± 0	0 ± 0	0 (0)	0 ± 0
No-take zones (13)	0 ± 0	0 ± 0	0 ± 0	0 (0)	0 ± 0
Habitat total (49)	0 ± 0	0 ± 0	0 ± 0	0 (0)	0 ± 0

IV. Abundance, Size, and Condition of Scleractinian Corals

Background

Benthic coral cover is a metric commonly used to measure the status and trends of coral reefs. However, cover is not a population metric. Instead, it is an emergent property that integrates density (number of organisms per unit area) and sizes of corals. While cover provides important information at the community level, it does not address significant process-based features of the reef system, nor does it allow for the scaling-up of samples to the larger study area. For example, similar cover estimates might be obtained from a reef with a few large corals or from one with many small colonies. The fates of these two reefs, so characterized, are likely to have quite different trajectories. Thus, as part of our long-term monitoring in the Florida Keys, we use a stratified sampling design to assess coral density, size (max. diameter), and condition to determine patterns in distribution and abundance (see Smith et al. 2011 and Swanson 2011). Using these data, we then derive population abundance estimates structured by species and size based upon: habitat type (cross-shelf position and depth), geographic region (along-shelf position), and management zone (inside and outside of FKNMS no-take zones). The 2011 program was similar to 1999-2001, 2005, and 2009 field surveys, except that we were limited in 2011 to the geographic area between the southern boundary of Biscayne National Park (northern Key Largo) to Alligator Reef offshore of Islamorada. Assessments of coral condition included percent live tissue vs. dead skeleton, bleaching, disease, predation, overgrowth, and presence of clionid sponges. Figure 4-1 provides representative examples of some of the larger coral species surveyed.

Field Sampling Methods and Data Analysis

Field methodology

At each of the 280 sites visited during 2011, two replicate 10-m x 1-m belt transects were surveyed for all scleractinian (Cnidaria, Anthozoa, Scleractinia) coral species. Each colony greater than 4 cm in maximum diameter was identified, measured, and assessed for condition (e.g. mortality, bleaching, disease, predation, overgrowth). For previous sample intervals we also measured coral recruitment, but this is a relatively time intensive effort, so we omitted the metric in 2011. We intend to include recruitment in our 2012 Keys-wide effort. All scleractinian colonies located within the belt transect were included in the survey, even if a portion of the colony extended outside of the boundaries of the belt transect. Individual colonies were identified as continuous skeletal units, regardless of whether the skeletal unit contained multiple patches of separate live tissue. Only colonies containing live tissue were included in the survey. The size and condition of the colonies were recorded on PVC slates using the following codes:

Code	Max Diameter (cm)	Code	Disease Condition	Code	Overgrowth Condition
0	0 to 4 cm	NODZ	No disease	NOG	No overgrowth
1	4 to 10 cm	BBDZ	Black band	AOG	Algae
2	10 to 20 cm	RBDZ	Red band	BOG	Bryozoans
3	20 to 30 cm	WBDZ	White band	COG	Corals
4	30 to 40 cm	YBDZ	Yellow band	GOG	Gorgonians
5	40 to 50 cm	WPII	White plague type 2	MOG	*Millepora*
6	50 to 60 cm	WPOX	White pox	POG	*Palythoa*
7	60 to 70 cm	DKSP	Dark spot	SOG	Sponges
8	70 to 80 cm	NECR	Necrosis	TOG	Tunicates
9	80 to 90 cm	UNKD	Unknown	ZOG	Zoanthids
↓	↓			UOG	Unknown

Code	Mortality Condition	Code	Bleaching Condition	Code	Other Condition
A	0-20% dead	NOBL	No bleaching	NOTH	No other mortality
B	20-40% dead	PPAL	Partly pale	ABRA	Abrasion
C	40-60% dead	PALE	Pale	CLIO	*Cliona* spp.
D	60-80% dead	PBLC	Partly bleached	DAMS	Damselfish
F	80-100% dead	BLCH	Bleached	FISH	Fish bites/scrapes
		MOTT	Mottled	GAST	Gastropod feeding
				UNKM	Unknown

Colony size was recorded using 10-cm incremental classes, to facilitate rapid assessment. Size class 0 was used to record the maximum diameter of species that have a small maximum size, such as *Favia fragum* and *Scolymia* spp., which would otherwise be excluded due to the overall adult (non-juvenile) size class lower-limit of 4 cm. There is no upper limit imposed on the maximum diameter size classes. Mortality was recorded using 20% incremental classes and included visual estimates of recent and long-term tissue death.

Each colony was also assessed for condition. Any colonies with lighter tissue coloration than normal were assessed for bleaching. Partially pale and pale colonies were not included in the bleaching data analyses, although their condition was recorded. Mottling, or small patterns of light and dark discolorations often found on colonies of *Siderastrea siderea*, was also recorded, but not included in the bleaching data analyses. Only disease conditions that were actively causing tissue death or lesions on a colony were recorded. If a colony showed signs of a disease that could not be clearly identified, the condition was recorded as unknown disease. If a colony contained patches of necrotic issue with no identifiable cause, it was recorded as necrosis. Dark-spot condition/syndrome was recorded as a disease, even though it does not typically result in lesions or rapid tissue death. Overgrowth of coral tissue by another organism (e.g. algae, sponges, gorgonians, *Palythoa*, and other corals) was noted only if overgrowth by the organism was clearly causing tissue death or lesions. Overgrowth of organisms onto dead portions of a colony was not recorded, nor was overgrowth or shading of live tissue with no resulting lesions or tissue death.

Physical impacts, such a sediment scour, contact with other organisms, and fishing gear damage (e.g. trap rope abrasion) were recorded as abrasion. The presence of boring sponges such as *Cliona delitrix* was recorded if a sponge was actively causing tissue death lesions, but was not recorded if a sponge was only visible on dead portions of a colony. The presence of damselfish nests or gardens was recorded whenever they were found adjacent to, or surrounded by, live tissue. Likewise, fish bites/scrapes were only recorded if they were found on live tissue. Whenever gastropods were observed on a coral colony, the identity and total length of each individual was noted, regardless of whether the gastropods were actively feeding on live coral tissue. However, only gastropods actively feeding on live coral tissue were recorded as a mortality condition. Apparent gastropod feeding scars with no gastropods present was recorded as unknown mortality. Any tissue death that could not be attributed to disease, abrasion, boring sponges, or predation was also recorded as unknown mortality.

Statistical analyses

A two-stage sampling design following Cochran (1977) and Smith et al. (2011) was employed. Using this two-stage design, 200-m by 200-m grid cells on bathymetry and benthic habitat maps of the Florida Keys are used to help allocate targeted coral reef and hard-bottom habitats. Grid cells are designated as primary sample units (sites), while second-stage sample units (stations) are defined as 10-m x 1-m belt transects; two stations were sampled at each site. Coral density and abundance calculations were based upon the number of corals recorded within the stations (i.e. within each of the 10-m x 1-m belt transects). First, coral density (no. colonies per m^2) was calculated for each station. Next, mean coral density and variance were calculated for each site, using the coral densities of the two stations. The mean site-level coral densities and variances were then used to calculate mean stratum-level (habitat, management zones, and habitat by management zone) coral densities and variances. Finally, stratum-level and domain abundance estimates were calculated based upon the stratum-level coral densities and variances, as well as the proportional areas of each stratum within the domain (Smith et al. 2011).

Statistical comparisons of stratum-level mean colony densities and abundances were made among habitat types, between protected zones and reference areas, and among habitat types within protected zones and references areas. Statistical comparisons of means were conducted by calculating confidence intervals (CI) based on the equation CI = mean $\pm$ t[α, df] *standard error, with standard errors estimated by the two-stage, stratified design (Cochran 1977; Smith et al. 2011). Confidence intervals were adjusted for multiple comparisons using the Bonferroni procedure (Miller 1981). While this adjustment made for relatively conservative statistical testing, it reduced the probability of spurious significant pair-wise comparisons. The experiment-wise error rate was held at $\alpha = 0.05$ and the comparison-wise error rate was adjusted based on the number of multiple comparisons (comparison-wise error rate = α /c, where c = k (k-1)/2). For example, if an alpha-level of 0.05 was used to test for differences in mean coral densities among six habitat types (k = 6), then the alpha level was adjusted by dividing 0.05 by 15 to yield an adjusted alpha of 0.0033.

2011 Survey Results

We are primarily interested in describing factors affecting the distribution and abundance of coral reef organisms in the Florida Keys, with management zones embedded in our stratified sample design that includes habitat types and geographic regions. The results discussed below are divided into two main sections to address: 1) overall sampling effort for scleractinian corals and their condition and 2) patterns in distribution, density, abundance, and size by habitat type and management zone.

1. Overall sampling effort for scleractinian corals and their condition

Table 4-1 summarizes the sampling effort for scleractinian corals at 280 upper Florida Keys sites surveyed during May-September 2011 by habitat type and management zone. A total of 560 belt transects (10-m x 1-m) were surveyed for corals. Also provided in Table 4-1 are the total areas of the habitats surveyed. This is important for two reasons as it pertains to the results below. First, the 2011 benthic sampling was optimized for *Acropora* corals (see Section 3), whose distribution patterns, especially *A. palmata*, are different than the more abundant coral species in the Florida Keys. Secondly, the abundance estimates presented herein reflect density AND habitat areas, so a given habitat with a lower density of an organism, but comprising a larger area, might yield a greater total number of organisms than a higher density, smaller habitat area. It is also worth noting the relatively small amount of area contained within the FKNMS zones (5.8% of the total area for the six habitats sampled), which dramatically affects abundance estimates.

There is a pool of approximately 51 common reef-associated coral taxa (species, forms, and subspecies) that occur in the wider Caribbean, most of which also occur in the Florida Keys that we therefore target in our benthic surveys. The more cryptic, solitary ahermatypic species are generally not encountered. During

2011, we recorded 40 taxa, including the three subspecies of *Porites porites*. A total of 19,716 corals were counted among these taxa (Table 4-1). Note that more species were encountered in reference areas compared to no-take zones. This reflects two things: the fewer number of sites allocated to the no-take zones and not optimizing transect number or length for species richness in the no-take zones.

Table 4-2 summarizes site presence, transect frequency, abundance estimates, and relative abundance by species for all sites and for all of the coral species encountered during 2011. Six species were encountered at more than 65% of the 280 sites visited: *Siderastrea siderea* (89.3%), *Porites astreoides* (85.0%), *P. porites porites* (83.6%), *Agaricia agaricites* (70.0%), *S. radians* (67.1%), and *Dichocoenia stokesi* (65.7%). These same six species were also the most frequently encountered and comprised about 82% of all of the corals from the sampled habitats (Table 4-2). Figure 4-2 shows the rank-order abundance of all scleractinian corals surveyed for all sites. Five species combined represented about 80% of all corals surveyed: *S. siderea* (5,303 colonies, 26.9%), *P. astreoides* (4,087 colonies, 20.7%), *A. agaricites* (2,821 colonies, 14.3%), *P. porites porites* (2,699 colonies, 13.7%), and *P. porites furcata* (899 colonies, 4.6%). It is worth noting that all but one of the most abundant species are brooding corals. An additional seven coral species were relatively uncommon (1.0-3.6% of all corals), while the remaining 28 taxa were rare (< 1% of all corals surveyed), mostly represented by either larger, broadcast spawning corals (e.g. *Diploria strigosa*), or small, understory species that were probably never abundant (e.g. *Mussa angulosa*).

Table 4-3 summarizes the size distribution and relative abundance of size classes for the 20 most common coral species (~99% of all corals) for all habitats sampled. Nearly 80% of the 19,415 corals shown in Table 4-3 were 4-20 cm in maximum diameter. Of course, this overall value represents many coral species that differ in maximum colony size attainable. So, for example, it is not surprising that most lettuce corals (*Agaricia agaricites*), golf-ball corals (*Favia fragum*), and lesser starlet corals (*Siderastrea radians*) were mostly comprised of smaller colonies. For many, but not all of the massive and previously abundant branching coral species, smaller skeletal colony sizes currently predominate. For example, none of the staghorn coral (*Acropora cervicornis*) colonies encountered were larger than 60 cm in maximum diameter (Table 4-3). A similar pattern was evident for *Diploria labyrinthiformis*, *Montastraea cavernosa*, *S. siderea*, and *Stephanocoenia michelinii*, where less than 7% of all colonies exceeded 60 cm in maximum diameter. However, larger colonies of some species such as *Acropora palmata*, *Colpophyllia natans*, *Diploria clivosa*, *M. annularis*, and *M. faveolata* were relatively abundant (Table 4-3).

Condition metrics for all coral species encountered in the upper Keys are summarized in Table 4-4, including bleaching, disease, *Cliona* sponges, *Coralliophila* grazing, and active overgrowth. The numbers presented in Table 4-4 reflect colony abundance and prevalence of different conditions; therefore, these estimates take into account density and habitat area. Overall, 7% of all corals in the upper Keys were experiencing bleaching, disease, clionid sponge boring, snail grazing, or overgrowth by other organisms, with active overgrowth (3.1%) and bleaching (1.5%) the most prevalent of the conditions. Disease prevalence was relatively low (0.8% of all corals), but low prevalence numbers can have dramatic impacts on populations, depending on incidence and mortality rates. Few data are available on disease incidence and mortality for corals, but disease has obviously and dramatically affected some coral species (e.g. white-band disease in *Acropora palmata*, and *A. cervicornis*). For the top five most abundant species, active disease prevalence was low for *Siderastrea siderea* (0.7%), *Porites astreoides* (< 0.1%), *Agaricia agaricites* (1.9%), *P. porites furcata* (< 0.1%), and absent in *P. porites porites*. Of the 138 instances of disease observed in the belt transect surveys, 128 (92.7%) were dark-spot condition, three (2.2%) were black-band disease, and seven (5.1%) were unidentified disease-like symptoms. For the top five most abundant species, active bleaching was present on 1.5% of *S. siderea*, 0.1% of *P. astreoides*, 1.6% of *A. agaricites*, 2.2% of *P. porites porites*, and 7.8% of *P. porites furcata*. Although slightly pale, partly pale, and mottled conditions were noted whenever these conditions were observed, only partly bleached or fully bleached colonies were included in the bleaching condition analyses.

Clionid sponges such as *Cliona delitrix* were observed most often on larger coral colonies, especially *Acropora palmata*, *Colpophyllia natans*, *Diploria clivosa*, *D. labyrinthiformis*, *Montastraea annularis*, *M. cavernosa*, *M. faveolata*, and *Siderastrea siderea*. Overgrowth most commonly affected branching corals, such as the *Porites porites* species complex (4.4% to 5.55% of colonies) and *A. cervicornis* (3.3% of colonies). However, some of the more abundant mounding corals, such as *P. astreoides*, *S. siderea*, and *Stephanocoenia michelinii* were also prone to overgrowth. Of the 626 instances of overgrowth observed, nearly half (304 or 48.6%) were sponge overgrowth and nearly one-third (186, 29.7%) were algal overgrowth. Encrusting gorgonians (e.g. *Briareum asbestinum* and *Erythropodium caribaeorum*), *Millepora*, and *Palythoa* comprised most of the remaining overgrowth observations. Snail predation, specifically by corallivorous gastropods (*Coralliophila* spp.), was most often observed on *D. clivosa* (4.7%), *M. faveolata* (3.3%), *A. agaricites* (2.9%), *C. natans* (2.4%), and *D. labyrinthiformis* (1.6%); however, gastropods were also observed feeding on an addition eight coral species (Table 4-4).

2. Patterns in coral distribution, density, abundance, and size by habitat and management zone

Habitat-related patterns in distribution, density, and abundance were evident for many of the coral species surveyed during 2011 in the upper Keys. Table 4-5 summarizes the site presence, transect frequency, and relative abundance of all scleractinian corals among the habitats surveyed. Density and abundance values by habitat and management zone are provided for the more common corals (> 10% relative abundance) below. Abundance estimates for *Acropora palmata* and *A. cervicornis* in this chapter differ somewhat from results in Chapter 3 because they are based on replicate 10 m x 1 m transects used for the coral measurements. Chapter 3 results are based on replicate 15 m x 1 m transects, which were optimized for *Acropora* sampling. *Porites astreoides* and *Siderastrea siderea* dominated the coral fauna on inshore and mid-channel patch reefs, while these two species, together with *Agaricia agaricites* and *P. porites*, were dominant on offshore patch reefs and shallow hard-bottom. These four species were also the most abundant corals on inner line reef tract/high-relief spur and groove, as well as deeper fore-reef habitats.

Tables 4-6 and 4-7 summarize statistical differences in mean transect frequency, mean colony density, and total colony abundance for the 20 most abundant species and for all species combined among habitats and between no-take zones and reference areas by habitat type. In terms of among-habitat differences, the first two evident among the habitat types sampled were the lower transect frequency of occurrence and mean colony density for most species in the back-reef rubble habitat (Table 4-6). Back-reef rubble was sampled in 2011 mostly because *Acropora* corals have been encountered in years past and because this habitat type is important for urchin recruitment. The third major pattern is the importance of the patch reef environment for many species. Figures 4-3 to 4-5 illustrate cross-shelf patterns in total scleractinian coral density for the upper Keys study area. Evident from these density distribution maps are the relatively high total densities of corals in the patch reef environment encompassing inshore, mid-channel (including banks such as Mosquito Bank), and offshore patch reef sites. Also evident is the importance of patch reef habitats in terms of total colony abundance for most species; this pattern reflects relatively high densities for many species and the relatively large area of these habitats (see Table 4-1) in the upper Keys. Table 4-8 summarizes patterns in total scleractinian density and abundance by habitat type. Mean densities were greatest on mid-channel and offshore patch reefs, followed by high-relief spur and groove. Note that abundance estimates were also greater on mid-channel and offshore patch reefs, as well as the deeper fore reef due to the large area of habitat available.

Habitat- and management zone-related distribution, density, and abundance patterns by species are provided in a series of tables and figures to highlight some of the results for the top ten most abundant corals, as these species represented 93% of all of the corals surveyed during 2011. Tables 4-9 to 4-18 provide transect frequency, density, and density by size class by habitat and management zone, while Figures 4-6 to 4-15 illustrate patterns in transect frequency, density, and abundance by habitat type. Table 4-7 lists the significant differences in mean transect frequency, density, and abundance estimates for the top 20 species between no-take zones and reference areas by habitat type. It is important to note that the no-take zones were initially established to address the need to manage multiple user groups in areas that were considered among the best for coral cover and diversity, and also for fishing. Thus, differences between no-take zones and reference sites reflect this initial site-selection bias. The no-take zones, while designed to protect habitat, were generally not considered large enough to achieve improved benthic condition based on no-take protection. Indeed, the relationship between no-take protection and changes to the benthos remains an active area of research. Thus, results from 2011 are best interpreted relative to results from our sampling in 1999-2001, 2005, and 2009 (Swanson 2011). We are currently analyzing temporal trends in our data to evaluate potential changes in the no-take zones relative to areas outside of the zones.

An example comparison of habitat- and management zone-related patterns is briefly summarized here for two species: *Siderastrea siderea* and *Montastraea faveolata*. *S. siderea* was the most common coral in the upper Keys and exhibited some of the highest densities of any coral in the habitats surveyed (Table 4-9, Figure 4-6). *M. faveolata* was also broadly distributed among habitats, but had lower densities, yet a greater proportion of larger colony sizes (Table 4-18, Figure 4-15). Both species are massive, reef-building corals that are broadcast spawners. *S. siderea* was encountered in all of the habitats surveyed during 2011 and was particularly common on inshore and mid-channel patch reefs and least common in back-reef rubble (Figure 4-6, top). Similarly, *M. faveolata* was most frequently encountered on mid-channel and offshore patch reefs, albeit at lower frequencies than *S. siderea* (Figure 4-15, top). Mean densities of both species were greatest on mid-channel and offshore patch reefs. Mean densities of larger (> 60 cm) colonies of both species were also four times greater or more on mid-channel patch reefs (Tables 4-9 and 4-18). Abundance estimates for both *S. siderea* (Figure 4-6) and *M. faveolata* (Figure 4-15) illustrate the relative large proportion of colonies of each species found on mid-channel patch reefs, although overall abundance estimates for *S. siderea* are approximately 20 times greater. Between no-take zones and reference areas, the only significant difference in mean transect frequency of occurrence of *S. siderea* was a greater mean value in no-take zones (Figure 4-16), although frequencies in other habitats tended to be greater in no-take zones (Table 4-9). *M. faveolata* was more frequently encountered in mid-channel patch reef no-take zones (i.e. Hen and Chickens SPA and Cheeca Rocks SPA), but transect frequencies were generally greater in reference areas for other habitats (Figure 4-25 and Table 4-18). Mean colony density for *S. siderea* was greater in reference offshore patch reefs and high-relief spur and groove compared to corresponding no-take zones (Figure 4-16). Densities of 20-60 cm and 60-100 cm size colonies were greater in mid-channel patch reef zones, but the opposite was true in the high-relief spur and groove habitat (Table 4-9). On mid-channel patch reefs, mean density of *M. faveolata* was significantly greater in no-take zones (Figure 4-25, middle), but was either similar or greater in reference areas, but not significantly so, for other habitats (Table 4-18). Finally, comparisons of colony abundance, reflecting density and habitat area, for both *S. siderea* (Figure 4-16) and M. faveolata (Figure 4-25) illustrate the importance of the patch reef habitat, especially inshore and mid-channel patch reefs, as well as the relatively large proportion of total colonies that are in reference areas. This latter result is not surprising, for although mid-channel patch reef zones in the upper Keys (Hen and Chickens SPA and Cheeca Rocks SPA) support greater densities of larger colonies of many corals, the total area of these sites is very small compared to reference areas (Table 4-1).

As a final illustrative example of differences between no-take zones and reference areas, Figures 4-26 to 4-29 show colony abundances by size classes (max. diameter) in three habitats for four of the top ten most abundant species, all which are massive reef framework builders: *Siderastrea siderea*, *Stephanocoenia michelinii*, *Montastraea cavernosa*, and *M. faveolata*. For all four species, although colony abundances were greater in reference areas compared to no-take zones, there were differences in size structure. While *S. siderea* was dominated by smaller (4-20 cm) colonies among these three habitats, there was a greater abundance and proportion of larger colonies (> 20 cm) on inshore and mid-channel patch reefs (Figure 4-26). A somewhat similar pattern was evident for *S. michelinii* (Figure 4-27); however, deeper fore-reef habitats support nearly as many colonies as mid-channel patch reefs. The pattern for *M. cavernosa* is different from these other species in two ways (Figure 4-28). First, although mid-channel patch reefs and the deeper fore-reef have the most number of colonies, there is a greater abundance and proportion of larger (> 20 cm) colonies, especially in the 20-60 cm size class. *M. faveolata* shows the most distinctive pattern in abundance by size among these habitats (Figure 4-29). For all three habitats, there are greater proportions of larger size classes, especially for colonies > 60 cm. *M. faveolata* also had the greatest abundances of the largest size class (> 100 cm), especially in the mid-channel patch reef habitat.

Discussion

Coral density, size, and condition surveys conducted in the upper Florida Keys during 2011 provide a snapshot of the status of coral assemblages over a large section of the Florida Reef Tract. Most of the reef-building (hermatypic) and reef-associated coral species known to occur in the Florida Keys were encountered during the 2011 surveys. Similar to earlier surveys, most colonies encountered were represented by ten coral species and these corals typically had the greatest site presence, transect frequency of occurrence, and density for most of the habitat types sampled. Other species were somewhat common and usually abundant in particular habitats, while others were rare. Prevalence of adverse colony conditions such as bleaching, disease, predation, and overgrowth were relatively low (< 2%) for most species. Abundance estimates indicate a very large number of corals in the upper Keys (> 1 billion), despite the fact that we did not sample the deeper fore-reef beyond 15-m depth in 2011, which supports a high-diversity, high-density coral assemblage along most of the reef tract.

Distribution, density, and abundance patterns for many corals illustrate the importance of the patch reef environment, a pattern our program and others continue to document. For the massive framework-building species, patch reefs support greater numbers of species, colony densities, and because of the presence of several thousand patch reefs, the greatest proportion of total colonies for the habitats surveyed in 2011. Most corals in the patch reef environment fall outside of existing FKNMS no-take zones.

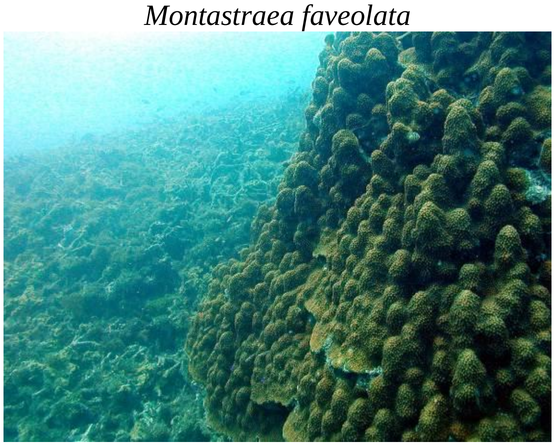
Finally, the high-relief spur and groove habitat, noted for the historically high abundances of *Acropora* corals, especially elkhorn coral, are dominated by a coral assemblage consisting of smaller, brooding species such as *Agaricia agaricites* and *Porites astreoides*. Thickets of elkhorn coral only persist at a few reefs in the upper Keys. The lack of larger, hermatypic (reef-building) coral species at many spur and grooves has implications for the long-term persistence of this habitat in lieu physical weathering, bioerosion, and rising sea level.

Figure 4-1. Examples of larger scleractinian coral species surveyed for distribution, density, size, and condition in the Florida Keys during 2011.

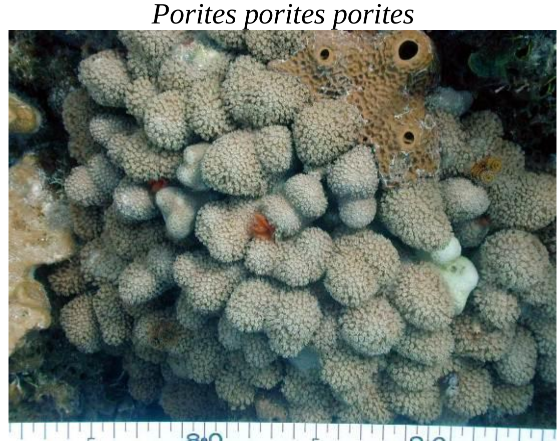
Colpophyllia natans

Dendrogyra cylindrus

Montastraea faveolata



Porites porites porites



Siderastrea siderea

Solanastrea bournoni

Figure 4-2. Rank-order abundance of scleractinian coral species (> 4 cm max. diameter) surveyed at 280 sites in the upper Florida Keys during May-September 2011. Data include colony counts from all sites and habitats combined. A total of 19,697 colonies among 37 coral taxa were surveyed.

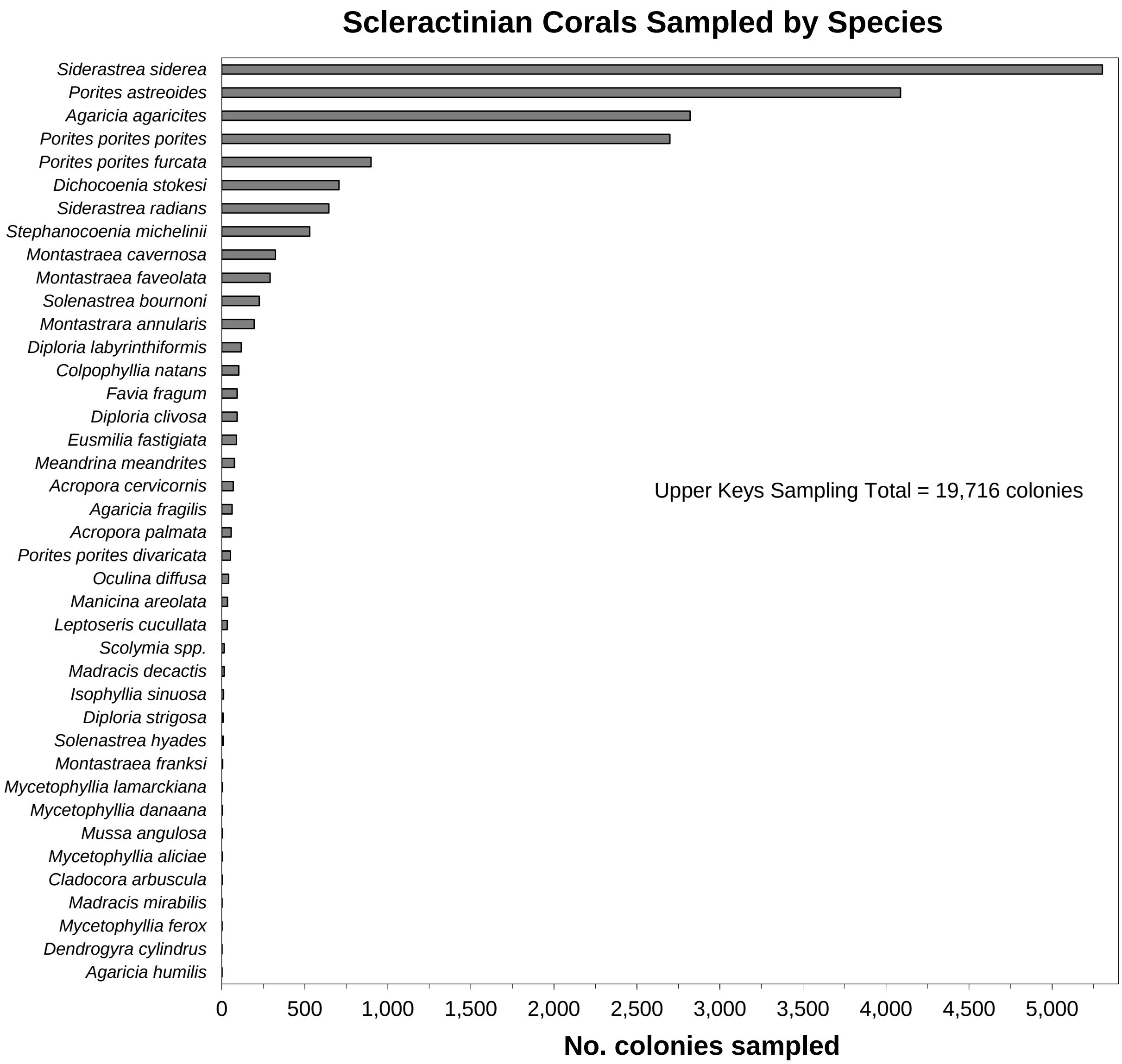


Figure 4-3. Total scleractinian coral densities (no. colonies per m^2) in the upper Florida Keys National Marine Sanctuary from the southern boundary of Biscayne National Park to Carysfort/S. Carysfort Reef surveyed during May-September 2011.

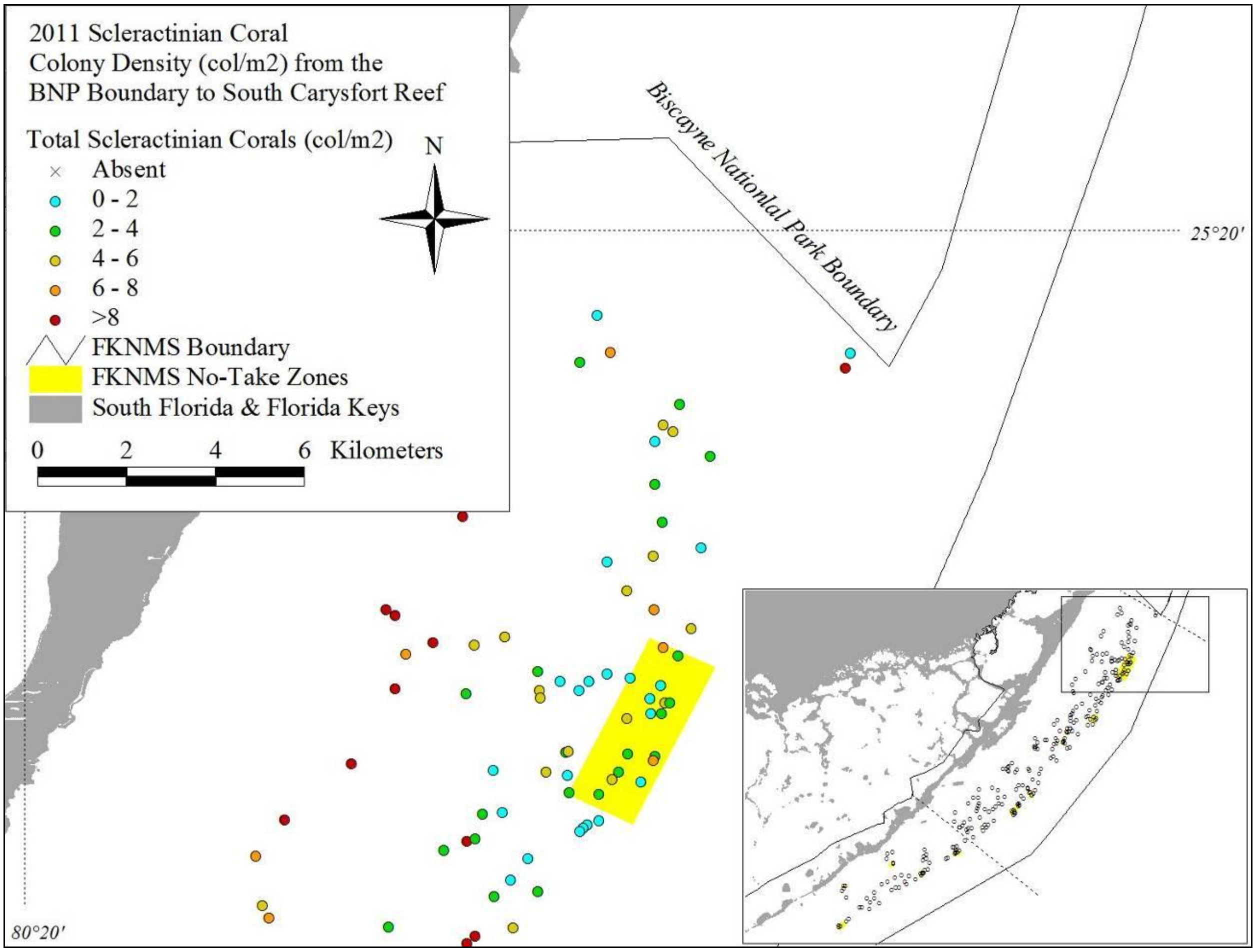


Figure 4-4. Total scleractinian coral densities (no. colonies per m^2) in the upper Florida Keys National Marine Sanctuary from Elbow Reef to Pickles Reef surveyed during May-September 2011.

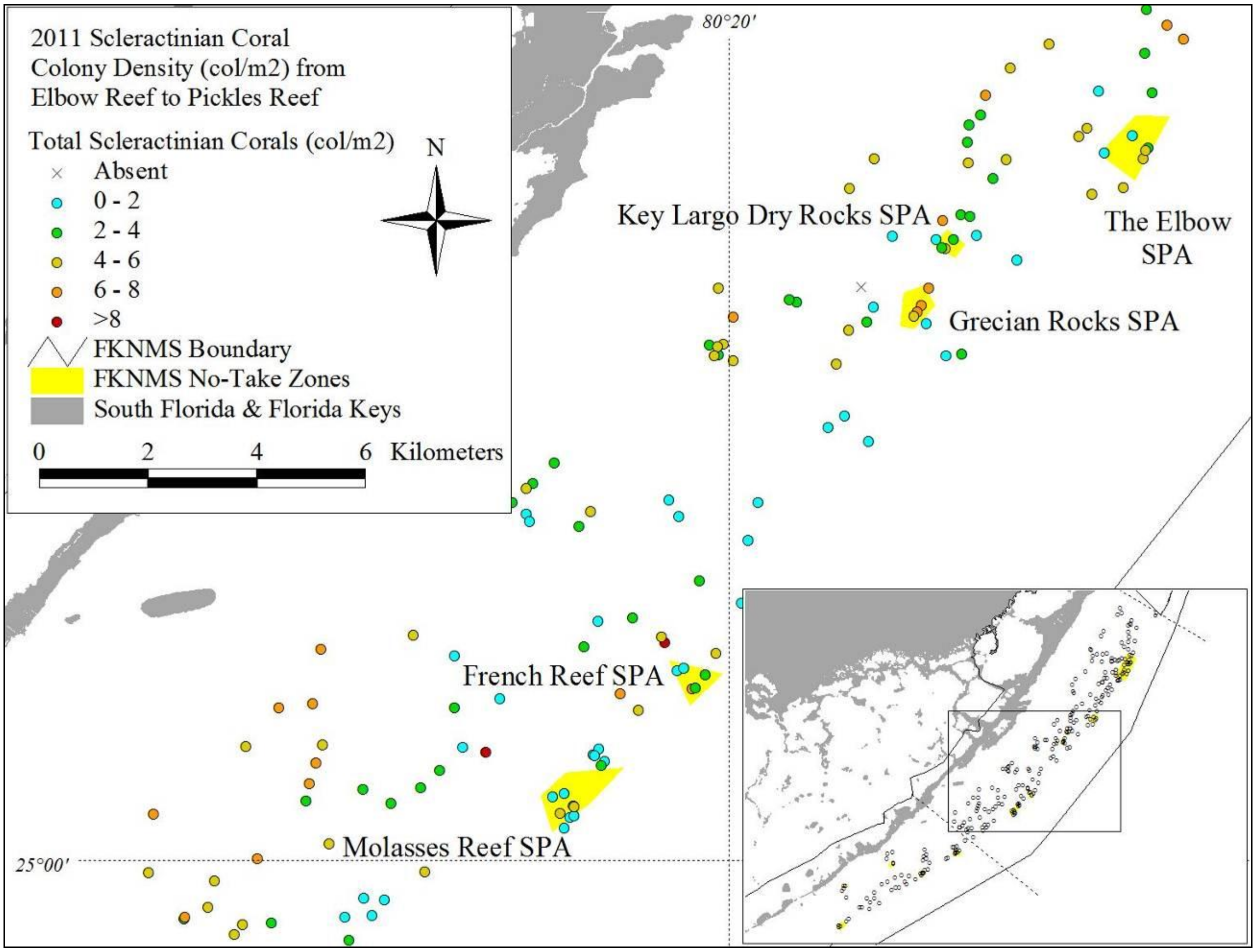


Figure 4-5. Total scleractinian coral densities (no. colonies per m^2) in the upper Florida Keys National Marine Sanctuary from Conch Reef SPA to Alligator Reef surveyed during May-September 2011.

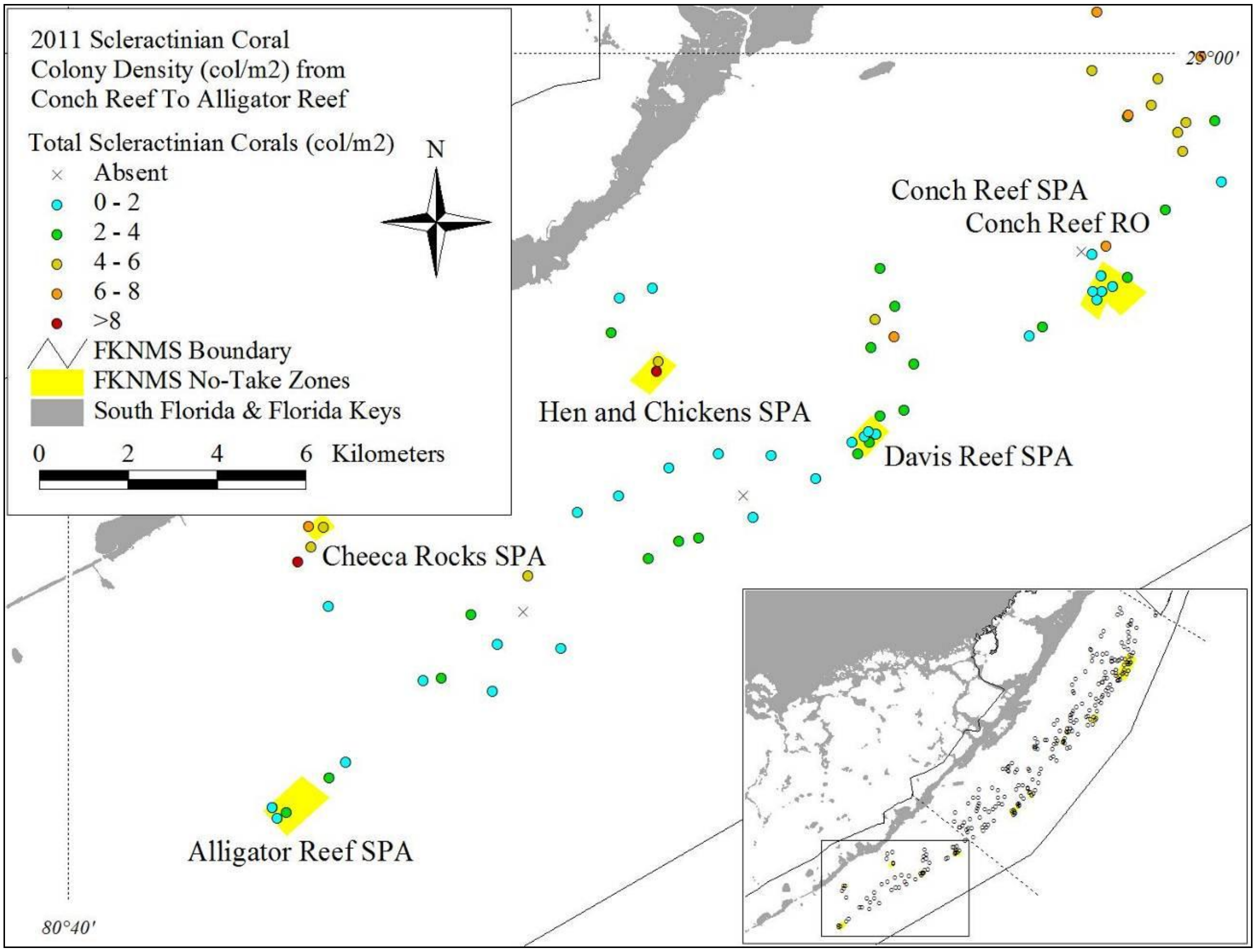
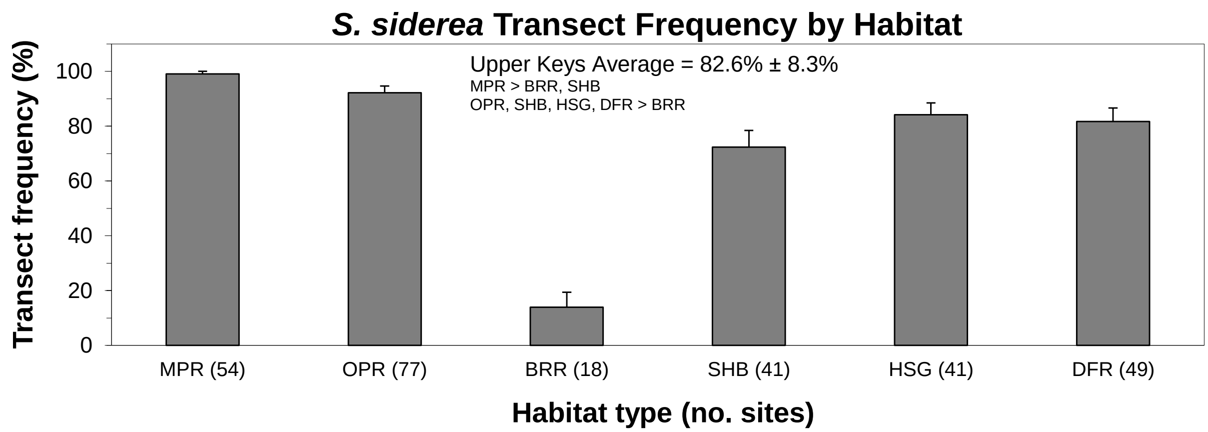
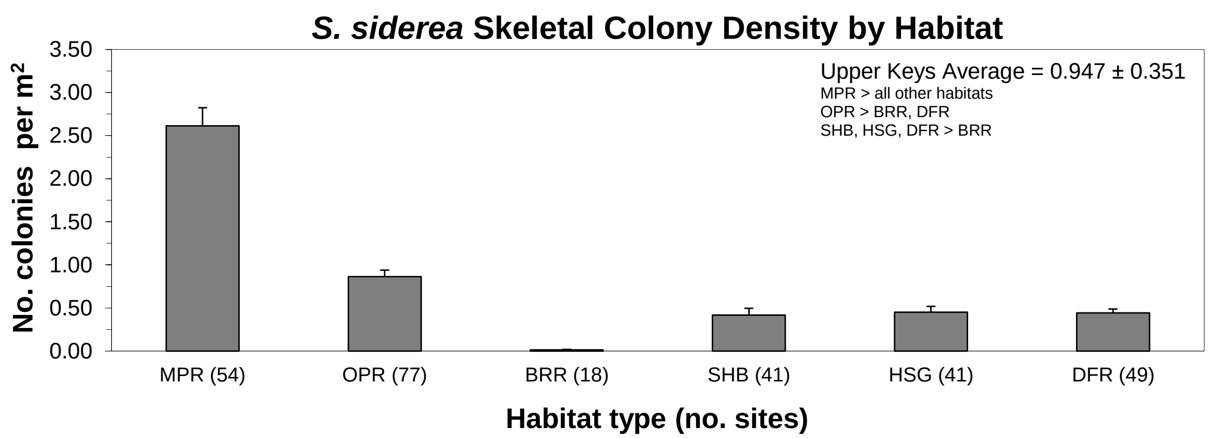


Figure 4-6. Mean (+ 1 SE) transect frequency (top), density (no. per m^2) of skeletal colonies (middle), and total colony abundance estimates (bottom) of the massive starlet coral (*Siderastrea siderea*) by habitat type in the upper Florida Keys, as determined from surveys of replicate 10-m x 1-m belt transects per site at 280 sites. Upper Keys total values for the top two graphs are weighted averages and standard errors. Values on the x-axis in parentheses are the number of sites surveyed in each habitat type. Notation below upper Keys averages indicates significant differences or not (NS) at the adjusted α-level comparison (α_{adj} = 0.0033).





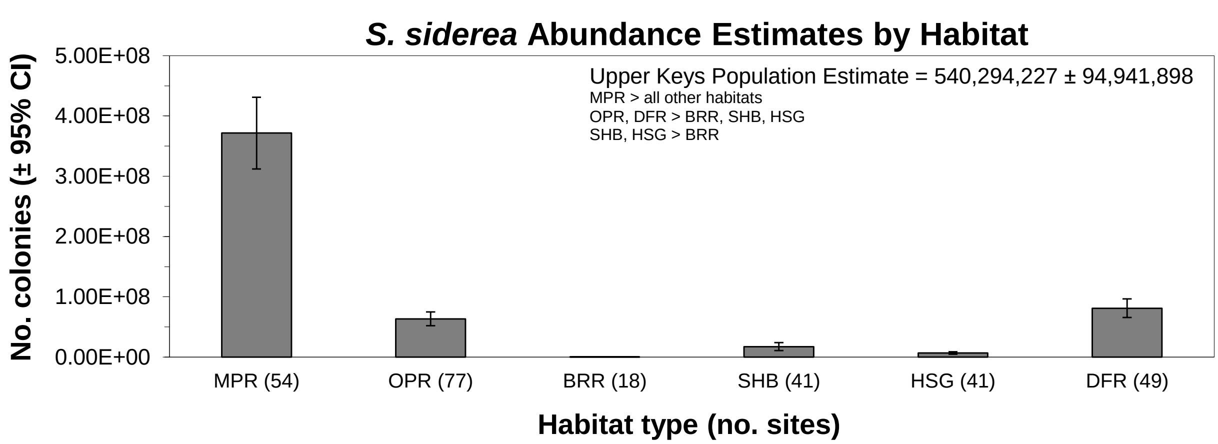
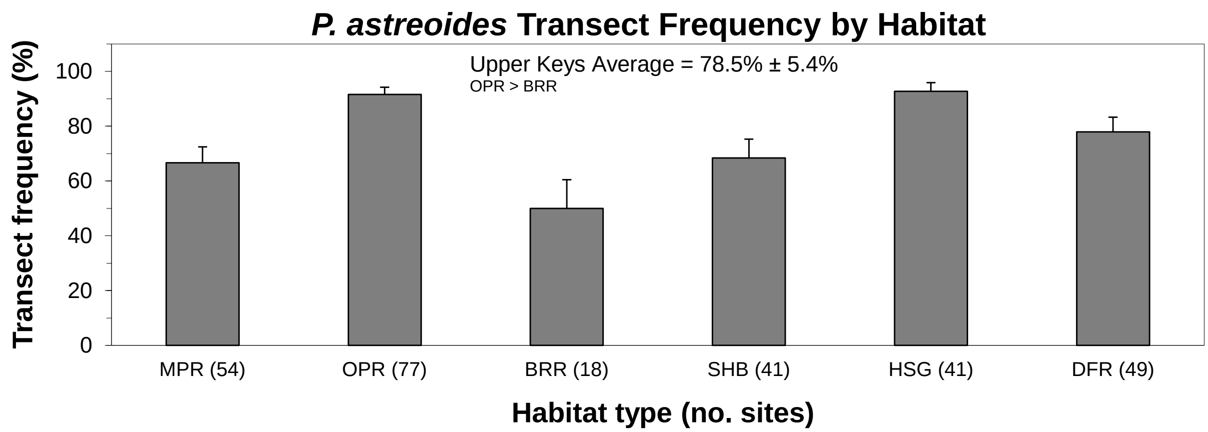
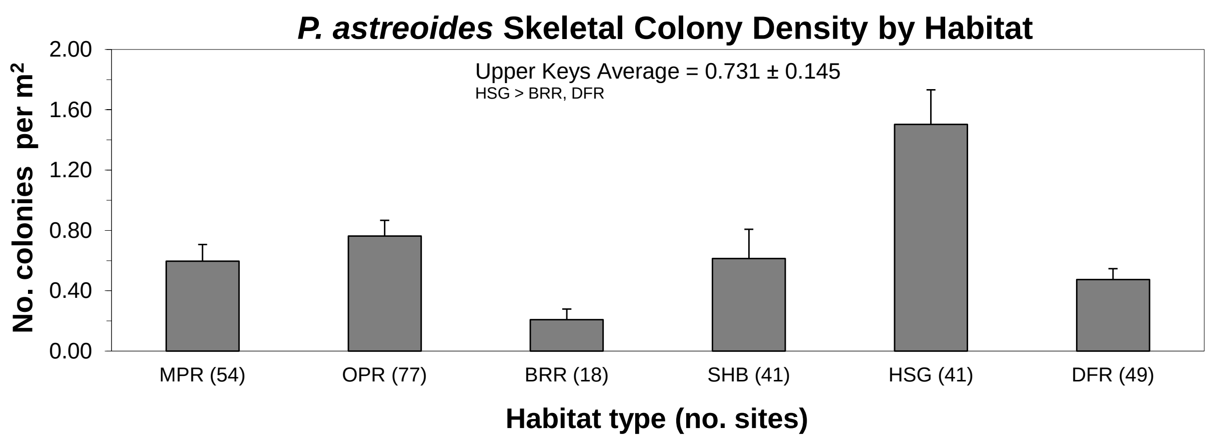


Figure 4-7. Mean (+ 1 SE) transect frequency (top), density (no. per m^2) of skeletal colonies (middle), and total colony abundance estimates (bottom) of the mustard hill coral (*Porites astreoides*) by habitat type in the upper Florida Keys, as determined from surveys of replicate 10-m x 1-m belt transects per site at 280 sites. Upper Keys total values for the top two graphs are weighted averages and standard errors. Values on the x-axis in parentheses are the number of sites surveyed in each habitat type. Notation below upper Keys averages indicates significant differences or not (NS) at the adjusted α-level comparison (α_{adj} = 0.0033).





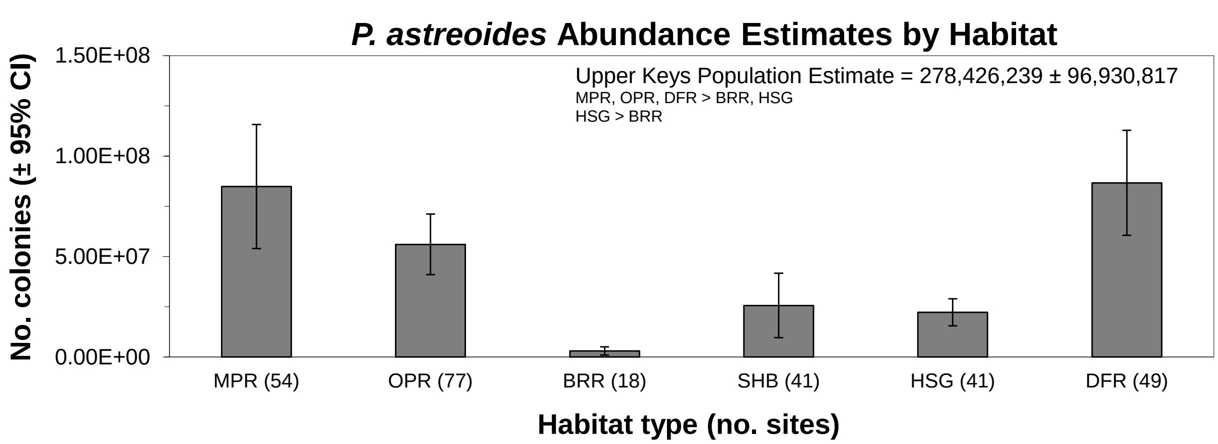


Figure 4-8. Mean (+ 1 SE) transect frequency (top), density (no. per m^2) of skeletal colonies (middle), and total colony abundance estimates (bottom) of the lettuce coral (*Agaricia agaricites*) by habitat type in the upper Florida Keys, as determined from surveys of replicate 10-m x 1-m belt transects per site at 280 sites. Upper Keys total values for the top two graphs are weighted averages and standard errors. Values on the x-axis in parentheses are the number of sites surveyed in each habitat type. Notation below upper Keys averages indicates significant differences or not (NS) at the adjusted α-level comparison (α_{adj} = 0.005).

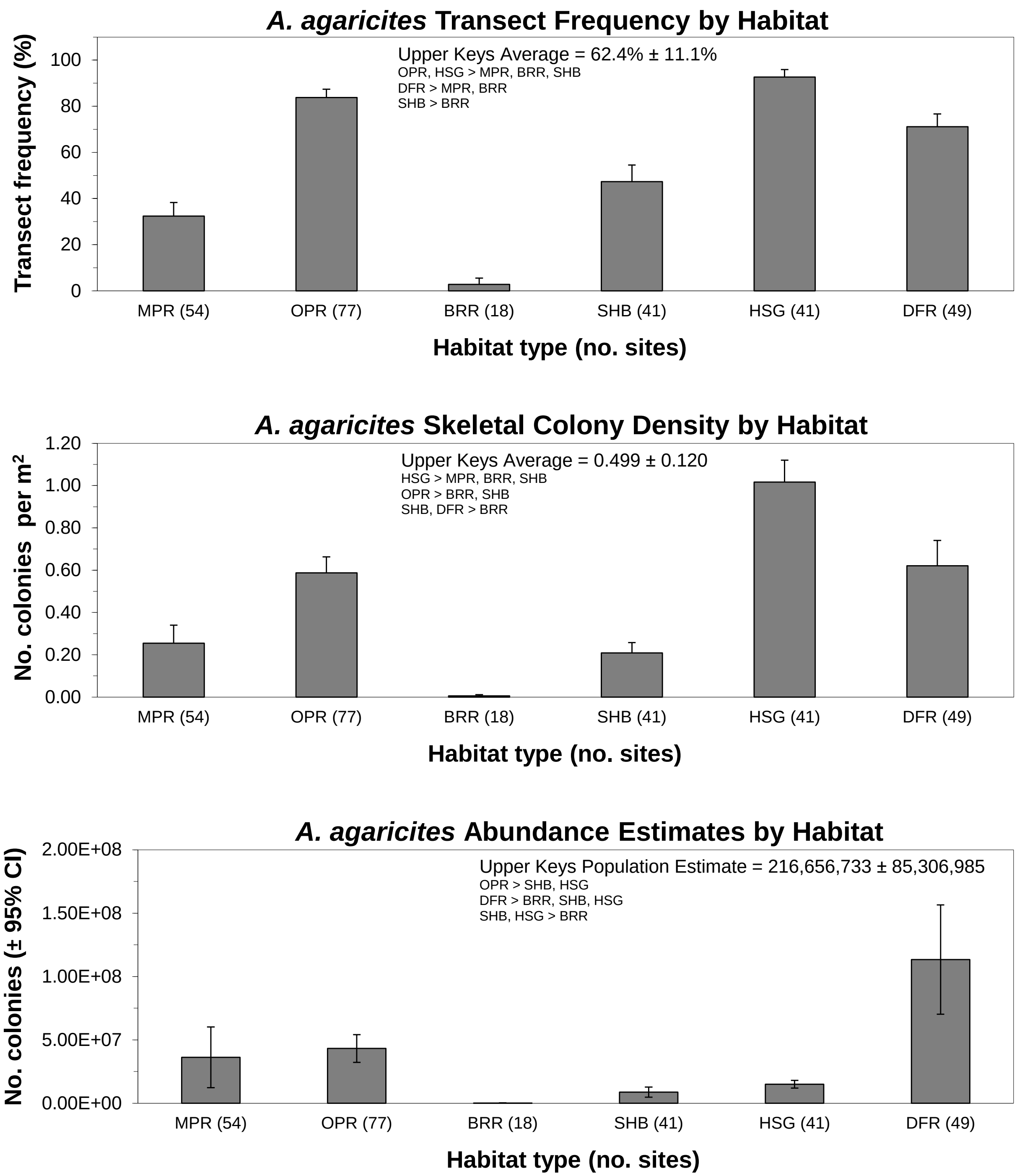
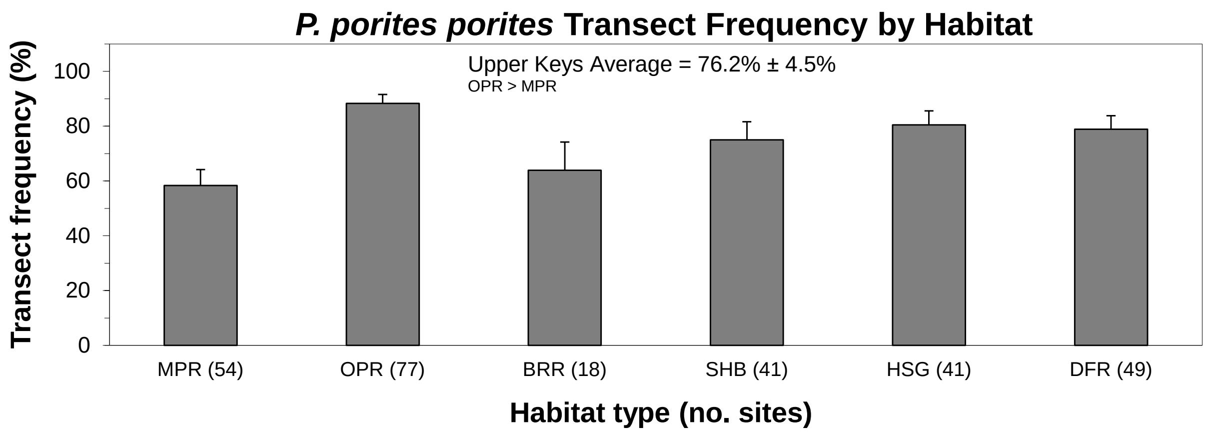
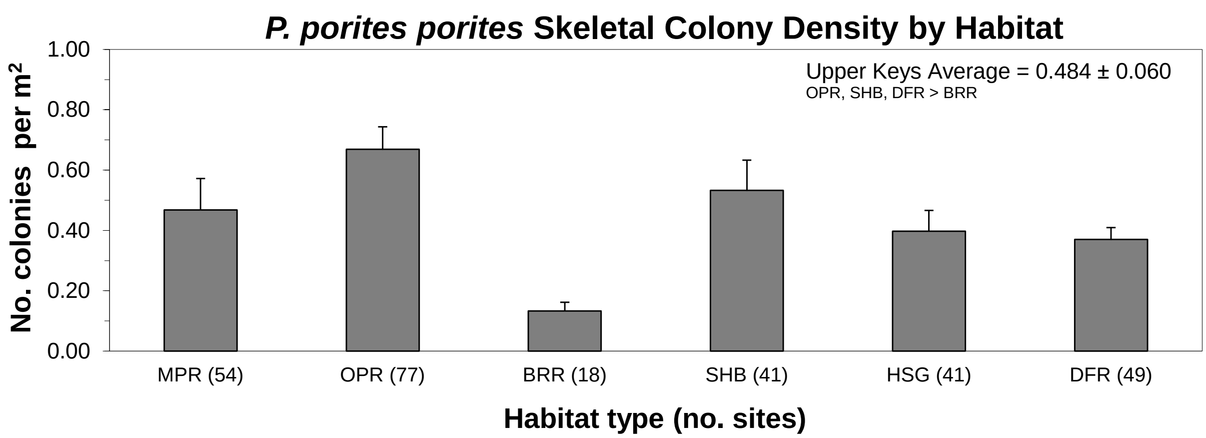


Figure 4-9. Mean (+ 1 SE) transect frequency (top), density (no. per m^2) of skeletal colonies (middle), and total colony abundance estimates (bottom) of the clubtip finger coral (*Porites porites porites*) by habitat type in the upper Florida Keys, as determined from surveys of replicate 10-m x 1-m belt transects per site at 280 sites. Upper Keys total values for the top two graphs are weighted averages and standard errors. Values on the x-axis in parentheses are the number of sites surveyed in each habitat type. Notation below upper Keys averages indicates significant differences or not (NS) at the adjusted α-level comparison (α_{adj} = 0.0033).





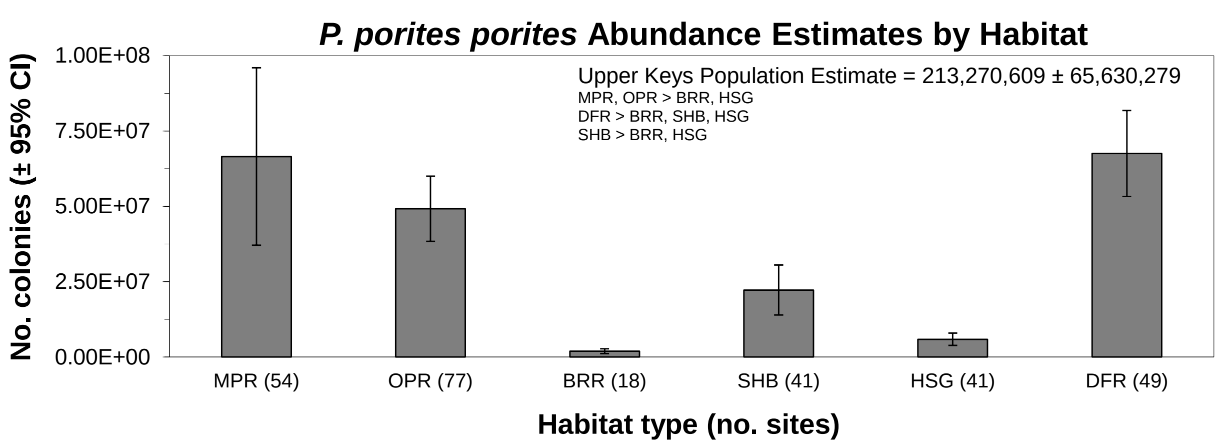
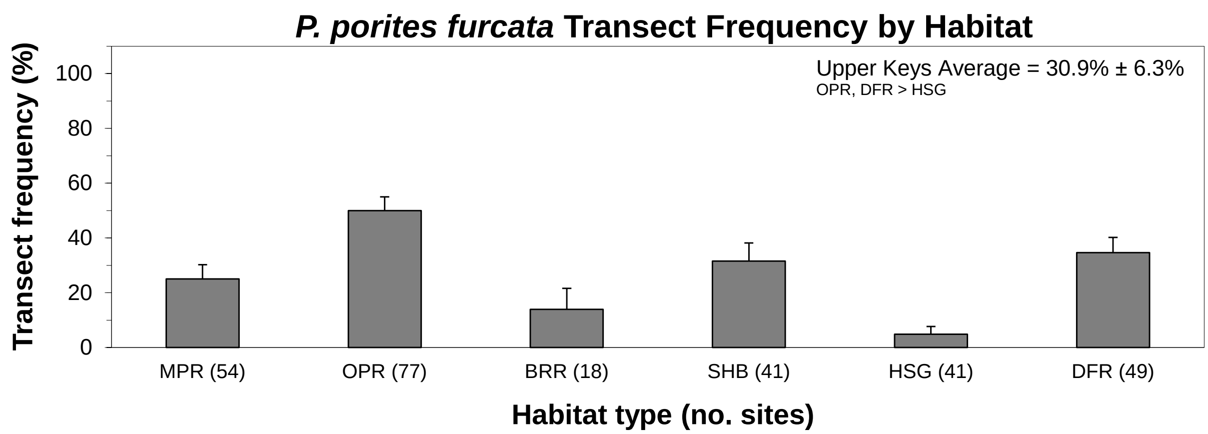
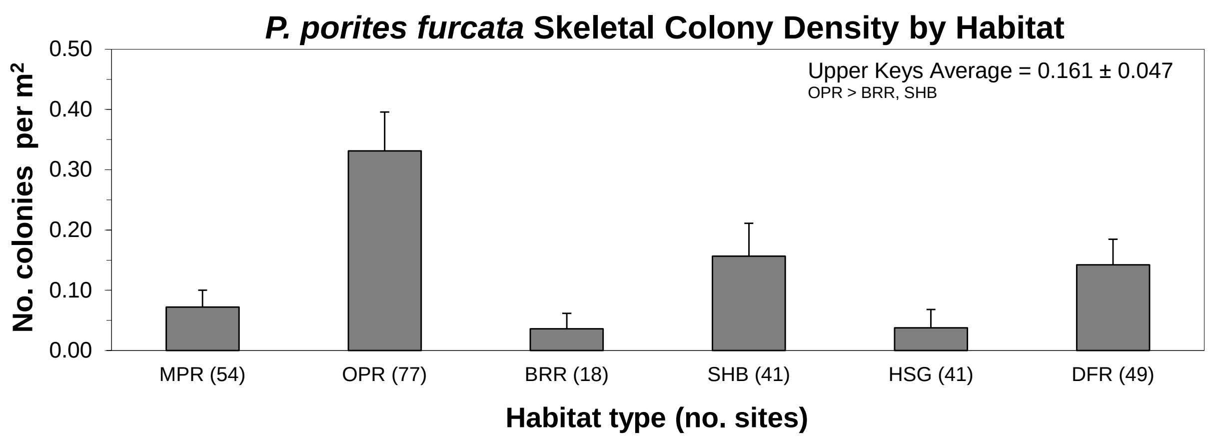


Figure 4-10. Mean (+ 1 SE) transect frequency (top), density (no. per m^2) of skeletal colonies (middle), and total colony abundance estimates (bottom) of the branched finger coral (*Porites porites furcata*) by habitat type in the upper Florida Keys, as determined from surveys of replicate 10-m x 1-m belt transects per site at 280 sites. Upper Keys total values for the top two graphs are weighted averages and standard errors. Values on the x-axis in parentheses are the number of sites surveyed in each habitat type. Notation below upper Keys averages indicates significant differences or not (NS) at the adjusted α-level comparison (α_{adj} = 0.0033).





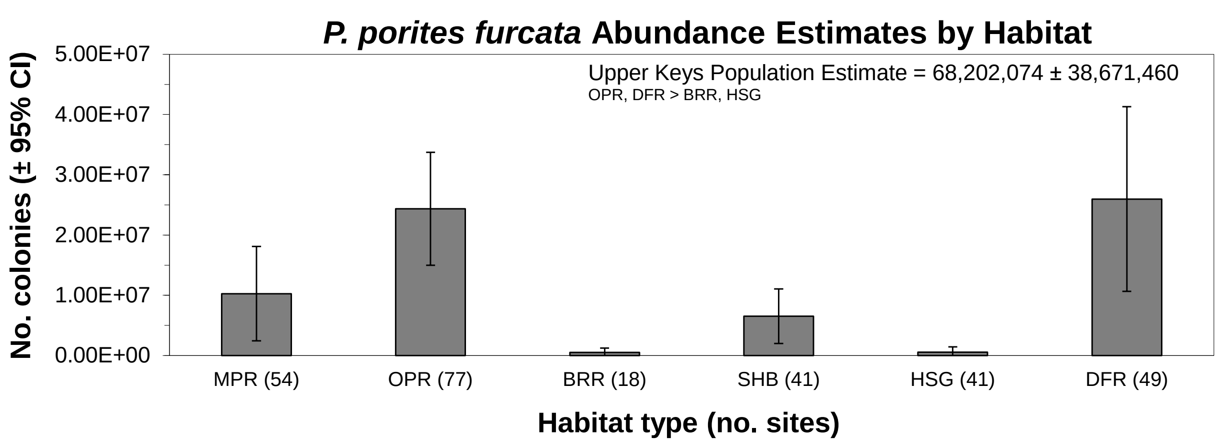
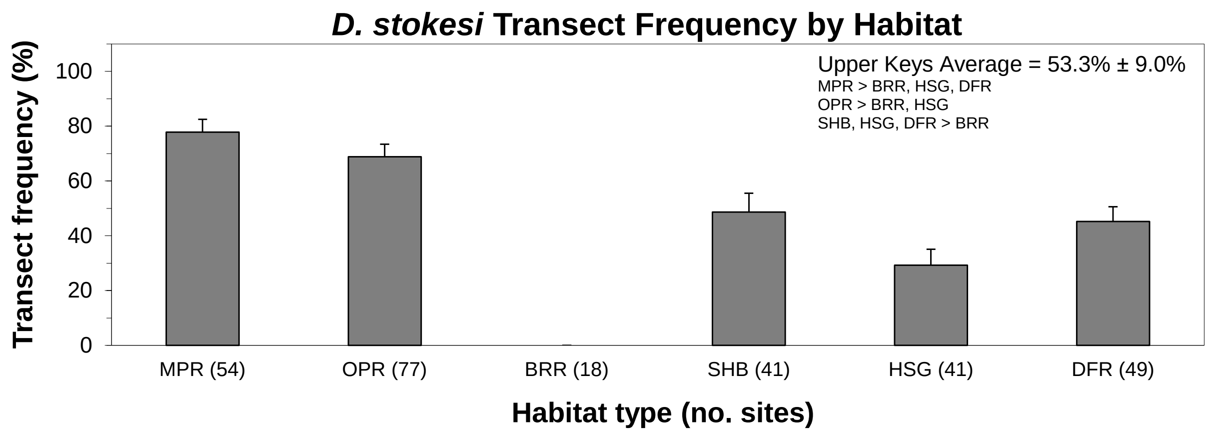
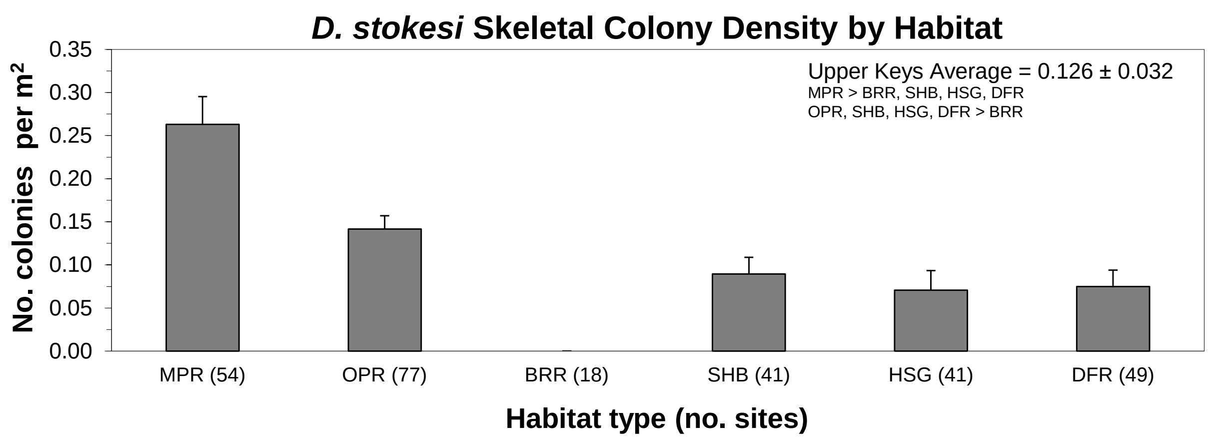


Figure 4-11. Mean (+ 1 SE) transect frequency (top), density (no. per m^2) of skeletal colonies (middle), and total colony abundance estimates (bottom) of the pineapple coral (*Dichocoenia stokesi*) by habitat type in the upper Florida Keys, as determined from surveys of replicate 10-m x 1-m belt transects per site at 280 sites. Upper Keys total values for the top two graphs are weighted averages and standard errors. Values on the x-axis in parentheses are the number of sites surveyed in each habitat type. Notation below upper Keys averages indicates significant differences or not (NS) at the adjusted α-level comparison (α_{adj} = 0.0033).





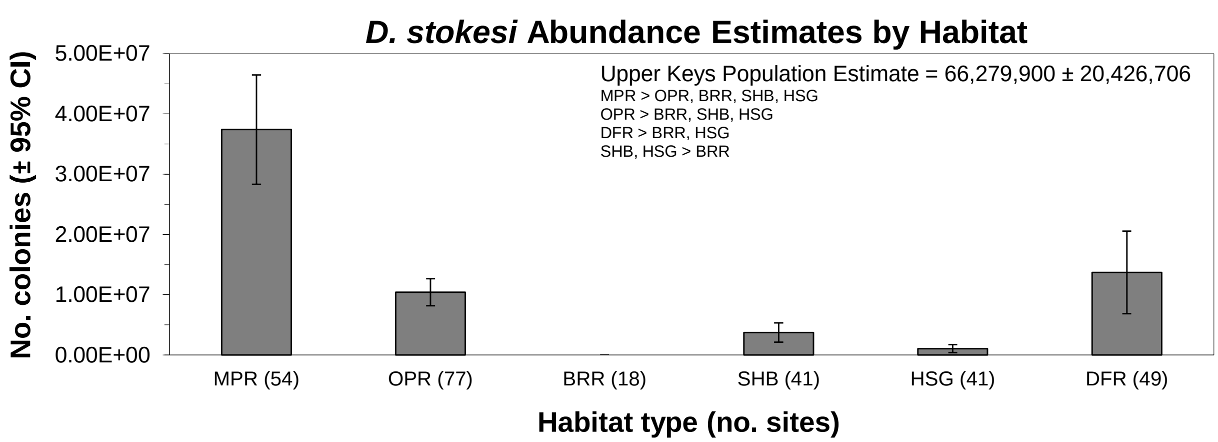
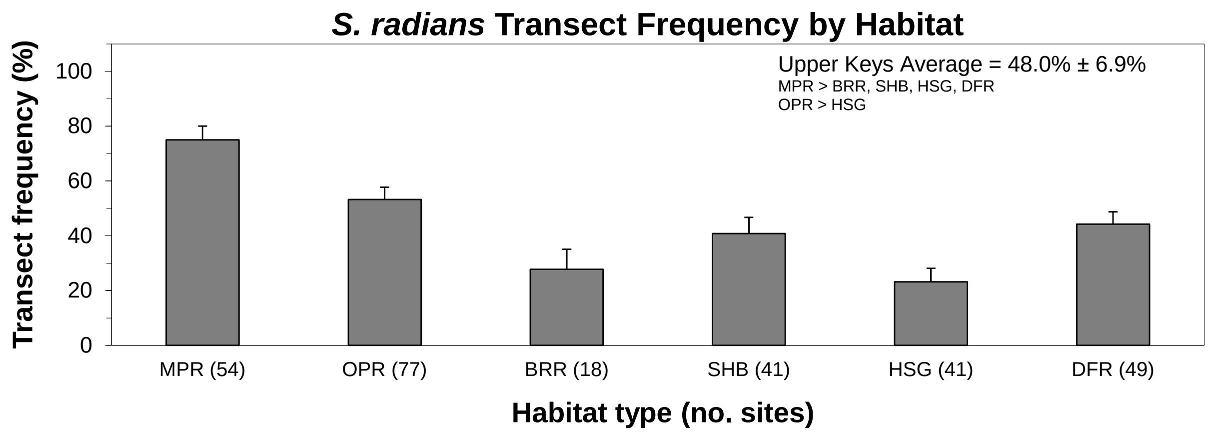
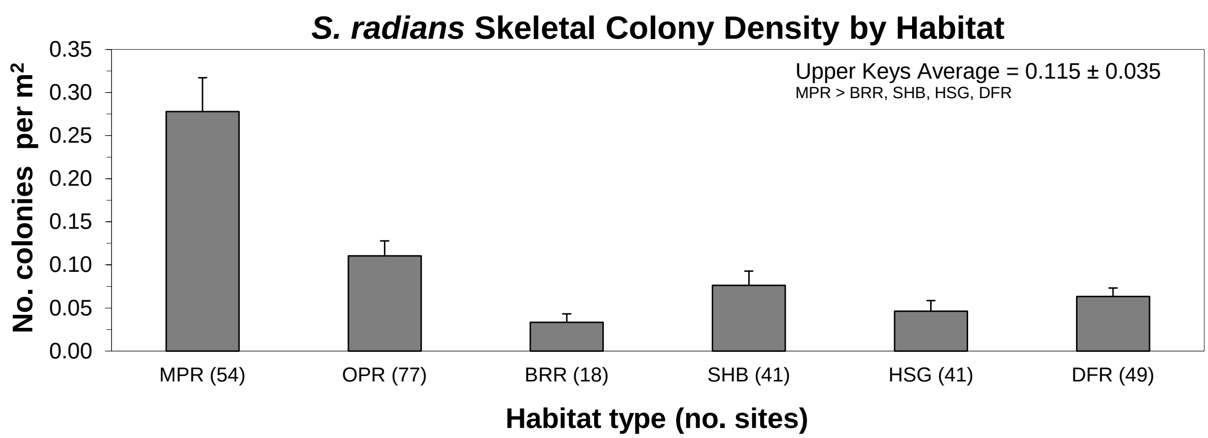


Figure 4-12. Mean (+ 1 SE) transect frequency (top), density (no. per m^2) of skeletal colonies (middle), and total colony abundance estimates (bottom) of the lesser starlet coral (*Siderastrea radians*) by habitat type in the upper Florida Keys, as determined from surveys of replicate 10-m x 1-m belt transects per site at 280 sites. Upper Keys total values for the top two graphs are weighted averages and standard errors. Values on the x-axis in parentheses are the number of sites surveyed in each habitat type. Notation below upper Keys averages indicates significant differences or not (NS) at the adjusted α-level comparison (α_{adj} = 0.0033).





