Reef Communities in the Dry Tortugas (Florida, USA): Baseline Surveys for the New No-take Area

I. B. Kuffner[1], V. J. Paul[2], R. Ritson-Williams[2], T. D. Hickey[1], L. J. Walters[3]

1) U.S. Geological Survey, 600 4th St. So., St. Petersburg, FL 33701, USA
2) Smithsonian Marine Station at Fort Pierce, 701 Seaway Drive, Fort Pierce, FL 34949, USA
3) University of Central Florida, Dept. of Biology, 4000 Central Florida Blvd., Orlando, FL 32816, USA

Abstract. To understand the current community structure on reefs in the Dry Tortugas, we conducted species-level surveys of macroalgae, coral diversity, herbivorous and game fishes, urchins, and substratum composition (e.g., rugosity) in shallow (3- to 5-m depth) low-relief reef and hardbottom habitats in October 2007. We had particular interest in the ecological process of herbivory inside and outside of the "no-take" Research Natural Area (RNA) designated by the U.S. National Park Service in 2007, and establishing a baseline to assess future changes to trophic functioning. *Diadema antillarum* and herbivorous fish abundance, percent cover of macroalgae, and species richness of corals and gorgonians at the 18 randomly selected survey sites were not significantly different inside vs. outside of the RNA. Mean densities of *D. antillarum* ranged from 0.01 to 0.54 individuals m^{-2}, with 11 of the 18 sites having densities above 0.10 individuals m^{-2}. Both *D. antillarum* density and coral species richness were positively correlated to rugosity of the substratum. *Diadema antillarum* density was also positively related to percentage of the substratum composed of *Acropora cervicornis* rubble. Improved trophic functioning and increases in *D. antillarum* can improve reef condition in the Dry Tortugas, and the RNA is an important management tool to achieve increases in reef resilience to global-scale stressors.

Key words: community structure, urchins, herbivory, marine protected areas, marine reserves, *Diadema*

Introduction

The Dry Tortugas is a unique and isolated atoll-like reef system at the terminus of the Florida Keys. Like other reefs in the Florida/Caribbean region, this area has experienced significant community shifts indicative of degradation, with reduced live coral coverage, increases in macroalgae, and decreases in species targeted in fisheries. However, both local and global stressors probably contributed to these community shifts, and meteorological events are known to have impacted the reefs. Reef research has a fairly long history in the Dry Tortugas, beginning before the establishment of the Carnegie Institute Tortugas Laboratory on Loggerhead Key in 1905 (Davis 1982; Shinn and Jaap 2005). Alexander Agassiz mapped the Dry Tortugas benthos in 1881 (Davis 1982), showing tens of hectares of *Acropora palmata*, but coring has revealed that this species was not responsible for reef accretion in the Dry Tortugas (Shinn et al. 1977). In 1976, a comprehensive habitat map was created to examine community change since the Agassiz map, showing that the *A. palmata* had all but disappeared and that *A. cervicornis* coverage was vast (Davis 1982). In January 1977, a severe cold front killed most of the *A. cervicornis* reefs in the Dry Tortugas (Davis 1982; Porter et al. 1982). Populations have not recovered on patch reefs once dominated by this species in the early 1970s; in fact, a representative site showed continued decline from 1999 to 2005 due to bleaching and disease (Beaver et al. 2005).

