

Rapid Ecological Assessment for Yap, Ngulu, and Ulithi. Yap State, Federated States of Micronesia.

Quantitative Assessments of Coral-Reef Assemblages and Macroinvertebrate Abundances



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Executive Summary

This report describes the modern coral and invertebrate assemblages around Yap, Ngulu, and Ulithi based upon quantitative ecological surveys conducted as part of Yap State's Rapid Ecological Assessment (REA). Surveys were conducted to estimate the abundances and diversity of corals and macroinvertebrates, and provide a baseline to detect changes from future disturbances and resource use. At each survey location, a replicated, quadrat-based technique was employed to estimate coral species abundances and diversity at two depths, 10 and 3 meters. Populations of macroinvertebrates were counted during replicated, timed swims at both depths. The resultant data are discussed at the regional, island, and site-specific scale to assist Yap's resource management agencies in understanding probable causes for discovered ecological patterns and evaluate the current status of their resources.

Large-scale patterns:

Preliminary results showed each of the three surveyed island had significantly different modern coral assemblages. The two atolls, Ngulu and Ulithi, had a greater similarity in coral composition compared with Yap, that was expected based upon geological differences (atolls versus islands). One consequence of varying geology is higher long-term, average surface chlorophyll-a concentrations for the atolls compared with Yap, consistent with regional findings from other studies throughout the Pacific Ocean. Enhanced primary productivity, in part, explains why lower coral diversity is found on atolls compared with islands. Accordingly, other sections of this REA reported 167 coral species for Ngulu, 180 for Ulithi, and 214 for Yap. Besides geology, the regional surface currents are also probable drivers of coral reef assemblages. The study region is influenced by two major ocean circulation patterns: 1) the North Equatorial Current (NEC) (east to west) places the greatest influence on Ulithi, while 2) the North Equatorial Counter Current (NECC) (west to east) has the greatest influence on Ngulu. These differences may enhance isolation of populations within the study area, and probably are responsible for the marked differences in coral reef assemblages between the two geologically similar atolls.

Regional comparisons showed that coral cover varied from 23% on Ngulu, to 29% on Yap, and 53% on Ulithi, however this trend follows closely with the percentage of outer reefs that were surveyed, being highest for Ulithi. More interestingly, two measures of coral community evenness (how evenly coral species are distributed) indicated that Ngulu's coral cover was more evenly distributed among different species, followed by Ulithi and then Yap. The relatively high human population and development on Yap may be affiliated with higher levels of land-based pollution that is known to reduce evenness.

Island patterns:

Within each island group consistent trends were found between a qualitative estimate of wave exposure and shallow (3 meter) coral assemblages. Diverse *Acropora* communities

were mainly found on moderately exposed reefs associated with the channels and outer reefs. *Porites*, *Heliopora*, *Lobophyllia*, and *Montipora* reached highest abundances in protected, shallow-water environments. These findings are consistent with previous studies showing that variation in exposure influences coral species' presence and growth. Variation in cover and evenness was greatest at low to medium exposure, especially on Yap, indicating that reefs in closest proximity to land may be differentially impacted by the degree and nature of land-and-population-associated disturbances.

Deeper (10 meter) coral assemblages were best predicted by 'reef type', a descriptor of the location and geological nature of the underlying reef substrate. 'Channels' and 'Outer reefs' typically held greater coral coverage and evenness as compared with 'inner' and 'patch' reefs. The Tomil channel on the east coast of Yap held the greatest diversity, coverage, and evenness as compared with all other survey locations, suggesting optimal environmental conditions may exist for growth in this unique location. 'Inner' and 'patch' reefs typically hold fewer species and less coverage at the 10 meter depth, consisting mainly of Faviids and Poritiids.

Yap Island:

Besides the Tomil channel, notable coral assemblages existed at the Goofnuw channel and relatively high macroinvertebrate populations were found at the Miil channel. The outer reefs associated with Yap's southern tip held the greatest coral coverage and evenness, furthering that this reef-line also deserves a high consideration for management. With respect to the inner lagoon, blue holes, the reef in front of Tomil village had the greatest coral coverage, diversity, and invertebrate populations as compared with all others.

Ngulu Atoll:

Shallow and deep coral assemblage data highlight the central-western barrier reef of Ngulu as being biologically-enriched. High coral coverage and evenness estimates, as well as macroinvertebrate abundances, were found in this geographic region. Personal communication with other members of this REA indicate that signs of poaching and perhaps destructive fishing may be evident, and thus, locally based management should incorporate a means of surveillance and transportation to this unique region. Clearly, this region deserves enhanced consideration for management, and is unique to the atoll.