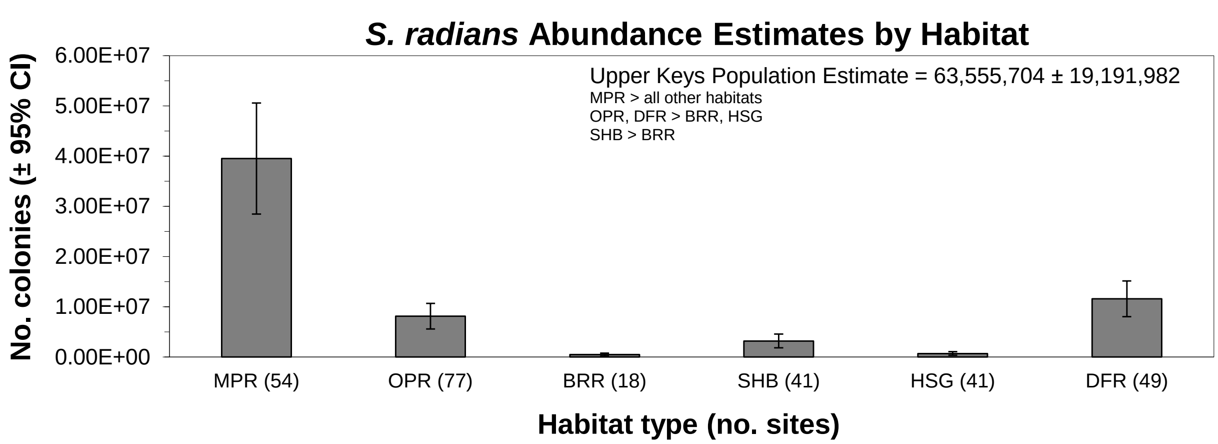
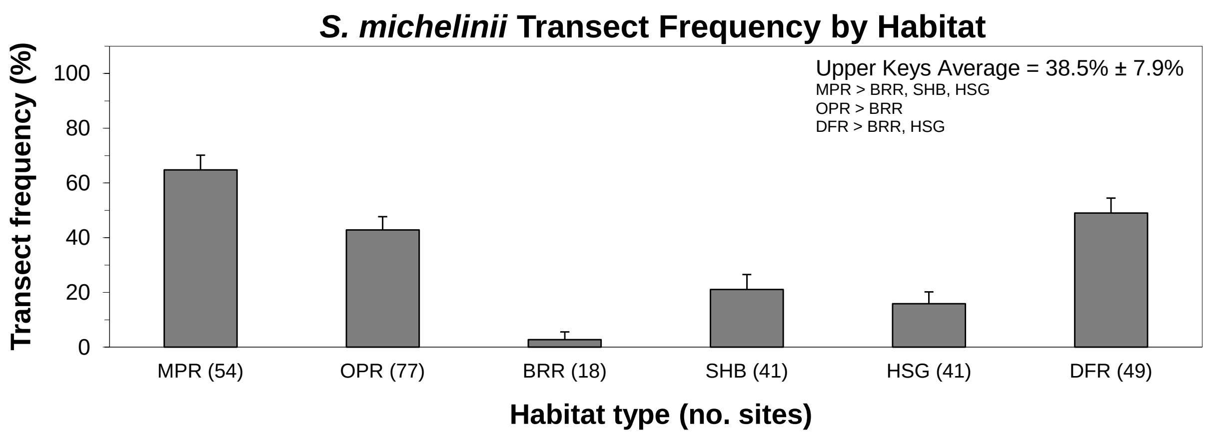
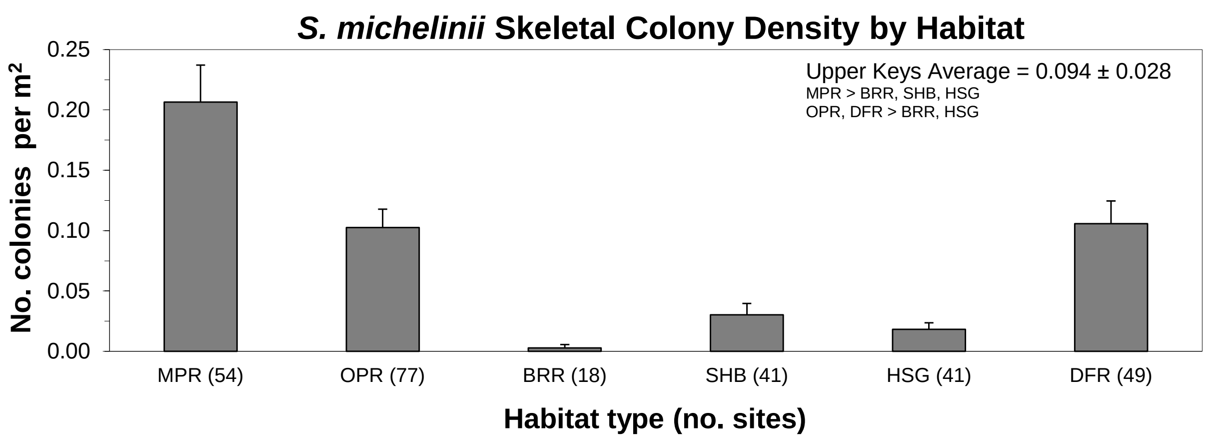


Figure 4-13. Mean (+ 1 SE) transect frequency (top), density (no. per m^2) of skeletal colonies (middle), and total colony abundance estimates (bottom) of the blushing star coral (*Stephanocoenia michelinii*) by habitat type in the upper Florida Keys, as determined from surveys of replicate 10-m x 1-m belt transects per site at 280 sites. Upper Keys total values for the top two graphs are weighted averages and standard errors. Values on the x-axis in parentheses are the number of sites surveyed in each habitat type. Notation below upper Keys averages indicates significant differences or not (NS) at the adjusted α-level comparison ($\alpha_{adj} = 0.0033$).





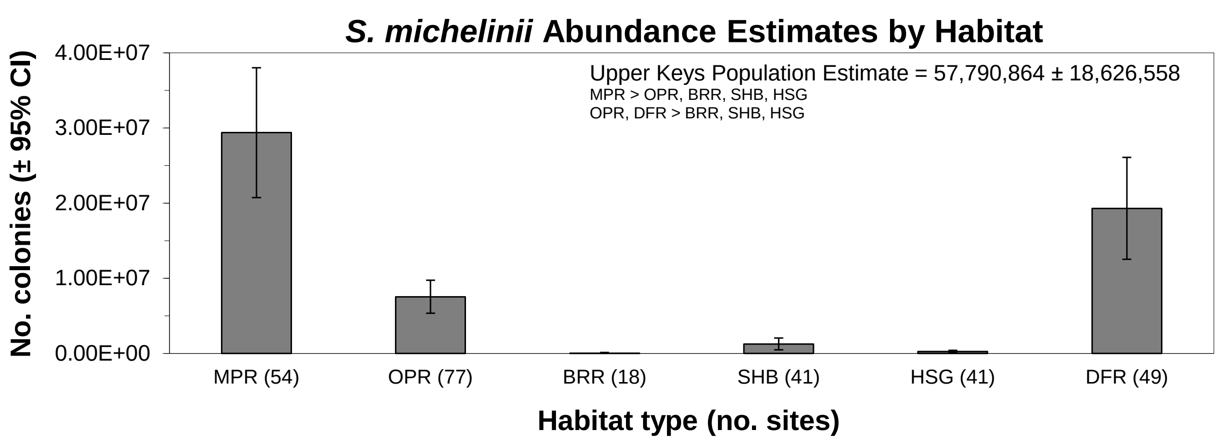
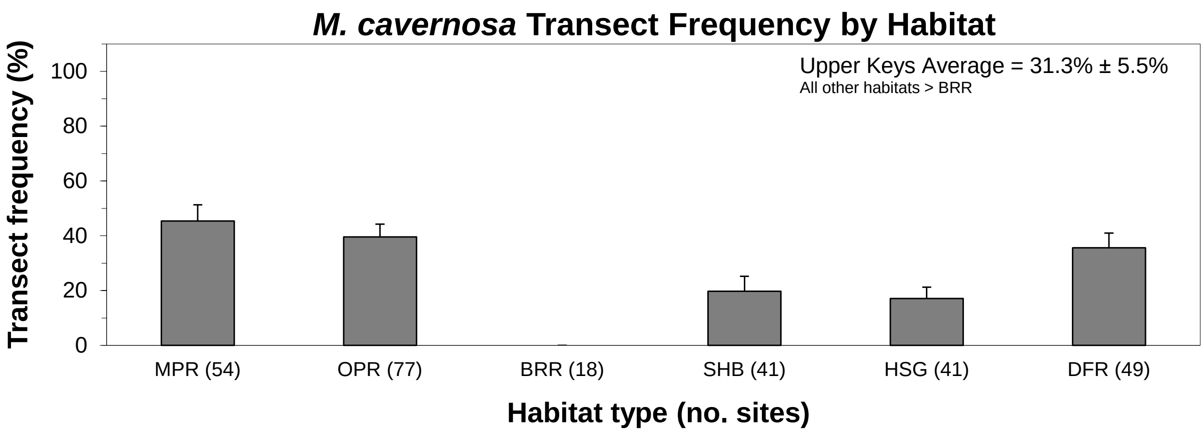
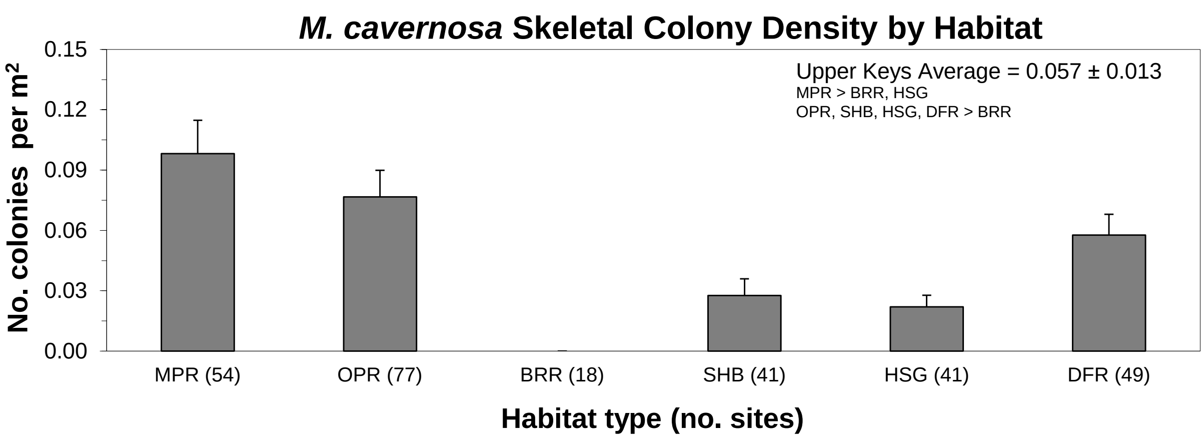


Figure 4-14. Mean (+ 1 SE) transect frequency (top), density (no. per m^2) of skeletal colonies (middle), and total colony abundance estimates (bottom) of the great star coral (*Montastraea cavernosa*) by habitat type in the upper Florida Keys, as determined from surveys of replicate 10-m x 1-m belt transects per site at 280 sites. Upper Keys total values for the top two graphs are weighted averages and standard errors. Values on the x-axis in parentheses are the number of sites surveyed in each habitat type. Notation below upper Keys averages indicates significant differences or not (NS) at the adjusted α-level comparison (α_{adj} = 0.0033).





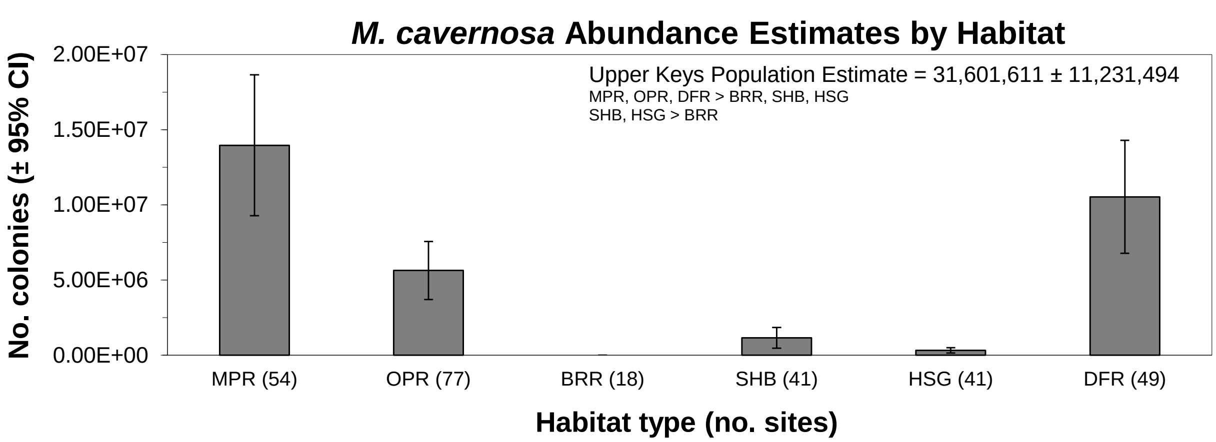


Figure 4-15. Mean (+ 1 SE) transect frequency (top), density (no. per m^2) of skeletal colonies (middle), and total colony abundance estimates (bottom) of the mountainous star coral (*Montastraea faveolata*) by habitat type in the upper Florida Keys, as determined from surveys of replicate 10-m x 1-m belt transects per site at 280 sites. Upper Keys total values for the top two graphs are weighted averages and standard errors. Values on the x-axis in parentheses are the number of sites surveyed in each habitat type. Notation below upper Keys averages indicates significant differences or not (NS) at the adjusted α-level comparison ($\alpha_{adj} = 0.0033$).

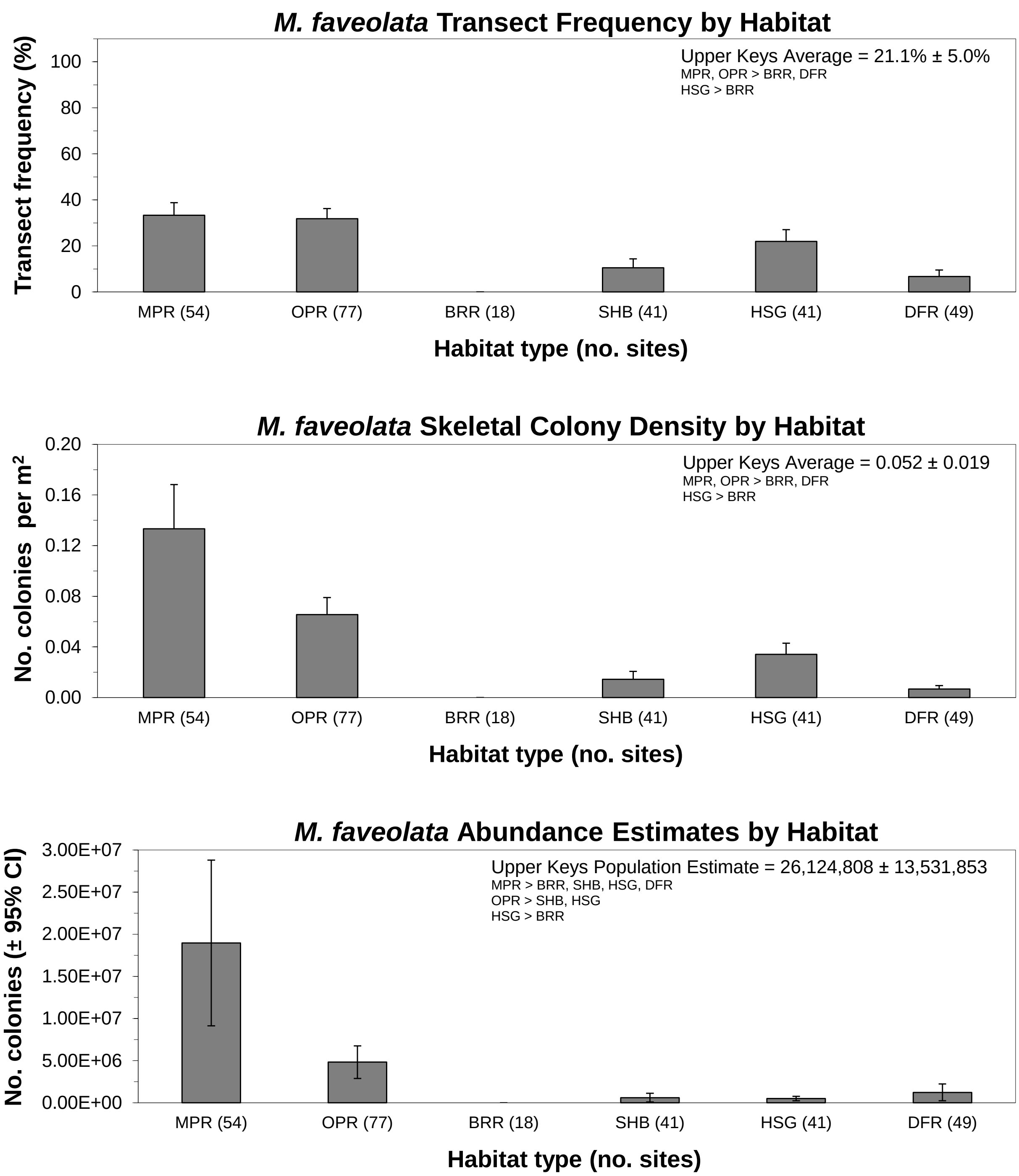
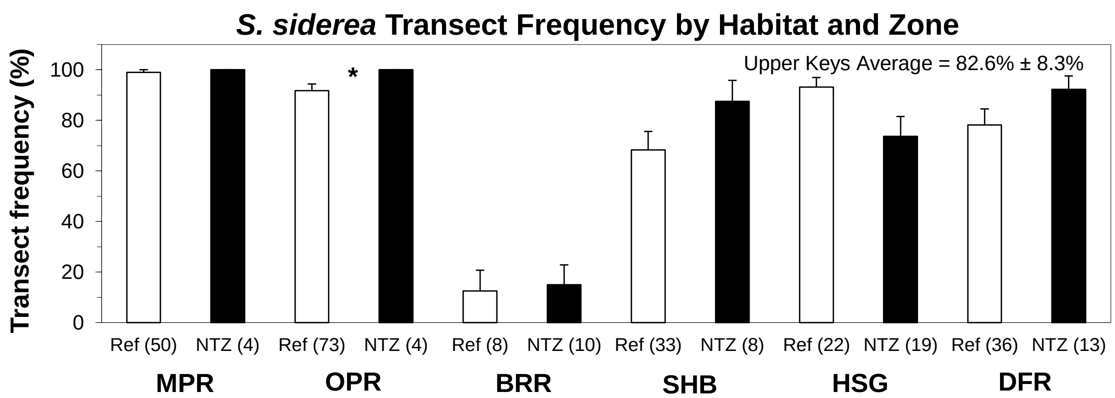
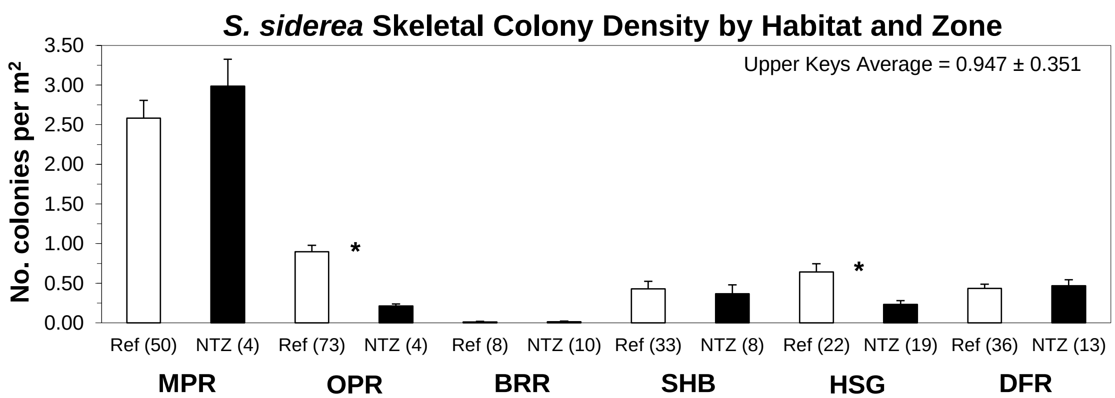


Figure 4-16. Mean (+ 1 SE) transect frequency (top), density (no. per m^2) of skeletal colonies (middle), and total colony abundance estimates (bottom) of the massive starlet coral (*Siderastrea siderea*) by habitat type and management zone in the upper Florida Keys, as determined from surveys of replicate 10-m x 1-m belt transects per site at 280 sites. Open bars = reference areas (Ref), filled bars = no-take zones (NTZ). Upper Keys total values for the top two graphs are weighted averages and standard errors. Habitat abbreviations are: MPR = inshore and mid-channel patch reefs, OPR = offshore patch reefs, BRR = back-reef rubble, SHB = shallow (< 6 m) hard-bottom, HSG = high-relief and groove, and DFR = deeper (6-15 m) fore-reef habitats. Numbers in parentheses on the x-axis are the number of sites surveyed. An asterisk (*) indicates a significant difference (P < 0.05).





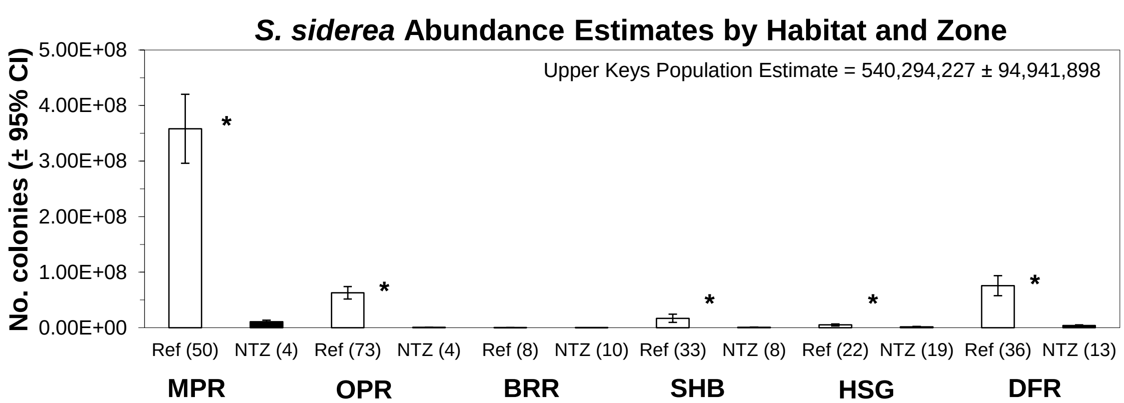
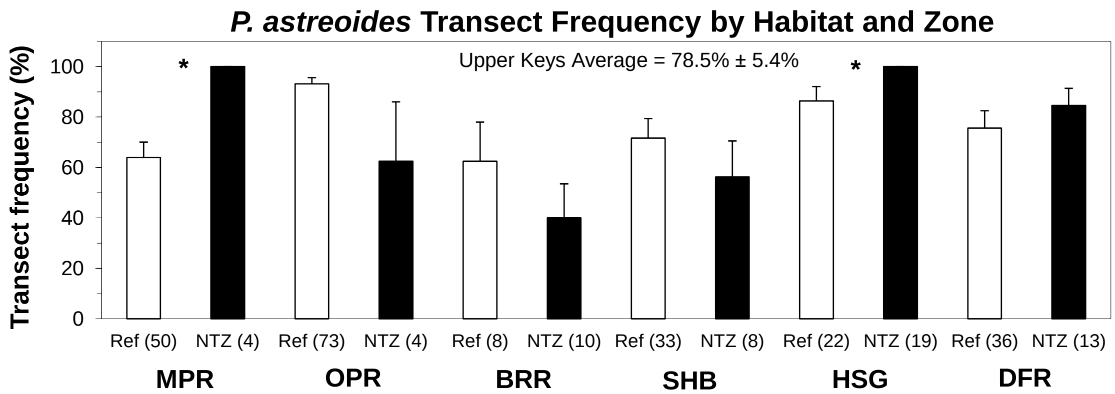
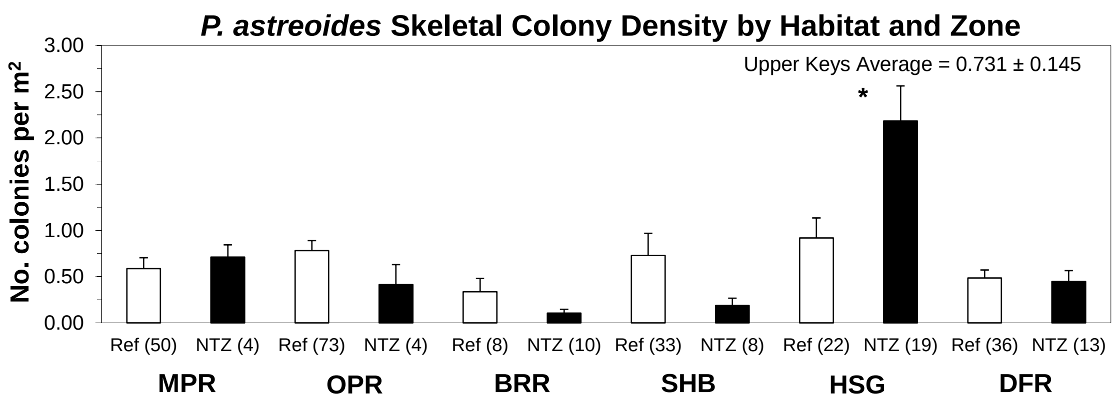


Figure 4-17. Mean (+ 1 SE) transect frequency (top), density (no. per m^2) of skeletal colonies (middle), and total colony abundance estimates (bottom) of the mustard hill coral (*Porites astreoides*) by habitat type and management zone in the upper Florida Keys, as determined from surveys of replicate 10-m x 1-m belt transects per site at 280 sites. Open bars = reference areas (Ref), filled bars = no-take zones (NTZ). Upper Keys total values for the top two graphs are weighted averages and standard errors. Habitat abbreviations are: MPR = inshore and mid-channel patch reefs, OPR = offshore patch reefs, BRR = back-reef rubble, SHB = shallow (< 6 m) hard-bottom, HSG = high-relief and groove, and DFR = deeper (6-15 m) fore-reef habitats. Numbers in parentheses on the x-axis are the number of sites surveyed. An asterisk (*) indicates a significant difference (P < 0.05).





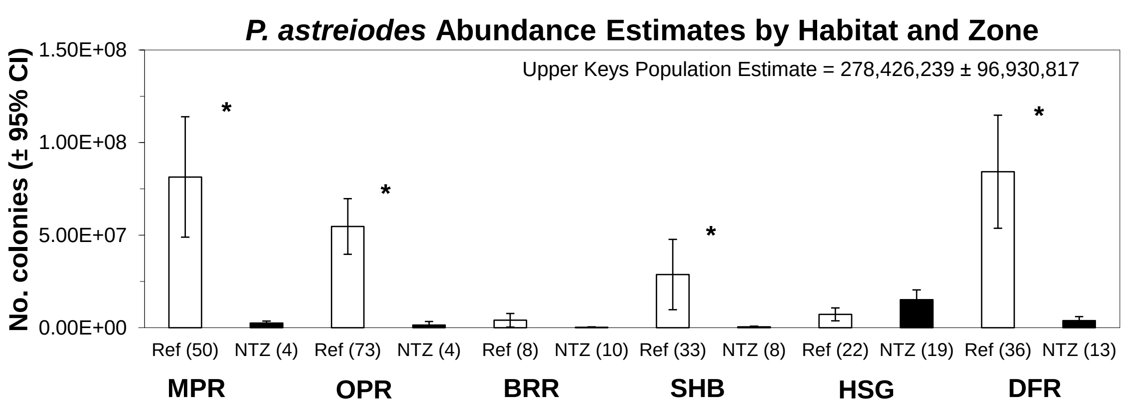
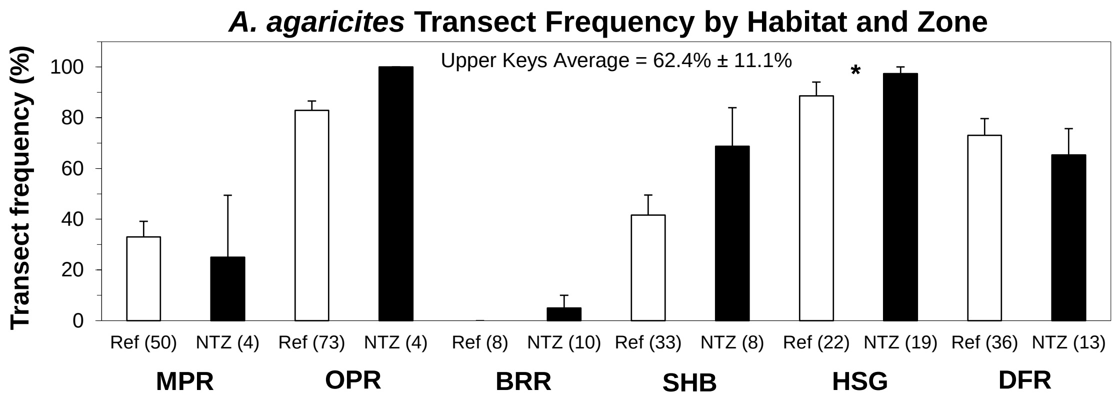
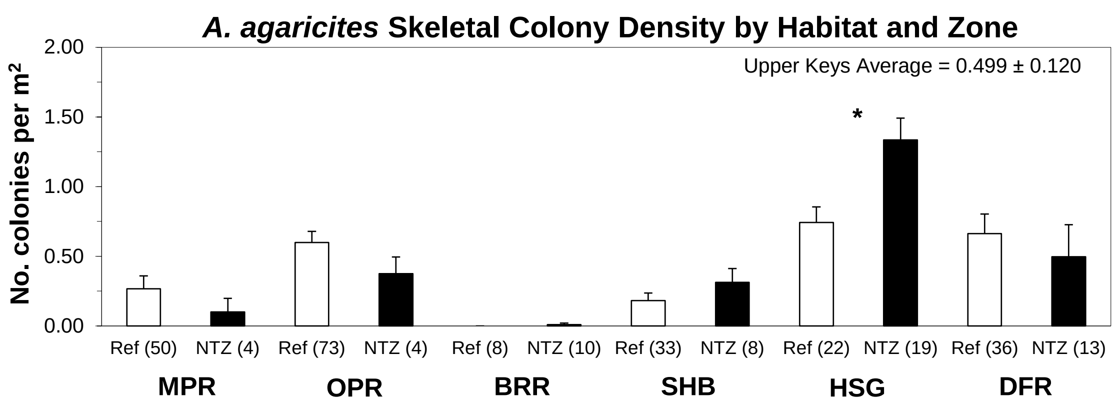


Figure 4-18. Mean (+ 1 SE) transect frequency (top), density (no. per m^2) of skeletal colonies (middle), and total colony abundance estimates (bottom) of the lettuce coral (*Agaricia agaricites*) by habitat type and management zone in the upper Florida Keys, as determined from surveys of replicate 10-m x 1-m belt transects per site at 280 sites. Open bars = reference areas (Ref), filled bars = no-take zones (NTZ). Upper Keys total values for the top two graphs are weighted averages and standard errors. Habitat abbreviations are: MPR = inshore and mid-channel patch reefs, OPR = offshore patch reefs, BRR = back-reef rubble, SHB = shallow (< 6 m) hard-bottom, HSG = high-relief and groove, and DFR = deeper (6-15 m) fore-reef habitats. Numbers in parentheses on the x-axis are the number of sites surveyed. An asterisk (*) indicates a significant difference (P < 0.05).





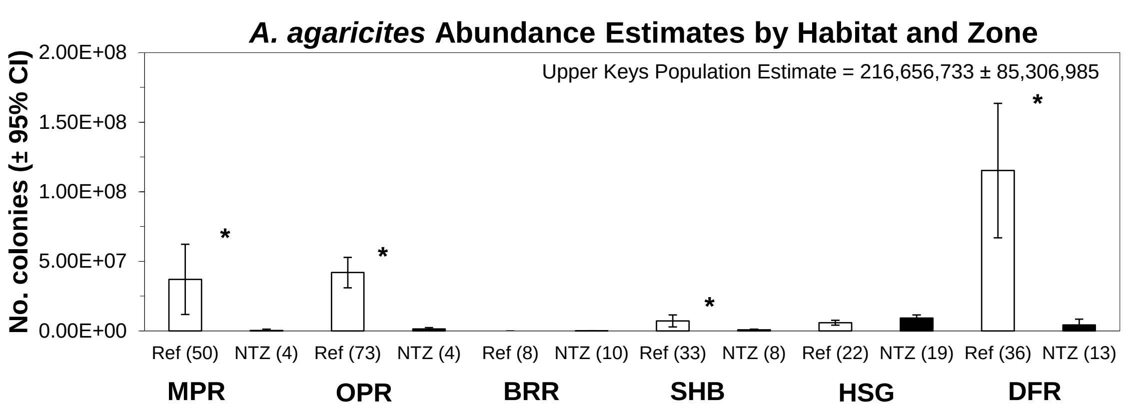


Figure 4-19. Mean (+ 1 SE) transect frequency (top), density (no. per m^2) of skeletal colonies (middle), and total colony abundance estimates (bottom) of the clubtip finger coral (*Porites porites porites*) by habitat type and management zone in the upper Florida Keys, as determined from surveys of replicate 10-m x 1-m belt transects per site at 280 sites. Open bars = reference areas (Ref), filled bars = no-take zones (NTZ). Upper Keys total values for the top two graphs are weighted averages and standard errors. Habitat abbreviations are: MPR = inshore and mid-channel patch reefs, OPR = offshore patch reefs, BRR = back-reef rubble, SHB = shallow (< 6 m) hard-bottom, HSG = high-relief and groove, and DFR = deeper (6-15 m) fore-reef habitats. Numbers in parentheses on the x-axis are the number of sites surveyed. An asterisk (*) indicates a significant difference (P < 0.05).

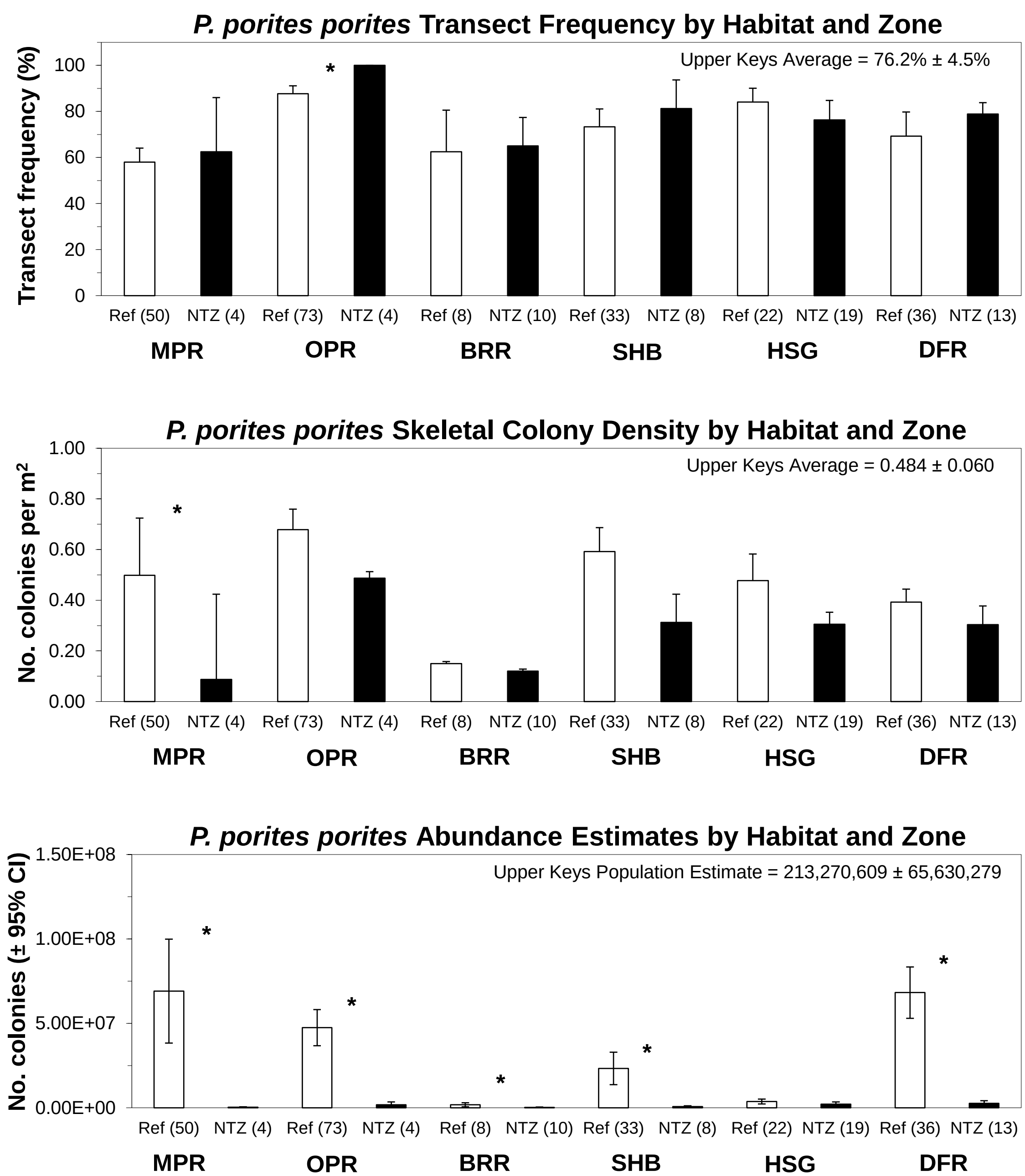


Figure 4-20. Mean (+ 1 SE) transect frequency (top), density (no. per m^2) of skeletal colonies (middle), and total colony abundance estimates (bottom) of the branched finger coral (*Porites porites furcata*) by habitat type and management zone in the upper Florida Keys, as determined from surveys of replicate 10-m x 1-m belt transects per site at 280 sites. Open bars = reference areas (Ref), filled bars = no-take zones (NTZ). Upper Keys total values for the top two graphs are weighted averages and standard errors. Habitat abbreviations are: MPR = inshore and mid-channel patch reefs, OPR = offshore patch reefs, BRR = back-reef rubble, SHB = shallow (< 6 m) hard-bottom, HSG = high-relief and groove, and DFR = deeper (6-15 m) fore-reef habitats. Numbers in parentheses on the x-axis are the number of sites surveyed. An asterisk (*) indicates a significant difference (P < 0.05).

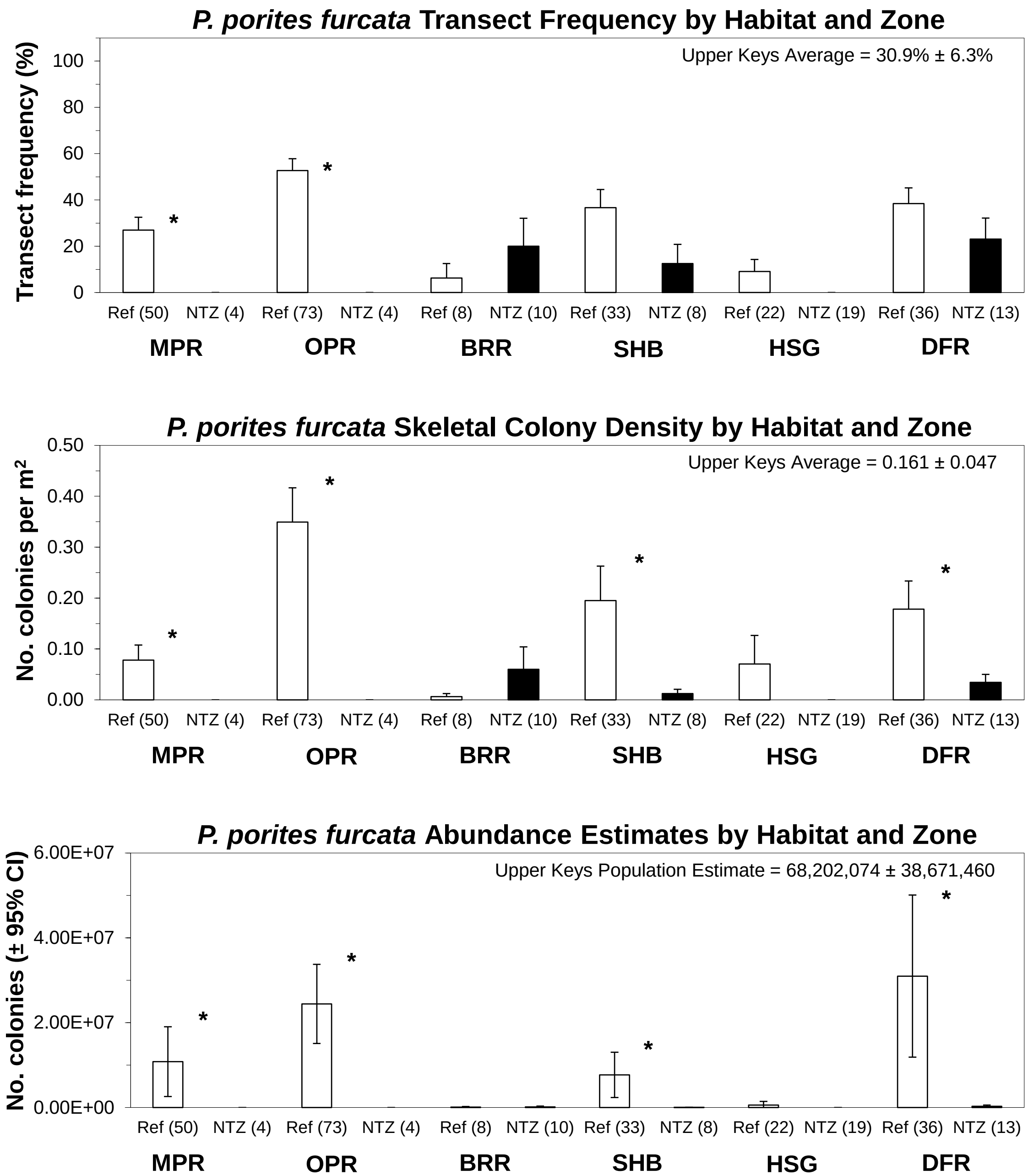


Figure 4-21. Mean (+ 1 SE) transect frequency (top), density (no. per m^2) of skeletal colonies (middle), and total colony abundance estimates (bottom) of the pineapple coral (*Dichocoenia stokesi*) by habitat type and management zone in the upper Florida Keys, as determined from surveys of replicate 10-m x 1-m belt transects per site at 280 sites. Open bars = reference areas (Ref), filled bars = no-take zones (NTZ). Upper Keys total values for the top two graphs are weighted averages and standard errors. Habitat abbreviations are: MPR = inshore and mid-channel patch reefs, OPR = offshore patch reefs, BRR = back-reef rubble, SHB = shallow (< 6 m) hard-bottom, HSG = high-relief and groove, and DFR = deeper (6-15 m) fore-reef habitats. Numbers in parentheses on the x-axis are the number of sites surveyed. An asterisk (*) indicates a significant difference (P < 0.05).

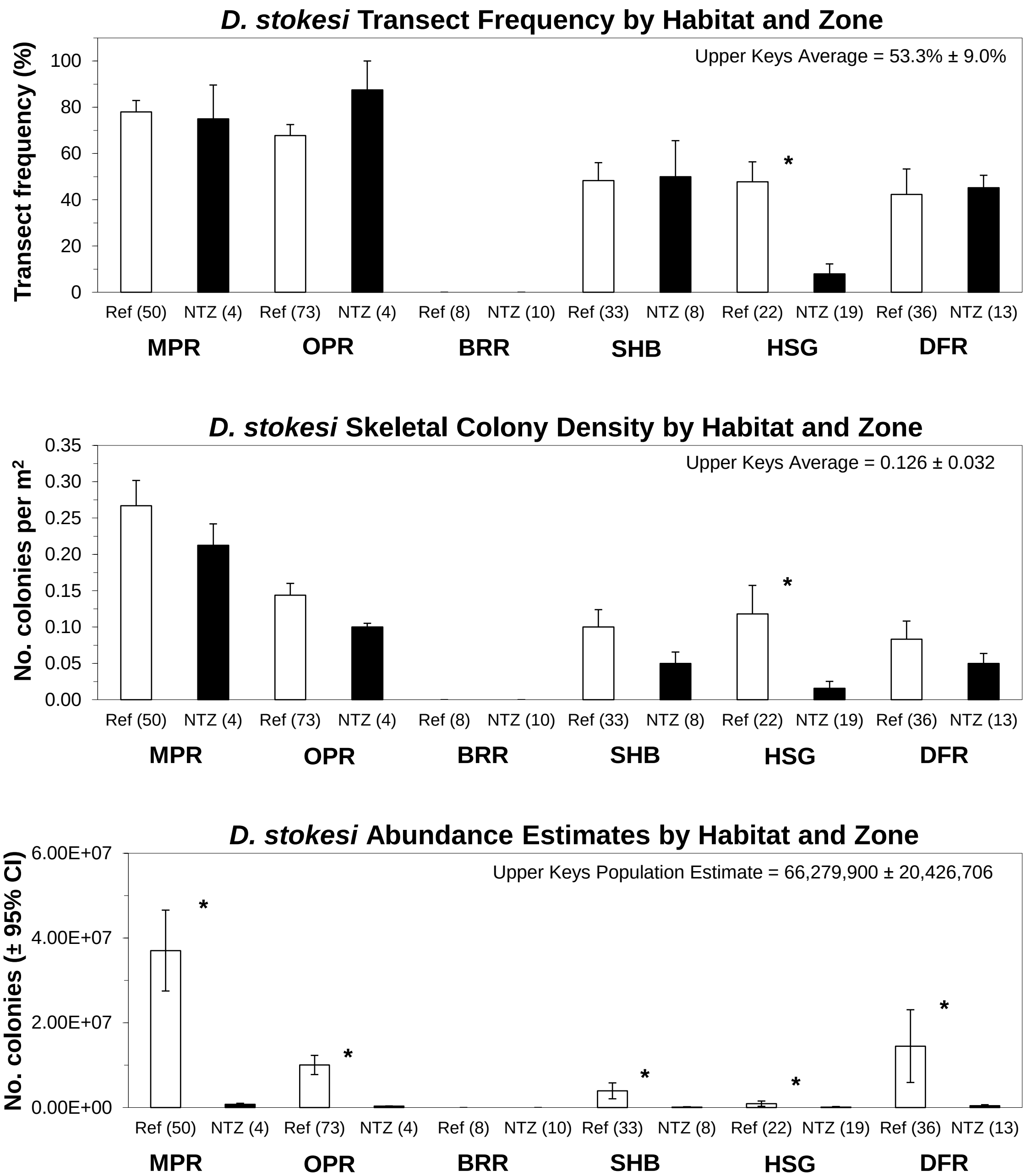


Figure 4-22. Mean (+ 1 SE) transect frequency (top), density (no. per m^2) of skeletal colonies (middle), and total colony abundance estimates (bottom) of the lesser starlet coral (*Siderastrea radians*) by habitat type and management zone in the upper Florida Keys, as determined from surveys of replicate 10-m x 1-m belt transects per site at 280 sites. Open bars = reference areas (Ref), filled bars = no-take zones (NTZ). Upper Keys total values for the top two graphs are weighted averages and standard errors. Habitat abbreviations are: MPR = inshore and mid-channel patch reefs, OPR = offshore patch reefs, BRR = back-reef rubble, SHB = shallow (< 6 m) hard-bottom, HSG = high-relief and groove, and DFR = deeper (6-15 m) fore-reef habitats. Numbers in parentheses on the x-axis are the number of sites surveyed. An asterisk (*) indicates a significant difference (P < 0.05).

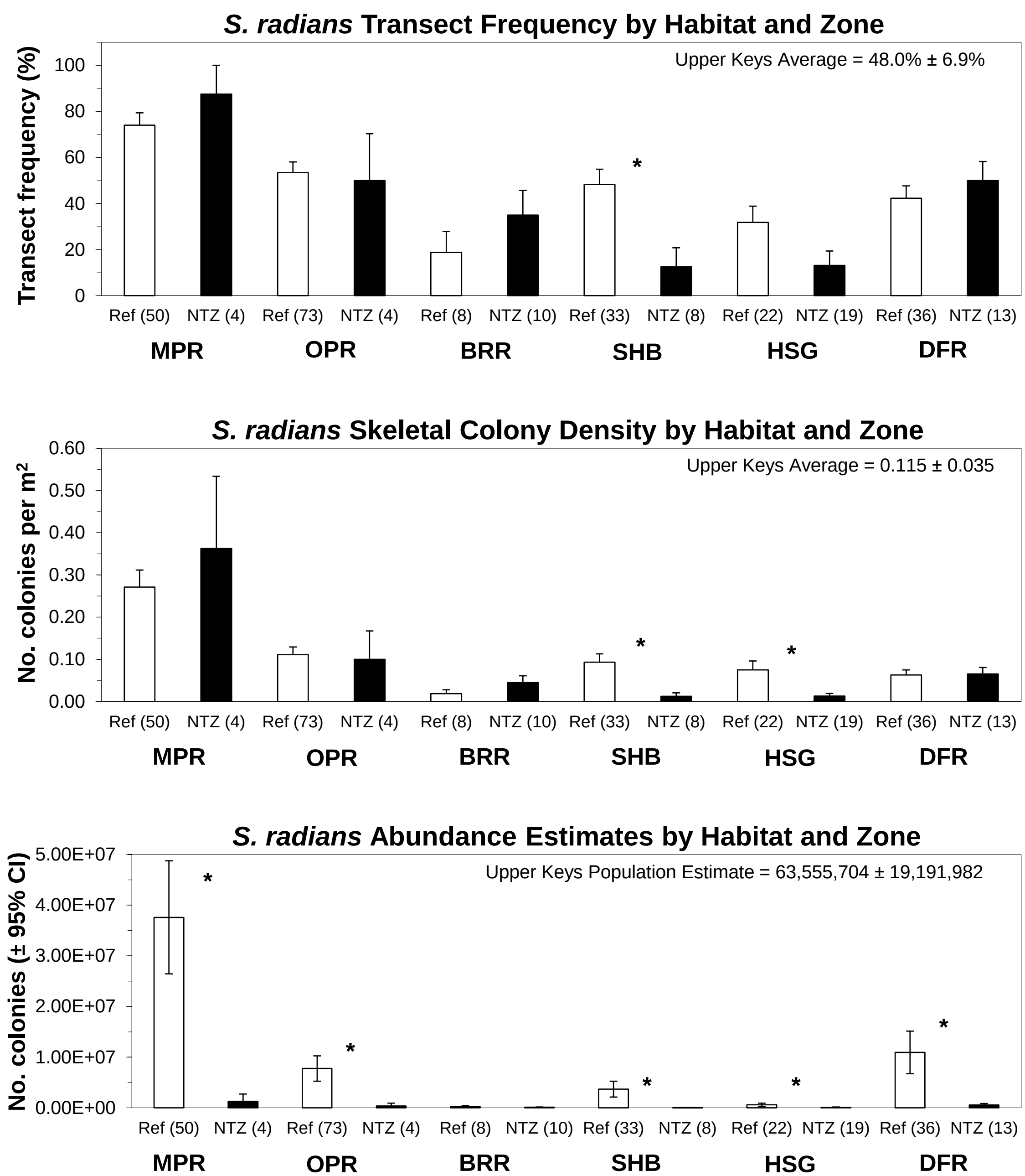
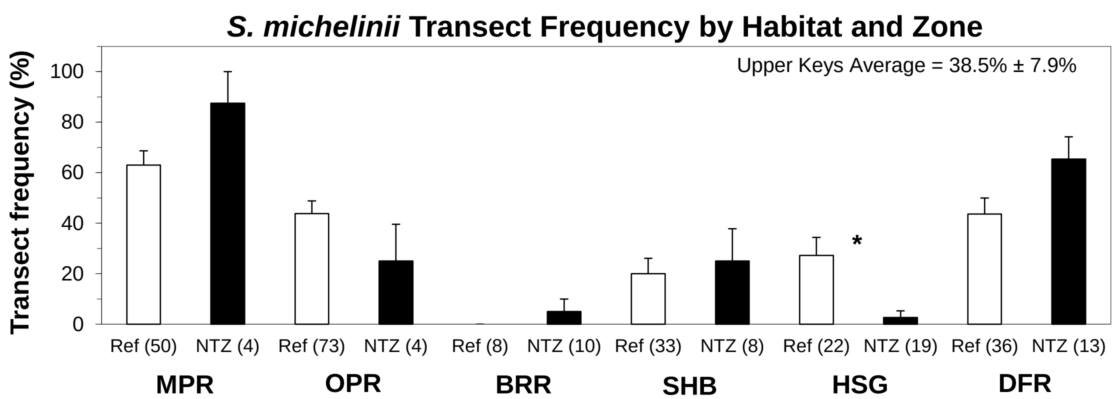
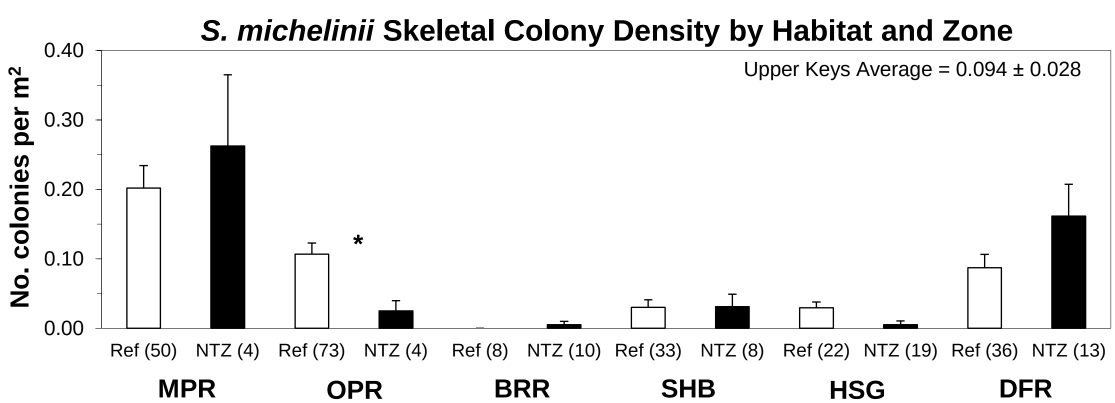


Figure 4-23. Mean (+ 1 SE) transect frequency (top), density (no. per m^2) of skeletal colonies (middle), and total colony abundance estimates (bottom) of the blushing star coral (*Stephanocoenia michelinii*) by habitat type and management zone in the upper Florida Keys, as determined from surveys of replicate 10-m x 1-m belt transects per site at 280 sites. Open bars = reference areas (Ref), filled bars = no-take zones (NTZ). Upper Keys total values for the top two graphs are weighted averages and standard errors. Habitat abbreviations are: MPR = inshore and mid-channel patch reefs, OPR = offshore patch reefs, BRR = back-reef rubble, SHB = shallow (< 6 m) hard-bottom, HSG = high-relief and groove, and DFR = deeper (6-15 m) fore-reef habitats. Numbers in parentheses on the x-axis are the number of sites surveyed. An asterisk (*) indicates a significant difference (P < 0.05).





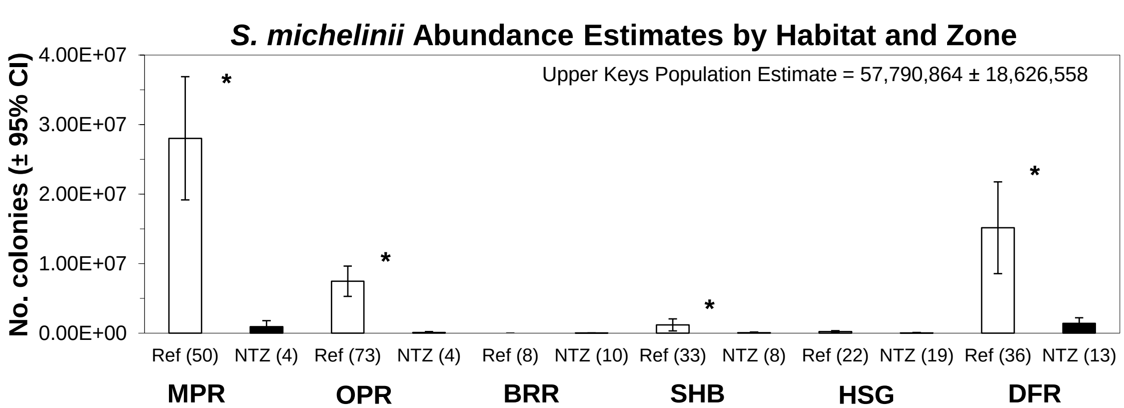
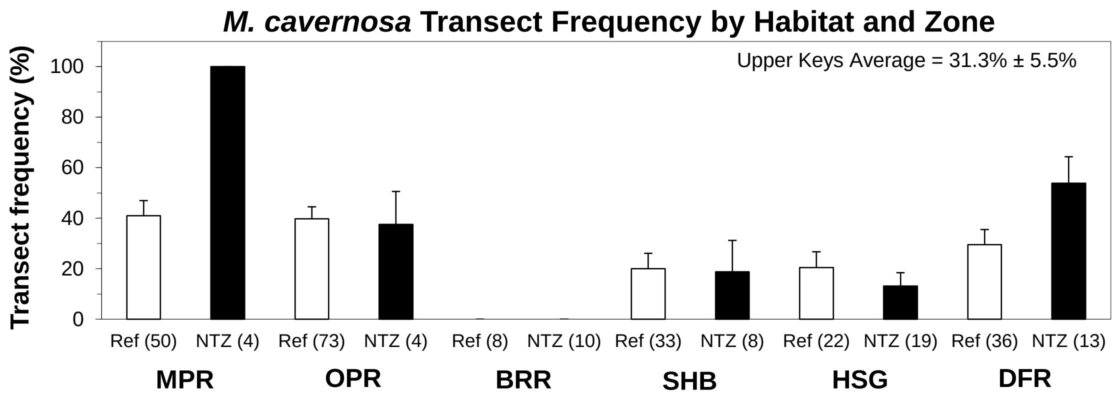
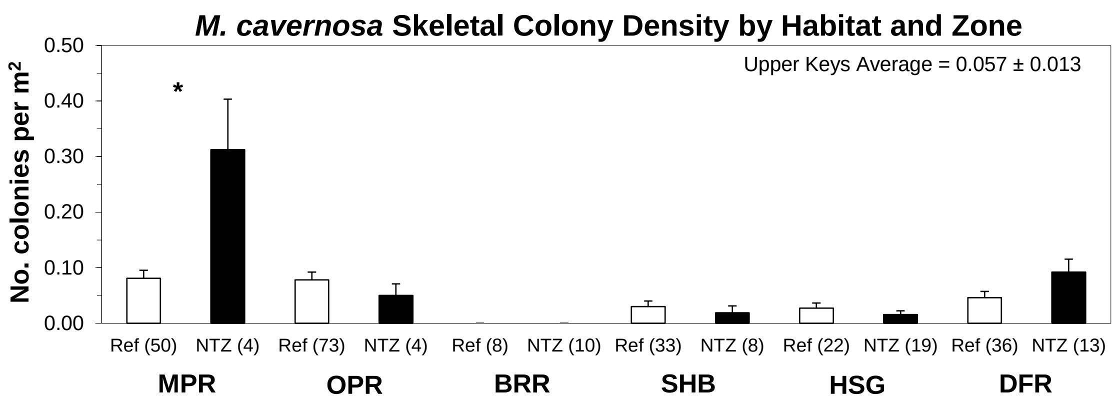


Figure 4-24. Mean (+ 1 SE) transect frequency (top), density (no. per m^2) of skeletal colonies (middle), and total colony abundance estimates (bottom) of the great star coral (*Montastraea cavernosa*) by habitat type and management zone in the upper Florida Keys, as determined from surveys of replicate 10-m x 1-m belt transects per site at 280 sites. Open bars = reference areas (Ref), filled bars = no-take zones (NTZ). Upper Keys total values for the top two graphs are weighted averages and standard errors. Habitat abbreviations are: MPR = inshore and mid-channel patch reefs, OPR = offshore patch reefs, BRR = back-reef rubble, SHB = shallow (< 6 m) hard-bottom, HSG = high-relief and groove, and DFR = deeper (6-15 m) fore-reef habitats. Numbers in parentheses on the x-axis are the number of sites surveyed. An asterisk (*) indicates a significant difference (P < 0.05).





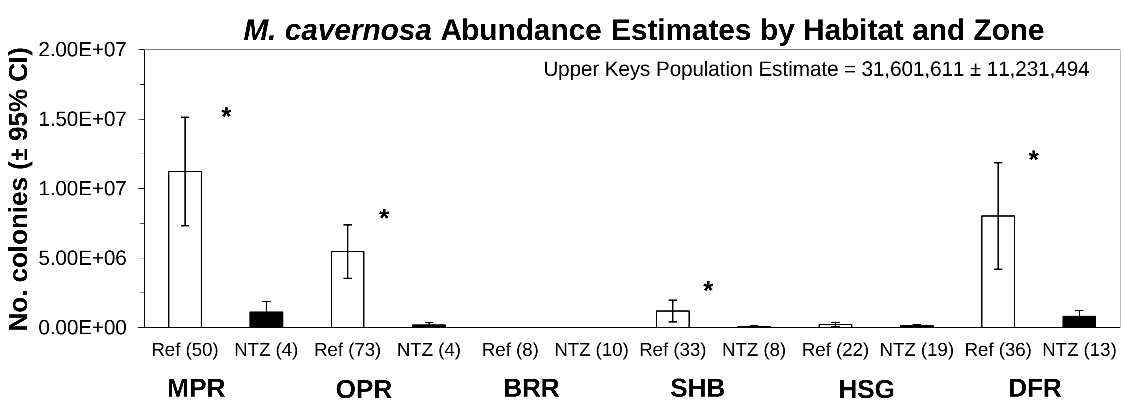


Figure 4-25. Mean (+ 1 SE) transect frequency (top), density (no. per m^2) of skeletal colonies (middle), and total colony abundance estimates (bottom) of the mountainous star coral (*Montastraea faveolata*) by habitat type and management zone in the upper Florida Keys, as determined from surveys of replicate 10-m x 1-m belt transects per site at 280 sites. Open bars = reference areas (Ref), filled bars = no-take zones (NTZ). Upper Keys total values for the top two graphs are weighted averages and standard errors. Habitat abbreviations are: MPR = inshore and mid-channel patch reefs, OPR = offshore patch reefs, BRR = back-reef rubble, SHB = shallow (< 6 m) hard-bottom, HSG = high-relief and groove, and DFR = deeper (6-15 m) fore-reef habitats. Numbers in parentheses on the x-axis are the number of sites surveyed. An asterisk (*) indicates a significant difference (P < 0.05).

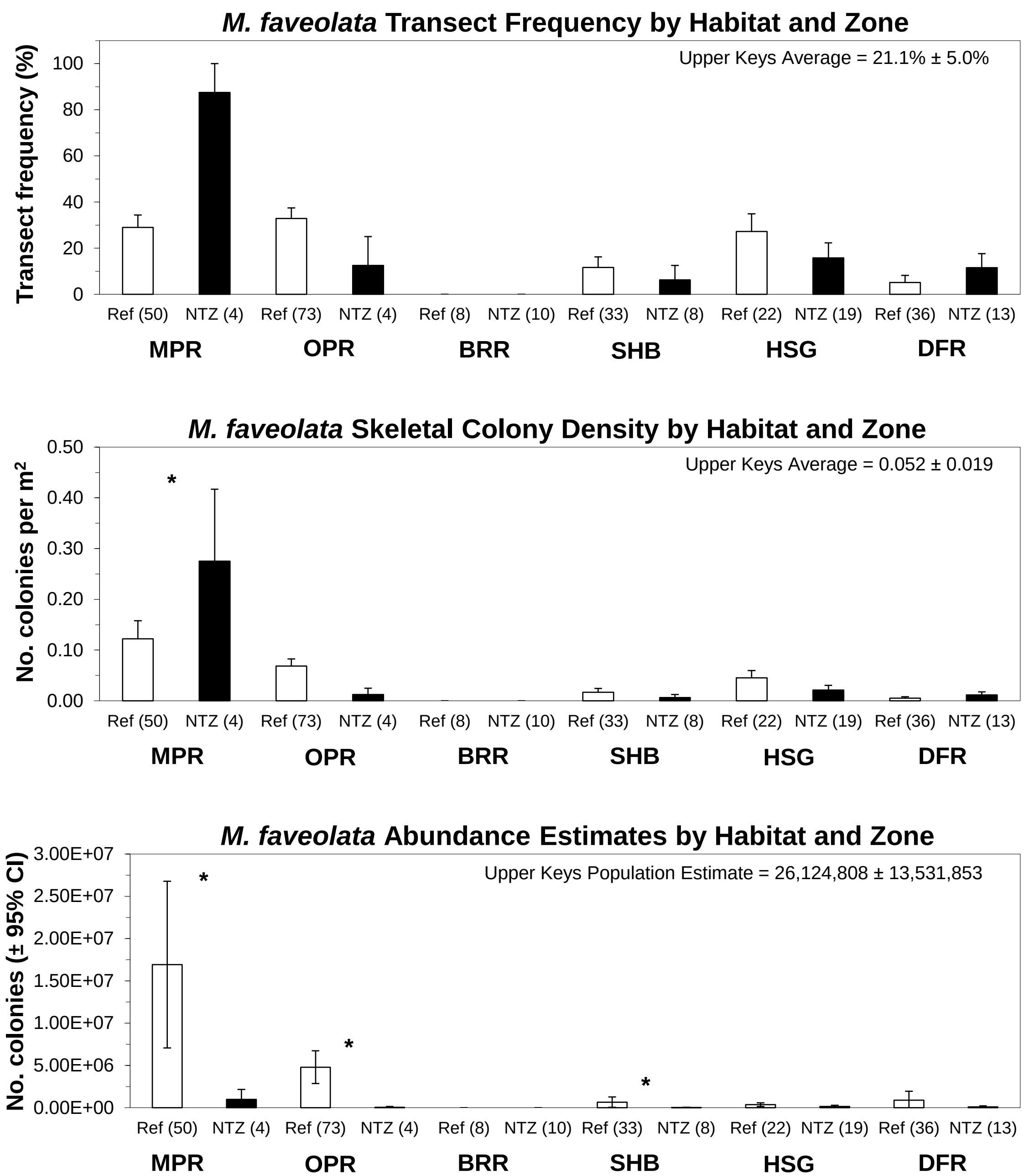
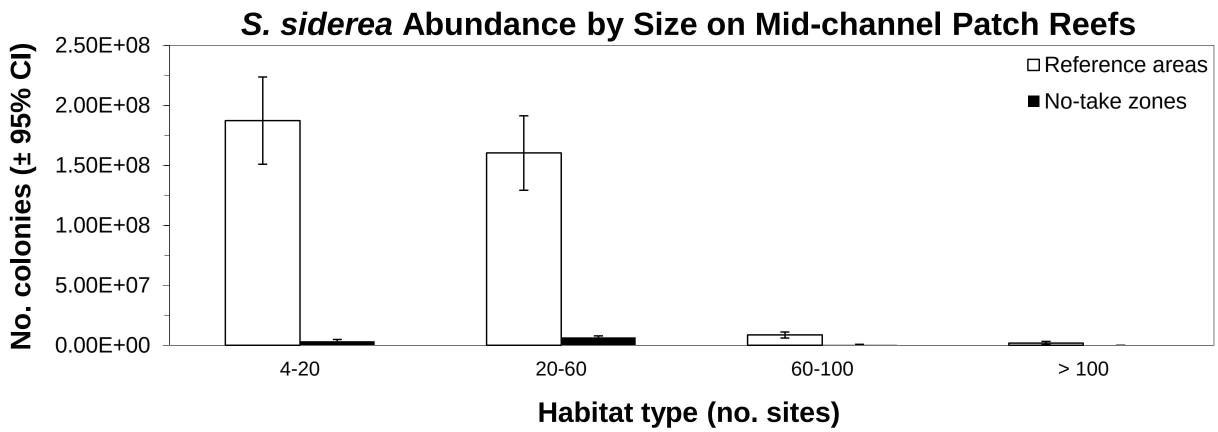
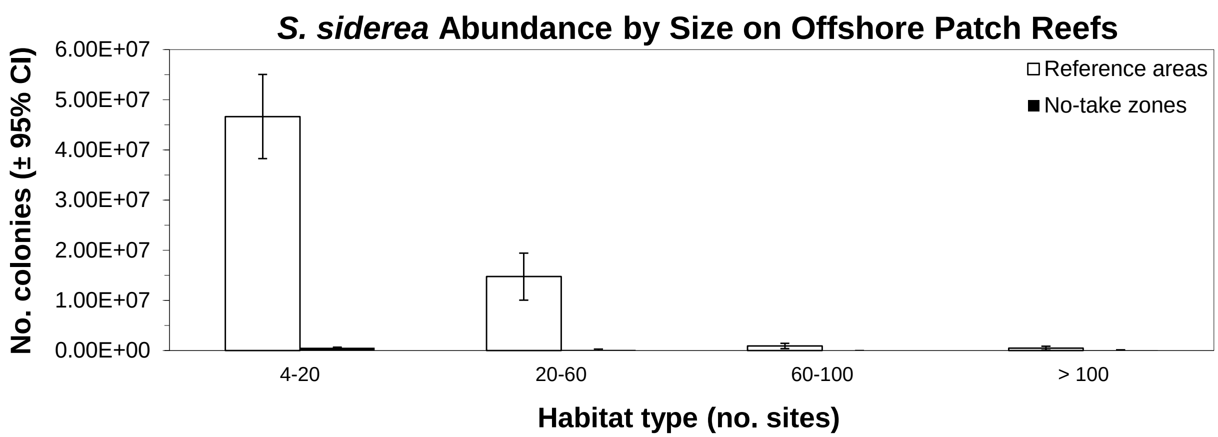


Figure 4-26. Abundance estimates (± 95% CI) of massive starlet coral (*Siderastrea siderea*) by maximum diameter of skeletal colonies in the upper Florida Keys (northern Key Largo to Alligator Reef) between reference areas (open bars) and no-take zones (filled bars) for inshore and mid-channel patch reefs (top), offshore patch reefs (middle), and deeper fore-reef habitats (bottom). Note the scale change for abundance on the y-axis among the three habitat types.





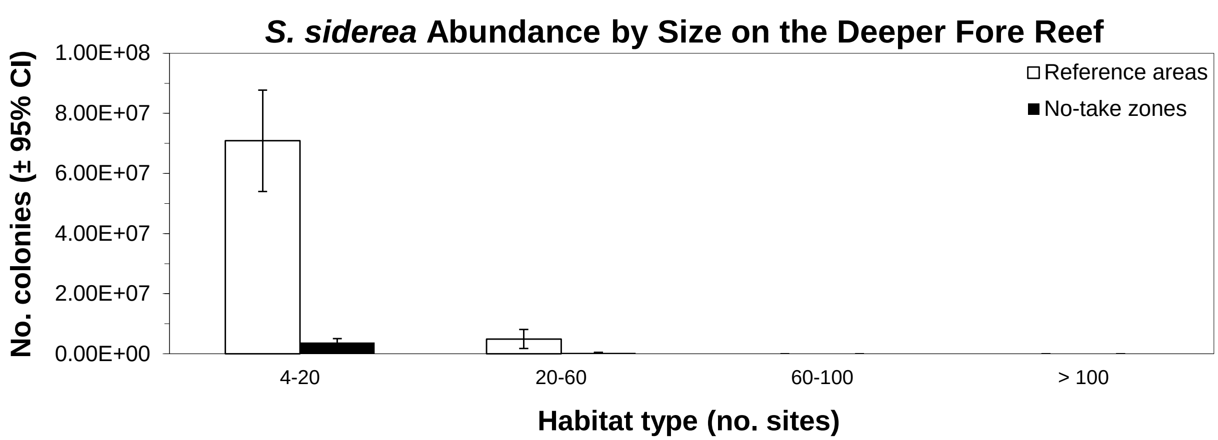


Figure 4-27. Abundance estimates (± 95% CI) of blushing star coral (*Stephanocoenia michelinii*) by maximum diameter of skeletal colonies in the upper Florida Keys (northern Key Largo to Alligator Reef) between reference areas (open bars) and no-take zones (filled bars) for inshore and mid-channel patch reefs (top), offshore patch reefs (middle), and deeper fore-reef habitats (bottom).

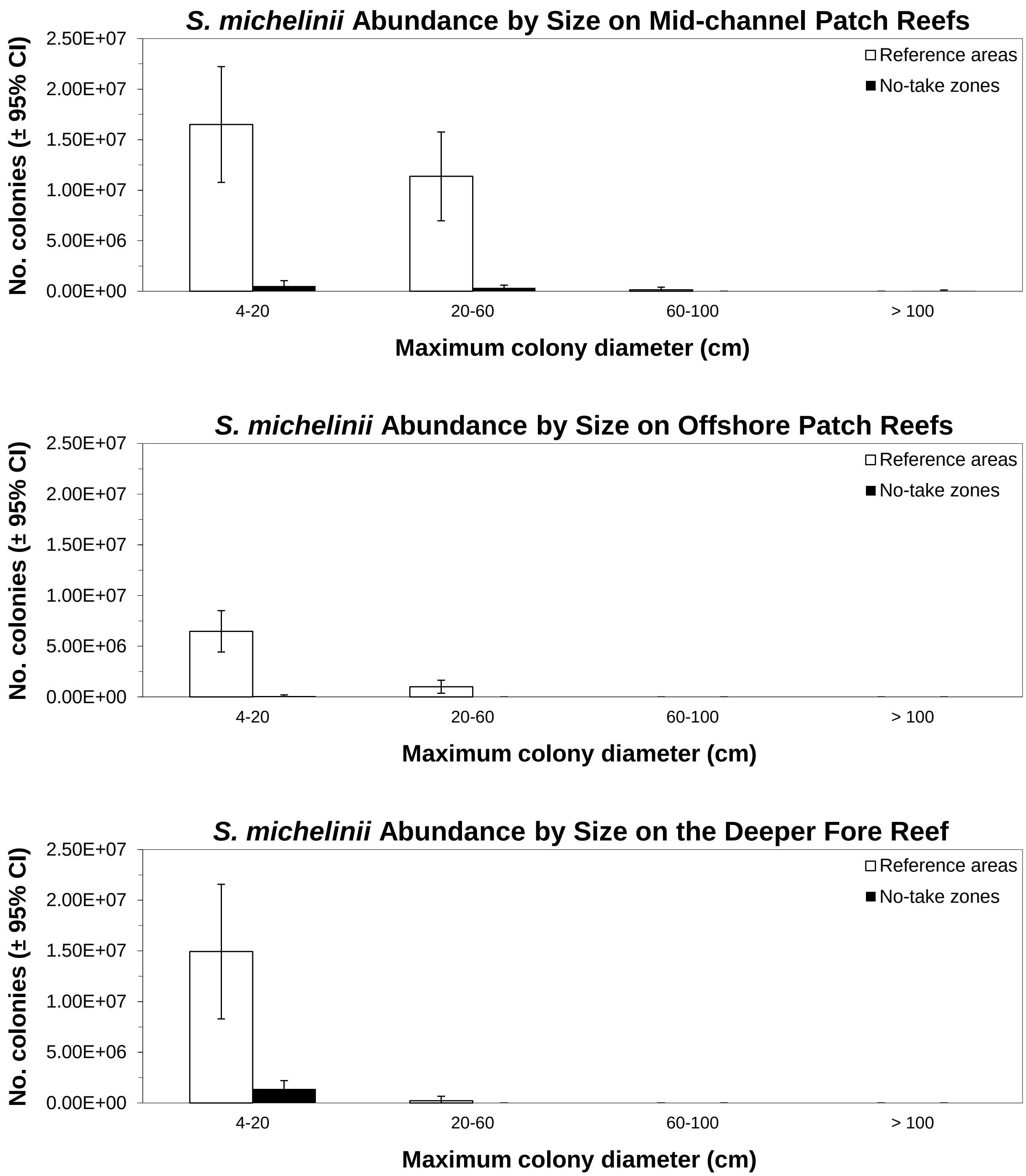


Figure 4-28. Abundance estimates (± 95% CI) of great star coral (*Montastraea cavernosa*) by maximum diameter of skeletal colonies in the upper Florida Keys (northern Key Largo to Alligator Reef) between reference areas (open bars) and no-take zones (filled bars) for inshore and mid-channel patch reefs (top), offshore patch reefs (middle), and deeper fore-reef habitats (bottom).

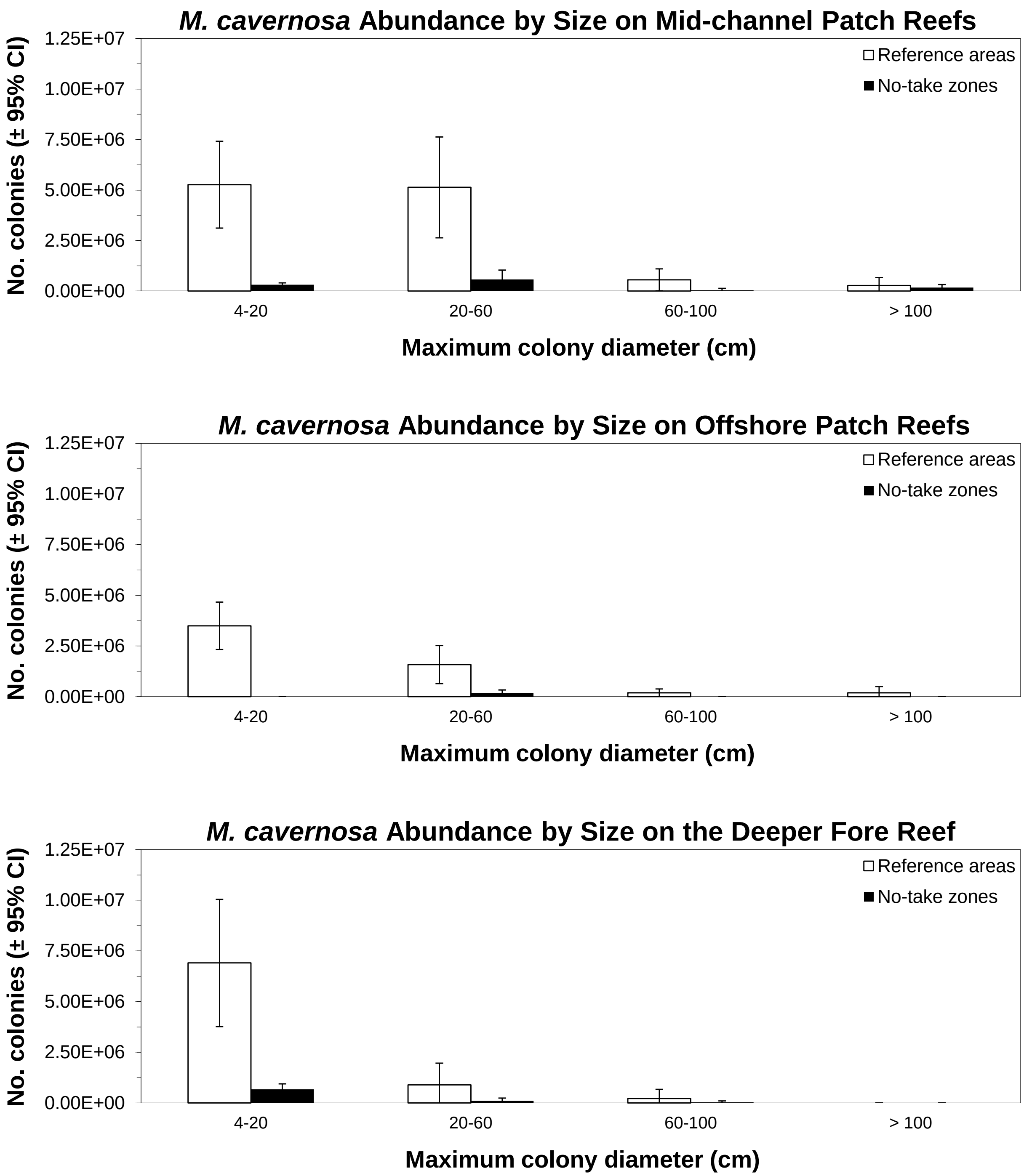


Figure 4-29. Abundance estimates (± 95% CI) of mountainous star coral (*Montastraea faveolata*) by maximum diameter of skeletal colonies in the upper Florida Keys (northern Key Largo to Alligator Reef) between reference areas (open bars) and no-take zones (filled bars) for inshore and mid-channel patch reefs (top), offshore patch reefs (middle), and deeper fore-reef habitats (bottom). Note the scale change for abundance on the y-axis among the three habitat types.

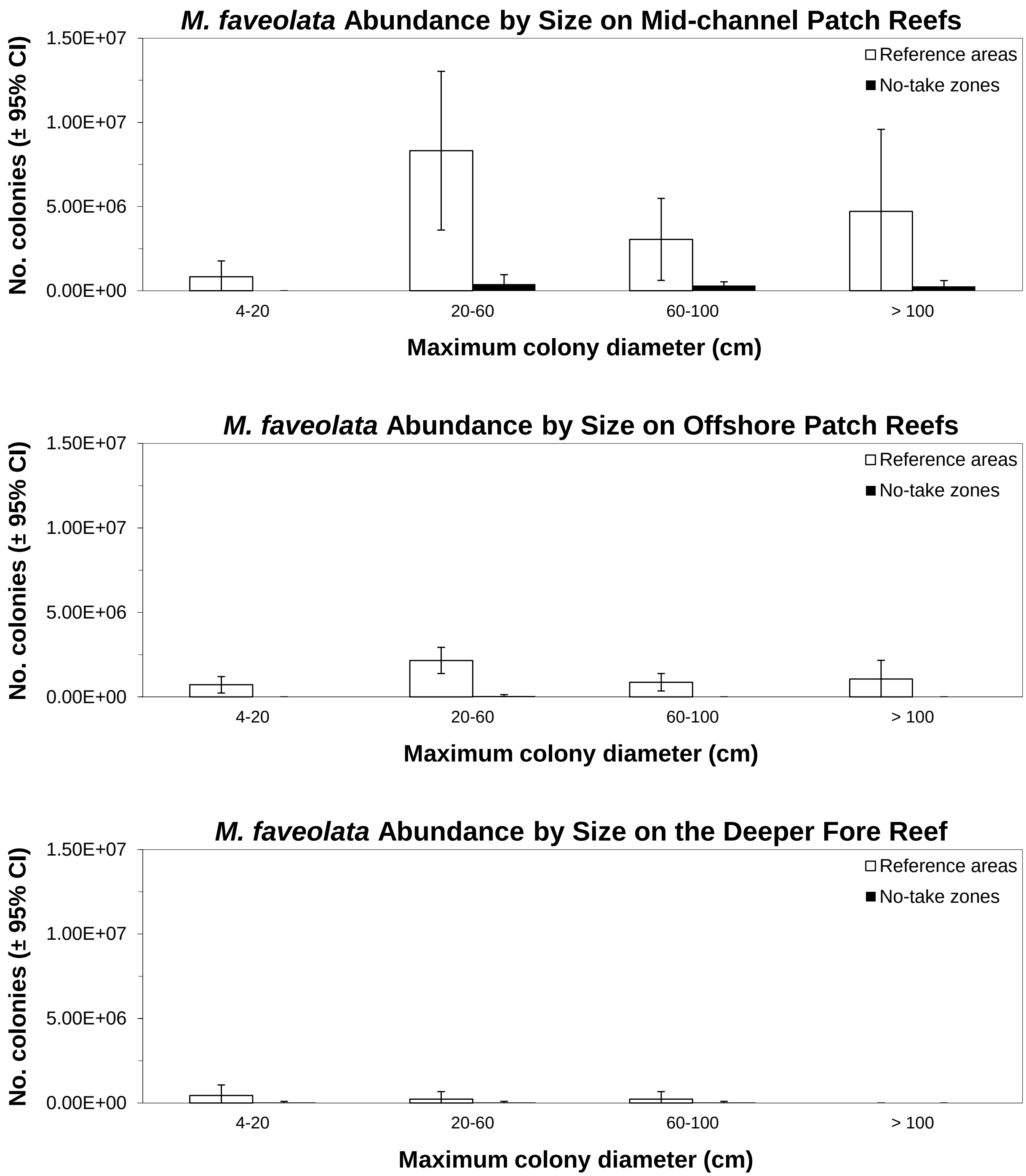


Table 4-1. Sampling effort for scleractinian corals by habitat type and management zone in the upper Florida Keys. The sampling effort included 280 sites from northern Key Largo to Alligator Reef during May-September 2011. Habitat types are arranged from inshore to offshore and no-take zones represent Sanctuary Preservation Areas and Research Only areas.