The purpose of our study was to characterize the current biological communities within Dry Tortugas National Park to provide important baseline data for assessing the effects of the "no-take" Research Natural Area (RNA) designated by the U.S. National Park Service (NPS) in 2007. We also sought to document any recovery of populations impacted during documented disturbances (Porter et al. 1982; Beaver et al. 2005), and to assess the ecological process of herbivory inside and outside of the RNA prior to any RNA-induced changes to trophic structure that may occur due to the new management regime. Because of our interest in herbivory, and because most other monitoring programs (e.g., NPS-South Florida/Caribbean Inventory and Monitoring Network, National Oceanic and Atmospheric Administration, NPS-DTNP and Florida Fish and Wildlife Research Institute) have focused on habitat > 6 m, we chose to focus our study on the shallow (< 5 m) reef environment. Recovery rates of the benthic community can increase within well-enforced marine protected areas (Mumby et al. 2006; Hughes et al. 2007); our long-term goal is to test this hypothesis.
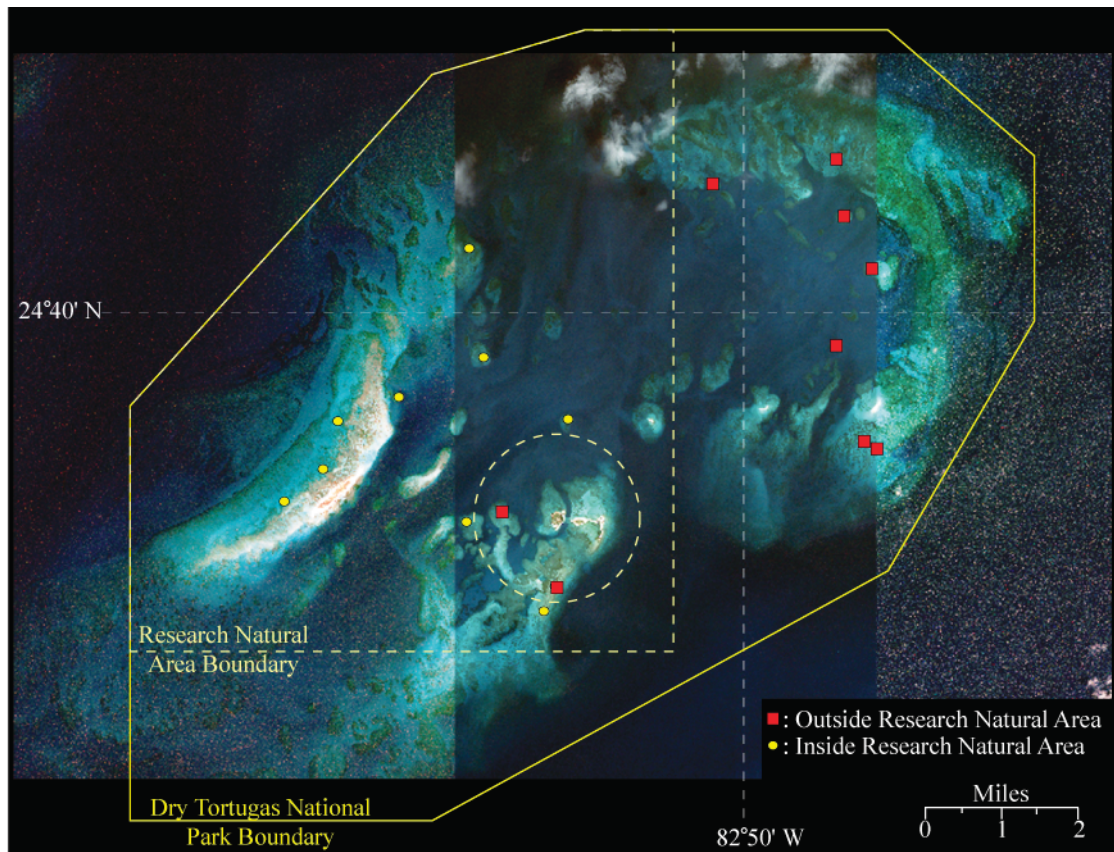
Figure 1: IKONOS satellite mosaic of Dry Tortugas National Park with the locations of 18 randomly selected sites where *in-situ* surveys were conducted October 16 – 20, 2007. The "no-take" Research Natural Area is within the dashed lines in the NW quadrant of the park and does not include the area within the circle.