Ulithi Atoll:

Unlike Ngulu, no single geographic region was indicated to consistently hold a relatively rich reef system across different depths and exposures. Specific locations from Ulithi Atoll, Falalop, Turtle, and Lizard Islands show high coverage, evenness, and macroinvertebrate populations. One unique site on the southeast side of Lizard Island holds a unique mono-stand of *Acropora palifera* that was not seen elsewhere in the REA and deserves special management concern. Elsewhere, strategies may best benefit from a spatially-encompassing approach.

Conclusions:

The results presented here provide a contemporary snapshot of the coral-reef assemblages on Yap, Ngulu, and Ulithi, Federated States of Micronesia. Most influentially, depth-stratified, quantitative data provide a baseline for Yap's local marine monitoring program to assess change over time resultant from natural and human disturbances, and to assess the effectiveness of management strategies. It is strongly recommended that these sites, or a subset of inner, channel, and outer reef sites continues to be monitored. One notable limitation of this REA is our inability to understand resiliency. Continued monitoring after future disturbances will provide insight into resiliency, whereby the sites that are least impacted or that rebound quickly deserve high management consideration.

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Introduction

This report quantitatively describes the coral and invertebrate communities that were assessed during a rapid ecological assessment (REA) in Yap State, Federated States of Micronesia in July 2007. Three localities within Yap State were visited during the surveys, Yap Island, Ngulu and Ulithi Atoll. A brief oceanographic background is first presented to characterize the region and provide a context for understanding inherent differences in the coral and invertebrate abundances that are resultant from large-scale, forcing environmental variables.

Yap, Ngulu, and Ulithi reside in the Western Pacific Ocean between 8° – 10° N and 135° – 140° E (Figure 1). Interestingly, this region is influenced by two major ocean circulation patterns: 1) the North Equatorial Current (NEC) (east to west), and 2) the North Equatorial Counter Current (NECC) (west to east) (Bonjean and Lagerloef 2002). Depending upon the location and the season, the islands surveyed are influenced by different surface currents (Figure 2). Convergence between the westward NECC and the eastward NEC is strongest during the spring (Figure 2c-d), between Yap and Ngulu, and moves southward during the latter months. Thus, Ngulu is seasonally influenced by the NEC to a greater degree compared with Yap and Ulithi. In contrast, the NECC has a greater influence on Yap and Ulithi, especially during the summer, fall, and winter (Figure 2).

Besides surface currents, average surface chlorophyll-a concentrations show a second, large-scale environmental pattern that varies among the study islands (Figure 3). Long-term averages of chlorophyll-a data show a clear trend of higher concentrations affiliated with Ulithi and Ngulu (atolls), as compared with Yap (island). This is probably a consequence of the nutrient dynamics associated with atolls (Webb et al. 1975, Charpy et al. 1990, Charpy 2001), whereby high primary productivity is attributed to the presence of a soft-sediment bottom providing ideal conditions for phytoplankton growth.

Given the notable differences in surface currents and chlorophyll-a concentrations (proxies of nutrient dynamics) it can be hypothesized that each island might hold unique coral and invertebrate assemblages. It has been shown that modern assemblages are a consequence of the time-integrated response of species to the environment, with favorable environments holding higher species richness and greater abundances (van Woesik and Done 1997, Houk 2006). Here, the greater influence of the NECC on Ngulu compared with Ulithi Atoll is expected to result in differing local populations (relative abundances) between the two, despite their geographic proximity (~200 km apart) and similar geology (atolls). The increased habitat complexity associated with Yap, accompanied by the lower chlorophyll-a concentrations found on islands compared with atolls, are expected to enhance species richness and coral abundance (Cornell and Karlson 1996).

After investigating large-scale trends in the modern coral and invertebrate communities this report then approaches each island individually. Within each island, we first investigated the influences that ‘reef type’ and wave exposure place upon modern

communities to understand the distribution of local populations, as both are noted drivers of coral communities (Storlazzi et al. 2005, Done et al 2007). Efforts should account for as much inherent variation as possible before identifying localities where favorable growth and populations exist. In summary, this approach groups ecologically-similar sites and subsequently examines each group to identify where individual, ‘valuable’ reefs exist and where management should focus.

Figure 1. The Western Pacific Ocean showing Yap State, from northeast to southwest Ulithi atoll, Yap Island, and Ngulu atoll are shown in blue.