Habitat/management zone	**Habitat area (km^2)**	**% of Total habitat**	**No. sites**	**Area surveyed (m^2)**	**No. species**	**No. colonies**
Inshore and mid-channel patch reefs						
Reference areas	138.68	29.6	50	1,000	31	5,488
No-take zones	3.56	0.8	4	80	17	505
Habitat total	142.24	30.3	54	1,080	31	5,993
Offshore patch reefs						
Reference area	69.92	14.9	73	1,460	32	5,966
No-take zones	3.60	0.8	4	80	12	145
Habitat total	73.52	15.7	77	1,540	32	6,111
Back-reef rubble						
Reference areas	12.00	2.6	8	160	7	88
No-take zones	2.28	0.5	10	200	8	73
Habitat total	14.28	3.0	18	360	10	161
Shallow (< 6 m) hard-bottom						
Reference areas	39.40	8.4	33	660	23	1,468
No-take zones	2.32	0.5	8	160	13	206
Habitat total	41.72	8.9	41	820	23	1,674
High-relief spur and groove						
Reference areas	7.88	1.7	22	440	27	1,474
No-take zones	6.92	1.5	19	380	18	1,659
Habitat total	14.80	3.2	41	820	27	3,133
Deeper fore reef						
Reference areas	173.84	37.1	36	720	25	2,062
No-take zones	8.68	1.9	13	260	19	581
Habitat total	182.52	38.9	49	980	28	2,643
Total	469.00	100.0	280	5,600	40	19,716

Table 4-2. Site presence (% of sites encountered), mean transect frequency (% of belt transects encountered), abundance estimates (± 1 SE), and relative abundance of all scleractinian coral species (> 4 cm max. diameter) in the upper Florida Keys, as determined from two replicate 10-m x 1-m belt transects surveyed per site at 280 sites from northern Key Largo to Alligator Reef during May-September 2011.

Coral species	**Site presence (%)**	**Transect frequency (%)**	**Total abundance (± 1 SE)**	**Relative abundance (%)**
Acropora cervicornis	21 (7.5)	4.5	3,458,470 ± 1,065,873	0.20
A. palmata	8 (2.9)	2.7	1,017,378 ± 398,587	0.06
Agaricia agaricites	196 (70.0)	62.7	223,163,479 ± 28,127,014	13.05
A. fragilis	29 (10.4)	6.6	5,647,478 ± 1,791,997	0.33
A. humilis	1 (0.4)	0.2	47,890 ± 47,890	0.00
Cladocora arbuscula	2 (0.7)	0.4	277,360 ± 194,140	0.02
Colpophyllia natans	40 (14.3)	8.8	9,675,008 ± 2,263,972	0.57
Dendrogyra cylindrus	1 (0.4)	0.2	65,667 ± 65,666	0.00
Dichocoenia stokesi	184 (65.7)	53.2	68,218,249 ± 6,631,457	3.99
Diploria clivosa	44 (15.7)	9.6	6,284,737 ± 1,491,565	0.37
D. labyrinthiformis	68 (24.3)	15.4	11,330,226 ± 1,693,542	0.66
D. strigosa	7 (2.5)	1.3	656,639 ± 338,767	0.04
Eusmilia fastigiata	49 (17.5)	10.5	7,358,798 ± 1,366,448	0.43
Favia fragum	44 (15.7)	9.5	8,338,311 ± 2,249,410	0.49
Isophyllia sinuosa	3 (1.1)	0.5	1,386,800 ± 1,010,314	0.08
Leptoseris cucullata	17 (6.1)	3.6	2,565,270 ± 654,786	0.15
Madracis decactis	9 (3.2)	1.8	1,184,307 ± 547,171	0.07
M. mirabilis	1 (0.4)	0.2	222,872 ± 222,871	0.01
Manicina areolata	10 (3.6)	2.5	4,065,087 ± 1,912,775	0.24
Meandrina meandrites	44 (15.7)	8.4	6,803,372 ± 1,456,648	0.40
Montastraea annularis	39 (13.9)	9.5	18,593,026 ± 5,472,010	1.09
M. cavernosa	124 (44.3)	31.4	28,359,374 ± 2,974,210	1.66
M. faveolata	87 (31.1)	21.1	24,898,675 ± 5,124,339	1.46
M. franksi	4 (1.4)	0.7	296,870 ± 175,233	0.02
Mycetophyllia aliciae	2 (0.7)	0.4	172,065 ± 142,641	0.01
M. danaana	2 (0.7)	0.5	161,447 ± 114,468	0.01
M. ferox	1 (0.4)	0.2	47,890 ± 47,890	0.00
M. lamarckiana	2 (0.7)	0.4	143,671 ± 106,513	0.01
Mussa angulosa	3 (1.1)	0.5	416,040 ± 235,319	0.02
Oculina diffusa	25 (8.9)	4.8	4,845,699 ± 1,050,656	0.28
Porites astreoides	238 (85.0)	78.6	283,940,305 ± 25,793,823	16.61
Porites porites divaricata	19 (6.8)	4.3	5,215,427 ± 1,824,893	0.31
P. porites furcata	112 (40.0)	30.9	74,999,772 ± 11,785,791	4.39
P. porites porites	234 (83.6)	76.3	221,408,288 ± 18,817,793	12.95
Scolymia spp.	9 (3.2)	1.8	1,317,304 ± 514,328	0.08
Siderastrea radians	188 (67.1)	48.0	63,195,269 ± 6,227,626	3.70
S. siderea	250 (89.3)	82.7	536,740,512 ± 33,364,692	31.40
Solenastrea bournoni	80 (28.6)	19.1	27,111,441 ± 4,313,048	1.59
S. hyades	6 (2.1)	1.3	1,307,527 ± 581,952	0.08
Stephanocoenia michelinii	146 (52.1)	38.8	54,601,339 ± 5,713,321	3.19
All coral species	276 (98.6)	97.7	1,709,587,232 ± 57,413,250	100.00

Table 4-3. Size distribution and relative abundance (%) summary for 20 of the 37 scleractinian coral species (54%) counted and measured in the upper Florida Keys during May-September 2011. All skeletal colonies > 4 cm in maximum diameter were surveyed in two replicate 10-m x 1-m belt transects per site at 280 sites from northern Key Largo to Alligator Reef. The data below represent 19,415 colonies or about 98.6% of all corals measured during 2011. For each species, numbers in parentheses represent the proportion (%) of colonies in a particular size class. For example, 36 colonies or 52.94% of the 68 total staghorn corals (*A. cervicornis*) were 20-60 cm in maximum diameter.

Coral species	**Size class (maximum colony diameter, cm)**				
	4-20 cm	**20-60 cm**	**60-100 cm**	**>100 cm**	**Total**
Acropora cervicornis	32 (47.06)	36 (52.94)	0 (0.00)	0 (0.00)	68 (100)
A. palmata	13 (23.21)	15 (26.79)	7 (12.50)	21 (37.50)	56 (100)
Agaricia agaricites	2,738 (97.13)	81 (2.87)	0 (0.00)	0 (0.00)	2,819 (100)
Colpophyllia natans	19 (18.63)	45 (44.12)	26 (25.49)	12 (11.76)	102 (100)
Dichocoenia stokes	608 (86.12)	90 (12.75)	4 (0.57)	4 (0.57)	706 (100)
Diploria clivosa	34 (36.96)	37 (40.22)	16 (17.39)	5 (5.43)	92 (100)
D. labyrinthiformis	57 (48.31)	57 (48.31)	4 (3.39)	0 (0.00)	118 (100)
Eusmilia fastigiata	83 (94.32)	5 (5.68)	0 (0.00)	0 (0.00)	88 (100)
Favia fragum	93 (100.00)	0 (0.00)	0 (0.00)	0 (0.00)	93 (100)
Meandrina meandrites	45 (59.21)	26 (34.21)	3 (3.95)	2 (2.63)	76 (100)
Montastraea annularis	15 (7.69)	59 (30.26)	40 (20.51)	81 (41.54)	195 (100)
M. cavernosa	196 (60.68)	105 (32.51)	11 (3.41)	11 (3.41)	323 (100)
M. faveolata	28 (9.62)	138 (47.42)	55 (18.90)	70 (24.05)	291 (100)
Porites astreoides	3,711 (90.80)	366 (8.96)	5 (0.12)	5 (0.12)	4,087 (100)
P. porites furcata	738 (82.09)	148 (16.46)	11 (1.22)	2 (0.22)	899 (100)
P. porites porites	2,433 (90.14)	245 (9.08)	4 (0.15)	17 (0.63)	2,699 (100)
Siderastrea radians	639 (99.22)	5 (0.78)	0 (0.00)	0 (0.00)	644 (100)
S. siderea	3,401 (64.13)	1,774 (33.45)	102 (1.92)	26 (0.49)	5,303 (100)
Solenastrea bournoni	147 (65.04)	79 (34.96)	0 (0.00)	0 (0.00)	226 (100)
Stephanocoenia michelinii	412 (77.74)	116 (21.89)	1 (0.19)	1 (0.19)	530 (100)
Total	15,442 (79.54)	3,427 (17.65)	289 (1.49)	257 (1.32)	19,415 (100)

Table 4-4. Abundance (no. colonies) and prevalence (%) of conditions for scleractinian corals in the upper Florida Keys, as determined from two replicate 10-m x 1-m belt transects surveyed per site at 280 sites from northern Key Largo to Alligator Reef during May-September 2011.

Coral Species	**Total abundance (± 1 SE)**	**Active bleaching**	**Active disease**	***Cliona* sponges present**	***Coralliophila* snail grazing**	**Active overgrowth**
Acropora cervicornis	3,458,470 ± 1,065,873	0 (0)	0 (0%)	0 (0%)	0 (0%)	113,690 (3.29%)
A. palmata	1017,378 ± 398,587	17,909 (1.76%)	0 (0%)	163,895 (16.11%)	0 (0%)	0 (0%)
Agaricia agaricites	223,163,479 ± 28,127,014	3,519,207 (1.58%)	4,242,190 (1.90%)	452,433 (0.20%)	6,444,246 (2.89%)	3,254,891 (1.46%)
A. fragilis	5,647,478 ± 1,791,997	0 (0%)	0 (0%)	0 (0%)	0 (0%)	47,890 (0.85%)
A. humilis	47,890 ± 47,890	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)
Cladocora arbuscula	277,360 ± 194,140	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)
Colpophyllia natans	9,675,008 ± 2,263,972	0 (0%)	0 (0%)	186,570 (1.93%)	227,680 (2.35%)	44,500 (0.46%)
Dendrogyra cylindrus	65,667 ± 65,666	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)
Dichocoenia stokesi	68,218,249 ± 6,631,457	500,232 (0.73%)	138,680 (0.20%)	277,360 (0.41%)	577,028 (0.85%)	764,499 (1.12%)
Diploria clivosa	6,284,737 ± 1,491,565	0 (0%)	0 (0%)	138,680 (2.21%)	296,444 (4.72%)	408,826 (6.51%)
D. labyrinthiformis	11,330,226 ± 1,693,542	416,040 (3.67%)	0 (0%)	379,762 (3.35%)	179,489 (1.58%)	325,250 (2.87%)
D. strigosa	656,639 ± 338,767	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)
Eusmilia fastigiata	7,358,798 ± 1,366,448	0 (0%)	325,250 (4.42%)	0 (0%)	0 (0%)	0 (0%)
Favia fragum	8,338,311 ± 2,249,410	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)
Isophyllia sinuosa	1,386,800 ± 1,010,314	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)
Leptoseris cucullata	2,565,270 ± 654,786	143,671 (5.60%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)
Madracis decactis	1,184,307 ± 547,171	0 (0%)	47,890 (4.04%)	0 (0%)	0 (0%)	47,890 (4.04%)
M. mirabilis	222,872 ± 222,871	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)
Manicina areolata	4,065,087 ± 1,912,775	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)
Meandrina meandrites	6,803,372 ± 1,456,648	0 (0%)	0 (0%)	0 (0%)	0 (0%)	172,065 (2.53%)
Montastraea annularis	18,593,026 ± 5,472,010	47,890 (0.26%)	416,040 (2.24%)	970,760 (5.22%)	140,781 (0.76%)	541,404 (2.91%)
M. cavernosa	28,359,374 ± 2,974,210	17,909 (0.06%)	92,390 (0.33%)	295,269 (1.04%)	95,781 (0.34%)	129,165 (0.46%)
M. faveolata	24,898,675 ± 5,124,339	0 (0%)	44,500 (0.18%)	711,611 (2.86%)	821,037 (3.30%)	138,680 (0.56%)
Montastraea franksi	296,870 ± 175,233	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)
Mussa angulosa	416,040 ± 235,319	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)
Mycetophyllia aliciae	172,065 ± 142,641	0 (0%)	0 (0%)	0 (0%)	33,385 (19.40%)	0 (0%)
M. danaana	161,447 ± 114,468	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)
M. ferox	47,890 ± 47,890	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)
M. lamarckiana	143,671 ± 106,513	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)
Oculina diffusa	4,845,699 ± 1,050,656	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)
Porites astreoides	283,940,305 ± 25,793,823	373,071 (0.13%)	47,890 (0.02%)	2,631,206 (0.93%)	18,211 (0.01%)	8,447,325 (2.98%)
P. porites divaricata	5,215,427 ± 1,824,893	0 (0%)	0 (0%)	0 (0%)	17,909 (0.34%)	275,005 (5.27%)
P. porites furcata	74,999,772 ± 11,785,791	5,839,852 (7.79%)	47,890 (0.06%)	0 (0%)	0 (0%)	4,090,352 (5.45%)
P. porites porites	221,408,288 ± 18,817,793	4,962,937 (2.24%)	0 (0%)	650,210 (0.29%)	0 (0%)	9,664,716 (4.37%)
Scolymia spp.	1,317,304 ± 514,328	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)
Siderastrea radians	63,195,269 ± 6,227,626	1,518,009 (2.40%)	113,557 (0.18%)	138,680 (0.22%)	0 (0%)	328,654 (0.52%)
S. siderea	536,740,512 ± 33,364,692	8,026,586 (1.50%)	3,697,209 (0.69%)	8,654,851 (1.61%)	237,864 (0.04%)	21,605,807 (4.03%)
Solenastrea bournoni	27,111,441 ± 4,313,048	409,442 (1.51%)	204,347 (0.75%)	270,762 (1.00%)	138,680 (0.51%)	475,109 (1.75%)
S. hyades	1,307,527 ± 581,952	138,680 (10.61%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)
Stephanocoenia michelinii	54,601,339 ± 5,713,321	457,333 (0.84%)	3,587,665 (6.57%)	533,616 (0.98%)	0 (0%)	1,686,796 (3.09%)
All coral species	1,709,587,232 ± 57,413,250	26,388,770 (1.54%)	13,005,499 (0.76%)	16,455,666 (0.96%)	9,228,535 (0.54%)	52,562,515 (3.07%)

Table 4-5. Summary of numbers of scleractinian coral colonies (> 4 cm max. diameter) and relative abundance (%) by habitat type in the upper Florida Keys, as determined from two replicate 10-m x 1-m belt transects surveyed per site at 280 sites from northern Key Largo to Alligator Reef during May-September 2011. Habitat types are arranged from inshore to offshore. Habitat abbreviations are: IPR/MPR = inshore and mid-channel patch reefs, OPR = offshore patch reefs, BRR = back-reef rubble, SHB = shallow (< 6 m) hard-bottom, IRT/HSG = inner line reef tract and high-relief spur and groove, and DFR = deeper fore reef. See Table 4-1 for the sampling effort by habitat type.

Coral species	**IPR/MPR**	**OPR**	**BRR**	**SHB**	**IRT/HSG**	**DFR**
Acropora cervicornis	5 (0.08)	26 (0.43)		17 (1.02)	20 (0.64)	
A. palmata					56 (1.79)	
Agaricia agaricites	275 (4.59)	905 (14.82)	2 (1.24)	132 (7.89)	834 (26.62)	673 (25.46)
A. fragilis	4 (0.07)	31 (0.51)		1 (0.06)	11 (0.35)	15 (0.57)
A. humilis	1 (0.02)					
Cladocora arbuscula	2 (0.03)					
Colpophyllia natans	82 (1.37)	13 (0.21)		1 (0.06)	3 (0.10)	3 (0.11)
Dendrogyra cylindrus				1 (0.06)		
Dichocoenia stokesi	284 (4.74)	218 (3.57)		72 (4.30)	58 (1.85)	74 (2.80)
Diploria clivosa	23 (0.38)	26 (0.43)	1 (0.62)	27 (1.61)	13 (0.41)	2 (0.08)
D. labyrinthiformis	65 (1.08)	27 (0.44)		2 (0.12)	13 (0.41)	11 (0.42)
D. strigosa	4 (0.07)	1 (0.02)			3 (0.10)	
Eusmilia fastigiata	28 (0.47)	41 (0.67)	1 (0.62)	2 (0.12)	6 (0.19)	10 (0.38)
Favia fragum	47 (0.78)	11 (0.18)	3 (1.86)	6 (0.36)	22 (0.70)	4 (0.15)
Isophyllia sinuosa	10 (0.17)					
Leptoseris cucullata		17 (0.28)			7 (0.22)	8 (0.30)
Madracis decactis		9 (0.15)			1 (0.03)	5 (0.19)
M. mirabilis						1 (0.04)
Manicina areolata	27 (0.45)	6 (0.10)				1 (0.04)
Meandrina meandrites	6 (0.10)	40 (0.65)		8 (0.48)	3 (0.10)	19 (0.72)
Montastraea annularis	119 (1.99)	61 (1.00)			13 (0.41)	2 (0.08)
M. cavernosa	106 (1.77)	118 (1.93)		22 (1.31)	18 (0.57)	59 (2.23)
M. faveolata	144 (2.40)	101 (1.65)		7 (0.42)	28 (0.89)	11 (0.42)
M. franksi	2 (0.03)	2 (0.03)			1 (0.03)	
Mussa angulosa	3 (0.05)					
Mycetophyllia aliciae	1 (0.02)					1 (0.04)
M. danaana		2 (0.03)				1 (0.04)
M. ferox		1 (0.02)				
M. lamarckiana		3 (0.05)				
Oculina diffusa	32 (0.53)	5 (0.08)		4 (0.24)		
Porites astreoides	644 (10.74)	1,174 (19.21)	75 (46.58)	447 (26.70)	1,233 (39.36)	514 (19.45)
P. porites divaricata	6 (0.10)	15 (0.25)		6 (0.36)	8 (0.26)	17 (0.64)
P. porites furcata	78 (1.30)	510 (8.35)	13 (8.07)	115 (6.87)	31 (0.99)	152 (5.75)
P. porites porites	505 (8.43)	1,030 (16.86)	48 (29.81)	371 (22.16)	326 (10.41)	419 15.85)
Scolymia spp.	5 (0.08)	8 (0.13)			1 (0.03)	1 (0.04)
Siderastrea radians	300 (5.01)	170 (2.78)	12 (7.45)	68 (4.06)	38 (1.21)	56 (2.12)
S. siderea	2,821 (47.06)	1,328 (21.73)	5 (3.11)	334 (19.95)	370 (11.81)	445 (16.84)
Solenastrea bournoni	139 (2.32)	53 (0.87)		7 (0.42)	1 (0.03)	26 (0.98)
S. hyades	3 (0.05)			2 (0.12)		2 (0.08)
Stephanocoenia michelinii	223 (3.72)	158 (2.59)	1 (0.62)	22 (1.31)	15 (0.48)	111 (4.20)
Total	5,994 (100)	6,110 (100)	161 (100)	1,674 (100)	3,133 (100)	2,643 (100)

Table 4-6. Summary of significant differences in mean transect frequency, density (no. colonies per m^2), and colony abundance estimates among habitat types for the top 20 most abundant scleractinian coral species surveyed during May-September 2011 in the upper Florida Keys. Habitat type abbreviations are: IPR/MPR = inshore and mid-channel patch reefs, OPR = offshore patch reefs, BRR = back-reef rubble, SHB = shallow (< 6 m) hard-bottom, IRT/HSG = inner line reef tract and high-relief spur and groove, and DFR = deeper fore reef. ns = not significant at the adjusted alpha-level comparison (a_{adj} = 0.0033).

Coral species	Transect frequency	Mean colony density	Total colony abundance
Acropora cervicornis	ns	ns	ns
A. palmata	HSG > all other habitats	ns	ns
Agaricia agaricites	OPR, HSG > MPR, BRR, SHB DFR > MPR, BRR SHB > BRR	HSG > MPR, BRR, SHB OPR > BRR, SHB SHB, DFR > BRR	OPR > SHB, HSG DFR > BRR, SHB, HSG SHB, HSG > BRR
Colpophyllia natans	MPR > BRR, SHB, HSG, DFR OPR > BRR	MPR > BRR, SHB, HSG, DFR OPR > RUBB	MPR > all other habitats OPR > BRR
Dichocoenia stokesi	MPR > BRR, HSG, DFR OPR > BRR, HSG SHB, HSG, DFR > BRR	MPR > BRR, SHB, HSG, DFR OPR, SHB, HSG, DFR > BRR	MPR > OPR, BRR, SHB, HSG OPR > BRR, SHB, HSG DFR > BRR, HSG SHB, HSG > BRR
Diploria clivosa	ns	ns	OPR > BRR
D. labyrinthiformis	MPR > SHB, DFR OPR, HSG > BRR	MPR > BRR, SHB, DFR OPR, HSG > BRR	MPR > OPR, BRR, SHB, HSG OPR > BRR, SHB, HSG HSG > BRR
Eusmilia fastigiata	ns	ns	MPR, OPR > BRR, HSG
Favia fragum	ns	ns	ns
Meandrina meandrites	OPR, DFR > BRR	DFR > BRR	DFR > BRR, HSG
Montastraea annularis	MPR > BRR, SHB, HSG, DFR OPR > BRR, SHB	MPR > BRR	MPR > BRR, SHB
M. cavernosa	All other habitats > BRR	MPR > BRR, HSG OPR, SHB, HSG, DFR > BRR	MPR, OPR, DFR > BRR, SHB, HSG SHB, HSG > BRR
M. faveolata	MPR, OPR > BRR, DFR HSG > BRR	MPR, OPR > BRR, DFR HSG > BRR	MPR > BRR, SHB, HSG, DFR OPR > SHB, HSG HSG > BRR
Porites astreoides	OPR > BRR	HSG > BRR, DFR	MPR, OPR, DFR > BRR, HSG HSG > BRR
P. porites furcata	OPR, DFR > HSG	OPR > BRR, HSG	OPR, DFR > BRR, HSG
P. porites porites	OPR > MPR	OPR, SHB, DFR > BRR	MPR, OPR > BRR, HSG DFR > BRR, SHB, HSG SHB > BRR, HSG
Siderastrea radians	MPR > BRR, SHB, HSG, DFR OPR > HSG	MPR > BRR, SHB, HSG, DFR	MPR > all other habitats OPR, DFR > BRR, HSG SHB > BRR

Coral species	Transect frequency	Mean colony density	Total colony abundance
S. siderea	MPR > BRR, SHB OPR, SHB, HSG, DFR > BRR	MPR > all other habitats OPR > BRR, DFR SHB, HSG, DFR > BRR	MPR > all other habitats OPR, DFR > BRR, SHB, HSG SHB, HSG > BRR
Solenastrea bournoni	MPR > BRR, SHB, HSG, DFR OPR > BRR, HSG DFR > BRR	MPR > BRR, SHB, HSG, DFR OPR > BRR, HSG DFR > BRR	MPR > OPR, BRR, SHB, HSG OPR, DFR > BRR, HSG
Stephanocoenia michelinii	MPR > BRR, SHB, HSG OPR > BRR DFR > BRR, HSG	MPR > BRR, SHB, HSG OPR, DFR > BRR, HSG	MPR > OPR, BRR, SHB, HSG OPR, DFR > BRR, SHB, HSG
All scleractinian species	ns	MPR > SHB, DFR BRR < all other habitats	MPR > all other habitats All other habitats > BRR OPR, DFR > BRR, SHB, HSG

Table 4-7. Summary of significant differences in mean transect frequency, density (no. colonies per m^2), and colony abundance estimates among between no-take zones and reference areas by habitat type for the top 20 most abundant scleractinian coral species surveyed during May-September 2011 in the upper Florida Keys. Habitat type abbreviations are: IPR/MPR = inshore and mid-channel patch reefs, OPR = offshore patch reefs, BRR = back-reef rubble, SHB = shallow (< 6 m) hard-bottom, IRT/HSG = inner line reef tract and high-relief spur and groove, and DFR = deeper fore reef. An open triangle (Δ) indicates a significantly greater (P < 0.05) value in no-take zones, while an up-side down triangle (▼) indicates a significantly greater value in reference areas.

Coral species	Habitat type	Transect frequency	Mean colony density	Total colony abundance
Acropora cervicornis	OPR	▼	▼	▼
	SHB	▼		▼
A. palmata	IRT/HSG			
Agaricia agaricites	IPR/MPR			▼
	OPR			▼
	SHB			▼
	IRT/HSG	Δ	Δ	
	DFR			▼
Colpophyllia natans	IPR/MPR	Δ	Δ	▼
	OPR	▼	▼	▼
Dichocoenia stokesi	IPR/MPR			▼
	OPR			▼
	SHB			▼
	IRT/HSG	▼	▼	▼
	DFR			▼
Diploria clivosa	IPR/MPR			▼
	OPR	▼	▼	▼
D. labyrinthiformis	IPR/MPR			▼
	OPR			▼
Eusmilia fastigiata	IPR/MPR			▼
	OPR			▼
	DFR			▼
Favia fragum	IPR/MPR			▼
	OPR	▼	▼	▼
	DFR			▼
Meandrina meandrites	IPR/MPR	▼	▼	▼
	OPR	▼	▼	▼
	SHB	▼	▼	▼
	DFR			▼
Montastraea annularis	IPR/MPR			▼
	OPR			▼
M. cavernosa	IPR/MPR		Δ	▼
	OPR			▼
	SHB			▼
	DFR			▼
M. faveolata	IPR/MPR		Δ	▼
	OPR			▼
	SHB			▼

Coral species	Habitat type	Transect frequency	Mean colony density	Total colony abundance
Porites astreoides	IPR/MPR	Δ		▼
	OPR			▼
	SHB			▼
	IRT/HSG	Δ	Δ	
	DFR			▼
P. porites furcata	IPR/MPR	▼	▼	▼
	OPR	▼	▼	▼
	SHB		▼	▼
	DFR		▼	▼
P. porites porites	IPR/MPR		▼	▼
	OPR	Δ		▼
	BRR			▼
	SHB			▼
	DFR			▼
Siderastrea radians	IPR/MPR			▼
	OPR			▼
	SHB	▼	▼	▼
	IRT/HSG		▼	▼
	DFR			▼
S. siderea	IPR/MPR			▼
	OPR	Δ	▼	▼
	SHB			▼
	IRT/HSG		▼	▼
	DFR			▼
Solenastrea bournoni	IPR/MPR	▼	▼	▼
	OPR	▼	▼	▼
	SHB	▼	▼	▼
	DFR		▼	▼
Stephanocoenia michelinii	IPR/MPR			▼
	OPR		▼	▼
	SHB			▼
	IRT/HSG	▼		
	DFR			▼
All scleractinian species	IPR/MPR			▼
	OPR		▼	▼
	BRR			▼
	SHB			▼
	IRT/HSG			
	DFR			▼

Table 4-8. Mean colony density (no. per m^2) and total abundance estimates of all stony coral species (> 4 cm max. diameter) by habitat type and management zone in the upper Florida Keys, as determined from surveys of two replicate 10-m x 1-m belt transects per site at 280 sites from northern Key Largo to Alligator Reef during May-September 2011. Habitat types are arranged from inshore to offshore and no-take zones represent Sanctuary Preservation Areas and Research Only areas. SE = standard error, 95% CI = 95% confidence interval.

All scleractinian coral species (40 taxa)

Habitat/management zone (no. sites)	Mean density (no. per m^2)	SE	Abundance (total colonies)	95% CI (total colonies)
Inshore and mid-channel patch reefs				
Reference areas (50)	5.488	0.491	761,075,840	135,063,719
No-take zones (4)	6.325	0.642	22,517,000	5,401,139
Habitat total (54)	5.550	0.457	789,432,000	128,824,994
Offshore patch reefs				
Reference areas (73)	4.087	0.262	285,762,082	36,258,516
No-take zones (4)	1.813	0.400	6,525,000	3,405,480
Habitat total (77)	3.969	0.256	291,788,468	37,134,052
Back-reef rubble				
Reference areas (8)	0.550	0.161	6,600,000	4,111,102
No-take zones (10)	0.365	0.097	832,200	463,059
Habitat total (18)	0.447	0.090	6,386,333	2,618,389
Shallow (< 6 m) hard-bottom				
Reference areas (33)	2.537	0.401	99,944,667	31,621,221
No-take zones (8)	1.350	0.254	3,132,000	1,255,738
Habitat total (41)	2.287	0.328	95,407,053	27,290,128
High-relief spur and groove				
Reference areas (22)	3.350	0.357	26,398,000	5,669,311
No-take zones (19)	4.366	0.311	30,211,263	4,364,271
Habitat total (41)	3.821	0.249	56,546,829	7,320,831
Deeper fore reef				
Reference areas (36)	2.574	0.307	447,526,564	106,129,612
No-take zones (13)	2.196	0.407	19,062,615	7,269,108
Habitat total (49)	2.480	0.251	452,614,500	90,921,206

Table 4-9. Transect frequency (%), total colony density (no. per m^2), and density by size class (max. diameter) of the massive starlet coral (*Siderastrea siderea*) by habitat type and management zone in the upper Florida Keys, as determined from surveys of two replicate 10-m x 1-m belt transects per site at 280 sites from northern Key Largo to Alligator Reef during May-September 2011. Habitat types are arranged from inshore to offshore and no-take zones represent Sanctuary Preservation Areas and Research Only areas. Values represent mean ± 1 SE. Only corals with a maximum diameter > 4 cm were surveyed.

Siderastrea siderea **(Ellis and Solander) (massive starlet coral)**

Habitat/management zone (no. sites)	**Frequency (%)**	**Density by skeletal colony size (max. diameter, cm)**				
		4-20	**20-60**	**60-100**	**>100**	**Total**
Inshore and mid-channel patch reefs						
Reference areas (50)	99.0 ± 1.0	1.350 ± 0.131	1.156 ± 0.112	0.062 ± 0.009	0.014 ± 0.005	2.582 ± 0.226
No-take zones (4)	100.0 ± 0.0	0.988 ± 0.196	1.875 ± 0.178	0.125 ± 0.052	0 ± 0	2.988 ± 0.337
Habitat total (54)	99.1 ± 0.9	1.323 ± 0.136	1.209 ± 0.117	0.067 ± 0.012	0.013 ± 0.005	2.612 ± 0.234
Offshore patch reefs						
Reference areas (73)	91.8 ± 2.6	0.667 ± 0.060	0.211 ± 0.034	0.013 ± 0.004	0.007 ± 0.003	0.898 ± 0.081
No-take zones (4)	100.0 ± 0.0	0.163 ± 0.014	0.038 ± 0.024	0 ± 0	0.013 ± 0.013	0.213 ± 0.026
Habitat total (77)	92.2 ± 2.4	0.630 ± 0.057	0.198 ± 0.033	0.012 ± 0.004	0.007 ± 0.003	0.847 ± 0.077
Back-reef rubble						
Reference areas (8)	12.5 ± 8.2	0.013 ± 0.008	0 ± 0	0 ± 0	0 ± 0	0.013 ± 0.008
No-take zones (10)	15.0 ± 7.8	0.015 ± 0.008	0 ± 0	0 ± 0	0 ± 0	0.015 ± 0.008
Habitat total (18)	13.9 ± 5.5	0.013 ± 0.008	0 ± 0	0 ± 0	0 ± 0	0.013 ± 0.008
Shallow (< 6 m) hard-bottom						
Reference areas (33)	68.3 ± 7.3	0.377 ± 0.084	0.052 ± 0.017	0.002 ± 0.002	0 ± 0	0.430 ± 0.095
No-take zones (8)	87.5 ± 8.3	0.306 ± 0.115	0.038 ± 0.013	0.025 ± 0.013	0 ± 0	0.369 ± 0.111
Habitat total (41)	72.4 ± 6.1	0.371 ± 0.087	0.051 ± 0.017	0.003 ± 0.003	0 ± 0	0.426 ± 0.096
High-relief spur and groove						
Reference areas (22)	93.2 ± 3.8	0.484 ± 0.087	0.146 ± 0.035	0.009 ± 0.004	0.002 ± 0.002	0.641 ± 0.105
No-take zones (19)	73.7 ± 7.8	0.161 ± 0.038	0.066 ± 0.015	0.005 ± 0.004	0 ± 0	0.232 ± 0.048
Habitat total (41)	84.1 ± 4.4	0.460 ± 0.083	0.140 ± 0.034	0.009 ± .0040	0.002 ± 0.002	0.611 ± 0.101
Deeper fore reef						
Reference areas (36)	78.2 ± 6.3	0.408 ± 0.049	0.028 ± 0.009	0 ± 0	0 ± 0	0.436 ± 0.052
No-take zones (13)	92.3 ± 5.2	0.435 ± 0.071	0.035 ± 0.009	0 ± 0	0 ± 0	0.469 ± 0.073
Habitat total (49)	81.7 ± 4.9	0.410 ± 0.050	0.029 ± 0.009	0 ± 0	0 ± 0	0.438 ± 0.054

Table 4-10. Transect frequency (%), total colony density (no. per m^2), and density by size class (max. diameter) of the mustard hill coral (*Porites astreoides*) by habitat type and management zone in the upper Florida Keys, as determined from surveys of two replicate 10-m x 1-m belt transects per site at 280 sites from northern Key Largo to Alligator Reef during May-September 2011. Habitat types are arranged from inshore to offshore and no-take zones represent Sanctuary Preservation Areas and Research Only areas. Values represent mean ± 1 SE. Only corals with a maximum diameter > 4 cm were surveyed.

Porites astreoides **Lamarck (mustard hill coral)**

Habitat/management zone (no. sites)	**Frequency (%)**	**Density by skeletal colony size (max. diameter, cm)**				
		4-20	**20-60**	**60-100**	**>100**	**Total**
Inshore and mid-channel patch reefs						
Reference areas (50)	64.0 ± 6.0	0.524 ± 0.110	0.061 ± 0.015	0 ± 0	0.002 ± 0.002	0.587 ± 0.118
No-take zones (4)	100.0 ± 0.0	0.525 ± 0.097	0.188 ± 0.077	0 ± 0	0 ± 0	0.713 ± 0.132
Habitat total (54)	66.7 ± 5.7	0.524 ± 0.109	0.070 ± 0.020	0 ± 0	0.002 ± 0.002	0.596 ± 0.119
Offshore patch reefs						
Reference areas (73)	93.2 ± 2.4	0.705 ± 0.084	0.075 ± 0.030	0.001 ± 0.001	0 ± 0	0.782 ± 0.109
No-take zones (4)	62.5 ± 23.5	0.413 ± 0.218	0 ± 0	0 ± 0	0 ± 0	0.413 ± 0.218
Habitat total (77)	91.6 ± 2.6	0.683 ± 0.094	0.070 ± 0.028	0.001 ± 0.001	0 ± 0	0.754 ± 0.117
Back-reef rubble						
Reference areas (8)	62.5 ± 15.5	0.338 ± 0.144	0 ± 0	0 ± 0	0 ± 0	0.338 ± 0.144
No-take zones (10)	40.0 ± 13.5	0.105 ± 0.042	0 ± 0	0 ± 0	0 ± 0	0.105 ± 0.042
Habitat total (18)	50.0 ± 10.5	0.320 ± 0.137	0 ± 0	0 ± 0	0 ± 0	0.320 ± 0.137
Shallow (< 6 m) hard-bottom						
Reference areas (33)	71.7 ± 7.7	0.708 ± 0.227	0.018 ± 0.014	0 ± 0	0.002 ± 0.002	0.728 ± 0.241
No-take zones (8)	56.3 ± 14.3	0.188 ± 0.080	0 ± 0	0 ± 0	0 ± 0	0.188 ± 0.080
Habitat total (41)	68.4 ± 6.8	0.670 ± 0.216	0.017 ± 0.013	0 ± 0	0.002 ± 0.002	0.688 ± 0.229
High-relief spur and groove						
Reference areas (22)	86.4 ± 5.7	0.809 ± 0.200	0.105 ± 0.033	0 ± 0	0.005 ± 0.003	0.918 ± 0.217
No-take zones (19)	100.0 ± 0.0	1.853 ± 0.333	0.321 ± 0.084	0.008 ± 0.004	0 ± 0	2.182 ± 0.382
Habitat total (41)	92.7 ± 3.2	0.886 ± 0.210	0.121 ± 0.037	0.001 ± 0.001	0.004 ± 0.003	1.012 ± 0.229
Deeper fore reef						
Reference areas (36)	75.6 ± 6.8	0.483 ± 0.088	0.001 ± 0.001	0 ± 0	0 ± 0	0.485 ± 0.088
No-take zones (13)	84.6 ± 6.7	0.446 ± 0.119	0 ± 0	0 ± 0	0 ± 0	0.446 ± 0.119
Habitat total (49)	77.9 ± 5.4	0.481 ± 0.090	0.001 ± 0.001	0 ± 0	0 ± 0	0.482 ± 0.090

Table 4-11. Transect frequency (%), total colony density (no. per m^2), and density by size class (max. diameter) of the lettuce coral (*Agaricia agaricites*) by habitat type and management zone in the upper Florida Keys, as determined from surveys of two replicate 10-m x 1-m belt transects per site at 280 sites from northern Key Largo to Alligator Reef during May-September 2011. Habitat types are arranged from inshore to offshore and no-take zones represent Sanctuary Preservation Areas and Research Only areas. Values represent mean ± 1 SE. Only corals with a maximum diameter > 4 cm were surveyed.

***Agaricia agaricites* (Linnaeus) (lettuce coral)**

Habitat/management zone (no. sites)	Frequency (%)	Density by skeletal colony size (max. diameter, cm) 4-20	20-60	60-100	>100	Total
Inshore and mid-channel patch reefs						
Reference areas (50)	33.0 ± 6.1	0.254 ± 0.089	0.012 ± 0.005	0 ± 0	0 ± 0	0.267 ± 0.092
No-take zones (4)	25.0 ± 24.4	0.063 ± 0.061	0.038 ± 0.037	0 ± 0	0 ± 0	0.100 ± 0.098
Habitat total (54)	32.4 ± 5.9	0.240 ± 0.087	0.014 ± 0.007	0 ± 0	0 ± 0	0.255 ± 0.092
Offshore patch reefs						
Reference areas (73)	82.9 ± 3.8	0.579 ± 0.076	0.021 ± 0.005	0 ± 0	0 ± 0	0.599 ± 0.079
No-take zones (4)	100.0 ± 0.0	0.375 ± 0.120	0 ± 0	0 ± 0	0 ± 0	0.375 ± 0.120
Habitat total (77)	83.8 ± 3.6	0.564 ± 0.079	0.019 ± 0.005	0 ± 0	0 ± 0	0.583 ± 0.082
Back-reef rubble						
Reference areas (8)	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0
No-take zones (10)	5.0 ± 5.0	0.005 ± 0.005	0.005 ± 0.005	0 ± 0	0 ± 0	0.010 ± 0.010
Habitat total (18)	2.8 ± 2.8	0.001 ± 0.001	0.001 ± 0.001	0 ± 0	0 ± 0	0.001 ± 0.001
Shallow (< 6 m) hard-bottom						
Reference areas (33)	41.7 ± 7.9	0.180 ± 0.054	0 ± 0	0 ± 0	0 ± 0	0.182 ± 0.055
No-take zones (8)	68.8 ± 15.2	0.313 ± 0.099	0 ± 0	0 ± 0	0 ± 0	0.313 ± 0.099
Habitat total (41)	47.4 ± 7.2	0.190 ± 0.057	0 ± 0	0 ± 0	0 ± 0	0.191 ± 0.058
High-relief spur and groove						
Reference areas (22)	88.6 ± 5.5	0.730 ± 0.109	0.014 ± 0.006	0 ± 0	0 ± 0	0.743 ± 0.112
No-take zones (19)	97.4 ± 2.6	1.282 ± 0.154	0.053 ± 0.012	0 ± 0	0 ± 0	1.334 ± 0.157
Habitat total (41)	92.7 ± 3.2	0.770 ± 0.113	0.017 ± 0.006	0 ± 0	0 ± 0	0.787 ± 0.115
Deeper fore reef						
Reference areas (36)	73.1 ± 6.6	0.655 ± 0.139	0.008 ± 0.004	0 ± 0	0 ± 0	0.663 ± 0.140
No-take zones (13)	65.4 ± 10.3	0.485 ± 0.223	0.012 ± 0.008	0 ± 0	0 ± 0	0.496 ± 0.230
Habitat total (49)	71.2 ± 5.5	0.643 ± 0.145	0.008 ± 0.005	0 ± 0	0 ± 0	0.651 ± 0.146

Table 4-12. Transect frequency (%), total colony density (no. per m^2), and density by size class (max. diameter) of the clubtip finger coral (*Porites porites porites*) by habitat type and management zone in the upper Florida Keys, as determined from surveys of two replicate 10-m x 1-m belt transects per site at 280 sites from northern Key Largo to Alligator Reef during May-September 2011. Habitat types are arranged from inshore to offshore and no-take zones represent Sanctuary Preservation Areas and Research Only areas. Values represent mean ± 1 SE. Only corals with a maximum diameter > 4 cm were surveyed.

***Porites porites porites* (Pallas) (clubtip finger coral)**

Habitat/management zone (no. sites)	**Frequency (%)**	**Density by skeletal colony size (max. diameter, cm)**				
		4-20	**20-60**	**60-100**	**>100**	**Total**
Inshore and mid-channel patch reefs						
Reference areas (50)	58.0 ± 6.1	0.402 ± 0.097	0.080 ± 0.019	0 ± 0	0.016 ± 0.011	0.498 ± 0.112
No-take zones (4)	62.5 ± 23.5	0.075 ± 0.043	0 ± 0	0 ± 0	0.013 ± 0.013	0.088 ± 0.042
Habitat total (54)	58.3 ± 5.8	0.378 ± 0.093	0.074 ± 0.017	0 ± 0	0.016 ± 0.011	0.468 ± 0.107
Offshore patch reefs						
Reference areas (73)	87.7 ± 3.4	0.616 ± 0.072	0.062 ± 0.011	0.001 ± 0.001	0 ± 0	0.679 ± 0.078
No-take zones (4)	100.0 ± 0.0	0.463 ± 0.185	0.025 ± 0.015	0 ± 0	0 ± 0	0.488 ± 0.198
Habitat total (77)	88.3 ± 3.3	0.604 ± 0.080	0.060 ± 0.011	0.001 ± 0.001	0 ± 0	0.665 ± 0.087
Back-reef rubble						
Reference areas (8)	62.5 ± 18.1	0.150 ± 0.047	0 ± 0	0 ± 0	0 ± 0	0.150 ± 0.047
No-take zones (10)	65.0 ± 12.4	0.120 ± 0.035	0 ± 0	0 ± 0	0 ± 0	0.120 ± 0.035
Habitat total (18)	63.9 ± 10.3	0.148 ± 0.046	0 ± 0	0 ± 0	0 ± 0	0.148 ± 0.046
Shallow (< 6 m) hard-bottom						
Reference areas (33)	73.3 ± 7.7	0.533 ± 0.105	0.057 ± 0.028	0.002 ± 0.002	0 ± 0	0.592 ± 0.122
No-take zones (8)	81.3 ± 12.4	0.313 ± 0.097	0 ± 0	0 ± 0	0 ± 0	0.313 ± 0.097
Habitat total (41)	75.0 ± 6.6	0.517 ± 0.104	0.053 ± 0.026	0.002 ± 0.002	0 ± 0	0.571 ± 0.121
High-relief spur and groove						
Reference areas (22)	84.1 ± 6.0	0.434 ± 0.074	0.039 ± 0.019	0.005 ± 0.005	0 ± 0	0.477 ± 0.092
No-take zones (19)	76.3 ± 8.5	0.287 ± 0.097	0.018 ± 0.007	0 ± 0	0 ± 0	0.305 ± 0.102
Habitat total (41)	80.5 ± 5.0	0.423 ± 0.076	0.037 ± 0.018	0.004 ± 0.004	0 ± 0	0.465 ± 0.093
Deeper fore reef						
Reference areas (36)	82.1 ± 5.6	0.377 ± 0.043	0.015 ± 0.005	0 ± 0	0 ± 0	0.392 ± 0.044
No-take zones (13)	69.2 ± 10.5	0.296 ± 0.084	0.008 ± 0.005	0 ± 0	0 ± 0	0.304 ± 0.085
Habitat total (49)	78.8 ± 5.0	0.371 ± 0.046	0.015 ± 0.005	0 ± 0	0 ± 0	0.386 ± 0.047

Table 4-13. Transect frequency (%), total colony density (no. per m^2), and density by size class (max. diameter) of the branched finger coral (*Porites porites furcata*) by habitat type and management zone in the upper Florida Keys, as determined from surveys of two replicate 10-m x 1-m belt transects per site at 280 sites from northern Key Largo to Alligator Reef during May-September 2011. Habitat types are arranged from inshore to offshore and no-take zones represent Sanctuary Preservation Areas and Research Only areas. Values represent mean ± 1 SE. Only corals with a maximum diameter > 4 cm were surveyed.

***Porites porites furcata* Lamarck (branched finger coral)**

Habitat/management zone (no. sites)	Frequency (%)	Density by skeletal colony size (max. diameter, cm) 4-20	20-60	60-100	>100	Total
Inshore and mid-channel patch reefs						
Reference areas (50)	27.0 ± 5.5	0.068 ± 0.028	0.010 ± 0.004	0 ± 0	0 ± 0	0.078 ± 0.030
No-take zones (4)	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0
Habitat total (54)	25.0 ± 5.2	0.063 ± 0.026	0.009 ± 0.003	0 ± 0	0 ± 0	0.072 ± 0.028
Offshore patch reefs						
Reference areas (73)	52.7 ± 5.1	0.277 ± 0.053	0.064 ± 0.018	0.006 ± 0.002	0.001 ± 0.001	0.349 ± 0.067
No-take zones (4)	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0
Habitat total (77)	50.0 ± 5.0	0.257 ± 0.049	0.060 ± 0.017	0.006 ± 0.002	0.001 ± 0.001	0.323 ± 0.062
Back-reef rubble						
Reference areas (8)	6.3 ± 6.2	0.006 ± 0.006	0 ± 0	0 ± 0	0 ± 0	0.006 ± 0.006
No-take zones (10)	20.0 ± 12.1	0.060 ± 0.044	0 ± 0	0 ± 0	0 ± 0	0.060 ± 0.044
Habitat total (18)	13.9 ± 7.7	0.010 ± 0.009	0 ± 0	0 ± 0	0 ± 0	0.010 ± 0.009
Shallow (< 6 m) hard-bottom						
Reference areas (33)	36.7 ± 7.8	0.173 ± 0.059	0.022 ± 0.010	0 ± 0	0 ± 0	0.195 ± 0.068
No-take zones (8)	12.5 ± 8.3	0.013 ± 0.008	0 ± 0	0 ± 0	0 ± 0	0.013 ± 0.008
Habitat total (41)	31.6 ± 6.6	0.161 ± 0.055	0.020 ± 0.009	0 ± 0	0 ± 0	0.182 ± 0.063
High-relief spur and groove						
Reference areas (22)	9.1 ± 5.1	0.055 ± 0.043	0.016 ± 0.013	0 ± 0	0 ± 0	0.071 ± 0.056
No-take zones (19)	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0
Habitat total (41)	4.9 ± 2.8	0.051 ± 0.040	0.015 ± 0.012	0 ± 0	0 ± 0	0.065 ± 0.052
Deeper fore reef						
Reference areas (36)	38.5 ± 6.7	0.145 ± 0.044	0.031 ± 0.011	0.003 ± 0.003	0 ± 0	0.178 ± 0.055
No-take zones (13)	23.1 ± 9.1	0.035 ± 0.015	0 ± 0	0 ± 0	0 ± 0	0.035 ± 0.015
Habitat total (49)	34.6 ± 5.6	0.137 ± 0.042	0.029 ± 0.010	0.002 ± 0.002	0 ± 0	0.168 ± 0.052

Table 4-14. Transect frequency (%), total colony density (no. per m^2), and density by size class (max. diameter) of the pineapple coral (*Dichocoenia stokesi*) by habitat type and management zone in the upper Florida Keys, as determined from surveys of two replicate 10-m x 1-m belt transects per site at 280 sites from northern Key Largo to Alligator Reef during May-September 2011. Habitat types are arranged from inshore to offshore and no-take zones represent Sanctuary Preservation Areas and Research Only areas. Values represent mean ± 1 SE. Only corals with a maximum diameter > 4 cm were surveyed.

Dichocoenia stokesi **Milne Edwards and Haime (pineapple coral)**

Habitat/management zone (no. sites)	Frequency (%)	Density by skeletal colony size (max. diameter, cm) 4-20	20-60	60-100	>100	Total
Inshore and mid-channel patch reefs						
Reference areas (50)	78.0 ± 5.0	0.208 ± 0.030	0.056 ± 0.010	0.001 ± 0.001	0.002 ± 0.001	0.267 ± 0.035
No-take zones (4)	75.0 ± 14.6	0.138 ± 0.027	0.050 ± 0.021	0.013 ± 0.013	0.013 ± 0.013	0.213 ± 0.030
Habitat total (54)	77.8 ± 4.7	0.203 ± 0.030	0.056 ± 0.011	0.002 ± 0.002	0.003 ± 0.002	0.263 ± 0.034
Offshore patch reefs						
Reference areas (73)	67.8 ± 4.7	0.133 ± 0.016	0.010 ± 0.003	0.001 ± 0.001	0.001 ± 0.001	0.144 ± 0.016
No-take zones (4)	87.5 ± 12.5	0.075 ± 0.016	0.025 ± 0.015	0 ± 0	0 ± 0	0.100 ± 0.005
Habitat total (77)	68.8 ± 4.6	0.129 ± 0.016	0.011 ± 0.004	0.001 ± 0.001	0.001 ± 0.001	0.141 ± 0.015
Back-reef rubble						
Reference areas (8)	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0
No-take zones (10)	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0
Habitat total (18)	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0
Shallow (< 6 m) hard-bottom						
Reference areas (33)	48.3 ± 7.7	0.092 ± 0.022	0.008 ± 0.004	0 ± 0	0 ± 0	0.100 ± 0.024
No-take zones (8)	50.0 ± 15.5	0.050 ± 0.016	0 ± 0	0 ± 0	0 ± 0	0.050 ± 0.016
Habitat total (41)	48.7 ± 6.8	0.089 ± 0.022	0.008 ± 0.004	0 ± 0	0 ± 0	0.096 ± 0.023
High-relief spur and groove						
Reference areas (22)	47.7 ± 8.7	0.102 ± 0.033	0.014 ± 0.009	0.002 ± 0.002	0 ± 0	0.118 ± 0.039
No-take zones (19)	7.9 ± 4.3	0.013 ± 0.008	0.003 ± 0.003	0 ± 0	0 ± 0	0.016 ± 0.010
Habitat total (41)	29.3 ± 5.8	0.096 ± 0.031	0.013 ± 0.009	0.002 ± 0.002	0 ± 0	0.111 ± 0.037
Deeper fore reef						
Reference areas (36)	46.2 ± 6.2	0.081 ± 0.025	0.003 ± 0.002	0 ± 0	0 ± 0	0.083 ± 0.025
No-take zones (13)	42.3 ± 11.0	0.050 ± 0.014	0 ± 0	0 ± 0	0 ± 0	0.050 ± 0.014
Habitat total (49)	45.2 ± 5.4	0.079 ± 0.002	0.002 ± 0.002	0 ± 0	0 ± 0	0.081 ± 0.024

Table 4-15. Transect frequency (%), total colony density (no. per m^2), and density by size class (max. diameter) of the lesser starlet coral (*Siderastrea radians*) by habitat type and management zone in the upper Florida Keys, as determined from surveys of two replicate 10-m x 1-m belt transects per site at 280 sites from northern Key Largo to Alligator Reef during May-September 2011. Habitat types are arranged from inshore to offshore and no-take zones represent Sanctuary Preservation Areas and Research Only areas. Values represent mean ± 1 SE. Only corals with a maximum diameter > 4 cm were surveyed.

Siderastrea radians **(Pallas) (lesser starlet coral)**

Habitat/management zone (no. sites)	**Frequency (%)**	**Density by skeletal colony size (max. diameter, cm)** 4-20	20-60	60-100	>100	Total
Inshore and mid-channel patch reefs						
Reference areas (50)	74.0 ± 5.4	0.266 ± 0.039	0.005 ± 0.003	0 ± 0	0 ± 0	0.271 ± 0.041
No-take zones (4)	87.5 ± 12.5	0.363 ± 0.171	0 ± 0	0 ± 0	0 ± 0	0.363 ± 0.171
Habitat total (54)	75.0 ± 5.1	0.273 ± 0.049	0.005 ± 0.003	0 ± 0	0 ± 0	0.278 ± 0.050
Offshore patch reefs						
Reference areas (73)	53.4 ± 4.7	0.111 ± 0.018	0 ± 0	0 ± 0	0 ± 0	0.111 ± 0.018
No-take zones (4)	50.0 ± 20.3	0.100 ± 0.067	0 ± 0	0 ± 0	0 ± 0	0.100 ± 0.067
Habitat total (77)	53.2 ± 4.5	0.110 ± 0.022	0 ± 0	0 ± 0	0 ± 0	0.110 ± 0.022
Back-reef rubble						
Reference areas (8)	18.8 ± 9.2	0.019 ± 0.009	0 ± 0	0 ± 0	0 ± 0	0.019 ± 0.009
No-take zones (10)	35.0 ± 10.8	0.045 ± 0.016	0 ± 0	0 ± 0	0 ± 0	0.045 ± 0.016
Habitat total (18)	27.8 ± 7.3	0.021 ± 0.010	0 ± 0	0 ± 0	0 ± 0	0.021 ± 0.010
Shallow (< 6 m) hard-bottom						
Reference areas (33)	48.3 ± 6.6	0.093 ± 0.020	0 ± 0	0 ± 0	0 ± 0	0.093 ± 0.020
No-take zones (8)	12.5 ± 8.3	0.013 ± 0.008	0 ± 0	0 ± 0	0 ± 0	0.013 ± 0.008
Habitat total (41)	40.8 ± 5.9	0.087 ± 0.019	0 ± 0	0 ± 0	0 ± 0	0.087 ± 0.019
High-relief spur and groove						
Reference areas (22)	31.8 ± 7.0	0.075 ± 0.021	0 ± 0	0 ± 0	0 ± 0	0.075 ± 0.021
No-take zones (19)	13.2 ± 6.3	0.013 ± 0.006	0 ± 0	0 ± 0	0 ± 0	0.013 ± 0.006
Habitat total (41)	23.2 ± 4.9	0.070 ± 0.020	0 ± 0	0 ± 0	0 ± 0	0.070 ± 0.020
Deeper fore reef						
Reference areas (36)	42.3 ± 5.4	0.063 ± 0.012	0 ± 0	0 ± 0	0 ± 0	0.063 ± 0.012
No-take zones (13)	50.0 ± 8.3	0.065 ± 0.015	0 ± 0	0 ± 0	0 ± 0	0.065 ± 0.015
Habitat total (49)	44.2 ± 4.5	0.063 ± 0.012	0 ± 0	0 ± 0	0 ± 0	0.063 ± 0.012

Table 4-16. Transect frequency (%), total colony density (no. per m^2), and density by size class (max. diameter) of the blushing star coral (*Stephanocoenia michelinii*) by habitat type and management zone in the upper Florida Keys, as determined from surveys of two replicate 10-m x 1-m belt transects per site at 280 sites from northern Key Largo to Alligator Reef during May-September 2011. Habitat types are arranged from inshore to offshore and no-take zones represent Sanctuary Preservation Areas and Research Only areas. Values represent mean ± 1 SE. Only corals with a maximum diameter > 4 cm were surveyed.

Stephanocoenia michelinii **Milne Edwards and Haime (blushing star coral)**

Habitat/management zone (no. sites)	Frequency (%)	Density by skeletal colony size (max. diameter, cm) 4-20	20-60	60-100	>100	Total
Inshore and mid-channel patch reefs						
Reference areas (50)	63.0 ± 5.7	0.119 ± 0.021	0.082 ± 0.016	0.001 ± 0.001	0 ± 0	0.202 ± 0.032
No-take zones (4)	87.5 ± 12.5	0.150 ± 0.072	0.100 ± 0.035	0 ± 0	0.013 ± 0.013	0.263 ± 0.103
Habitat total (54)	64.8 ± 5.4	0.121 ± 0.025	0.083 ± 0.017	0.001 ± 0.001	0.001 ± 0.001	0.207 ± 0.037
Offshore patch reefs						
Reference areas (73)	0 ± 0	0.093 ± 0.015	0.014 ± 0.005	0 ± 0	0 ± 0	0.107 ± 0.016
No-take zones (4)	5.0 ± 5.0	0.025 ± 0.015	0 ± 0	0 ± 0	0 ± 0	0.025 ± 0.015
Habitat total (77)	2.8 ± 2.8	0.088 ± 0.015	0.013 ± 0.004	0 ± 0	0 ± 0	0.101 ± 0.016
Back-reef rubble						
Reference areas (8)	43.8 ± 5.0	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0
No-take zones (10)	25.0 ± 14.6	0.005 ± 0.005	0 ± 0	0 ± 0	0 ± 0	0.005 ± 0.005
Habitat total (18)	42.9 ± 4.8	0.001 ± 0.001	0 ± 0	0 ± 0	0 ± 0	0.001 ± 0.001
Shallow (< 6 m) hard-bottom						
Reference areas (33)	20.0 ± 6.1	0.027 ± 0.010	0.003 ± 0.002	0 ± 0	0 ± 0	0.030 ± 0.011
No-take zones (8)	25.0 ± 12.8	0.031 ± 0.018	0 ± 0	0 ± 0	0 ± 0	0.031 ± 0.018
Habitat total (41)	21.1 ± 5.5	0.027 ± 0.010	0.003 ± 0.002	0 ± 0	0 ± 0	0.031 ± 0.012
High-relief spur and groove						
Reference areas (22)	0 ± 0	0.025 ± 0.008	0.005 ± 0.003	0 ± 0	0 ± 0	0.030 ± 0.008
No-take zones (19)	0 ± 0	0.005 ± 0.005	0 ± 0	0 ± 0	0 ± 0	0.005 ± 0.005
Habitat total (41)	0 ± 0	0.024 ± 0.008	0.004 ± 0.003	0 ± 0	0 ± 0	0.028 ± 0.008
Deeper fore reef						
Reference areas (36)	27.3 ± 7.1	0.086 ± 0.019	0.001 ± 0.001	0 ± 0	0 ± 0	0.087 ± 0.019
No-take zones (13)	2.6 ± 2.6	0.162 ± 0.046	0 ± 0	0 ± 0	0 ± 0	0.162 ± 0.046
Habitat total (49)	15.9 ± 4.4	0.092 ± 0.021	0.001 ± 0.001	0 ± 0	0 ± 0	0.093 ± 0.021

Table 4-17. Transect frequency (%), total colony density (no. per m^2), and density by size class (max. diameter) of the great star coral (*Montastraea cavernosa*) by habitat type and management zone in the upper Florida Keys, as determined from surveys of two replicate 10-m x 1-m belt transects per site at 280 sites from northern Key Largo to Alligator Reef during May-September 2011. Habitat types are arranged from inshore to offshore and no-take zones represent Sanctuary Preservation Areas and Research Only areas. Values represent mean ± 1 SE. Only corals with a maximum diameter > 4 cm were surveyed.

Montastraea cavernosa **(Linnaeus) (great star coral)**

Habitat/management zone (no. sites)	**Frequency (%)**	**Density by skeletal colony size (max. diameter, cm)**				
		4-20	**20-60**	**60-100**	**>100**	**Total**
Inshore and mid-channel patch reefs						
Reference areas (50)	41.0 ± 6.0	0.038 ± 0.008	0.037 ± 0.009	0.004 ± 0.002	0.002 ± 0.001	0.081 ± 0.014
No-take zones (4)	100.0 ± 0.0	0.088 ± 0.014	0.163 ± 0.065	0.013 ± 0.013	0.050 ± 0.020	0.313 ± 0.091
Habitat total (54)	45.4 ± 5.9	0.042 ± 0.008	0.046 ± 0.013	0.005 ± 0.003	0.006 ± 0.003	0.098 ± 0.017
Offshore patch reefs						
Reference areas (73)	39.7 ± 4.8	0.050 ± 0.008	0.023 ± 0.007	0.003 ± 0.001	0.003 ± 0.002	0.078 ± 0.014
No-take zones (4)	37.5 ± 13.0	0 ± 0	0.050 ± 0.021	0 ± 0	0 ± 0	0.050 ± 0.021
Habitat total (77)	39.6 ± 4.6	0.046 ± 0.008	0.025 ± 0.008	0.003 ± 0.001	0.003 ± 0.002	0.076 ± 0.014
Back-reef rubble						
Reference areas (8)	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0
No-take zones (10)	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0
Habitat total (18)	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0
Shallow (< 6 m) hard-bottom						
Reference areas (33)	20.0 ± 6.1	0.027 ± 0.010	0.003 ± 0.002	0 ± 0	0 ± 0	0.030 ± 0.010
No-take zones (8)	18.8 ± 12.4	0.019 ± 0.012	0 ± 0	0 ± 0	0 ± 0	0.019 ± 0.012
Habitat total (41)	19.7 ± 5.5	0.026 ± 0.010	0.003 ± 0.002	0 ± 0	0 ± 0	0.029 ± 0.010
High-relief spur and groove						
Reference areas (22)	20.5 ± 6.3	0.007 ± 0.004	0.018 ± 0.007	0 ± 0	0.002 ± 0.002	0.027 ± 0.009
No-take zones (19)	13.2 ± 5.3	0.013 ± 0.005	0.003 ± 0.003	0 ± 0	0 ± 0	0.016 ± 0.007
Habitat total (41)	17.1 ± 4.1	0.007 ± 0.004	0.017 ± 0.007	0 ± 0	0.002 ± 0.002	0.026 ± 0.009
Deeper fore reef						
Reference areas (36)	29.5 ± 6.0	0.040 ± 0.009	0.005 ± 0.009	0.001 ± 0.001	0 ± 0	0.046 ± 0.011
No-take zones (13)	53.8 ± 10.5	0.077 ± 0.016	0.012 ± 0.008	0.004 ± 0.004	0 ± 0	0.092 ± 0.023
Habitat total (49)	35.6 ± 5.4	0.043 ± 0.010	0.006 ± 0.003	0.002 ± 0.002	0 ± 0	0.050 ± 0.012

Table 4-18. Transect frequency (%), total colony density (no. per m^2), and density by size class (max. diameter) of the mountainous star coral (*Montastraea faveolata*) by habitat type and management zone in the upper Florida Keys, as determined from surveys of two replicate 10-m x 1-m belt transects per site at 280 sites from northern Key Largo to Alligator Reef during May-September 2011. Habitat types are arranged from inshore to offshore and no-take zones represent Sanctuary Preservation Areas and Research Only areas. Values represent mean ± 1 SE. Only corals with a maximum diameter > 4 cm were surveyed.

Montastraea faveolata **(Ellis and Solander) (mountainous star coral)**

Habitat/management zone (no. sites)	Frequency (%)	Density by skeletal colony size (max. diameter, cm) 4-20	20-60	60-100	>100	Total
Inshore and mid-channel patch reefs						
Reference areas (50)	29.0 ± 5.3	0.006 ± 0.003	0.060 ± 0.017	0.022 ± 0.009	0.034 ± 0.018	0.122 ± 0.036
No-take zones (4)	87.5 ± 12.5	0 ± 0	0.113 ± 0.078	0.088 ± 0.032	0.075 ± 0.047	0.275 ± 0.142
Habitat total (54)	33.3 ± 5.4	0.006 ± 0.003	0.064 ± 0.022	0.027 ± 0.011	0.037 ± 0.020	0.133 ± 0.035
Offshore patch reefs						
Reference areas (73)	32.9 ± 5.4	0.010 ± 0.004	0.031 ± 0.006	0.012 ± 0.004	0.015 ± 0.008	0.069 ± 0.014
No-take zones (4)	12.5 ± 12.5	0 ± 0	0.013 ± 0.013	0 ± 0	0 ± 0	0.013 ± 0.013
Habitat total (77)	11.7 ± 4.6	0.010 ± 0.003	0.030 ± 0.006	0.011 ± 0.003	0.014 ± 0.007	0.066 ± 0.013
Back-reef rubble						
Reference areas (8)	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0
No-take zones (10)	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0
Habitat total (18)	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0
Shallow (< 6 m) hard-bottom						
Reference areas (33)	11.7 ± 4.6	0.002 ± 0.002	0.012 ± 0.005	0.003 ± 0.003	0 ± 0	0.017 ± 0.008
No-take zones (8)	6.3 ± 6.3	0 ± 0	0.006 ± 0.006	0 ± 0	0 ± 0	0.006 ± 0.006
Habitat total (41)	10.5 ± 3.8	0.002 ± 0.002	0.011 ± 0.005	0.003 ± 0.003	0 ± 0	0.015 ± 0.006
High-relief spur and groove						
Reference areas (22)	27.3 ± 7.7	0.007 ± 0.004	0.023 ± 0.007	0.007 ± 0.005	0.009 ± 0.005	0.046 ± 0.014
No-take zones (19)	15.8 ± 6.5	0 ± 0	0.008 ± 0.004	0.003 ± 0.003	0.011 ± 0.006	0.021 ± 0.009
Habitat total (41)	22.0 ± 5.1	0.006 ± 0.004	0.022 ± 0.007	0.007 ± 0.005	0.009 ± 0.005	0.034 ± 0.009
Deeper fore reef						
Reference areas (36)	5.1 ± 3.1	0.003 ± 0.002	0.001 ± 0.001	0.001 ± 0.001	0 ± 0	0.005 ± 0.003
No-take zones (13)	11.5 ± 6.1	0.004 ± 0.004	0.004 ± 0.004	0.004 ± 0.004	0 ± 0	0.012 ± 0.006
Habitat total (49)	6.7 ± 2.8	0.003 ± 0.002	0.002 ± 0.002	0.002 ± 0.002	0 ± 0	0.007 ± 0.003

V. Urchin Abundance and Size

Background

The 1983-84 Caribbean-wide mass mortality of the long-spined sea urchin *Diadema antillarum* represents one of the more spatially expansive and prolonged disturbances to coral reef ecosystems in the region (Carpenter 1988; Lessios 1988, 2005). Prior to the mass mortality event, *D. antillarum* attained high (>20 per m^2) densities on many Caribbean reefs (Lessios 1988), but after the disease epidemic, which was highly species-specific, abundances declined by several orders of magnitude and have largely remained in this state for over 25 years (Lessios 2005; Weil et al. 2005; Debrot and Nagelkerken 2006). Together with physical impacts from storms, coral disease outbreaks, and severe bleaching episodes (Gardner et al. 2003), the reduction in urchin densities changed coral-algal dominance patterns (Carpenter 1988; Lessios 1988). In the Florida Keys, the few historical data available prior to 1983-84 indicate that *D. antillarum* densities were lower (up to 4 to 5 per m^2) (Kier and Grant 1965; Bauer 1976, 1980) than values reported for some Caribbean reefs (i.e. Jamaica and the U.S. Virgin Islands). Historical densities of upwards of 3-4 individuals per m^2, however, are still one to two orders of magnitude greater than current densities in the Florida Keys. A general trend of greater algal cover was reported after the urchin mortality at several Florida Keys offshore reefs in the late 1980s and early 1990s (Jaap et al. 1988; Porter and Meier 1992). However, identifying clear relationships between urchin grazing and algae – and ultimately coral recovery – remains problematic for at least three reasons. First, few, if any, specifically designed before-and-after studies were conducted in the Florida Keys related to urchin decline. Second, the regional die-off of *Acropora* corals from white-band disease occurred at the same time, which opened up large amounts of dead coral substrate for algal colonization. Third, populations of herbivorous fish in the Florida Keys are in relatively good condition compared to many Caribbean locations, potentially confounding the story. In contrast to the rest of the wider Caribbean, a second disease event, similar to the first mortality in 1983-84, occurred seven years later in the Florida Keys. After initially modest recovery to 0.30-0.58 individuals per m^2, the second mass mortality once again depressed *D. antillarum* densities to < 0.01 individuals per m^2 in patch reef and shallow (< 7 m) fore-reef habitats that were sampled (Forcucci 1994). With the exception of a few shallow-water areas in the Dry Tortugas (Chiappone et al. 2001), large-scale surveys of urchin densities conducted by our program during 1999-2001 confirmed the continued pattern of poor recovery (Chiappone et al. 2002a, b).

Since the mass mortality, several investigators have reported limited or moderate recovery of *Diadema antillarum* populations for some Caribbean reef areas (Lessios 2005; Carpenter and Edmunds 2006; Debrot and Nagelkerken 2006), but recovery in the Florida Keys appears to be occurring slower (Chiappone et al. 2002a, in press; Lazar et al. 2005). Still, beginning in 2005 up to and including 2011, we have documented increases in the frequency of occurrence, density, and the sizes of *D. antillarum* from surveys of hundreds of sites in the Florida Keys. While some researchers suggest that population recovery will help to promote coral recruitment and a return to pre-mortality baseline reef conditions (Carpenter and Edmunds 2006; Macia et al. 2007; Myhre and Acevedo-Gutierrez 2007), diseases, bleaching episodes, and human activities may counteract any positive influences of increased urchin grazing. Despite these uncertainties, and because of these uncertainties, there is keen interest in the spatial and temporal patterns of *D. antillarum* recovery in the Florida Keys. In addition, the slow and incomplete recovery of this urchin raises the question of what factors currently limit population recovery (Miller et al. 2010).

Beginning in 1999, we have conducted periodic, large-scale surveys of urchin density, abundance and size structure in a diversity of habitats across the south Florida shelf encompassing hundreds of sites (Chiappone et al. 2001, 2002a, b). More recently, we described the population status of *Diadema antillarum* based upon surveys of 235 sites along ~200 km of the Florida reef tract surveyed during 2007 (Chiappone et al. 2009). Additional surveys were conducted Keyswide in 2008 (145 sites), 2009 (160 sites), and 2010 (120 sites). Below is a summary of the 2011 survey results for all echinoid species encountered in terms of site presence (% of sites encountered), transect frequency of occurrence, density, and size for the 280 sites sampled in the upper Florida Keys. To our knowledge, this effort constitutes the only large-scale, repeated, and long-term surveys for urchins in the Florida Keys ecosystem.

2011 Survey Results

During May-September 2011, a total of 280 sites were sampled for urchins by surveying two (2) replicate 15-m x 1-m belt transects per site, yielding a total survey area of 8,400 m^2 of benthic habitat in the upper Florida Keys between northern Key Largo and Alligator Reef. Seven (7) species were encountered within transects: *Arbacia punctulata*, *Diadema antillarum*, *Echinometra lucunter*, *E. viridis*, *Eucidaris tribuloides*, *Lytechinus variegatus*, and *Tripneustes ventricosus* (Figure 5-1). Tables 5-1 to 5-7 summarize mean site presence, transect frequency of occurrence, densities, and size (test diameter) among habitats and management zones (i.e. inside and outside of FKNMS no-take zones). A total of 1,958 urchins were identified, counted, and measured, listed alphabetically as follows with total numbers counted and relative abundance:

- *Arbacia punctulata* (2 individuals, 0.1% of all urchins),
- *Diadema antillarum* (147 individuals, 7.5%),
- *Echinometra lucunter* (240 individuals, 12.3%),

- *E. viridis* (726 individuals, 37.1%),
- *Eucidaris tribuloides* (819 individuals, 41.8%),
- *Lytechinus variegatus* (17 individuals, 0.9%), and
- *Tripneustes ventricosus* (7 individuals, 0.4%).

Echinoids were encountered at approximately 70% of the 280 sites surveyed. Figure 5-2 illustrates the patterns in site presence (percentage of sites encountered) of all urchin species and species richness (no. species encountered per 30 m^2). Urchins were more frequently encountered at the site-level in back-reef rubble sites, followed by patch reefs, compared to shallow and deeper fore-reef habitats. Urchin species richness among habitats exhibited a similar pattern. Back-reef rubble continues to be an important recruitment habitat for most of the urchins occurring in the Florida Keys. Figure 5-3 illustrates patterns in site presence and urchin species by habitat and management zone (i.e. inside and outside of FKNMS no-take zones). For many of the habitats surveyed, urchins tended to be encountered at more reference sites compared to no-take zones, especially on shallow (< 6 m) hard-bottom, high-relief spur and groove, and deeper (6-15 m) fore-reef habitats. A similar pattern was evident for species richness, where reference areas yielded greater numbers of species compared to no-take zones across all habitat types sampled.

Arbacia punctulata (Lamarck)

For the first time since 1999, we encountered *Arbacia punctulata* (Figure 5-1), which is normally associated with seagrass and other soft-sediment habitats. A total of two individuals were recorded within belt transect surveys, both from two reference offshore patch reefs, with a test size range of 4.1-4.2 cm (Table 5-1).

Diadema antillarum (Philippi)

A total of 147 *Diadema antillarum* were recorded, with individuals distributed among all of the habitats sampled, albeit at different densities and sizes (Table 5-1). The maximum site-level density of 0.267 individuals per m^2 was recorded from an offshore patch reef west of Carysfort Reef. Since 2001, we continue to document an increase in the number of sites where *D. antillarum* is found and a trend towards larger test sizes, especially on offshore patch reefs. In addition, back-reef rubble areas continue to support mostly recently settled juveniles, as evidenced by the relatively small (< 2 cm TD) sizes of individuals (Table 5-1). Figures 5-4 to 5-6 illustrate the spatial distribution of *D. antillarum* densities throughout the upper Florida Keys study area. Site presence (percentage of sites encountered), transect frequency (percentage of transects encountered), and mean density (no. individuals per m^2) were greatest on offshore patch reefs, followed by back-reef rubble, shallow (< 6 m) hard-bottom, and high-relief spur and groove habitats (Figure 5-7). Similar to other echinoid species, site presence, transect frequency, and density, but not necessarily average size, tended to be greater in reference areas compared to FKNMS no-take zones, a trend evident for several years now (Table 5-1 and Figure 5-8). *D. antillarum* test sizes ranged from 0.6 to 9.1 cm and averaged 5.5 ± 0.2 cm from all sites, which includes 14 of the 147 individuals recorded from back-reef rubble sites, most (86%) of which were early (< 1 year) post-settlement juveniles. An encouraging sign in the D. antillarum population is the presence of both recently settled recruits, as well as individuals that have survived beyond 1-2 years of age (Figure 5-9 top), a pattern not evident prior to 2006. Patch reefs and shallow hard-bottom sites yielded the largest average and maximum sizes, while back reef rubble sites and the deeper fore-reef yielded the lowest average sizes (Figure 5-9, bottom).

Echinometra lucunter (Linnaeus)

Two species of *Echinometra* were recorded during the 2011 surveys. *E. lucunter* was the less abundant of the two species (240 individuals) and occurred in all habitats surveyed except deeper (6-15 m) fore sites (Table 5-3). Back-reef rubble sites yielded the greatest site presence, transect frequency, and mean density values, followed by mid-channel and offshore patch reefs. *E. lucunter* test sizes ranged from 0.4 to 4.0 cm and averaged 2.4 ± 0.9 cm. The size range (0.4-2.7 cm) and mean test diameter in rubble zones (1.41 ± 0.03 cm) illustrates the predominance of recently settled recruits in this habitat (Table 5-3). Mean and maximum test diameters were greater on mid-channel and offshore patch reefs compared to rubble and high-relief spur and groove habitats. Unlike other echinoids, there were no consistent differences in *E. lucunter* site presence, transect frequency, or density between reference areas and no-take zones among habitats.

Echinometra viridis Agassiz

The second most abundant urchin during 2011 was *Echinometra viridis*, which was encountered in all habitats except the deeper fore reef, but also exhibited habitat-specific patterns of distribution and abundance similar to previous years (Table 5-1). Figures 5-10 to 5-12 illustrate the spatial distribution and density patterns throughout the upper Keys study area. *E. viridis* was especially abundant on mid-channel patch reefs and back-reef rubble, which yielded the greatest site presence, transect frequency, and density values (Figure 5-13). Densities were especially high (upwards of 7.2 individual per m^2) on mid-channel patch reefs in the Basin Hill Shoals area west of Carysfort Reef (Figure 5-10). Similar to the pattern evident for other abundant echinoids, the frequency of occurrence and density of *E. viridis* tended to be greater on reference sites compared to FKNMS no-take zones (Figure 5-14), although there appeared to be little difference in size (Table 5-4). The test diameter (TD) of the 726 individuals measured from all sites ranged from 0.4 cm to 4.2 cm and averaged 2.43 ± 0.03 cm. The combined size distribution indicated a modal size class of 2.0-2.9 cm (Figure 5-15). Inshore and mid-channel patch reefs, followed by offshore patch reefs, yielded the largest average and maximum sizes, while back-reef rubble and shallow (< 6 m) hard-bottom habitats yielded smaller average and maximum sizes (Figure 5-15).

Eucidaris tribuloides (Lamarck)

The slate pencil urchin, *Eucidaris tribuloides*, was recorded from all habitats sampled, exhibited habitat-specific patterns of distribution and density similar to historical surveys during 1999-2010 (Table 5-5), and was the most abundant (819 individuals) urchin species surveyed in the upper Keys during 2011. The greatest site-level density estimate of 3.0 ± 0.6 individuals/m^2 was recorded from a back-reef rubble site at Conch Reef. Figures 5-16 to 5-18 illustrate the spatial distribution of *E. tribuloides* densities throughout the upper Florida Keys study area. Back-reef rubble, offshore patch reefs, shallow hard-bottom, and high relief spur and groove yielded the greatest site presence, transect frequency, and density values (Figure 5-19). Densities were particularly high in back-reef rubble, where mostly recently settled juveniles were encountered (Table 5-5). Similar to other urchin species, *E. tribuloides* site presence, transect frequency, and density, but not size, tended to be greater on reference sites compared to no-take zones (Figure 5-20). For the 819 individuals encountered, test diameters ranged from 0.3 cm to 5.0 cm, averaged 2.2 cm, and exhibited a modal size class of 2.0-2.9 cm (Figure 5-21). A slightly larger average size was apparent on patch reefs compared to other habitats, similar to previous years, while back-reef rubble was dominated by juveniles (average size of 1.7 cm TD) (Figure 5-21)

Lytechinus variegatus (Lamarck)

Seventeen (17) individuals of *Lytechinus variegatus* were encountered from the 280 upper Keys sites. Individuals were found on mid-channel and offshore patch reefs and back-reef rubble sites (Table 5-6). Site presence, transect frequency, and density were greatest in back-reef rubble sites, especially in reference areas compared to no-take zones. A maximum site-level density of 0.333 ± 0.200 individuals per m^2 was recorded from a back-reef rubble site at Conch Reef. Larger individuals (> 6 cm TD) were observed on patch reefs, while mostly juveniles (< 3 cm TD) were found on back-reef rubble.

Tripneustes ventricosus (Lamarck)

Similar to previous years, *Tripneustes ventricosus* was one of the least abundant urchins encountered in 2011, which is expected since the sampling effort did not include seagrass habitats. A total of seven (7) individuals were recorded from the 280 upper Keys sites, with a maximum site-level density of 0.033 ± 0.033 individuals per m^2. Individuals were only found on a few mid-channel and offshore patch reefs, followed by one deeper fore-reef site, and no individuals were encountered in no-take zones (Table 5-7). The size range of the seven individuals sampled ranged from 4.6 to 9.8 cm, with a mean size of 7.8 ± 0.8 cm.

Discussion

Large-scale surveys encompassing hundreds of sites in the Florida Keys since 1999 indicate that *Diadema antillarum* continues to persist at densities well below values reported before the Caribbean-wide mass mortality in 1983-84 and the Florida Keys mortality event in 1991 (Kier and Grant 1965; Bauer 1980; Forcucci 1994). Despite this pattern, the Florida Keys population continues to show signs of increasing spatial distribution and abundance, as well as an increase in mean test size, with a greater proportion of larger individuals present. In addition, the back-reef rubble habitat appears to continue to be an important recruitment habitat, although the fate of post-settlement individuals compared to other habitat types has not been studied. Earlier reports and recent observations indicate that other urchins show density and habitat distribution patterns similar to pre-1983 observations, indicating that other species have apparently not compensated for the loss of *D. antillarum* (Chiappone et al. 2002a). In areas with relatively high (> 0.1 individuals/m^2) and larger (> 5 cm TD) *D. antillarum,* there are obvious effects of grazing on the substratum, particularly the removal of turf and macroalgae and exposure of the substratum (Chiappone et al. 2001). This is also apparent in areas with relatively high Echinometra densities, despite the smaller sizes of the two congeners compared to *D. antillarum*. It remains unclear whether or not increasing *D. antillarum* densities and sizes will lead to other changes to the benthos such as increased coral or urchin recruitment.