Material and Methods

We randomly selected 18 sites for surveys, nine inside and nine outside of the RNA (Fig. 1), all within shallow (3- to 6-m depth) low-relief reef and hardbottom habitat. We conducted species-level surveys of macroalgae, scleractinian and gorgonian corals, herbivorous and game fishes, urchins, and substratum composition (e.g., rugosity). Three 15-m transects were laid out radially from each GPS location at bearings of 0°, 120°, and 240°. One Bohnsack-Bannerot visual fish census (7.5-m radius cylinder with stationary observer) was conducted on each transect line (Bohnsack and Bannerot 1986). The benthic community was assessed at n = 4 quadrats (0.0625 m^2 with line demarking 25 equal boxes) per transect by visually estimating percent cover of taxa within the quadrat, and urchins and damselfish were counted in a 2-m-wide belt along each transect line. Rugosity was estimated by draping a chain (3-cm link size) on the substratum underneath each transect line, giving the ratio between contoured and linear distance. Gorgonian and scleractinian diversity at each site was determined by recording all species observed throughout the approximately one-hour-long dive in

the proximity of the three transect lines (≈700 m^2 area). The "game fish" category used here included grouper (*Epinephelus*, *Mycteroperca*, *Cephalopholis*, but excluded the small-bodied *Hypoplectrus*), jacks (*Caranx*), snapper (*Lutjanus* and *Ocyurus*), and hogfish (*Lachnolaimus maximus*). Biomass of herbivores was calculated by using length to weight conversions W=aL^b, where W = weight in g, L = fork or total length (species dependent) in cm, and a and b are species-specific constants reported by www.fishbase.org. Total length was estimated during visual surveys and then converted to fork length when necessary using regression relationships published on www.fishbase.org.

Results

Our initial assessment of the 18 randomly selected shallow low-relief hardbottom sites revealed that no variables measured were significantly different inside vs. outside of the newly established Research Natural Area (Table 1). *Diadema antillarum* was present and fairly evenly distributed at all 18 sites. Mean densities ranged from 0.01 to 0.54 individuals m^{-2}, with 11 of the 18 sites having densities above 0.10 individuals m^{-2}.

Table 1. Variables measured during *in-situ* surveys October 16 – 20, 2007, in Dry Tortugas National Park. Means, standard errors, and p-values of two-tailed two-sample t-tests are reported for variables comparing sites inside (n = 9) and outside (n = 9) of the "no-take" Research Natural Area established in January 2007. The sites outside are still within the National Park boundaries where there are limited restrictions on resource use, including a ban on spear fishing. "Encrusting invertebrates" includes only *Briareum asbestinum*, *Erythropodium caribaeorum*, and *Palythoa caribaeorum*. [a] = T-test assuming unequal variance using Satterthwait's method as reported by Statistix© 9 software.

Variable	Inside RNA		Outside RNA		T-test
	mean	SE	mean	SE	p =
Rugosity	1.33	0.04	1.29	0.03	0.49
No. of coral species	14.1	0.9	12.2	1.0	0.19
No. of gorgonian taxa	13.3	1.0	14.9	0.8	0.23
Diadema antillarum (no. m^{-2})	0.18	0.05	0.16	0.06	0.79
Acanthurids (no. cylinder^{-1})	4.4	0.85	2.4	0.72	0.09
Acanthurid biomass (g cylinder^{-1})	151	34	143	85	[a]0.93
Scarids (no. cylinder^{-1})	14.4	3.2	13.9	2.9	0.91
Scarid biomass (g cylinder^{-1})	418	105	283	152	0.48
Stegastes spp. (no. m^{-2})	0.66	0.04	0.7	0.13	[a]0.74
Game fish (no. cylinder^{-1})	5.3	1.6	5.2	1.9	0.96
Crustose coralline algae (% cover)	33.9	4.7	24.8	2.9	0.12
Total calcified macroalgae (% cover)	9.0	1.1	9.0	0.44	[a]1.00
Total fleshy macroalgae (% cover)	32.9	3.8	34.3	2.6	0.80
Halimeda tuna (% cover)	6.2	1.0	6.8	0.5	[a]0.59
Dictyota spp. (% cover)	25.1	3.0	23.0	3.6	0.66
Encrusting invertebrates (% cover)	3.6	1.0	5.5	1.2	0.26

Table 2. Linear regression analysis of variables measured during *in-situ* surveys October 16 – 20, 2007 in Dry Tortugas National Park.