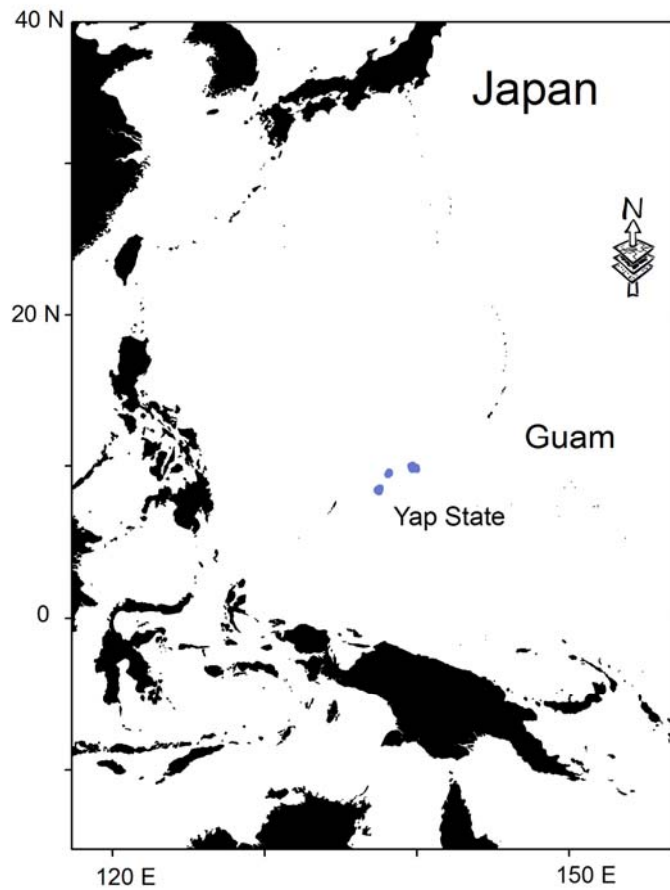
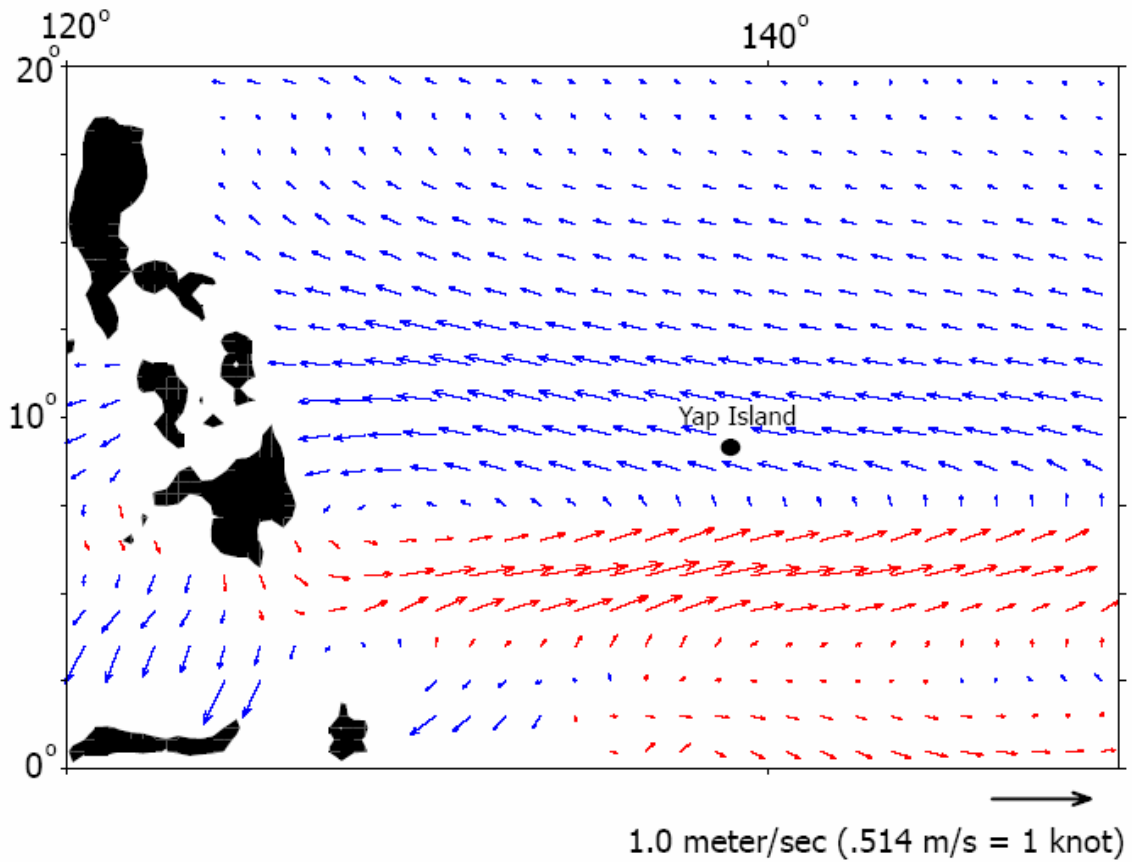