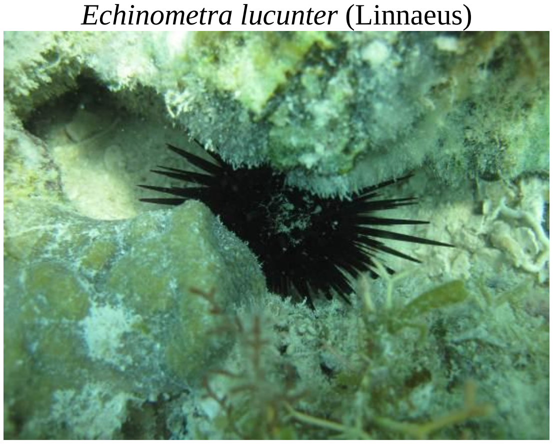
The slow and prolonged recovery of *Diadema antillarum* in the Florida Keys, especially compared to reports of more rapid recovery in some Caribbean reef areas, raises several questions pertaining to factors that may inhibit population recovery (Lessios 1988). Possible causes of slow recovery include poor larval survivorship, lack of adult conspecifics and hence protection from predators, suitable recruitment sites, and inter-specific competition. The sources of urchin larvae to the south Florida shelf are not known, but may include both local and regional sources (Lee et al. 1994). Nonetheless, it is apparent that *D. antillarum* have continually recruited to benthic habitats, especially rubble areas, but the fate of these recently settled juveniles is unknown (Chiappone et al. 2002a). A recent study of *D. antillarum* larval settlement rates in the Florida Keys, however, indicate that low larval supply may be one factor limiting recovery (Miller et al. 2010). The predominance of relatively small test sizes from 1999-2005 indicated that recently settled individuals likely have poor survivorship into larger size classes, perhaps due to predation or physical disturbance from storms. However, since 2005, there has been a notable shift in the size distribution towards larger individuals in the population. Because *D. antillarum* was historically significant as a grazer, it is anticipated that continued recovery will influence patterns in benthic community structure throughout the Florida Keys.

Figure 5-1. Urchin species surveyed for density and size (test diameter) in the Florida Keys during 2010. Not shown is *Tripneustes ventricosus* (Lamarck).

Arbacia punctulata (Lamarck)

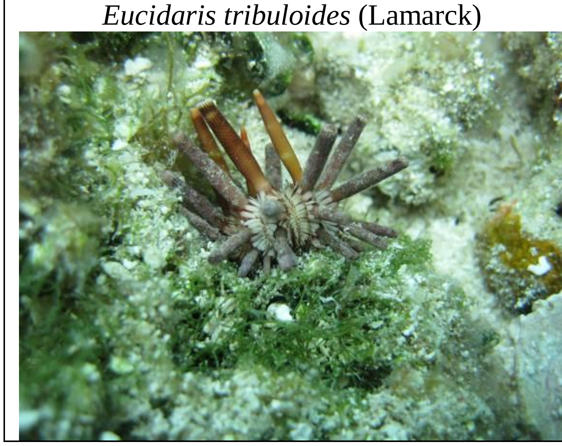
Diadema antillarum (Philippi)

Echinometra lucunter (Linnaeus)



Echinometra viridis (Agassiz)

Eucidaris tribuloides (Lamarck)



Lytechinus variegates (Lamarck)

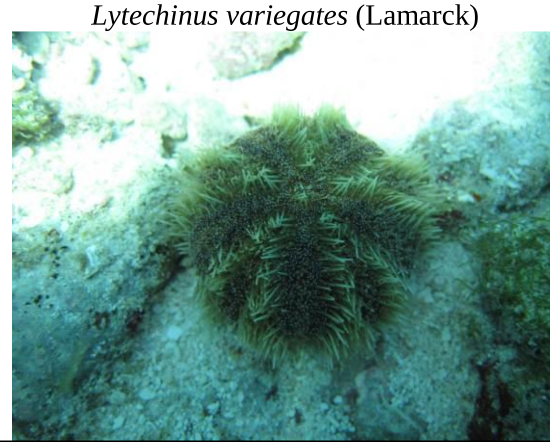
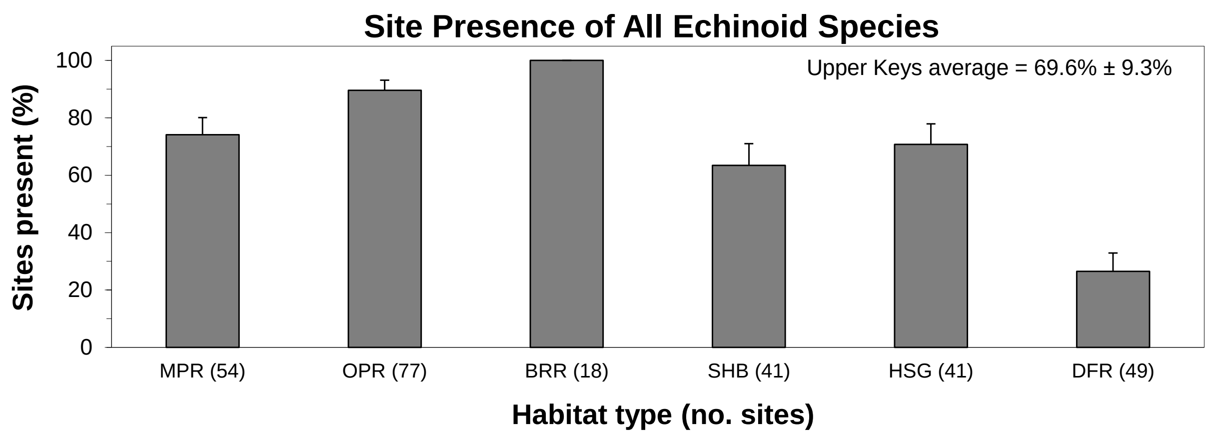


Figure 5-2. Mean (+ 1 SE) site presence (top) and site species richness (no. species per 30 m^2) (bottom) of all echinoid species by habitat type in the upper Florida Keys during May-September 2011. Domain-wide (upper Keys) values are weighted averages and standard errors. Values on the x-axis in parentheses are the number of sites surveyed in each habitat type, with two 15-m x 1-m transects surveyed per site.



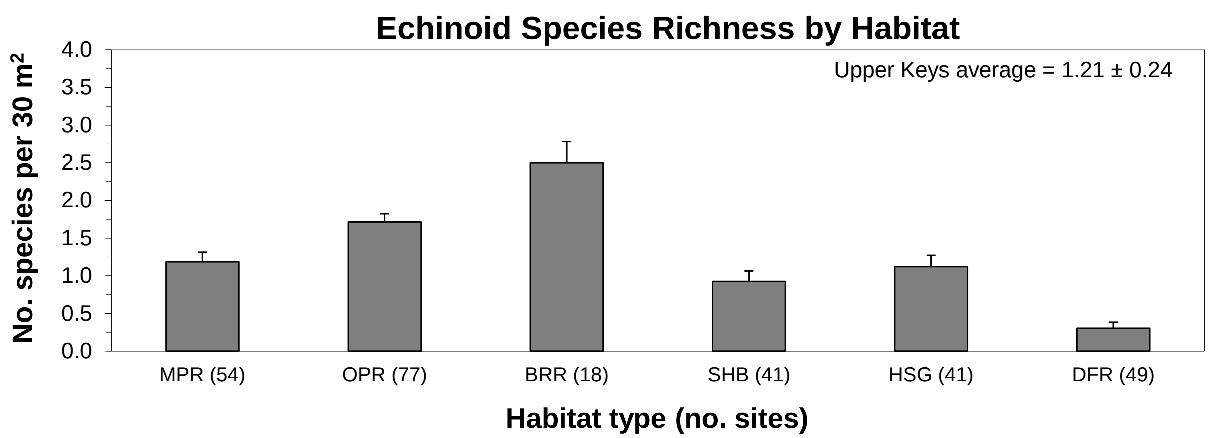
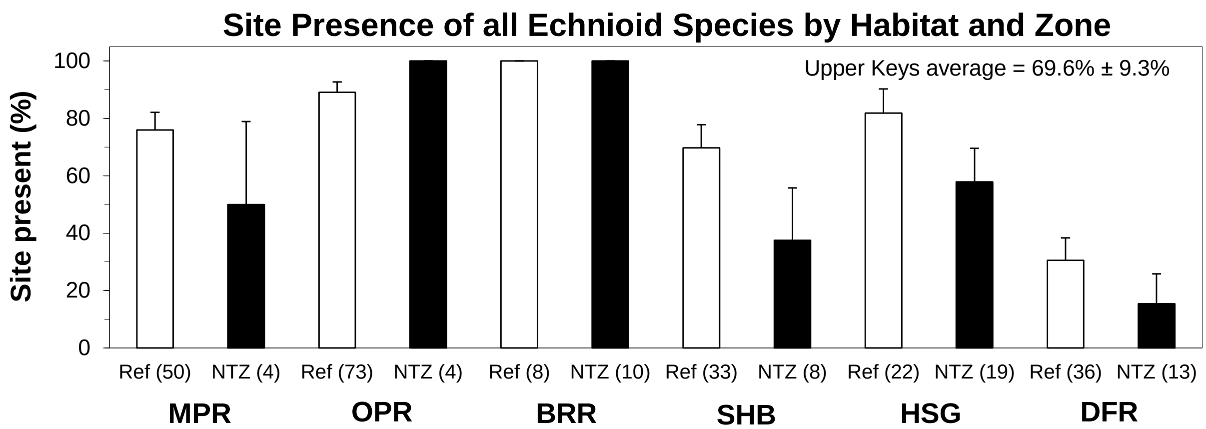


Figure 5-3. Mean (+ 1 SE) site presence (top) and site species richness (no. species per 30 m^2) (bottom) of all echinoid species by habitat type and management zone in the upper Florida Keys during May-September 2011. Open bars = reference areas (Ref), filled bars = no-take zones (NTZ). Domain-wide (upper Keys) values are weighted averages and standard errors. Habitat abbreviations are MPR = inshore and mid-channel patch reefs, OPR = offshore patch reefs, BRR = back-reef rubble, SHB = shallow (< 6 m) hard-bottom, HSG = high-relief and groove, and DFR = deeper (6-15 m) fore-reef habitats. Numbers in parentheses on the x-axis are the number of sites surveyed, with two replicate 15-m x 1-m transects surveyed per site (30 m^2 per site).



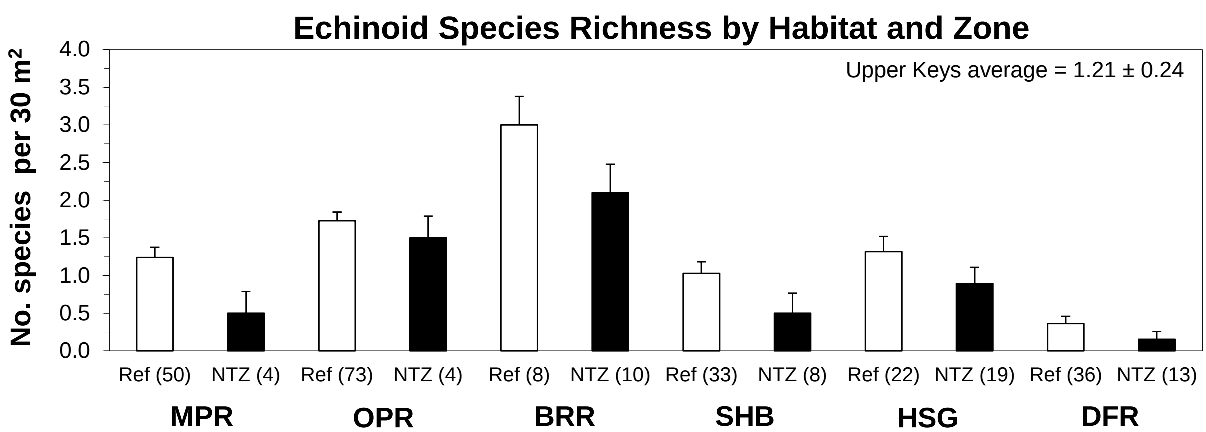


Figure 5-4. Densities (no. per m^2) of long-spined sea urchins (*Diadema antillarum*) in the upper Florida Keys National Marine Sanctuary from the southern boundary of Biscayne National Park to Carysfort/S. Carysfort Reef surveyed during May-September 2011.

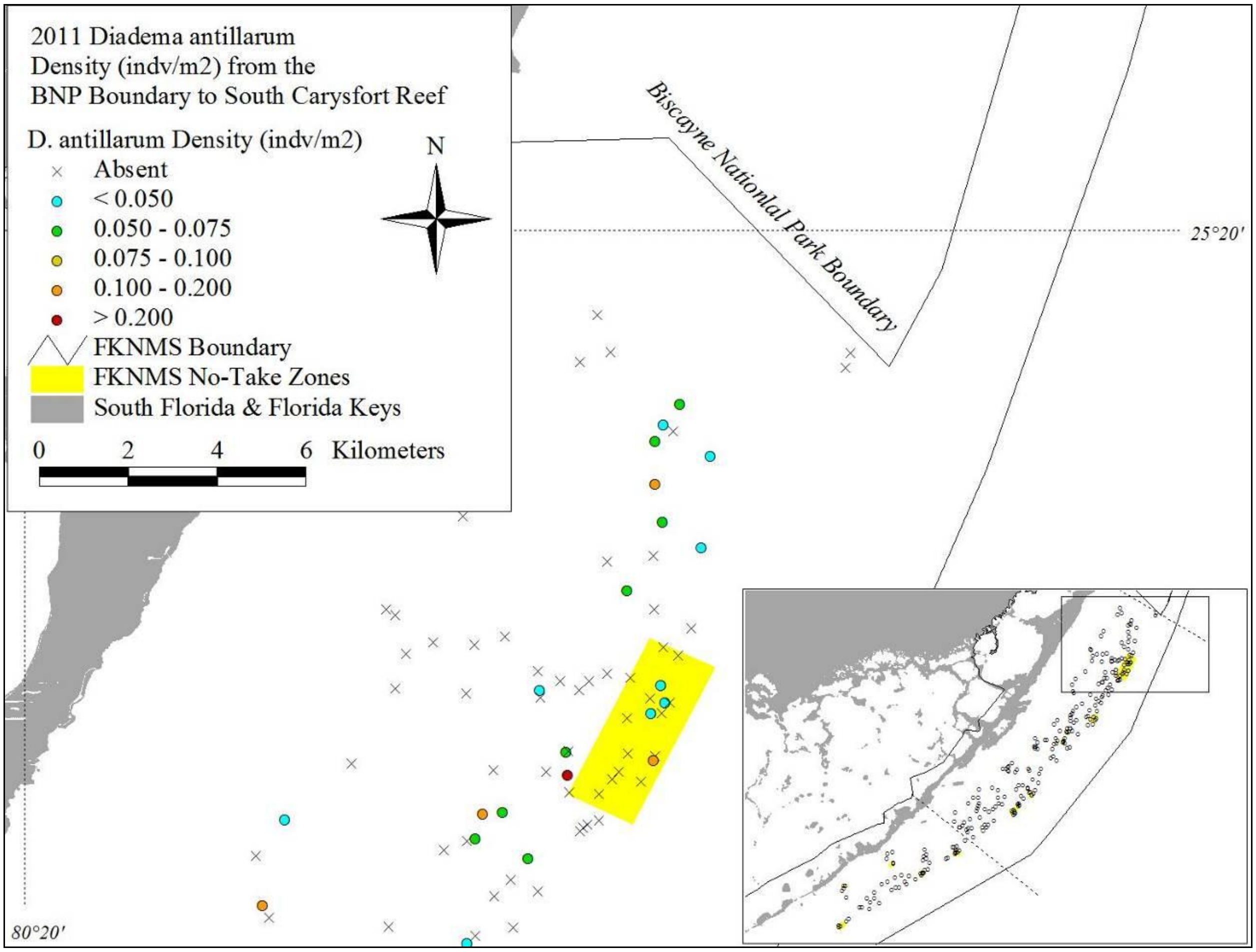


Figure 5-5. Densities (no. per m^2) of long-spined sea urchins (*Diadema antillarum*) in the upper Florida Keys National Marine Sanctuary from Elbow Reef to Pickles Reef surveyed during May-September 2011.

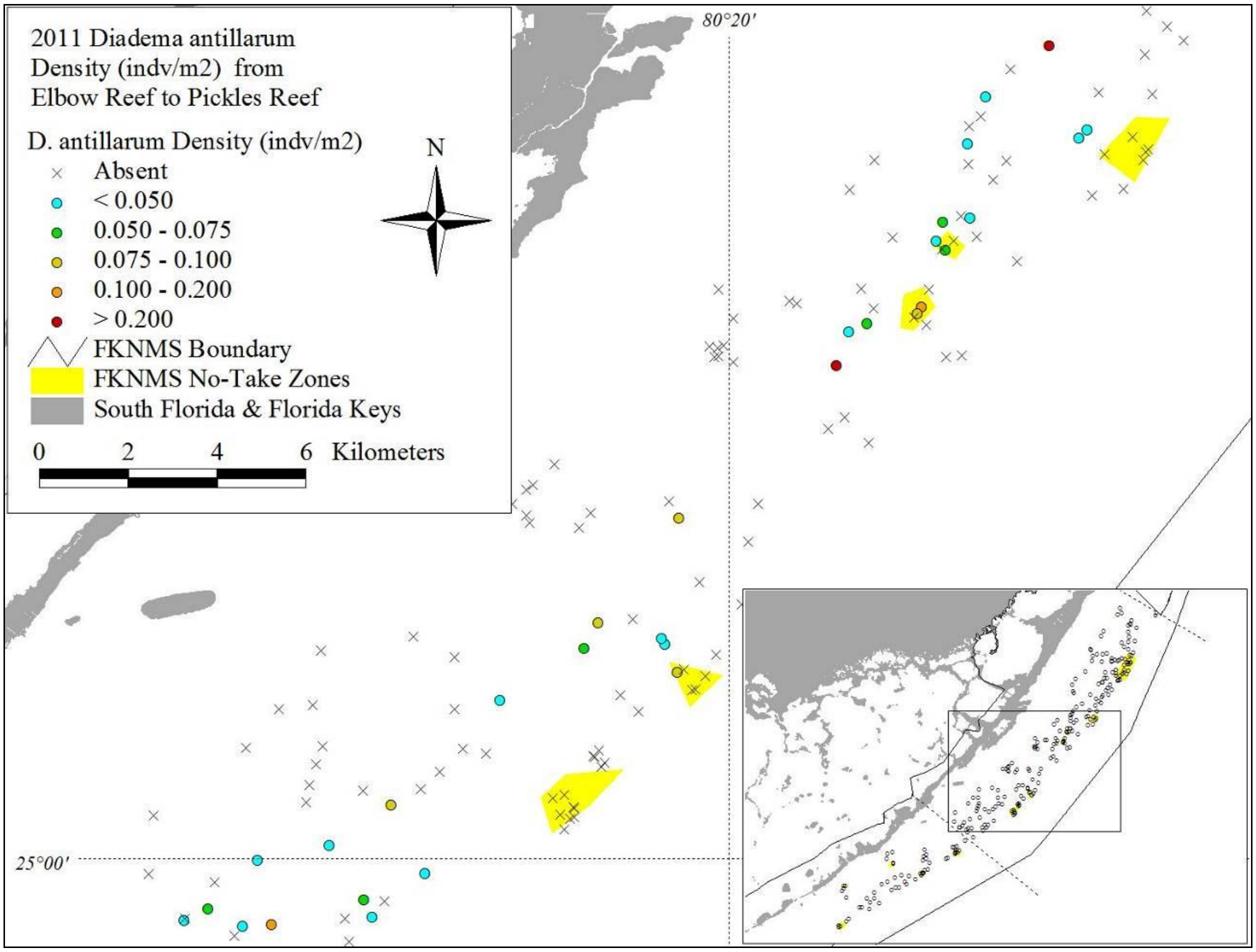


Figure 5-6. Densities (no. per m^2) of long-spined sea urchins (*Diadema antillarum*) in the upper Florida Keys National Marine Sanctuary from Conch Reef SPA to Alligator Reef surveyed during May-September 2011.

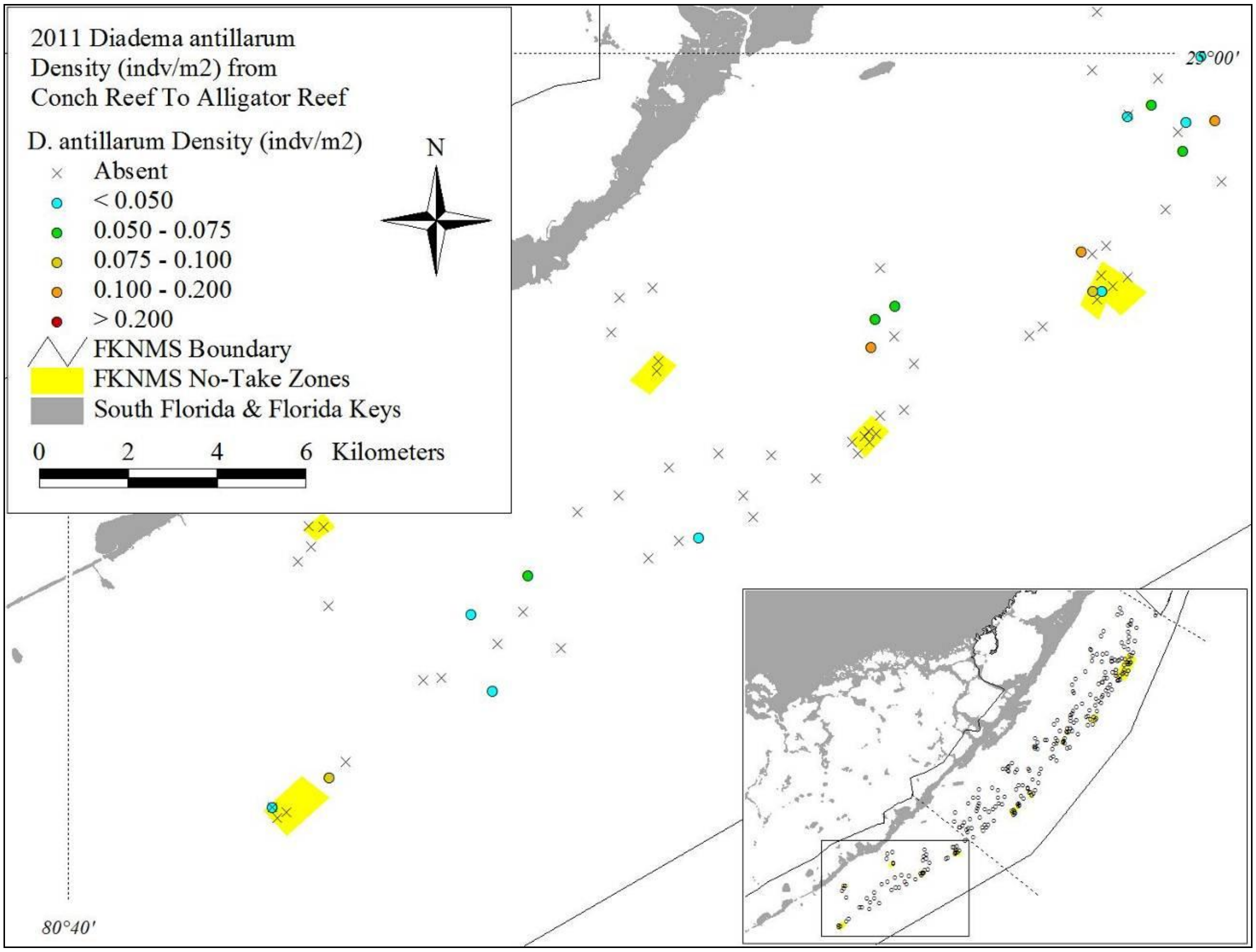
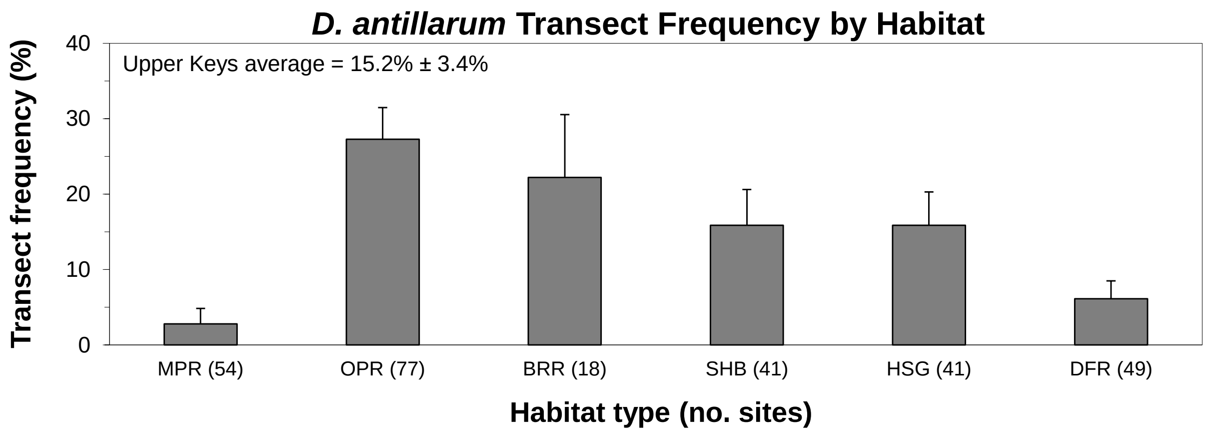


Figure 5-7. Mean (+ 1 SE) transect frequency (top) and density (no. individuals per m^2) (bottom) of long-spined sea urchins (*Diadema antillarum*) by habitat type in the upper Florida Keys during May-September 2011. Domain-wide (upper Keys) values are weighted averages and standard errors. Values on the x-axis in parentheses are the number of sites surveyed in each habitat type, with two 15-m x 1-m transects surveyed per site.



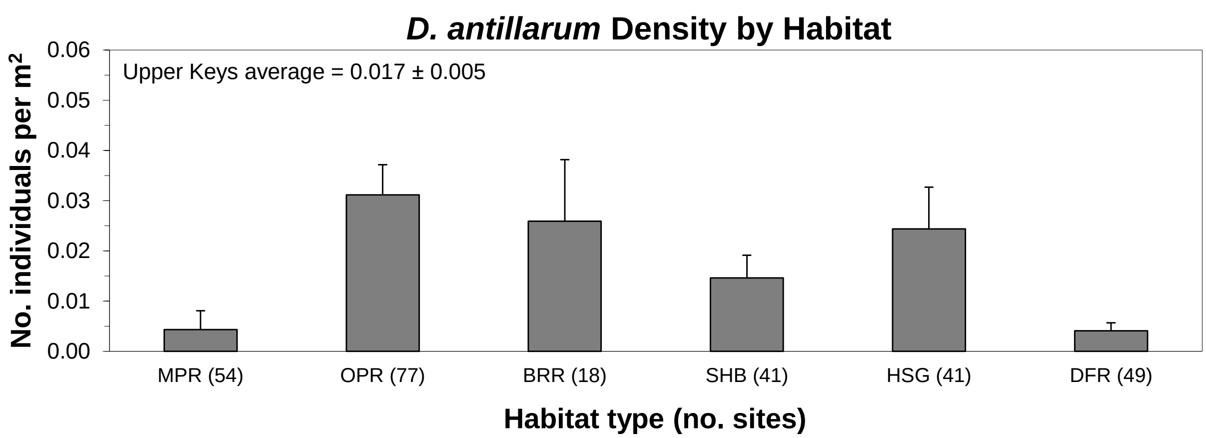
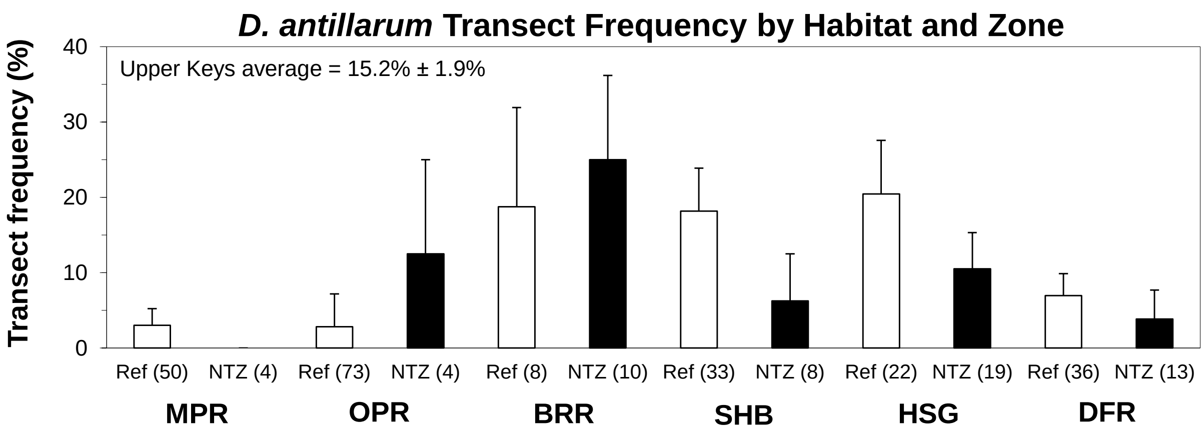


Figure 5-8. Mean (+ 1 SE) transect frequency (top) and density (no. individuals per m^2) (bottom) of long-spined sea urchins (*Diadema antillarum*) by habitat type and management zone in the upper Florida Keys during May-September 2011. Open bars = reference areas (Ref), filled bars = no-take zones (NTZ). Domain-wide (upper Keys) values are weighted averages and standard errors. Habitat abbreviations are MPR = inshore and mid-channel patch reefs, OPR = offshore patch reefs, BRR = back-reef rubble, SHB = shallow (< 6 m) hard-bottom, HSG = high-relief and groove, and DFR = deeper (6-15 m) fore-reef habitats. Numbers in parentheses on the x-axis are the number of sites surveyed, with two replicate 15-m x 1-m transects surveyed per site (30 m^2 per site).



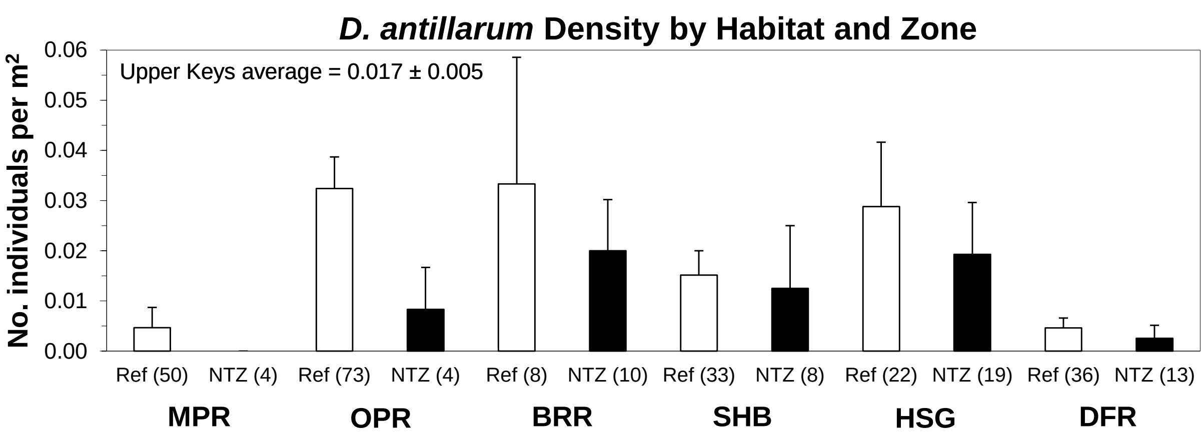
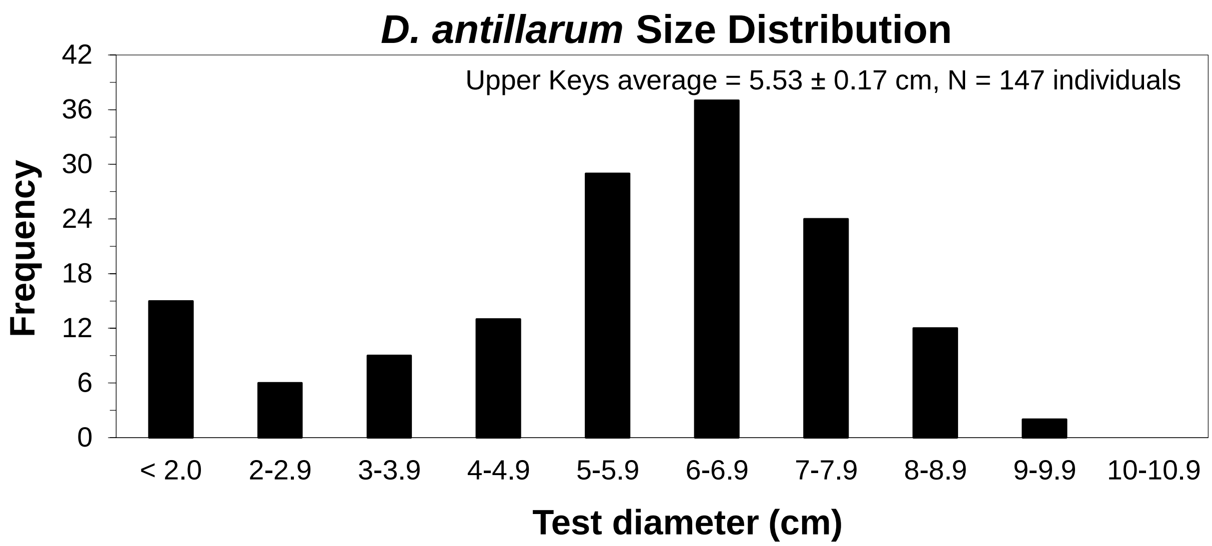


Figure 5-9. Distribution of urchin test diameter sizes (top) and mean (± 1 SE) (filled circles) and maximum sizes (open circles) across habitats (bottom) for *Diadema antillarum* in the upper Florida Keys National Marine Sanctuary, as determined from surveys at 280 sites during May-September 2011. Habitat abbreviations in the bottom figure are MPR = inshore and mid-channel patch reefs, OPR = offshore patch reefs, BRR = back-reef rubble, SHB = shallow (< 6 m) hard-bottom, HSG = high-relief and groove, and DFR = deeper (6-15 m) fore-reef habitats.



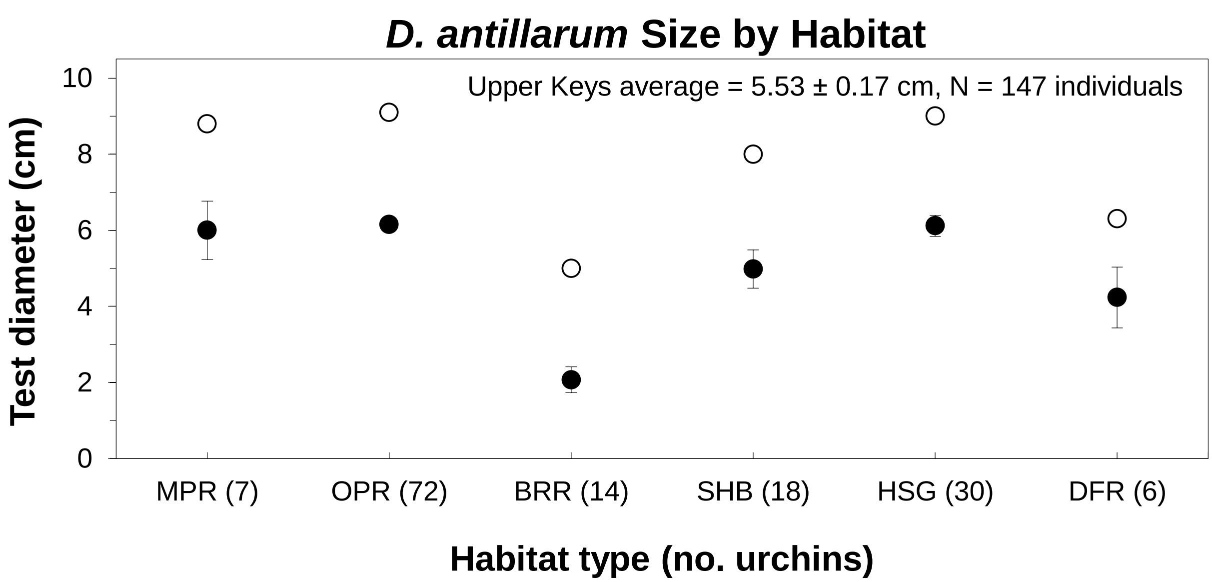


Figure 5-10. Densities (no. per m^2) of green rock-boring urchins (*Echinometra viridis*) in the upper Florida Keys National Marine Sanctuary from the southern boundary of Biscayne National Park to Carysfort/S. Carysfort Reef surveyed during May-September 2011.

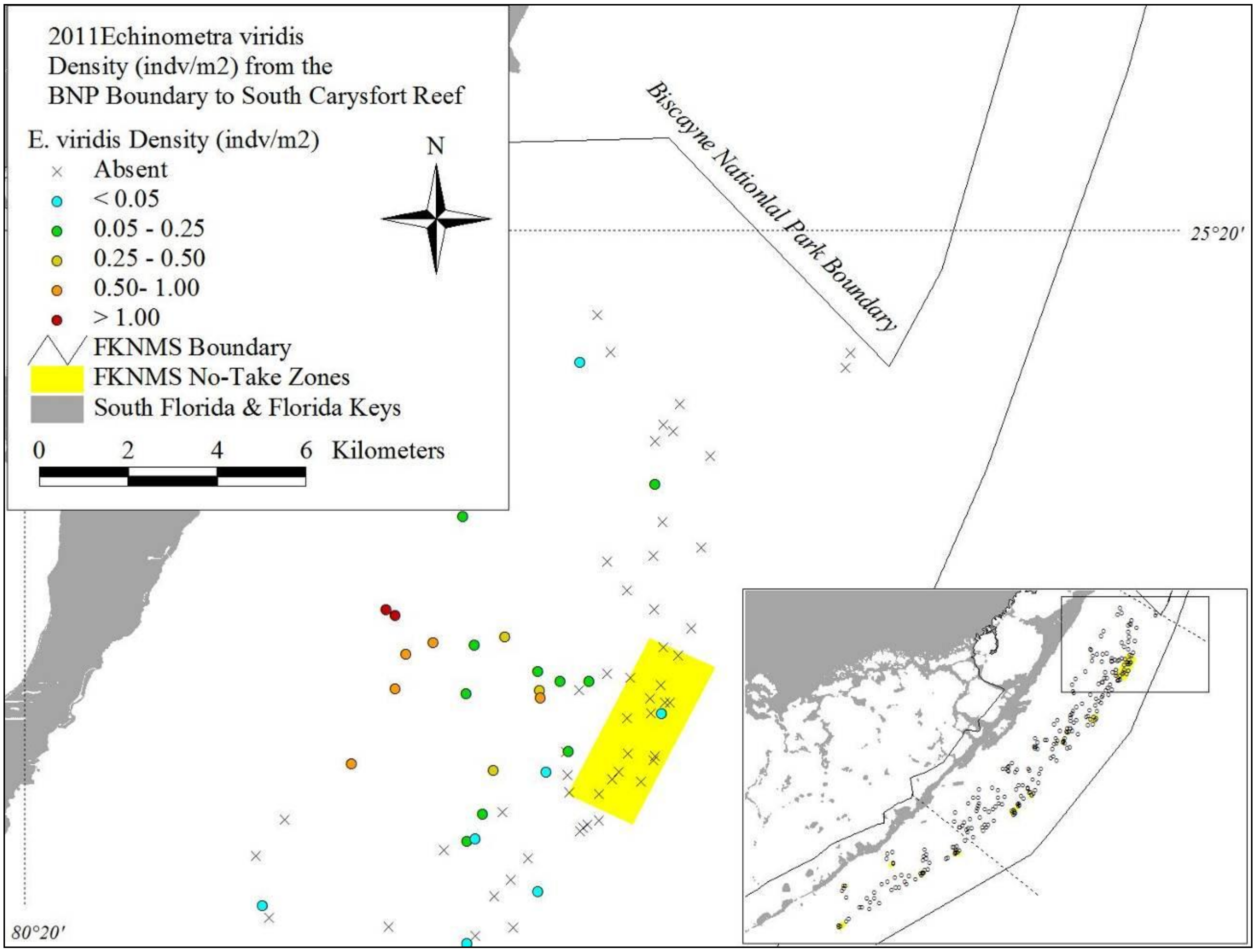


Figure 5-11. Densities (no. per m^2) of green rock-boring urchins (*Echinometra viridis*) in the upper Florida Keys National Marine Sanctuary from Elbow Reef to Pickles Reef surveyed during May-September 2011.

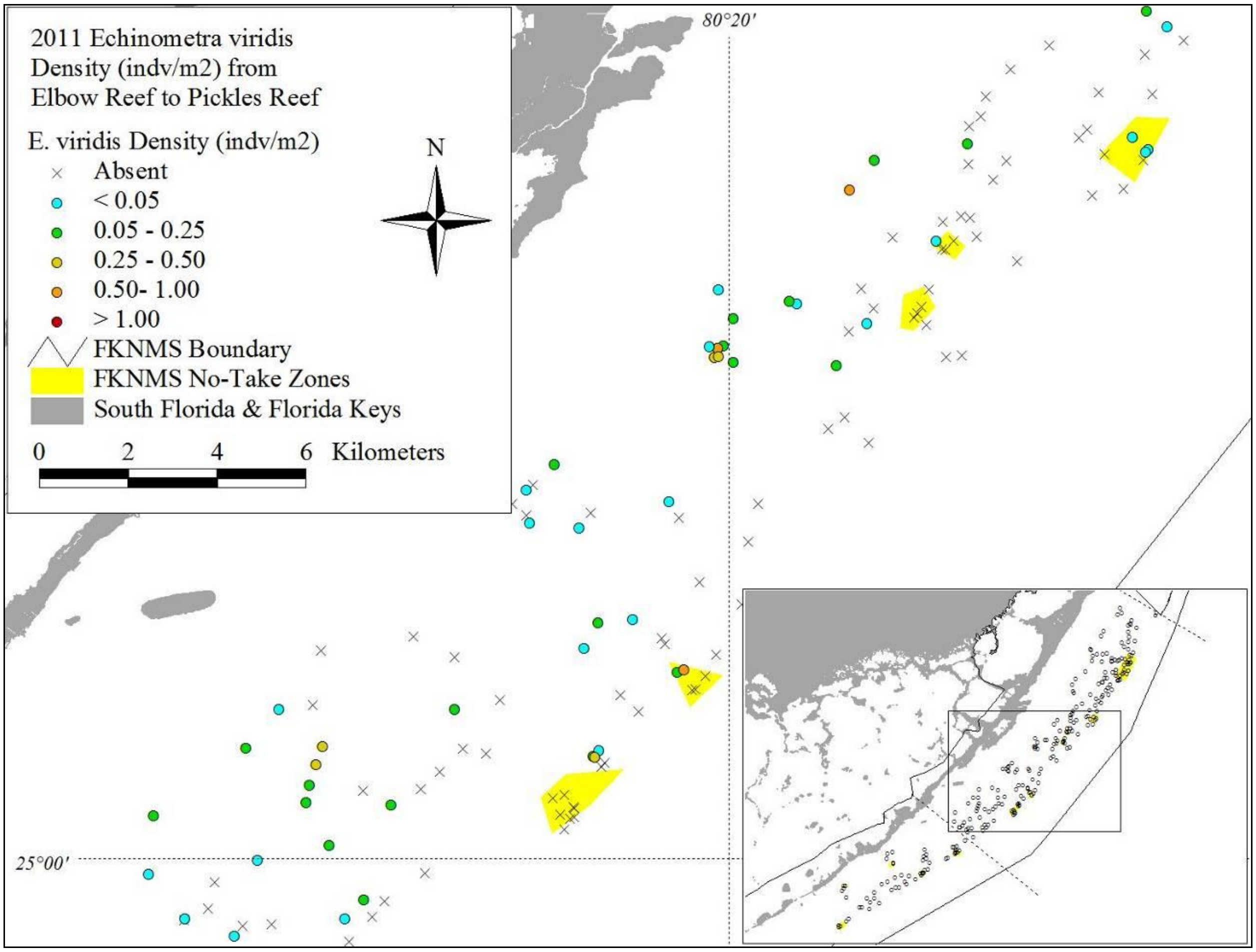


Figure 5-12. Densities (no. per m^2) of green rock-boring urchins (*Echinometra viridis*) in the upper Florida Keys National Marine Sanctuary from Conch Reef SPA to Alligator Reef surveyed during May-September 2011.

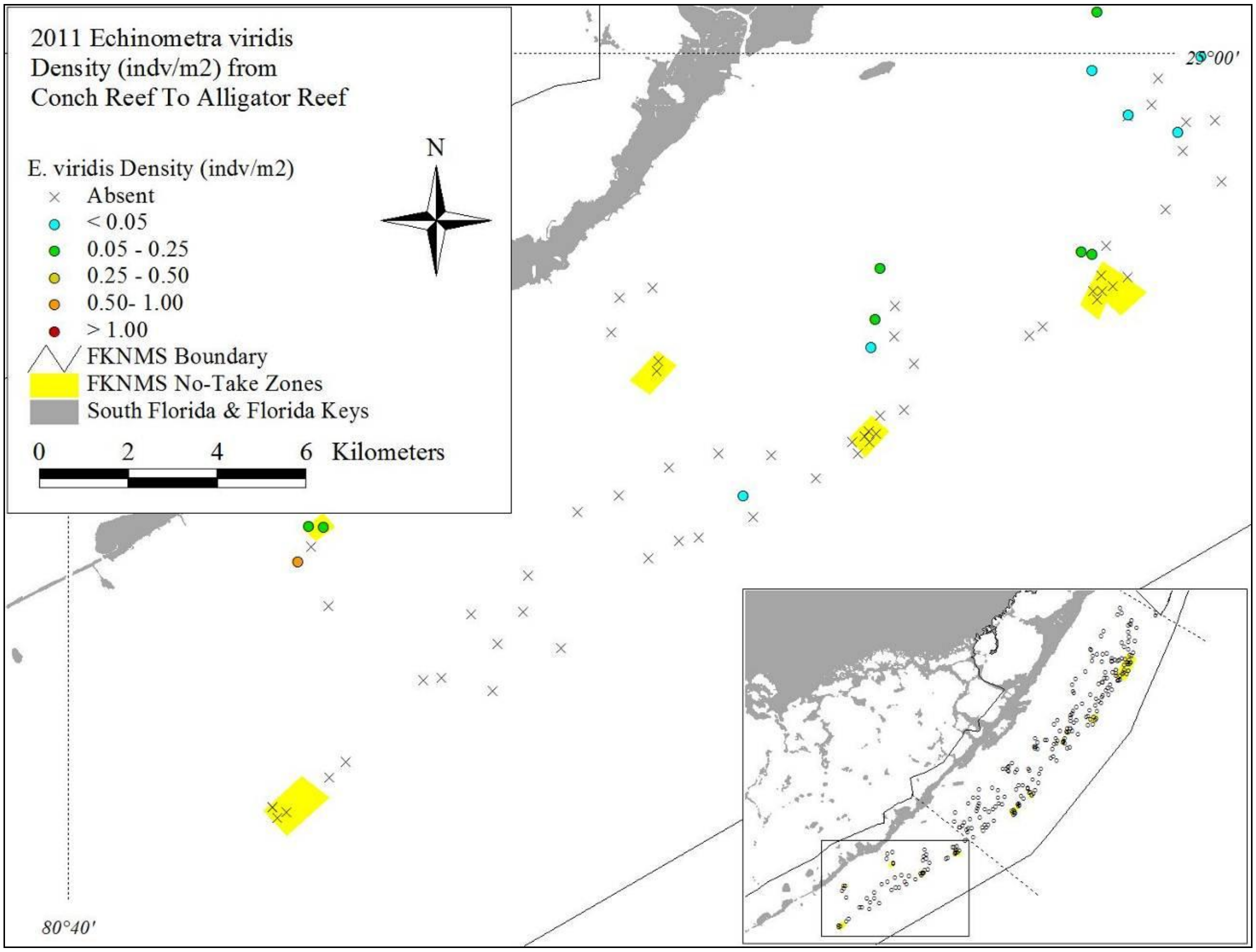
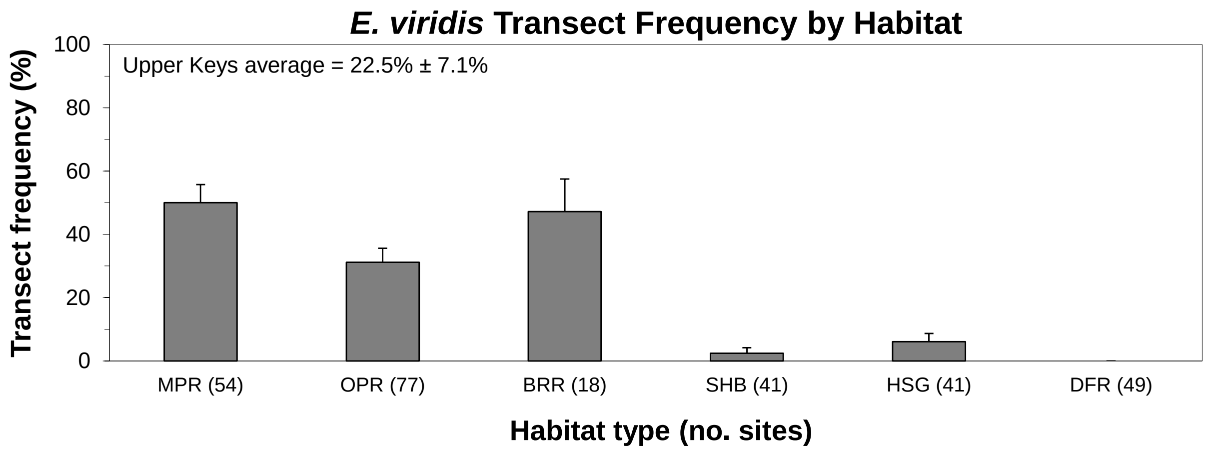


Figure 5-13. Mean (+ 1 SE) transect frequency (top) and density (no. individuals per m^2) (bottom) of green rock-boring urchins (*Echinometra viridis*) by habitat type in the upper Florida Keys during May-September 2011. Domain-wide (upper Keys) values are weighted averages and standard errors. Values on the x-axis in parentheses are the number of sites surveyed in each habitat type, with two 15-m x 1-m transects surveyed per site.



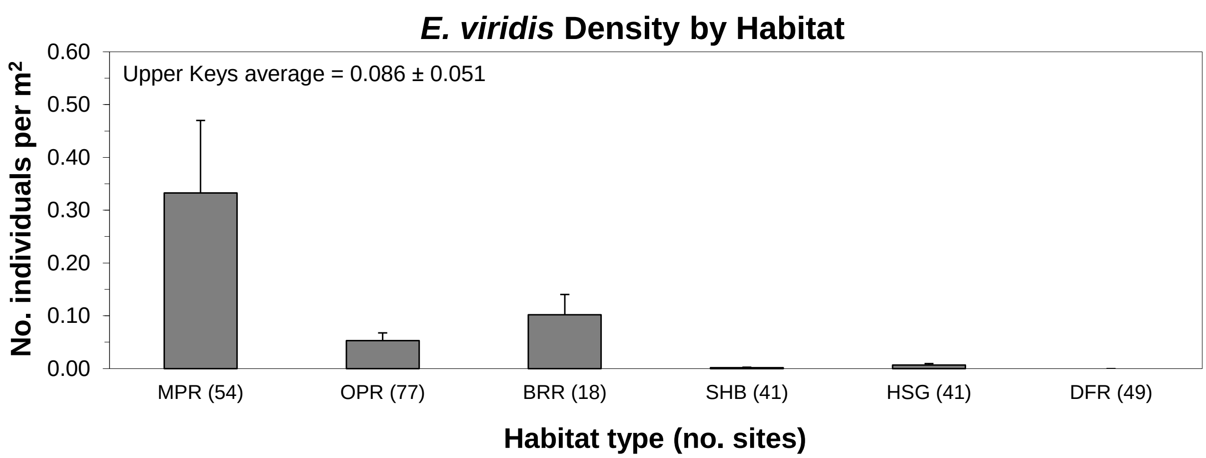
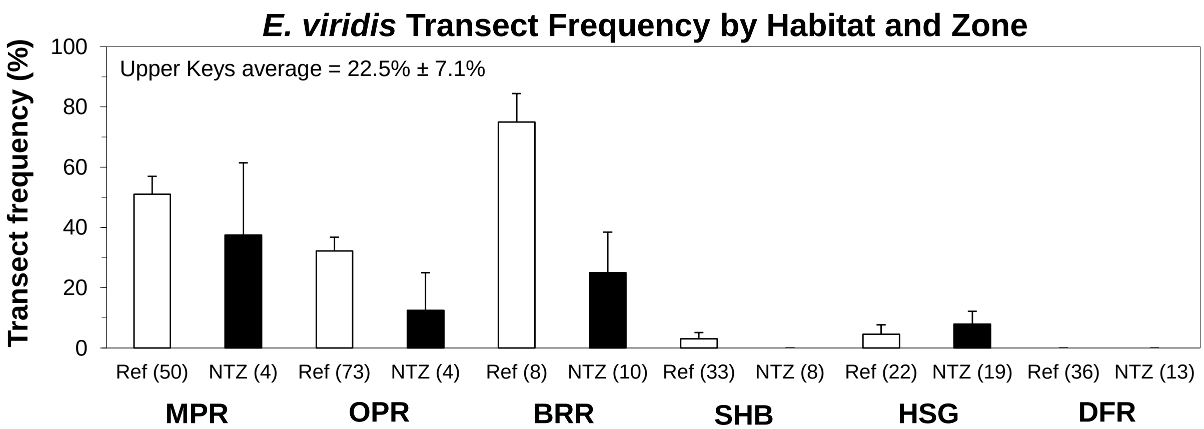


Figure 5-14. Mean (+ 1 SE) transect frequency (top) and density (no. individuals per m^2) (bottom) of green rock-boring urchins (*Echinometra viridis*) by habitat type and management zone in the upper Florida Keys during May-September 2011. Open bars = reference areas (Ref), filled bars = no-take zones (NTZ). Domain-wide (upper Keys) values are weighted averages and standard errors. Habitat abbreviations are MPR = inshore and mid-channel patch reefs, OPR = offshore patch reefs, BRR = back-reef rubble, SHB = shallow (< 6 m) hard-bottom, HSG = high-relief and groove, and DFR = deeper (6-15 m) fore-reef habitats. Numbers in parentheses on the x-axis are the number of sites surveyed, with two replicate 15-m x 1-m transects surveyed per site (30 m^2 per site).



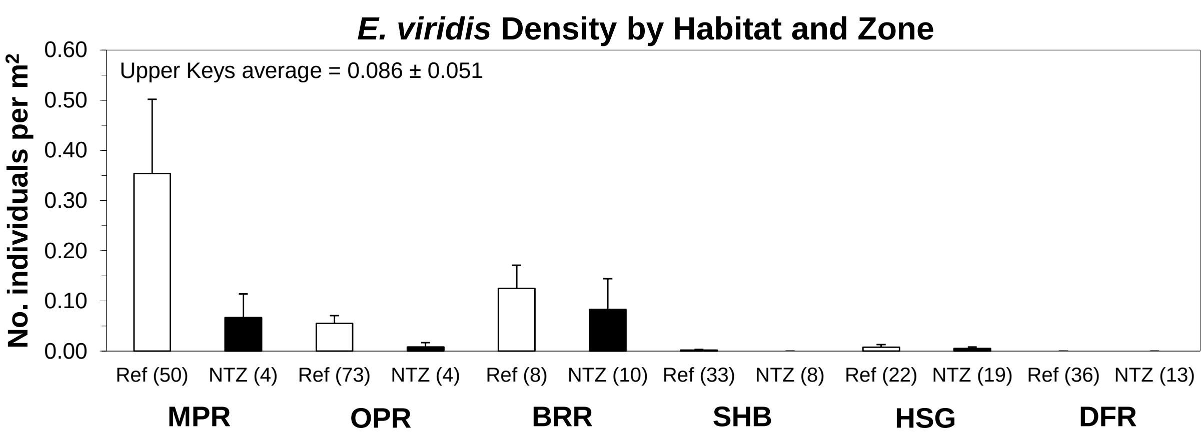
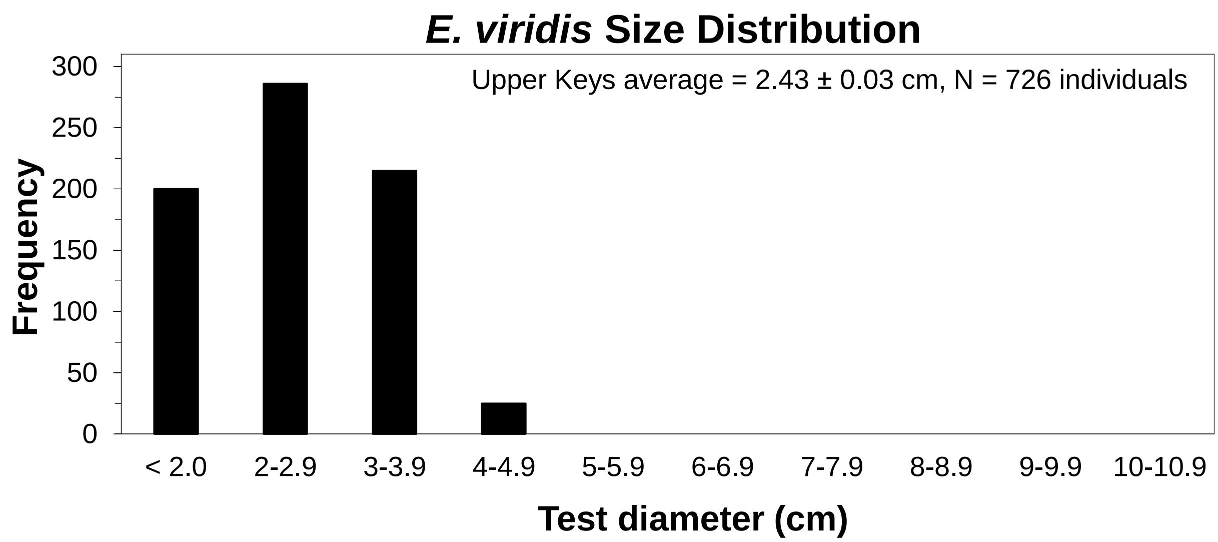


Figure 5-15. Distribution of urchin test diameter sizes (top) and mean (± 1 SE) (filled circles) and maximum sizes (open circles) across habitats (bottom) for *Echinometra viridis* in the upper Florida Keys National Marine Sanctuary, as determined from surveys at 280 sites during May-September 2011. Habitat abbreviations in the bottom figure are MPR = inshore and mid-channel patch reefs, OPR = offshore patch reefs, BRR = back-reef rubble, SHB = shallow (< 6 m) hard-bottom, HSG = high-relief and groove, and DFR = deeper (6-15 m) fore-reef habitats.



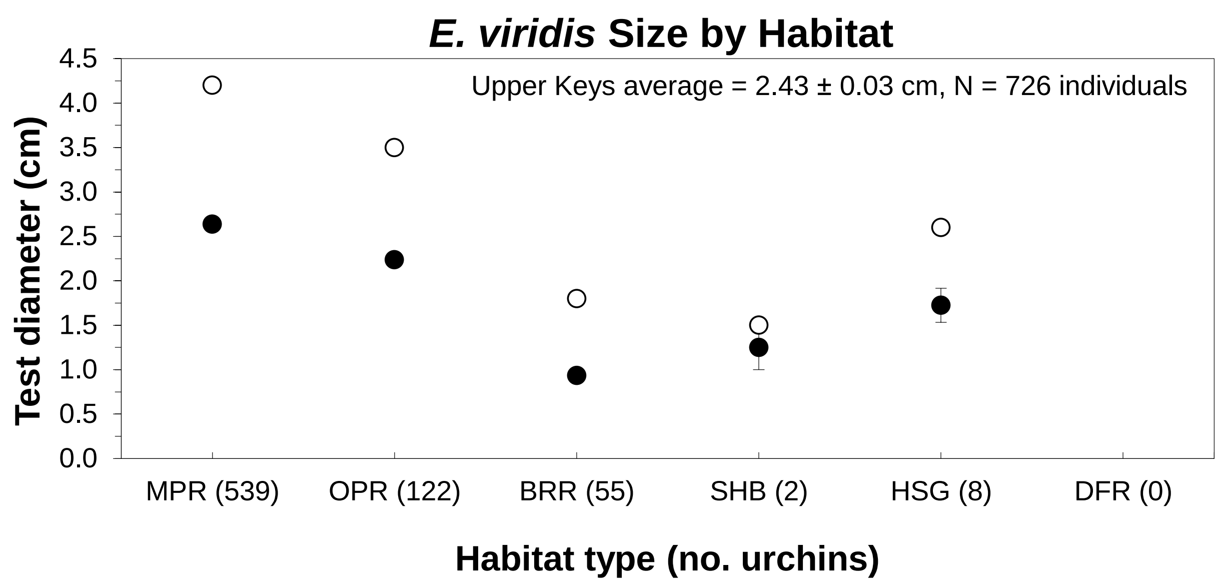


Figure 5-16. Densities (no. per m^2) of green slate pencil urchins (*Eucidaris tribuloides*) in the upper Florida Keys National Marine Sanctuary from the southern boundary of Biscayne National Park to Carysfort/S. Carysfort Reef surveyed during May-September 2011.

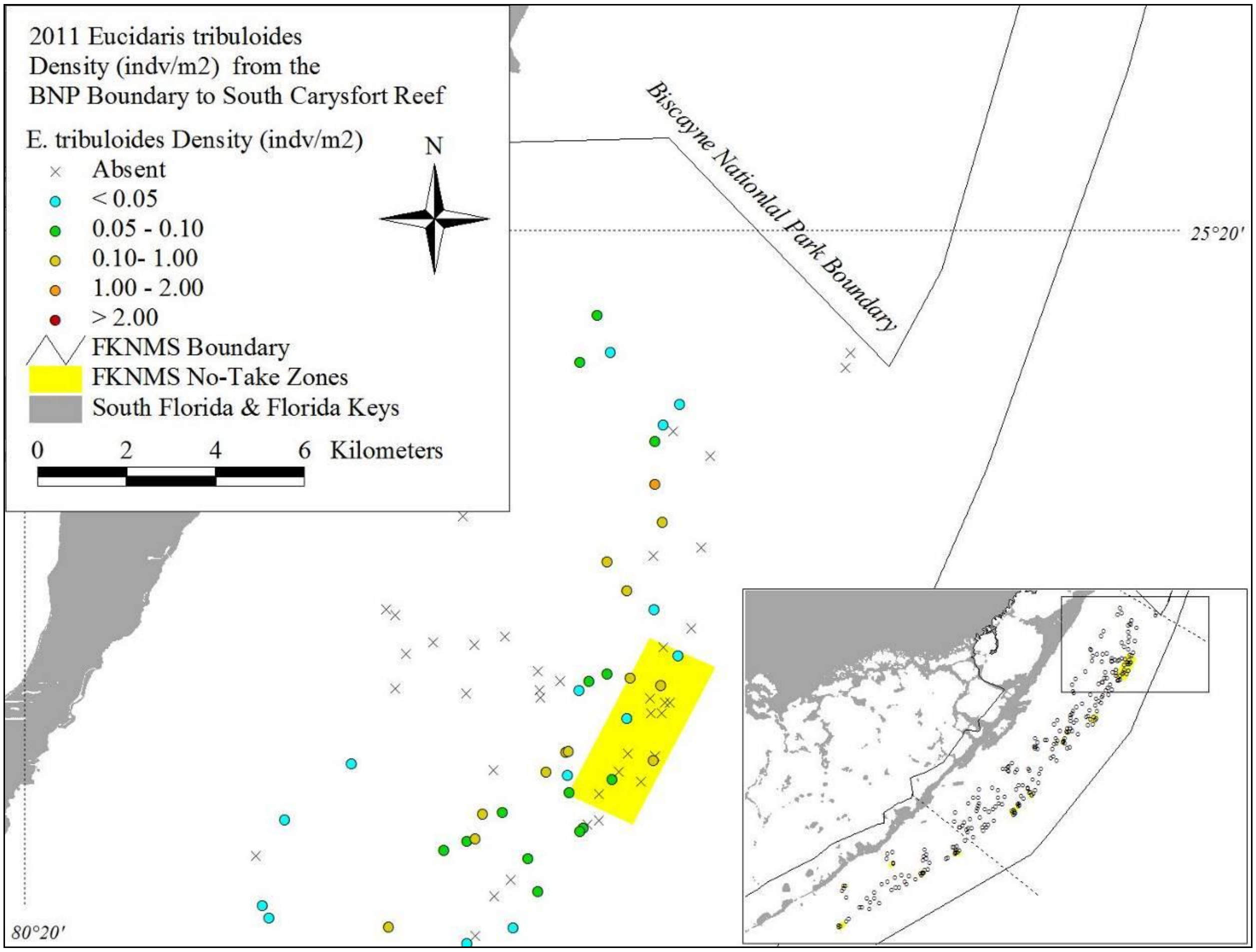


Figure 5-17. Densities (no. per m^2) of slate pencil urchins (*Eucidaris tribuloides*) in the upper Florida Keys National Marine Sanctuary from Elbow Reef to Pickles Reef surveyed during May-September 2011.

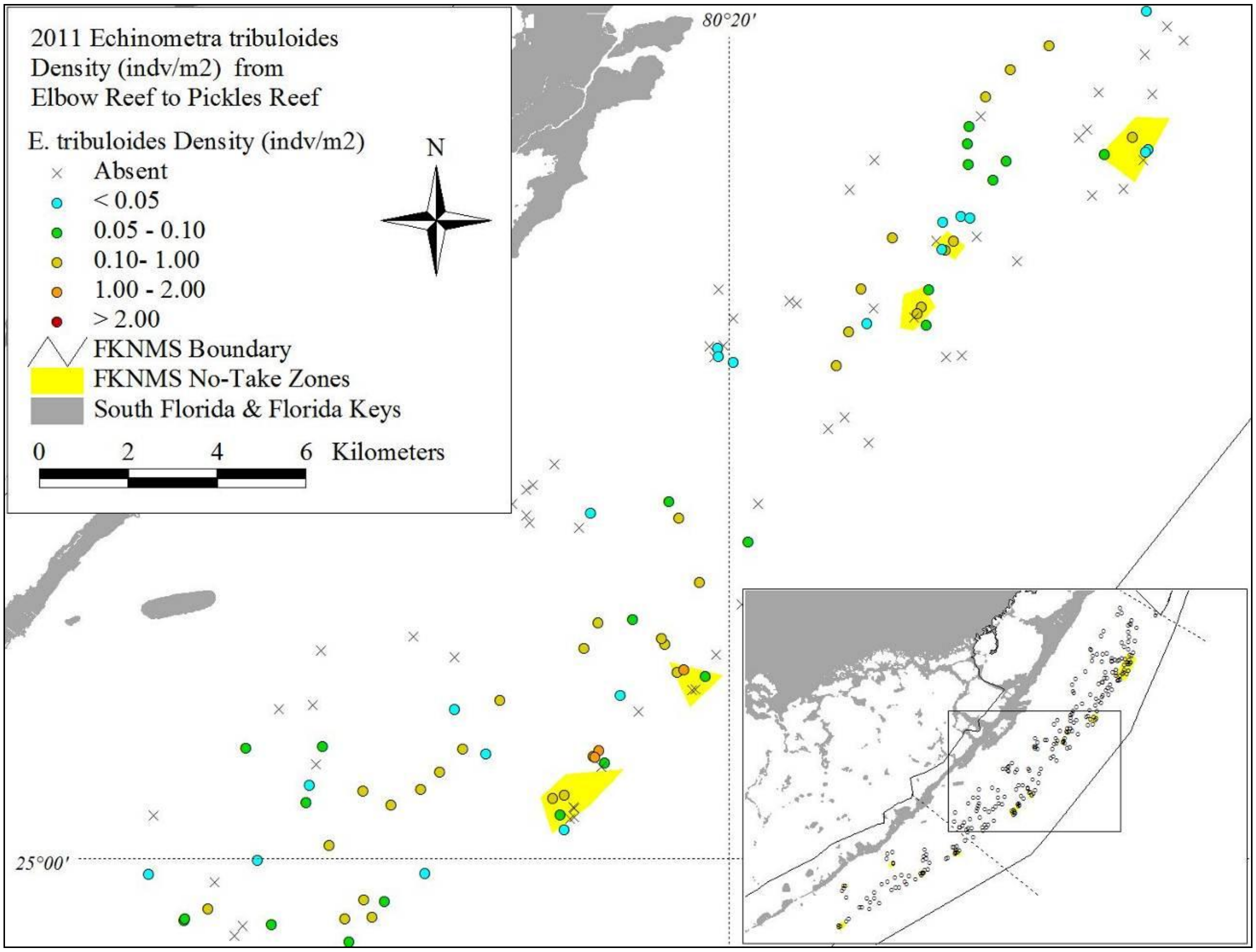


Figure 5-18. Densities (no. per m^2) of slate pencil urchins (*Eucidaris tribuloides*) in the upper Florida Keys National Marine Sanctuary from Conch Reef SPA to Alligator Reef surveyed during May-September 2011.

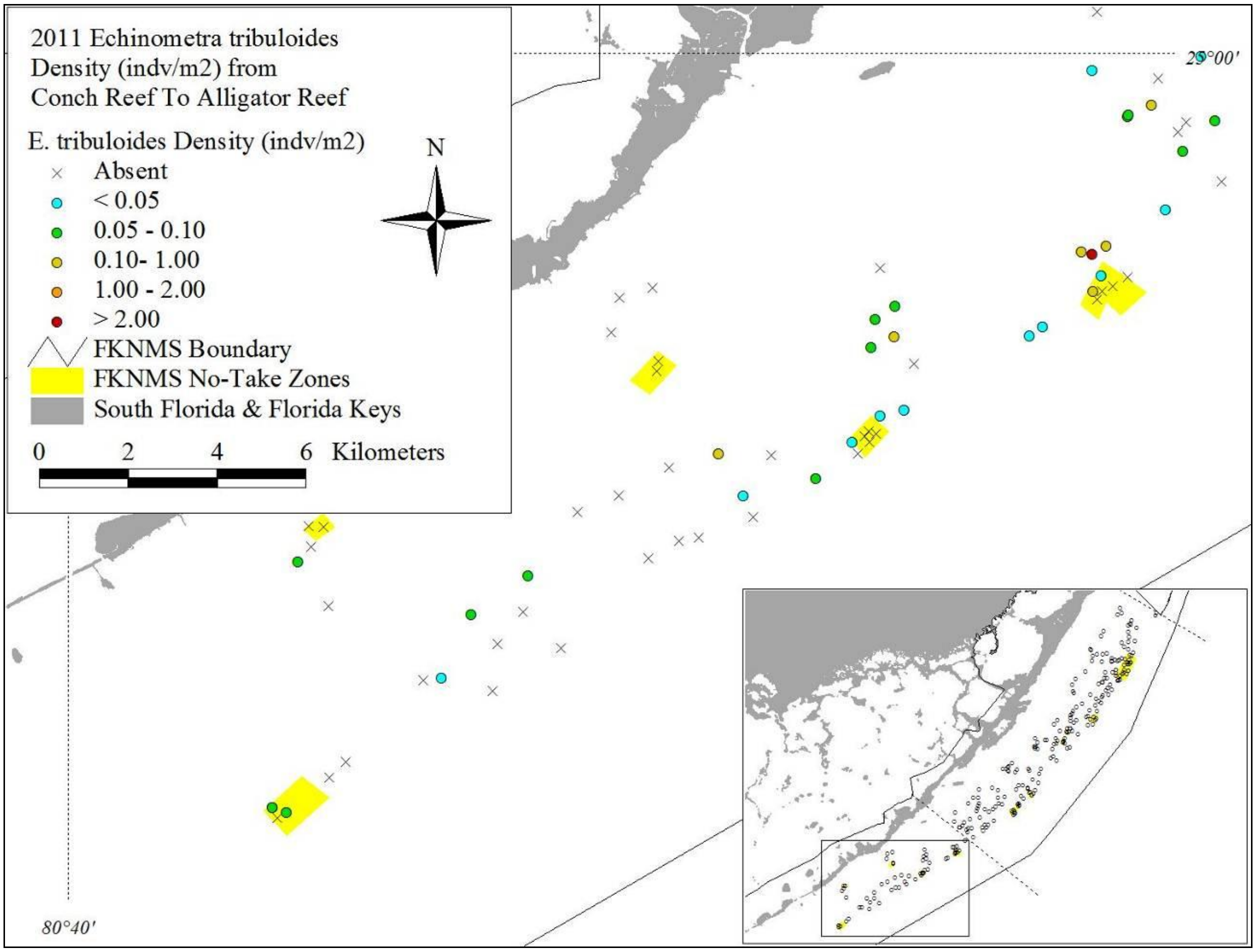
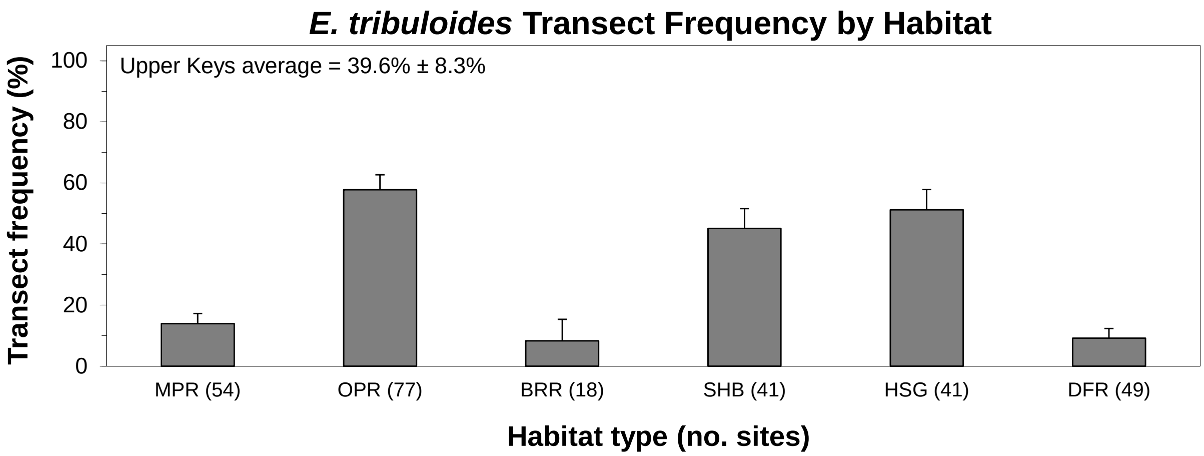


Figure 5-19. Mean (+ 1 SE) transect frequency (top) and density (no. individuals per m^2) (bottom) of slate pencil urchins (*Eucidaris tribuloides*) by habitat type in the upper Florida Keys during May-September 2011. Domain-wide (upper Keys) values are weighted averages and standard errors. Values on the x-axis in parentheses are the number of sites surveyed in each habitat type, with two 15-m x 1-m transects surveyed per site.



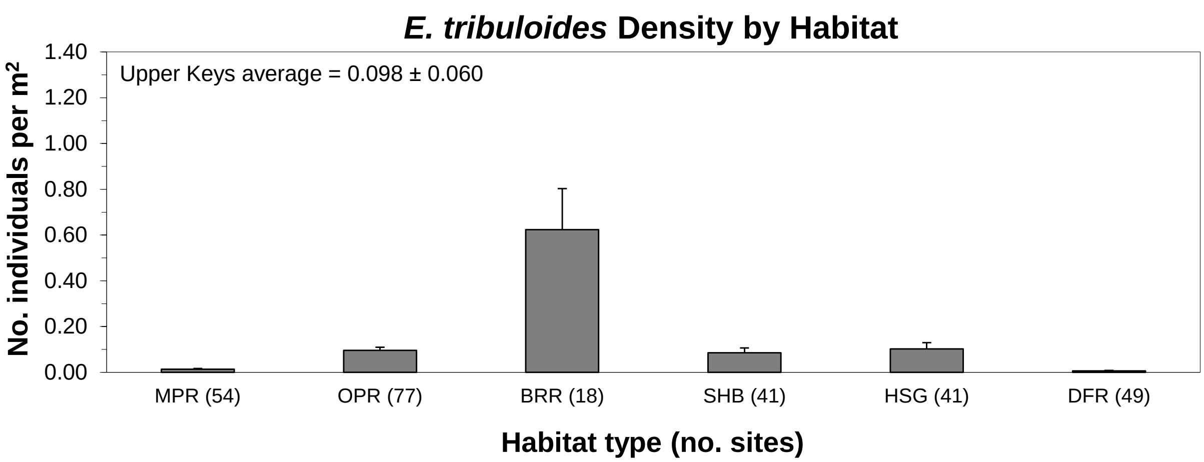
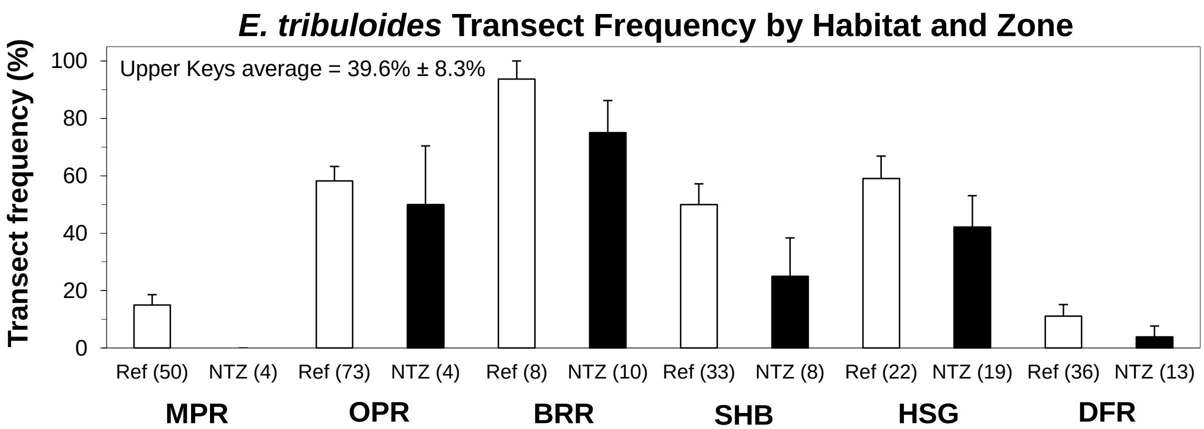


Figure 5-20. Mean (+ 1 SE) transect frequency (top) and density (no. individuals per m^2) (bottom) of slate pencil urchins (*Eucidaris tribuloides*) by habitat type and management zone in the upper Florida Keys during May-September 2011. Open bars = reference areas (Ref), filled bars = no-take zones (NTZ). Domain-wide (upper Keys) values are weighted averages and standard errors. Habitat abbreviations are MPR = inshore and mid-channel patch reefs, OPR = offshore patch reefs, BRR = back-reef rubble, SHB = shallow (< 6 m) hard-bottom, HSG = high-relief and groove, and DFR = deeper (6-15 m) fore-reef habitats. Numbers in parentheses on the x-axis are the number of sites surveyed, with two replicate 15-m x 1-m transects surveyed per site (30 m^2 per site).



