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.

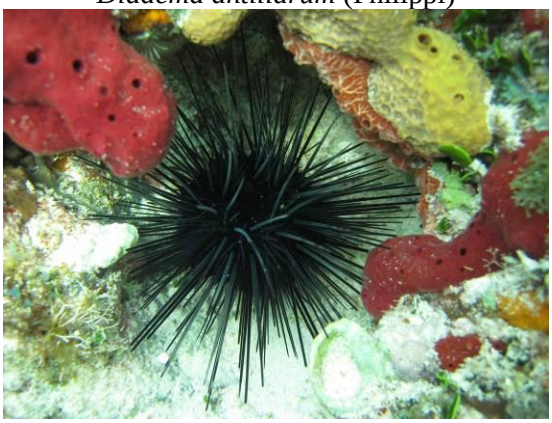
The slow and prolonged recovery of *Diadema antillarum* in the Florida Keys, especially compared to reports of more rapid recovery in some Caribbean reef areas, raises several questions pertaining to factors that may inhibit population recovery (Lessios 1988). Possible causes of slow recovery include 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)

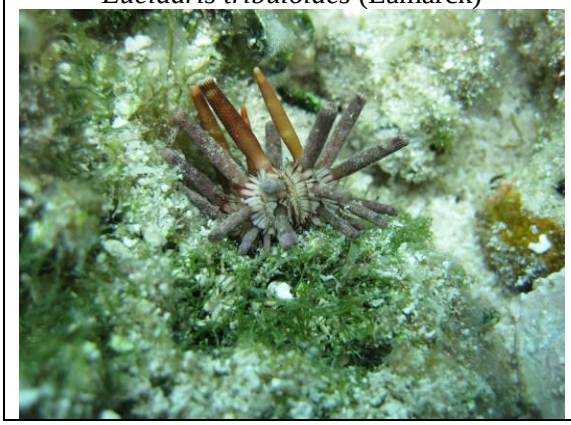
Diadema antillarum (Philippi)



Echinometra lucunter (Linnaeus)

Echinometra viridis (Agassiz)

Eucidaris tribuloides (Lamarck)



Lytechinus variegates (Lamarck)

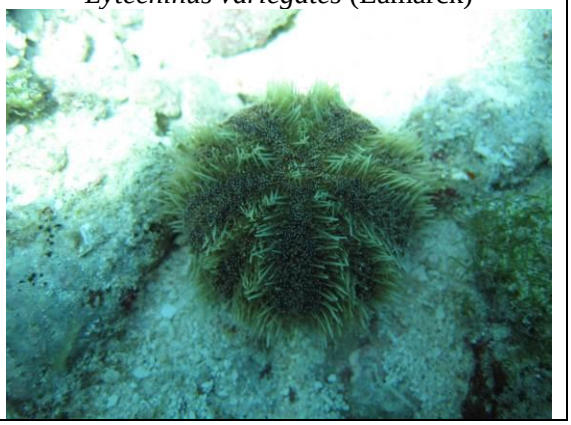
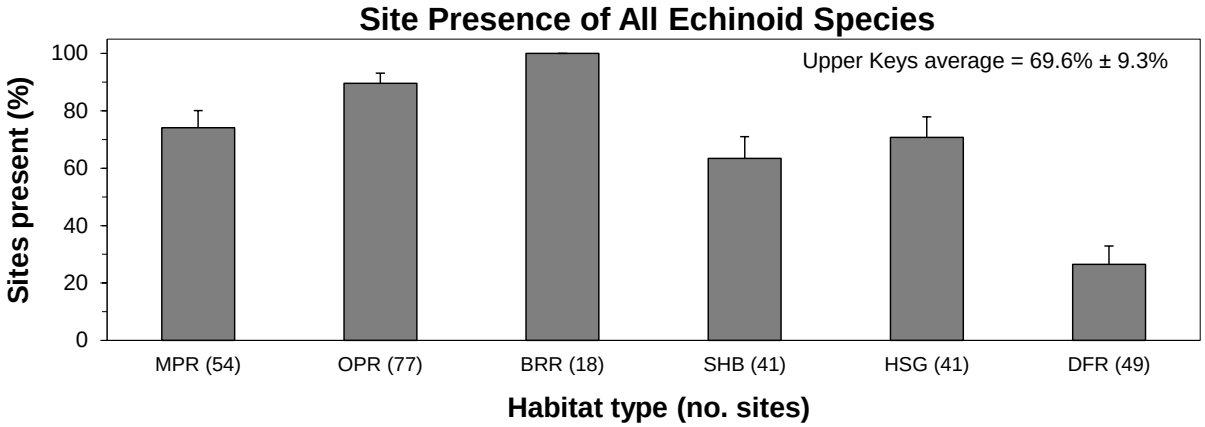


Figure 5-2. Mean (+ 1 SE) site presence (top) and site species richness (no. species per 30 m^2) (bottom) of all echinoid species by habitat type in the upper Florida Keys during May-September 2011. Domain-wide (upper Keys) values are weighted averages and standard errors. Values on the x-axis in parentheses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



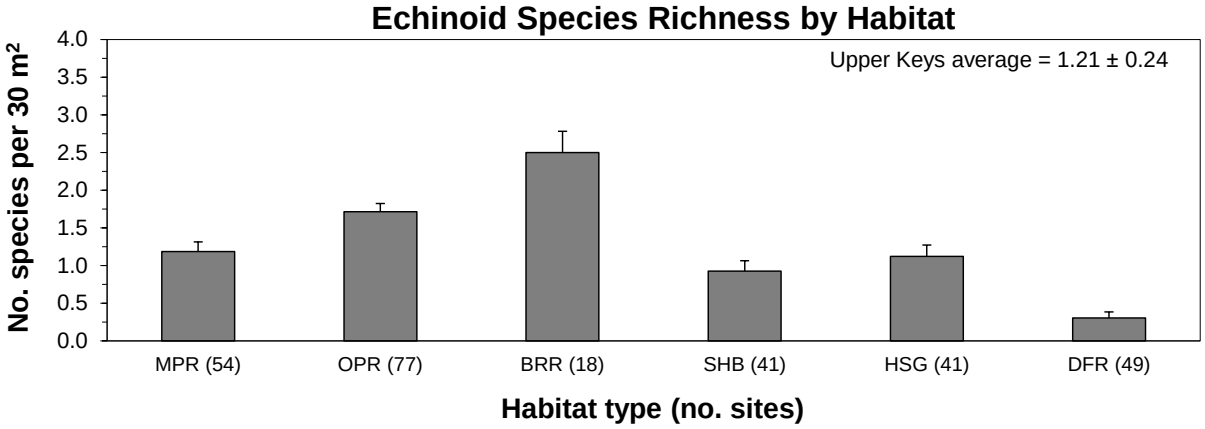


Figure 5-3. Mean (+ 1 SE) site presence (top) and site species richness (no. species per 30 m^2) (bottom) of all echinoid species by habitat type and management zone in the upper Florida Keys during May-September 2011. Open bars = reference areas (Ref), filled bars = no-take zones (NTZ). Domain-wide (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).

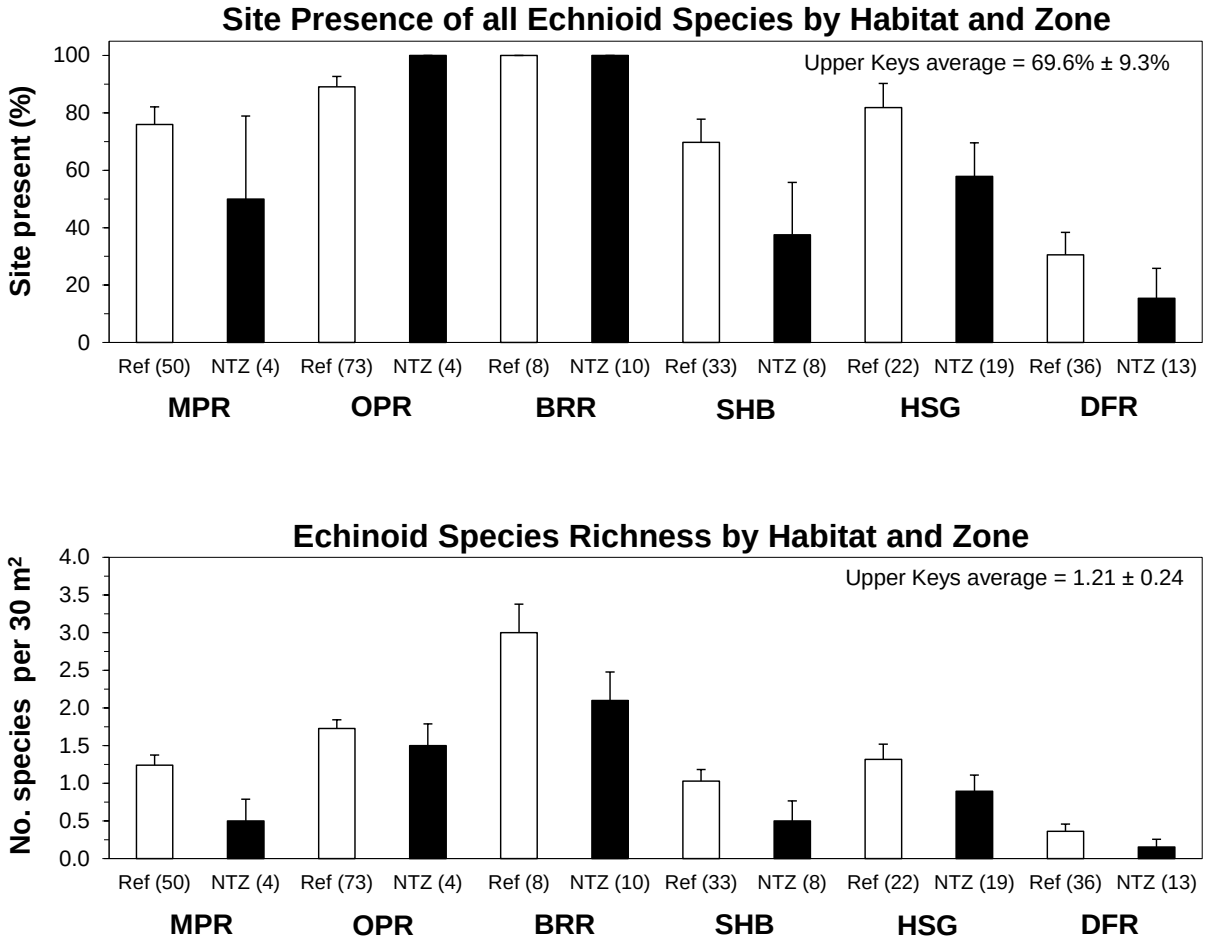


Figure 5-4. Densities (no. per m^2) of long-spined sea urchins (*Diadema antillarum*) in the upper Florida Keys National Marine Sanctuary from the southern boundary of Biscayne National Park to Carysfort/S. Carysfort Reef surveyed during May-September 2011.