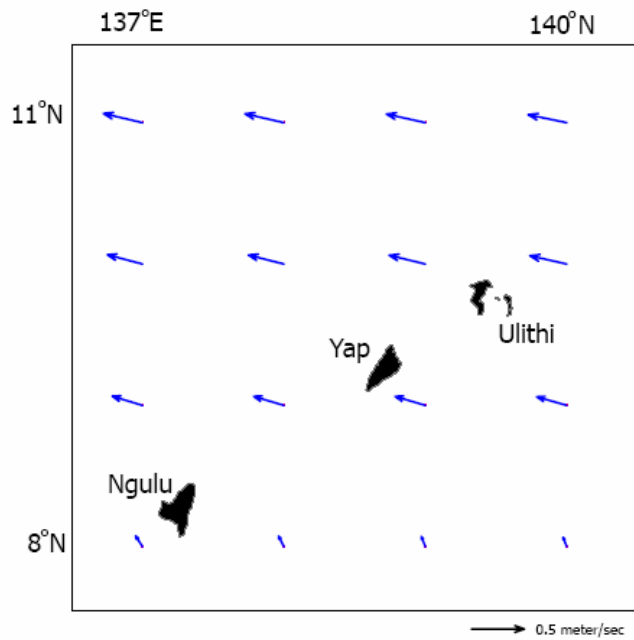
Figure 2a-h. Seasonal surface current vectors for the Western Pacific and Yap.

2a)

January - February 2006 Mean Surface Currents

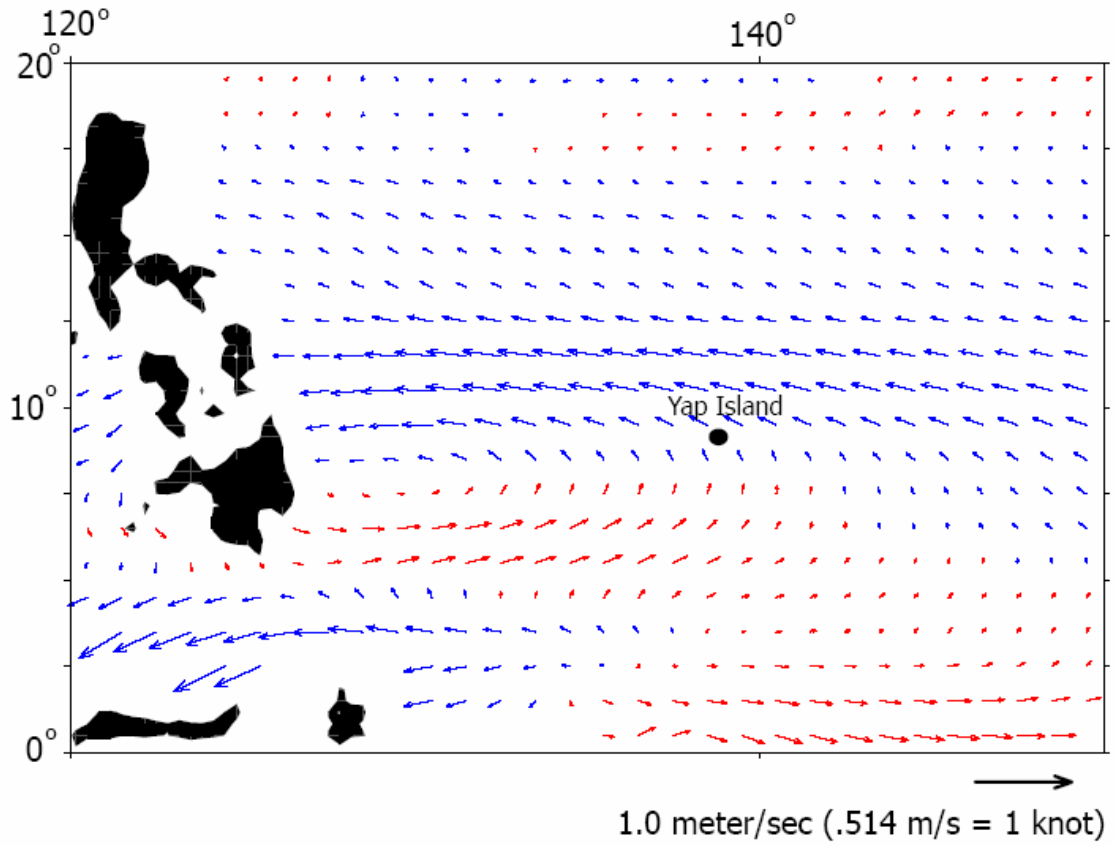


2b)