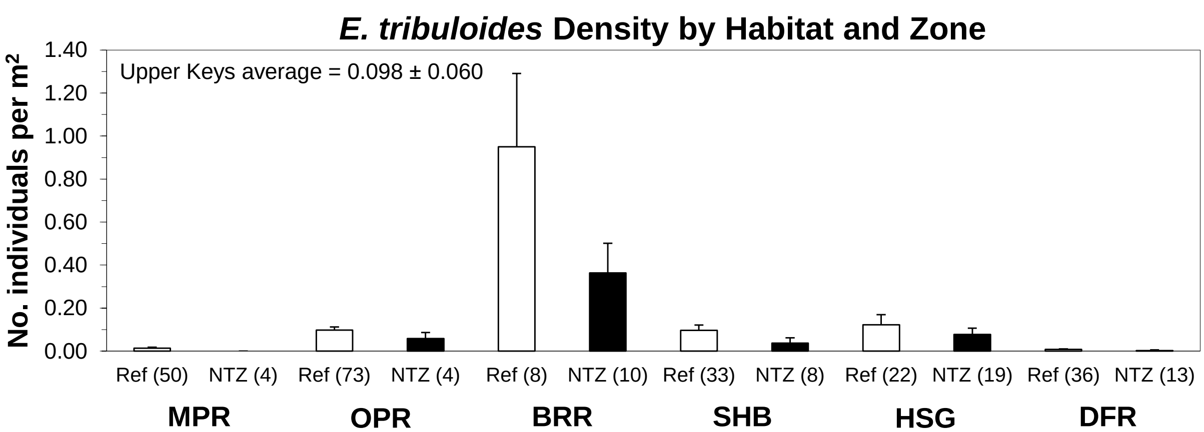
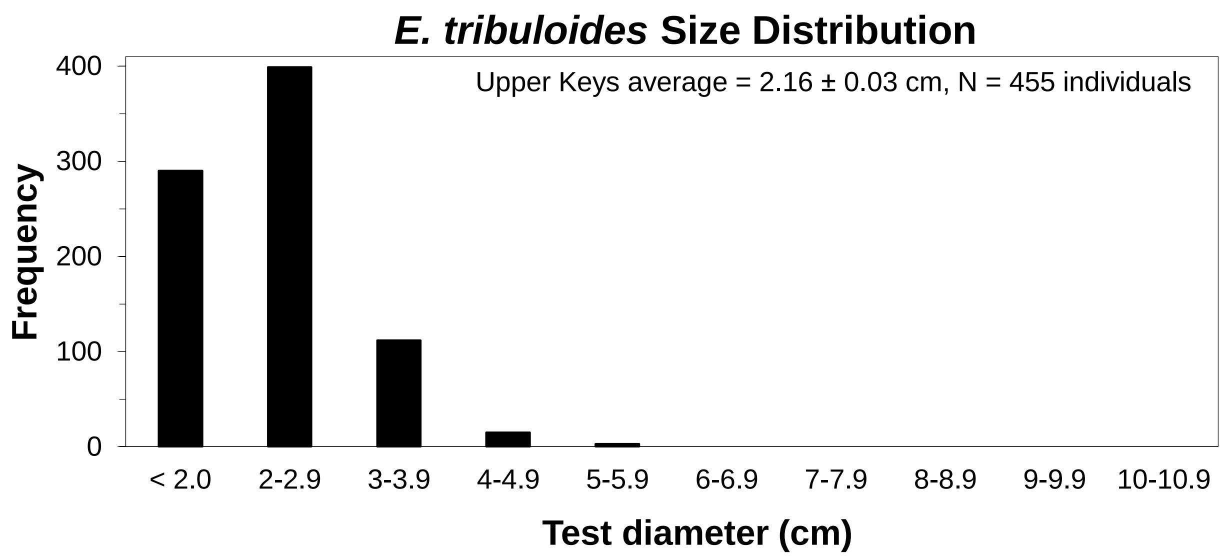


Figure 5-21. Distribution of urchin test diameter sizes (top) and mean (± 1 SE) (filled circles) and maximum sizes (open circles) across habitats (bottom) for *Eucidaris tribuloides* in the upper Florida Keys National Marine Sanctuary, as determined from surveys at 280 sites during May-September 2011. Habitat abbreviations in the bottom figure are MPR = inshore and mid-channel patch reefs, OPR = offshore patch reefs, BRR = back-reef rubble, SHB = shallow (< 6 m) hard-bottom, HSG = high-relief and groove, and DFR = deeper (6-15 m) fore-reef habitats.



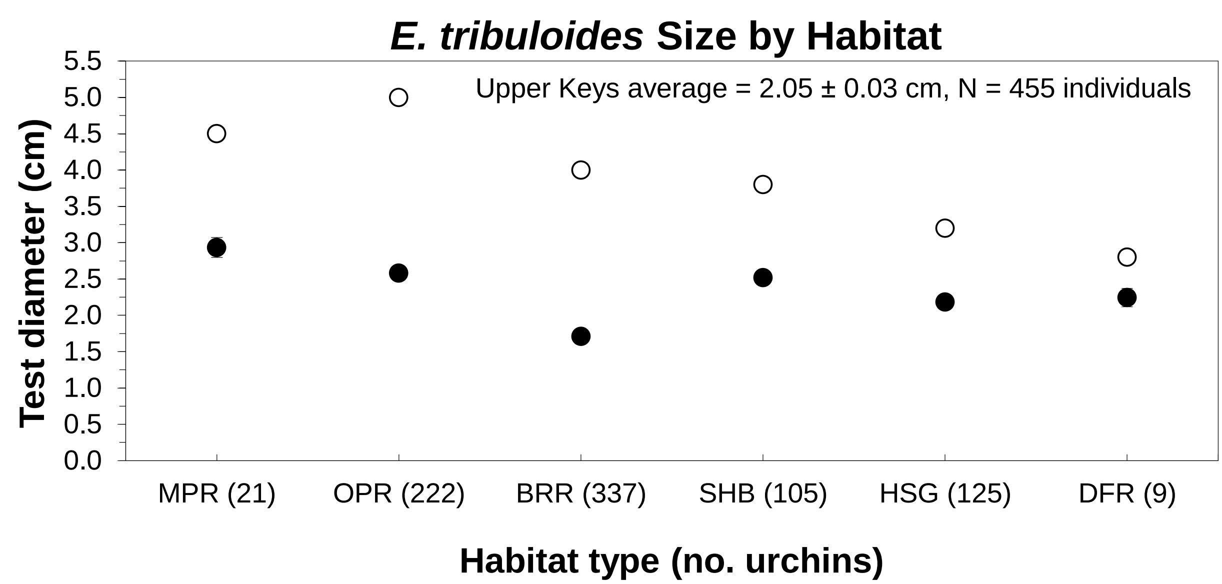


Table 5-1. Summary of habitat distribution, density, and size (test diameter) of the urchin *Arbacia punctulata* (Lamarck) among habitat types and management zones in the upper Florida Keys, as determined from two replicate 15-m x 1-m belt transect surveys per site at 280 sites from northern Key Largo to Alligator Reef during May-September 2011. Habitat types are arranged from inshore to offshore and no-take zones represent Sanctuary Preservation Areas and Research Only areas. Values represent means ± 1 SE. N = number of individuals counted and measured for test size.

Habitat/management zone (no. sites)	**Site presence (%)**	**Transect frequency (%)**	**Density (no. per m^2)**	**Mean size (cm)**	**N**
Inshore and mid-channel patch reefs					
Reference areas (50)	0 ± 0	0 ± 0	0 ± 0		0
No-take zones (4)	0 ± 0	0 ± 0	0 ± 0		0
Habitat total (54)	0 ± 0	0 ± 0	0 ± 0		0
Offshore patch reefs					
Reference areas (73)	2.7 ± 1.9	1.4 ± 1.0	0.001 ± 0.001	4.2 ± 0.1	2
No-take zones (4)	0 ± 0	0 ± 0	0 ± 0		0
Habitat total (77)	2.6 ± 1.8	1.3 ± 0.9	0.001 ± 0.001	4.2 ± 0.1	2
Back-reef rubble					
Reference areas (8)	0 ± 0	0 ± 0	0 ± 0		0
No-take zones (10)	0 ± 0	0 ± 0	0 ± 0		0
Habitat total (18)	0 ± 0	0 ± 0	0 ± 0		0
Shallow (< 6 m) hard-bottom					
Reference areas (33)	0 ± 0	0 ± 0	0 ± 0		0
No-take zones (8)	0 ± 0	0 ± 0	0 ± 0		0
Habitat total (41)	0 ± 0	0 ± 0	0 ± 0		0
High-relief spur and groove					
Reference areas (22)	0 ± 0	0 ± 0	0 ± 0		0
No-take zones (19)	0 ± 0	0 ± 0	0 ± 0		0
Habitat total (41)	0 ± 0	0 ± 0	0 ± 0		0
Deeper fore reef					
Reference areas (36)	0 ± 0	0 ± 0	0 ± 0		0
No-take zones (13)	0 ± 0	0 ± 0	0 ± 0		0
Habitat total (49)	0 ± 0	0 ± 0	0 ± 0		0

Table 5-2. Summary of habitat distribution, density, and size (test diameter) of the long-spined sea urchin *Diadema antillarum* (Philippi) among habitat types and management zones in the upper Florida Keys, as determined from two replicate 15-m x 1-m belt transect surveys per site at 280 sites from northern Key Largo to Alligator Reef during May-September 2011. Habitat types are arranged from inshore to offshore and no-take zones represent Sanctuary Preservation Areas and Research Only areas. Values represent means ± 1 SE. N = number of individuals counted and measured for test size.

Habitat/management zone (sites)	Site presence (%)	Transect frequency (%)	Density (no. per m^2)	Mean size (cm)	N
Inshore and mid-channel patch reefs					
Reference areas (50)	4.0 ± 2.8	3.0 ± 2.2	0.005 ± 0.004	4.9 ± 1.5	7
No-take zones (4)	0 ± 0	0 ± 0	0 ± 0		0
Habitat total (54)	3.7 ± 2.6	2.8 ± 2.1	0.004 ± 0.004	4.9 ± 1.5	7
Offshore patch reefs					
Reference areas (73)	41.1 ± 5.8	28.1 ± 4.4	0.032 ± 0.006	5.9 ± 0.3	71
No-take zones (4)	25.0 ± 25.0	12.5 ± 12.5	0.008 ± 0.008	5.8	1
Habitat total (77)	40.3 ± 5.6	27.3 ± 4.2	0.031 ± 0.006	5.9 ± 0.2	72
Back-reef rubble					
Reference areas (8)	25.0 ± 16.4	18.8 ± 13.2	0.033 ± 0.025	2.8 ± 0.3	8
No-take zones (10)	40.0 ± 16.3	25.0 ± 11.2	0.020 ± 0.010	1.2 ± 0.2	6
Habitat total (18)	33.3 ± 11.4	22.2 ± 8.3	0.026 ± 0.012	1.8 ± 0.4	14
Shallow (< 6 m) hard-bottom					
Reference areas (33)	27.3 ± 7.9	18.2 ± 5.7	0.015 ± 0.005	4.5 ± 0.7	15
No-take zones (8)	12.5 ± 12.5	6.3 ± 6.3	0.013 ± 0.013	5.9 ± 1.6	3
Habitat total (41)	24.4 ± 6.8	15.9 ± 4.8	0.015 ± 0.005	4.6 ± 0.6	18
High-relief spur and groove					
Reference areas (22)	31.8 ± 10.2	20.5 ± 7.1	0.029 ± 0.013	6.5 ± 0.6	19
No-take zones (19)	21.1 ± 9.6	10.5 ± 4.8	0.019 ± 0.010	5.4 ± 0.8	11
Habitat total (41)	26.8 ± 7.0	15.9 ± 4.4	0.024 ± 0.008	6.1 ± 0.5	30
Deeper fore reef					
Reference areas (36)	13.9 ± 5.8	6.9 ± 2.9	0.005 ± 0.002	3.8 ± 0.8	5
No-take zones (13)	7.7 ± 7.7	3.8 ± 3.8	0.003 ± 0.003	6.3	1
Habitat total (49)	12.2 ± 14.7	6.1 ± 2.4	0.004 ± 0.002	5.2 ± 0.2	6

Table 5-3. Summary of habitat distribution, density, and size (test diameter) of the rock-boring urchin *Echinometra lucunter* (Linnaeus) among habitat types and management zones in the upper Florida Keys, as determined from two replicate 15-m x 1-m belt transect surveys per site at 280 sites from northern Key Largo to Alligator Reef during May-September 2011. Habitat types are arranged from inshore to offshore and no-take zones represent Sanctuary Preservation Areas and Research Only areas. Values represent means ± 1 SE. N = number of individuals counted and measured for test size.

Habitat/management zone (sites)	Site presence (%)	Transect frequency (%)	Density (no. per m^2)	Mean size (cm)	N
Inshore and mid-channel patch reefs					
Reference areas (50)	12.0 ± 4.6	6.0 ± 2.3	0.004 ± 0.002	2.9 ± 0.4	6
No-take zones (4)	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0
Habitat total (54)	11.1 ± 4.3	5.6 ± 2.2	0.004 ± 0.001	2.9 ± 0.4	6
Offshore patch reefs					
Reference areas (73)	9.6 ± 3.5	5.5 ± 2.1	0.009 ± 0.004	1.9 ± 0.2	19
No-take zones (4)	25.0 ± 25.0	12.5 ± 12.5	0.008 ± 0.008	0.8	1
Habitat total (77)	10.4 ± 3.5	5.8 ± 2.1	0.009 ± 0.004	1.7 ± 0.2	20
Back-reef rubble					
Reference areas (8)	37.5 ± 18.3	37.5 ± 18.3	0.750 ± 0.582	1.3 ± 0.2	180
No-take zones (10)	40.0 ± 16.3	35.0 ± 15.0	0.100 ± 0.066	0.9 ± 0.1	30
Habitat total (18)	38.9 ± 11.8	36.1 ± 11.3	0.389 ± 0.263	1.1 ± 0.1	210
Shallow (< 6 m) hard-bottom					
Reference areas (33)	3.0 ± 3.0	1.5 ± 1.5	0.001 ± 0.001	1.1	1
No-take zones (8)	0 ± 0	0 ± 0	0 ± 0		0
Habitat total (41)	2.4 ± 2.4	1.2 ± 1.2	0.001 ± 0.001	1.1	1
High-relief spur and groove					
Reference areas (22)	9.1 ± 6.3	4.5 ± 3.1	0.003 ± 0.002	2.6 ± 1.5	2
No-take zones (19)	5.3 ± 5.3	2.6 ± 2.6	0.002 ± 0.002	2.1	1
Habitat total (41)	7.3 ± 4.1	3.7 ± 2.1	0.002 ± 0.001	2.4 ± 0.9	3
Deeper fore reef					
Reference areas (36)	0 ± 0	0 ± 0	0 ± 0		0
No-take zones (13)	0 ± 0	0 ± 0	0 ± 0		0
Habitat total (49)	0 ± 0	0 ± 0	0 ± 0		0

Table 5-4. Summary of habitat distribution, density, and size (test diameter) of the green urchin *Echinometra viridis* (Agassiz) among habitat types and management zones in the upper Florida Keys, as determined from two replicate 15-m x 1-m belt transect surveys per site at 280 sites from northern Key Largo to Alligator Reef during May-September 2011. Habitat types are arranged from inshore to offshore and no-take zones represent Sanctuary Preservation Areas and Research Only areas. Values represent means ± 1 SE. N = number of individuals counted and measured for test size.

Habitat/management zone (sites)	**Site presence (%)**	**Transect frequency (%)**	**Density (no. per m^2)**	**Mean size (cm)**	**N**
Inshore and mid-channel patch reefs					
Reference areas (50)	66.0 ± 6.8	51.0 ± 6.0	0.354 ± 0.148	2.3 ± 0.1	531
No-take zones (4)	50.0 ± 28.9	37.5 ± 23.9	0.067 ± 0.047	2.1 ± 0.2	8
Habitat total (54)	64.8 ± 6.6	50.0 ± 5.8	0.333 ± 0.137	2.3 ± 0.1	539
Offshore patch reefs					
Reference areas (73)	45.2 ± 5.9	32.2 ± 4.6	0.055 ± 0.015	2.0 ± 0.1	121
No-take zones (4)	25.0 ± 25.0	12.5 ± 12.5	0.008 ± 0.008	1.5	1
Habitat total (77)	44.2 ± 5.7	31.2 ± 4.4	0.053 ± 0.015	2.0 ± 0.1	122
Back-reef rubble					
Reference areas (8)	100.0 ± 0.0	75.0 ± 9.4	0.125 ± 0.046	1.0 ± 0.1	30
No-take zones (10)	30.0 ± 15.3	25.0 ± 13.4	0.083 ± 0.061	0.8 ± 0.0	25
Habitat total (18)	61.1 ± 11.8	47.2 ± 10.3	0.102 ± 0.039	1.0 ± 0.1	55
Shallow (< 6 m) hard-bottom					
Reference areas (33)	6.1 ± 4.2	3.0 ± 2.1	0.002 ± 0.001	1.3 ± 0.3	2
No-take zones (8)	0 ± 0	0 ± 0	0 ± 0		0
Habitat total (41)	4.9 ± 3.4	2.4 ± 1.7	0.002 ± 0.001	1.3 ± 0.3	2
High-relief spur and groove					
Reference areas (22)	9.1 ± 6.3	4.5 ± 3.1	0.008 ± 0.005	2.0 ± 0.2	5
No-take zones (19)	15.8 ± 8.6	7.9 ± 4.3	0.005 ± 0.003	1.4 ± 0.4	3
Habitat total (41)	12.2 ± 5.2	6.1 ± 2.6	0.007 ± 0.003	1.6 ± 0.3	8
Deeper fore reef					
Reference areas (36)	0 ± 0	0 ± 0	0 ± 0		0
No-take zones (13)	0 ± 0	0 ± 0	0 ± 0		0
Habitat total (49)	0 ± 0	0 ± 0	0 ± 0		0

Table 5-5. Summary of habitat distribution, density, and size (test diameter) of the slate pencil urchin *Eucidaris tribuloides* (Lamarck) among habitat types and management zones in the upper Florida Keys, as determined from two replicate 15-m x 1-m belt transect surveys per site at 280 sites from northern Key Largo to Alligator Reef during May-September 2011. Habitat types are arranged from inshore to offshore and no-take zones represent Sanctuary Preservation Areas and Research Only areas. Values represent means ± 1 SE. N = number of individuals counted and measured for test size.

Habitat/management zone (sites)	**Site presence (%)**	**Transect frequency (%)**	**Density (no. per m^2)**	**Mean size (cm)**	**N**
Inshore and mid-channel patch reefs					
Reference areas (50)	28.0 ± 6.4	15.0 ± 3.6	0.014 ± 0.004	2.8 ± 0.1	21
No-take zones (4)	0 ± 0	0 ± 0	0 ± 0		0
Habitat total (54)	25.9 ± 6.0	13.9 ± 3.3	0.013 ± 0.003	2.8 ± 0.1	21
Offshore patch reefs					
Reference areas (73)	69.9 ± 5.4	58.2 ± 5.1	0.098 ± 0.014	2.4 ± 0.1	215
No-take zones (4)	75.0 ± 25.0	50.0 ± 20.4	0.058 ± 0.028	2.4 ± 0.2	7
Habitat total (77)	70.1 ± 5.3	57.8 ± 4.9	0.096 ± 0.013	2.4 ± 0.1	222
Back-reef rubble					
Reference areas (8)	100.0 ± 0.0	93.8 ± 6.3	0.950 ± 0.341	1.9 ± 0.1	228
No-take zones (10)	90.0 ± 10.0	75.0 ± 11.2	0.363 ± 0.138	1.4 ± 0.1	109
Habitat total (18)	94.4 ± 5.6	83.3 ± 7.0	0.624 ± 0.179	1.6 ± 0.1	337
Shallow (< 6 m) hard-bottom					
Reference areas (33)	66.7 ± 8.3	50.0 ± 7.2	0.097 ± 0.025	2.5 ± 0.1	96
No-take zones (8)	37.5 ± 18.3	25.0 ± 13.4	0.038 ± 0.025	1.7 ± 0.2	9
Habitat total (41)	61.0 ± 7.7	45.1 ± 6.5	0.085 ± 0.021	2.4 ± 0.1	105
High-relief spur and groove					
Reference areas (22)	81.8 ± 8.4	59.1 ± 7.8	0.123 ± 0.047	2.3 ± 0.1	81
No-take zones (19)	47.4 ± 11.8	42.1 ± 11.0	0.077 ± 0.029	2.1 ± 0.1	44
Habitat total (41)	65.9 ± 7.5	51.2 ± 6.6	0.102 ± 0.028	2.2 ± 0.1	125
Deeper fore reef					
Reference areas (36)	19.4 ± 6.7	11.1 ± 4.0	0.007 ± 0.003	2.2 ± 0.1	8
No-take zones (13)	7.7 ± 7.7	3.8 ± 3.8	0.003 ± 0.003	2.3	1
Habitat total (49)	16.3 ± 5.3	9.2 ± 3.2	0.006 ± 0.002	2.3 ± 0.0	9

Table 5-6. Summary of habitat distribution, density, and size (test diameter) of the urchin *Lytechinus variegatus* (Lamarck) among habitat types and management zones in the upper Florida Keys, as determined from two replicate 15-m x 1-m belt transect surveys per site at 280 sites from northern Key Largo to Alligator Reef during May-September 2011. Habitat types are arranged from inshore to offshore and no-take zones represent Sanctuary Preservation Areas and Research Only areas. Values represent means ± 1 SE. N = number of individuals counted and measured for test size.

Habitat/management zone (sites)	**Site presence (%)**	**Transect frequency (%)**	**Density (no. per m^2)**	**Mean size (cm)**	**N**
Inshore and mid-channel patch reefs					
Reference areas (50)	6.0 ± 3.4	3.0 ± 1.7	0.002 ± 0.001	8.0 ± 0.6	3
No-take zones (4)	0 ± 0	0 ± 0	0 ± 0		0
Habitat total (54)	5.6 ± 3.1	2.8 ± 1.6	0.002 ± 0.001	8.0 ± 0.6	3
Offshore patch reefs					
Reference areas (73)	1.4 ± 1.4	0.7 ± 0.7	0.0005 ± 0.0005	7.1	1
No-take zones (4)	0 ± 0	0 ± 0	0 ± 0		0
Habitat total (77)	1.3 ± 1.3	0.6 ± 0.6	0.0004 ± 0.0004	7.1	1
Back-reef rubble					
Reference areas (8)	37.5 ± 18.3	25.0 ± 13.4	0.054 ± 0.041	3.3 ± 0.7	13
No-take zones (10)	0 ± 0	0 ± 0	0 ± 0		0
Habitat total (18)	16.7 ± 0.9	11.1 ± 6.5	0.024 ± 0.019	3.3 ± 0.7	13
Shallow (< 6 m) hard-bottom					
Reference areas (33)	0 ± 0	0 ± 0	0 ± 0		0
No-take zones (8)	0 ± 0	0 ± 0	0 ± 0		0
Habitat total (41)	0 ± 0	0 ± 0	0 ± 0		0
High-relief spur and groove					
Reference areas (22)	0 ± 0	0 ± 0	0 ± 0		0
No-take zones (19)	0 ± 0	0 ± 0	0 ± 0		0
Habitat total (41)	0 ± 0	0 ± 0	0 ± 0		0
Deeper fore reef					
Reference areas (36)	0 ± 0	0 ± 0	0 ± 0		0
No-take zones (13)	0 ± 0	0 ± 0	0 ± 0		0
Habitat total (49)	0 ± 0	0 ± 0	0 ± 0		0

Table 5-7. Summary of habitat distribution, density, and size (test diameter) of the urchin *Tripneustes ventricosus* (Lamarck) among habitat types and management zones in the upper Florida Keys, as determined from two replicate 15-m x 1-m belt transect surveys per site at 280 sites from northern Key Largo to Alligator Reef during May-September 2011. Habitat types are arranged from inshore to offshore and no-take zones represent Sanctuary Preservation Areas and Research Only areas. Values represent means ± 1 SE. N = number of individuals counted and measured for test size.

Habitat/management zone (sites)	**Site presence (%)**	**Transect frequency (%)**	**Density (no. per m^2)**	**Mean size (cm)**	**N**
Inshore and mid-channel patch reefs					
Reference areas (50)	8.0 ± 3.9	4.0 ± 1.9	0.003 ± 0.001	7.1 ± 1.3	4
No-take zones (4)	0 ± 0	0 ± 0	0 ± 0		0
Habitat total (54)	7.4 ± 3.6	3.7 ± 1.8	0.002 ± 0.001	7.1 ± 1.3	4
Offshore patch reefs					
Reference areas (73)	2.7 ± 1.9	1.4 ± 1.0	0.001 ± 0.001	9.0 ± 0.0	2
No-take zones (4)	0 ± 0	0 ± 0	0 ± 0		0
Habitat total (77)	2.6 ± 1.8	1.3 ± 0.9	0.001 ± 0.001	9.0 ± 0.0	2
Back-reef rubble					
Reference areas (8)	0 ± 0	0 ± 0	0 ± 0		0
No-take zones (10)	0 ± 0	0 ± 0	0 ± 0		0
Habitat total (18)	0 ± 0	0 ± 0	0 ± 0		0
Shallow (< 6 m) hard-bottom					
Reference areas (33)	0 ± 0	0 ± 0	0 ± 0		0
No-take zones (8)	0 ± 0	0 ± 0	0 ± 0		0
Habitat total (41)	0 ± 0	0 ± 0	0 ± 0		0
High-relief spur and groove					
Reference areas (22)	0 ± 0	0 ± 0	0 ± 0		0
No-take zones (19)	0 ± 0	0 ± 0	0 ± 0		0
Habitat total (41)	0 ± 0	0 ± 0	0 ± 0		0
Deeper fore reef					
Reference areas (36)	2.8 ± 2.8	1.4 ± 1.4	0.001 ± 0.001	8.6	1
No-take zones (13)	0 ± 0	0 ± 0	0 ± 0		0
Habitat total (49)	2.0 ± 2.0	1.0 ± 1.0	0.001 ± 0.001	8.6	1

VI. Anemone and Corallimorpharian Distribution and Abundance

Background

The Florida Keys has a long history of commercial and recreational fisheries exploitation of an incredible diversity of invertebrates and fishes (Bohnsack et al. 1994). A portion of this effort is represented by commercial marine-life fisheries and aquarium hobbyists. Otherwise known as the marine ornamental fishery, aquarium fisheries from West Palm Beach to Key West target many fish, invertebrate, and algal species, in addition to sand and live rock (FWCC 2001). State and Federal waters near Key West and Marathon in the Florida Keys constitute 94% of the total fishes and invertebrates removed in southeast Florida for the marine aquarium trade. Commercial data do not include an undocumented effort from recreational fishers, nor are data available concerning species abundance patterns and population trends relative to fishing effort (NOAA 1996). Key Largo has been protected from marine aquarium trade species collection since 1960 in John Pennekamp Coral Reef State Park, followed by the protection in federal waters in 1975 with the establishment of Key Largo National Marine Sanctuary (now known as the Key Largo Management Area). The Looe Key area has been protected since 1981, as well as Everglades National Park (Florida Bay), portions of the Dry Tortugas area, Biscayne National Park, and Fish and Wildlife Service management areas.

The paucity of basic ecological information for most Florida Keys anemone and corallimorpharian (Cnidaria, Anthozoa) species persists, with even fewer studies reporting on the effects of populations under exploitation. During 2011, we continued a time series dating back to 1999 that quantifies the habitat distribution and abundance patterns of selected actinians (O. Actiniaria) and corallimorpharians (O. Corallimorpharia) in the Florida Keys in relation to habitat type and management zone (i.e. inside and outside of no-take zones). Besides general Caribbean field guides (e.g. Sefton and Webster 1986; Kaplan 1988; Humann 1992) and isolated distribution studies (Voss and Voss 1955; Wheaton and Jaap 1988; reviewed in Levy et al. 1996), our program represents the only large-scale concerted effort to quantify distribution and abundance patterns over large areas of hard-bottom and coral reef habitat in the Florida Keys. The ecological importance of these organisms is best exemplified by the many anemones that form associations with several invertebrates such as cleaner shrimps (Limbaugh et al. 1961; Shick 1991) and provide refuge for smaller reef fishes (Hanlon and Kaufman 1976; Colin and Heiser 1973). Some of these associations, such as cleaning stations, provide a valuable function to reef fishes (Herrnkind et al. 1976; Sluka et al. 1999) and the large-scale removal of certain species may have important, but as of yet, undocumented effects on other biota. The establishment of the Florida Keys National Marine Sanctuary (FKNMS) in 1990 and the subsequent designation of 23 no-fishing zones in 1997 afford the opportunity to evaluate the effects of exploitation for a variety of species, including those targeted by the marine aquarium fishery (Bohnsack 1997). These data provide a means from which to measure the responses of organisms to protection from exploitation. The results presented below only consider differences in distribution and density among habitats and FKNMS no-take zones. Subsequent analyses will consider differences inside and outside of other management zones that have a much longer history of protection from marine aquarium collection.

Quantitative surveys in the upper Florida Keys during May-September 2011 targeted anemones (O. Actiniaria) and corallimorpharians (O. Corallimorpharia) known or suspected to occur in the Florida Keys, and focused on the larger and conspicuous or field-identifiable members of both orders. Similar surveys were conducted in the study area during 1999-2001 (211 sites), 2005 (195 sites), 2008 (145 sites), 2009 (160 sites), and 2010 (120 sites), as well as in the Dry Tortugas region during 2000, 2006, and 2008 (see previous Quick Look Reports at http://people.uncw.edu/millers). Three anemone species were recorded during 2011 (classification according to Cairns et al. 1991), all of which tend to have solitary and larger polyps compared to other cnidarians: the giant Caribbean or pink-tipped anemone *Condylactis gigantea* in the Family Actiniidae, the ringed or corkscrew anemone *Bartholomea annulata* in the Family Aiptasiidae, and *Lebrunia danae* in the Family Aliciidae. Although surveyed in previous years, we did not encounter the speckled anemone *Epicystes* (=*Phymanthus*) *crucifera* in the Family Phymanthidae, *Bunodosoma granuliferum* in the Family Actiniidae, the knobby anemone (*Heteractis lucida*), or the Caribbean sun anemone *Stichodactyla* (=*Stoichactis*) *helianthus*. Corallimorpharians, sometimes called false corals, differ from anemones in the arrangement of the tentacles, and may be solitary, but are typically found in clusters. Three corallimorpharian species were encountered during 2011: *Discosoma* (=*Paradiscosoma*) *carlgreni* and *D. sanctithomae* in the Family Actinodiscidae and *Ricordea florida* in the Family Corallimorpharidae.

2011 Survey Results

Anemones

Three anemone species representing 595 individuals were recorded from the 280 upper Florida Keys sites in 2011 (Figure 6-1). The five anemone species were represented by: *Bartholomea annulata* (480 individuals, 81% of all anemones), *Condylactis gigantea* (83 individuals, 13.9%), and *Lebrunia danae* (32 individuals, 5.4%). *Bunodosoma granuliferum*, *Epicystis crucifera*, *Heteractis lucida*, and *Stichodactyla helianthus* were searched for, but not encountered during 2011. Overall, 77% of the surveyed sites yielded anemones from 30 m^2 search areas per site. Site presence of all species combined was greatest on offshore patch reefs (90%) and mid-channel patch reefs (82%) and lowest in back reef rubble (22%). The species richness of anemones (total species encountered per 30 m^2) followed a similar pattern. For all species combined, there were no consistent patterns in site presence or species richness. For both metrics, reference areas yielded greater values for mid-channel patch reefs, high-relief spur and groove, and deep fore-reef habitats, but not for the remaining habitats.

Bartholomea annulata (corkscrew anemone) (Lesueur)

As in previous years, the corkscrew anemone (*Bartholomea annulata*) was the most abundant and wide-ranging anemone that we surveyed, with individuals recorded from 73% of the 280 sites and within 52% of the sampled transects. *B. annulata* was distributed among all of the cross-shelf habitats sampled in the upper Florida Keys (Table 6-1). Site-level densities were as high as 0.300 ± 0.167 individuals per m^2, with the greatest density recorded from an inner line reef tract site north of Grecian Rocks. Figures 6-2 to 6-4 show the spatial distribution of *B. annulata* densities across the upper Florida Keys study area. Site presence, transect frequency, and density were greater on mid-channel and offshore patch reefs and lowest in back-reef rubble sites (Figure 6-5). Among habitats sampled, there was no consistent pattern in site presence or transect frequency of corkscrew anemones between no-take zones and reference areas (Table 6-1 and Figure 6-6). However, overall mean densities were greater in reference areas compared to no-take zones for four of the six major habitats sampled, particularly inshore and mid-channel patch reefs, high-relief spur and groove, and deeper fore-reef habitats (Table 6-1). In contrast, no-take zones yielded greater overall mean densities in the shallow hard-bottom habitat.

Condylactis gigantea (giant Caribbean anemone) (Weinland)

Similar to previous surveys dating back to 1999, the site presence, transect frequency, and density of the giant Caribbean anemone (*Condylactis gigantea*) were relatively low in 2011 for the upper Keys habitats surveyed (Table 6-2). A total of 83 individuals were found among the 280 sites, with individuals present at 18.6% of all sites and within 11.1% of the sampled transects. A maximum site-level density of 0.200 ± 0.133 individuals per m^2 was recorded from a mid-channel patch reef south of the Basin Hill Shoals area. Proportional site presence, transect frequency, and density were greatest on offshore patch reefs, followed by shallow hard-bottom and mid-channel patch reef habitats (Table 6-2). For four of the six habitats, *C. gigantea* were more common and occurred in greater densities in no-take zones compared to reference areas.

Lebrunia danae (Duchassaing and Michelotti)

The branching anemone *Lebrunia danae* was the least common anemone recorded (32 individuals) in the upper Keys during 2011, but was distributed among all habitats except back-reef rubble (Table 6-3). Site presence, transect frequency, and density were greater on inshore and mid-channel patch reefs, followed by offshore patch reefs, high-relief spur and groove, and the deeper fore reef.

Corallimorpharians

A total of 820 corallimorpharians representing three species were recorded from 280 sites: *Discosoma carlgreni* (9 individuals, 1.1%), *D. sanctithomae* (23 individuals, 2.8%), and *Ricordea florida* (788 individuals, 96.1%) (Figure 6-7). Tables 6-4 to 6-6 provide summary values for site presence, transect frequency, and density by habitat and management zone for each species. Corallimorpharians were recorded from 15% of all sites surveyed and 17% of sampled belt transects. Among habitats for all species combined, corallimorpharians were more frequently encountered on offshore patch reefs (23.4% of sites) and high-relief spur and groove (29.3%). Back-reef rubble was the only habitat type sampled where corallimorpharians were not encountered. Similar to anemones, there were no consistent patterns for site presence and transect frequency between no-take zones and reference areas for all corallimorpharian species combined. For example, these metrics were greater on reference mid-channel patch reef and high-relief spur and groove, but not for offshore patch reef and shallow hard-bottom habitats.

Discosoma carlgreni (Watzl)

The forked-tentacle corallimorpharian, *Discosoma carlgreni*, was only found on offshore patch reefs (3 out of 77 total sites), with a maximum site-level density of 0.133 ± 0.133 individuals per m^2 (Table 6-4). Although we have documented aggregations (10-20 individuals) in other areas of the Florida Keys, this corallimorpharian continues to be relatively rare in the upper Keys.

Discosoma sanctithomae (Duchassaing and Michelotti)

The warty corallimorpharian, *Discosoma sanctithomae,* similar to its congener, was rarely encountered in the upper Keys during 2011, with only 23 individuals recorded among three habitat types (Table 6-5). All but four of the individuals were recorded from inshore and mid-channel patch reefs (2 out of 54 sites), and most were recorded from one patch reef site.

Ricordea florida Duchassaing and Michelotti

The Florida corallimorpharian, *Ricordea florida*, was the most common and widely distributed corallimorpharian in the upper Keys during 2011 (Figures 6-8 to 6-10), with 788 individuals recorded from all 280 sites combined. *R. florida* was found in all habitats except back-reef rubble (Table 6-6). The greatest site-level mean density (9.83 ± 2.70 per m^2) was recorded from a mid-channel patch reef northeast of Cannon Patch Reef. Similar to previous years, most individuals were encountered on mid-channel and offshore patch reefs (Figure 6-11), especially in reference areas outside of FKNMS no-take zones (Figure 6-12). Site presence and transect frequency were greatest on offshore patch reefs and high-relief spur and groove (Figure 6-11), while mean densities were greatest on mid-channel patch reefs; the latter result reflects a large (295 individuals) aggregation found on one patch reef site northeast of Cannon Patch. Site presence and transect frequency were not consistent between reference areas and no-take zones by habitat type, although overall mean densities were greater for reference areas for three of the habitats where *R. florida* was the most abundant (Figure 6-12).

Discussion

While numerous studies address the life history characteristics of anemones and corallimorpharians, including feeding behavior (Bursey and Guanciale 1977; Bursey and Harmer 1979; Elliot and Cook 1989), reproduction (Jennison 1981), and associations with other fauna (Limbaugh et al. 1961; Colin and Heiser 1973; Hanlon and Kaufman 1976), studies that describe or quantify habitat distribution and abundance in the Florida Keys are limited. Nine actinian species are common in the Caribbean; of these, seven are planktivores, while the two larger species (*Condylactis gigantea* and *Stichodactyla helianthus*) can eat macroscopic prey such as gastropods and echinoids (Van-Praët 1985). Several field guidebooks provide qualitative descriptions of habitat occurrence, biogeographic distribution, and taxonomic characters (Voss 1976; Kaplan 1988; Humann 1992), but with the exception of one quantitative study of benthic cnidarians at Looe Key, in which *Ricordea florida* was included (Wheaton and Jaap 1988), the data collected by our program represent the only large-scale assessments of habitat distribution and abundance of actinians and corallimorpharians on Florida Keys ocean-side habitats dating back over a decade. Levy et al. (1996) reviewed Florida Keys invertebrate inventories as of 1995 and found only three publications (e.g. Voss and Voss 1955; Voss et al. 1969) that discussed abundance and habitat distribution of these organisms.

The 2011 upper Florida Keys survey results indicate that, with the exception of the corallimorpharian *Ricordea florida* on some mid-channel and offshore patch reefs, mean densities of the anemones and corallimorpharians sampled were usually below one individual per 100 m^2 for the habitats sampled. All but one of the three actinians and one of the three corallimorpharians species were rare and/or exhibited limited habitat distribution. The more commonly encountered species exhibited different density and distribution patterns. *B. annulata* was the most frequently encountered anemone and generally had similar densities among most habitats, while *Condylactis gigantea* and *Lebrunia danae* were more common on patch reefs. The most abundant corallimorpharian, *R. florida*, was most abundant on mid-channel and offshore patch reefs.

Conclusions from the 2011 surveys are confined because of poor life history knowledge and the paucity of historical abundance data for anemones and corallimorpharians. Interpretation of density patterns is further complicated because of the possibility that large numbers of these organisms are removed from the Florida Keys by commercial and private collectors. However, surveys dating back to 1999 confirm, at least for an 11-year period, consistent patterns in habitat-based patterns of abundance. It is also possible that locations not sampled by our program, including nearshore hard-bottom and seagrass beds (ocean-side and bay-side), mangrove channels, and tidal channels into Florida Bay, comprise important habitat types for various anemones and corallimorpharians. We did not sample any soft-sediment communities such as seagrass beds, and it is well known that some of the actinians (e.g. *Bartholomea annulata* and *Condylactis gigantea*) form relatively large aggregations in these habitats. Subsequent analyses will compare distribution and abundance patterns for John Pennekamp Coral Reef State Park (protected since 1960) and the Key Largo Management Area (protected since 1975), which contain six of the FKNMS no-take zones (established in 1997), to areas further south with a longer history of exploitation for marine life species. To our knowledge, no other studies are looking at this group or other cnidarians inside and outside of no-take zones in the FKNMS.

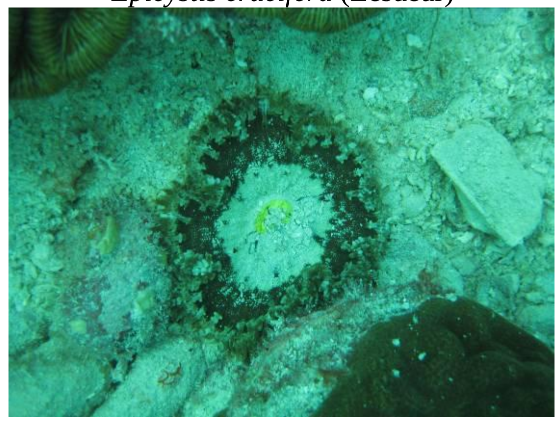
Certain aspects of cnidarian life history have implications for fisheries management. For example, recruitment of sexually produced planula into natural populations of sea anemones seems rare, and it appears that most anemones studied (see review in Shick 1991) have great longevity of adults, low and sporadic larval recruitment, and high juvenile mortality. Asexual reproduction, especially for corallimorpharians, appears to be very important for maintenance of local aggregations if recruitment is successful (Elliot and Cook 1989), and probably explains the very high, but localized densities or clusters of *Discosoma sanctithomae* and *Ricordea florida*. Without basic information on life history, it will remain difficult to ascertain the ability of these organisms to maintain populations, especially considering the apparent level of exploitation in the Florida Keys (Bohnsack et al. 1994).

Although spatially explicit (e.g. at the scale of individual reefs) landings and fishing effort data are not available for Florida Keys anemones and corallimorpharians, the possibility that the observed density patterns are influenced by fishing should not be dismissed. For example, anecdotal observations, acquired from interviews with Florida Keys residents in 1993, indicated that *Condylactis gigantea* declined by the early 1990s, possibly due to collection, disease, or other causes (DeMaria 1996). Commercial marine life collectors and aquarium hobbyists potentially collect all of the cnidarians surveyed in this study (Bohnsack et al. 1994). Only a saltwater license is needed for recreational fishing, and a saltwater products license and commercial vessel registration is required to fish commercial quantities of unregulated species (NOAA 1996; FWCC 2000). In addition to a prohibition on collection in 23 of the no-take zones within the FKNMS (not including Tortugas North and South), fishing for these “unregulated” species is also prohibited in Biscayne National Park, John Pennekamp Coral Reef State Park/Key Largo National Marine Sanctuary (since 1960), the Florida Bay area within Everglades National Park, and Dry Tortugas National Park. Management of exploited species obviously requires information on fishing effort, population trends, and life history parameters. Density estimates for anemones and corallimorpharians provide a baseline from which to measure the effects of protection within no-fishing zones. When coupled with important and much needed information on the marine life fishery, the outputs of this sampling approach can furnish state and federal resource managers with improved guidelines on population estimates and trends relative to fishing intensity. Moreover, the implementation of no-fishing zones in the Florida Keys National Marine Sanctuary presents a unique opportunity to evaluate the effects of fishing (Bohnsack 1997), not only on the most economically important species (Bohnsack et al. 1994), but also on a diversity of targeted, but relatively understudied taxa.

Figure 6-1. Anemones (Cnidaria, Anthozoa) surveyed for presence-absence, density, and habitat distribution in the upper Florida Keys during May-September 2011. Not pictured is the Caribbean sun anemone, *Stichodactyla helianthus* (Ellis). Only *Bartholomea annulata*, *Condylactis gigantea*, and *Lebrunia danae* were encountered in the upper Florida Keys during 2011.

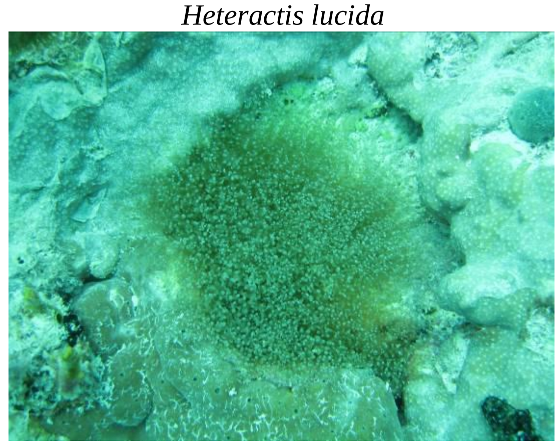
Bartholomea annulata (Lesueur)

Epicystis crucifera (Lesueur)

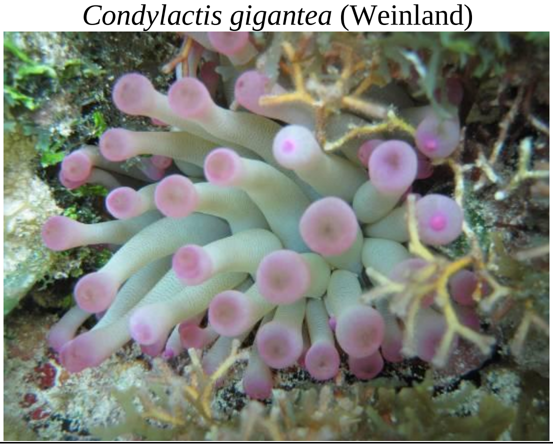


Bunodosoma granuliferum (Lesueur)

Heteractis lucida



Condylactis gigantea (Weinland)



Lebrunia danae (D & M)

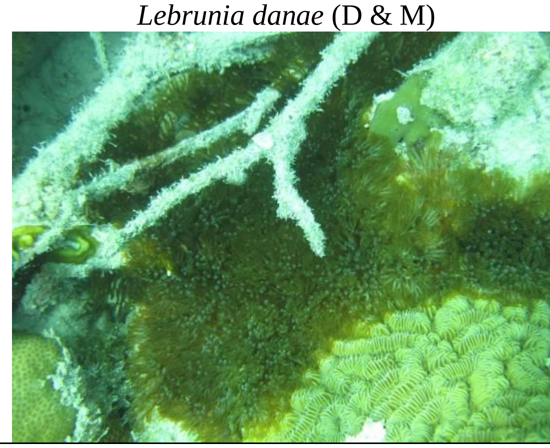


Figure 6-2. Densities (no. per m^2) of corkscrew anemones (*Bartholomea annulata*) in the upper Florida Keys National Marine Sanctuary from the southern BNP boundary to Carysfort/S. Carysfort SPA surveyed during May-September 2011.

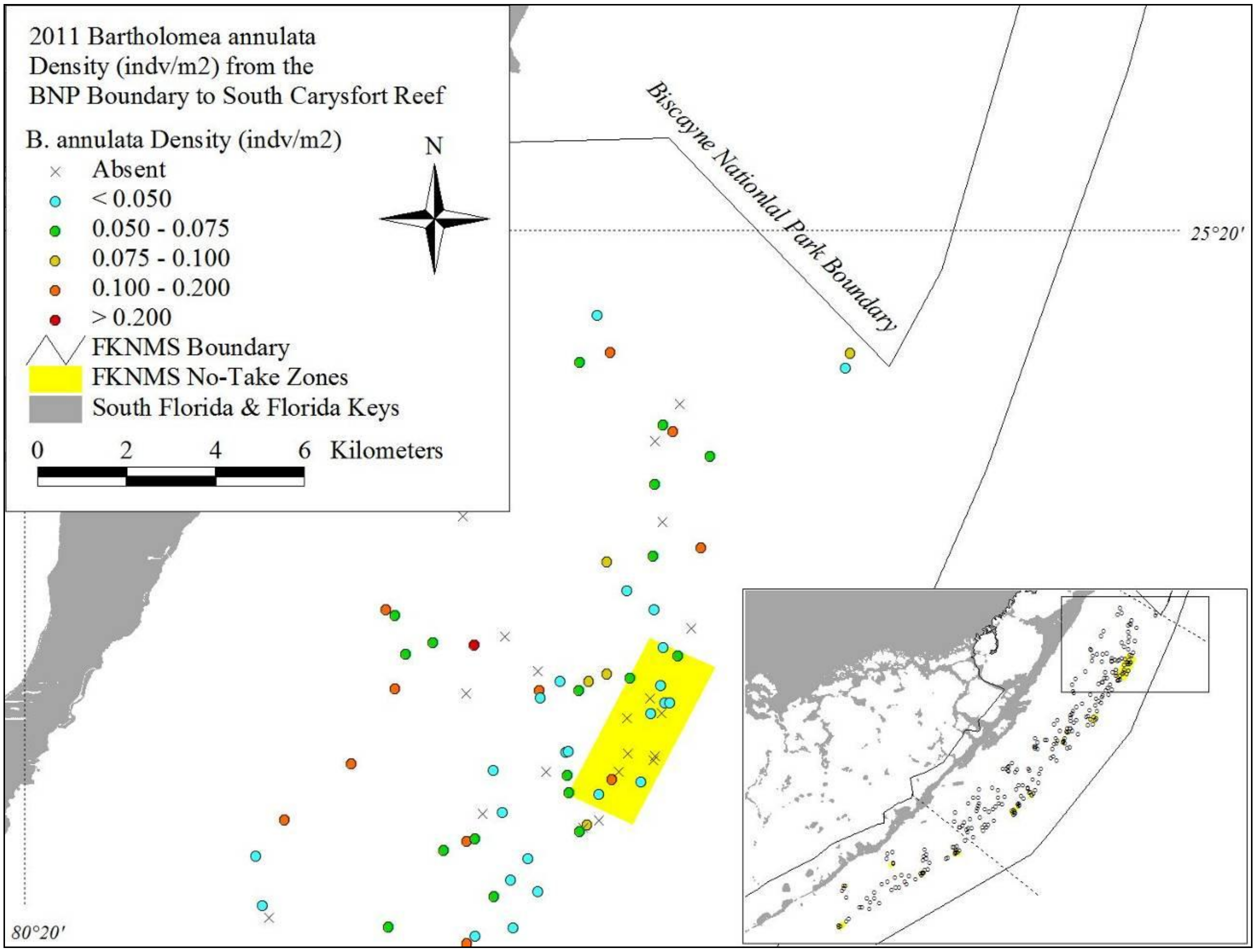


Figure 6-3. Densities (no. per m^2) of corkscrew anemones (*Bartholomea annulata*) in the upper Florida Keys National Marine Sanctuary from Elbow Reef to Pickles Reef surveyed during May-September 2011.

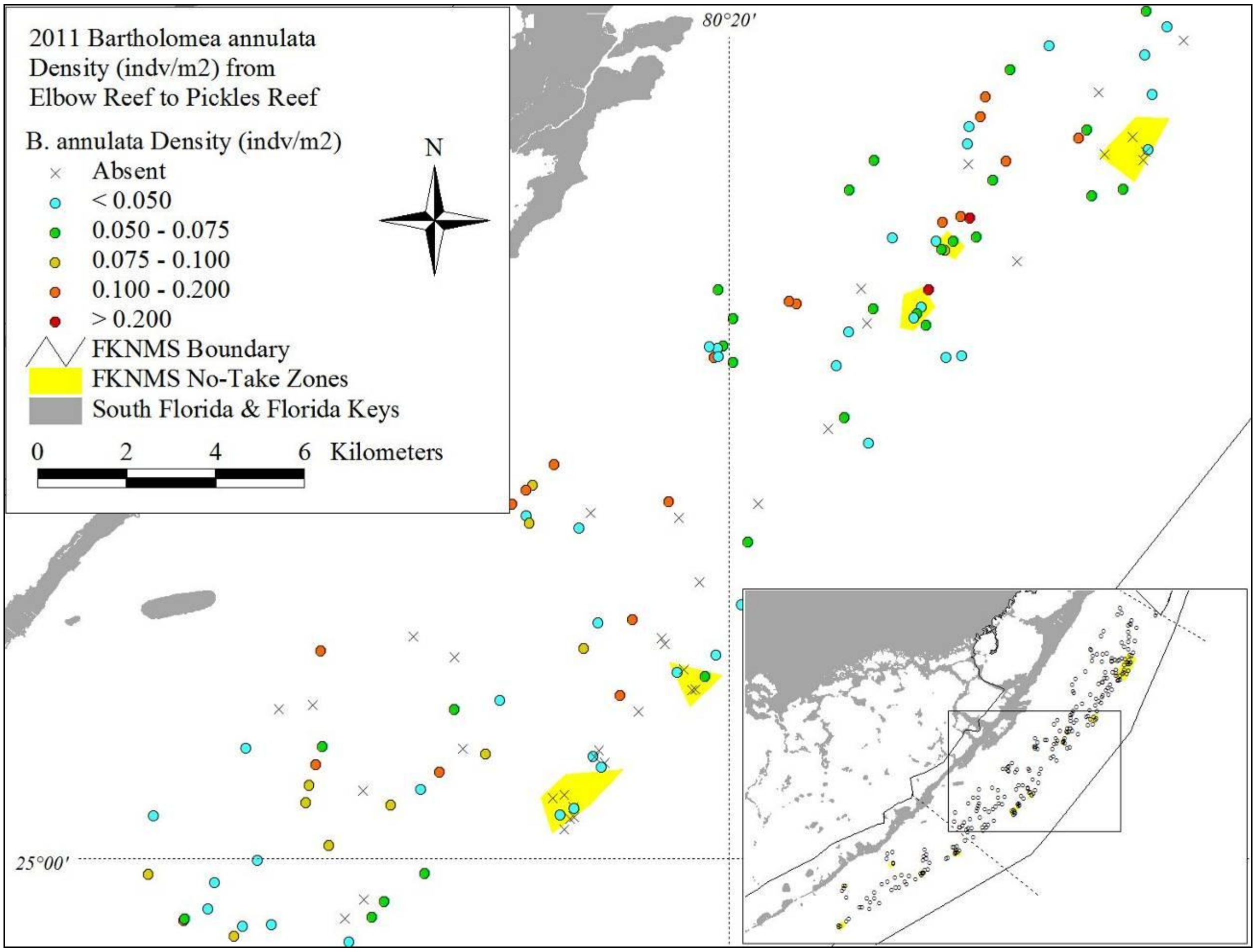


Figure 6-4. Densities (no. per m^2) of corkscrew anemones (*Bartholomea annulata*) in the upper Florida Keys National Marine Sanctuary from Conch Reef SPA to Alligator Reef SPA surveyed during May-September 2011.

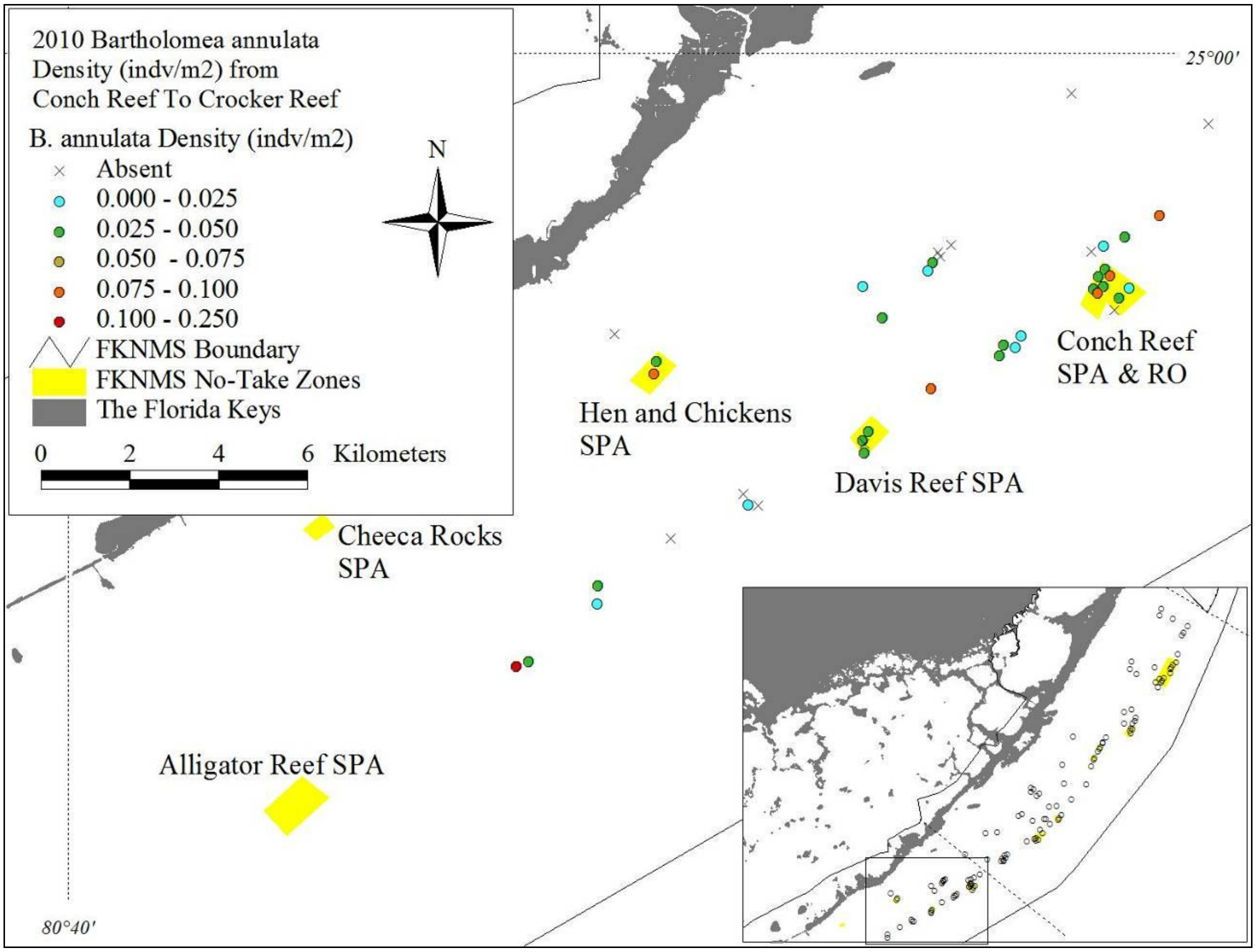
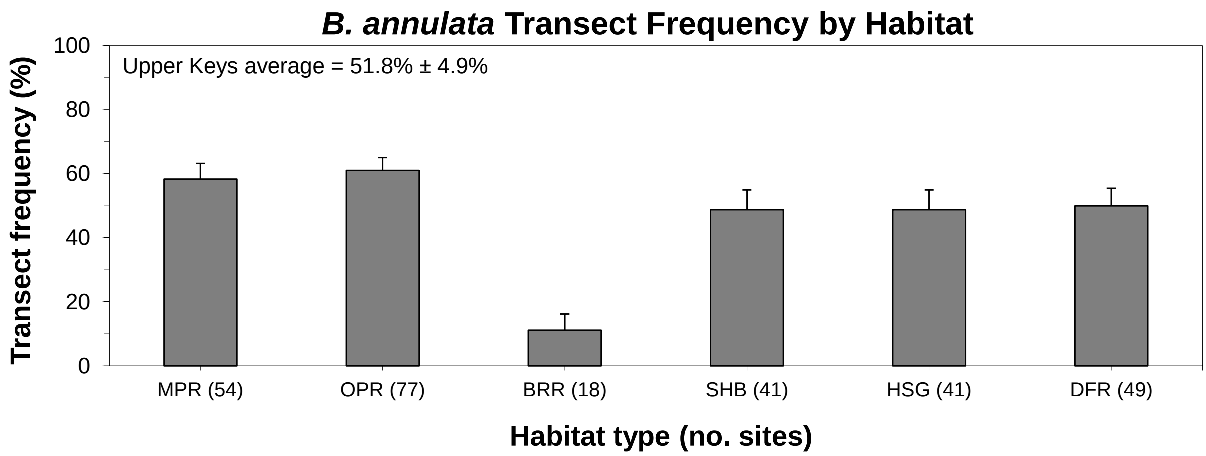


Figure 6-5. Mean (+ 1 SE) transect frequency (top) and density (no. individuals per m^2) (bottom) of corkscrew anemones (*Bartholomea annulata*) by habitat type in the upper Florida Keys during May-September 2011. Domain-wide (upper Keys) values are weighted averages and standard errors. Values on the x-axis in parentheses are the number of sites surveyed in each habitat type, with two 15-m x 1-m transects surveyed per site.



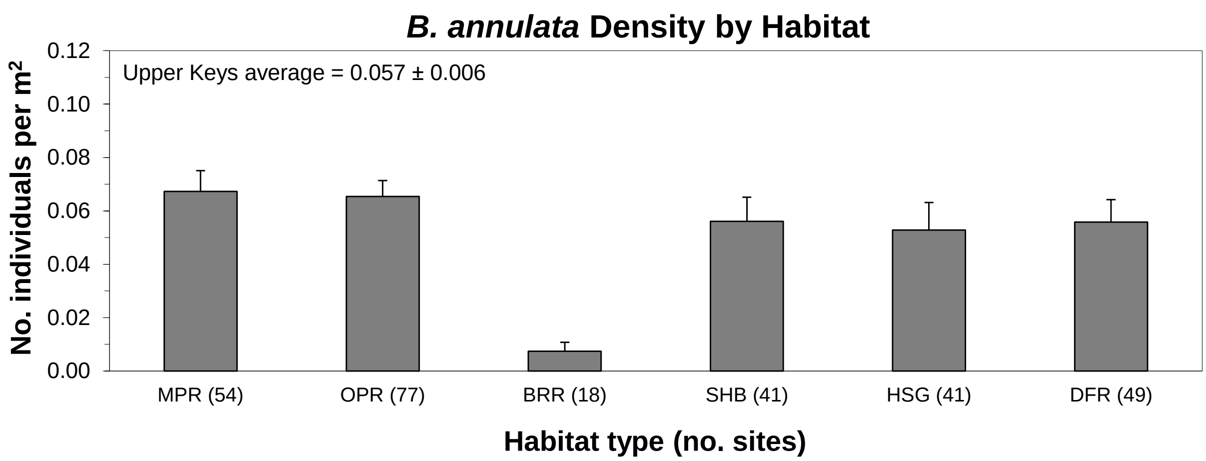
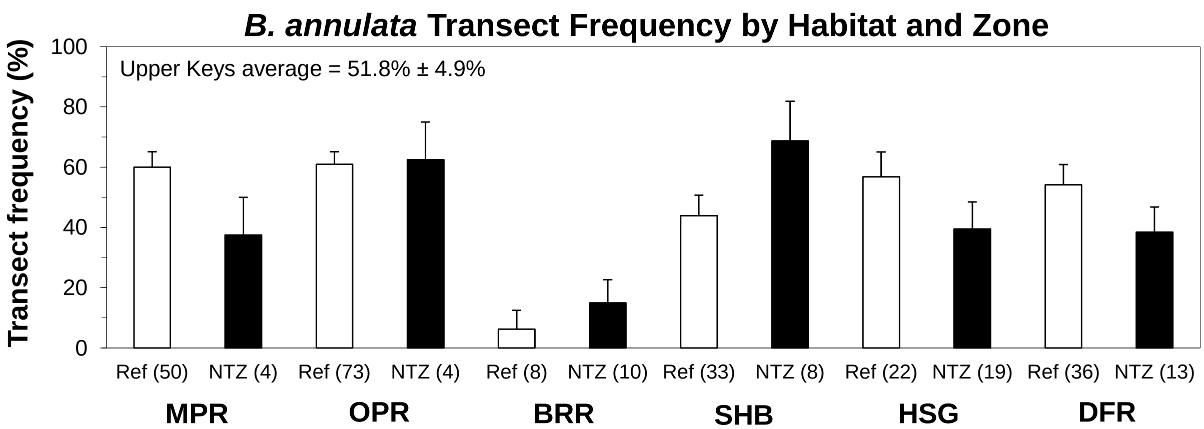


Figure 6-6. Mean (+ 1 SE) transect frequency (top) and density (no. individuals per m^2) (bottom) of corkscrew anemones (*Bartholomea annulata*) by habitat type and management zone in the upper Florida Keys during May-September 2011. Open bars = reference areas (Ref), filled bars = no-take zones (NTZ). Domain-wide (upper Keys) values are weighted averages and standard errors. Habitat abbreviations are: MPR = inshore and mid-channel patch reefs, OPR = offshore patch reefs, BRR = back-reef rubble, SHB = shallow (< 6 m) hard-bottom, HSG = high-relief and groove, and DFR = deeper (6-15 m) fore-reef habitats. Numbers in parentheses on the x-axis are the number of sites surveyed, with two replicate 15-m x 1-m transects surveyed per site (30 m^2 per site).



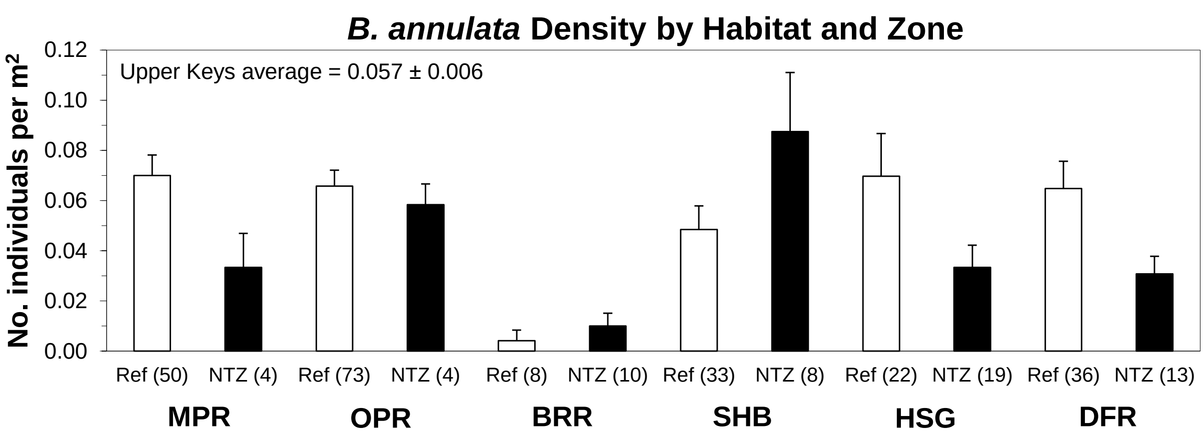
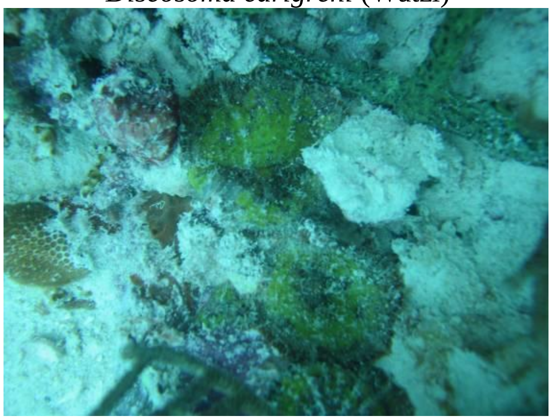


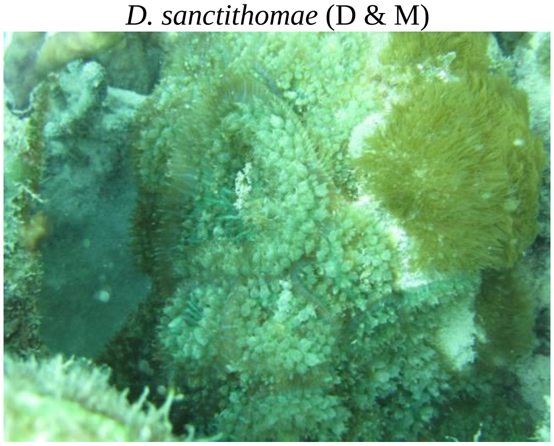
Figure 6-7. Corallimorpharians (Cnidaria, Anthozoa, Corallimorpharia) surveyed for presence-absence, density and habitat distribution in the upper Florida Keys National Marine Sanctuary during May-September 2011.

Discosoma carlgreni (Watzl)

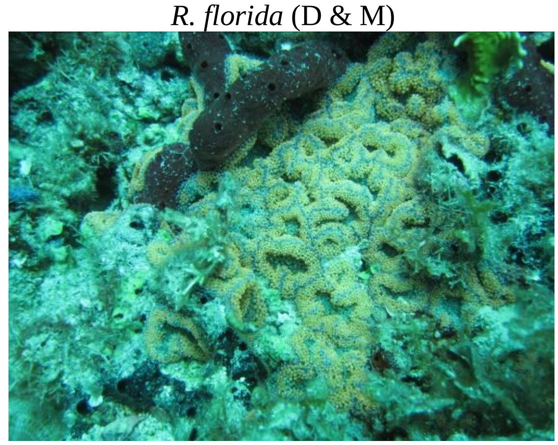


Ricordea florida (D & M)

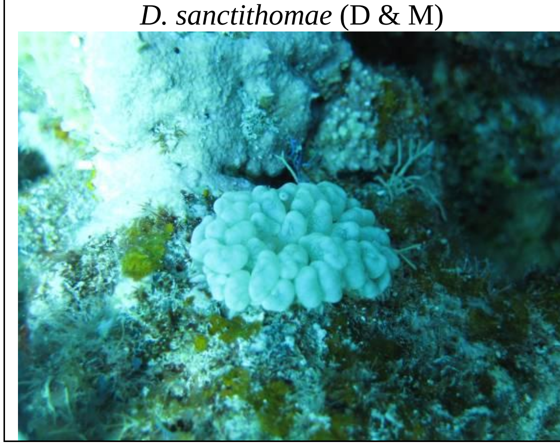
D. sanctithomae (D & M)



R. florida (D & M)



D. sanctithomae (D & M)



R. florida (D & M)

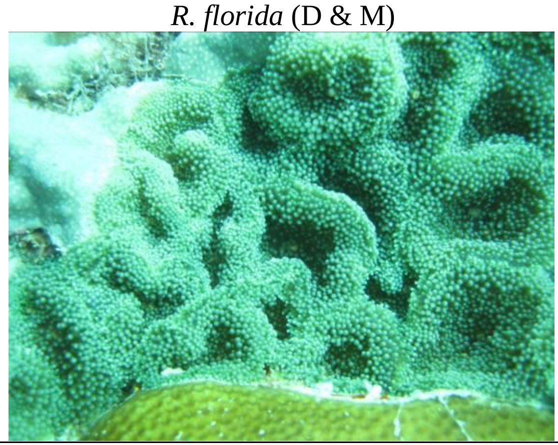


Figure 6-8. Densities (no. per m^2) of the Florida corallimorph (*Ricordea florida*) in the upper Florida Keys National Marine Sanctuary from the southern BNP boundary to Carysfort/S. Carysfort SPA surveyed during May-September 2011.

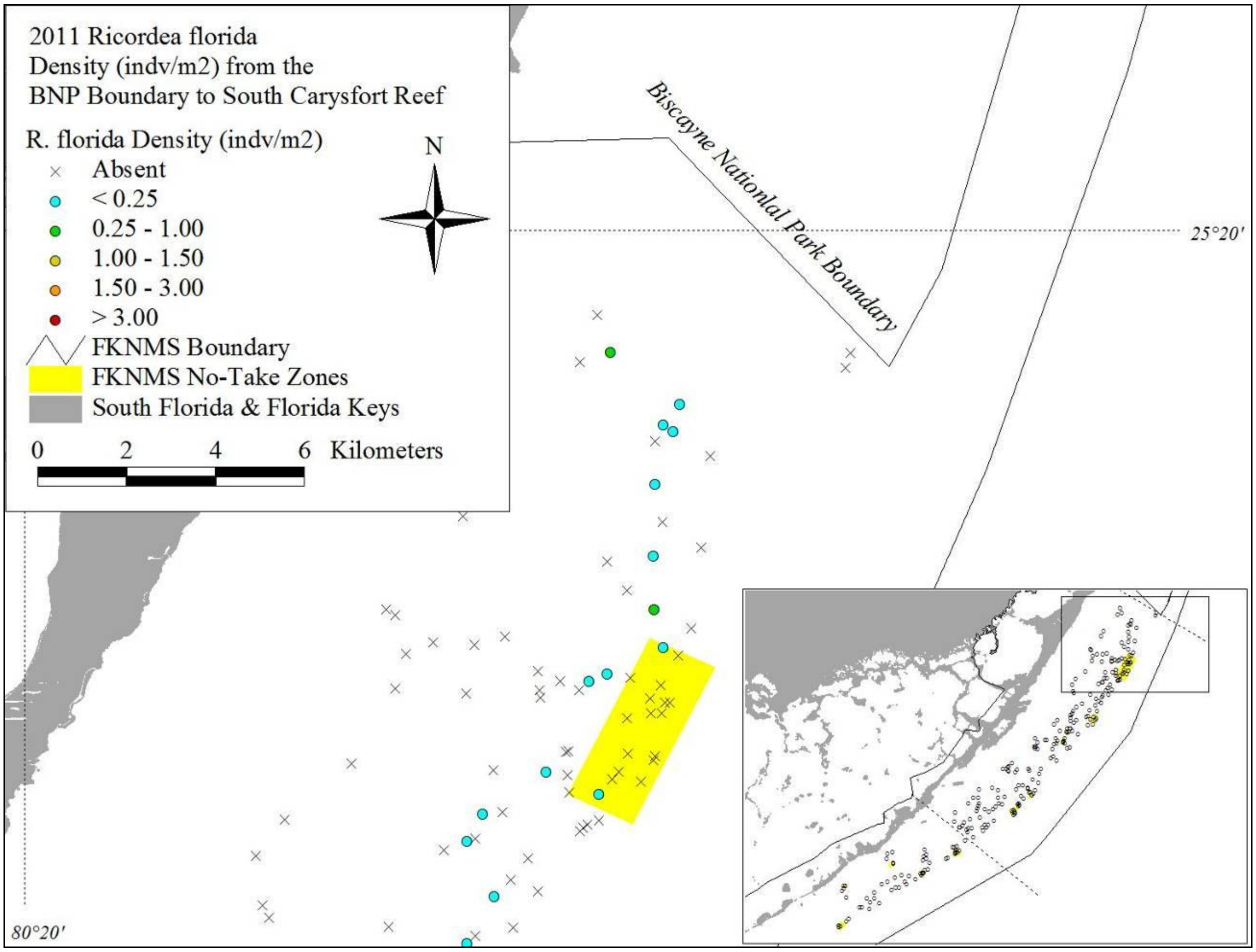


Figure 6-9. Densities (no. per m^2) of the Florida corallimorph (*Ricordea florida*) in the upper Florida Keys National Marine Sanctuary from Elbow Reef to Pickles Reef surveyed during May-September 2011.

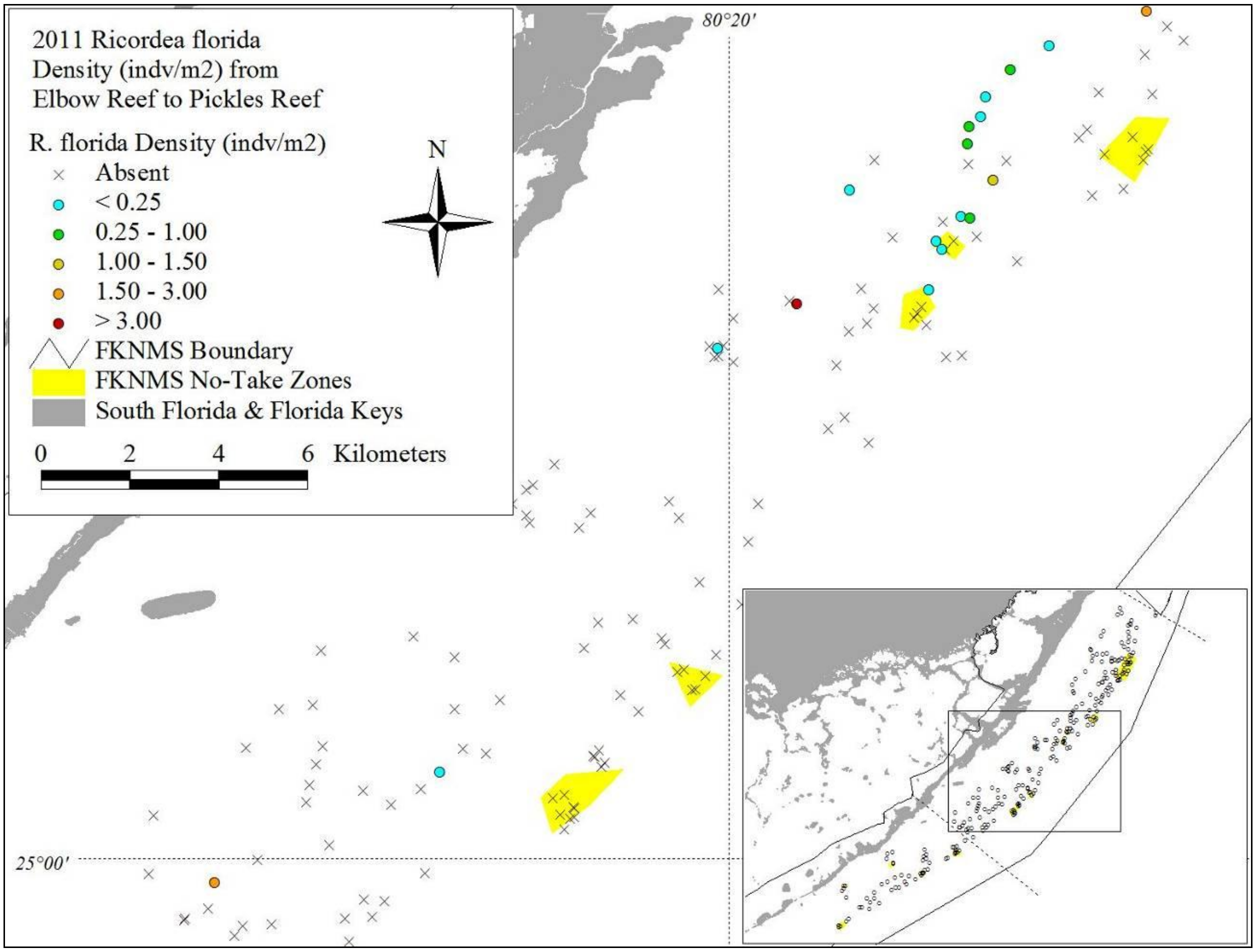


Figure 6-10. Densities (no. per m^2) of the Florida corallimorph (*Ricordea florida*) in the upper Florida Keys National Marine Sanctuary from Conch Reef SPA to Alligator Reef SPA surveyed during June-August 2010.

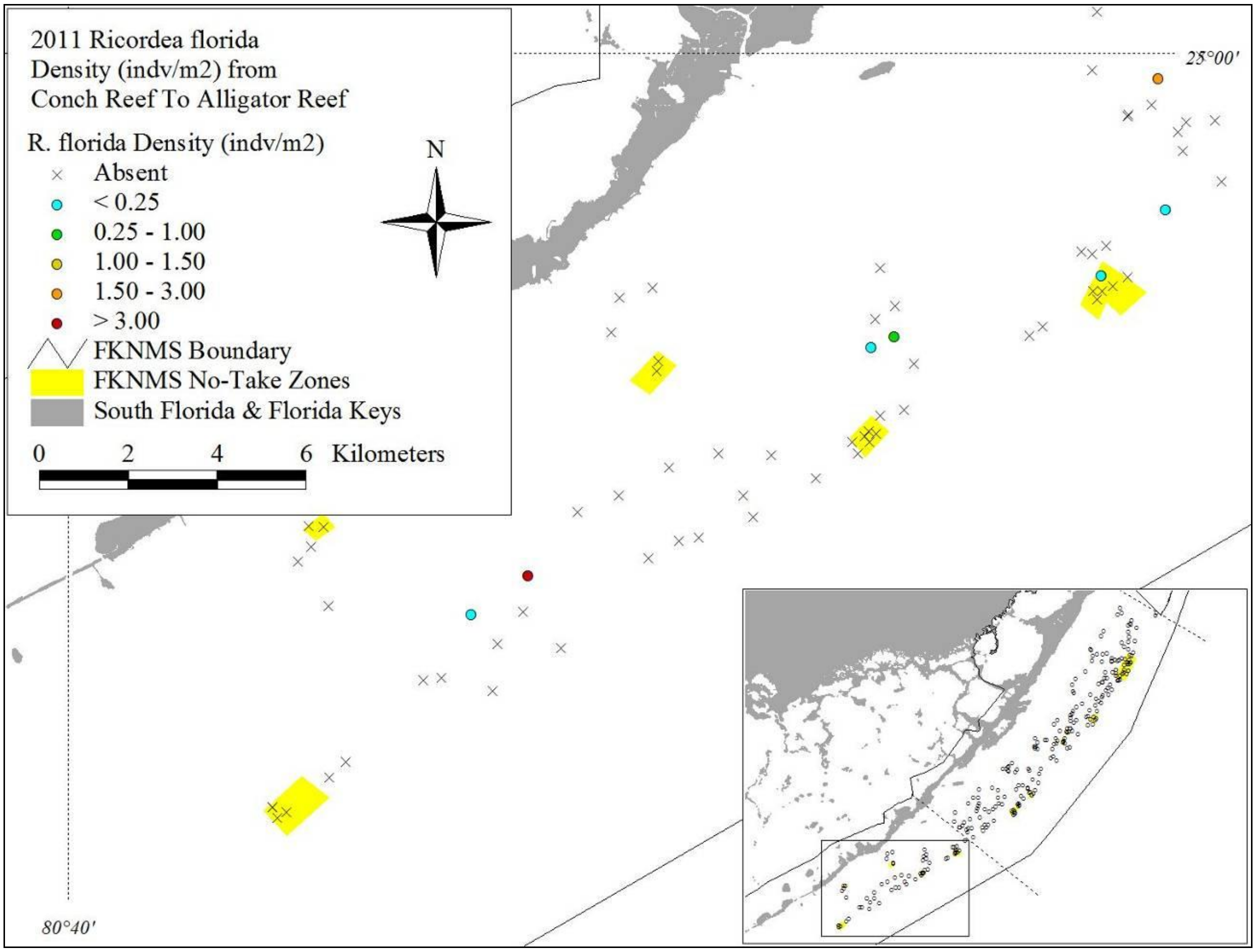
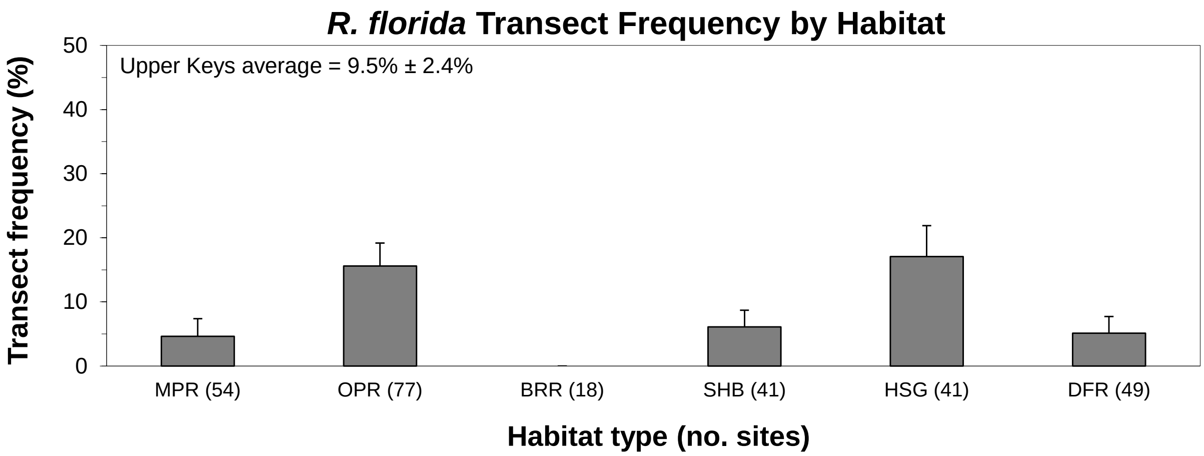


Figure 6-11. Mean (+ 1 SE) transect frequency (top) and density (no. individuals per m^2) (bottom) of the Florida corallimorph (*Ricordea florida*) by habitat type in the upper Florida Keys during May-September 2011. Domain-wide (upper Keys) values are weighted averages and standard errors. Values on the x-axis in parentheses are the number of sites surveyed in each habitat type, with two 15-m x 1-m transects surveyed per site.



