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Examination of Algal Diversity and Benthic Community Structure at Palmyra Atoll, U.S. Line Islands

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Abstract. Palmyra Atoll National Wildlife Refuge is the second largest atoll under U.S. jurisdiction in the Pacific Ocean. Until recently, little was known about benthic communities and, more specifically, algal abundance at Palmyra aside from species lists generated during 1916, 1955 and 1959 expeditions. Since 2000, NOAA's Pacific Islands Fisheries Science Center, Coral Reef Ecosystem Division has conducted six rapid ecological assessment surveys to monitor and gather baseline data for reefs surrounding Palmyra. Additionally, Scripps Institute of Oceanography documented benthic community structure on Palmyra's reefs during a 2005 expedition. This study reports on the current state of knowledge for benthic community composition and algal community structure across the atoll. Benthic communities in fore reef areas (10 m depth) were dominated by reef builders (coral and crustose coralline algae) covering ~50% of the benthos, while turf algae, macroalgae, soft corals, and other invertebrates covered the remaining surfaces. Species of *Halimeda*, *Lobophora*, *Dictyosphaeria*, *Galaxaura* and *Dichotomaria* were among the 5 most common macroalgae recorded. Overall, the reef communities around Palmyra appear relatively healthy. Developing comprehensive species lists and continuing benthic monitoring will allow reef managers to detect ecosystem changes, including possible introduced and invasive species.

Key words: algae, benthic community, coral, monitoring

Introduction

Palmyra Atoll, located in the northern portion of the Line Island Archipelago, is situated 1692 kilometers southwest of the Hawaiian Islands in the intertropical convergence zone (Maragos et al. 2008, Miller et al. 2008). It is the second largest of 10 atolls under US jurisdiction, and is composed of 182 and 6,277 hectares of emergent and submerged habitat, respectively (Handler et al. 2007; Rohmann et al. 2005). Although composed of several vegetated islets, Palmyra Atoll's geographically remote location has never fostered permanent human population. Thus, the atoll remained in near pristine condition until the early 1940s when it was turned into an US military airbase during World War II. An airstrip was constructed by dredging the central lagoon and using the debris to connect existing islets. A large ship channel was also dredged to allow military vessels to enter the calm lagoonal waters.

In 2000, Palmyra's largest island (Cooper Island) was purchased by the Nature Conservancy and a research station was built (Miller et al. 2008). In 2001, all remaining areas of Palmyra Atoll (excluding Cooper Island) were purchased by the US Fish and Wildlife Service and were designated a National Wildlife Refuge, thus increasing Palmyra's protected status (Miller et al. 2008). A recent study investigating the fish and benthic communities of the northern Line Islands found that the reefs of Palmyra and the more northerly Kingman Reef were characterized by high apex predator biomass in similar proportions to those found in the uninhabited Northwestern Hawaiian Islands (Sandin et al. 2008; Stevenson et al. 2007). Therefore, in spite of previous environmental changes made by the US military, 60 years devoid of human disturbance and Palmyra Atoll's distance from large human populations have allowed marine communities around the outside of the atoll to remain in a reasonably pristine state (Brainard et al. 2005; Sandin et al. 2008), offering a relatively unperturbed marine system for study.

Despite several early species lists (Rock 1916, Dawson et al. 1955, Dawson 1959), little has been reported about algal communities surrounding Palmyra Atoll. New species of marine algae from Palmyra were reported through the 1960s (Hollenberg

1968) and recent coral community monitoring has been performed (Williams et al. 2008; Maragos et al. 2008; Miller et al. 2008). However, no comprehensive analysis of algal community composition has yet occurred.

The goals of this study were to use two of the most comprehensive data sets available on benthic community composition of Palmyra's reefs to examine spatial patterns in functional group abundance, and more specifically, macroalgal abundance around the atoll. NOAA's Pacific Islands Fisheries Science Center (PIFSC), Coral Reef Ecosystem Division (CRED) has been examining benthic community biodiversity and abundance on reefs surrounding the atoll in 2000 and 2001 and biennially from 2002 to 2008. Additionally, in 2005, a comprehensive study of Palmyra reef communities was conducted by Scripps Institute of Oceanography (SIO; Sandin et al. 2008). Using these two complementary data sets, benthic communities were examined to (1) understand spatial patterns in percent cover of benthic functional groups, and (2) increase knowledge of macroalgal community composition. These results will be used as a baseline for future monitoring of Line Islands reefs, providing valuable insight for management efforts investigating the role played by algal communities at Palmyra Atoll (National Marine Fisheries Service, 2006).