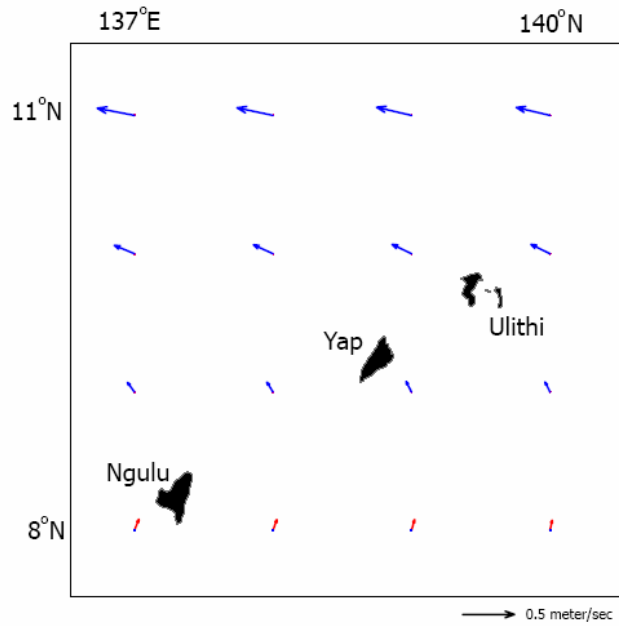


2c)

March - May 2006 Mean Surface Current Vectors

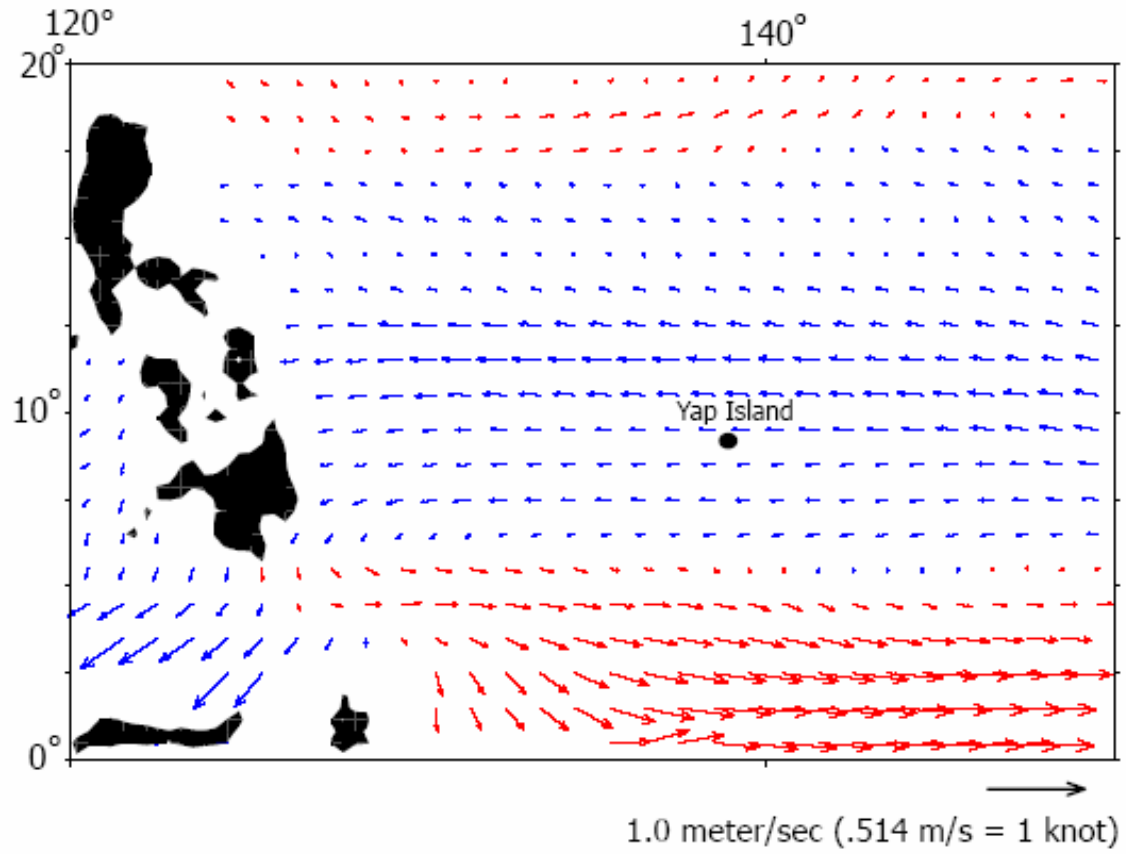


2d)

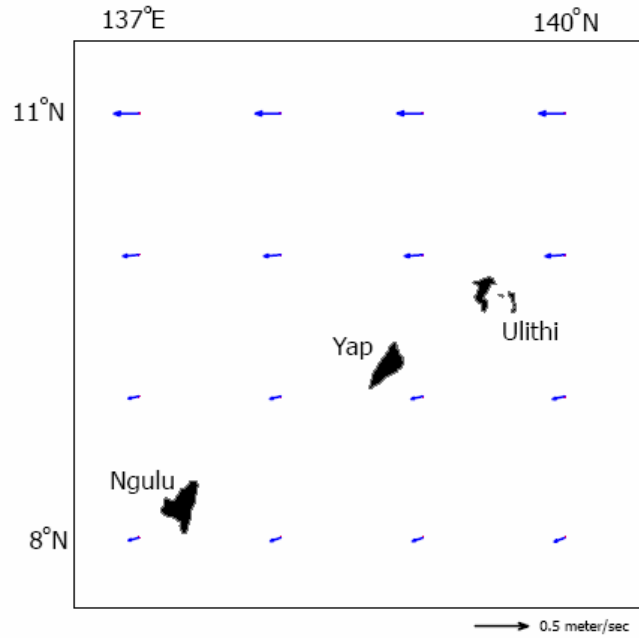


2e)