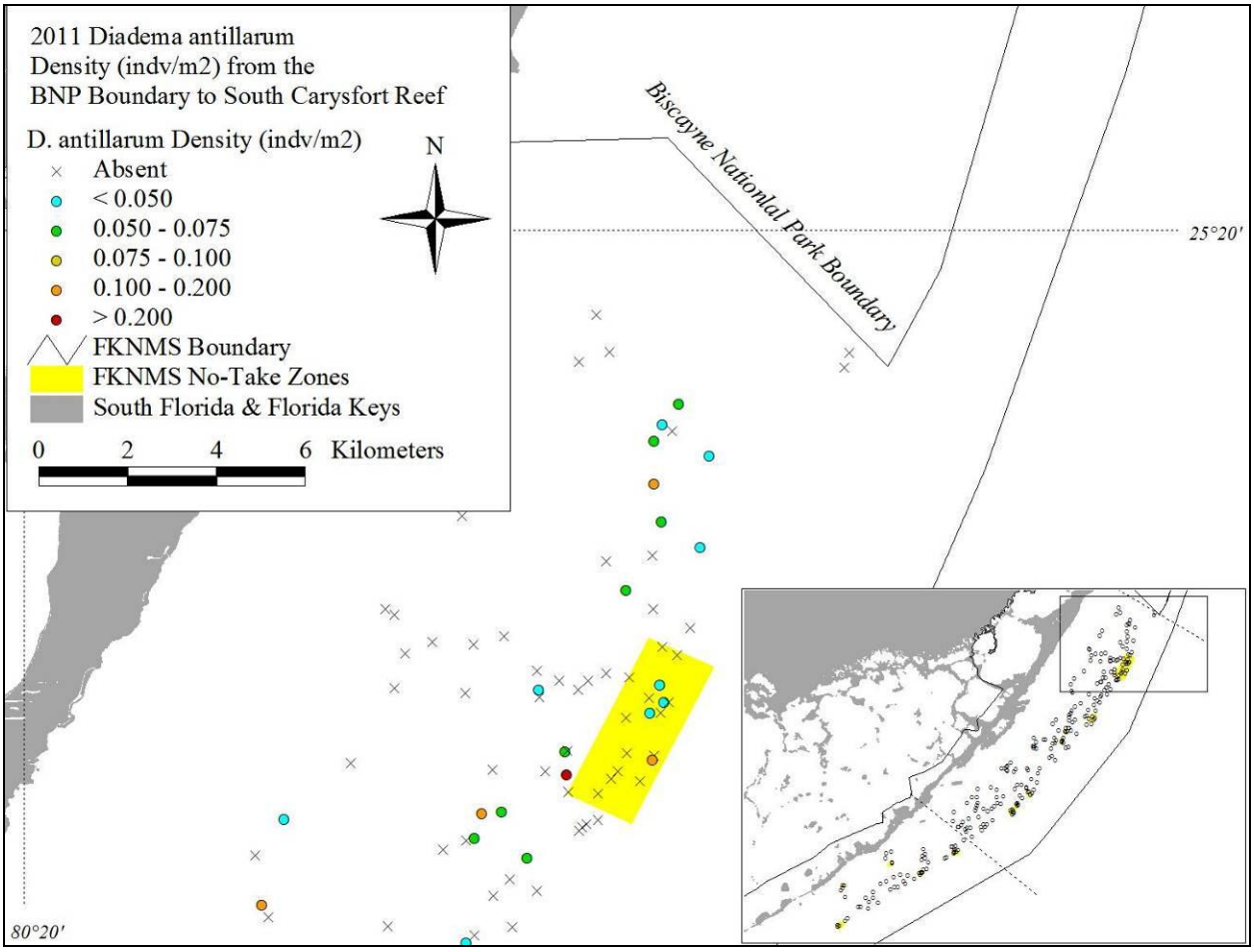


Figure 5-5. Densities (no. per m^2) of long-spined sea urchins (*Diadema antillarum*) in the upper Florida Keys National Marine Sanctuary from Elbow Reef to Pickles Reef surveyed during May-September 2011.

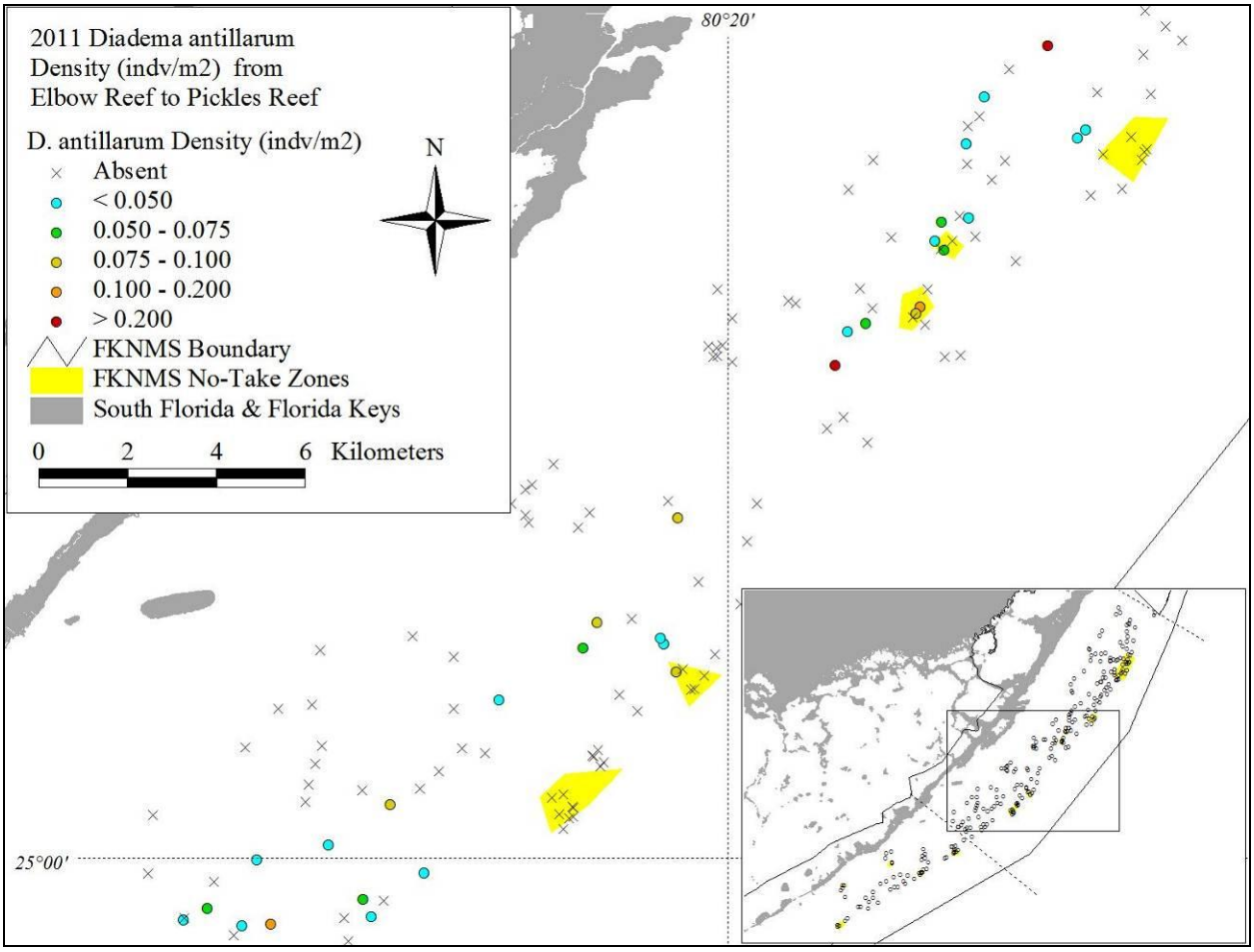


Figure 5-6. Densities (no. per m^2) of long-spined sea urchins (*Diadema antillarum*) in the upper Florida Keys National Marine Sanctuary from Conch Reef SPA to Alligator Reef surveyed during May-September 2011.