Site Number	Location	Latitude	Longitude
PAL-01	S Fore Reef	5N 52.183	162W 4.137
PAL-02	W Terrace	5N 52.952	162W 7.878
PAL-04	W Terrace	5N 52.424	162W 6.990
PAL-05	N Fore Reef	5N 53.761	162W 8.247
PAL-06P	W Terrace	5N 52.294	162W 7.098
PAL-09	S Fore Reef	5N 52.046	162W 5.751
PAL-10	W Terrace	5N 51.961	162W 2.909
PAL-11	W Terrace	5N 53.027	162W 8.006
PAL-12	N Fore Reef	5N 53.834	162W 6.459
PAL-15P	E Terrace	5N 52.221	162W 2.697
PAL-16P	W Terrace	5N 52.2913	162W 6.7377
PAL-18	N Fore Reef	5N 53.765	162W 8.899
PAL-19	S Fore Reef	5N 51.9929	162W 6.5716
PAL-20	N Fore Reef	5N 53.7906	162W 7.1567
PAL-21	N Fore Reef	5N 53.7494	162W 5.0846
PAL-25	S Fore Reef	5N 51.8394	162W 1.8743
PAL-26	W Terrace	5N 51.831	162W 7.6128
PALB1	S Fore Reef	5N 51.986	162W 6.558
PALB2	S Fore Reef	5N 52.156	162W 4.539
PALB3	S Fore Reef	5N 51.925	162W 2.378
PALB4	N Fore Reef	5N 53.745	162W 4.888
PALB5	N Fore Reef	5N 53.810	162W 6.019
PALB6	N Fore Reef	5N 53.358	162W 2.799
PALB7	N Fore Reef	5N 53.870	162W 3.769
PALB8	N Fore Reef	5N 53.761	162W 7.172
PALB10	S Fore Reef	5N 51.976	162W 3.483
PALB12	N Fore Reef	5N 53.805	162W 7.707

Table 1: CRED and SIO (indicated with a B) benthic survey sites at Palmyra Atoll.

Materials and methods

Field Location

Palmyra Atoll (Figs 1, 2, Table 1) is one of 11 atolls and low islands situated in the Line Island chain, and sits atop a shallow bank <100 m below sea level. Large shallow (<30m) reef terraces extend from the eastern and western shores, with northern and southern shores exhibiting relatively narrow strips of fore reef area that rapidly drop to abysmal depths (National Marine Fisheries Service 2006; Maragos et al. 2008; Miller et al. 2008). Survey sites occurred between 3m to 15m depths in both reef terrace and fore reef habitats (Figs. 1, 2, Table 1). No survey sites were located within lagoonal habitats, although survey sites PAL-04 and PAL-16P were located adjacent to a dredged channel leading to the SW corner of the lagoon (Table 1, Figs. 1, 2).

Benthic Surveys

Quantitative Rapid Ecological Assessment (REA) surveys were conducted across the atoll by two research organizations: (1) NOAA's CRED established 20 sites between 2000 and 2008, and (2) SIO conducted an expedition in 2005 that surveyed 10 sites. CRED sites were stratified across reef terrace and fore reef habitats at ~15m depths (when possible) (Table 1) and subsequent surveys emphasized previously surveyed sites. SIO sites were all located in fore reef habitats at 10m depths and were located at 2km intervals around the atoll (Table 1). At each site, 2 transect lines of either 25m (CRED) or 50m (SIO) were deployed and 12 – 20 photographs were taken using a photoquadrat (CRED = 0.18m^2, SIO = 0.54m^2) equipped with a digital still camera (Preskitt et al. 2004) along each line for a total area surveyed of 2 – 10m^2 per site. Photographs serve as permanent documentation of each site and were analyzed for benthic percent cover using the Coral Point Count with Microsoft Excel extensions (CRED; CPCe; Kohler and Gill 2006) or PhotoGrid (SIO) software to assign one hundred stratified random points to each digital image.