June - August 2006 Mean Surface Current Vectors

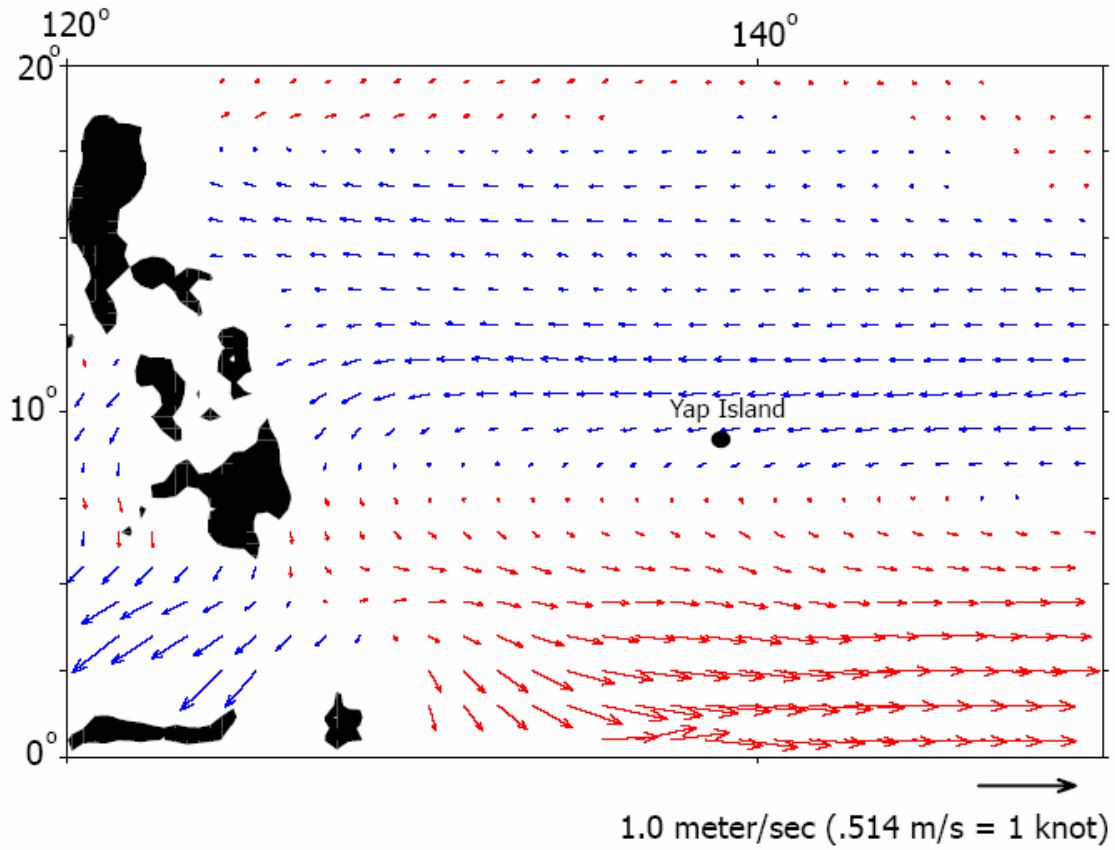


2f)



2g)

August - November 2006 Mean Surface Currents



2h)