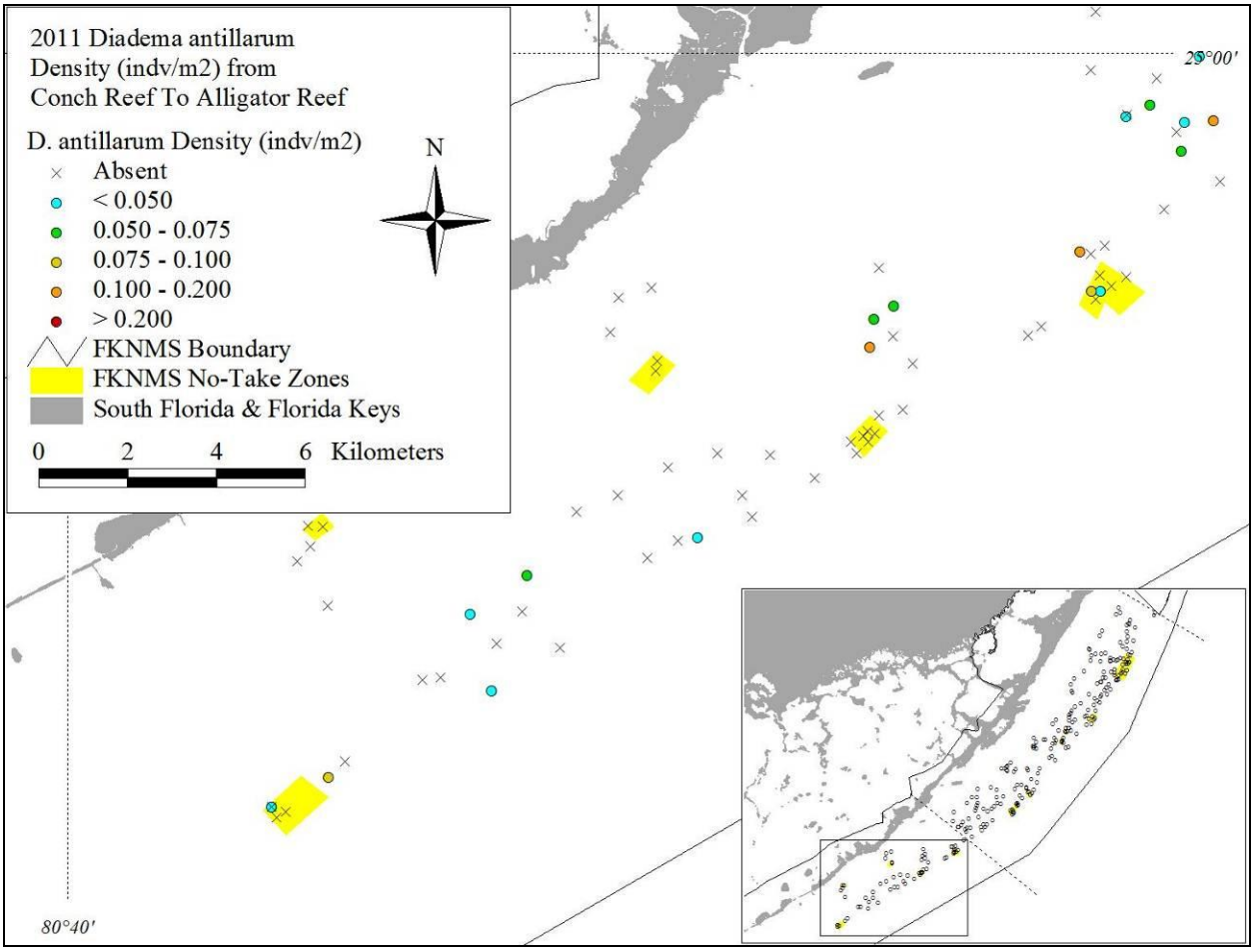
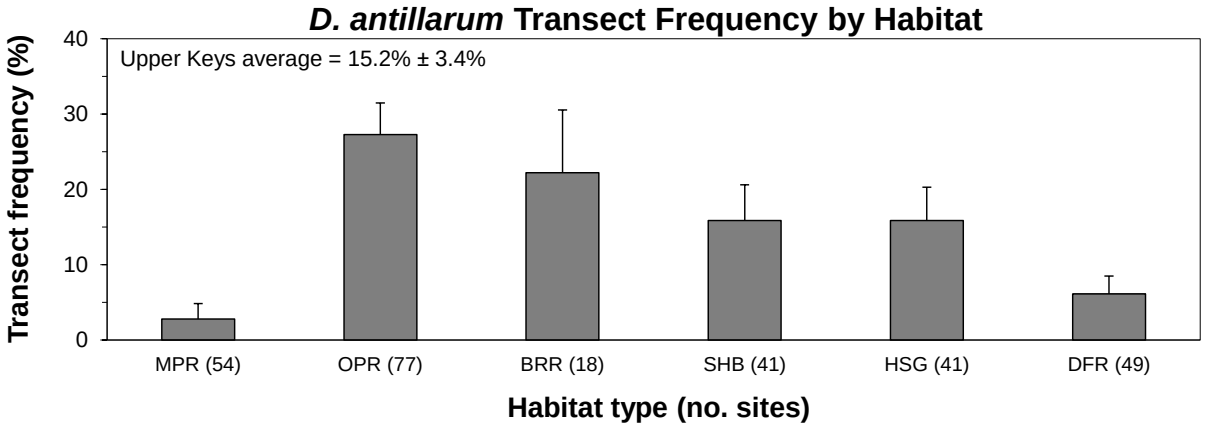


Figure 5-7. Mean (+ 1 SE) transect frequency (top) and density (no. individuals per m^2) (bottom) of long-spined sea urchins (*Diadema antillarum*) by habitat type in the upper Florida Keys during May-September 2011. Domain-wide (upper Keys) values are weighted averages and standard errors. Values on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



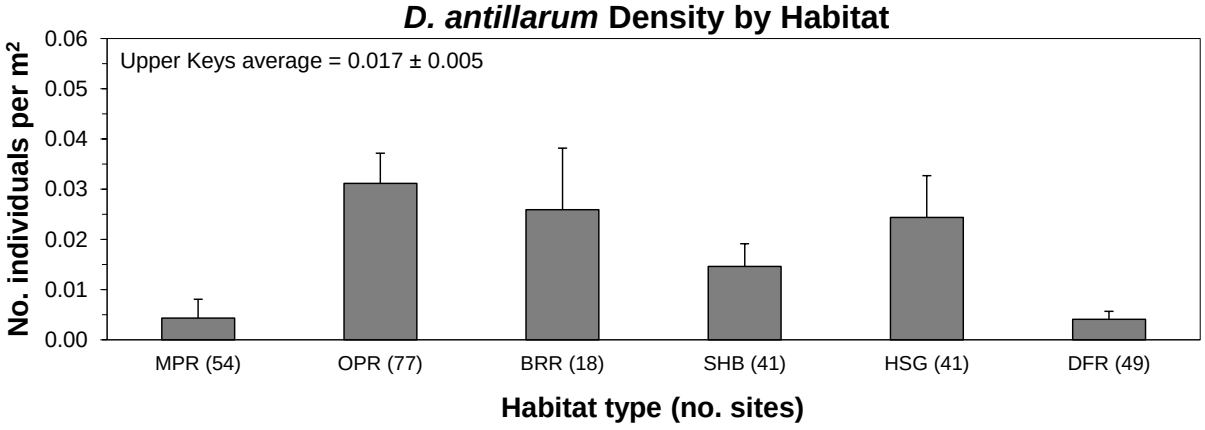
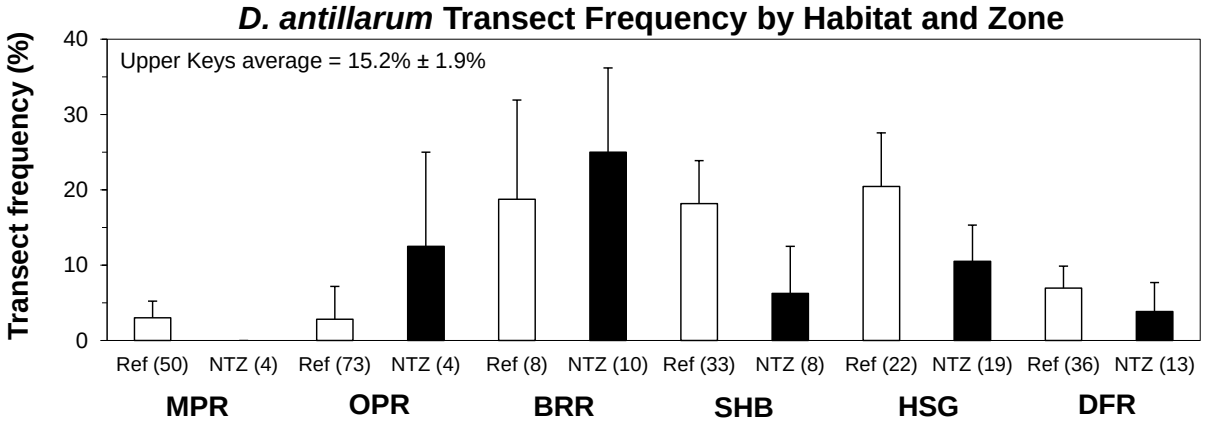


Figure 5-8. Mean (+ 1 SE) transect frequency (top) and density (no. individuals per m^2) (bottom) of long-spined sea urchins (*Diadema antillarum*) by habitat type and management zone in the upper Florida Keys during May-September 2011. Open bars = reference areas (Ref), filled bars = no-take zones (NTZ). 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).



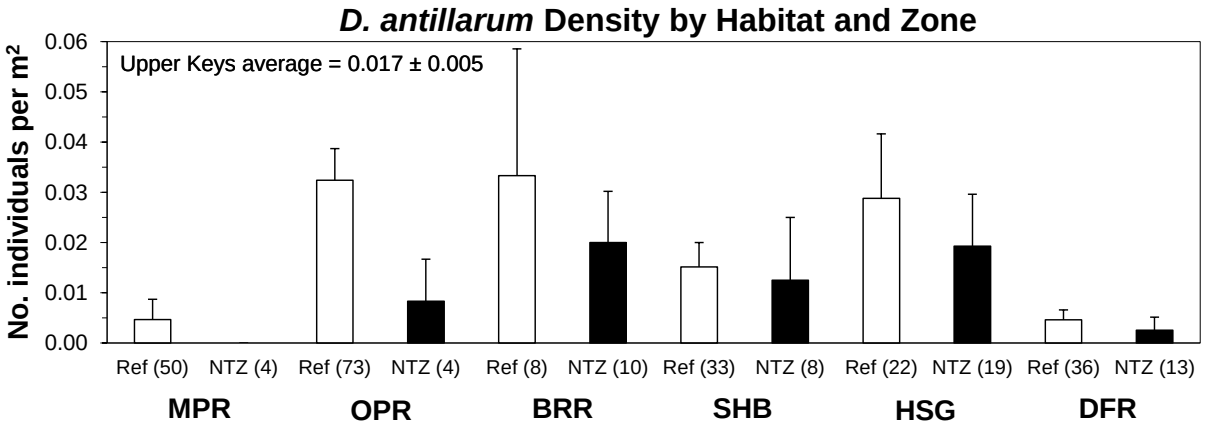
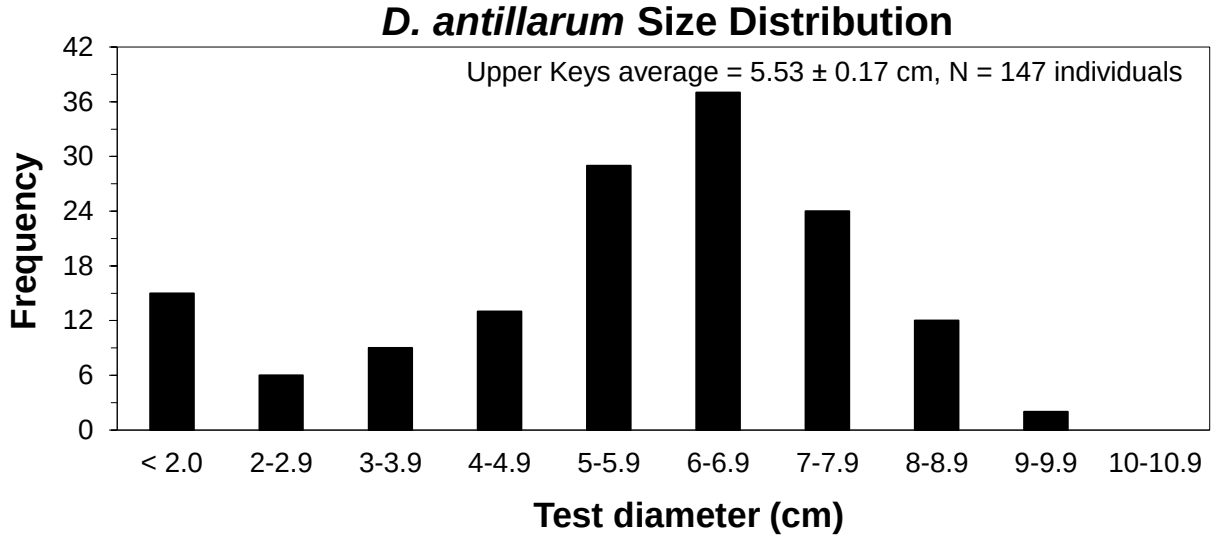


Figure 5-9. Distribution of urchin test diameter sizes (top) and mean (± 1 SE) (filled circles) and maximum sizes (open circles) across habitats (bottom) for *Diadema antillarum* in the upper Florida Keys National Marine Sanctuary, as determined from surveys at 280 sites during May-September 2011. Habitat 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.