Benthic percent cover data were divided into the functional groups of coral, crustose coralline red algae (CCA), turf, and macroalgae. Macroalgal data were further identified to the lowest taxonomic level possible. To examine whether community composition (functional group abundance) was similar across habitats within each sampling year, one-way analyses of similarity were performed (ANOSIM; number of permutations = 5,000) using Bray-Curtis Similarity Indices (based on fourth root transformed abundance data) performed in PRIMER-

E v.6. Data between sampling years were not combined in spatial analyses. SIMPER analyses were performed to determine which functional groups and/or algal species were contributing the most to differences or similarities between sites.

Results

Benthic Community Composition

Benthic communities surrounding Palmyra Atoll were relatively homogeneous in terms of functional group abundance (Table 2). ANOSIM results examining benthic community composition between fore reef and terrace habitats found no differences within each sampling year (Global R (p-value): 2004 = 0.071 (0.003), 2006 = 0.15 (0.018), 2008 = 0.131 (0.0002)). Similarly, no differences were observed among sites (regardless of habitat) in 2004, 2005 or 2006 (Global R (p-value): 2004 = 0.214 (0.0002), 2005 = 0.174 (0.0002), 2006 = 0.098 (0.0002)); although ANOSIM site comparisons revealed differences in 2008 (Global R (p-value) = 0.351 (0.0002)). From 2004 through 2008, percent cover of macroalgae ranged from 3 to 58% (Fig. 1) (average = 19%), reef builders (coral and crustose coralline red algae) ranged from 10% to 71% (average = 45%), and turf algal cover ranged from 7% to 70% (average = 30%).

In 2008, individual pairwise *r*-values from the ANOSIM test revealed that the difference observed in Global R values stemmed from differences in benthic community composition between western terrace sites (PAL-02, PAL-04, PAL-05,and PAL-06) and the rest of the atoll (Figs 1, 2). SIMPER revealed *Halimeda opuntia* to exhibit a percent cover of 32% at PAL-02, accounting for 17 – 31% of observed dissimilarities between this site and all others (PAL-02 pairwise *r*-value range = 0.022 – 0.824, median = 0.279). PAL-04, located on the western reef terrace near the boat channel, contained a dense community of the red macroalga *Dichotomaria marginata* that covered 37% of the substrate. The alga was not observed elsewhere around the atoll, therefore driving statistical differences between PAL-04 and other sites (pairwise *r*-value range = 0.01 – 0.853, median = 0.333). SIMPER analysis revealed that *D. marginata* accounted for 21 – 59% of the dissimilarity between PAL-04 and all other sites. Similarly, PAL-05, located on the NE fore reef, was different from 6 of the 8 sites surveyed in 2008 (*r*-value range = 0.204-0.853, median = 0.638). At PAL-05, turf algae covered 70% of the substrate and accounted for 34 – 39% of the dissimilarity found between this and other sites. A corallimorph that covered 69% of the substrate at PAL-06 (and was not seen elsewhere around the atoll) contributed to 38 – 43% of dissimilarities observed (PAL-06 *r*-value range = 0.553 – 0.664, median = 0.633).