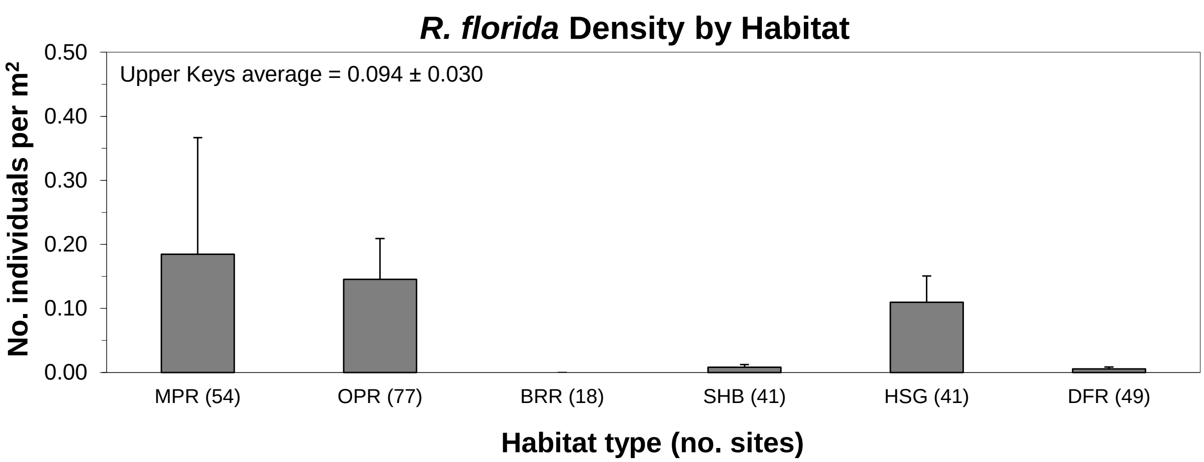
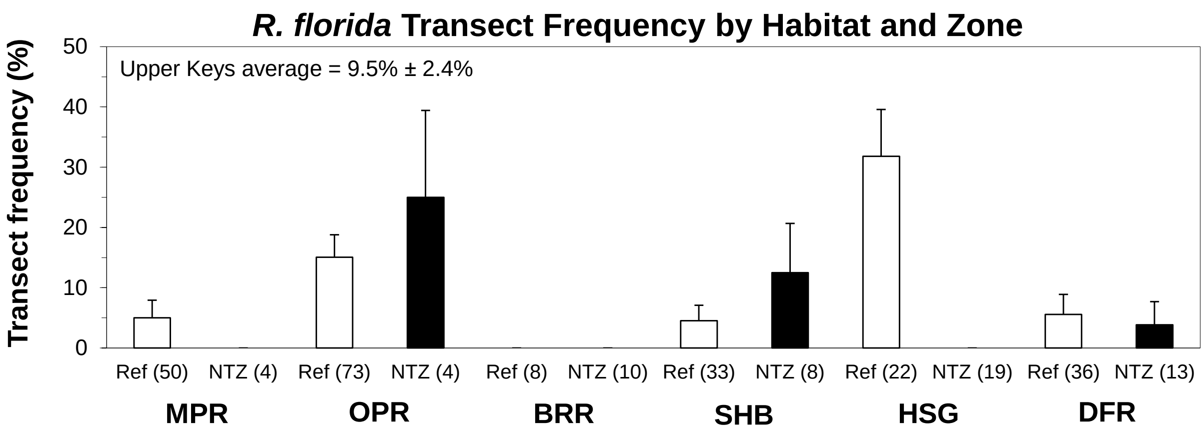


Figure 6-12. Mean (+ 1 SE) transect frequency (top) and density (no. individuals per m^2) (bottom) of the Florida corallimorph (*Ricordea florida*) by habitat type and management zone in the upper Florida Keys during May-September 2011. Open bars = reference areas (Ref), filled bars = no-take zones (NTZ). Domain-wide (upper Keys) values are weighted averages and standard errors. Habitat abbreviations are: MPR = inshore and mid-channel patch reefs, OPR = offshore patch reefs, BRR = back-reef rubble, SHB = shallow (< 6 m) hard-bottom, HSG = high-relief and groove, and DFR = deeper (6-15 m) fore-reef habitats. Numbers in parentheses on the x-axis are the number of sites surveyed, with two replicate 15-m x 1-m transects surveyed per site (30 m^2 per site).



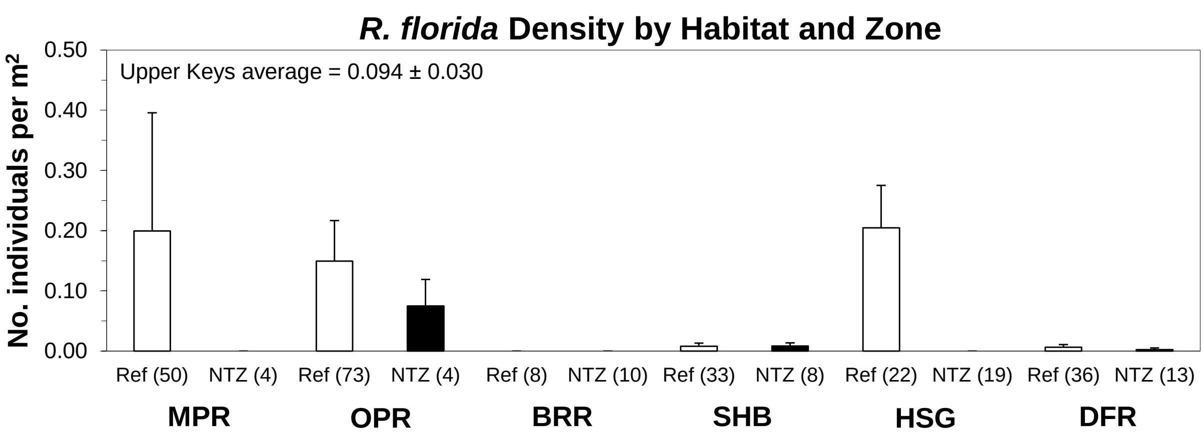


Table 6-1. Summary of habitat distribution and density of the corkscrew anemone *Bartholomea annulata* among habitat types and management zones in the upper Florida Keys, as determined from two replicate 15-m x 1-m belt transect surveys per site at 280 sites from northern Key Largo to Alligator Reef during May-September 2011. Habitat types are arranged from inshore to offshore and no-take zones represent Sanctuary Preservation Areas and Research Only areas. Values represent means ± 1 SE.

Habitat/management zone (no. sites)	**Site presence (%)**	**Transect frequency (%)**	**Density (no. per m^2)**	**No. individuals**
Inshore and mid-channel patch reefs				
Reference areas (50)	82.0 ± 5.5	60.0 ± 5.2	0.070 ± 0.008	105
No-take zones (4)	75.0 ± 25.0	37.5 ± 12.5	0.033 ± 0.014	4
Habitat total (54)	81.5 ± 5.3	58.3 ± 4.9	0.067 ± 0.008	109
Offshore patch reefs				
Reference areas (73)	83.6 ± 4.4	61.0 ± 4.2	0.066 ± 0.006	144
No-take zones (4)	100.0 ± 0.0	62.5 ± 12.5	0.058 ± 0.008	7
Habitat total (77)	84.4 ± 4.2	61.0 ± 4.0	0.065 ± 0.006	151
Back-reef rubble				
Reference areas (8)	12.5 ± 12.5	6.3 ± 6.3	0.004 ± 0.004	1
No-take zones (10)	30.0 ± 15.3	15.0 ± 7.6	0.010 ± 0.005	3
Habitat total (18)	22.2 ± 10.1	11.1 ± 5.0	0.007 ± 0.003	4
Shallow (< 6 m) hard-bottom				
Reference areas (33)	63.6 ± 8.5	43.9 ± 6.8	0.048 ± 0.009	48
No-take zones (8)	87.5 ± 12.5	68.8 ± 13.2	0.088 ± 0.024	21
Habitat total (41)	68.3 ± 7.4	48.8 ± 6.2	0.056 ± 0.009	69
High-relief spur and groove				
Reference areas (22)	77.3 ± 9.1	56.8 ± 8.3	0.070 ± 0.017	46
No-take zones (19)	57.9 ± 11.6	39.5 ± 9.0	0.033 ± 0.009	19
Habitat total (41)	68.3 ± 7.4	48.8 ± 6.2	0.053 ± 0.010	65
Deeper fore reef				
Reference areas (36)	72.2 ± 7.6	54.2 ± 6.7	0.065 ± 0.011	70
No-take zones (13)	69.2 ± 13.3	38.5 ± 8.3	0.031 ± 0.007	12
Habitat total (49)	71.4 ± 6.5	50.0 ± 5.5	0.056 ± 0.008	82

Table 6-2. Summary of habitat distribution and density of the giant, pink-tipped anemones *Condylactis gigantea* among habitat types and management zones in the upper Florida Keys, as determined from two replicate 15-m x 1-m belt transect surveys per site at 280 sites from northern Key Largo to Alligator Reef during May-September 2011. Habitat types are arranged from inshore to offshore and no-take zones represent Sanctuary Preservation Areas and Research Only areas. Values represent means ± 1 SE.

Habitat/management zone (no. sites)	**Site presence (%)**	**Transect frequency (%)**	**Density (no. per m^2)**	**No. individuals**
Inshore and mid-channel patch reefs				
Reference areas (50)	22.0 ± 5.9	13.0 ± 3.7	0.013 ± 0.005	19
No-take zones (4)	0 ± 0	0 ± 0	0 ± 0	0
Habitat total (54)	20.4 ± 5.5	12.0 ± 3.5	0.012 ± 0.004	19
Offshore patch reefs				
Reference areas (73)	28.8 ± 5.3	17.1 ± 3.4	0.016 ± 0.004	35
No-take zones (4)	75.0 ± 25.0	62.5 ± 23.9	0.058 ± 0.028	7
Habitat total (77)	31.2 ± 5.3	19.5 ± 3.6	0.018 ± 0.004	42
Back-reef rubble				
Reference areas (8)	0 ± 0	0 ± 0	0 ± 0	0
No-take zones (10)	10.0 ± 10.0	5.0 ± 5.0	0.003 ± 0.003	1
Habitat total (18)	5.6 ± 5.6	2.8 ± 2.8	0.002 ± 0.002	1
Shallow (< 6 m) hard-bottom				
Reference areas (33)	21.2 ± 7.2	12.1 ± 4.4	0.010 ± 0.004	10
No-take zones (8)	37.5 ± 18.3	18.8 ± 9.1	0.017 ± 0.009	4
Habitat total (41)	24.4 ± 6.8	13.4 ± 3.9	0.011 ± 0.004	14
High-relief spur and groove				
Reference areas (22)	13.6 ± 7.5	9.1 ± 5.3	0.006 ± 0.004	4
No-take zones (19)	0 ± 0	0 ± 0	0 ± 0	0
Habitat total (41)	7.3 ± 4.1	4.9 ± 2.9	0.003 ± 0.002	4
Deeper fore reef				
Reference areas (36)	5.6 ± 3.9	2.8 ± 1.9	0.002 ± 0.001	2
No-take zones (13)	7.7 ± 7.7	3.8 ± 3.8	0.003 ± 0.003	1
Habitat total (49)	6.1 ± 3.5	3.1 ± 1.7	0.002 ± 0.001	3

Table 6-3. Summary of habitat distribution and density of the anemone *Lebrunia danae* among habitat types and management zones in the upper Florida Keys, as determined from two replicate 15-m x 1-m belt transect surveys per site at 280 sites from northern Key Largo to Alligator Reef during May-September 2011. Habitat types are arranged from inshore to offshore and no-take zones represent Sanctuary Preservation Areas and Research Only areas. Values represent mean ± 1 SE.

Habitat/management zone (no. sites)	**Site presence (%)**	**Transect frequency (%)**	**Density (no. per m^2)**	**No. individuals**
Inshore and mid-channel patch reefs				
Reference areas (50)	16.0 ± 5.2	8.0 ± 2.6	0.005 ± 0.002	8
No-take zones (4)	25.0 ± 25.0	12.5 ± 12.5	0.008 ± 0.008	1
Habitat total (54)	16.7 ± 5.1	8.3 ± 2.6	0.006 ± 0.002	9
Offshore patch reefs				
Reference areas (73)	11.0 ± 3.7	7.5 ± 2.7	0.006 ± 0.002	14
No-take zones (4)	0 ± 0	0 ± 0	0 ± 0	0
Habitat total (77)	10.4 ± 3.5	7.1 ± 2.6	0.006 ± 0.002	14
Back-reef rubble				
Reference areas (8)	0 ± 0	0 ± 0	0 ± 0	0
No-take zones (10)	0 ± 0	0 ± 0	0 ± 0	0
Habitat total (18)	0 ± 0	0 ± 0	0 ± 0	0
Shallow (< 6 m) hard-bottom				
Reference areas (33)	3.0 ± 3.0	1.5 ± 1.5	0.001 ± 0.001	1
No-take zones (8)	0 ± 0	0 ± 0	0 ± 0	0
Habitat total (41)	2.4 ± 2.4	1.2 ± 1.2	0.001 ± 0.001	1
High-relief spur and groove				
Reference areas (22)	13.6 ± 7.5	6.8 ± 3.7	0.005 ± 0.002	3
No-take zones (19)	5.3 ± 5.3	2.6 ± 2.6	0.002 ± 0.002	1
Habitat total (41)	9.8 ± 4.7	4.9 ± 2.3	0.003 ± 0.002	4
Deeper fore reef				
Reference areas (36)	8.3 ± 4.7	4.2 ± 2.3	0.004 ± 0.002	4
No-take zones (13)	0 ± 0	0 ± 0	0 ± 0	0
Habitat total (49)	6.1 ± 3.5	3.1 ± 1.7	0.003 ± 0.002	4

Table 6-4. Summary of habitat distribution and density of the corallimorpharian *Discosoma carlgreni* among habitat types and management zones in the upper Florida Keys, as determined from two replicate 15-m x 1-m belt transect surveys per site at 280 sites from northern Key Largo to Alligator Reef during May-September 2011. Habitat types are arranged from inshore to offshore and no-take zones represent Sanctuary Preservation Areas and Research Only areas. Values represent mean ± 1 SE.

Habitat/management zone (no. sites)	**Site presence (%)**	**Transect frequency (%)**	**Density (no. per m^2)**	**No. individuals**
Inshore and mid-channel patch reefs				
Reference areas (50)	0 ± 0	0 ± 0	0 ± 0	0
No-take zones (4)	0 ± 0	0 ± 0	0 ± 0	0
Habitat total (54)	0 ± 0	0 ± 0	0 ± 0	0
Offshore patch reefs				
Reference areas (73)	4.1 ± 2.3	2.1 ± 1.2	0.004 ± 0.003	9
No-take zones (4)	0 ± 0	0 ± 0	0 ± 0	0
Habitat total (77)	3.9 ± 2.2	1.9 ± 1.1	0.004 ± 0.002	9
Back-reef rubble				
Reference areas (8)	0 ± 0	0 ± 0	0 ± 0	0
No-take zones (10)	0 ± 0	0 ± 0	0 ± 0	0
Habitat total (18)	0 ± 0	0 ± 0	0 ± 0	0
Shallow (< 6 m) hard-bottom				
Reference areas (33)	0 ± 0	0 ± 0	0 ± 0	0
No-take zones (8)	0 ± 0	0 ± 0	0 ± 0	0
Habitat total (41)	0 ± 0	0 ± 0	0 ± 0	0
High-relief spur and groove				
Reference areas (22)	0 ± 0	0 ± 0	0 ± 0	0
No-take zones (19)	0 ± 0	0 ± 0	0 ± 0	0
Habitat total (41)	0 ± 0	0 ± 0	0 ± 0	0
Deeper fore reef				
Reference areas (36)	0 ± 0	0 ± 0	0 ± 0	0
No-take zones (13)	0 ± 0	0 ± 0	0 ± 0	0
Habitat total (49)	0 ± 0	0 ± 0	0 ± 0	0

Table 6-5. Summary of habitat distribution and density of the corallimorpharian *Discosoma sanctithomae* among habitat types and management zones in the upper Florida Keys, as determined from two replicate 15-m x 1-m belt transect surveys per site at 280 sites from northern Key Largo to Alligator Reef during May-September 2011. Habitat types are arranged from inshore to offshore and no-take zones represent Sanctuary Preservation Areas and Research Only areas. Values represent mean ± 1 SE.

Habitat/management zone (no. sites)	**Site presence (%)**	**Transect frequency (%)**	**Density (no. per m^2)**	**No. individuals**
Inshore and mid-channel patch reefs				
Reference areas (50)	4.0 ± 2.8	2.0 ± 1.4	0.013 ± 0.010	19
No-take zones (4)	0 ± 0	0 ± 0	0 ± 0	0
Habitat total (54)	3.7 ± 2.6	1.9 ± 1.3	0.012 ± 0.010	19
Offshore patch reefs				
Reference areas (73)	0 ± 0	0 ± 0	0 ± 0	0
No-take zones (4)	0 ± 0	0 ± 0	0 ± 0	0
Habitat total (77)	0 ± 0	0 ± 0	0 ± 0	0
Back-reef rubble				
Reference areas (8)	0 ± 0	0 ± 0	0 ± 0	0
No-take zones (10)	0 ± 0	0 ± 0	0 ± 0	0
Habitat total (18)	0 ± 0	0 ± 0	0 ± 0	0
Shallow (< 6 m) hard-bottom				
Reference areas (33)	3.0 ± 3.0	1.5 ± 1.5	0.001 ± 0.001	1
No-take zones (8)	0 ± 0	0 ± 0	0 ± 0	0
Habitat total (41)	2.4 ± 2.4	1.2 ± 1.2	0.001 ± 0.001	1
High-relief spur and groove				
Reference areas (22)	9.1 ± 6.3	4.5 ± 3.1	0.005 ± 0.003	3
No-take zones (19)	0 ± 0	0 ± 0	0 ± 0	0
Habitat total (41)	4.9 ± 3.4	2.4 ± 1.7	0.002 ± 0.002	3
Deeper fore reef				
Reference areas (36)	0 ± 0	0 ± 0	0 ± 0	0
No-take zones (13)	0 ± 0	0 ± 0	0 ± 0	0
Habitat total (49)	0 ± 0	0 ± 0	0 ± 0	0

Table 6-6. Summary of habitat distribution and density of the corallimorpharian *Ricordea florida* among habitat types and management zones in the upper Florida Keys, as determined from two replicate 15-m x 1-m belt transect surveys per site at 280 sites from northern Key Largo to Alligator Reef during May-September 2011. Habitat types are arranged from inshore to offshore and no-take zones represent Sanctuary Preservation Areas and Research Only areas. Values represent mean ± 1 SE.

Habitat/management zone (no. sites)	**Site presence (%)**	**Transect frequency (%)**	**Density (no. per m^2)**	**No. individuals**
Inshore and mid-channel patch reefs				
Reference areas (50)	6.0 ± 3.4	5.0 ± 2.9	0.199 ± 0.197	299
No-take zones (4)	0 ± 0	0 ± 0	0 ± 0	0
Habitat total (54)	5.6 ± 3.1	4.6 ± 2.7	0.185 ± 0.182	299
Offshore patch reefs				
Reference areas (73)	20.5 ± 4.8	15.1 ± 3.7	0.149 ± 0.067	327
No-take zones (4)	50.0 ± 28.9	25.0 ± 14.4	0.075 ± 0.044	9
Habitat total (77)	22.1 ± 4.8	15.6 ± 3.6	0.145 ± 0.064	336
Back-reef rubble				
Reference areas (8)	0 ± 0	0 ± 0	0 ± 0	0
No-take zones (10)	0 ± 0	0 ± 0	0 ± 0	0
Habitat total (18)	0 ± 0	0 ± 0	0 ± 0	0
Shallow (< 6 m) hard-bottom				
Reference areas (33)	9.1 ± 5.1	4.5 ± 2.5	0.008 ± 0.005	8
No-take zones (8)	25.0 ± 16.4	12.5 ± 8.2	0.008 ± 0.005	2
Habitat total (41)	12.2 ± 5.2	6.1 ± 2.6	0.008 ± 0.004	10
High-relief spur and groove				
Reference areas (22)	50.0 ± 10.9	31.8 ± 7.7	0.205 ± 0.071	135
No-take zones (19)	0 ± 0	0 ± 0	0 ± 0	0
Habitat total (41)	26.8 ± 7.0	17.1 ± 4.8	0.110 ± 0.041	135
Deeper fore reef				
Reference areas (36)	8.3 ± 4.7	5.6 ± 3.3	0.006 ± 0.004	7
No-take zones (13)	7.7 ± 7.7	3.8 ± 3.8	0.003 ± 0.003	1
Habitat total (49)	8.2 ± 4.0	5.1 ± 2.6	0.005 ± 0.003	8

VII. Mollusk Abundance and Size

Background

The Florida Keys marine ecosystem supports a diverse fauna of mollusks belonging to several orders. Opisthobranch mollusks, for example, are represented by at least 30 species of sea slugs (Sacoglossa) and 23 species of nudibranchs (Nudibranchia) (Clark and DeFreese 1987; Levy et al. 1996), including several endemic species (Clark 1994). Data on the status and trends of mollusk populations and habitat utilization patterns in the Florida Keys, with the exception of queen conch (*Strombus gigas*), are generally limited and mostly qualitative in nature (Marcus 1960; Jensen and Clark 1983; Clark and DeFreese 1987). Clark (1994) noted a declining population trend for the lettuce sea slug, *Elysia* (*Tridachia*) *crispata* Mörch (see cladistic analyses in Gosliner 1995; Jensen 1996) in southern Florida, based upon qualitative comparisons of occurrence and population densities between 1969-80 and 1987-93. About 50% of the nearshore populations assessed by Clark (1994) nearly 17 years ago were declining due to habitat destruction, siltation, eutrophication, and over-collection, particularly evident in nearshore habitats.

Since 2001, we have conducted intermittent surveys of various gastropod mollusk species in conjunction with assessments of other benthic coral reef organisms. For example, we encountered unusually high densities of lettuce sea slugs among 63 shallow fore reef sites during June-September 2001. While sacoglossans are not particularly rare in many shallow-water marine habitats where densities tend to be correlated with algal biomass (Clarke and DeFreese 1987), our observations offshore were considered unusual because fleshy algal cover tends to be relatively low (Chiappone et al. 1997; Miller et al. 2002). In 2007, 2009, and 2010 we surveyed *Coralliophila* snail predation on corals, including *Acropora* species, and also quantified the density of two other Neogastropoda species that were especially abundant on high-relief spur and groove reefs. During 2001 and 2008-2009, we surveyed *Cyphoma* abundance, size, and gorgonian host occupation patterns (Chiappone et al. 2003).

During May-September 2011, two 15-m x 1-m belt transects per site at all 280 sites (8,400 m^2) were surveyed for mollusk abundance, size (total length), and substratum occupancy. Based upon previous surveys, the following nudibranch, sacoglossan, and neogastropoda mollusks were targeted (Figures 7-1 and 7-2):

- The nudibranchs *Hypselodoris bayeri* (black-spotted sea goddess), *H. (edenticulata) picta* (Florida regal sea goddess), *Chromodoris (Mexichromis) kempfi* (purple-crowned sea goddess), *C. nyalya* (red-line blue sea goddess), and *Glossodoris sedna* (red-tipped sea goddess) of the Class Gastropoda, Subclass Opisthobranchia, Order Nudibranchia;

- The lettuce sea slug, *Elysia* (*Tradachia*) *crispata* (Mörch), Class Gastropoda, Subclass Opisthobranchia, Order Sacoglossa, Family Elysiidae;
- The Neogastropoda mollusks *Thais deltoidea* (Lamarck) of the Family Thaididae, *Coralliophila* sp. of the Family Coralliophilidae, *Leucozonia nassa* (Gmelin) of the Family Fasciolariidae, as well as *Strombus gigas* Linnaeus of the Family Strombidae.

Of these targeted species, all were found, in addition to two nudibranchs we have not encountered before: *Hypselodoris olgae* Ortea and Bacallado (Figure 7-1) and an undescribed *Flabellina* species (Figure 7-2) that may be *F. verta* (Marcus) (see The Sea Slug Forum at www.seaslugforum.net/find/flabvert). The results below summarize site presence, transect frequency, density, size, and substratum occupancy patterns by habitat and management zone for the mollusks encountered.

2011 Survey Results

A total of 560 belt transects, each 15-m x 1-m in dimension, comprising 8,400 m^2 of benthic habitat was surveyed among 280 upper Keys sites for mollusk site presence, transect frequency, density, size (total length or shell length, depending on species), and the substratum the organism was found occupying at the time of survey. The 2011 surveys yielded seven nudibranch species, one sacoglossan sea slug (*Elysia crispata*), and four Neogastropoda snails (*Coralliophila* sp., *Leucozonia nassa*, *Thais deltoidea*, and *Strombus gigas*). Tables 7-1 to 7-13 provide summary data by habitat and management zone for each mollusk species. Distribution maps are also provided for three of the Neogastropoda snails surveyed.

Nudibranchs

A total of 15 nudibranchs among 7 species were encountered during 2011, including two species not encountered before during benthic surveys dating back to 1999 (Figures 7-1 and 7-2). All species were rarely observed, which may at least partly reflect bias in our survey methods, which are designed, more or less, for larger, less cryptic invertebrates. Two individuals of *Chromodoris* (*Mexichromis*) *kempfi* were encountered, both from a shallow hard-bottom area within Conch Reef SPA (Table 7-1). The two individuals were found close together (Figure 7-1) and ranged in length from 1.6 to 1.7 cm TL. Five individuals of *C. nyalya* were encountered (Figure 7-1), distributed among just a few reference sites comprising offshore patch reef, shallow hard-bottom, and deeper fore-reef habitats (Figure 7-2). The mean total length of the five individuals was 1.2 cm TL, with a size range of 1.0 to 1.3 cm. A small (1.3 cm TL) undescribed *Flabellina* species (Figure 7-2), possibly *F. verta* (Marcus), was encountered in the back-reef rubble area of Molasses Reef SPA and was the specimen of this type encountered during 2011

(Table 7-3). Two individuals of *Glossodoris sedna* (Figure 7-1), ranging in total length from 2.3 to 2.6 cm, were encountered at one mid-channel patch reef south of Cannon Patch in John Pennekamp Coral Reef State Park. No other individuals of this species were observed (Table 7-4). Finally, five individuals among three *Hypselodoris* species were observed, represented by *H. bayeri* (1 individual), *H. olgae* (3 individuals, and *H. (edenticulata) picta* (1 individual) (Figure 7-1). The single specimen of *H. bayeri*, which was 1.3 cm TL, was found on a patchy hard-bottom site northeast of Alligator Light (Table 7-5). The three individuals of *H. olgae*, which ranged in size from 2.2 to 2.7 cm TL, were only found on two offshore patch reefs, one in the Watsons Reef area, and the other in the southwestern corner of Dry Rocks SPA (Table 7-6). The one specimen of *H. picta*, which was rather large (6.2 cm TL, see Figure 7-1), was observed on an offshore patch reef within Dry Rocks SPA (Table 7-7).

Ascoglossan lettuce sea slugs (*Elysia crispata*) (Mörch)

A total of 70 individuals of the lettuce sea slug (*Elysia crispata*) were encountered during 2011 (Figure 7-2), with all but two recorded from high-relief spur and groove reefs in the upper Keys (Table 7-8). This distribution pattern is similar to historical surveys conducted in the Florida Keys since 2001. A maximum site-level density of 0.633 ± 0.033 individuals per m^2 was recorded from the shallow fore-reef area at Grecian Rocks. *E. crispata* was encountered at 39% of the 41 high-relief spur and groove sites sampled and was encountered within 27% of the sampled transects. Total lengths of 54 individuals measured ranged from 1.6 to 4.2 cm, with a mean (± 1 SE) size of 2.8 ± 0.1 cm. All *E. crispata* were found on algae when encountered, with most (78%) occurring on algal turf (Table 7-9). Similar to previous years, *E. crispata* was more common and occurred in greater densities in FKNMS no-take zones compared to reference areas (Table 7-8). Site presence, transect frequency, and mean density were all more than four times greater in no-take zones.

Neogastropoda mollusks

Four Neogastropoda mollusk species were surveyed in 2011, three of which we have surveyed previously since 2007: *Coralliophila* sp., *Leucozonia nassa*, and *Thais deltoidea* (Figure 7-2). Additionally, we surveyed queen conch (*Strombus gigas*). These surveys initially began in 2007 with the intent of documenting *Coralliophila* snail abundance and predation in conjunction with *Acropora* coral surveys. We added two additional gastropods (*L. nassa* and *T. deltoidea*) to our target list, as we continue to encounter large numbers of individuals in particular habitats. We are also interested in assessing whether the abundance patterns of these species may be related to fishing pressure inside and outside of FKNMS no-take zones. *T. deltoidea*, for example, is an important micro-herbivore that grazes on mostly algal turf, and differential predation pressure from fishes and perhaps lobsters inside and outside of protected areas could affect benthic coverage patterns.

A total of 147 *Coralliophila* sp. individuals (Figure 7-2) were found, distributed among all habitats except back-reef rubble (Table 7-10). The maximum site-level density of 0.80 ± 0.80 individuals per m^2 was recorded from an offshore patch reef north of the Carysfort Reef area. Site presence, transect frequency, and mean density were greatest on offshore patch reefs, high-relief spur and groove reefs, and the deeper fore reef (Figure 7-3). Similar to previous years, the spatial distribution of this snail is highly aggregated. No consistent patterns in abundance or distribution were evident between no-take zones and reference areas for the majority of habitats sampled (Figure 7-4). On offshore patch reefs and the deeper fore reef, *Coralliophila* was only recorded from reference sites, while transect frequency and mean density were similar between reference areas and no-take zones in high-relief spur and groove habitat. The 147 *Coralliophila* sp. enumerated and measured ranged in size (shell length) from 1.0 cm to 4.1 cm, with a mean (± 1 SE) size of 1.89 ± 0.04 cm. Of the individuals measured, all but one were found occupying coral tissue when encountered (Table 7-9). *Coralliophila* sp. exhibited a highly aggregated distribution and was almost always found as clusters of a few to tens of individuals on the edges of live coral colonies. Since 2007, we have noted an increase in the frequency of encounter and density of *Coralliophila*, as well as a greater number of species occupied by snails and/or exhibiting obvious signs of snail predation, including *Acropora* corals. Thirteen different scleractinian species were documented with *Coralliophila* snails, with *Agaricia agaricites* and *Montastraea* spp. the most frequently affected.

Also sampled in 2011, the common lesser tulip shell (*Leucozonia nassa*) (Figure 7-2) exhibited a relatively restricted habitat distribution, similar to observations from previous survey years, with greater frequency and higher density on high-relief spur and groove reefs (Table 7-11 and Figure 7-5). The maximum site-level density of 0.233 ± 0.033 per m^2 was recorded from a high-relief spur and groove site in the South Carysfort Reef area. In the high-relief spur and groove habitat, both transect frequency and mean density were greater in no-take zones compared to reference areas (Figure 7-6). Shell lengths of the 41 individuals recorded ranged from 1.2 to 7.1 cm, with a mean ± 1 SE size of 3.4 ± 0.2 cm. Most *L. nassa* snails were found on either algal turf (66%) or crustose coralline algae (~32%) (Table 7-9).

Similar to 2007, 2009, and 2010, the most abundant neogastropoda mollusk surveyed in 2011 was the deltoid rock shell (*Thais deltoidea*) (Figure 7-2). A total of 221 individuals were found, and similar to *Leucozonia nassa*, most *T. deltoidea* were encountered at high-relief spur and groove sites (Table 7-12).

Figures 7-7 to 7-9 show the spatial distribution of site densities for the upper Keys study area, illustrating the aggregated distribution of this snail on the shallow fore reef. Site presence (65.9% ± 7.5%), transect frequency (52.4% ± 6.8%) and mean density (0.127 ± 0.024) were all substantially higher in high-relief spur and groove compared to all other habitats (Figure 7-10). The maximum site-level density of 0.70 ± 0.10 individuals per m^2 was recorded from the shallow fore reef at Grecian Rocks SPA. On shallow hard-bottom and high-relief spur and groove, these metrics were greater in no-take zones compared to reference areas much greater on high-relief spur and groove reefs compared to other habitats (Figure 7-11). For the 221 *T. deltoidea* individuals measured, total shell lengths ranged from 1.2 to 5.2 cm, with a mean ± 1 SE size of 2.71 ± 0.03 cm. Nearly 82% of *T. deltoidea* were found on algal turf, with the balance found on crustose coralline algae, *Dictyota* algae, sand, or on other *T. deltoidea* individuals (Table 7-9).

Strombus gigas Linnaeus

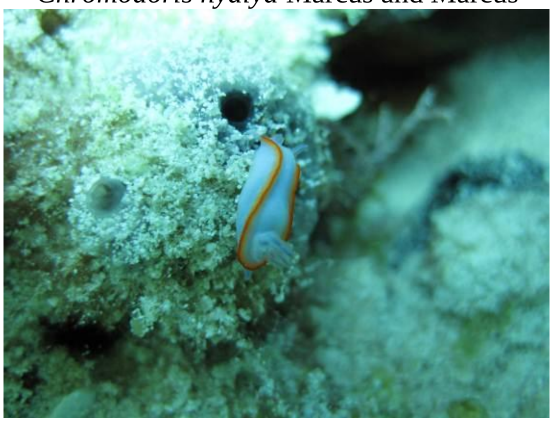
Surveys for queen conch (*Strombus gigas*) (Figure 7-2) were carried out in conjunction with surveys of other mollusks in the upper Keys during 2011, particularly since a large number (18) of back-reef rubble sites were included in the survey effort. Data from these surveys were sent to FWRI (R. Glazer and G. Delgado) to help supplement their queen conch population surveys in the Florida Keys. Like other mollusks, queen conch were counted and measured for total shell length, as well as shell lip thickness. A total of 102 queen conch were recorded from the 280 sites (560 15-m x 2-m transects, 8,400 m^2), with most encountered, not surprisingly, in the back-reef rubble habitat (Table 7-13). A few shallow hard-bottom and deeper fore-reef sites yielded a total of 12 individuals. The maximum site-level density of 0.667 ± 0.333 individuals per m^2 was recorded from the back-reef rubble area within Molasses Reef SPA. Relative high (> 0.5 individuals per m^2) were also encountered in the back reef areas of French Reef SPA and Alligator Reef SPA. The 102 queen conch measured ranged in total shell length from 10.0 to 26.5 cm SL, with an average (± 1 SE) of 17.6 ± 0.4 cm. For the back-reef rubble habitat, site presence, transect frequency, and mean density were all at least two times greater in no-take zones than in reference sites, although mean size was similar (Table 7-13). Since queen conch have been protected from collection in the State of Florida since 1985, the entire Florida Keys area should theoretically function as one large no-take zone for this species. In other words, there should be no difference in density between FKNMS no-take zones and reference areas, unless there is perhaps a habitat difference between management zones, or poaching, or some other factor.

Figure 7-1. Images of nudibranch mollusks surveyed for habitat distribution, density, and size in in the upper Florida Keys National Marine Sanctuary during May-September 2011.

Chromodoris (*Mexichromis*) *kempfi* Marcus

Hypselodoris bayeri (Marcus and Marcus)

Chromodoris nyalya Marcus and Marcus



Hypselodoris olgae Ortea and Bacallado

Glossodoris sedan (Marcus and Marcus)

Hypselodoris picta (Schultz in Philippi)

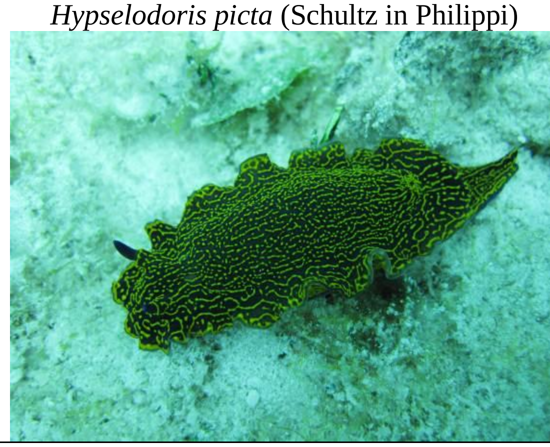


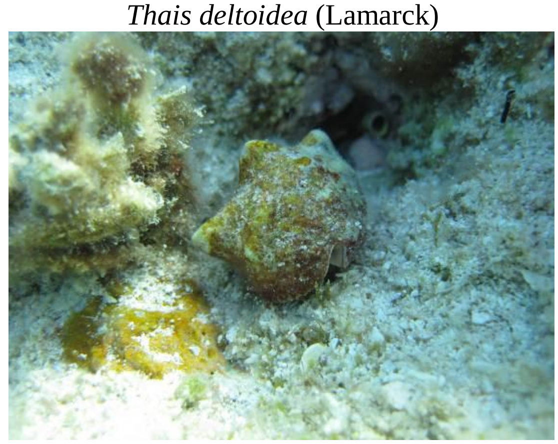
Figure 7-2. Images of an undescribed nudibranch, the sacoglossan lettuce sea slug, and gastropods surveyed for habitat distribution, density, and size in in the upper Florida Keys National Marine Sanctuary during May-September 2011.

Flabellina sp.

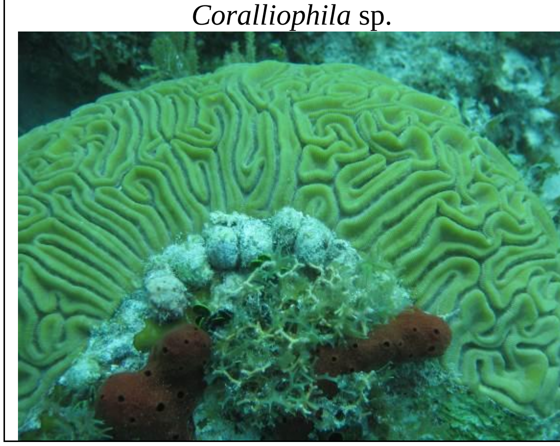
Leucozonia nassa (Gmelin)

Elysia crispata (Mörch)

Thais deltoidea (Lamarck)

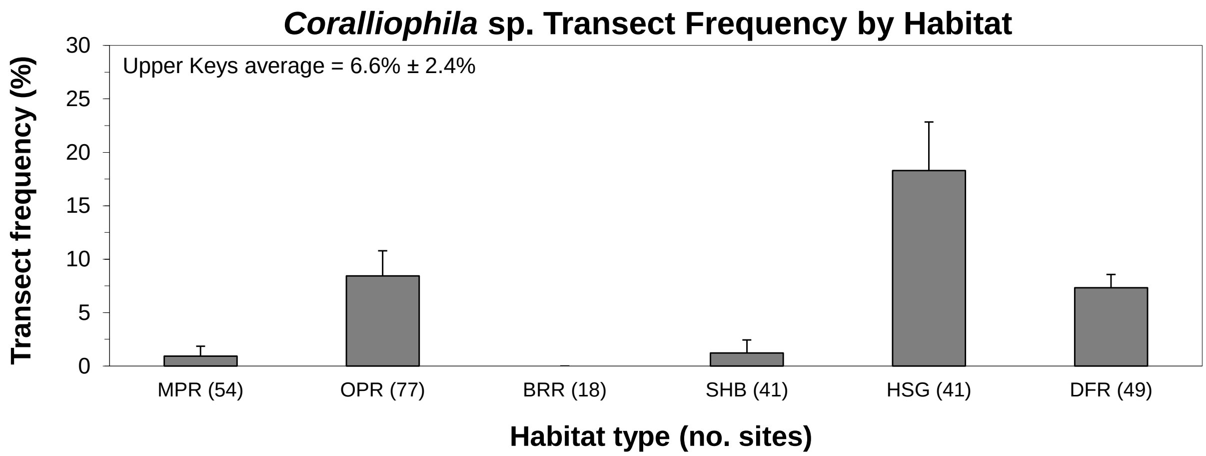


Coralliophila sp.



Strombus gigas Linnaeus

Figure 7-3. Mean (+ 1 SE) transect frequency (top) and density (no. individuals per m^2) (bottom) of the corallivorous snail *Coralliophila* sp. by habitat type in the upper Florida Keys during May-September 2011. Domain-wide (upper Keys) values are weighted averages and standard errors. Values on the x-axis in parentheses are the number of sites surveyed in each habitat type, with two 15-m x 1-m transects surveyed per site.



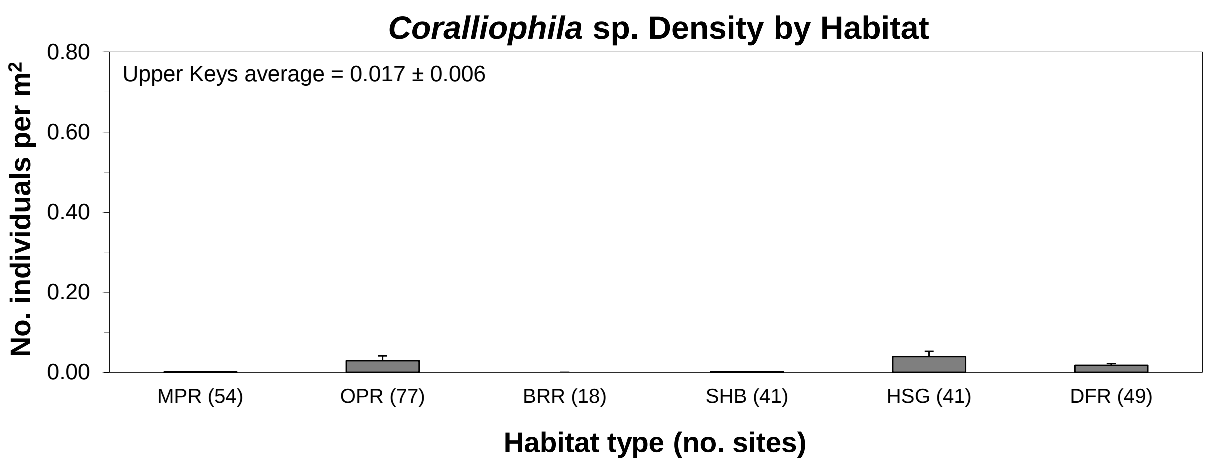
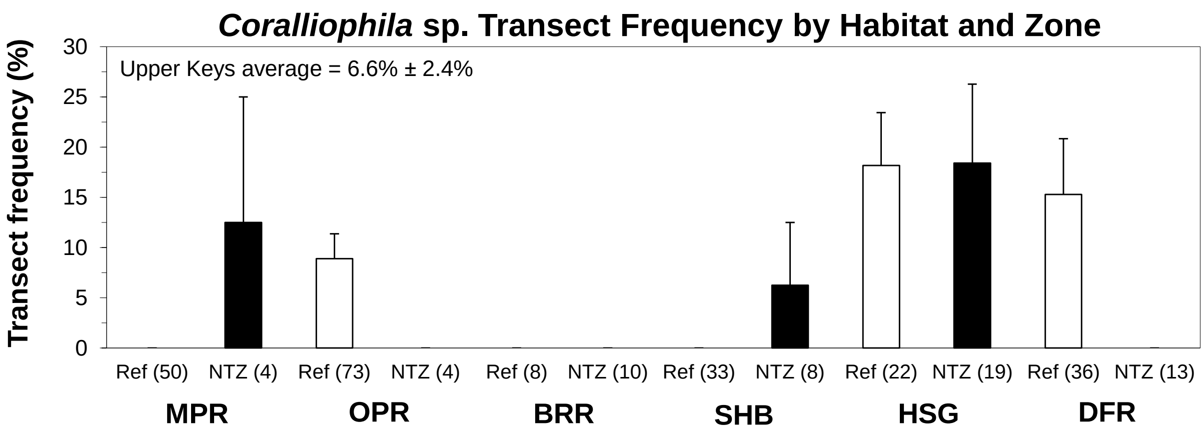


Figure 7-4. Mean (+ 1 SE) transect frequency (top) and density (no. individuals per m^2) (bottom) of the corallivorous snail *Coralliophila* sp. by habitat type and management zone in the upper Florida Keys during May-September 2011. Open bars = reference areas (Ref), filled bars = no-take zones (NTZ). Domain-wide (upper Keys) values are weighted averages and standard errors. Habitat abbreviations are: MPR = inshore and mid-channel patch reefs, OPR = offshore patch reefs, BRR = back-reef rubble, SHB = shallow (< 6 m) hard-bottom, HSG = high-relief and groove, and DFR = deeper (6-15 m) fore-reef habitats. Numbers in parentheses on the x-axis are the number of sites surveyed, with two replicate 15-m x 1-m transects surveyed per site (30 m^2 per site).



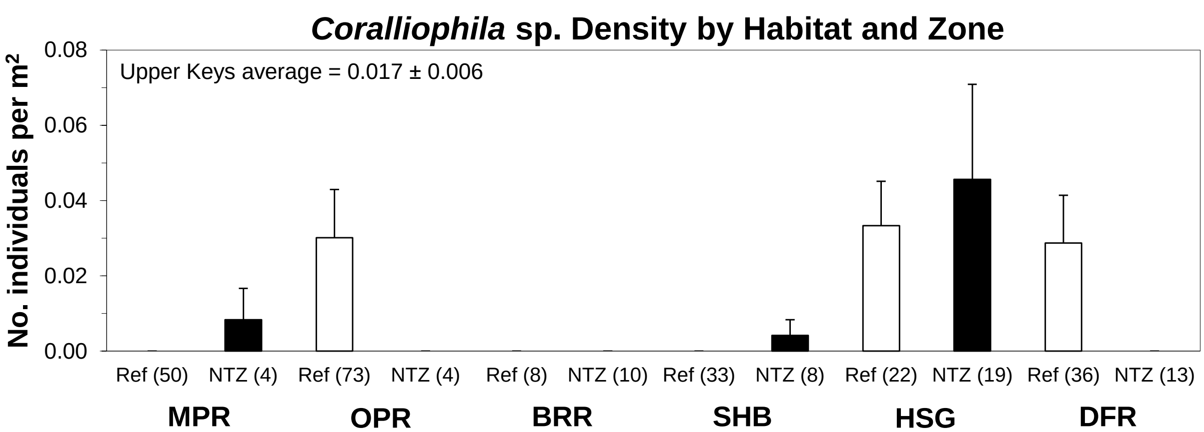
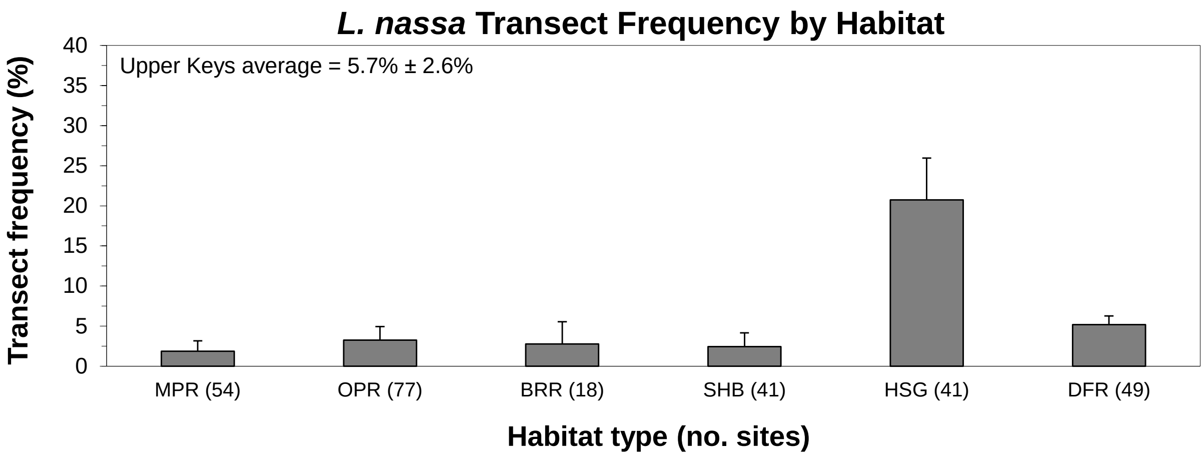


Figure 7-5. Mean (+ 1 SE) transect frequency (top) and density (no. individuals per m^2) (bottom) of the lesser tulip shell *Leucozonia nassa* by habitat type in the upper Florida Keys during May-September 2011. Domain-wide (upper Keys) values are weighted averages and standard errors. Values on the x-axis in parentheses are the number of sites surveyed in each habitat type, with two 15-m x 1-m transects surveyed per site.



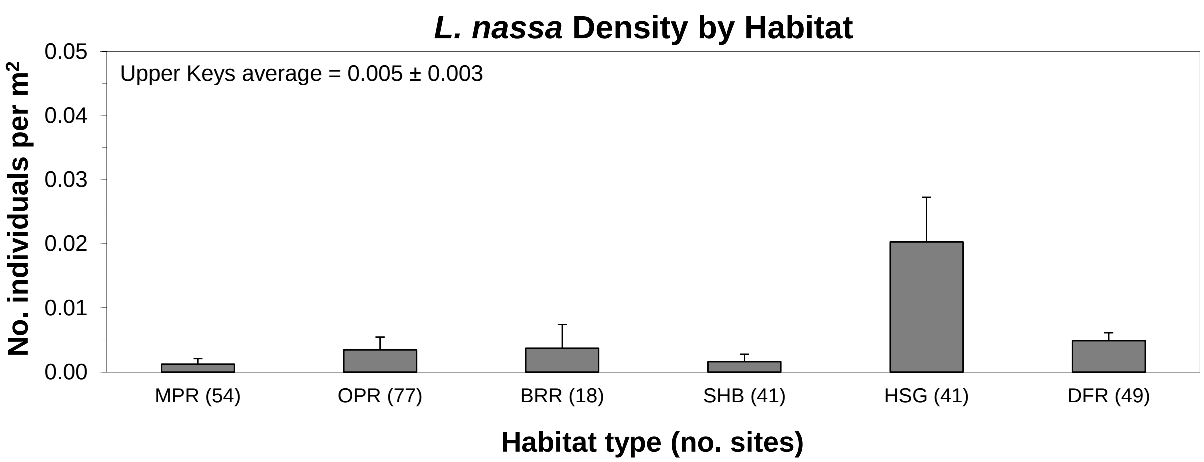
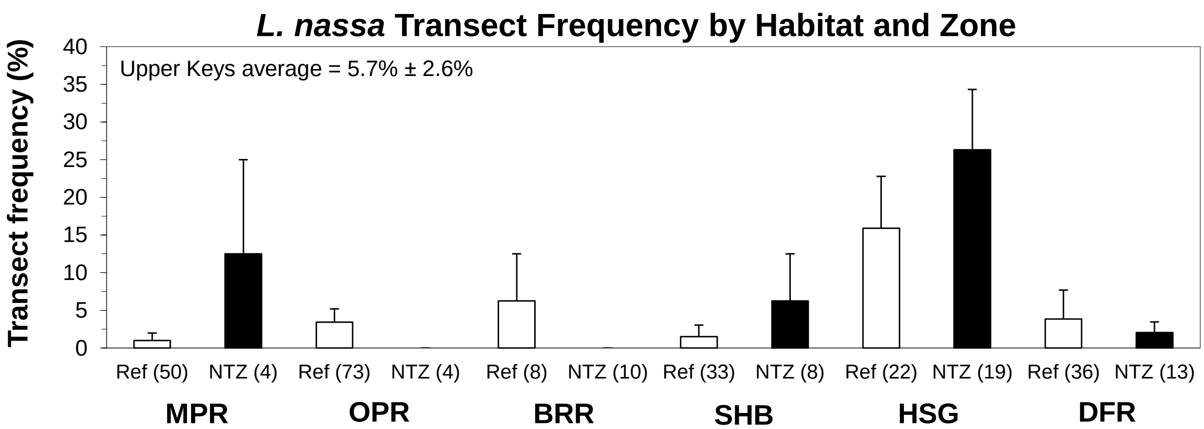


Figure 7-6. Mean (+ 1 SE) transect frequency (top) and density (no. individuals per m^2) (bottom) of the lesser tulip shell *Leucozonia nassa* by habitat type and management zone in the upper Florida Keys during May-September 2011. Open bars = reference areas (Ref), filled bars = no-take zones (NTZ). Domain-wide (upper Keys) values are weighted averages and standard errors. Habitat abbreviations are: MPR = inshore and mid-channel patch reefs, OPR = offshore patch reefs, BRR = back-reef rubble, SHB = shallow (< 6 m) hard-bottom, HSG = high-relief and groove, and DFR = deeper (6-15 m) fore-reef habitats. Numbers in parentheses on the x-axis are the number of sites surveyed, with two replicate 15-m x 1-m transects surveyed per site (30 m^2 per site).



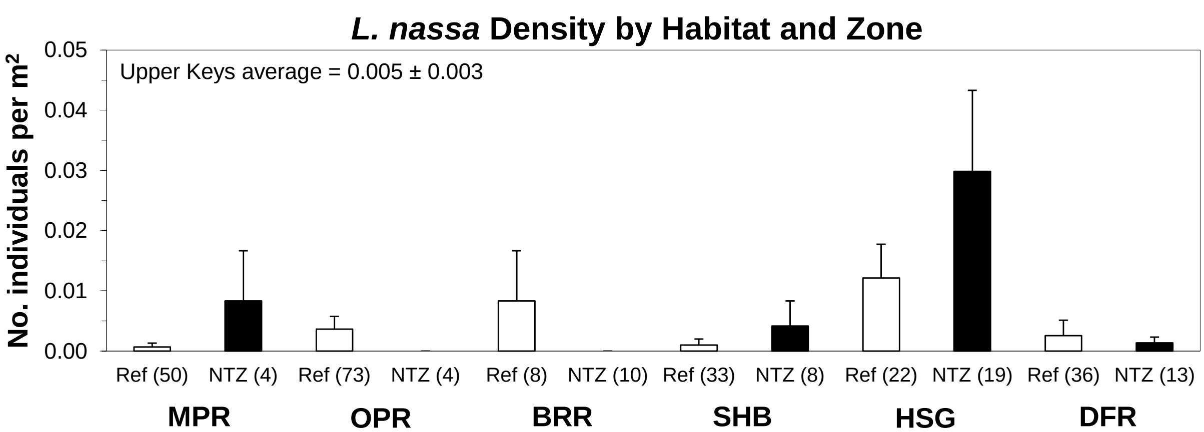


Figure 7-7. Densities (no. per m^2) of deltoid rock snails (*Thais deltoidea*) in the upper Florida Keys National Marine Sanctuary from the southern boundary of Biscayne National Park to Carysfort/S. Carysfort Reef surveyed during May-September 2011.

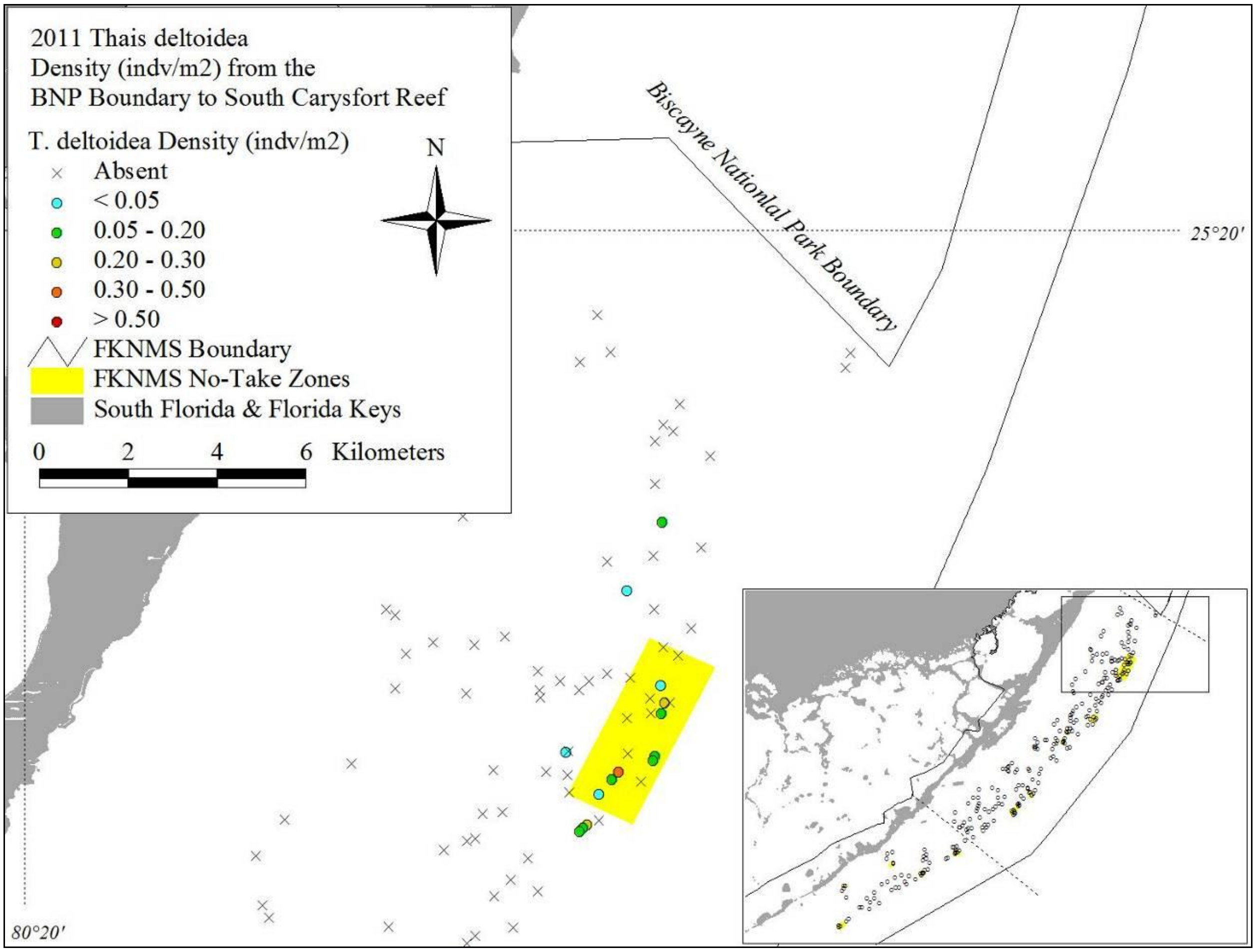


Figure 7-8. Densities (no. per m^2) of deltoid rock snails (*Thais deltoidea*) in the upper Florida Keys National Marine Sanctuary from Elbow Reef to Pickles Reef surveyed during May-September 2011.

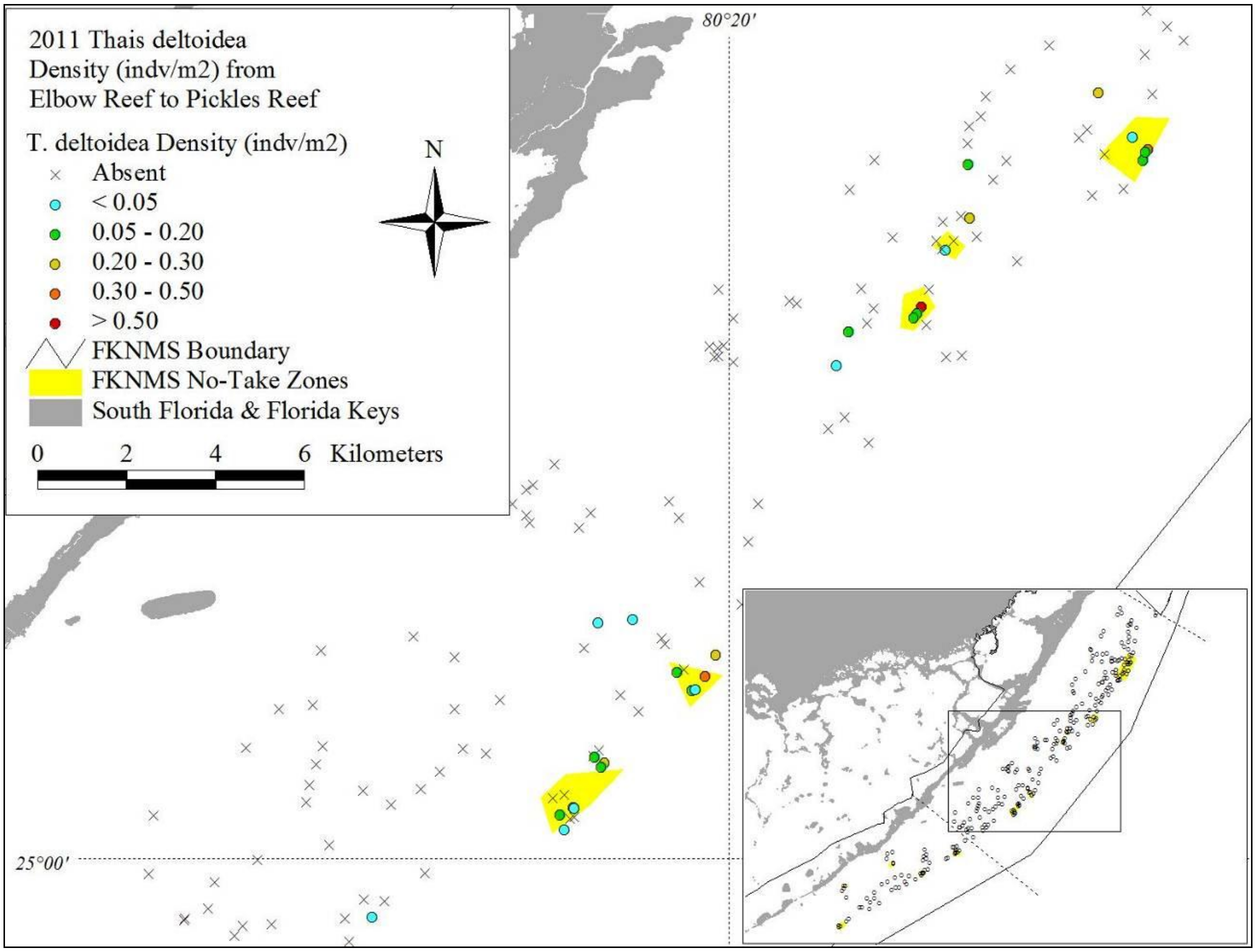


Figure 7-9. Densities (no. per m^2) of deltoid rock snails (*Thais deltoidea*) in the upper Florida Keys National Marine Sanctuary from Conch Reef SPA to Alligator Reef surveyed during May-September 2011.

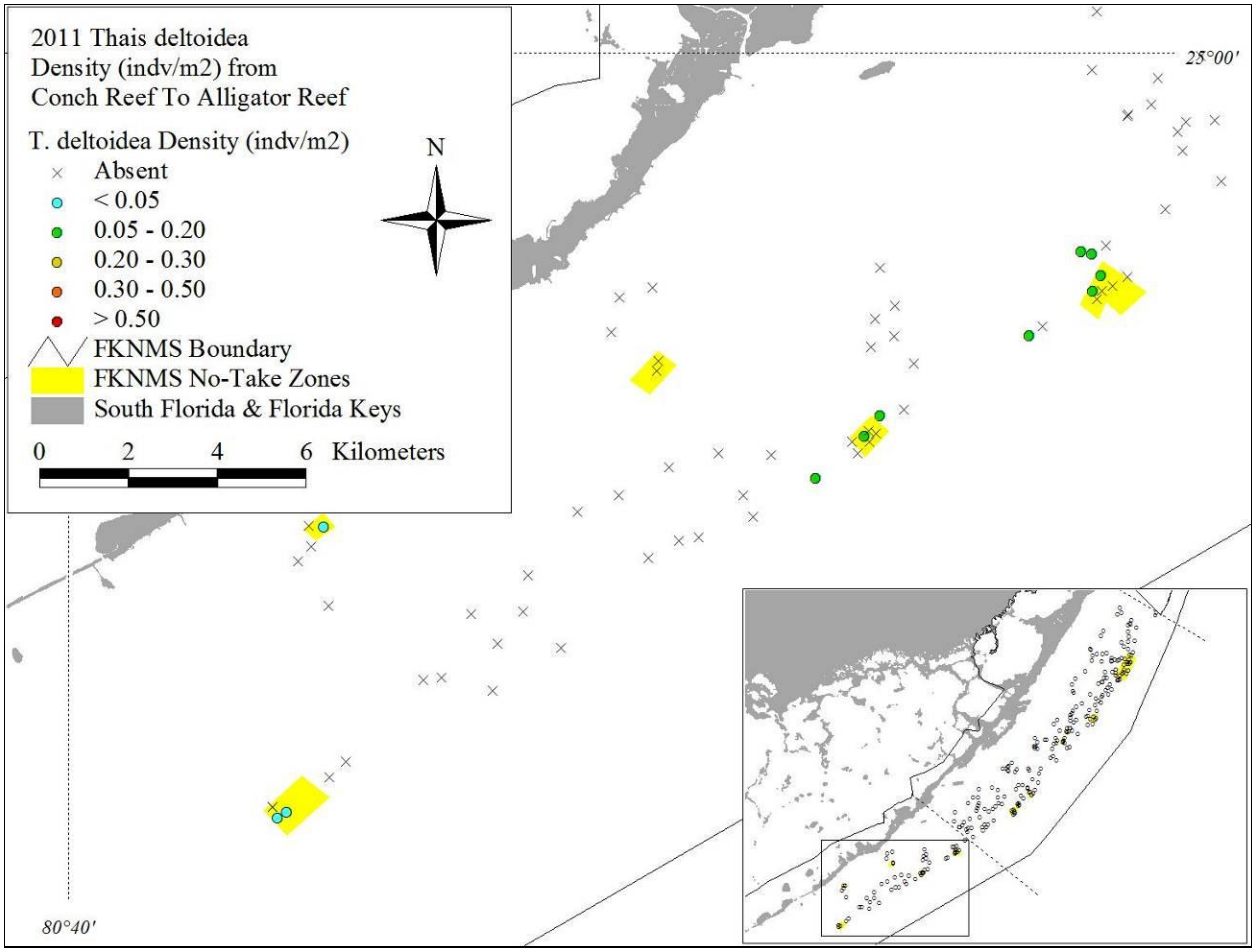
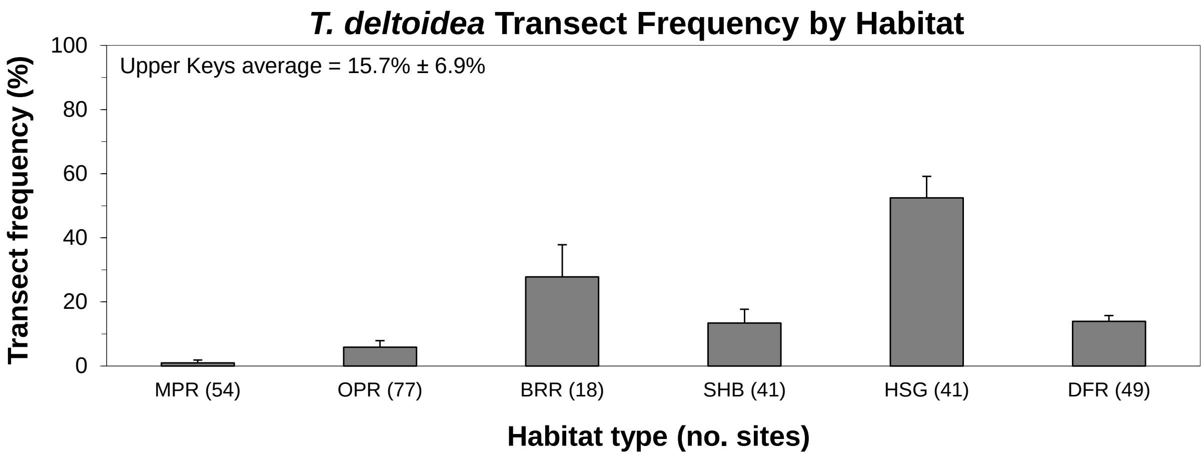


Figure 7-10. Mean (+ 1 SE) transect frequency (top) and density (no. individuals per m^2) (bottom) of the deltoid rock snail *Thais deltoidea* by habitat type in the upper Florida Keys during May-September 2011. Domain-wide (upper Keys) values are weighted averages and standard errors. Values on the x-axis in parentheses are the number of sites surveyed in each habitat type, with two 15-m x 1-m transects surveyed per site.



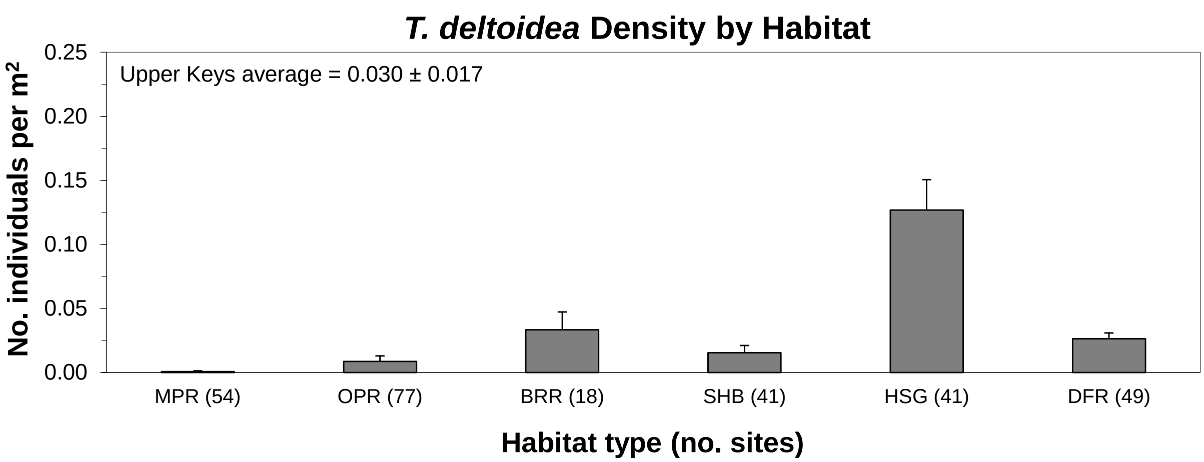
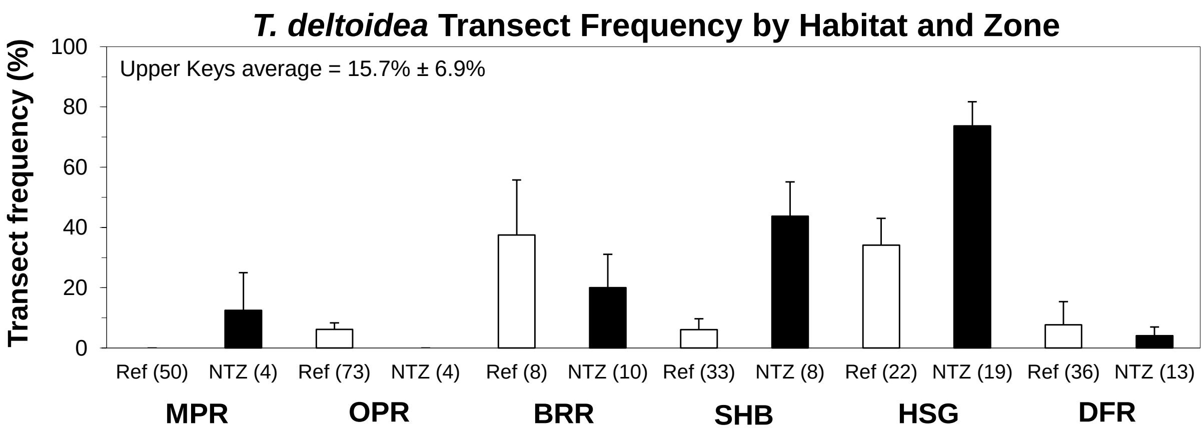


Figure 7-11. Mean (+ 1 SE) transect frequency (top) and density (no. individuals per m^2) (bottom) of the deltoid rock snail *Thais deltoidea* by habitat type and management zone in the upper Florida Keys during May-September 2011. Open bars = reference areas (Ref), filled bars = no-take zones (NTZ). Domain-wide (upper Keys) values are weighted averages and standard errors. Habitat abbreviations are: MPR = inshore and mid-channel patch reefs, OPR = offshore patch reefs, BRR = back-reef rubble, SHB = shallow (< 6 m) hard-bottom, HSG = high-relief and groove, and DFR = deeper (6-15 m) fore-reef habitats. Numbers in parentheses on the x-axis are the number of sites surveyed, with two replicate 15-m x 1-m transects surveyed per site (30 m^2 per site).



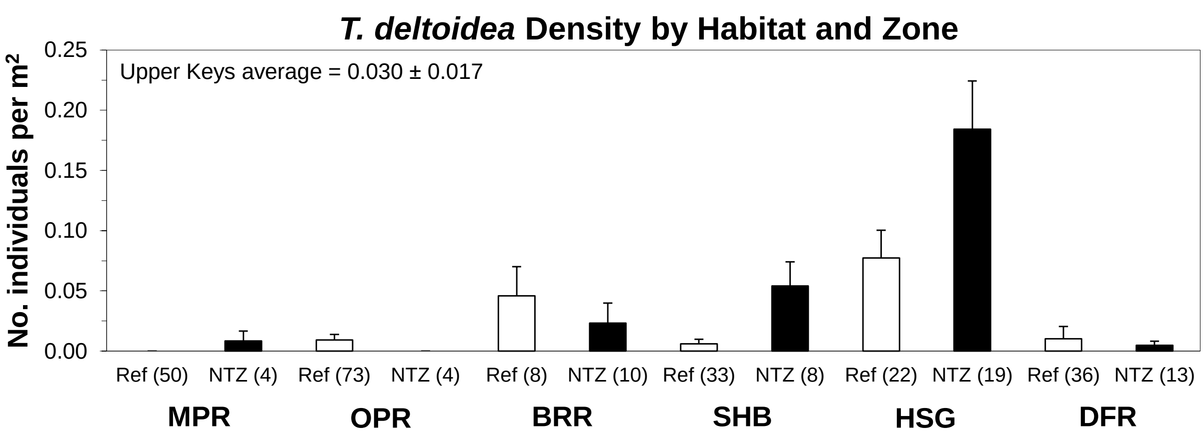


Table 7-1. Summary of habitat distribution, density, and length of the nudibranch *Chromodoris kempfi* among habitat types and management zones in the upper Florida Keys, as determined from two replicate 15-m x 1-m belt transect surveys per site at 280 sites from northern Key Largo to Alligator Reef during May-September 2011. Habitat types are arranged from inshore to offshore and no-take zones represent Sanctuary Preservation Areas and Research Only areas. Values represent mean ± 1 SE. N = number of individuals counted and measured for length.

Habitat/management zone (no. sites)	**Site presence (%)**	**Transect frequency (%)**	**Density (no. per m^2)**	**Mean size (cm)**	**N**
Inshore and mid-channel patch reefs					
Reference areas (50)	0 ± 0	0 ± 0	0 ± 0		0
No-take zones (4)	0 ± 0	0 ± 0	0 ± 0		0
Habitat total (54)	0 ± 0	0 ± 0	0 ± 0		0
Offshore patch reefs					
Reference areas (73)	0 ± 0	0 ± 0	0 ± 0		0
No-take zones (4)	0 ± 0	0 ± 0	0 ± 0		0
Habitat total (77)	0 ± 0	0 ± 0	0 ± 0		0
Back-reef rubble					
Reference areas (8)	0 ± 0	0 ± 0	0 ± 0		0
No-take zones (10)	0 ± 0	0 ± 0	0 ± 0		0
Habitat total (18)	0 ± 0	0 ± 0	0 ± 0		0
Shallow (< 6 m) hard-bottom					
Reference areas (33)	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0
No-take zones (8)	12.5 ± 12.5	6.3 ± 6.3	0.008 ± 0.008	1.7 ± 0.1	2
Habitat total (41)	2.4 ± 2.4	1.2 ± 1.2	0.002 ± 0.002	1.7 ± 0.1	2
High-relief spur and groove					
Reference areas (22)	0 ± 0	0 ± 0	0 ± 0		0
No-take zones (19)	0 ± 0	0 ± 0	0 ± 0		0
Habitat total (41)	0 ± 0	0 ± 0	0 ± 0		0
Deeper fore reef					
Reference areas (36)	0 ± 0	0 ± 0	0 ± 0		0
No-take zones (13)	0 ± 0	0 ± 0	0 ± 0		0
Habitat total (49)	0 ± 0	0 ± 0	0 ± 0		0

Table 7-2. Summary of habitat distribution, density, and shell length of the nudibranch *Chromodoris nyalya* among habitat types and management zones in the upper Florida Keys, as determined from two replicate 15-m x 1-m belt transect surveys per site at 280 sites from northern Key Largo to Alligator Reef during May-September 2011. Habitat types are arranged from inshore to offshore and no-take zones represent Sanctuary Preservation Areas and Research Only areas. Values represent mean ± 1 SE. N = number of individuals counted and measured for length.

Habitat/management zone (no. sites)	**Site presence (%)**	**Transect frequency (%)**	**Density (no. per m^2)**	**Mean size (cm)**	**N**
Inshore and mid-channel patch reefs					
Reference areas (50)	0 ± 0	0 ± 0	0 ± 0		0
No-take zones (4)	0 ± 0	0 ± 0	0 ± 0		0
Habitat total (54)	0 ± 0	0 ± 0	0 ± 0		0
Offshore patch reefs					
Reference areas (73)	1.4 ± 1.4	0.7 ± 0.7	0.0005 ± 0.005	1.3	1
No-take zones (4)	0 ± 0	0 ± 0	0 ± 0		0
Habitat total (77)	1.3 ± 1.3	0.6 ± 0.6	0.004 ± 0.004	1.3	1
Back-reef rubble					
Reference areas (8)	0 ± 0	0 ± 0	0 ± 0		0
No-take zones (10)	0 ± 0	0 ± 0	0 ± 0		0
Habitat total (18)	0 ± 0	0 ± 0	0 ± 0		0
Shallow (< 6 m) hard-bottom					
Reference areas (33)	3.0 ± 3.0	1.5 ± 1.5	0.002 ± 0.002	1.0 ± 0.0	2
No-take zones (8)	0 ± 0	0 ± 0	0 ± 0		0
Habitat total (41)	2.4 ± 2.4	1.2 ± 1.2	0.002 ± 0.002	1.0 ± 0.0	2
High-relief spur and groove					
Reference areas (22)	0 ± 0	0 ± 0	0 ± 0		0
No-take zones (19)	0 ± 0	0 ± 0	0 ± 0		0
Habitat total (41)	0 ± 0	0 ± 0	0 ± 0		0
Deeper fore reef					
Reference areas (36)	5.6 ± 3.9	2.8 ± 1.9	0.002 ± 0.001	1.3 ± 0.1	2
No-take zones (13)	0 ± 0	0 ± 0	0 ± 0		0
Habitat total (49)	4.1 ± 2.9	2.0 ± 1.4	0.001 ± 0.001	1.3 ± 0.1	2

Table 7-3. Summary of habitat distribution, density, and shell length of the nudibranch *Flabellina* sp. among habitat types and management zones in the upper Florida Keys, as determined from two replicate 15-m x 1-m belt transect surveys per site at 280 sites from northern Key Largo to Alligator Reef during May-September 2011. Habitat types are arranged from inshore to offshore and no-take zones represent Sanctuary Preservation Areas and Research Only areas. Values represent mean ± 1 SE. N = number of individuals counted and measured for length.

Habitat/management zone (no. sites)	**Site presence (%)**	**Transect frequency (%)**	**Density (no. per m^2)**	**Mean size (cm)**	**N**
Inshore and mid-channel patch reefs					
Reference areas (50)	0 ± 0	0 ± 0	0 ± 0		0
No-take zones (4)	0 ± 0	0 ± 0	0 ± 0		0
Habitat total (54)	0 ± 0	0 ± 0	0 ± 0		0
Offshore patch reefs					
Reference areas (73)	0 ± 0	0 ± 0	0 ± 0		0
No-take zones (4)	0 ± 0	0 ± 0	0 ± 0		0
Habitat total (77)	0 ± 0	0 ± 0	0 ± 0		0
Back-reef rubble					
Reference areas (8)	0 ± 0	0 ± 0	0 ± 0		0
No-take zones (10)	10.0 ± 10.0	5.0 ± 5.0	0.003 ± 0.003	1.2	1
Habitat total (18)	5.6 ± 5.6	2.8 ± 2.8	0.002 ± 0.002	1.2	1
Shallow (< 6 m) hard-bottom					
Reference areas (33)	0 ± 0	0 ± 0	0 ± 0		0
No-take zones (8)	0 ± 0	0 ± 0	0 ± 0		0
Habitat total (41)	0 ± 0	0 ± 0	0 ± 0		0
High-relief spur and groove					
Reference areas (22)	0 ± 0	0 ± 0	0 ± 0		0
No-take zones (19)	0 ± 0	0 ± 0	0 ± 0		0
Habitat total (41)	0 ± 0	0 ± 0	0 ± 0		0
Deeper fore reef					
Reference areas (36)	0 ± 0	0 ± 0	0 ± 0		0
No-take zones (13)	0 ± 0	0 ± 0	0 ± 0		0
Habitat total (49)	0 ± 0	0 ± 0	0 ± 0		0

Table 7-4. Summary of habitat distribution, density, and shell length of the nudibranch *Glossodoris sedna* among habitat types and management zones in the upper Florida Keys, as determined from two replicate 15-m x 1-m belt transect surveys per site at 280 sites from northern Key Largo to Alligator Reef during May-September 2011. Habitat types are arranged from inshore to offshore and no-take zones represent Sanctuary Preservation Areas and Research Only areas. Values represent mean ± 1 SE. N = number of individuals counted and measured for length.