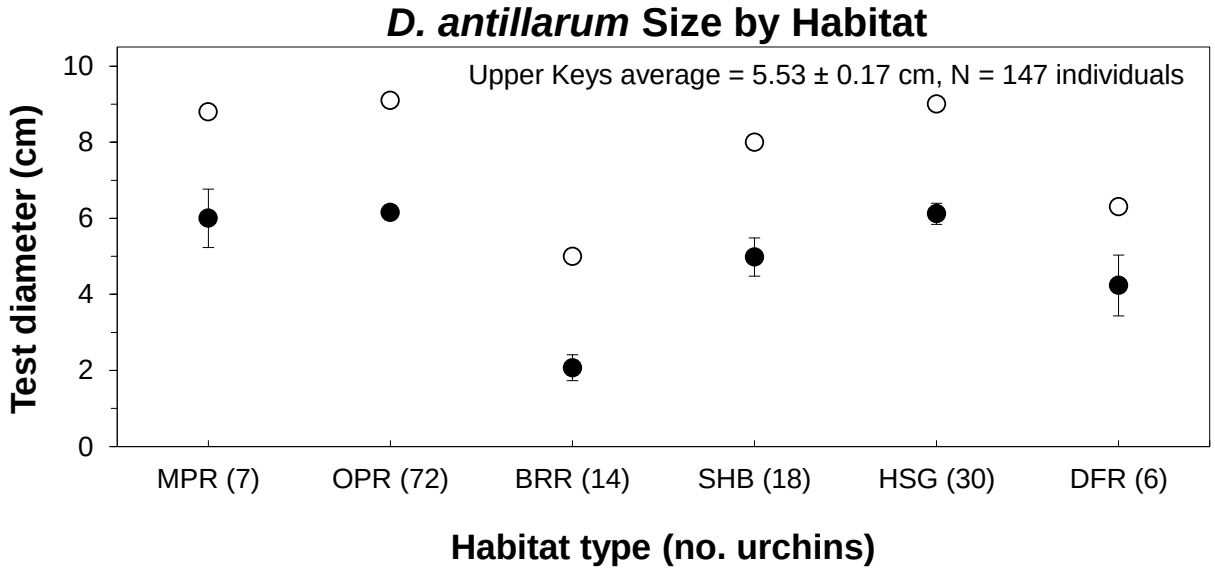


Figure 5-10. Densities (no. per m^2) of green rock-boring urchins (*Echinometra viridis*) in the upper Florida Keys National Marine Sanctuary from the southern boundary of Biscayne National Park to Carysfort/S. Carysfort Reef surveyed during May-September 2011.

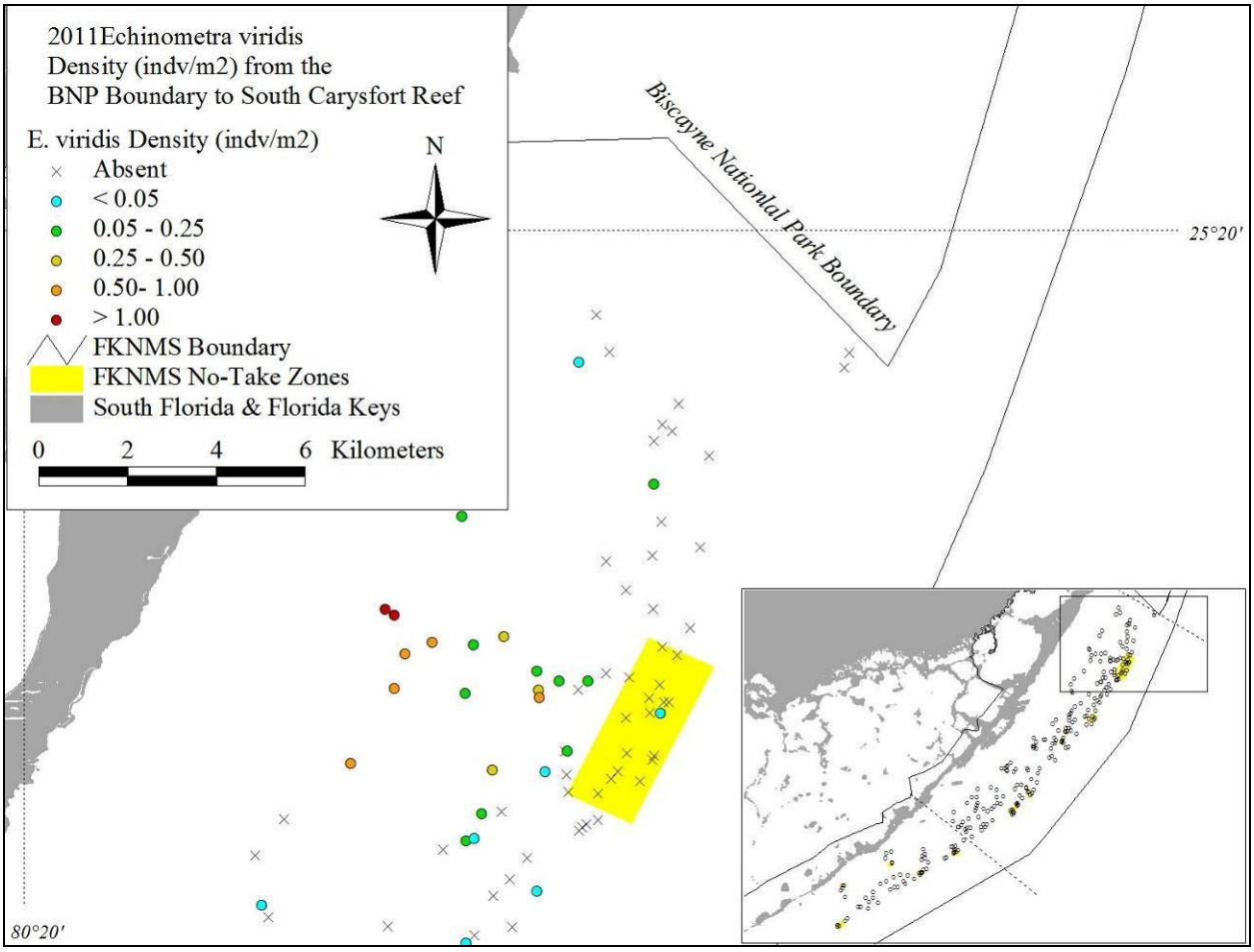


Figure 5-11. Densities (no. per m^2) of green rock-boring urchins (*Echinometra viridis*) in the upper Florida Keys National Marine Sanctuary from Elbow Reef to Pickles Reef surveyed during May-September 2011.

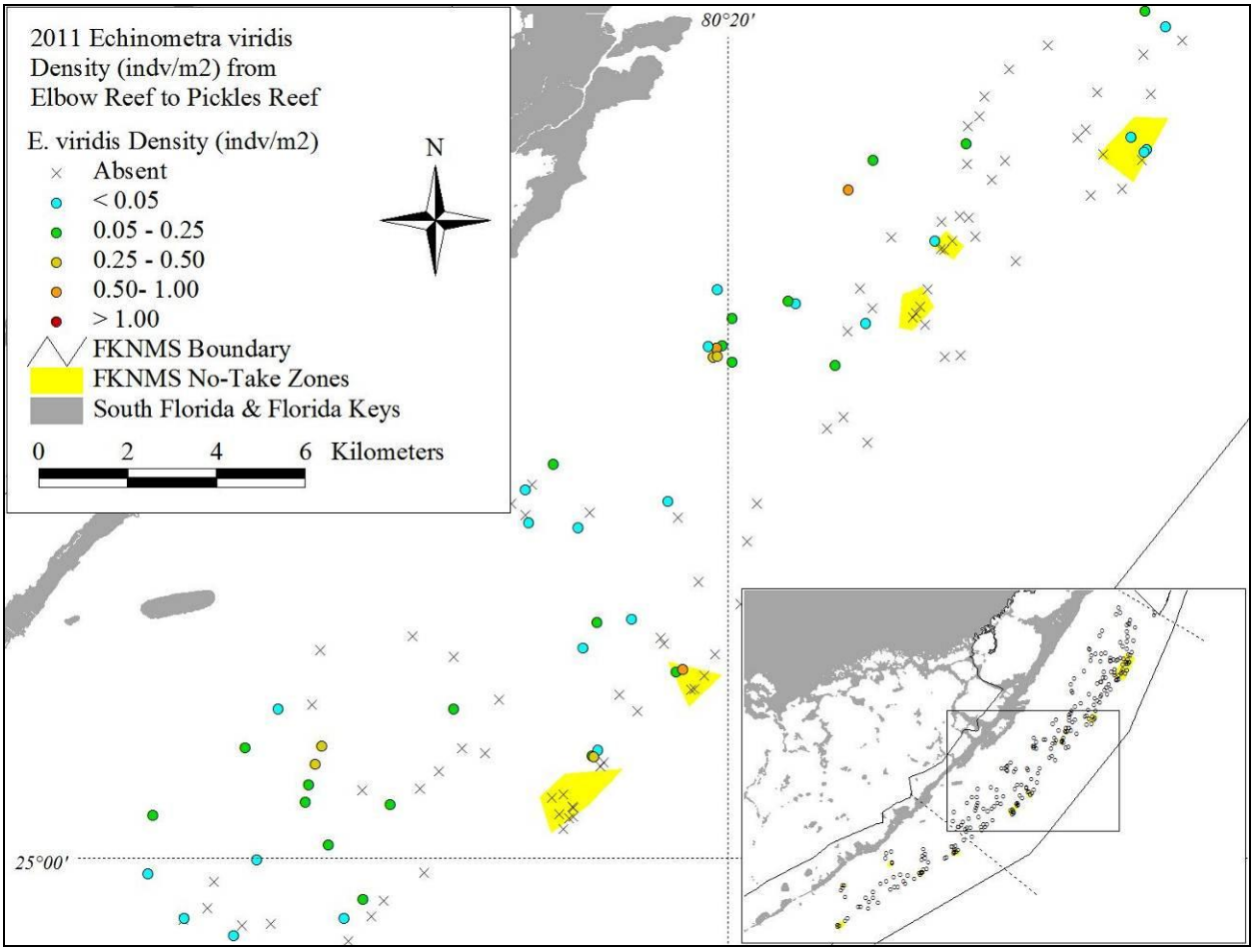


Figure 5-12. Densities (no. per m^2) of green rock-boring urchins (*Echinometra viridis*) in the upper Florida Keys National Marine Sanctuary from Conch Reef SPA to Alligator Reef surveyed during May-September 2011.