Site	Year	Coral	Turf Algae	CCA	Macroalgae
PAL-01	2004	14.33	24.67	28.42	32.57
	2006	19.58	40.00	18.50	19.25
	2008	16.25	44.17	19.42	18.25
PAL-02	2008	13.17	12.08	13.75	54.91
PAL-04	2008	6.92	20.17	10.00	62.49
PAL-05	2008	11.00	69.50	7.67	4.33
PAL-06P	2008	8.67	16.92	1.25	4.34
PAL-09	2004	29.42	32.00	18.00	20.51
	2006	20.83	33.00	11.83	32.83
	2008	16.33	17.33	12.50	53.76
PAL-10	2004	31.83	30.50	14.67	21.32
	2006	14.08	37.50	11.25	31.85
	2008	30.58	28.58	10.08	29.50
PAL-11	2004	25.50	24.58	24.58	24.75
	2006	30.17	24.25	13.67	29.92
	2008	22.58	23.25	27.58	25.5
PAL-12	2006	27.00	40.83	13.67	14.50
	2008	32.00	34.58	13.50	14.5
PAL-15P	2004	58.08	30.08	8.92	2.17
PAL-16P	2004	4.17	37.33	17.50	40.92
PAL-18	2004	65.50	23.00	4.50	7.00
PAL-19	2004	22.50	32.42	21.58	20.75
	2006	40.58	22.08	14.92	20.59
PAL-20	2006	31.58	39.50	21.92	6.75
PAL-21	2006	20.83	35.17	16.58	24.16
PAL-25	2004	52.42	33.08	9.08	4.83
PAL-26	2004	36.42	37.25	17.83	5.92
	2006	54.33	26.42	9.33	4.58
PALB1	2005	15.85	21.00	30.35	29.1
PALB2	2005	13.96	34.00	21.70	25.3
PALB3	2005	47.30	13.00	29.10	10.25
PALB4	2005	24.15	25.20	24.05	24.45
PALB5	2005	28.40	28.80	19.80	19.35
PALB6	2005	23.25	42.00	14.45	15.15
PALB7	2005	31.62	30.76	17.29	17.57
PALB8	2005	18.60	24.85	41.95	14.21
PALB10	2005	17.6	6.70	47.60	22.7
PALB12	2005	42.75	19.25	28.60	9.8

Table 2: Average percent cover of benthic functional groups from survey sites from 2004-2008. Average percent cover of photoquads for each site during each year are presented. Standard errors not shown because of space limitations. CCA = Crustose Coralline Red Algae.

In 2004, percent cover of live coral at site PAL-16P was only 4% (compared to an average of 37% around the rest of the atoll), and this functional group contributed to 13 – 47% dissimilarity between PAL-16P and other sites during this sampling year (PAL-16P *r*-value range = 0.257 – 0.734, median = 0.42). PAL-16P site has not been resurveyed since.

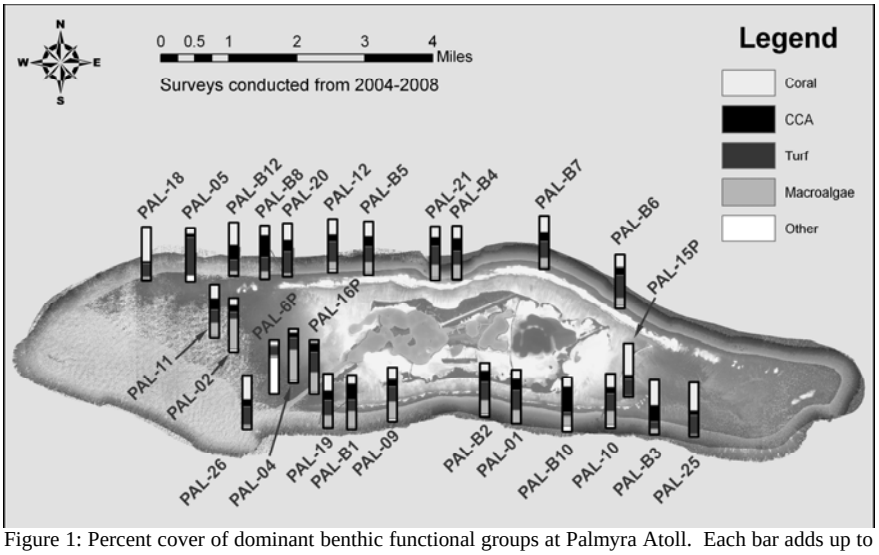

Figure 1: Percent cover of dominant benthic functional groups at Palmyra Atoll. Each bar adds up to 100% cover. Percent cover data from sites visited in multiple years were averaged (Table 2).