Habitat/management zone (no. sites)	**Site presence (%)**	**Transect frequency (%)**	**Density (no. per m^2)**	**Mean size (cm)**	**N**
Inshore and mid-channel patch reefs					
Reference areas (50)	2.0 ± 2.0	1.0 ± 1.0	0.001 ± 0.001	2.5 ± 0.1	2
No-take zones (4)	0 ± 0	0 ± 0	0 ± 0		0
Habitat total (54)	1.9 ± 1.9	0.9 ± 0.9	0.001 ± 0.001	2.5 ± 0.1	2
Offshore patch reefs					
Reference areas (73)	0 ± 0	0 ± 0	0 ± 0		0
No-take zones (4)	0 ± 0	0 ± 0	0 ± 0		0
Habitat total (77)	0 ± 0	0 ± 0	0 ± 0		0
Back-reef rubble					
Reference areas (8)	0 ± 0	0 ± 0	0 ± 0		0
No-take zones (10)	0 ± 0	0 ± 0	0 ± 0		0
Habitat total (18)	0 ± 0	0 ± 0	0 ± 0		0
Shallow (< 6 m) hard-bottom					
Reference areas (33)	0 ± 0	0 ± 0	0 ± 0		0
No-take zones (8)	0 ± 0	0 ± 0	0 ± 0		0
Habitat total (41)	0 ± 0	0 ± 0	0 ± 0		0
High-relief spur and groove					
Reference areas (22)	0 ± 0	0 ± 0	0 ± 0		0
No-take zones (19)	0 ± 0	0 ± 0	0 ± 0		0
Habitat total (41)	0 ± 0	0 ± 0	0 ± 0		0
Deeper fore reef					
Reference areas (36)	0 ± 0	0 ± 0	0 ± 0		0
No-take zones (13)	0 ± 0	0 ± 0	0 ± 0		0
Habitat total (49)	0 ± 0	0 ± 0	0 ± 0		0

Table 7-5. Summary of habitat distribution, density, and shell length of the nudibranch *Hypselodoris bayeri* among habitat types and management zones in the upper Florida Keys, as determined from two replicate 15-m x 1-m belt transect surveys per site at 280 sites from northern Key Largo to Alligator Reef during May-September 2011. Habitat types are arranged from inshore to offshore and no-take zones represent Sanctuary Preservation Areas and Research Only areas. Values represent mean ± 1 SE. N = number of individuals counted and measured for length.

Habitat/management zone (no. sites)	**Site presence (%)**	**Transect frequency (%)**	**Density (no. per m^2)**	**Mean size (cm)**	**N**
Inshore and mid-channel patch reefs					
Reference areas (50)	0 ± 0	0 ± 0	0 ± 0		0
No-take zones (4)	0 ± 0	0 ± 0	0 ± 0		0
Habitat total (54)	0 ± 0	0 ± 0	0 ± 0		0
Offshore patch reefs					
Reference areas (73)	0 ± 0	0 ± 0	0 ± 0		0
No-take zones (4)	0 ± 0	0 ± 0	0 ± 0		0
Habitat total (77)	0 ± 0	0 ± 0	0 ± 0		0
Back-reef rubble					
Reference areas (8)	0 ± 0	0 ± 0	0 ± 0		0
No-take zones (10)	0 ± 0	0 ± 0	0 ± 0		0
Habitat total (18)	0 ± 0	0 ± 0	0 ± 0		0
Shallow (< 6 m) hard-bottom					
Reference areas (33)	0 ± 0	0 ± 0	0 ± 0		0
No-take zones (8)	0 ± 0	0 ± 0	0 ± 0		0
Habitat total (41)	0 ± 0	0 ± 0	0 ± 0		0
High-relief spur and groove					
Reference areas (22)	0 ± 0	0 ± 0	0 ± 0		0
No-take zones (19)	0 ± 0	0 ± 0	0 ± 0		0
Habitat total (41)	0 ± 0	0 ± 0	0 ± 0		0
Deeper fore reef					
Reference areas (36)	2.8 ± 2.8	1.4 ± 1.4	0.001 ± 0.001	1.3	1
No-take zones (13)	0 ± 0	0 ± 0	0 ± 0		0
Habitat total (49)	2.0 ± 2.0	1.0 ± 1.0	0.001 ± 0.001	1.3	1

Table 7-6. Summary of habitat distribution, density, and shell length of the nudibranch *Hypselodoris olgae* among habitat types and management zones in the upper Florida Keys, as determined from two replicate 15-m x 1-m belt transect surveys per site at 280 sites from northern Key Largo to Alligator Reef during May-September 2011. Habitat types are arranged from inshore to offshore and no-take zones represent Sanctuary Preservation Areas and Research Only areas. Values represent mean ± 1 SE. N = number of individuals counted and measured for length.

Habitat/management zone (no. sites)	**Site presence (%)**	**Transect frequency (%)**	**Density (no. per m^2)**	**Mean size (cm)**	**N**
Inshore and mid-channel patch reefs					
Reference areas (50)	0 ± 0	0 ± 0	0 ± 0		0
No-take zones (4)	0 ± 0	0 ± 0	0 ± 0		0
Habitat total (54)	0 ± 0	0 ± 0	0 ± 0		0
Offshore patch reefs					
Reference areas (73)	1.4 ± 1.4	0.7 ± 0.7	0.001 ± 0.001	2.3 ± 0.0	2
No-take zones (4)	25.0 ± 25.0	12.5 ± 12.5	0.008 ± 0.008	2.7	1
Habitat total (77)	2.6 ± 1.8	1.3 ± 0.9	0.001 ± 0.001	2.5 ± 0.2	3
Back-reef rubble					
Reference areas (8)	0 ± 0	0 ± 0	0 ± 0		0
No-take zones (10)	0 ± 0	0 ± 0	0 ± 0		0
Habitat total (18)	0 ± 0	0 ± 0	0 ± 0		0
Shallow (< 6 m) hard-bottom					
Reference areas (33)	0 ± 0	0 ± 0	0 ± 0		0
No-take zones (8)	0 ± 0	0 ± 0	0 ± 0		0
Habitat total (41)	0 ± 0	0 ± 0	0 ± 0		0
High-relief spur and groove					
Reference areas (22)	0 ± 0	0 ± 0	0 ± 0		0
No-take zones (19)	0 ± 0	0 ± 0	0 ± 0		0
Habitat total (41)	0 ± 0	0 ± 0	0 ± 0		0
Deeper fore reef					
Reference areas (36)	0 ± 0	0 ± 0	0 ± 0		0
No-take zones (13)	0 ± 0	0 ± 0	0 ± 0		0
Habitat total (49)	0 ± 0	0 ± 0	0 ± 0		0

Table 7-7. Summary of habitat distribution, density, and shell length of the nudibranch *Hypselodoris picta* among habitat types and management zones in the upper Florida Keys, as determined from two replicate 15-m x 1-m belt transect surveys per site at 280 sites from northern Key Largo to Alligator Reef during May-September 2011. Habitat types are arranged from inshore to offshore and no-take zones represent Sanctuary Preservation Areas and Research Only areas. Values represent mean ± 1 SE. N = number of individuals counted and measured for length.

Habitat/management zone (no. sites)	**Site presence (%)**	**Transect frequency (%)**	**Density (no. per m^2)**	**Mean size (cm)**	**N**
Inshore and mid-channel patch reefs					
Reference areas (50)	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0
No-take zones (4)	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0
Habitat total (54)	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0
Offshore patch reefs					
Reference areas (73)	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0
No-take zones (4)	25.0 ± 25.0	12.5 ± 12.5	0.008 ± 0.008	6.2	1
Habitat total (77)	1.3 ± 1.3	0.6 ± 0.6	0.0004 ± 0.004	6.2	1
Back-reef rubble					
Reference areas (8)	0 ± 0	0 ± 0	0 ± 0		0
No-take zones (10)	0 ± 0	0 ± 0	0 ± 0		0
Habitat total (18)	0 ± 0	0 ± 0	0 ± 0		0
Shallow (< 6 m) hard-bottom					
Reference areas (33)	0 ± 0	0 ± 0	0 ± 0		0
No-take zones (8)	0 ± 0	0 ± 0	0 ± 0		0
Habitat total (41)	0 ± 0	0 ± 0	0 ± 0		0
High-relief spur and groove					
Reference areas (22)	0 ± 0	0 ± 0	0 ± 0		0
No-take zones (19)	0 ± 0	0 ± 0	0 ± 0		0
Habitat total (41)	0 ± 0	0 ± 0	0 ± 0		0
Deeper fore reef					
Reference areas (36)	0 ± 0	0 ± 0	0 ± 0		0
No-take zones (13)	0 ± 0	0 ± 0	0 ± 0		0
Habitat total (49)	0 ± 0	0 ± 0	0 ± 0		0

Table 7-8. Summary of habitat distribution, density, and shell length of the sacoglossan lettuce sea slug *Elysia* (*Tridachia*) *crispata* among habitat types and management zones in the upper Florida Keys, as determined from two replicate 15-m x 1-m belt transect surveys per site at 280 sites from northern Key Largo to Alligator Reef during May-September 2011. Habitat types are arranged from inshore to offshore and no-take zones represent Sanctuary Preservation Areas and Research Only areas. Values represent mean ± 1 SE. N = number of individuals counted and measured for length.

Habitat/management zone (no. sites)	**Site presence (%)**	**Transect frequency (%)**	**Density (no. per m^2)**	**Mean size (cm)**	**N**
Inshore and mid-channel patch reefs					
Reference areas (50)	2.0 ± 2.0	1.0 ± 1.0	0.001 ± 0.001	3.2	1
No-take zones (4)	0 ± 0	0 ± 0	0 ± 0		0
Habitat total (54)	1.9 ± 1.9	0.9 ± 0.9	0.001 ± 0.001	3.2	1
Offshore patch reefs					
Reference areas (73)	0 ± 0	0 ± 0	0 ± 0		0
No-take zones (4)	0 ± 0	0 ± 0	0 ± 0		0
Habitat total (77)	0 ± 0	0 ± 0	0 ± 0		0
Back-reef rubble					
Reference areas (8)	0 ± 0	0 ± 0	0 ± 0		0
No-take zones (10)	0 ± 0	0 ± 0	0 ± 0		0
Habitat total (18)	0 ± 0	0 ± 0	0 ± 0		0
Shallow (< 6 m) hard-bottom					
Reference areas (33)	0 ± 0	0 ± 0	0 ± 0		0
No-take zones (8)	0 ± 0	0 ± 0	0 ± 0		0
Habitat total (41)	0 ± 0	0 ± 0	0 ± 0		0
High-relief spur and groove					
Reference areas (22)	13.6 ± 7.5	6.8 ± 3.7	0.023 ± 0.018	3.1 ± 0.2	15
No-take zones (19)	68.4 ± 11.0	50.0 ± 9.4	0.093 ± 0.034	3.1 ± 0.1	53
Habitat total (41)	39.0 ± 7.7	26.8 ± 5.8	0.055 ± 0.019	3.1 ± 0.1	68
Deeper fore reef					
Reference areas (36)	0 ± 0	0 ± 0	0 ± 0		0
No-take zones (13)	0 ± 0	0 ± 0	0 ± 0		0
Habitat total (49)	0 ± 0	0 ± 0	0 ± 0		0

Table 7-9. Substratum occupancy patterns for lettuce sea slugs and gastropod mollusks surveyed at 280 sites in the upper Florida Keys National Marine Sanctuary during May-September 2011. Data represent the number of individuals (N) and the proportion (%) of individuals found on particular substrata.

Substratum type	*Elysia crispata*		*Coralliophila* sp.		*Leucozonia nassa*		*Thais deltoidea*	
	N	%	N	%	N	%	N	%
Scleractinian corals								
Agaricia agaricites	0	0.0	29	19.7	0	0.0	0	0.0
Acropora cervicornis	0	0.0	3	2.0	0	0.0	0	0.0
A. palmata	0	0.0	1	0.7	0	0.0	0	0.0
Colpophyllia natans	0	0.0	6	4.1	0	0.0	0	0.0
Dichocoenia stokesi	0	0.0	12	8.2	0	0.0	0	0.0
Diploria clivosa	0	0.0	10	6.8	0	0.0	0	0.0
D. labyrinthiformis	0	0.0	14	9.5	0	0.0	0	0.0
D. labyrinthiformis	0	0.0	14	9.5	0	0.0	0	0.0
Montastraea annularis	0	0.0	26	17.7	0	0.0	0	0.0
M. faveolata	0	0.0	13	8.8	0	0.0	0	0.0
M. franksii	0	0.0	2	1.4	0	0.0	0	0.0
M. cavernosa	0	0.0	13	8.8	0	0.0	0	0.0
Siderastrea siderea	0	0.0	3	2.0	0	0.0	0	0.0
Total coral	0	0.0	146	99.3	0	0.0	0	0.0
Algae								
Algal turf	42	77.8	1	0.7	27	65.9	181	81.9
Crustose coralline algae	6	11.1	0	0.0	13	31.7	25	11.3
Dictyota spp.	4	7.4	0	0.0	1	2.4	2	0.9
Green foliose algae	0	0.0	0	0.0	0	0.0	1	0.5
Total algae	52	96.3	1	0.7	41	100.0	209	94.6
Other snail	0	0.0	0	0.0	0	0.0	10	4.5
Sand	2	3.7	0	0.0	0	0.0	2	0.9
Total	54	100.0	147	100.0	41	100.0	221	100.0

Table 7-10. Summary of habitat distribution, density, and total shell length of the corallivorous snail *Coralliophila* sp. among habitat types and management zones in the upper Florida Keys, as determined from two replicate 15-m x 1-m belt transect surveys per site at 280 sites from northern Key Largo to Alligator Reef during May-September 2011. Habitat types are arranged from inshore to offshore and no-take zones represent Sanctuary Preservation Areas and Research Only areas. Values represent mean ± 1 SE. N = number of individuals counted and measured for length.

Habitat/management zone (no. sites)	**Site presence (%)**	**Transect frequency (%)**	**Density (no. per m^2)**	**Mean size (cm)**	**N**
Inshore and mid-channel patch reefs					
Reference areas (50)	0 ± 0	0 ± 0	0 ± 0		0
No-take zones (4)	25.0 ± 25.0	12.5 ± 12.5	0.008 ± 0.008	3.5	1
Habitat total (54)	1.9 ± 1.9	0.9 ± 0.9	0.001 ± 0.001	3.5	1
Offshore patch reefs					
Reference areas (73)	16.4 ± 4.4	8.9 ± 2.5	0.030 ± 0.013	1.8 ± 0.1	66
No-take zones (4)	0 ± 0	0 ± 0	0 ± 0		0
Habitat total (77)	15.6 ± 4.2	8.4 ± 2.3	0.029 ± 0.012	1.8 ± 0.1	66
Back-reef rubble					
Reference areas (8)	0 ± 0	0 ± 0	0 ± 0		0
No-take zones (10)	0 ± 0	0 ± 0	0 ± 0		0
Habitat total (18)	0 ± 0	0 ± 0	0 ± 0		0
Shallow (< 6 m) hard-bottom					
Reference areas (33)	0 ± 0	0 ± 0	0 ± 0		0
No-take zones (8)	12.5 ± 12.5	6.3 ± 6.3	0.004 ± 0.004	2.0	1
Habitat total (41)	2.4 ± 2.4	1.2 ± 1.2	0.001 ± 0.001	2.0	1
High-relief spur and groove					
Reference areas (22)	36.4 ± 10.5	18.2 ± 5.2	0.033 ± 0.012	2.0 ± 0.2	22
No-take zones (19)	26.3 ± 10.4	18.4 ± 7.8	0.046 ± 0.025	2.3 ± 0.4	26
Habitat total (41)	31.7 ± 7.4	18.3 ± 4.5	0.039 ± 0.013	2.1 ± 0.2	48
Deeper fore reef					
Reference areas (36)	19.4 ± 6.7	15.3 ± 5.6	0.029 ± 0.013	1.8 ± 0.1	31
No-take zones (13)	0 ± 0	0 ± 0	0 ± 0		0
Habitat total (49)	14.3 ± 5.1	11.2 ± 4.2	0.021 ± 0.009	1.8 ± 0.1	31

Table 7-11. Summary of habitat distribution, density, and total shell length of the lesser tulip shell *Leucozonia nassa* among habitat types and management zones in the upper Florida Keys, as determined from two replicate 15-m x 1-m belt transect surveys per site at 280 sites from northern Key Largo to Alligator Reef during May-September 2011. Habitat types are arranged from inshore to offshore and no-take zones represent Sanctuary Preservation Areas and Research Only areas. Values represent mean ± 1 SE. N = number of individuals counted and measured for length.

Habitat/management zone (no. sites)	**Site presence (%)**	**Transect frequency (%)**	**Density (no. per m^2)**	**Mean size (cm)**	**N**
Inshore and mid-channel patch reefs					
Reference areas (50)	2.0 ± 2.0	1.0 ± 1.0	0.001 ± 0.001	4.5	1
No-take zones (4)	25.0 ± 25.0	12.5 ± 12.5	0.008 ± 0.008	2.8	1
Habitat total (54)	3.7 ± 2.6	1.9 ± 1.3	0.001 ± 0.001	3.7 ± 0.9	2
Offshore patch reefs					
Reference areas (73)	5.5 ± 2.7	3.4 ± 1.8	0.004 ± 0.002	2.9 ± 0.6	8
No-take zones (4)	0 ± 0	0 ± 0	0 ± 0		0
Habitat total (77)	5.2 ± 2.5	3.2 ± 1.7	0.003 ± 0.002	2.9 ± 0.6	8
Back-reef rubble					
Reference areas (8)	12.5 ± 12.5	6.3 ± 6.3	0.008 ± 0.008	2.2 ± 0.4	2
No-take zones (10)	0 ± 0	0 ± 0	0 ± 0		0
Habitat total (18)	5.6 ± 5.6	2.8 ± 2.8	0.004 ± 0.004	2.2 ± 0.4	2
Shallow (< 6 m) hard-bottom					
Reference areas (33)	3.0 ± 3.0	1.5 ± 1.5	0.001 ± 0.001	2.4	1
No-take zones (8)	12.5 ± 12.5	6.3 ± 6.3	0.004 ± 0.004	2.8	1
Habitat total (41)	4.9 ± 3.4	2.4 ± 1.7	0.002 ± 0.001	2.6 ± 0.2	2
High-relief spur and groove					
Reference areas (22)	22.7 ± 9.1	15.9 ± 6.9	0.012 ± 0.006	3.1 ± 0.5	8
No-take zones (19)	42.1 ± 11.6	26.3 ± 8.0	0.030 ± 0.013	3.5 ± 0.2	17
Habitat total (41)	31.7 ± 7.4	20.7 ± 5.2	0.020 ± 0.007	3.3 ± 0.2	25
Deeper fore reef					
Reference areas (36)	2.8 ± 2.8	1.4 ± 1.4	0.001 ± 0.001	7.1	1
No-take zones (13)	7.7 ± 7.7	3.8 ± 3.8	0.003 ± 0.003	5.0	1
Habitat total (49)	4.1 ± 2.9	2.0 ± 1.4	0.001 ± 0.001	6.1 ± 1.1	2

Table 7-12. Summary of habitat distribution, density, and total shell length of the deltoid rock snail *Thais deltoidea* among habitat types and management zones in the upper Florida Keys, as determined from two replicate 15-m x 1-m belt transect surveys per site at 280 sites from northern Key Largo to Alligator Reef during May-September 2011. Habitat types are arranged from inshore to offshore and no-take zones represent Sanctuary Preservation Areas and Research Only areas. Values represent mean ± 1 SE. N = number of individuals counted and measured for length.

Habitat/management zone (no. sites)	**Site presence (%)**	**Transect frequency (%)**	**Density (no. per m^2)**	**Mean size (cm)**	**N**
Inshore and mid-channel patch reefs					
Reference areas (50)	0 ± 0	0 ± 0	0 ± 0		0
No-take zones (4)	25.0 ± 25.0	12.5 ± 12.5	0.008 ± 0.008	5.2	1
Habitat total (54)	1.9 ± 1.9	0.9 ± 0.9	0.001 ± 0.001	5.2	1
Offshore patch reefs					
Reference areas (73)	11.0 ± 3.7	6.2 ± 2.2	0.009 ± 0.005	2.8 ± 0.1	20
No-take zones (4)	0 ± 0	0 ± 0	0 ± 0		0
Habitat total (77)	10.4 ± 3.5	5.8 ± 2.1	0.009 ± 0.004	2.8 ± 0.1	20
Back-reef rubble					
Reference areas (8)	37.5 ± 18.3	37.5 ± 18.3	0.046 ± 0.024	2.7 ± 0.2	11
No-take zones (10)	30.0 ± 15.3	20.0 ± 11.1	0.023 ± 0.017	3.0 ± 0.5	7
Habitat total (18)	33.3 ± 11.4	27.8 ± 10.1	0.033 ± 0.014	2.8 ± 0.2	18
Shallow (< 6 m) hard-bottom					
Reference areas (33)	9.1 ± 5.1	6.1 ± 3.6	0.006 ± 0.004	3.2 ± 0.1	6
No-take zones (8)	75.0 ± 16.4	43.8 ± 11.3	0.054 ± 0.020	3.1 ± 0.1	13
Habitat total (41)	22.0 ± 6.5	13.4 ± 4.3	0.015 ± 0.006	3.1 ± 0.1	19
High-relief spur and groove					
Reference areas (22)	45.5 ± 10.9	34.1 ± 8.9	0.077 ± 0.023	2.7 ± 0.1	51
No-take zones (19)	89.5 ± 7.2	73.7 ± 8.0	0.184 ± 0.040	2.7 ± 0.1	105
Habitat total (41)	65.9 ± 7.5	52.4 ± 6.8	0.127 ± 0.024	2.7 ± 0.1	156
Deeper fore reef					
Reference areas (36)	2.8 ± 2.8	2.8 ± 2.8	0.003 ± 0.003	3.4 ± 0.6	3
No-take zones (13)	7.7 ± 7.7	7.7 ± 7.7	0.010 ± 0.010	3.4 ± 0.3	4
Habitat total (49)	4.1 ± 2.9	4.1 ± 2.9	0.005 ± 0.003	3.4 ± 0.0	7

Table 7-13. Summary of habitat distribution, density, and total shell length of the queen conch *Strombus gigas* among habitat types and management zones in the upper Florida Keys, as determined from two replicate 15-m x 1-m belt transect surveys per site at 280 sites from northern Key Largo to Alligator Reef during May-September 2011. Habitat types are arranged from inshore to offshore and no-take zones represent Sanctuary Preservation Areas and Research Only areas. Values represent mean ± 1 SE. N = number of individuals counted and measured for test size.

Habitat/management zone (no. sites)	**Site presence (%)**	**Transect frequency (%)**	**Density (no. per m^2)**	**Mean size (cm)**	**N**
Inshore and mid-channel patch reefs					
Reference areas (50)	0 ± 0	0 ± 0	0 ± 0		0
No-take zones (4)	0 ± 0	0 ± 0	0 ± 0		0
Habitat total (54)	0 ± 0	0 ± 0	0 ± 0		0
Offshore patch reefs					
Reference areas (73)	0 ± 0	0 ± 0	0 ± 0		0
No-take zones (4)	0 ± 0	0 ± 0	0 ± 0		0
Habitat total (77)	0 ± 0	0 ± 0	0 ± 0		0
Back-reef rubble					
Reference areas (8)	37.5 ± 18.3	31.3 ± 16.2	0.083 ± 0.048	18.0 ± 1.1	20
No-take zones (10)	70.0 ± 15.3	60.0 ± 14.5	0.233 ± 0.087	17.8 ± 1.0	70
Habitat total (18)	55.6 ± 12.1	47.2 ± 11.0	0.167 ± 0.055	17.9 ± 0.8	90
Shallow (< 6 m) hard-bottom					
Reference areas (33)	18.2 ± 6.8	12.1 ± 4.4	0.008 ± 0.003	16.9 ± 0.9	8
No-take zones (8)	0 ± 0	0 ± 0	0 ± 0		0
Habitat total (41)	14.6 ± 5.6	9.8 ± 3.6	0.007 ± 0.002	16.9 ± 0.9	8
High-relief spur and groove					
Reference areas (22)	0 ± 0	0 ± 0	0 ± 0		0
No-take zones (19)	0 ± 0	0 ± 0	0 ± 0		0
Habitat total (41)	0 ± 0	0 ± 0	0 ± 0		0
Deeper fore reef					
Reference areas (36)	11.1 ± 5.3	5.6 ± 2.7	0.004 ± 0.002	20.0 ± 1.5	4
No-take zones (13)	0 ± 0	0 ± 0	0 ± 0		0
Habitat total (49)	8.2 ± 4.0	4.1 ± 2.0	0.003 ± 0.001	20.0 ± 1.5	4

VIII. Marine Debris

Background

Fishing constitutes one of the most significant threats to marine biodiversity and ecosystem function, as evidenced by a significant body of information on the numerous impacts to populations, community structure, and habitats (Dayton et al. 1995; Roberts 1995; Jennings and Polunin 1996). In addition to the more obvious effects on the population structure of targeted species, fishing activities may also reduce the structural complexity of habitats or cause corresponding changes in ecological processes such as competition and predation (Russ 1991; Jones and Syms 1998; Auster and Langton 1999). These patterns are most obvious in areas where explosives, poisons, or other destructive fishing methods are used (Hatcher et al. 1989). However, ecological effects may occur in areas where traps, mobile fishing gear such as trawls, and potentially, even large numbers of recreational fishers operate where substantial losses of gear may occur (Russ 1991; Jennings and Lock 1996).

The Florida Keys have a long history of commercial and recreational fisheries that target a great diversity of fish and invertebrate species using a multitude of gears (Tilmant 1989; Bohnsack et al. 1994). In terms of volume of seafood landed, the Florida Keys is the most important area in the State of Florida in landings, dockside value, and numbers of commercial fishing vessels, especially for highly valued crustacean species, specifically pink shrimp, stone crab, and spiny lobster (Adams 1992). There are also significant, but largely undocumented effects of tens of thousands of recreational fishers, who target hundreds of species using mostly hook-and-line and spear guns (Davis 1977; Bohnsack et al. 1994).

Baseline data on marine debris on the seabed and the impacts to coral reef benthic organisms from entanglement were collected by our program during 2000, 2001, 2008, and 2010 (Chiappone et al. 2002c, 2004, 2005). Previous surveys included quantitative surveys of debris at 45 sites in the lower Keys from inshore to offshore during 2000, followed by surveys of 63 platform margin sites Keys-wide in 2001. These initial efforts addressed several questions pertaining to marine debris and the impacts to benthic coral reef organisms. First, what is the spatial extent and frequency of debris at multiple spatial scales in the Florida Keys? Second, what factors, such as habitat type (depth) or management regime (areas closed or open to fishing) affect the spatial variability of marine debris? Third, what is the frequency of impacts to benthic coral reef organisms, specifically entanglement that results in tissue/skeleton abrasion? A Keys-wide effort was expended in 2008 to document the different debris types, length (where applicable), weight, and impacts to benthic coral reef organisms (e.g. abrasion damage) at 145 sites partitioned by cross-shelf habitat type, geographic region, and management zone from northern Key Largo to SW of Key West. To our knowledge, these data represent the most comprehensive site-level assessment of marine debris and its corresponding impacts in the Florida Keys. These data demonstrate the ubiquitous and damaging characteristics of marine debris, particularly lost fishing gear, even within "protected" no-fishing zones in the Sanctuary. In 2011, we were able to incorporate marine debris measurements during surveys of 280 upper Keys sites to document the frequency of occurrence and biological impacts of marine debris encountered in the course of belt transect surveys for other benthic variables. Although logistics prevented us from retrieving much of the debris encountered, we were able to continue to build a temporal record of occurrence and impacts to benthic coral reef organisms. During May-September 2011, we added to a growing temporal dataset for marine debris by surveying the type, density, length, weight, of marine debris, as well as the frequencies of benthic coral reef organisms exhibiting abrasion damage from entanglement.

2011 Survey Results

Marine debris surveys were conducted at all 280 upper Keys sites surveyed during May-September 2011. At each site visited, two belt transects 15-m x 2-m in dimension were used to quantify the type, transect frequency of occurrence, density, length, weight, and impacts (abrasion from entanglement) of marine debris to benthic coral reef organisms. We measured lengths of debris, especially angling gear and trap rope, as well as the combined wet weight of all debris encountered per belt transect sampled. Figure 8-1 illustrates examples of marine debris encountered. Surveys of 560 belt transects comprising 16,800 m^2 of hard-bottom and coral reef habitat yielded 679 debris items, representing 50 different items or combinations of items (Table 8-1). Of these, 14 categories (28%) were clearly hook-and-line angling gear, 11 (22%) were lost lobster/crab trap gear, and the remaining 25 categories (50%) were designated as "other." Other marine debris included a range of metal, glass, cloth, ceramic, and plastic items. Of the 679 total debris items counted, 418 (62%) were hook-and-line gear (monofilament, wire leaders, hooks, and lead sinkers), followed by 172 trap debris items (25%), and other debris (89 items, 13%) (Table 8-1).

Many of the debris items encountered during 2011 were entangled and causing damage to either tissue and/or skeleton. A total of 363 organisms were identified as being impacted by entangled debris, represented by *Millepora* and scleractinian corals, gorgonians, sponges, and the colonial zoanthid *Palythoa* (Table 8-1). Trap debris, especially trap rope, impacted 174 organisms (48%), followed by lost hook-and-line gear (162 organisms, 45%), and other debris (27 impacted organisms, 7%). Similar to previous years, the data indicate that while lost hook-and-line fishing gear was the most prevalent in the upper Keys, the impact of entangled lobster/crab trap debris, especially trap rope, was proportionally larger than for other debris types. The most frequently impacted organisms from entangled marine debris were gorgonians (54% of the total impacts) and scleractinian corals (25%), followed by milleporid hydrocorals (12%), sponges (9%), and the colonial zoanthid *Palythoa* (< 1%) (Table 8-1). The sections below summarize the distribution, density, amount (length and weight) of the three main categories of debris on the seabed: hook-and-line angling gear, lobster/crab trap gear, and other debris.

Lost Hook-and-line Angling Gear

Hook-and-line gear was the most frequent type of marine debris in the upper Florida Keys during 2011 in terms of the number of sites (144 sites, 51% of all sites) and the number of items encountered (418 items, 62% of total). Hook-and-line gear was found in all habitats surveyed and nearly all of the 12 FKNMS no-take zones surveyed in the upper Keys (Table 8-2). Figures 8-2 to 8-4 illustrate the spatial distribution of lost hook-and-line fishing gear density (no. items per 30 m^2) throughout the upper Florida Keys study area. Site presence, transect frequency, density, and mean total length of gear recovered per 30-m^2 transect were greatest on mid-channel and offshore patch reefs, followed by high-relief spur and groove and deeper fore-reef habitats (Table 8-2). Hook-and-line gear was particularly prevalent on inshore and mid-channel patch reefs (Figure 8-5), where gear was encountered at 87% of the 54 sites and 71% of the 108 belt transects. Similar to previous years, we continued to document hook-and-line gear in most of the FKNMS no-take zones in the upper Keys (Table 8-2). For many of the habitats surveyed, both transect frequency and gear density in no-take zones was either similar to (e.g. high-relief spur and groove and the deeper fore reef), or in some cases was even greater (e.g. mid-channel patch reefs, shallow hard-bottom), than in reference areas open to fishing (Figure 8-6). No-take zones with relatively large amounts of hook-and-line debris included Hen and Chickens SPA, Cheeca Rocks SPA, Conch Reef SPA, and Carysfort/S. Carysfort SPA (Figures 8-2 to 8-4).

The 418 items of hook-and-line gear were measured for total length to the nearest cm. A total of 556.39 m of angling gear was retrieved from the seabed. Although this figure may not seem significant, our total sampling effort represents < 1% of the total hard-bottom and coral reef habitat in the upper Keys. Figures 8-7 to 8-9 show the distribution of lengths of angling gear retrieved per 30 m^2 belt transect. The lengths of angling gear debris ranged from 0.01 to 35.55 m and averaged (± 1 SE) 1.33 ± 0.12 m. Smaller items included lead sinkers and small pieces of monofilament and fishing wire. Larger items were usually longer strands of entangled monofilament. The length distribution of angling gear indicated that most (95%) of the angling gear debris was < 4.0 m in length (Figure 8-10). Similar to other metrics, the average length of angling gear per 30 m^2 was greater on inshore and mid-channel patch reefs, followed by offshore patch reefs and high-relief spur and groove (Figure 8-11, top). Average length retrieved per transect tended to be greater in reference areas compared to no-take zones for most, but not all, of the habitats surveyed (Figure 8-11, bottom).

Lost Lobster/Crab Trap Debris

Lost lobster/crab trap fishing gear was the second most abundant debris category encountered in terms of the number of sites (95 sites, 34% of all sites), transect frequency (21%), and items encountered (172 items, 25% of total) (Table 8-3). Figures 8-12 to 8-14 show the spatial distribution of trap debris density (no. items per 30 m^2) in the upper Keys. Of the 172 trap items recovered, approximately 44% consisted of rope (Table 8-1). Trap gear was encountered in all habitats except back-reef rubble (Table 8-3). Similar to angling gear, the site presence, transect frequency, and density of trap debris, but not necessarily length of entangled rope, was substantially greater on patch reefs compared to other habitats (Figure 8-15). Trap debris site presence, transect frequency, and density tended to be lower in no-take zones compared to reference sites, except for inshore and mid-channel patch reefs (Table 8-3 and Figure 8-16).

Seventy-six (76) of the 172 trap debris items (44%) consisted of trap rope, either free or attached to some other trap item (Table 8-1). The 76 instances of trap rope were measured for total length to the nearest cm. A total of 1,145.22 m (> 1 km) of trap rope was retrieved from the seabed. Figures 8-17 to 8-19 show the distribution of trap rope lengths retrieved per 30 m^2 belt transect. The lengths of trap rope ranged from 0.50 to 432.41 m and averaged (± 1 SE) 15.07 ± 5.66 m; the latter figure indicates that when trap rope was encountered, an average-size piece was nearly 50 feet in length. The length distribution of trap rope indicated that most (95%) of the angling gear debris was < 12.0 m in length, although larger pieces of rope were often found (Figure 8-10). The average length of trap rope per 30 m^2 was greatest on the deeper fore reef, followed by mid-channel and offshore patch reefs (Figure 8-20, top). The former result is largely due to a very long (> 400 m) section of trap rope retrieved from a low-relief spur and groove site south of South Carysfort Reef. Average length retrieved per transect was greater in reference areas compared to no-take zones for all of the habitats surveyed (Figure 8-20, bottom).

Other Marine Debris

Other debris items encountered in the upper Keys during 2011, meaning non-angling and non-trap debris, were represented mostly by glass bottles, plastics, metals, as well as anchors with or without chain and rope (Table 8-1). Other debris items were encountered at 23% of the 280 sites and 14% of the 560 transects. The maximum site-level density was two items per 30 m^2. Site presence, transect frequency, and density were greatest on patch reefs and shallow hard-bottom habitats (Table 8-4). The site presence, transect frequency, and density of other debris was either greater in no-take zones or similar to reference areas for all of the habitats where other debris was encountered (Table 8-4).

Total Marine Debris

The 679 total marine debris items encountered in 560 belt transects (15-m x 2-m in dimension) represents an overall mean density of 1.21 items per 30 m^2, similar to previous years. The maximum site-level mean density was 18.50 items per 30 m^2. Debris was encountered at 71% of the 280 sites surveyed and 51% of the sampled belt transects. Figures 8-21 to 8-23 show the spatial distribution of total marine debris and illustrate its ubiquitous nature in the Florida Keys. Site presence, transect frequency, density, and weight retrieved were greatest on mid-channel and offshore patch reefs, reflecting the relatively large amounts of angling gear and trap gear in these habitats (Table 8-5 and Figure 8-24). Except for offshore patch reef and high-relief spur and groove habitats, total marine debris tended to be more common and occurred in greater amounts in FKNMS no-take zones compared to reference areas (Table 8-5 and Figure 8-25). The 679 debris items recovered during 2011 were collected per 30 m^2 belt transect and brought back to the surface to determine wet weight. A total of 243.004 kg (> ½ ton) of debris was retrieved from the seabed. Total wet weight collected per belt transect (i.e. per 30 m^2) was greatest on inshore and mid-channel patch reefs, followed by offshore patch reefs, the deeper fore reef, and shallow hard-bottom (Figure 8-26, top). For all habitats except high-relief spur and groove, marine debris weight recovered was greater in reference areas compared to no-take zones (Figure 8-26, bottom).

Discussion

Methods of fishing that cause habitat modification or damage to benthic organisms are serious consequences of fishing (Russ 1991; Benaka 1999). While there is recognition of the impacts to benthic organisms from mobile fishing gear such as trawls (Watling and Norse 1998; Auster and Langton 1999) and other destructive fishing practices (Saila et al. 1993; Jennings and Polunin 1996), only a handful of studies in the Florida Keys have quantified the spatial extent of marine debris, as well as the biological impacts to organisms and habitats (Chiappone et al. 2002c, 2004, 2005). Recent investigations of lobster trap movement (e.g. T. Matthews et al. at FWRI), as well as large-scale studies of lobster trap abundance (T. Matthews and A. Uhrin), indicate the potential for extensive movement of deployed gear, especially during storms. Similar to debris surveys completed by our program in 2000, 2001, 2008, and 2010, the results from 2011 indicate the large-scale prevalence of marine debris, especially lost fishing gear, even within FKNMS no-fishing zones.

Interpretation of the biological impact data is complicated by several factors. Both the debris density and the distribution of sessile invertebrates sampled in this study are related to habitat type. It is probable that a coral-dominated reef with a given amount of hook-and-line gear will not be affected in the same way as a gorgonian-sponge dominated reef with the same density of gear. Estimates of the proportion of different taxa impacted by debris relative to total abundance estimates are also useful for placing the debris impact assessment into context. In addition, the long-term impacts to biota and the degree of recovery are unknown. For example, we do not mark and re-sample benthic organisms impacted by debris to determine whether organisms recover. We recognize that assessments would be more useful if data on the severity of each impact (e.g. amount of tissue damage) relative to the size of the organism were collected. The data presented in this report clearly indicate areas in the Florida Keys, particularly patch reefs, where public debris collection efforts such as "reef sweeps" should be focused. Considering the intensive fishing effort and the significant increases in registered recreational boats and angler days in the Florida Keys (Bohnsack et al. 1994), patterns in debris distribution and abundance, especially lost fishing gear, are not surprising. We usually found either similar or greater amounts of debris, especially lost fishing gear, in no-fishing zones compared to reference areas for most of the habitats sampled. Non-compliance certainly occurs in Sanctuary no-fishing zones and it is common to find "fresh" (un-fouled) hook-and-line gear in the zones. FKNMS no-take zones may attract people to fish illegally or to fish close to zone boundaries, otherwise known as "fishing the line." Storms also re-distribute debris from areas where it is initially lost into adjacent areas, including coral reefs, suggesting the need for either less mobile gear types or buffer areas to protect neighboring habitats from physical damage.

Figure 8-1. Examples of marine debris encountered in the upper Florida Keys National Marine Sanctuary during May-September 2011.

Monofilament entangling staghorn coral

Trap rope abrading a coral colony

Trap rope entangling a sea fan

Trap rope entangling staghorn coral

Intact ghost trap with line attached

Trap grating and rope

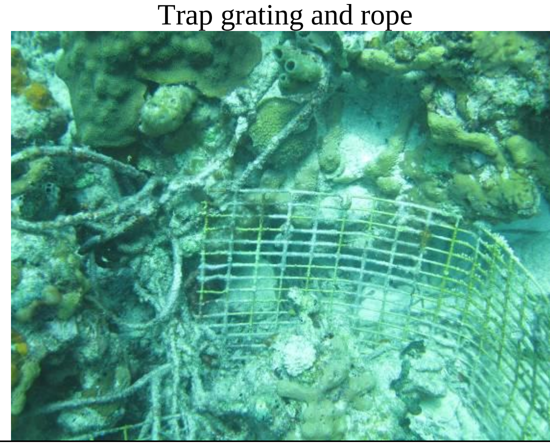


Figure 8-2. Densities (no. items per 30 m^2) of hook-and-line fishing gear debris in the upper Florida Keys National Marine Sanctuary from the southern boundary of Biscayne National Park (BNP) to the Watsons Reef area surveyed during May-September 2011.

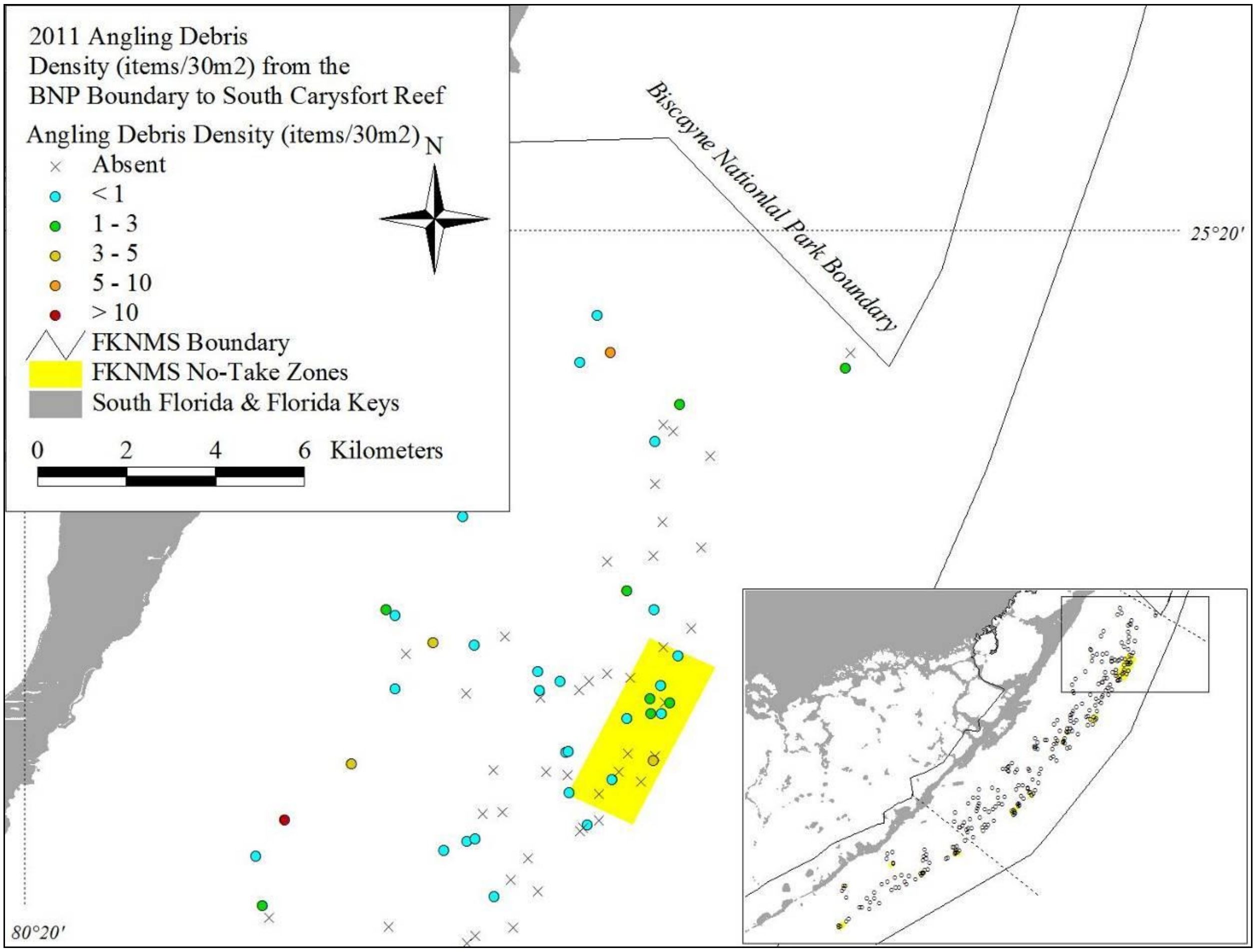


Figure 8-3. Densities (no. items per 30 m^2) of hook-and-line fishing gear debris in the upper Florida Keys National Marine Sanctuary from Elbow Reef to the Pickles Reef area surveyed during May-September 2011.

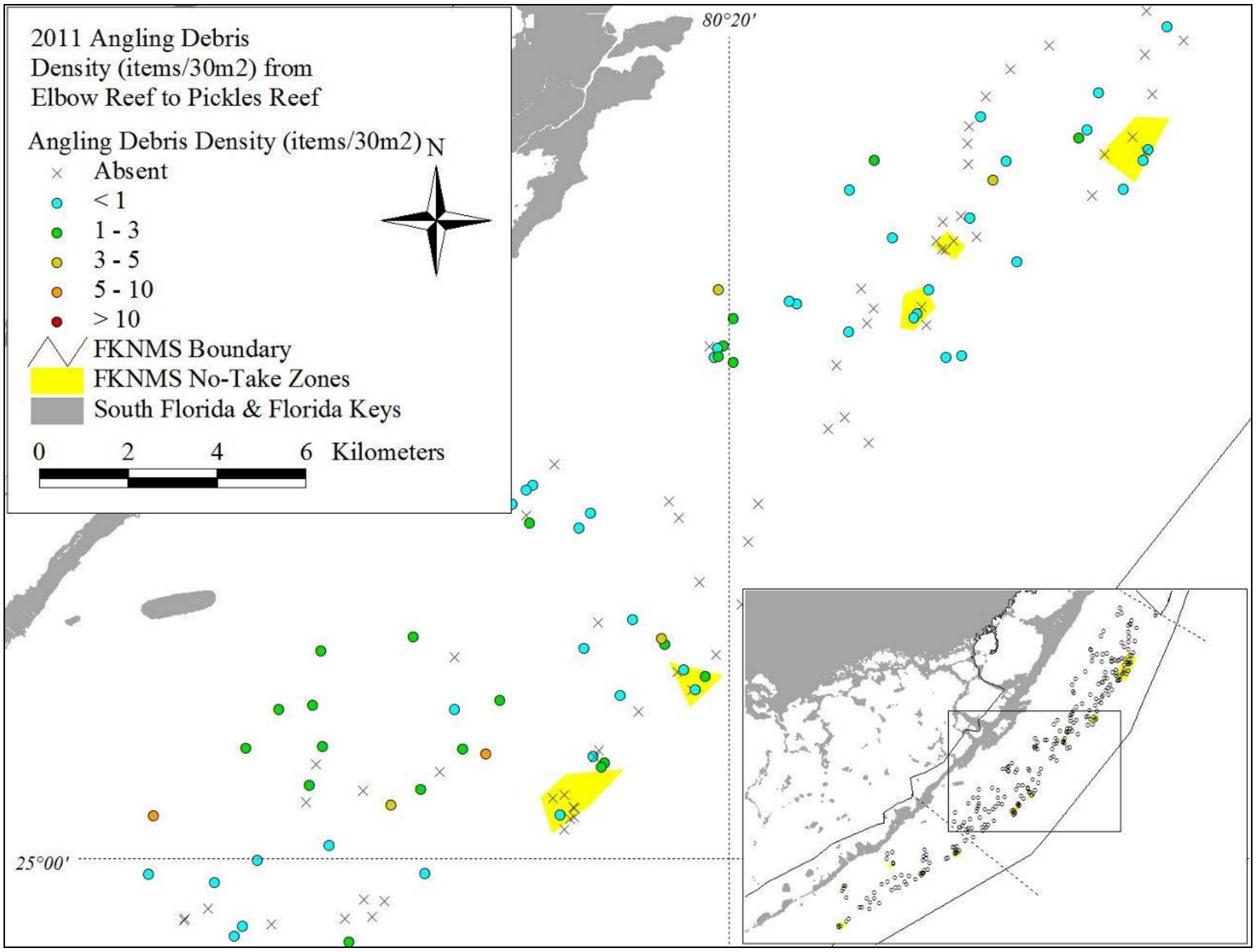


Figure 8-4. Densities (no. items per 30 m^2) of hook-and-line fishing gear debris in the upper Florida Keys National Marine Sanctuary from Conch Reef to Alligator Reef surveyed during May-September 2011.

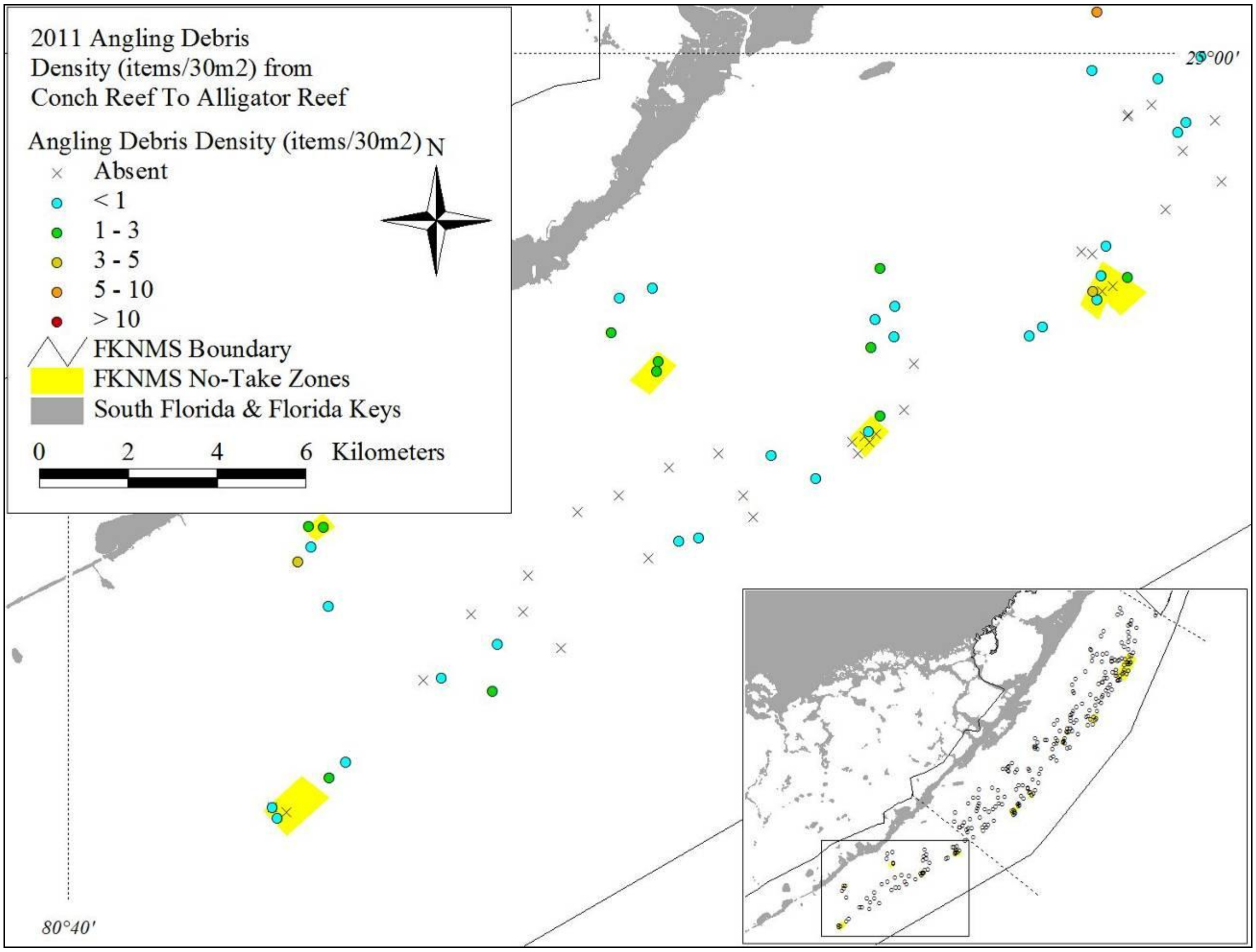
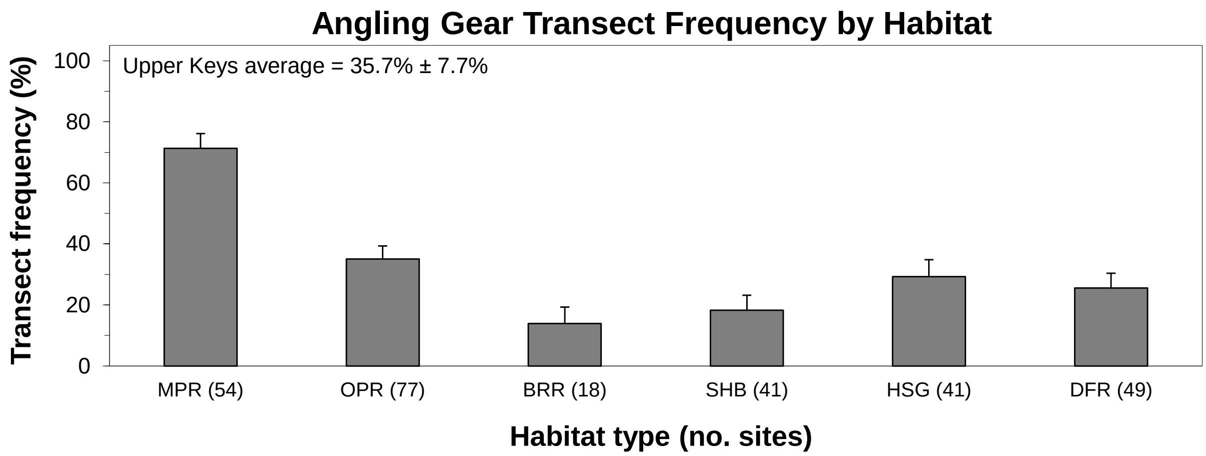


Figure 8-5. Mean (+ 1 SE) transect frequency (top) and density (no. items encountered per 30 m^2) (bottom) of lost hook-and-line fishing gear debris by habitat type in the upper Florida Keys during May-September 2011. Domain-wide (upper Keys) values are weighted averages and standard errors. Values on the x-axis in parentheses are the number of sites surveyed in each habitat type, with two 15-m x 1-m transects surveyed per site.



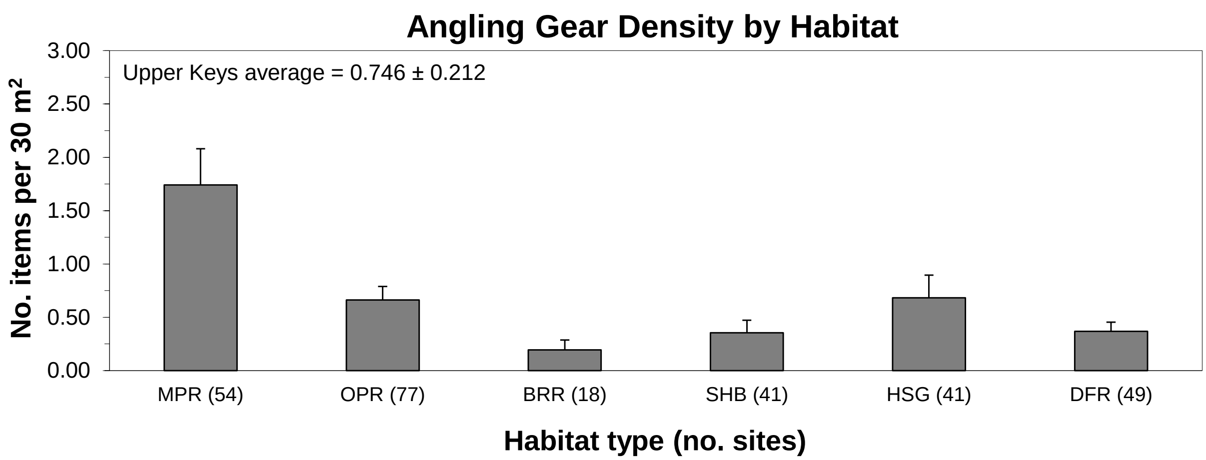
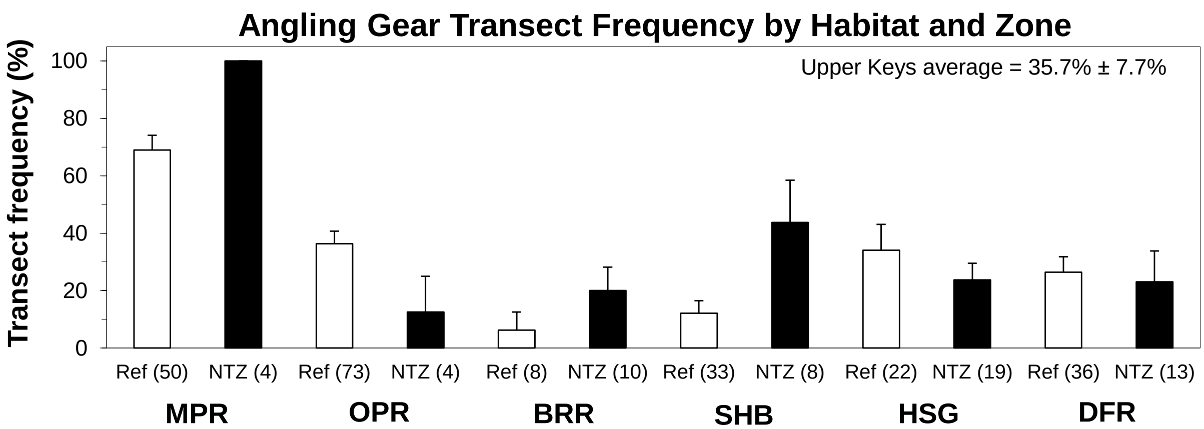


Figure 8-6. Mean (+ 1 SE) transect frequency (top) and density (no. items encountered per 30 m^2) (bottom) of lost hook-and-line fishing gear debris by habitat type and management zone in the upper Florida Keys during May-September 2011. Open bars = reference areas (Ref), filled bars = no-take zones (NTZ). Domain-wide (upper Keys) values are weighted averages and standard errors. Habitat abbreviations are: MPR = inshore and mid-channel patch reefs, OPR = offshore patch reefs, BRR = back-reef rubble, SHB = shallow (< 6 m) hard-bottom, HSG = high-relief and groove, and DFR = deeper (6-15 m) fore-reef habitats. Numbers in parentheses on the x-axis are the number of sites surveyed, with two replicate 15-m x 1-m transects surveyed per site (30 m^2 per site).



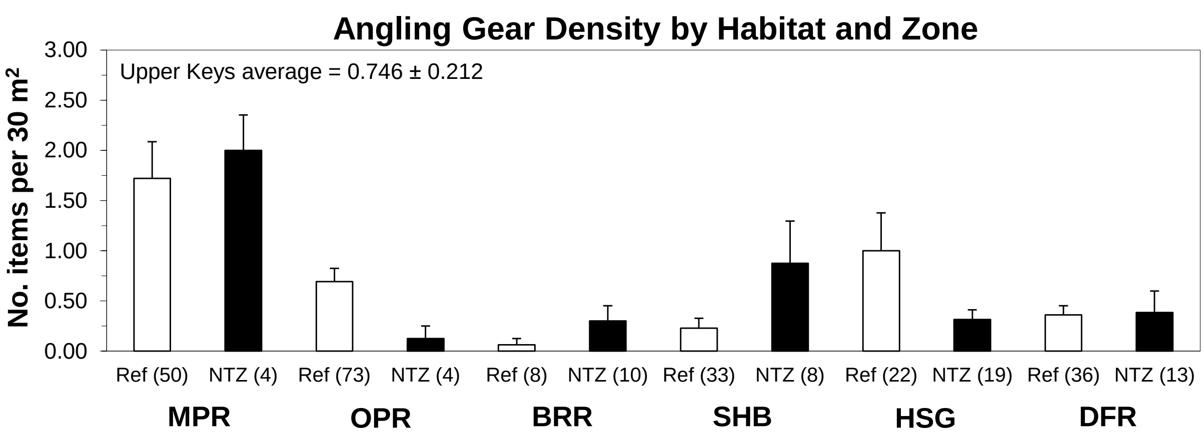


Figure 8-7. Length of lost hook-and-line fishing gear debris (m per 30 m^2) retrieved per 15-m x 2-m belt transect per site in the upper Florida Keys National Marine Sanctuary from the southern boundary of Biscayne National Park (BNP) to the Watsons Reef area surveyed during May-September 2011.

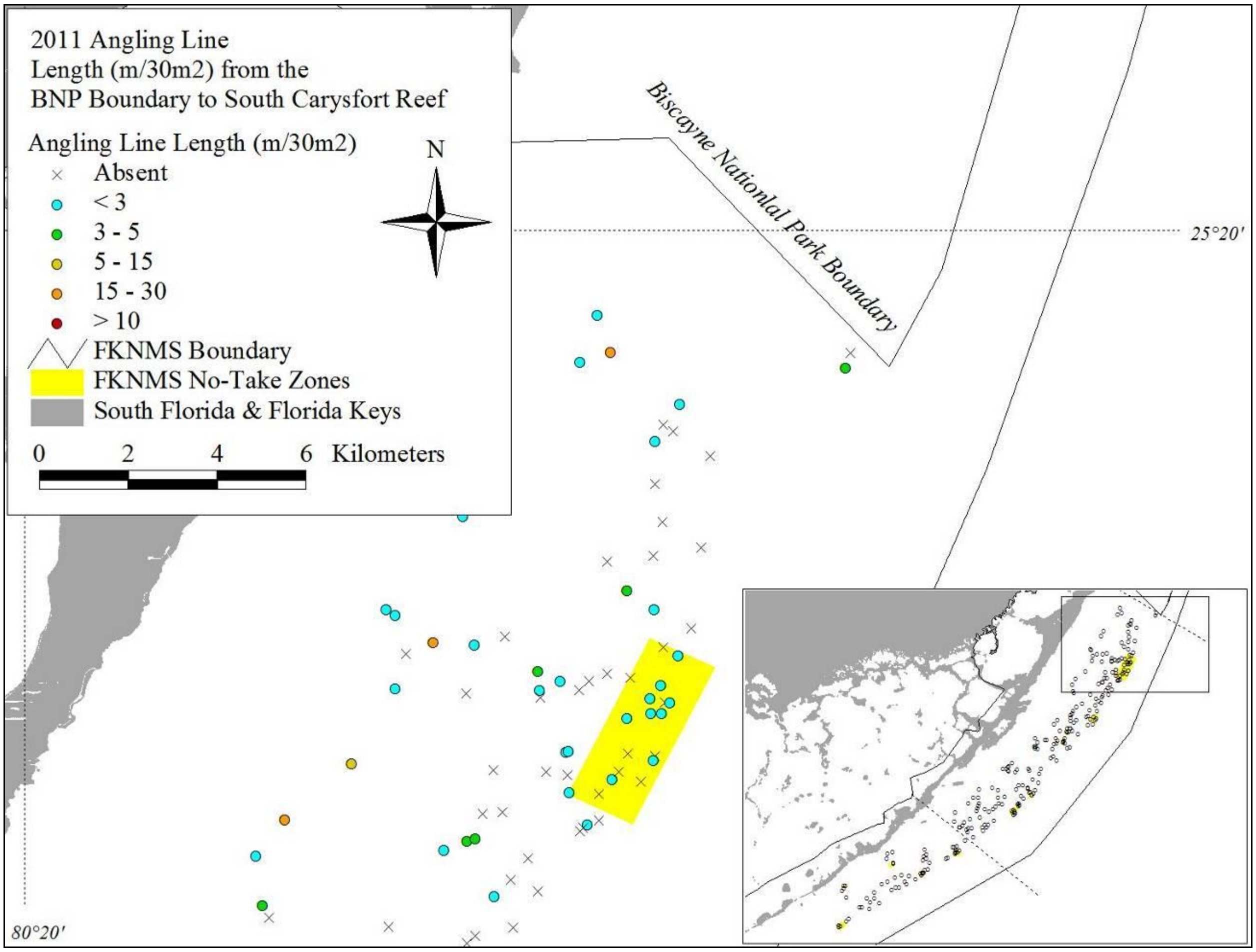


Figure 8-8. Length of angling gear debris (m per 30 m^2) retrieved per 15-m x 2-m belt transect per site in the upper Florida Keys National Marine Sanctuary from Elbow Reef to the Pickles Reef area surveyed during May-September 2011.

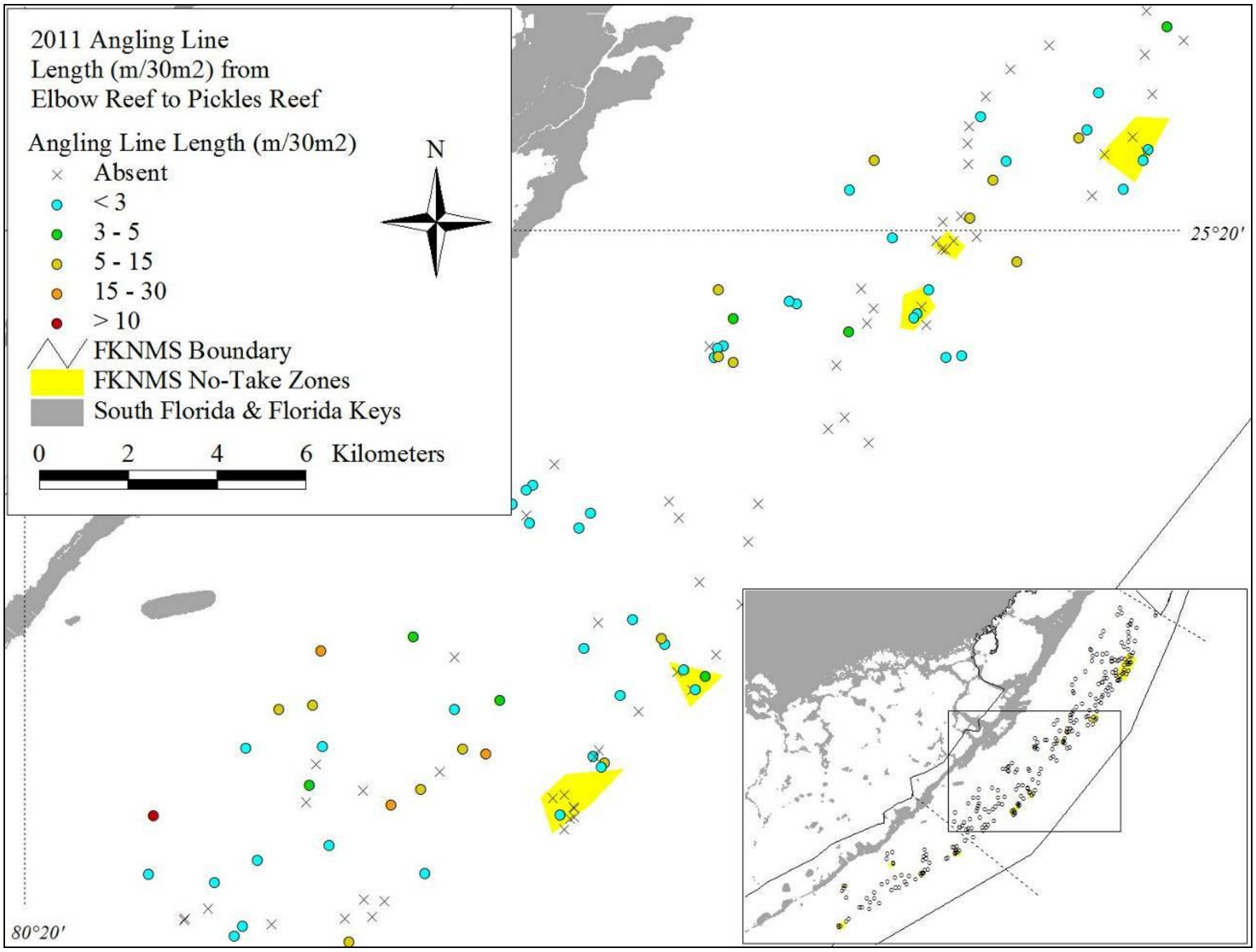


Figure 8-9. Length of angling gear debris (m per 30 m^2) retrieved per 15-m x 2-m belt transect per site in the upper Florida Keys National Marine Sanctuary from Conch Reef to Alligator Reef surveyed during May-September 2011.

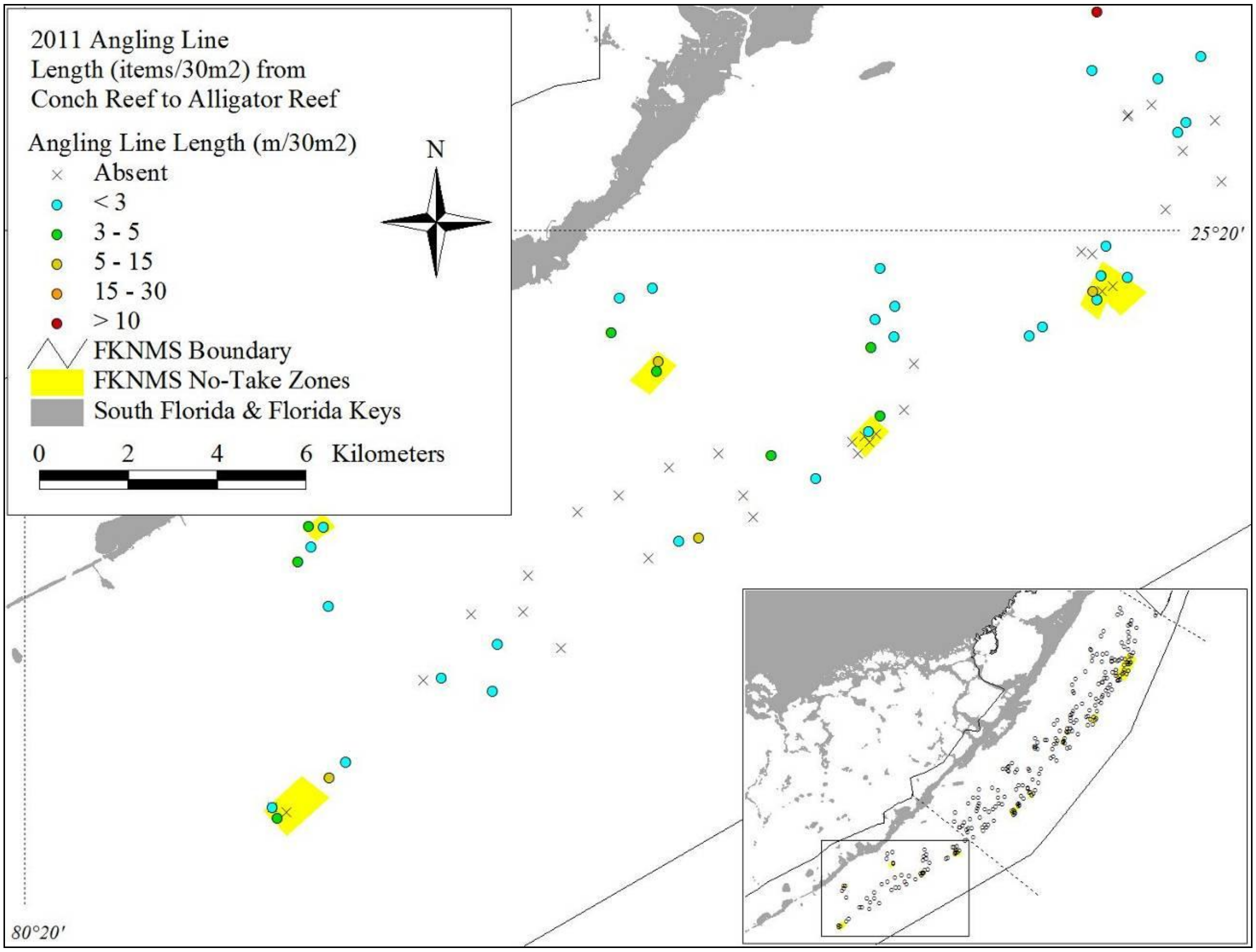
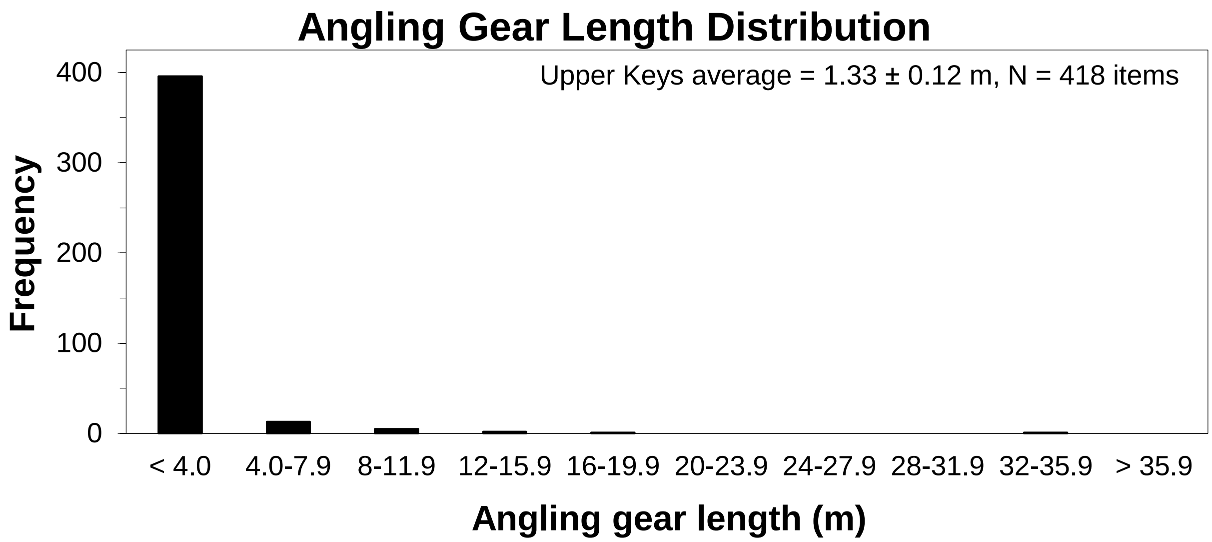


Figure 8-10. Length distributions of recovered angling gear debris (top) and lobster/crab trap rope (bottom) for all sites combined in the upper Florida Keys sampled during May-September 2011. Domain-wide (upper Keys) values are average lengths and standard errors.



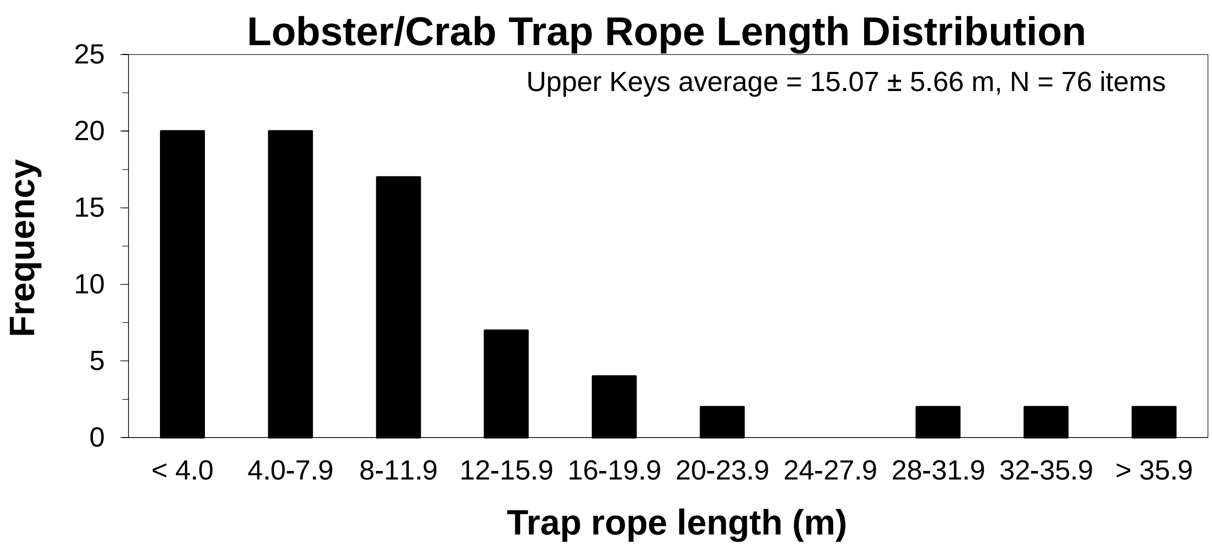
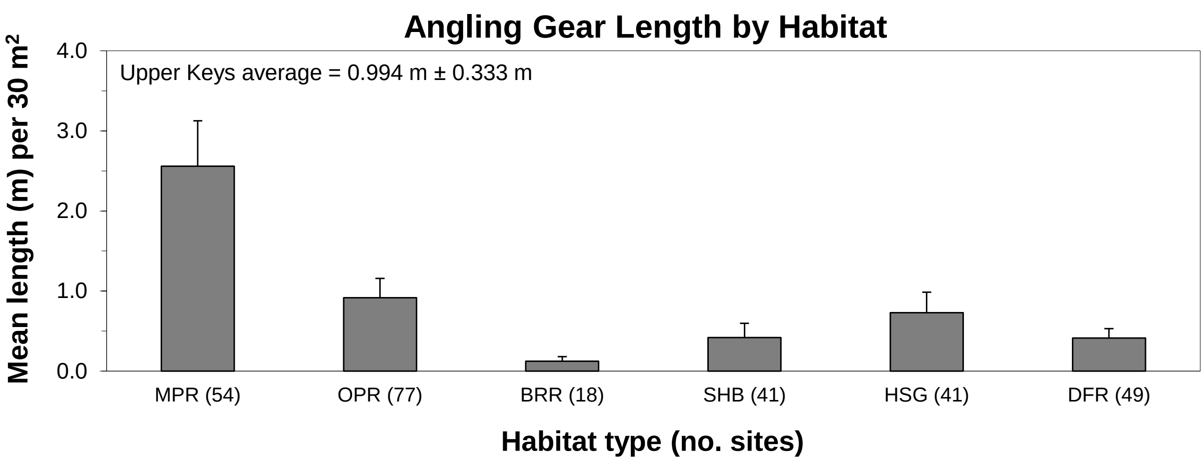


Figure 8-11. Mean (+ 1 SE) length of angling gear debris per transect by habitat type (top) and habitat type by management zone (bottom) in the upper Florida Keys during May-September 2011. Domain-wide (upper Keys) values are weighted averages and standard errors. Values on the x-axis in parentheses are the number of sites surveyed in each habitat type, with two 15-m x 1-m transects surveyed per site. Open bars = reference bars (Ref) and filled bars = no-take zones (NTZ) on the bottom figure. Habitat abbreviations are: MPR = inshore and mid-channel patch reefs, OPR = offshore patch reefs, BRR = back-reef rubble, SHB = shallow (< 6 m) hard-bottom, HSG = high-relief and groove, and DFR = deeper (6-15 m) fore-reef habitats.



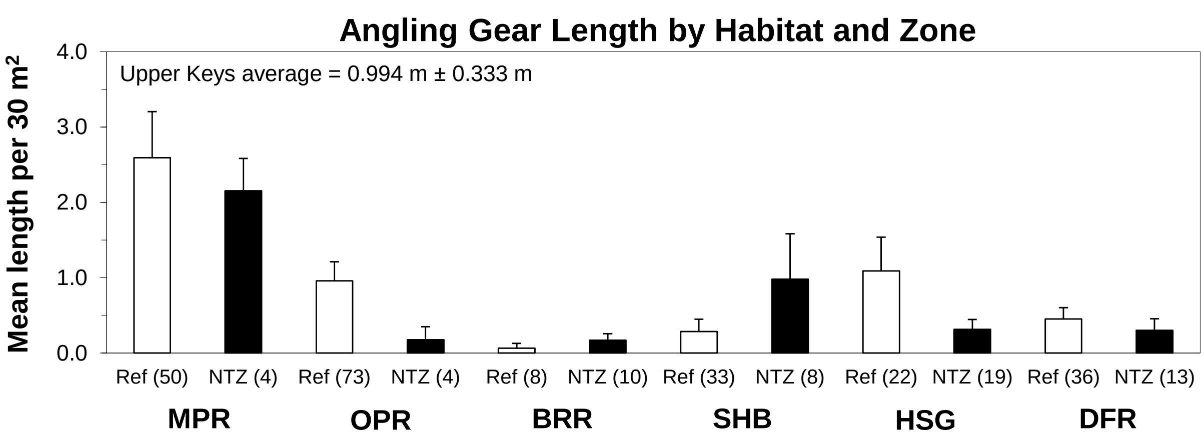


Figure 8-12. Densities (no. items per 30 m^2) of lobster/crab trap debris in the upper Florida Keys National Marine Sanctuary from the southern boundary of Biscayne National Park (BNP) to the Watsons Reef area surveyed during May-September 2011.