Independent variable	Dependent variable	Least squares linear regression		
		Transformation	R^2	p-value
Rugosity	*Diadema antillarum* density	Ln	0.31	0.017
Rugosity	Coral species richness	none	0.33	0.012
Rugosity	Scarid abundance	none	0.28	0.024
Rugosity	Scarid biomass	4th-root	0.49	0.001
Rugosity	*Stegastes* spp.	4th-root	0.29	0.021
Rubble (% cover)	*Diadema antillarum* density	none	0.36	0.009

Percent of the substratum covered by macroalgae was 34% and dominated by the brown algae *Dictyota* spp. *Diadema antillarum* density (Fig. 2A), scleractinian-coral species richness, scarid (parrotfish) abundance (Fig. 2B) and biomass, and *Stegastes* spp. (damselfish) abundance were positively related to rugosity of the substratum (Table 2). *Diadema antillarum* density was also positively related to percentage of the substratum composed of *Acropora cervicornis* rubble, and the amount of variance explained increased (adjusted R^2 = 0.49) when both the rugosity and rubble variables were included in a multiple linear regression model. Small (< 1-m-diameter), live colonies of *A. cervicornis* were noted at 12 of the 18 sites.

Discussion

The key question with respect to reef-resource conservation in the Dry Tortugas National Park is "Can we expect to reverse the decline in live coral coverage through the establishment and enforcement of the new no-take RNA?" To have realistic expectations for the RNA efficacy with respect to benthic communities, initial conditions must be assessed and forces that drive coral decline today and in the past must be understood. While there are too few ecological data to determine if the Caribbean-wide mortality of the key herbivore, *Diadema antillarum*, played a role in the replacement of live coral by macroalgae at this location since the early 1980s, it is reasonable to assume that similar changes in algal abundance documented after the die-off in other areas of the Caribbean (Morrison 1988; Carpenter 1990) also occurred in this location. Fishing pressure on herbivorous fishes is certainly a possible confounding factor in comparing sites within the Caribbean region, because scarids and acanthurids are not targeted in the local fisheries throughout the Florida Keys (Harper et al. 2000) whereas they are heavily targeted in places like Jamaica where fishing

pressure is especially intense (Hawkins and Roberts 2004). However, the grand mean of 24% coverage of the benthos by *Dictyota* spp. observed in this study indicates that the herbivorous fish population found in these hardbottom habitats is not sufficient to crop algae to levels documented prior to the 1980s, when benthic algae were thought of as "an inconspicuous component of coral reef environments" (Dahl 1974).
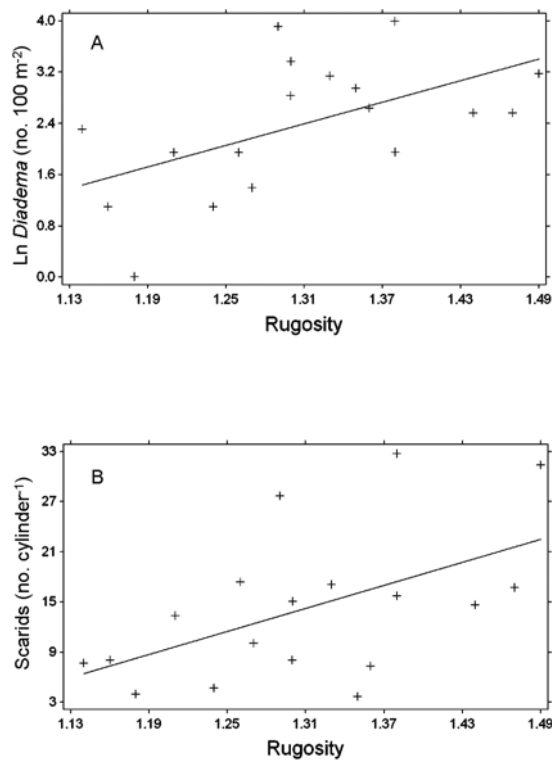

Figure 2: Linear-regression plots of A) *Diadema antillarum* density (Ln transformed data) and B) scarid (parrotfish) abundance (no. cylinder[-1]) vs. substratum rugosity at 18 sites within Dry Tortugas National Park.