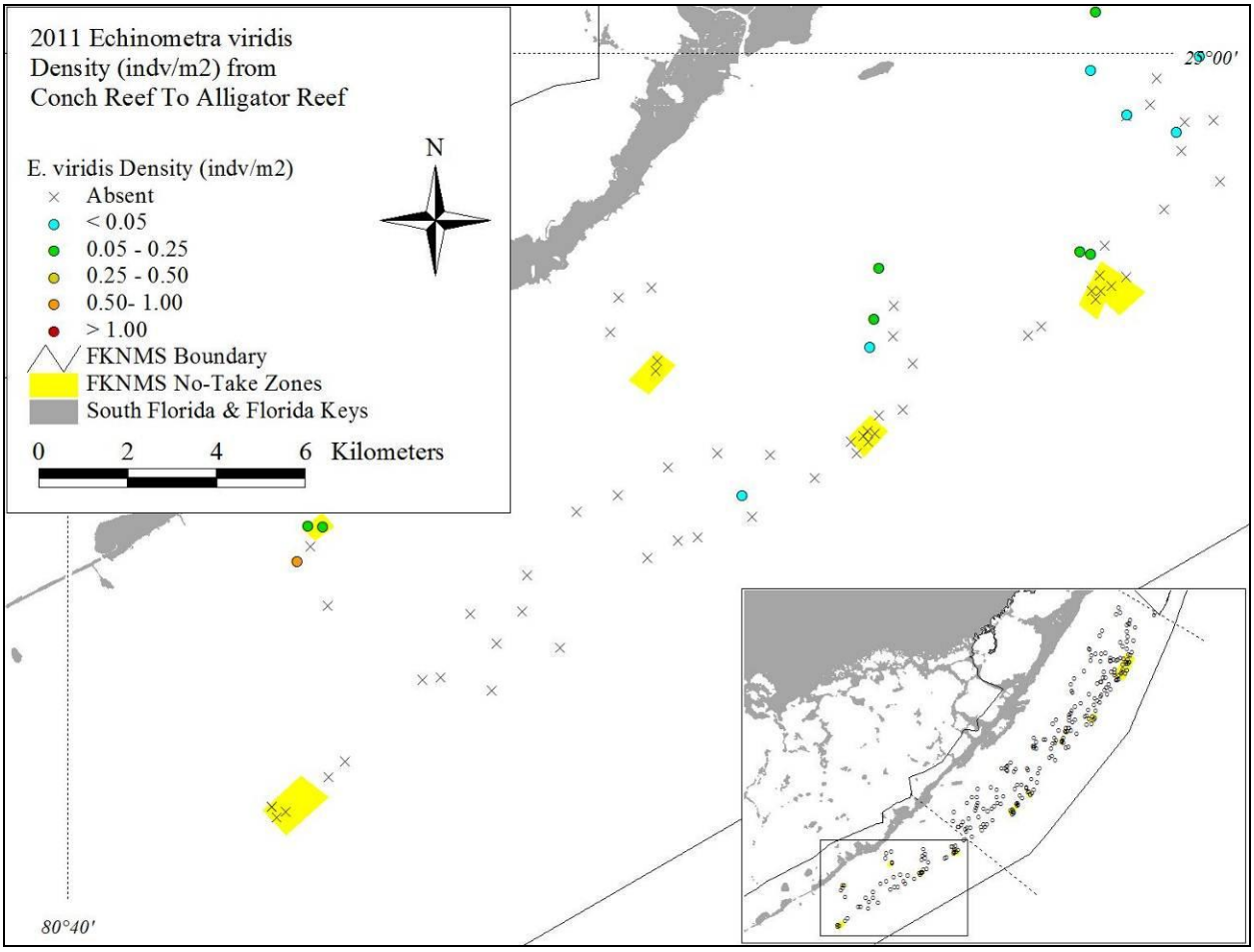
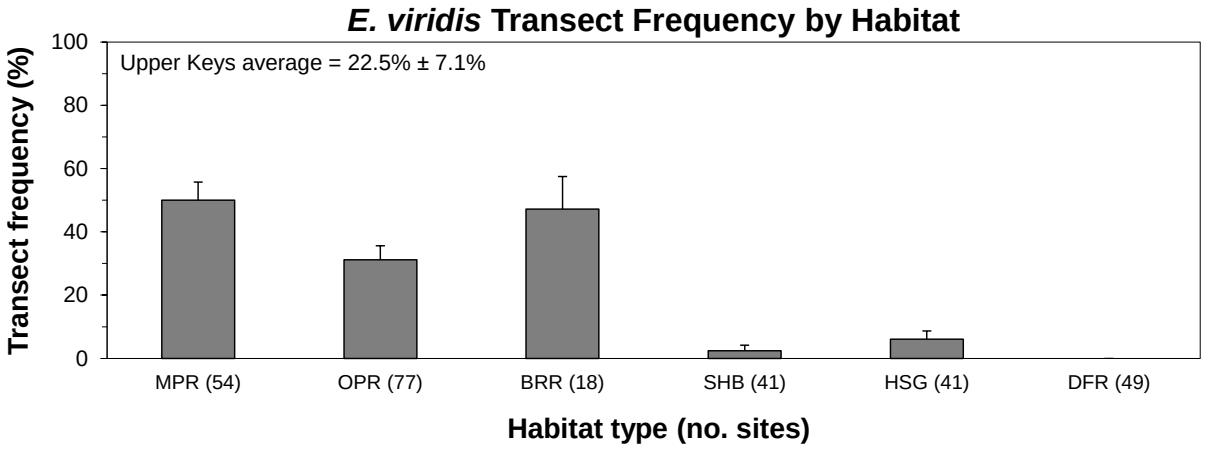


Figure 5-13. Mean (+ 1 SE) transect frequency (top) and density (no. individuals per m^2) (bottom) of green rock-boring urchins (*Echinometra viridis*) by habitat type in the upper Florida Keys during May-September 2011. Domain-wide (upper Keys) values are weighted averages and standard errors. Values 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.



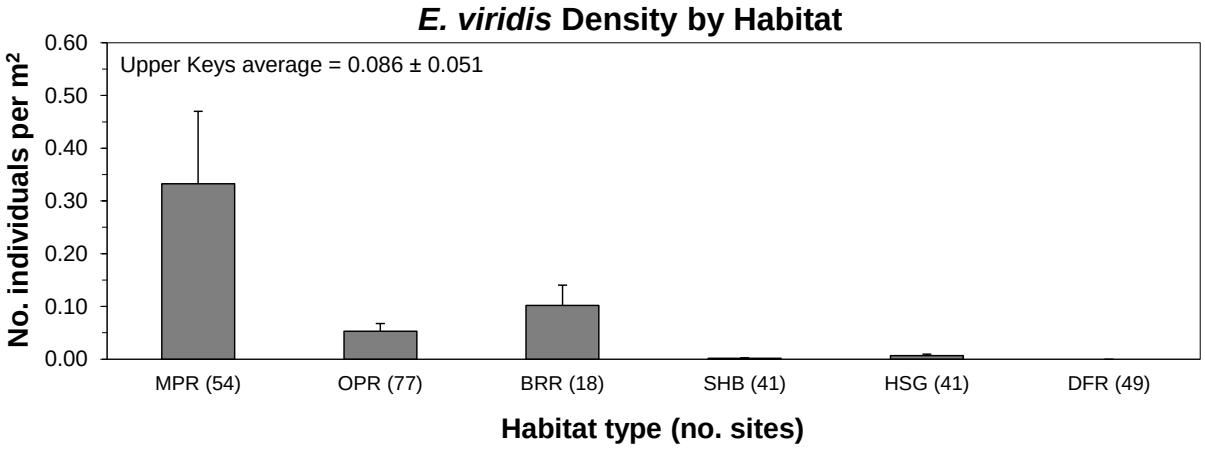


Figure 5-14. Mean (+ 1 SE) transect frequency (top) and density (no. individuals per m^2) (bottom) of green rock-boring urchins (*Echinometra viridis*) by habitat type and management zone in the upper Florida Keys during May-September 2011. Open bars = reference areas (Ref), filled bars = no-take zones (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).