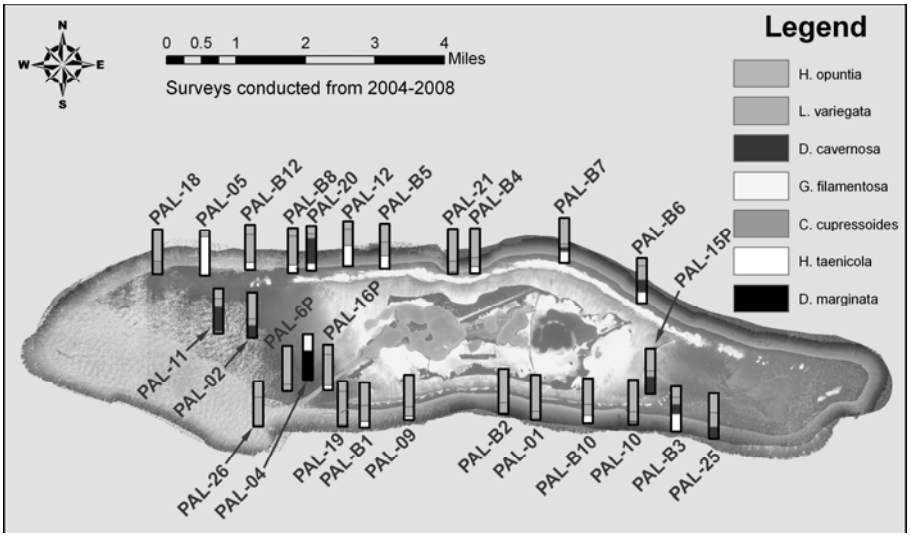

Figure 2: Relative abundance of select macroalgal species at Palmyra Atoll. Each bar shows percent contribution of each algal species to total macroalgal cover present at each site. Percent cover data from sites visited in multiple years were averaged (Table 2).

Algal Community Composition

Nineteen species of macroalgae were documented in photoquadrats at Palmyra Atoll. Of these, *Halimeda opuntia* was the most common, exhibiting a percent cover range of 0 – 46% (average = 8.2%). *Lobophora variegata* (percent cover = 0 - 27.7%, average = 5.3%), *Galaxaura filamentosa* (percent cover = 0 – 37%, average = 1) and *Dictyosphaeria cavernosa* (percent cover = 0 – 16.5%, average = 1.6%) were the next most common species.

ANOSIM analyses performed on macroalgal percent cover data (omitting all other functional groups) found algal communities to be relatively similar across the atoll (Global R: 2004 = 0.196; 2005 = 0.073; 2006 = 0.48; 2008 = 0.184, significance = 0.02%); however, PAL-04 (Fig. 2) showed a statistically significant difference in macroalgal percent cover from 5 of the 8 other sites surveyed in 2008 (*r*-value range = 0.623 – 0.997, significance.

Discussion

Overall, the outer fore reef areas of Palmyra Atoll remain healthy, presumably because of the lack of current anthropogenic influences. Benthic community structure is dominated by reef building organisms, primarily coral and CCA at 82% of sites. At only four sites did macroalgal cover exceed that of either reef builders or turf algae, a finding similar to that of a previous study at eight other relatively pristine Pacific reefs, where macroalgal cover was lower than that of coral at 67% of sites (Vroom et al. 2006). Findings at

Palmyra are also in line with those from Kingman Atoll, the closest island to Palmyra, where benthic cover was dominated by reef-building organisms in contrast to macroalgal dominated substrates around the more densely populated islands of Tabuaeran and Kiritimati (Sandin et al. 2008).

The high percent cover of the red alga *Dichotomaria marginata* and a corallomorph documented at PAL-04 and PAL-06, respectively, may be due to these site's close proximity (477m) to a 37m, steel-hulled, long line vessel which ran aground in 1991. Changes in algal communities have also been observed to occur in close proximity to a 1993 shipwreck on Rose Atoll (Schroeder et al. 2008). Rose Atoll was monitored by CRED from 2002 to 2006 and exhibits percent cover of opportunistic algal species two times higher at the shipwreck site as compared to sites further away. Additionally, Work et al. (2008) found high densities of the corallimorph, *Rhodactis howesii*, to occur within 1 km^2 of the Palmyra wreck suggesting possible correlations with nutrient availability and changes in benthic communities. Further research examining nutrient levels at PAL-04 and PAL-06 are needed to definitively link the shipwreck at Palmyra Atoll with increased percent cover of *D. marginata* and corallomorphs.

Finally, the protected status of Palmyra Atoll guarantees that the surrounding reef communities will be spared from any direct human impacts, allowing Palmyra Atoll and other remote reefs to serve as important natural laboratories for understanding the impacts of climate change on coral reefs.

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