Recent increases in the *Diadema* population (Morrison, pers. comm.) could potentially enhance coral recruitment through the removal of *Dictyota* spp. and other algae from otherwise suitable substratum (Kuffner et al. 2006). Increased abundance of coral recruits in areas where *Diadema* density has rebounded has been documented on Jamaican reefs (Edmunds and Carpenter 2001). The fairly even distribution of low densities of *Diadema* observed in the Dry Tortugas is encouraging, since one of the main factors thought to hinder the recovery of this species is low-fertilization success in remnant populations due to long distances between reproductive individuals, i.e., the "allee" effect (Knowlton 2001).

There is no doubt that increased herbivory could help foster coral recovery. In this vein, the RNA could potentially contribute to restoring a coral-dominated benthic-community structure. However, the removal of stressors that have caused coral mortality in the past is also necessary to reverse reef degradation. As adults, corals may be superior competitors for space compared to most macroalgae, but once coral mortality occurs, the competitive hierarchy changes in favor of selected species of weedy primary producers (McCook et al. 2001; Kuffner and Paul 2004; Kuffner et al. 2006). Coral bleaching and disease are documented causes of recent coral mortality in the Dry Tortugas (Beaver et al. 2005), and since these are global- and regional-scale stressors, respectively, it is not likely that the newly established RNA will be effective in reducing coral mortality; however, managing for resilience could improve coral population recovery rates.

The positive correlation between *D. antillarum* density and percentage of the substratum composed of rubble revealed in this study indicates that testing the hypothesis that *A. cervicornis* rubble acts as nursery habitat for *D. antillarum* would be worthwhile. In an unpublished survey in St. John, USVI, juvenile (< 1 cm-diameter test) *Diadema* were only observed in rubble fields of similar grain size as in this study (Kuffner, unpublished). Chiappone et al. (2001) also noted in June 2000 that the two sites in the Dry Tortugas where they observed the highest densities of *D. antillarum* had large patches of *A. cervicornis* rubble. Little is known about the habitat requirements for recruitment in this species, most likely due to the rarity of finding individuals of < 1-cm-diameter test size and their cryptic juvenile behavior (Bak 1985).

It is too early to speculate whether the RNA will play a constructive role in the future of the benthic community in Dry Tortugas National Park. There is reason for optimism given the recent findings that well-enforced no-take reserves can have restorative effects on trophic functioning (Mumby et al. 2006). Mumby et al. (2006) demonstrated that levels of herbivory increased within a reserve compared to outside, resulting in significant changes to benthic community structure in the form of reduced levels of macroalgae. No-take areas are considered a key tool in managing for reef resilience (Bellwood et al. 2004; Mumby et al. 2007), and there is a growing body of evidence that no-take areas facilitate the recovery of key ecological processes like coral recruitment and herbivory (Hughes et al. 2007). As enforcement of the new management regime gets underway, the Dry Tortugas NP presents a unique case study of no-take area efficacy with minimal underlying problems of land-based pollution found in the adjacent inhabited Florida Keys.