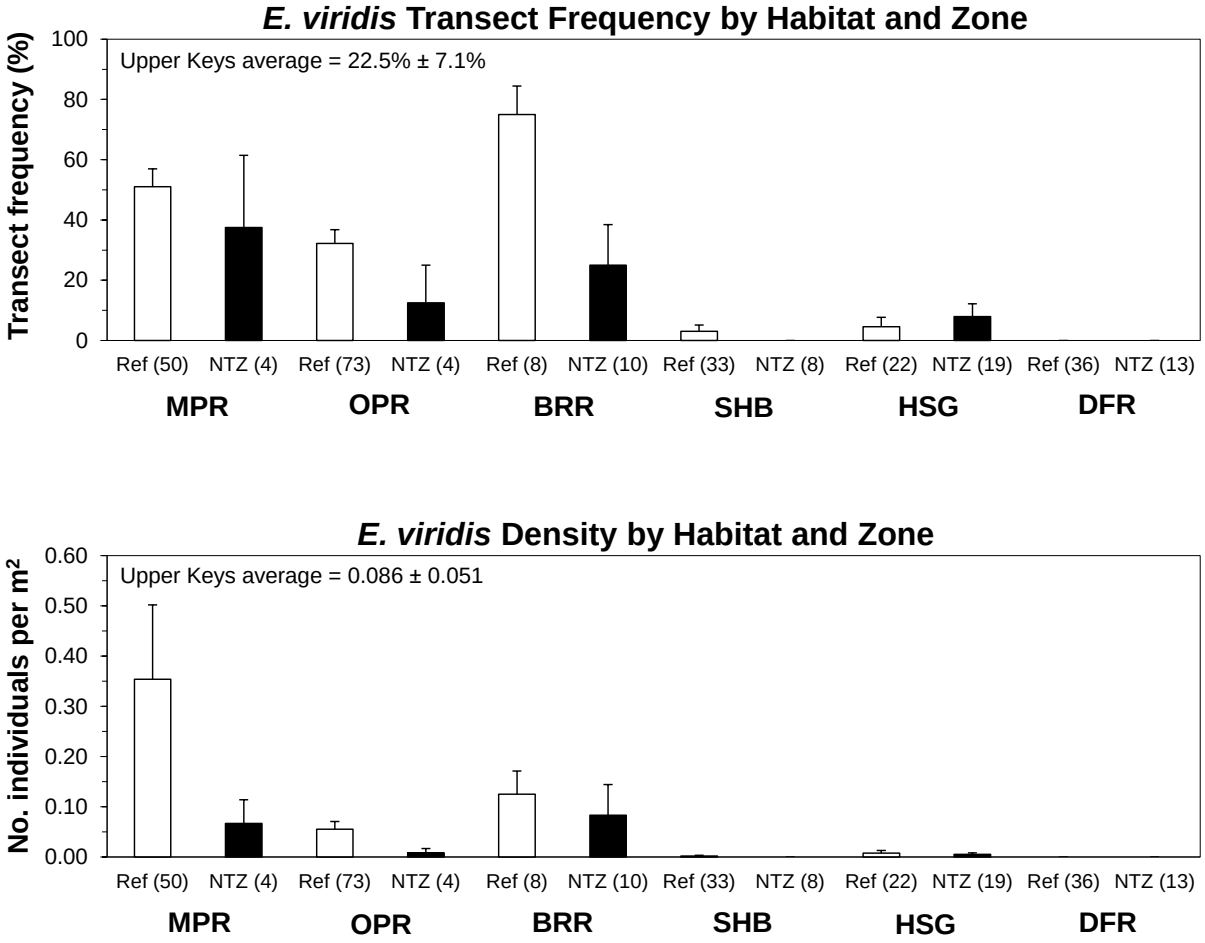
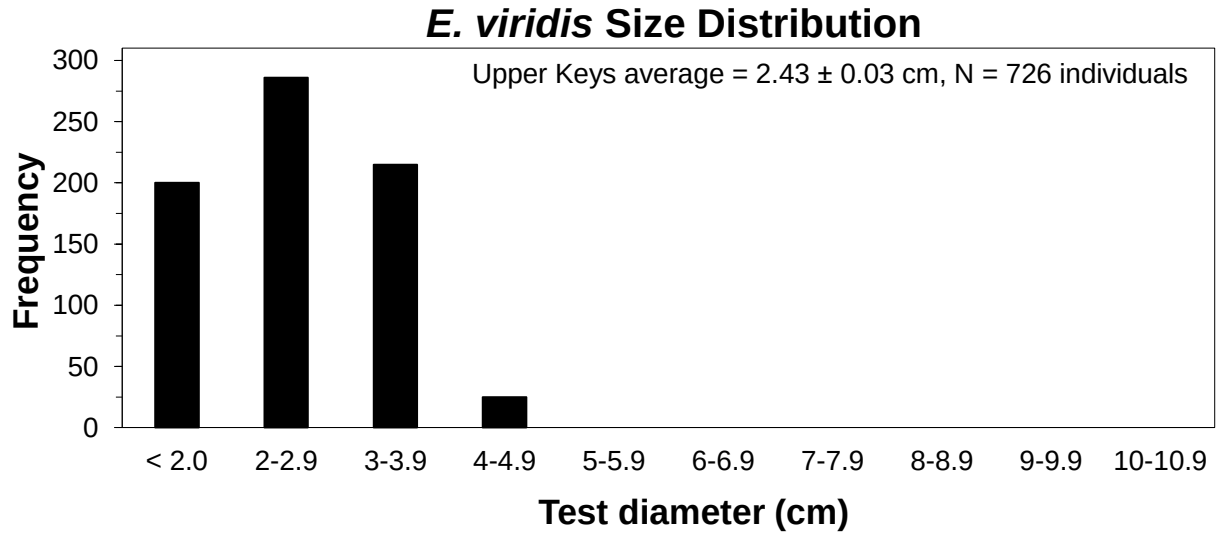


Figure 5-15. Distribution of urchin test diameter sizes (top) and mean (± 1 SE) (filled circles) and maximum sizes (open circles) across habitats (bottom) for *Echinometra viridis* in the upper Florida Keys National Marine Sanctuary, as determined from surveys at 280 sites during May-September 2011. 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.



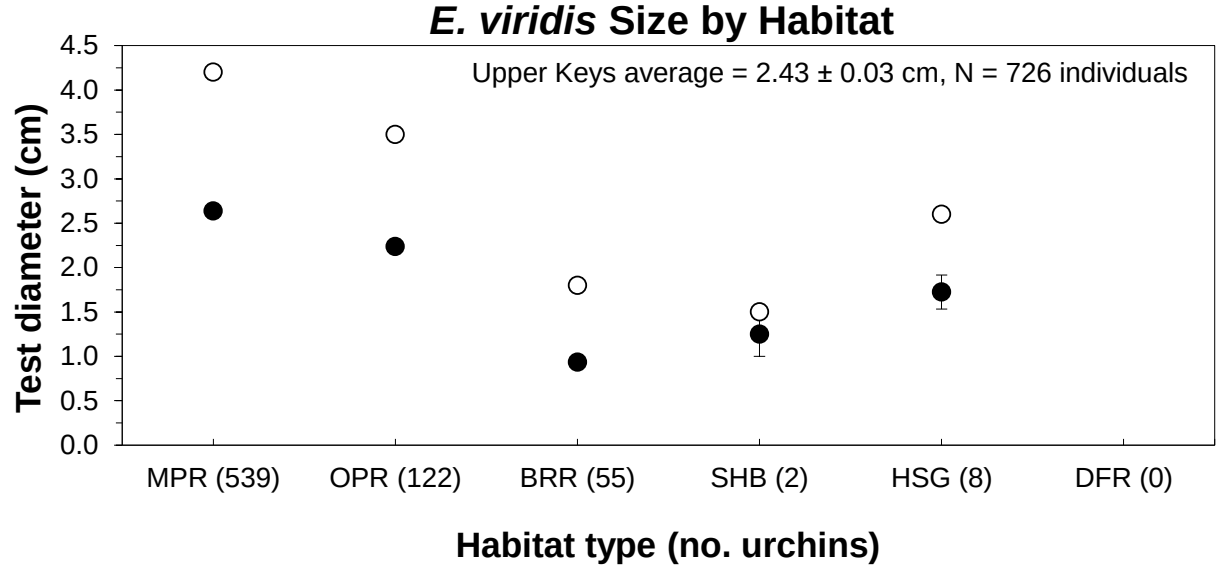


Figure 5-16. Densities (no. per m^2) of green slate pencil urchins (*Eucidaris tribuloides*) in the upper Florida Keys National Marine Sanctuary from the southern boundary of Biscayne National Park to Carysfort/S. Carysfort Reef surveyed during May-September 2011.

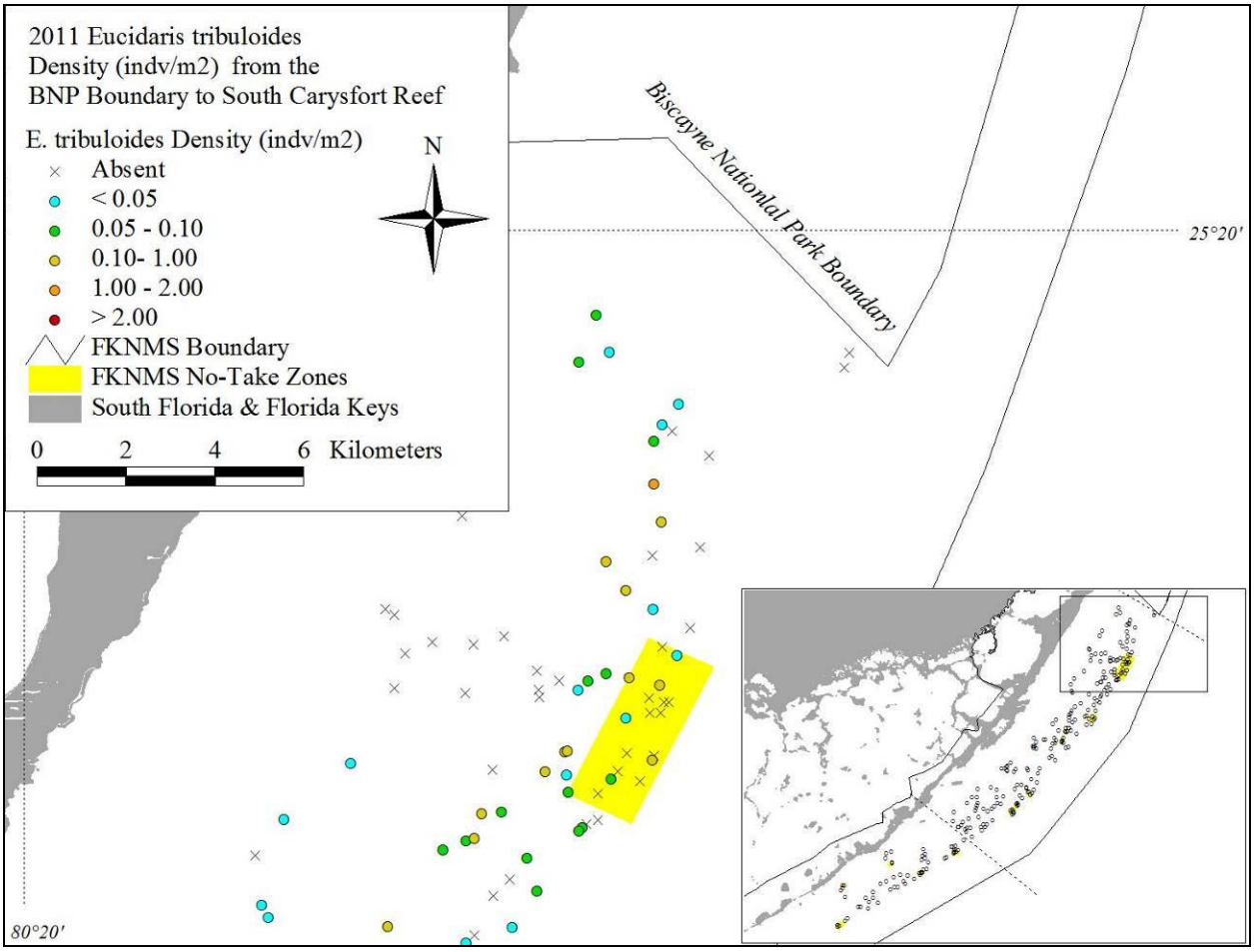


Figure 5-17. Densities (no. per m^2) of slate pencil urchins (*Eucidaris tribuloides*) in the upper Florida Keys National Marine Sanctuary from Elbow Reef to Pickles Reef surveyed during May-September 2011.