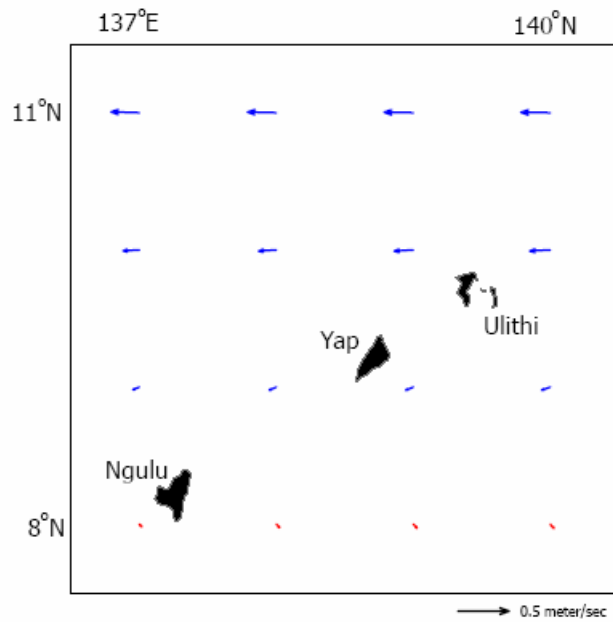
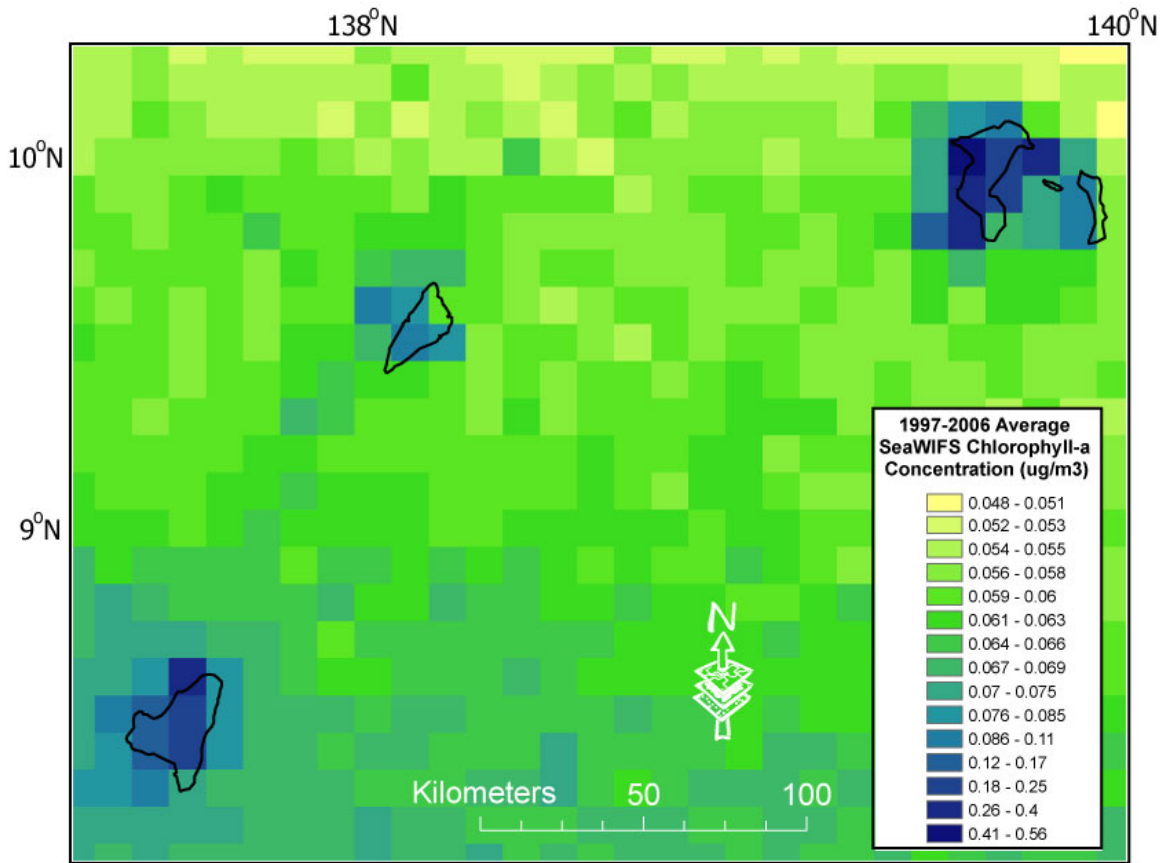


Figure 3. 1997 – 2006 average chlorophyll-a concentration in the vicinity of Yap Island, Ngulu and Ulithi Atoll.



Methods

Survey Sites –

Quantitative coral and invertebrate data were collected at 44 sites (Table 1); 18 on Yap (Figure 4), 11 on Ngulu (Figure 5), and 15 on Ulithi (Figure 6). Four ‘reef types’ were examined: 1) inner reefs including patches, 2) inner ‘sand-dominated’ reefs, 3) outer reefs, and 4) channels. Attempts were made to survey sites from varying exposures and ‘reef types’ when possible.

Coral Communities –

A standard, quadrat-based technique was employed to investigate modern coral and invertebrate communities (Randall 1988, Houk and Starmer 2004). Briefly, replicated 1 m² or .25 m² quadrats were haphazardly tossed at two depths (1 – 3 m and 8 - 10 m) while swimming a distance of ~250 m from the global-positioning-system-identified (GPS) survey point. Coral colonies whose center-point was inside the quadrat were identified and measured. Depending upon visual estimates of average colony size, either a large (1 m²) or small (.25 m²) quadrat was used for efficient sampling. Abundances, population densities, and geometric diameters were calculated for each coral species from these measurements.