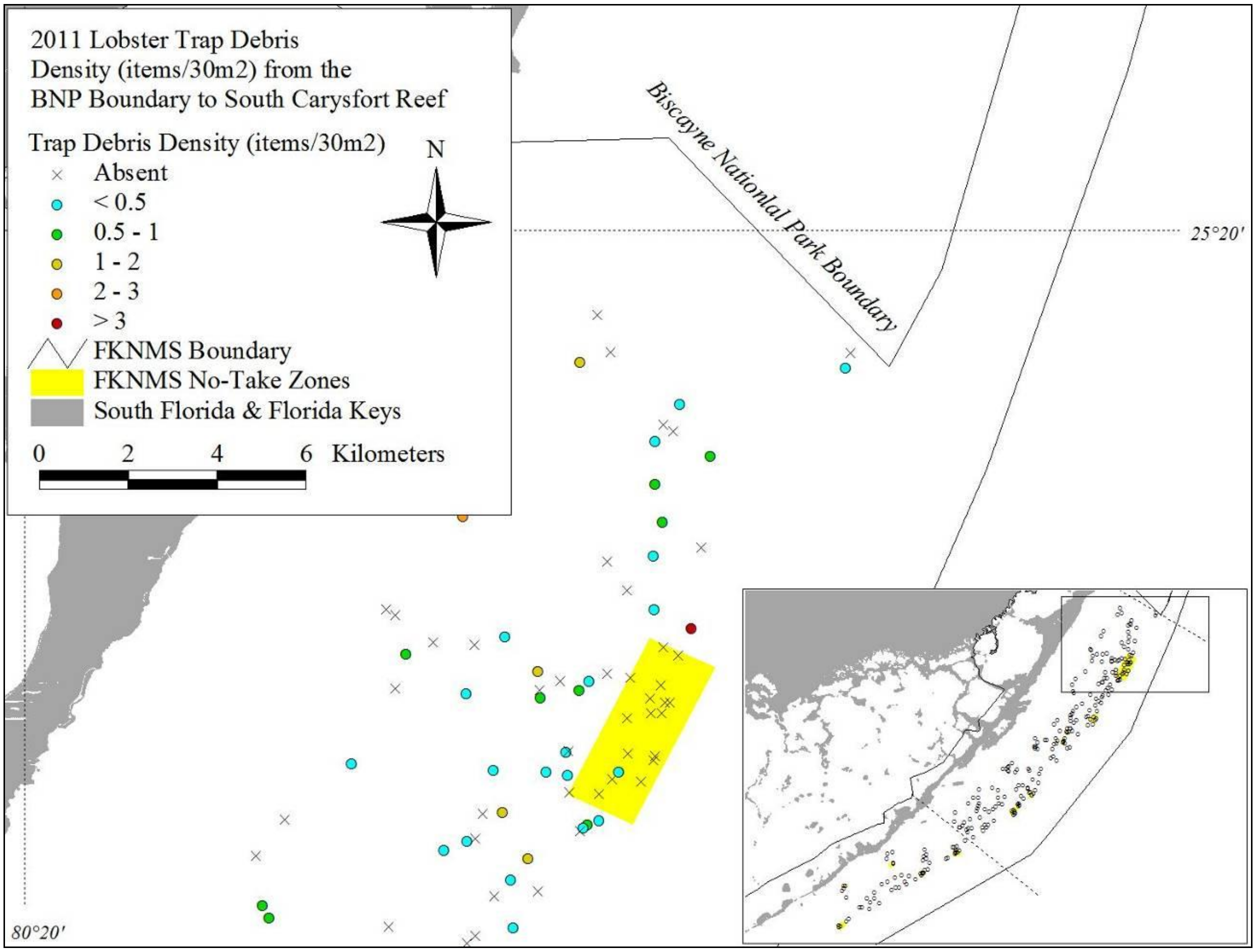


Figure 8-13. Densities (no. items per 30 m^2) of lobster/crab trap debris in the upper Florida Keys National Marine Sanctuary from Elbow Reef to the Pickles Reef area surveyed during May-September 2011.

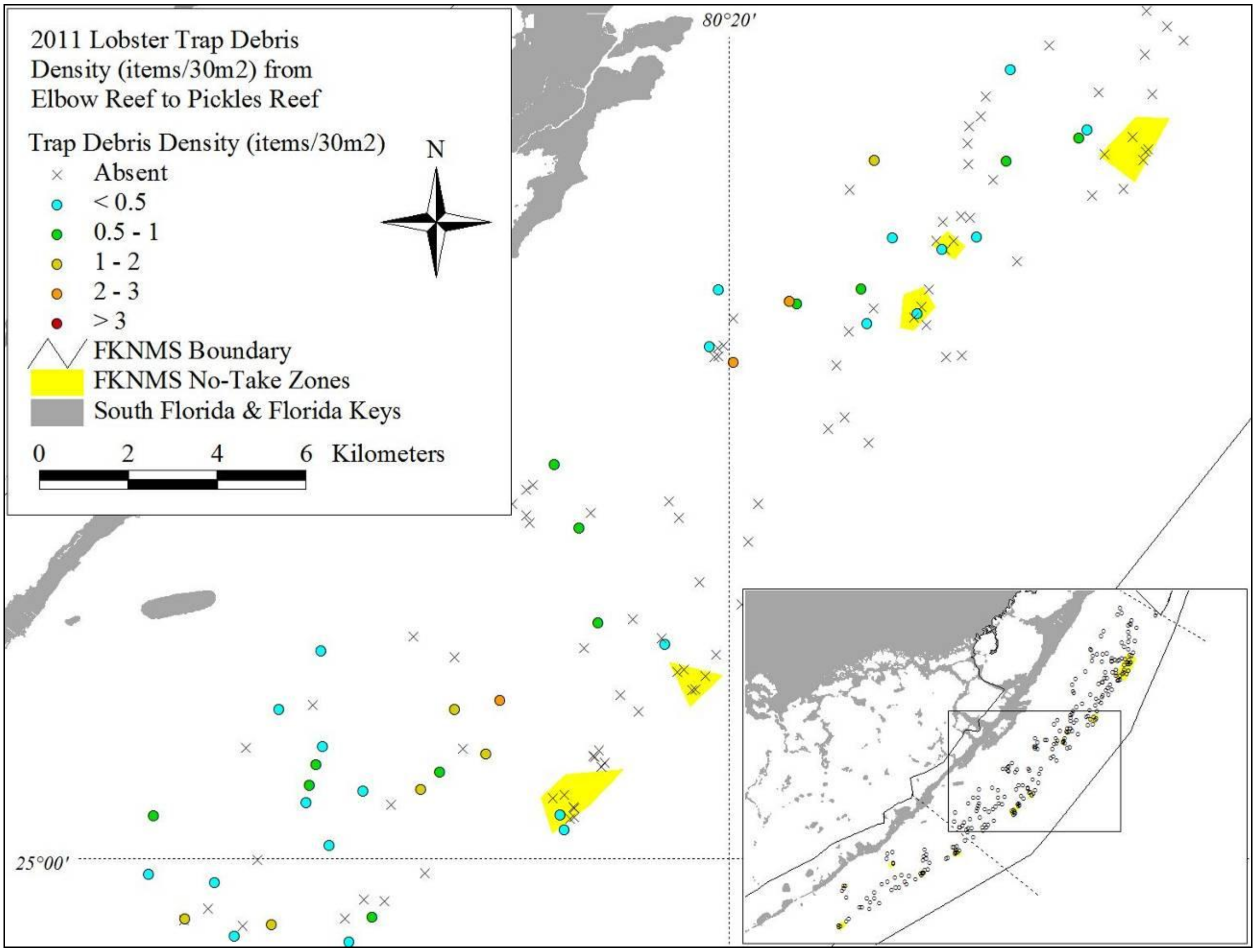


Figure 8-14. Densities (no. items per 30 m^2) of lobster/crab trap debris in the upper Florida Keys National Marine Sanctuary from Conch Reef to Alligator Reef surveyed during May-September 2011.

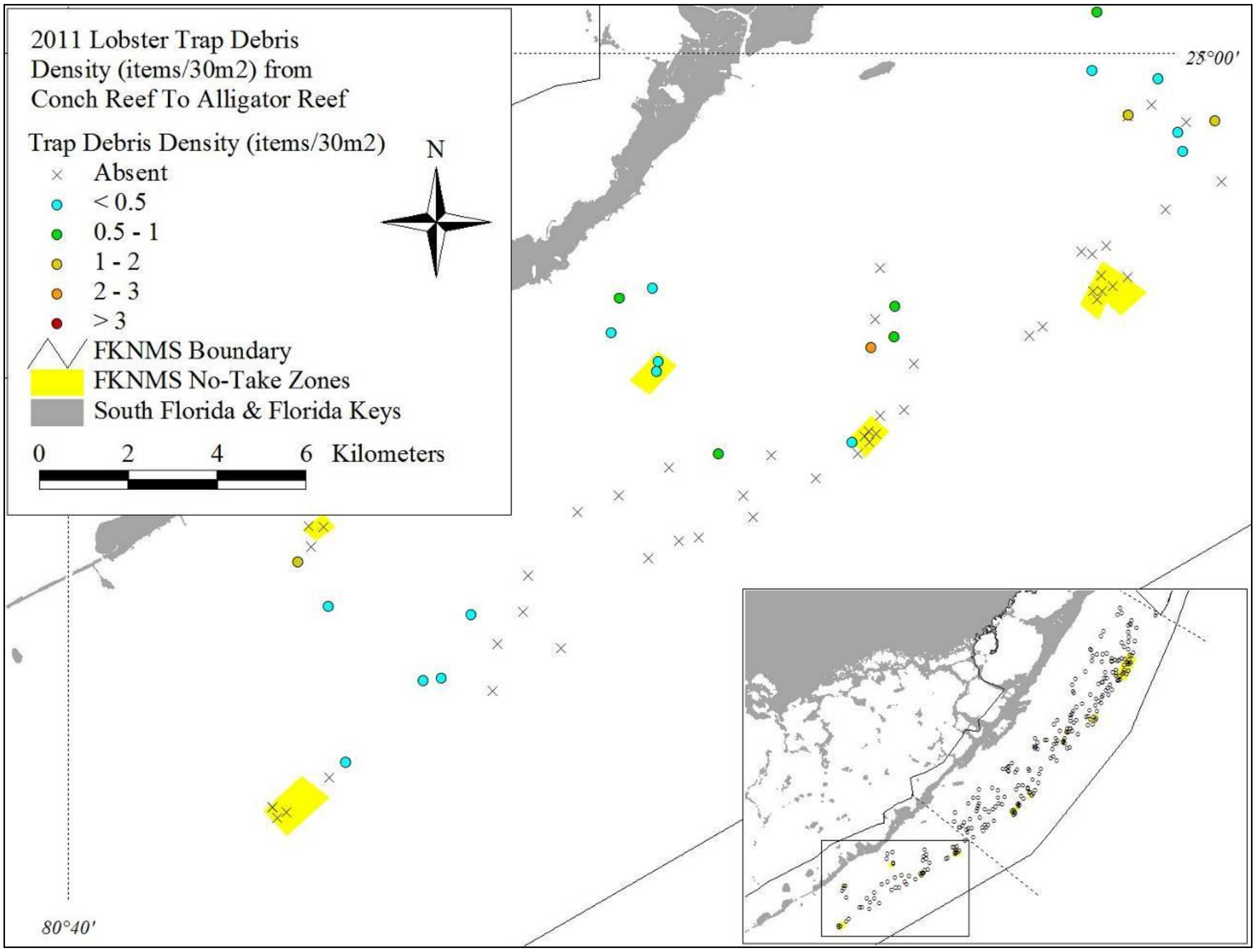
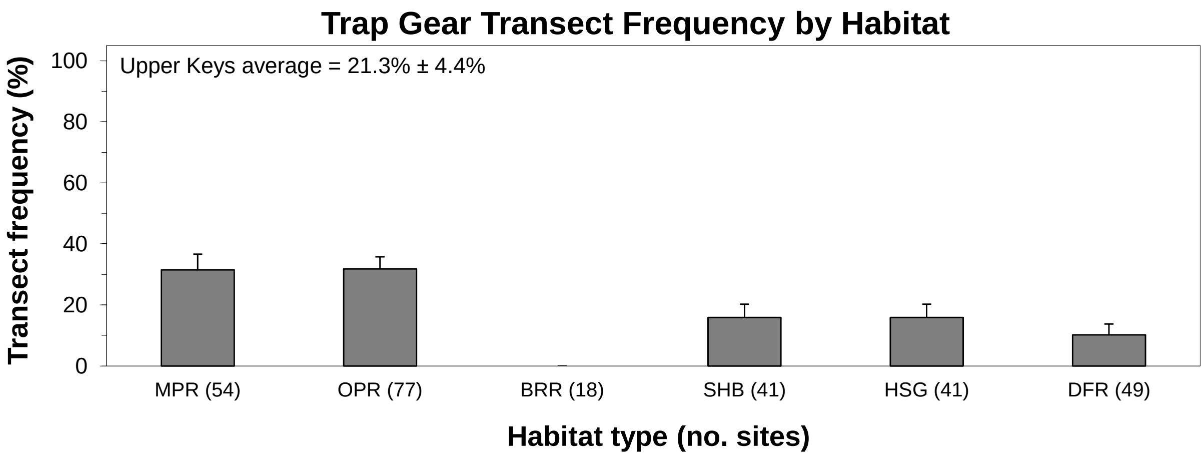


Figure 8-15. Mean (+ 1 SE) transect frequency (top) and density (no. items encountered per 30 m^2) (bottom) of lobster/crab trap debris by habitat type in the upper Florida Keys during May-September 2011. Domain-wide (upper Keys) values are weighted averages and standard errors. Values on the x-axis in parentheses are the number of sites surveyed in each habitat type, with two 15-m x 1-m transects surveyed per site.



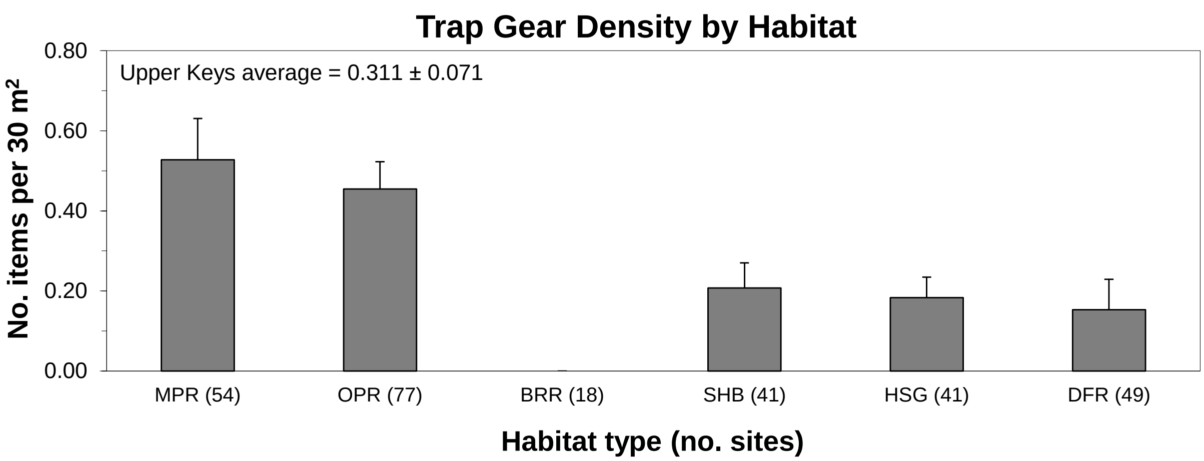
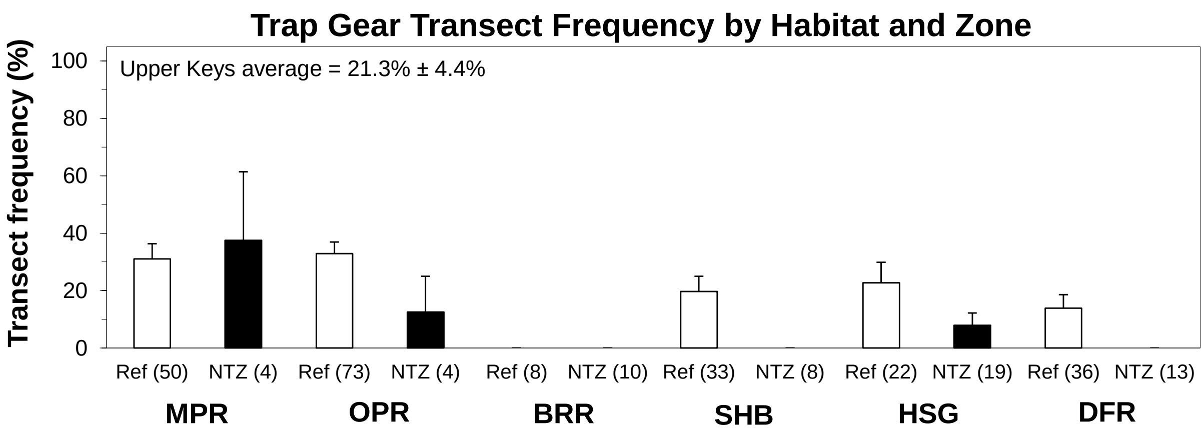


Figure 8-16. Mean (+ 1 SE) transect frequency (top) and density (no. items encountered per 30 m^2) (bottom) of lobster/crab trap debris by habitat type and management zone in the upper Florida Keys during May-September 2011. Open bars = reference areas (Ref), filled bars = no-take zones (NTZ). Domain-wide (upper Keys) values are weighted averages and standard errors. Habitat abbreviations are: MPR = inshore and mid-channel patch reefs, OPR = offshore patch reefs, BRR = back-reef rubble, SHB = shallow (< 6 m) hard-bottom, HSG = high-relief and groove, and DFR = deeper (6-15 m) fore-reef habitats. Numbers in parentheses on the x-axis are the number of sites surveyed, with two replicate 15-m x 1-m transects surveyed per site (30 m^2 per site).



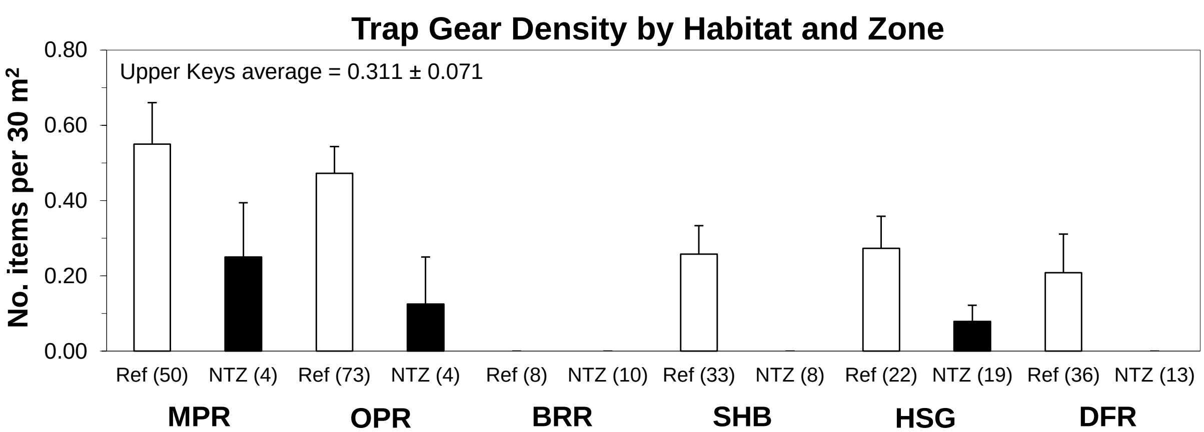


Figure 8-17. Length of lobster trap rope (m per 30 m^2) retrieved per 15-m x 2-m belt transect per site in the upper Florida Keys National Marine Sanctuary from the southern boundary of Biscayne National Park (BNP) to the Watsons Reef area surveyed during May-September 2011.

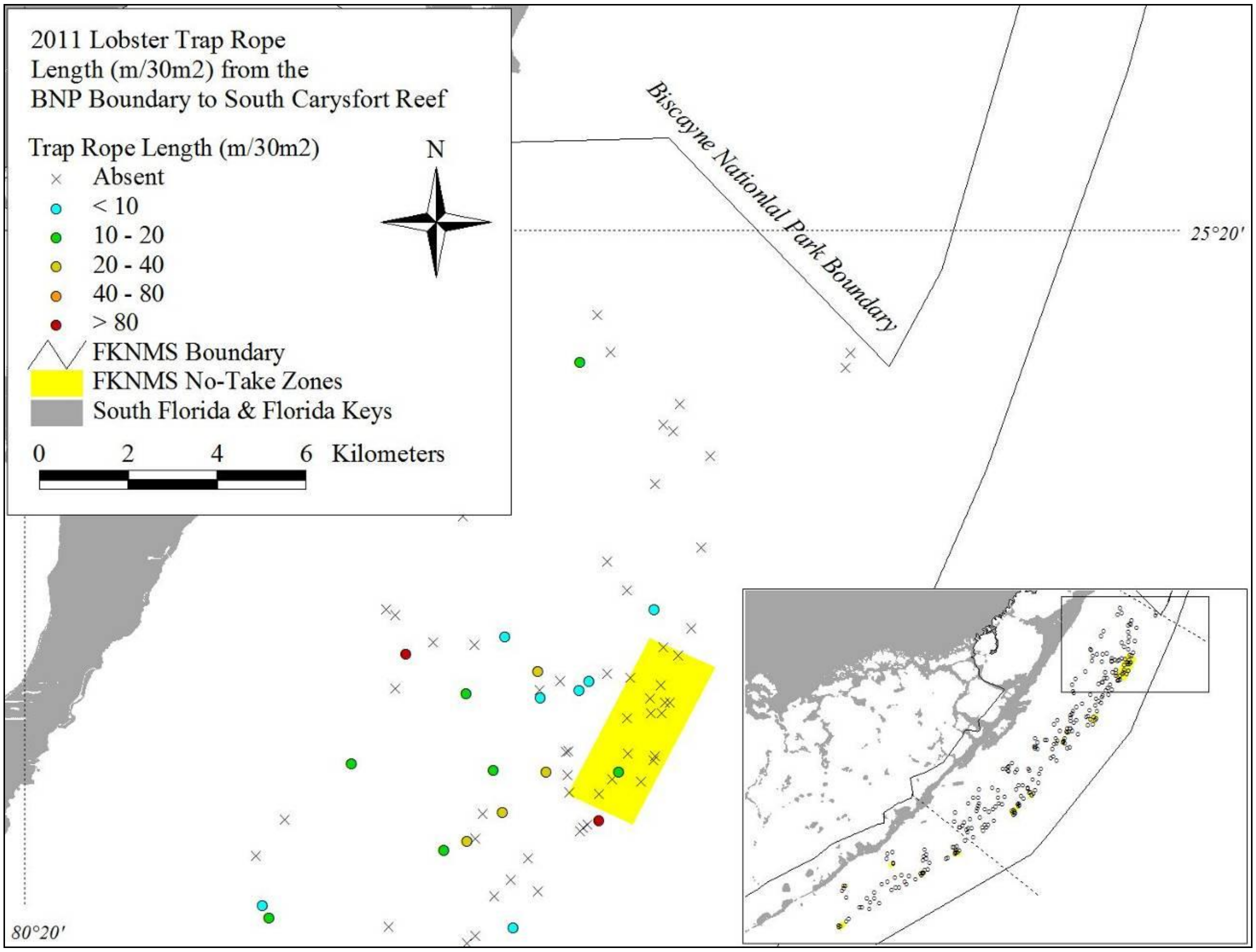


Figure 8-18. Length of lobster trap rope (m per 30 m^2) retrieved per 15-m x 2-m belt transect per site in the upper Florida Keys National Marine Sanctuary from Elbow Reef to the Pickles Reef area surveyed during May-September 2011.

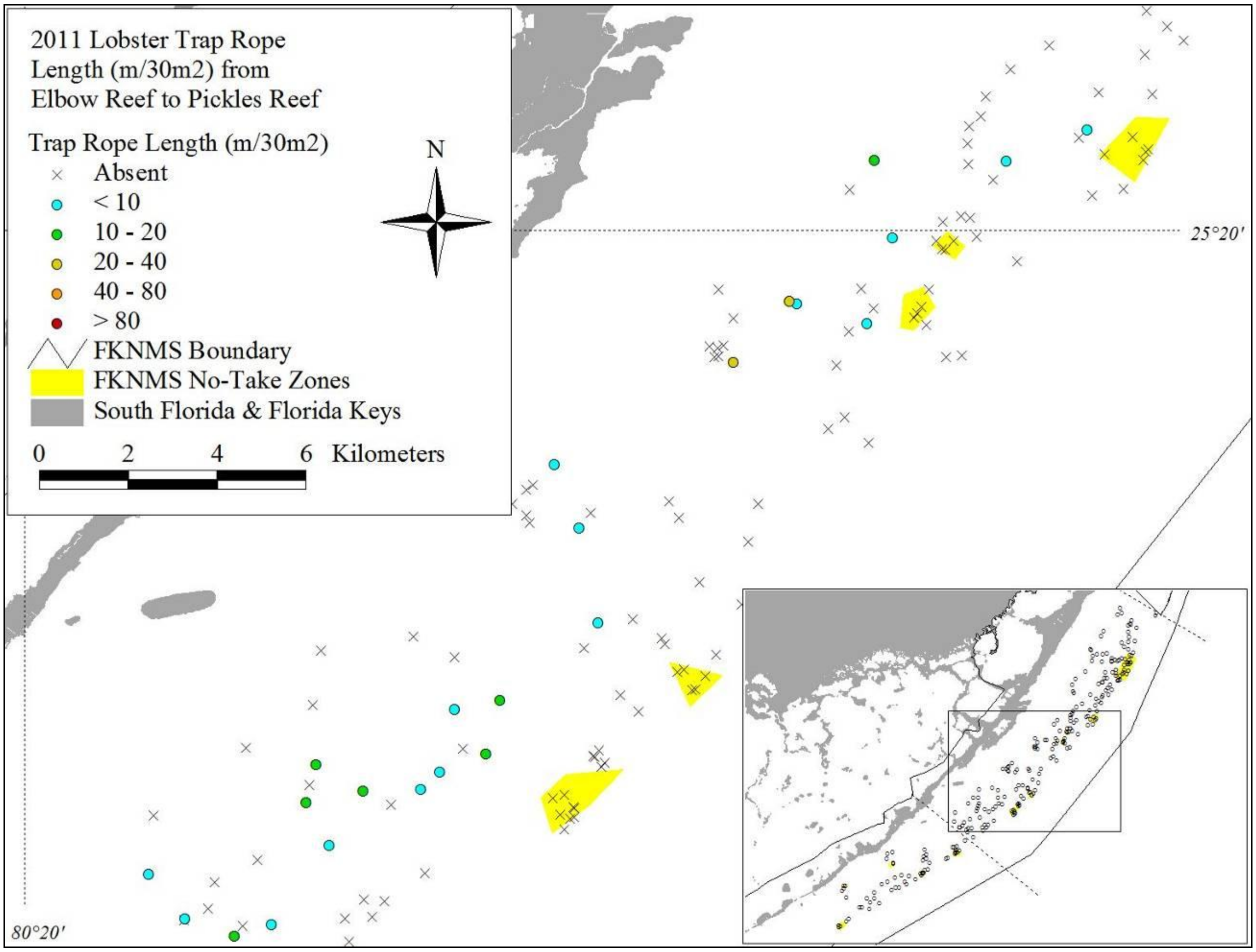


Figure 8-19. Length of lobster trap rope (m per 30 m^2) retrieved per 15-m x 2-m belt transect per site in the upper Florida Keys National Marine Sanctuary from Conch Reef to Alligator Reef surveyed during May-September 2011.

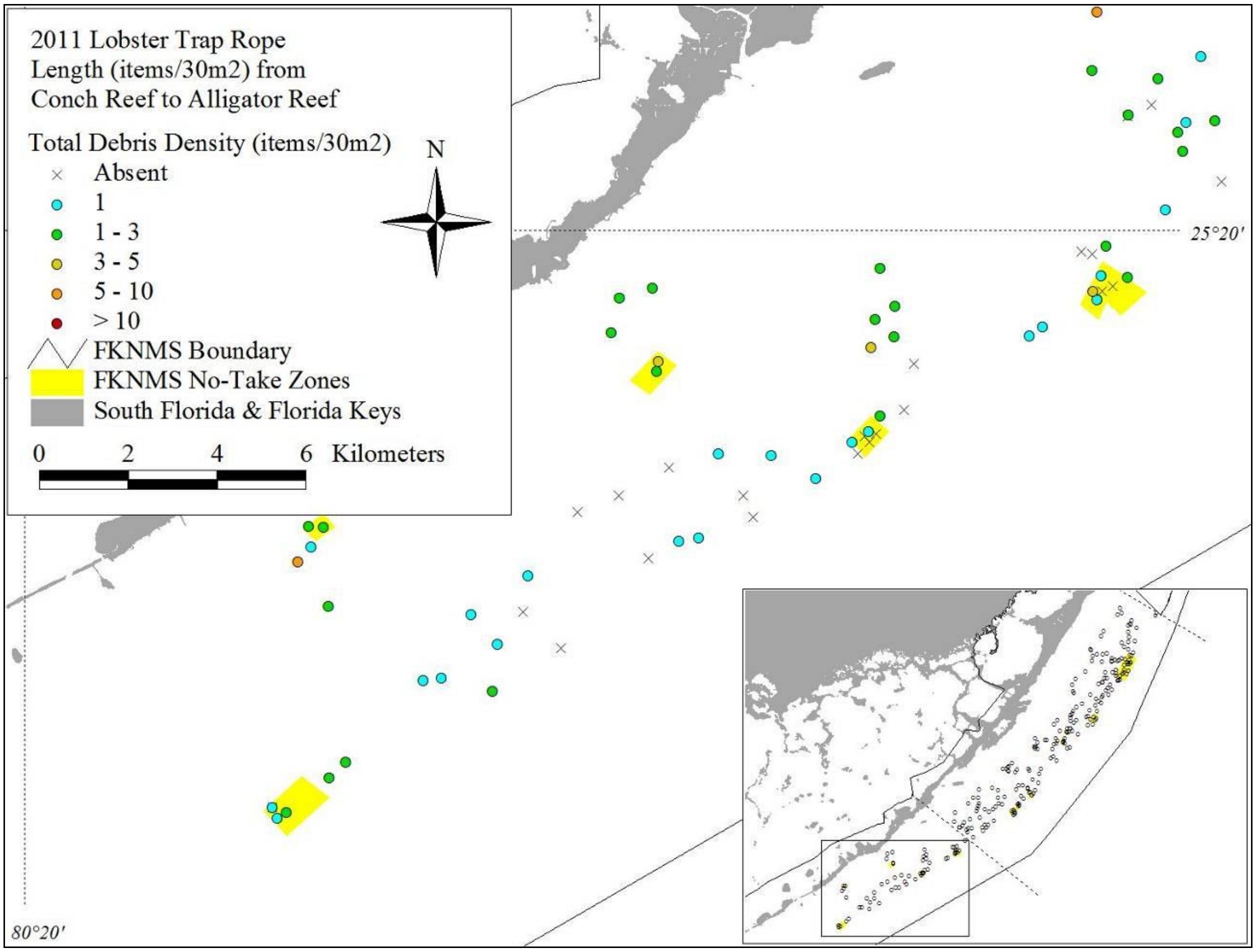
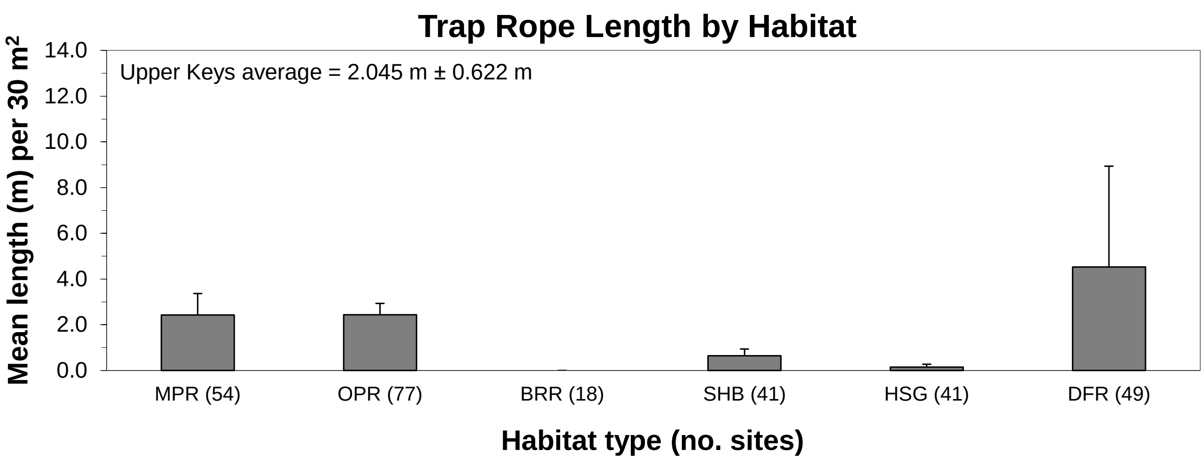


Figure 8-20. Mean (+ 1 SE) length of lobster/crab trap rope retrieved per transect by habitat type (top) and habitat type by management zone (bottom) in the upper Florida Keys during May-September 2011. Domain-wide (upper Keys) values are weighted averages and standard errors. Values on the x-axis in parentheses are the number of sites surveyed in each habitat type, with two 15-m x 1-m transects surveyed per site. Open bars = reference areas (Ref) and filled bars = no-take zones (NTZ) on the bottom figure. Habitat abbreviations are: MPR = inshore and mid-channel patch reefs, OPR = offshore patch reefs, BRR = back-reef rubble, SHB = shallow (< 6 m) hard-bottom, HSG = high-relief and groove, and DFR = deeper (6-15 m) fore-reef habitats.



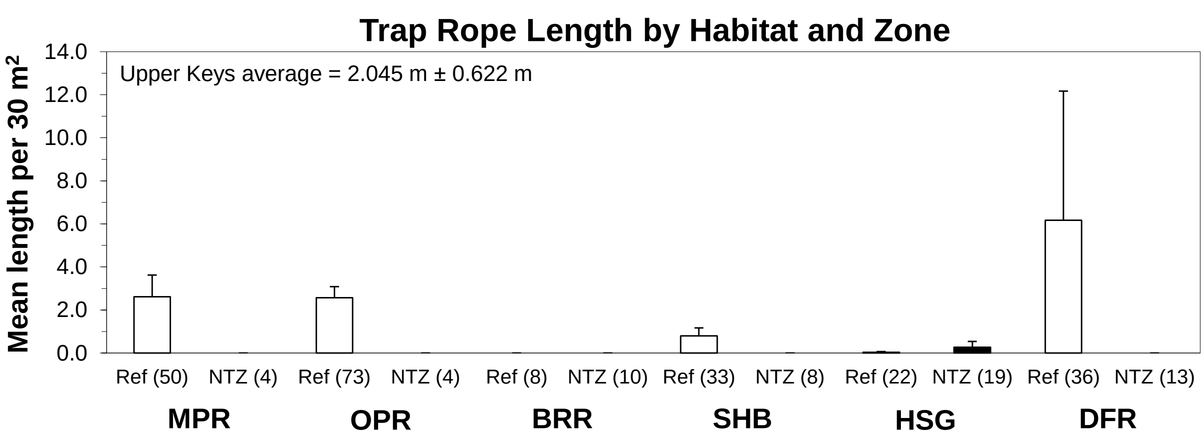


Figure 8-21. Densities (no. items per 30 m^2) of all marine debris items encountered in the upper Florida Keys National Marine Sanctuary from the southern boundary of Biscayne National Park (BNP) to the Watsons Reef area surveyed during May-September 2011.

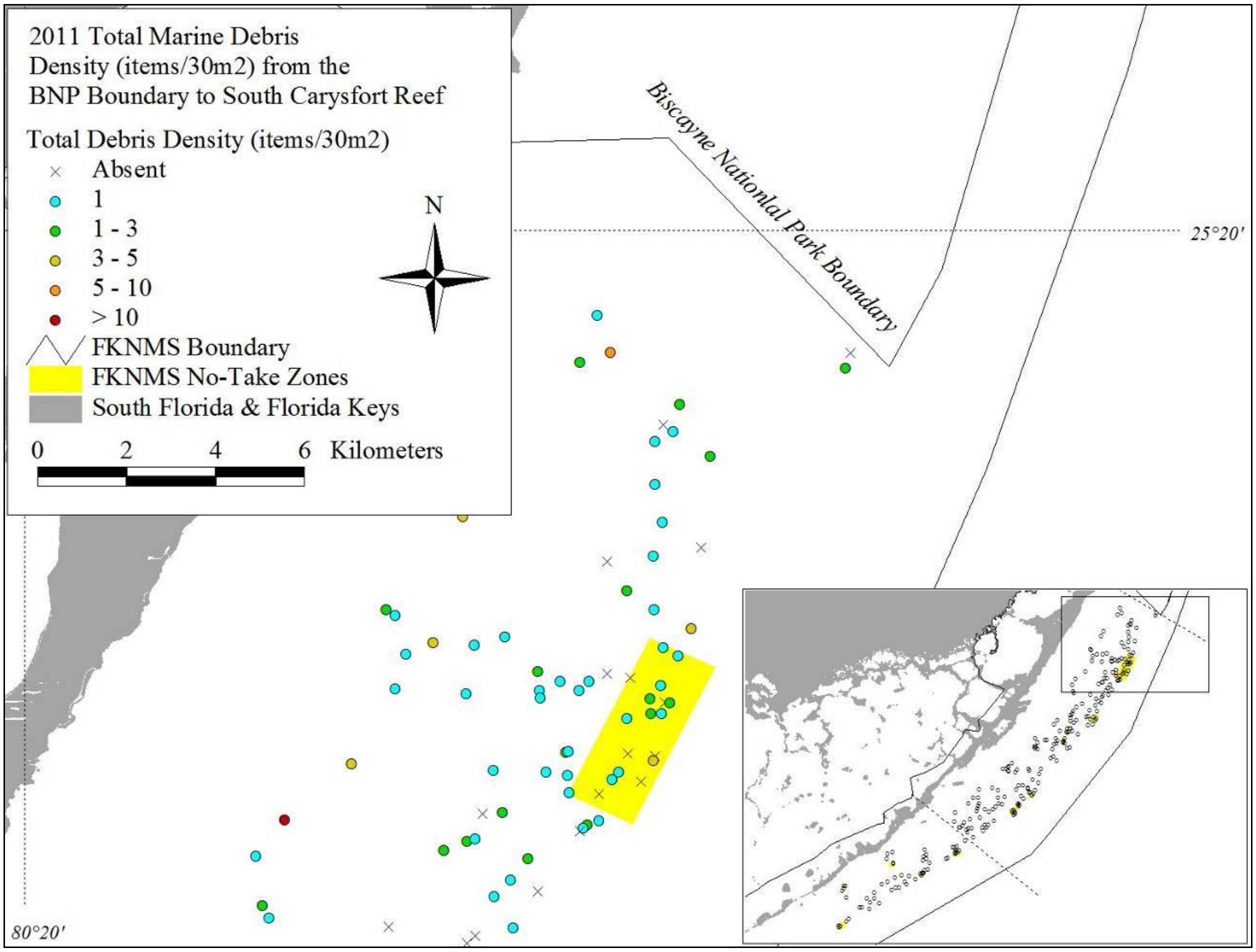


Figure 8-22. Densities (no. items per 30 m^2) of all marine debris items encountered in the upper Florida Keys National Marine Sanctuary from Elbow Reef to the Pickles Reef area surveyed during May-September 2011.

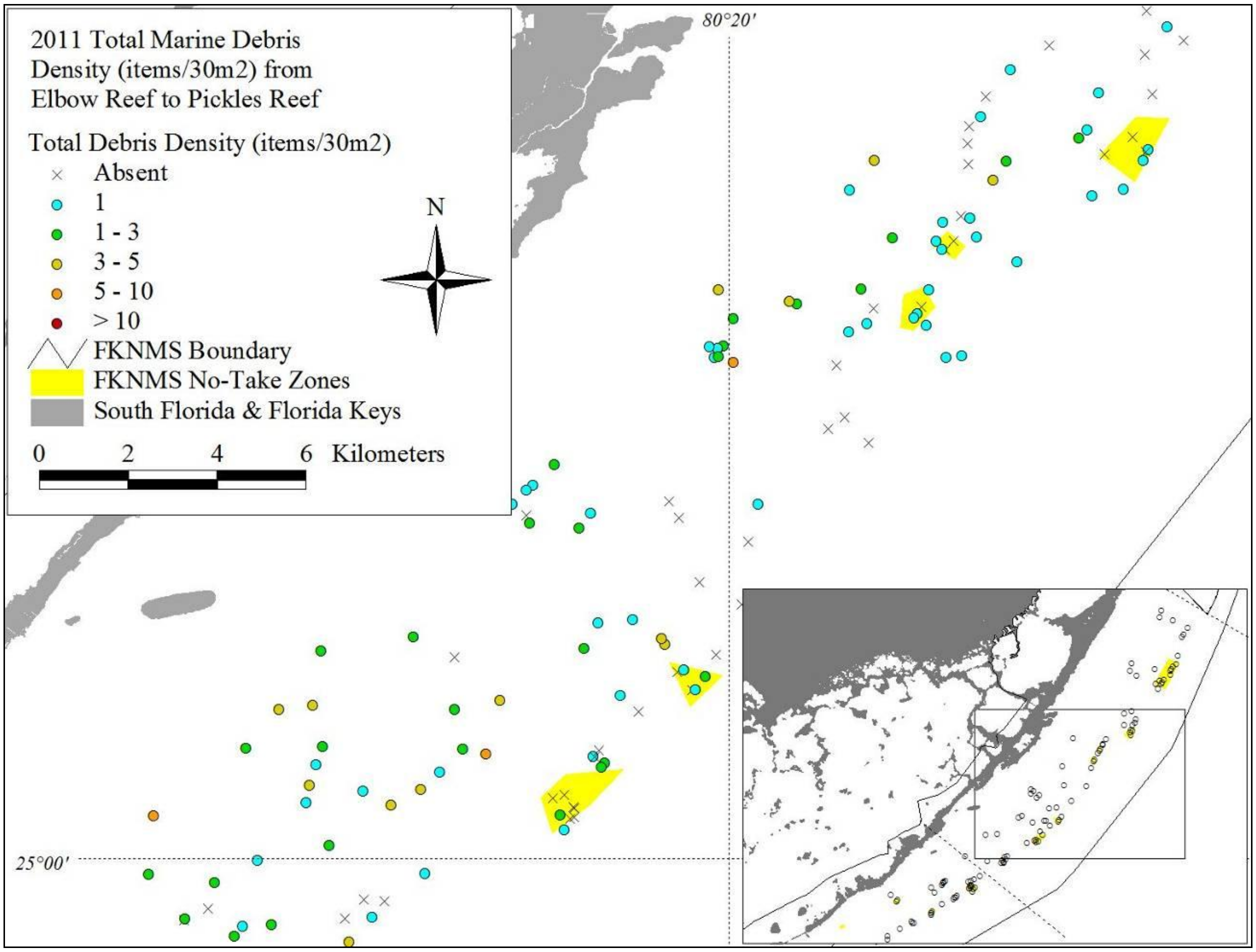


Figure 8-23. Densities (no. items per 30 m^2) of all marine debris items encountered in the upper Florida Keys National Marine Sanctuary from Conch Reef to Alligator Reef surveyed during May-September 2011.

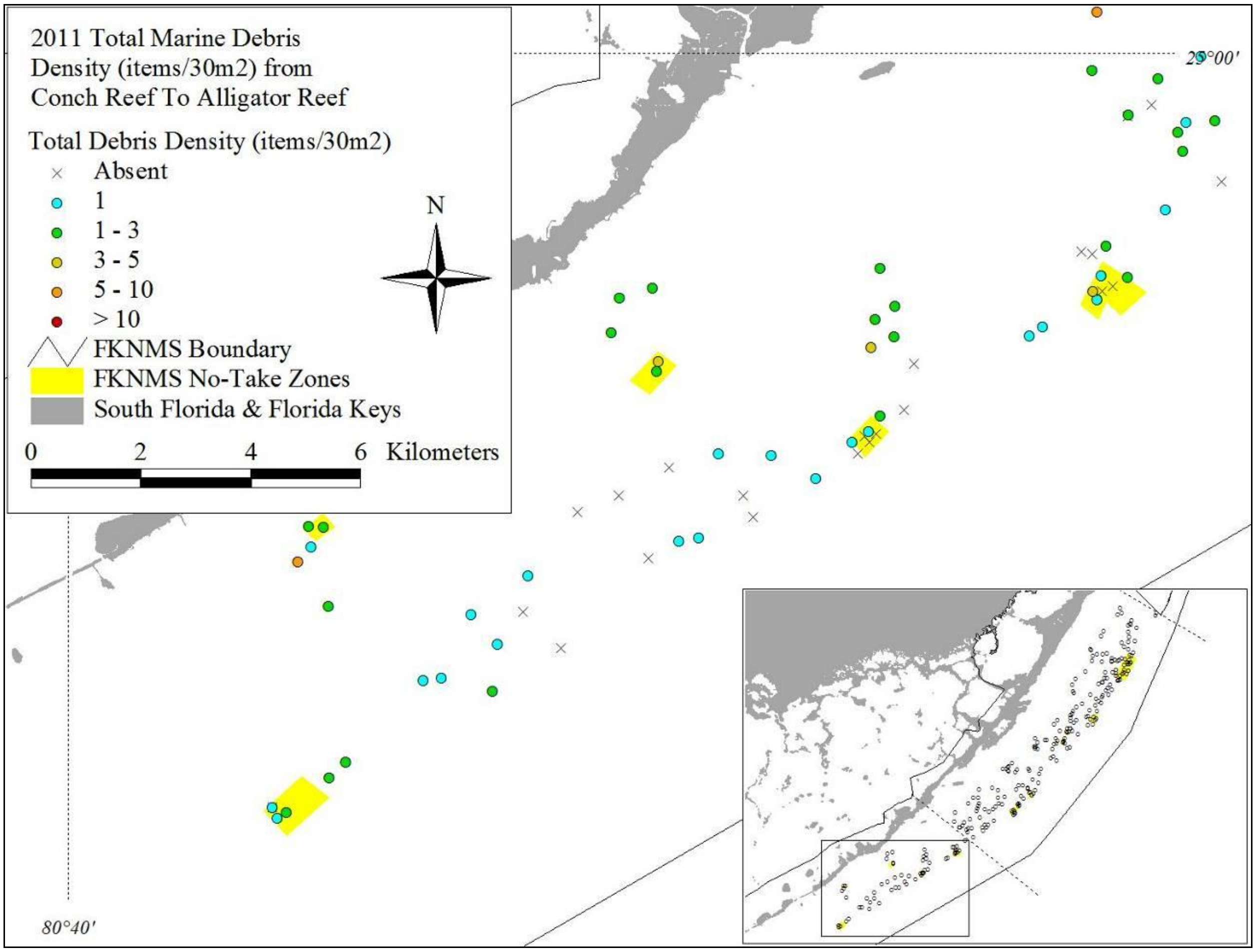
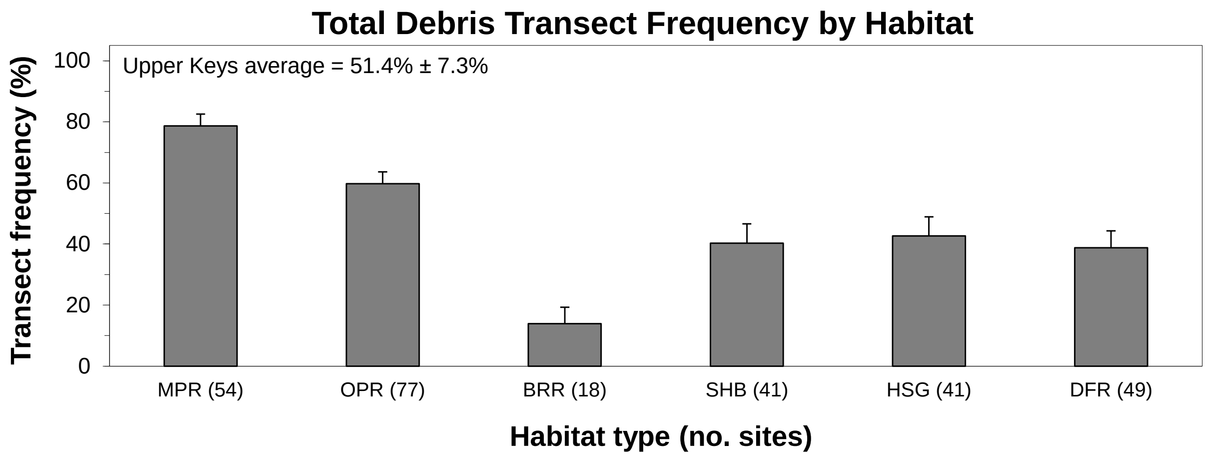


Figure 8-24. Mean (+ 1 SE) transect frequency (top) and density (no. items encountered per 30 m^2) (bottom) of all marine debris items encountered by habitat type in the upper Florida Keys during May-September 2011. Domain-wide (upper Keys) values are weighted averages and standard errors. Values on the x-axis in parentheses are the number of sites surveyed in each habitat type, with two 15-m x 1-m transects surveyed per site.



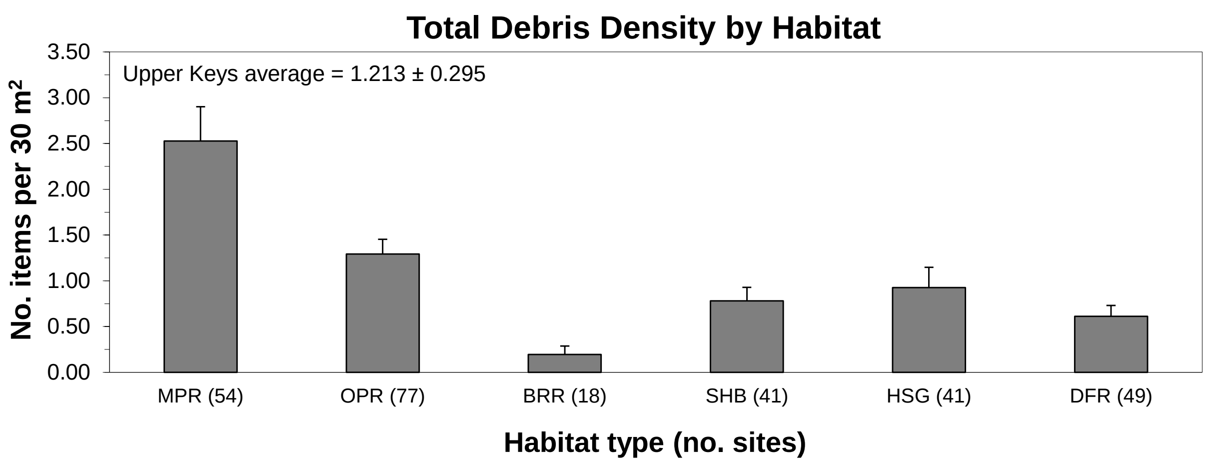
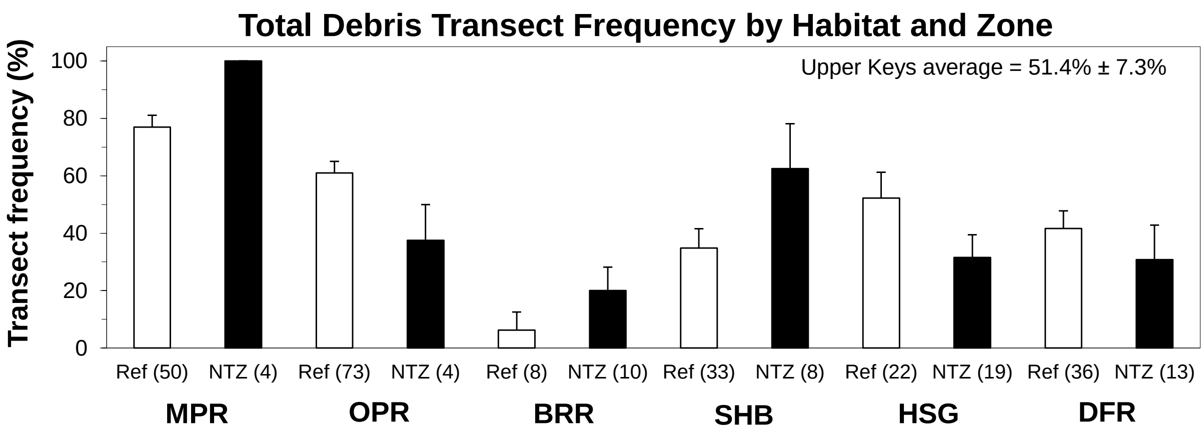


Figure 8-25. Mean (+ 1 SE) transect frequency (top) and density (no. items encountered per 30 m^2) (bottom) of all marine debris items encountered by habitat type and management zone in the upper Florida Keys during May-September 2011. Open bars = reference areas (Ref), filled bars = no-take zones (NTZ). Domain-wide (upper Keys) values are weighted averages and standard errors. Habitat abbreviations are: MPR = inshore and mid-channel patch reefs, OPR = offshore patch reefs, BRR = back-reef rubble, SHB = shallow (< 6 m) hard-bottom, HSG = high-relief and groove, and DFR = deeper (6-15 m) fore-reef habitats. Numbers in parentheses on the x-axis are the number of sites surveyed, with two replicate 15-m x 1-m transects surveyed per site (30 m^2 per site).



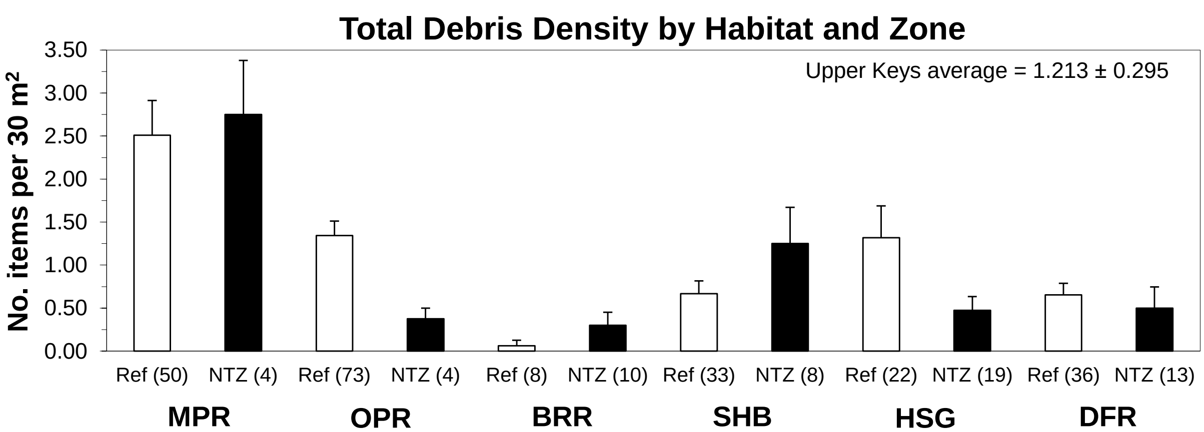
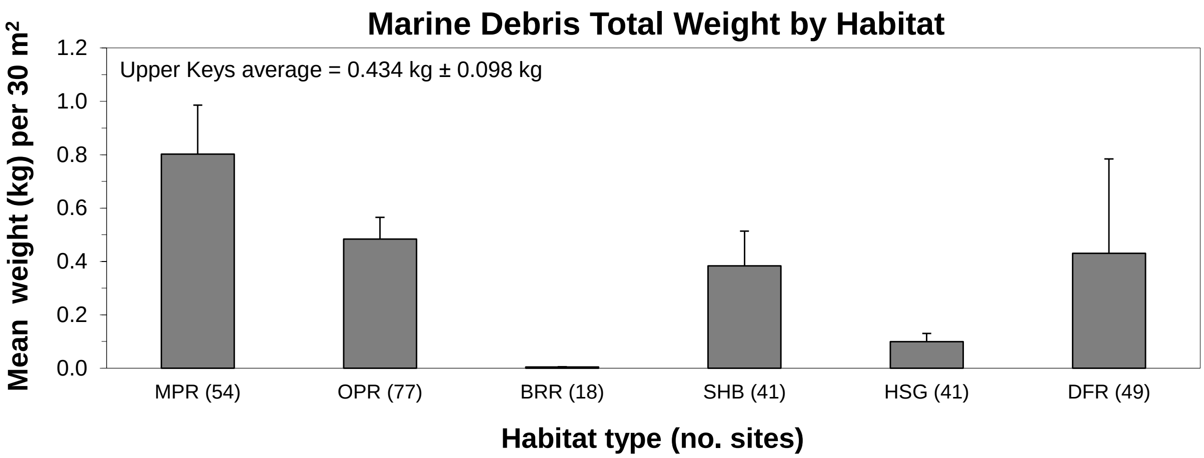


Figure 8-26. Mean (+ 1 SE) weight of all debris encountered per transect (per 30 m^2) by habitat type (top) and by habitat type and management zone (bottom) in the upper Florida Keys during May-September 2011. Domain-wide (upper Keys) values are weighted averages and standard errors. Values on the x-axis in parentheses are the number of sites surveyed in each habitat type or habitat x management zone combination, with two 15-m x 2-m transects surveyed per site. Habitat abbreviations are: MPR = inshore and mid-channel patch reefs, OPR = offshore patch reefs, BRR = back-reef rubble, SHB = shallow (< 6 m) hard-bottom, HSG = high-relief and groove, and DFR = deeper (6-15 m) fore-reef habitats. Numbers in parentheses on the x-axis are the number of sites surveyed, with two replicate 15-m x 1-m transects surveyed per site (30 m^2 per site).



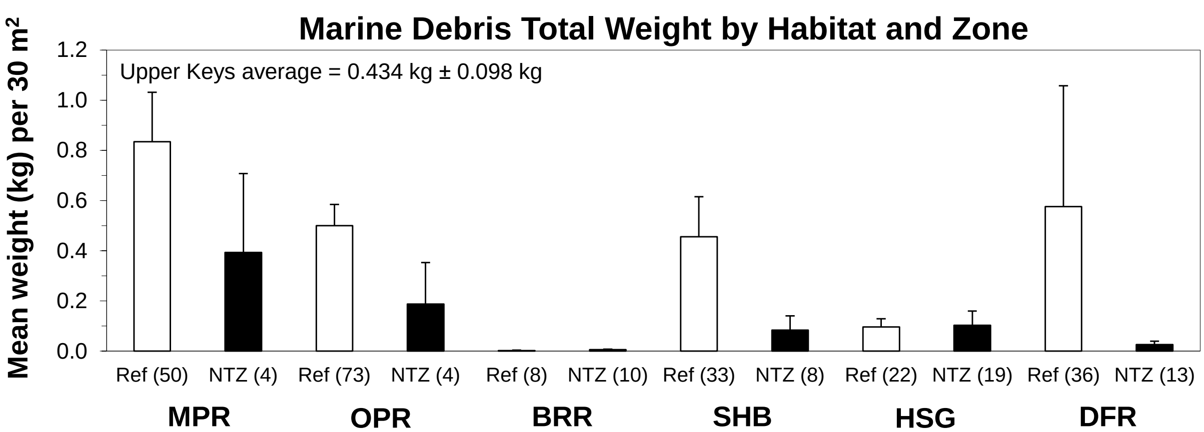


Table 8-1. Number and relative frequency (%) of marine debris items and number and relative frequency (%) of impacts to benthic coral reef organisms in the upper Florida Keys National Marine Sanctuary, as determined from surveys of two 15-m x 2-m belt transects per site at 280 sites during May-September 2011. Impacted organisms were those exhibiting abrasion damage from entangled debris.

Debris type	**N (%)**	***Millepora***	**Scleractinia**	**Gorgonians**	**Sponges**	***Palythoa***	**Total**
Angling gear debris							
Fishing rod	10 (1.5)		1 (1.1)	1 (0.5)			2
Lead sinker	15 (2.2)						0
Hook or lure	2 (0.3)						0
Monofilament	181 (26.7)	14 (31.8)	20 (22.5)	60 (30.8)	3 (9.4)	2 (66.7)	99
Monofilament+hook	19 (2.8)		1 (1.1)	3 (1.5)			4
Monofilament+hook+sinker	6 (0.9)						0
Monofilament+leader	4 (0.6)	1 (2.3)					1
Monofilament+leader+hook	2 (0.3)		1 (1.1)				1
Monofilament+leader+sinker	1 (0.1)						0
Monofilament+lure	2 (0.3)						0
Monofilament+sinker	27 (4.0)		5 (5.6)	8 (4.1)	1 (3.1)	1 (33.3)	15
Wire leader	142 (20.9)	6 (13.6)	7 (7.9)	18 (9.2)	3 (9.4)		34
Wire leader+hook	3 (0.4)			3 (1.5)			3
Wire leader+sinker	4 (0.6)		1 (1.1)	1 (0.5)	1 (3.1)		3
Total angling gear debris	**418 (61.6)**	**21 (47.7)**	**36 (40.4)**	**94 (48.2)**	**8 (25.0)**	**3 (100.0)**	**162**
Lobster/crab trap gear debris							
Cement block	21 (3.1)						0
Plastic trap grating	14 (2.1)			2 (1.0)			2
Plastic pot opening	7 (1.0)		1 (1.1)				1
Rope	73 (10.8)	15 (34.1)	46 (51.7)	83 (42.6)	19 (59.4)		163
Rope+trap	2 (0.3)	1 (2.3)	2 (2.2)	1 (0.5)			4
Rope+wood	1 (0.1)			4 (2.1)			4
Trap (intact)	3 (0.4)						0
Trap frame	1 (0.1)						0
Trap staple	1 (0.1)						0
Wood	48 (7.1)						0
Wood + pot opening	1 (0.1)						0
Total trap gear debris	**172 (0.0)**	**16 (36.4)**	**49 (55.1)**	**90 (46.2)**	**19 (54.9)**	**0 (0.0)**	**174**
Other debris							
Aluminum boat fitting	1 (0.1)						
Aluminum can or pull tab	2 (0.3)						
Anchor with or without rope	4 (0.6)			1 (0.5)	1 (3.1)		2
Boat rub rail	1 (0.1)						
Bottle cap	2 (0.3)						
Cloth	1 (0.1)						
Dive weight	2 (0.3)						
Fiberglass	1 (0.1)						
Glass bottle	26 (3.8)			1 (0.5)	1 (3.1)		2
Hair tie	1 (0.1)						
Metal bracket/other metal	7 (1.0)						
Plastic bag	8 (1.2)			3 (1.5)			3
Plastic band or cord	3 (0.4)	1 (2.3)					1
Plastic panel	3 (0.4)						
Plastic (other)	6 (0.9)						
Rope/string (non-trap)	15 (2.2)	5 (11.4)	2 (2.2)	4 (2.1)	1 (3.1)		12
Steel cable	1 (0.1)						
Stringer	3 (0.4)	1 (2.3)	2 (2.2)	2 (1.0)	2 (6.3)		7
Wood beam	2 (0.3)						
Total other debris	**89 (13.1)**	**7 (15.9)**	**4 (4.5)**	**11 (5.6)**	**5 (15.6)**	**0 (0.0)**	**27**
All marine debris	**679 (100.0)**	**44 (100.0)**	**89 (100.0)**	**195 (100.0)**	**32 (100.0)**	**3 (100.0)**	**363**

Table 8-2. Mean (± 1 SE) site presence, transect frequency, density (no. items per 30 m^2), and total length (m) recovered per transect of combined angling gear debris among habitat types and management zones in the upper Florida Keys, as determined from two replicate 15-m x 2-m belt transect surveys per site at 280 sites from northern Key Largo to Alligator Reef during May-September 2011. Habitat types are arranged from inshore to offshore and no-take zones represent Sanctuary Preservation Areas and Research Only areas. Values represent mean ± 1 SE. N = number of items encountered (total length of angling gear, m).

Habitat/management zone (no. sites)	**Site presence (%)**	**Transect frequency (%)**	**Density (no. per 30 m^2)**	**Total length (m)**	**N**
Inshore and mid-channel patch reefs					
Reference areas (50)	86.0 ± 5.0	69.0 ± 5.1	1.72 ± 0.37	2.59 ± 0.61	172 (259.10)
No-take zones (4)	100.0 ± 0.0	100.0 ± 0.0	2.00 ± 0.35	2.16 ± 0.43	16 (17.24)
Habitat total (54)	87.0 ± 4.6	71.3 ± 4.9	1.74 ± 0.34	2.56 ± 0.57	188 (276.34)
Offshore patch reefs					
Reference areas (73)	54.8 ± 5.9	36.3 ± 4.4	0.69 ± 0.13	0.96 ± 0.25	101 (139.68)
No-take zones (4)	25.0 ± 25.0	12.5 ± 12.5	0.13 ± 0.13	0.18 ± 0.18	1 (1.4)
Habitat total (77)	53.2 ± 5.7	35.1 ± 4.2	0.66 ± 0.13	0.92 ± 0.24	102 (141.08)
Back-reef rubble					
Reference areas (8)	12.5 ± 12.5	6.3 ± 6.3	0.06 ± 0.06	0.06 ± 0.06	1 (1.02)
No-take zones (10)	40.0 ± 16.3	20.0 ± 8.2	0.30 ± 0.15	0.17 ± 0.09	6 (3.38)
Habitat total (18)	27.8 ± 10.9	13.9 ± 5.4	0.19 ± 0.09	0 ± 0	7 (4.40)
Shallow (< 6 m) hard-bottom					
Reference areas (33)	21.2 ± 7.2	12.1 ± 4.4	0.23 ± 0.10	0.28 ± 0.16	15 (18.73)
No-take zones (8)	62.5 ± 18.3	43.8 ± 14.8	0.88 ± 0.42	0.98 ± 0.60	14 (15.68)
Habitat total (41)	29.3 ± 7.2	18.3 ± 4.9	0.35 ± 0.12	0.42 ± 0.18	29 (34.41)
High-relief spur and groove					
Reference areas (22)	45.5 ± 10.9	34.1 ± 8.9	1.00 ± 0.38	1.09 ± 0.45	44 (47.94)
No-take zones (19)	47.4 ± 11.8	23.7 ± 5.9	0.32 ± 0.10	0.31 ± 0.13	12 (11.92)
Habitat total (41)	46.3 ± 7.9	29.3 ± 5.5	0.68 ± 0.21	0.73 ± 0.25	56 (59.86)
Deeper fore reef					
Reference areas (36)	44.4 ± 8.4	26.4 ± 5.5	0.36 ± 0.09	0.45 ± 0.15	26 (32.44)
No-take zones (13)	30.8 ± 13.3	23.1 ± 10.8	0.38 ± 0.21	0.30 ± 0.15	10 (7.86)
Habitat total (49)	40.8 ± 7.1	25.5 ± 4.9	0.37 ± 0.09	0.41 ± 0.12	36 (40.30)

Table 8-3. Mean (± 1 SE) site presence, transect frequency, and density (no. items per 30 m^2) of combined lobster/crab trap debris and total trap rope length (m) recovered per transect among habitat types and management zones in the upper Florida Keys, as determined from two replicate 15-m x 2-m belt transect surveys per site at 280 sites from northern Key Largo to Alligator Reef during May-September 2011. Habitat types are arranged from inshore to offshore and no-take zones represent Sanctuary Preservation Areas and Research Only areas. Values represent mean ± 1 SE. N = number of items encountered (total length of trap rope, m).

Habitat/management zone (no. sites)	**Site presence (%)**	**Transect frequency (%)**	**Density (no. per 30 m^2)**	**Total length (m)**	**N**
Inshore and mid-channel patch reefs					
Reference areas (50)	46.0 ± 7.1	31.0 ± 5.3	0.55 ± 0.11	2.62 ± 1.01	29 (261.68)
No-take zones (4)	50.0 ± 28.9	37.5 ± 23.9	0.25 ± 0.14	0	0 (0)
Habitat total (54)	46.3 ± 6.8	31.5 ± 5.2	0.53 ± 0.10	2.42 ± 0.94	29 (261.68)
Offshore patch reefs					
Reference areas (73)	53.4 ± 5.9	32.9 ± 4.0	0.47 ± 0.07	2.57 ± 0.51	36 (375.44)
No-take zones (4)	25.0 ± 25.0	12.5 ± 12.5	0.13 ± 0.13	0	0 (0)
Habitat total (77)	51.9 ± 5.7	31.8 ± 3.9	0.45 ± 0.07	2.44 ± 0.49	36 (375.44)
Back-reef rubble					
Reference areas (8)	0 ± 0	0 ± 0	0 ± 0	0	0 (0)
No-take zones (10)	0 ± 0	0 ± 0	0 ± 0	0	0 (0)
Habitat total (18)	0 ± 0	0 ± 0	0 ± 0	0	0 (0)
Shallow (< 6 m) hard-bottom					
Reference areas (33)	33.3 ± 8.3	19.7 ± 5.3	0.26 ± 0.08	0.80 ± 0.37	6 (52.58)
No-take zones (8)	0 ± 0	0 ± 0	0 ± 0	0	0 (0)
Habitat total (41)	26.8 ± 7.0	15.9 ± 4.4	0.21 ± 0.06	0.64 ± 0.30	8 (52.58)
High-relief spur and groove					
Reference areas (22)	36.4 ± 10.5	22.7 ± 7.2	0.27 ± 0.09	0.03 ± 0.03	1 (1.53)
No-take zones (19)	15.8 ± 8.6	7.9 ± 4.3	0.08 ± 0.04	0.27 ± 0.27	1 (10.15)
Habitat total (41)	26.8 ± 7.0	15.9 ± 4.4	0.18 ± 0.05	0.14 ± 0.12	2 (11.68)
Deeper fore reef					
Reference areas (36)	22.2 ± 7.0	13.9 ± 4.7	0.21 ± 0.10	6.16 ± 6.00	3 (443.84)
No-take zones (13)	0 ± 0	0 ± 0	0 ± 0	0	0 (0)
Habitat total (49)	16.3 ± 5.3	10.2 ± 3.6	0.15 ± 0.08	4.53 ± 4.41	3 (443.84)

Table 8-4. Mean (± 1 SE) site presence, transect frequency, and density (no. items per 30 m^2) of combined "other" debris (plastics, glass, metals) among habitat types and management zones in the upper Florida Keys, as determined from two replicate 15-m x 2-m belt transect surveys per site at 280 sites from northern Key Largo to Alligator Reef during May-September 2011. Habitat types are arranged from inshore to offshore and no-take zones represent Sanctuary Preservation Areas and Research Only areas. Values represent mean ± 1 SE. N = number of items encountered.

Habitat/management zone (no. sites)	**Site presence (%)**	**Transect frequency (%)**	**Density (no. per 30 m^2)**	**N**
Inshore and mid-channel patch reefs				
Reference areas (50)	32.0 ± 6.7	20.0 ± 4.5	0.26 ± 0.06	26
No-take zones (4)	75.0 ± 25.0	50.0 ± 20.4	0.50 ± 0.20	4
Habitat total (54)	35.2 ± 6.6	22.2 ± 4.5	0.28 ± 0.06	30
Offshore patch reefs				
Reference areas (73)	26.0 ± 5.2	16.4 ± 3.5	0.18 ± 0.04	26
No-take zones (4)	25.0 ± 25.0	12.5 ± 12.5	0.13 ± 0.13	1
Habitat total (77)	26.0 ± 5.0	16.2 ± 3.4	0.18 ± 0.04	27
Back-reef rubble				
Reference areas (8)	0 ± 0	0 ± 0	0 ± 0	0
No-take zones (10)	0 ± 0	0 ± 0	0 ± 0	0
Habitat total (18)	0 ± 0	0 ± 0	0 ± 0	0
Shallow (< 6 m) hard-bottom				
Reference areas (33)	30.3 ± 8.1	16.7 ± 4.7	0.18 ± 0.05	12
No-take zones (8)	37.5 ± 18.3	25.0 ± 13.4	0.38 ± 0.25	6
Habitat total (41)	31.7 ± 7.4	18.3 ± 4.5	0.22 ± 0.06	18
High-relief spur and groove				
Reference areas (22)	9.1 ± 6.3	4.5 ± 3.1	0.05 ± 0.03	2
No-take zones (19)	10.5 ± 7.2	5.3 ± 3.6	0.08 ± 0.06	3
Habitat total (41)	9.8 ± 4.7	4.9 ± 2.3	0.06 ± 0.03	5
Deeper fore reef				
Reference areas (36)	16.7 ± 6.3	8.3 ± 3.1	0.08 ± 0.03	6
No-take zones (13)	15.4 ± 10.4	11.5 ± 8.3	0.12 ± 0.08	3
Habitat total (49)	16.3 ± 5.3	9.2 ± 3.2	0.09 ± 0.03	9

Table 8-5. Mean (± 1 SE) site presence, transect frequency, density (no. items per 30 m^2), and wet weight (kg per 30 m^2) recovered of all debris categories among habitat types and management zones in the upper Florida Keys, as determined from two replicate 15-m x 2-m belt transect surveys per site at 280 sites from northern Key Largo to Alligator Reef during May-September 2011. Habitat types are arranged from inshore to offshore and no-take zones represent Sanctuary Preservation Areas and Research Only areas. Values represent mean ± 1 SE. N = number of items encountered.

Habitat/management zone (no. sites)	**Site presence (%)**	**Transect frequency (%)**	**Density (no. per 30 m^2)**	**Wet weight (kg)**	**N**
Inshore and mid-channel patch reefs					
Reference areas (50)	96.0 ± 2.8	77.0 ± 4.1	2.51 ± 0.40	0.835 ± 0.197	251
No-take zones (4)	100.0 ± 100.0	100.0 ± 100.0	2.75 ± 0.63	0.393 ± 0.314	22
Habitat total (54)	96.3 ± 2.6	78.7 ± 3.9	2.53 ± 0.37	0.802 ± 0.184	273
Offshore patch reefs					
Reference areas (73)	84.9 ± 4.2	61.0 ± 4.1	1.34 ± 0.17	0.500 ± 0.084	196
No-take zones (4)	75.0 ± 25.0	37.5 ± 12.5	0.38 ± 0.13	0.188 ± 0.165	3
Habitat total (77)	84.4 ± 4.2	59.7 ± 3.9	1.29 ± 0.16	0.484 ± 0.081	199
Back-reef rubble					
Reference areas (8)	12.5 ± 12.5	6.3 ± 6.3	0.06 ± 0.06	0.002 ± 0.002	1
No-take zones (10)	40.0 ± 16.3	20.0 ± 8.2	0.30 ± 0.15	0.006 ± 0.002	6
Habitat total (18)	27.8 ± 10.9	13.9 ± 5.4	0.19 ± 0.09	0.004 ± 0.002	7
Shallow (< 6 m) hard-bottom					
Reference areas (33)	51.5 ± 8.8	34.8 ± 6.7	0.67 ± 0.15	0.456 ± 0.160	44
No-take zones (8)	75.0 ± 16.4	62.5 ± 15.7	1.25 ± 0.42	0.083 ± 0.058	20
Habitat total (41)	56.1 ± 7.8	40.2 ± 6.3	0.78 ± 0.15	0.383 ± 0.131	64
High-relief spur and groove					
Reference areas (22)	68.2 ± 10.2	52.3 ± 9.0	1.32 ± 0.37	0.096 ± 0.033	58
No-take zones (19)	52.6 ± 11.8	31.6 ± 7.8	0.47 ± 0.16	0.103 ± 0.056	18
Habitat total (41)	61.0 ± 7.7	42.7 ± 6.2	0.93 ± 0.22	0.099 ± 0.031	76
Deeper fore reef					
Reference areas (36)	63.9 ± 8.1	41.7 ± 6.1	0.65 ± 0.13	0.576 ± 0.481	47
No-take zones (13)	38.5 ± 14.0	30.8 ± 12.1	0.50 ± 0.25	0.026 ± 0.013	13
Habitat total (49)	57.1 ± 7.1	38.8 ± 5.5	0.61 ± 0.12	0.430 ± 0.354	60

IX. Conclusions and Future Efforts

Survey results from 2011 add to a growing dataset on the distribution, abundance, size, and condition of benthic coral reef organisms in the Florida Keys National Marine Sanctuary (FKNMS). For many of the variables assessed, we have now developed a 12-year record dating back to 1999 to evaluate benthic community structure and change in no-take zones throughout the Sanctuary. Our monitoring is also conducted to address the larger-scale habitat variability of coral reef and hard-bottom habitats found throughout the FKNMS. This larger perspective allows us to interpret results from no-take-zones within the context of natural system variability and the various factors that can impact hard-bottom and coral reef communities. Benthic surveys completed in 2011 in the upper Florida Keys region included *Acropora* corals, non-*Acropora* corals, urchins, anemones, corallimorpharians, mollusks, and marine debris. We have previously sampled the upper, middle, and lower Florida Keys three times in the last eleven years, with additional periodic efforts conducted in-between that focus regionally or on a subset of our total benthic variable list.

Despite the continual bad news typically reported in the press about the condition and fate of coral reefs, worldwide and in Florida, our results suggest that there is also good news to report, based on our 2011 surveys in the upper Florida Keys, including:

- Staghorn corals (*Acropora cervicornis*) still occur in relatively large numbers, even though colonies are mostly small (< 1 m) and found largely in the patch reef environment. Most of the staghorn corals in the upper Keys are currently found outside of FKNMS no-take zones.
- Large (10-15 m diameter) thickets of elkhorn coral (*A. palmata*) continue to persist at several platform margin reefs. Most of the remaining thickets of elkhorn coral occur within the boundaries of existing FKNMS no-take zones.
- Many other coral species continue to exist at relatively high densities and large sizes in certain habitats, especially patch reefs.
- Urchins, specifically *Diadema antillarum*, continue to show slow, but consistent increases in abundance and size. It appears the back-reef rubble continues to provide an important recruitment habitat for *D. antillarum* and other echinoids, although the fate of these post-settlement juveniles has not been studied.

There are also many observations and patterns that are not so encouraging.

- While staghorn corals are abundant and small (< 1 m diameter), no extensive thickets have been observed now for several years. In addition, fore-reef areas that historically supported extensive stands appear devoid of staghorn corals.
- Elkhorn corals are extremely limited in distribution and continue to suffer tissue loss from predation. Some reef flat and reef crest areas that historically supported dense stands appear to be devoid of this species.
- Urchin densities, specifically *Diadema antillarum*, are still a hundred times less abundant than values reported prior to the 1983-84 mortality event.
- *Coralliophila* snails appear to be increasing in abundance and are found preying upon a greater variety of coral species than we have observed before.
- Marine debris, especially lost fishing gear that becomes entangled on the seabed, continues to be pervasive in many habitats, especially patch reefs, and in most of the FKNMS no-take-zones.
- Inshore and some bank/channel patch reef areas affected by the January 2010 cold-front event suffered extensive mortality of some stony coral (e.g. *Montastraea* spp.) and gorgonian species and are now largely covered with turf and drift algae. However, this pattern is not apparent on reefs further offshore.
- During 2011, we encountered more lionfish at more sites than ever before. All of the individuals observed were relatively small (probably juveniles) and were largely found on patch reefs.

The cumulative results of our program define baseline conditions for coral reef community structure throughout the FKNMS and Dry Tortugas, including marine protected areas. However, sampling only began in 1999 and thus represents an effort established long after major declines had already occurred throughout the system, especially related to the loss of *Acropora* corals from disease, starting in the late 1970s, the demise of the urchin *Diadema antillarum* in the early 1980s, coral bleaching, first noted as a regional phenomenon in the early 1980s and periodically since then, and various other stressors that impact this ecosystem. However, because we sample system-wide, and because we sample much more than just corals, results from our program will help us distinguish between changes that result from no-take management strategies and natural system variability.

In 2012, we will be coordinating a region-wide assessment of *Acropora* corals in U.S. territorial waters, including southeast Florida, the U.S. Virgin Islands, and Puerto Rico. We plan to survey *Acropora* corals for abundance, size, and condition throughout most of the Florida Keys ecosystem, specifically from northern Biscayne National Park to the Marquesas Keys. Based upon funding, we also intend to sample Keys-wide for urchins, anemones/corallimorpharians, selected mollusks, and marine debris. We are also seeking funding to additionally sample our full suite of benthic variables, as we have done Keys-wide three times previously, including other corals, gorgonians, and sponges. Because we are coordinating the *Acropora* sampling efforts in the U.S. Caribbean, we completed a second draft of a Field Protocol Manual in December 2011 to help standardize regional survey efforts.

In 2012, we also plan to continue our collaboration with Nancy Sheridan of the Florida Fish & Wildlife Research Institute to sample ocean-side and nearshore-Florida Bay-Biscayne Bay hard-bottom and seagrass matrix habitats for benthic community structure, with a focus on several species targeted by the marine aquarium trade. Along with fishery-dependent data on landings and aggregation locations, these data will provide both fishery-dependent and independent population assessments of targeted species. This will also provide an unprecedented data set from nearshore to offshore habitats for evaluating the population status of benthic organisms.

In 2012, we will also continue to analyze data and prepare publications. Of particular note is work related to our long-term record of surveys in the FKNMS and additional multivariate work related to describe the distribution and abundance of species and habitat types throughout the region. The data set provides unmatched spatial coverage of organism habitat distribution, density, and size, as well as a means to evaluate temporal changes related to the FKNMS zoning action plan relative to larger-scale phenomena. Below is a list of manuscripts published to date. Of particular note is a Ph.D. dissertation completed this year by Dr. Dione Swanson, based on work conducted with our program (Swanson 2011).

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