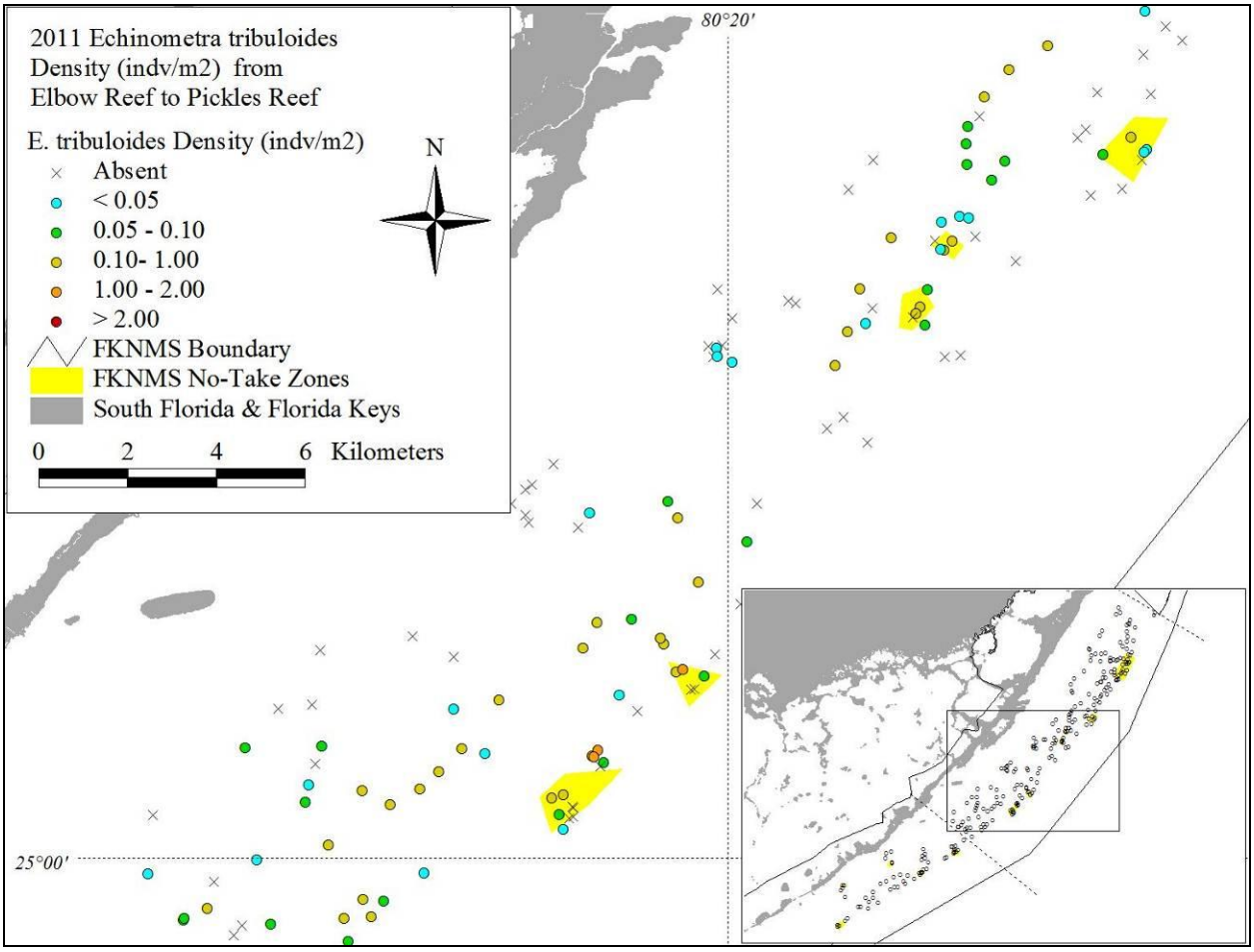


Figure 5-18. Densities (no. per m^2) of slate pencil urchins (*Eucidaris tribuloides*) in the upper Florida Keys National Marine Sanctuary from Conch Reef SPA to Alligator Reef surveyed during May-September 2011.

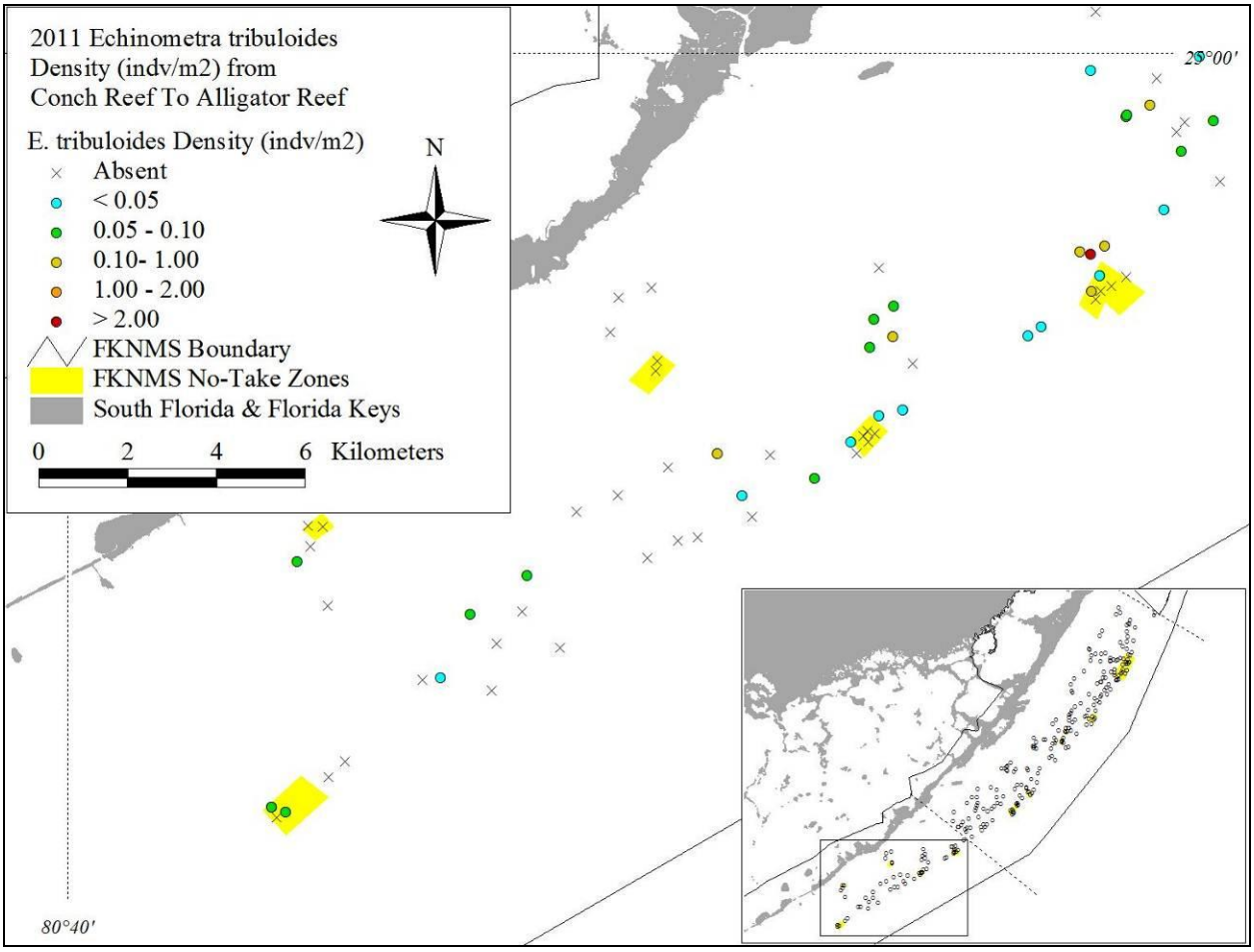


Figure 5-19. Mean (+ 1 SE) transect frequency (top) and density (no. individuals per m^2) (bottom) of slate pencil urchins (*Eucidaris tribuloides*) by habitat type in the upper Florida Keys during May-September 2011. Domain-wide (upper Keys) values are weighted averages and standard errors. Values on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