References

Bak RPM (1985) Recruitment patterns and mass mortalities in the sea urchin *Diadema antillarum*. Proc 5th Int Coral Reef Symp 5:267-272

Beaver C, Brooke S, Callahan M, Wade S, Johnson D, Kupfner S, Kidney J (2005) Long-term monitoring of selected coral reef sites at the Dry Tortugas National Park. Fish and Wildlife Research Institute, St. Petersburg, 28 p

Bellwood DR, Hughes TP, Folke C, Nystrom M (2004) Confronting the coral reef crisis. Nature 429:827-833

Bohnsack JA, Bannerot SP (1986) A stationary visual census technique for quantitatively assessing community structure of coral reef fishes. NOAA Technical Report 41, 15 p

Carpenter RC (1990) Mass mortality of *Diadema antillarum* I. Long term effects on sea urchin population-dynamics and coral reef algal communities. Mar Biol 104:67-77

Chiappone M, Miller SL, Swanson DW, Ault JS, Smith SG (2001) Comparatively high densities of the long-spined sea urchin in the Dry Tortugas, Florida. Coral Reefs 20:137-138

Dahl AL (1974) The structure and dynamics of benthic algae in the coral reef ecosystem. Proc 2nd Int Coral Reef Symp 1:21-25

Davis GE (1982) A century of natural change in coral distribution at the Dry Tortugas: a comparison of reef maps from 1881 and 1976. Bull Mar Sci 32:608-623

Edmunds PJ, Carpenter RC (2001) Recovery of *Diadema antillarum* reduces macroalgal cover and increases abundance of juvenile corals on a Caribbean reef. Proc Natl Acad Sci, USA 98:5067-5071

Harper DE, Bohnsack JA, Lockwood BR (2000) Recreational fisheries in Biscayne National Park, Florida, 1976-1991. Mar Fish Rev 62:8-26

Hawkins JP, Roberts CM (2004) Effects of artisanal fishing on Caribbean coral reefs. Conserv Biol 18:215-226

Hughes TP, Rodrigues MJ, Bellwood DR, Ceccarelli D, Hoegh-Guldberg O, McCook LJ, Moltschaniwskyj N, Pratchett MS, Steneck RS, Willis B (2007) Phase shifts, herbivory, and the resilience of coral reefs to climate change. Curr Biol 17:360-365

Knowlton N (2001) The future of coral reefs. Proc Natl Acad Sci, USA 98:5419-5425

Kuffner IB, Paul VJ (2004) Effects of the benthic cyanobacterium *Lyngbya majuscula* on larval recruitment of the reef corals *Acropora surculosa* and *Pocillopora damicornis*. Coral Reefs 23:455-458

Kuffner IB, Walters LJ, Becerro MA, Paul VJ, Ritson-Williams R, Beach KS (2006) Inhibition of coral recruitment by macroalgae and cyanobacteria. Mar Ecol Prog Ser 323:107-117

McCook LJ, Jompa J, Diaz-Pulido G (2001) Competition between corals and algae on coral reefs: a review of evidence and mechanisms. Coral Reefs 19:400-417

Morrison D (1988) Comparing fish and urchin grazing in shallow and deeper coral reef algal communities. Ecology 69:1367-1382

Mumby PJ, Dahlgren CP, Harborne AR, Kappel CV, Micheli F, Brumbaugh DR, Holmes KE, Mendes JM, Broad K, Sanchirico JN, Buch K, Box S, Stoffle RW, Gill AB (2006) Fishing, trophic cascades, and the process of grazing on coral reefs. Science 311:98-101

Mumby PJ, Hastings A, Edwards HJ (2007) Thresholds and the resilience of Caribbean coral reefs. Nature 450:98-101

Porter JW, Battey JF, Smith GJ (1982) Perturbation and change in coral reef communities. Proc Natl Acad Sci, USA 79:1678-1681

Shinn EA, Hudson JH, Halley RB, Lidz B (1977) Topographic control and accumulation rate of some Holocene coral reefs: South Florida and Dry Tortugas. Proc 3rd Int Coral Reef Symp 2:1-7

Shinn EA, Jaap WC (2005) Field guide to the major organisms and processes building reefs and islands of the Dry Tortugas: The Carnegie Dry Tortugas Laboratory centennial celebration (1905 - 2005), St. Petersburg, 43 p