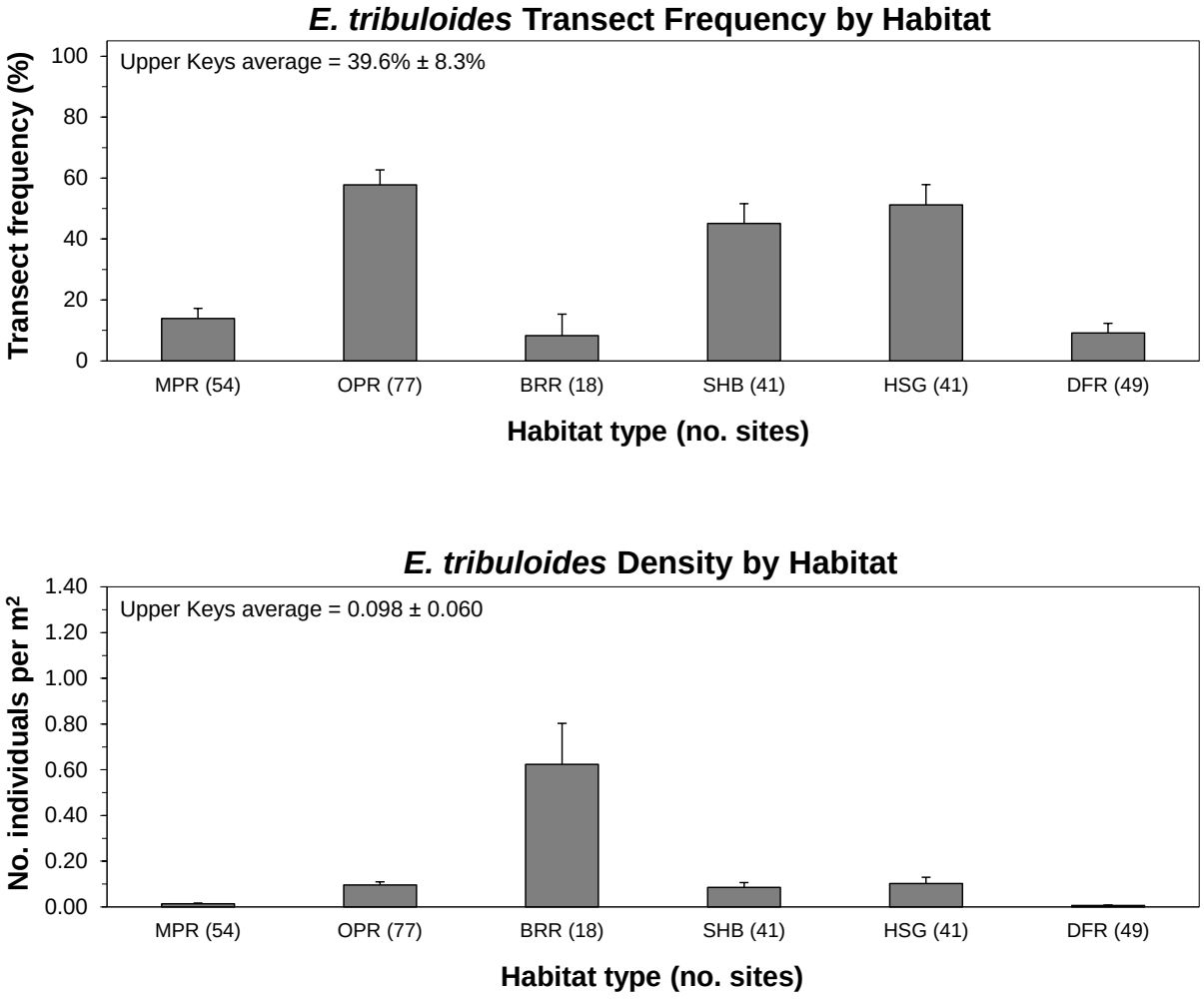
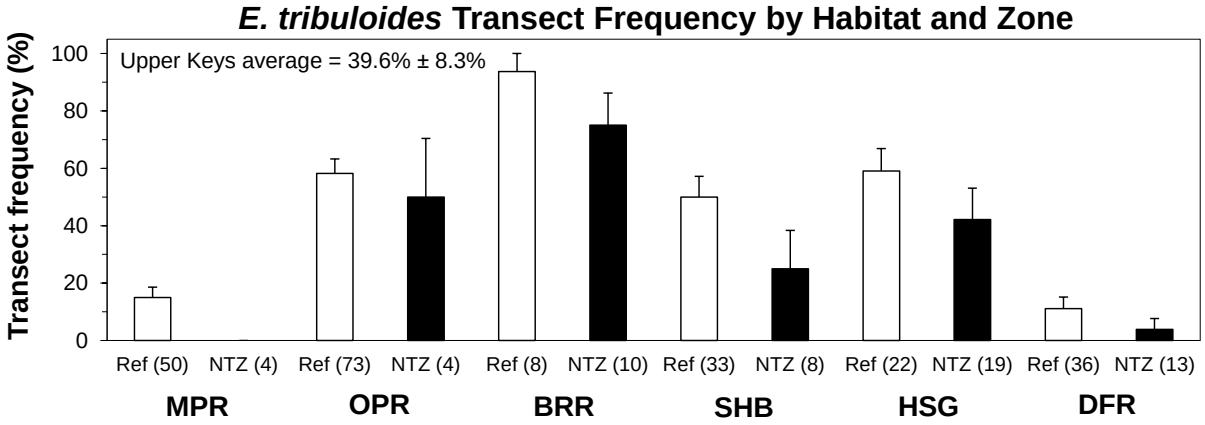


Figure 5-20. Mean (+ 1 SE) transect frequency (top) and density (no. individuals per m^2) (bottom) of slate pencil urchins (*Eucidaris tribuloides*) by habitat type and management zone in the upper Florida Keys during May-September 2011. Open bars = reference areas (Ref), filled bars = no-take zones (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).



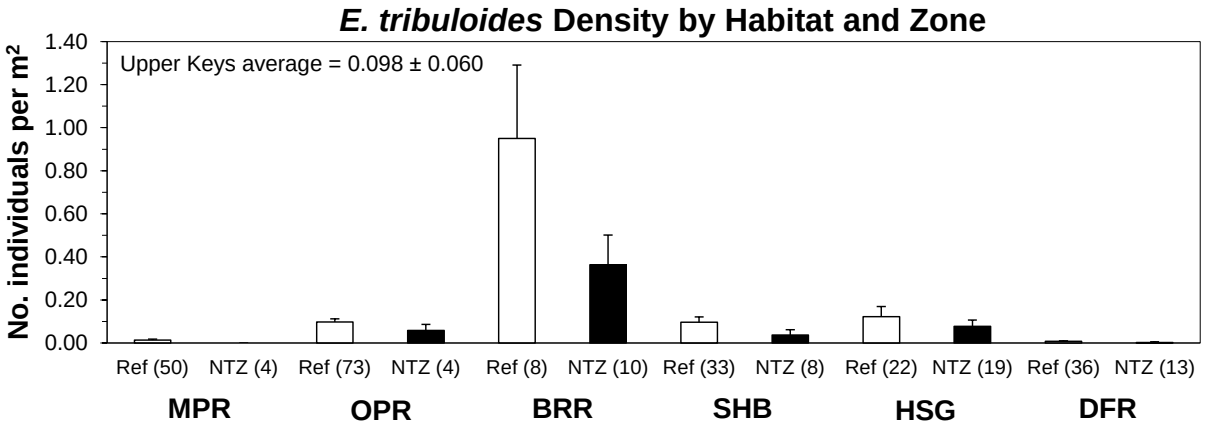
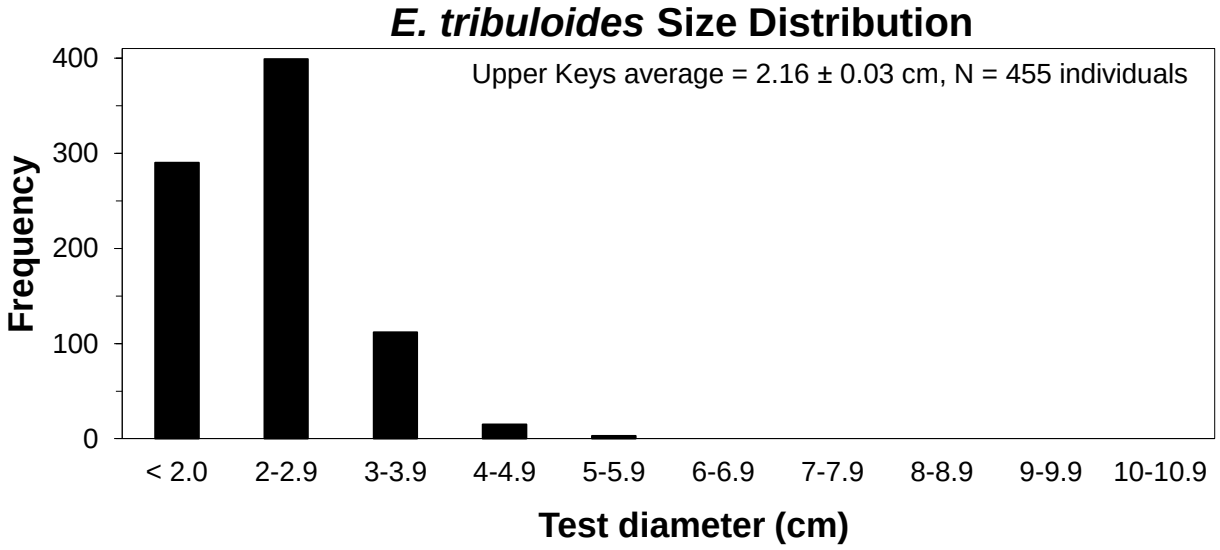


Figure 5-21. Distribution of urchin test diameter sizes (top) and mean (± 1 SE) (filled circles) and maximum sizes (open circles) across habitats (bottom) for *Eucidaris tribuloides* in the upper Florida Keys National Marine Sanctuary, as determined from surveys at 280 sites during May-September 2011. 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.



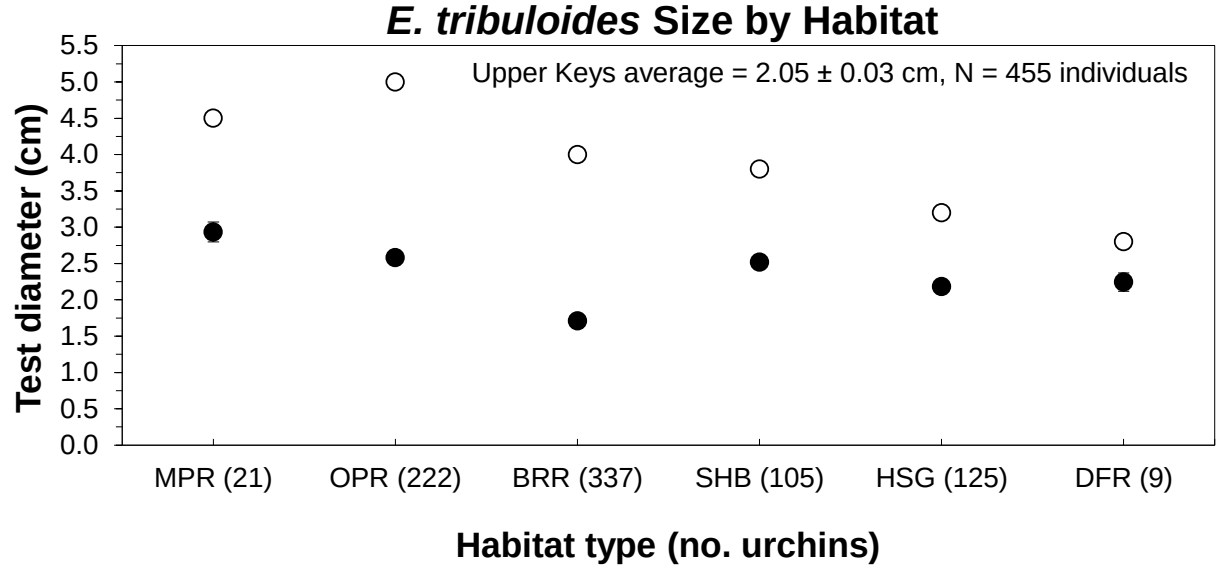


Table 5-1. Summary of habitat distribution, density, and size (test diameter) of the urchin *Arbacia punctulata* (Lamarck) among habitat types and management zones in the upper Florida Keys, as determined from two replicate 15-m x 1-m belt transect surveys per site at 280 sites from northern Key Largo 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