Geometric diameters (Z) were calculated based upon the geometric formula

$$Z \text{ (cm)} = (x \cdot y)^{1/2} \quad (1),$$

where (x) and (y) are the cross sectional diameters of each coral colony. Percent coverage (A) for each colony was calculated assuming that the coral colonies were circular using the formula

$$A \text{ (cm}^2\text{)} = \pi(z/2)^2 / \text{quadrat size (cm}^2\text{)} \quad (2),$$

where (z) is the geometric diameter from (1). Total percent coverage was simply the sum for all species.

Diversity Assessments –

Similar, quadrat based surveys were employed to quantitatively assess the occurrences and population densities of all taxon. Replicated 1 m² quadrats were haphazardly tossed at two depths (1 – 3 m and 8 - 10 m) while swimming a distance of ~250 m from the GPS-identified survey point. All taxon that partially or fully resided within each 1 m² replicate were identified. Population densities were calculated using

$$D \text{ (colonies/m}^2\text{)} = n / \text{total area surveyed (m}^2\text{)} \quad (4),$$

where n is the total number of observations of a species at a site and depth.

Macroinvertebrate Abundances –

Five, timed 5-minute swims were employed to estimate the populations of all macroinvertebrates at two depths (1 – 3 m and 8 - 10 m). Counts were made of all individuals within a 2 meter belt while swimming at a consistent speed and direction from the GPS-identified site.

Data Analyses –

In order to explore differences between modern assemblages from islands, reef types, and varying exposures (e.g. Table 1), Bray-Curtis dissimilarity matrices were created based upon multivariate, species abundance or population density data following

$$d_{il} = 100 \left\{ 1 - \frac{\sum_{j=1}^n |y_{ij} - y_{lj}|}{\sum_{j=1}^n (y_{ij} + y_{lj})} \right\} \quad (4),$$

where Σ represents the summation over all species, and the terms y_{ij} and y_{lj} represent the abundance of one species at two consecutive sample sites. The greater the dissimilarity between sites the larger d will be (equation 4). Dissimilarity matrices were visually interpreted using non-metric multi-dimensional scaling (Clarke and Warwick 2001). The resultant stress value indicates whether or not the multi-dimensional plot has been successfully interpreted by the two-dimensional representation, where values < .25 are considered acceptable (Clarke and Warwick 2001).

Margalef's d-statistic and Fishers α were calculated as measures of community evenness (Clarke and Warwick, 2001). These measures describe how evenly a variable (in this case percent coverage) was distributed throughout the community at any particular site. More than just the number of coral species present, these measures describe how evenly a variable (in this case percent coverage) was distributed throughout the community at any particular site. A high d-statistic or α suggest that a particular site is not dominated by one, or a few, species.

Table 1. A list of site characteristics corresponding with Figures 3 – 5.

Island	Site #	Reef Type	Exposure
Yap	1	Channel	Medium
Yap	2	Channel	Medium
Yap	3	Outer Reef	Moderate
Yap	4	Channel	Moderate
Yap	5	Channel	Moderate
Yap	6	Outer Reef	High
Yap	7	Channel	Medium
Yap	8	Inner Reef	Low
Yap	9	Inner Reef	Low
Yap	10	Outer Reef	Moderate
Yap	11	Channel	Moderate
Yap	12	Channel	Medium
Yap	13	Channel	Medium
Yap	14	Inner Reef	Low
Yap	15	Outer Reef	Moderate
Yap	16	Outer Reef	Moderate
Yap	17	Inner Reef	Low
Yap	19	Inner Reef	Low
Ngulu	1	Inner Reef	Medium
Ngulu	2	Outer Reef	Medium
Ngulu	3	Channel	Medium
Ngulu	4	Inner Reef	Moderate
Ngulu	5	Channel	Moderate
Ngulu	6	Outer Reef	High
Ngulu	7	Inner Reef	Moderate
Ngulu	8	Inner Sand Reef	Low
Ngulu	9	Inner Reef	Low
Ngulu	10	Outer Reef	Medium
Ngulu	11	Inner Sand Reef	Low
Ngulu	12	Inner Reef	Medium
Ulithi	1	Outer Reef	High
Ulithi	2	Inner Reef	Low
Ulithi	3	Outer Reef	Medium
Ulithi	4	Outer Reef	High
Ulithi	5	Outer Reef	High
Ulithi	6	Inner Reef	Low
Ulithi	7	Outer Reef	Medium
Ulithi	8	Inner Reef	Low
Ulithi	9	Inner Reef	Low
Ulithi	10	Outer Reef	Medium
Ulithi	11	Inner Reef	Low
Ulithi	12	Inner Reef	Low
Ulithi	13	Outer Reef	Medium
Ulithi	14	Inner Reef	Low
Ulithi	15	Inner Reef	Low

Figure 4. REA sites surveyed on Yap Island.

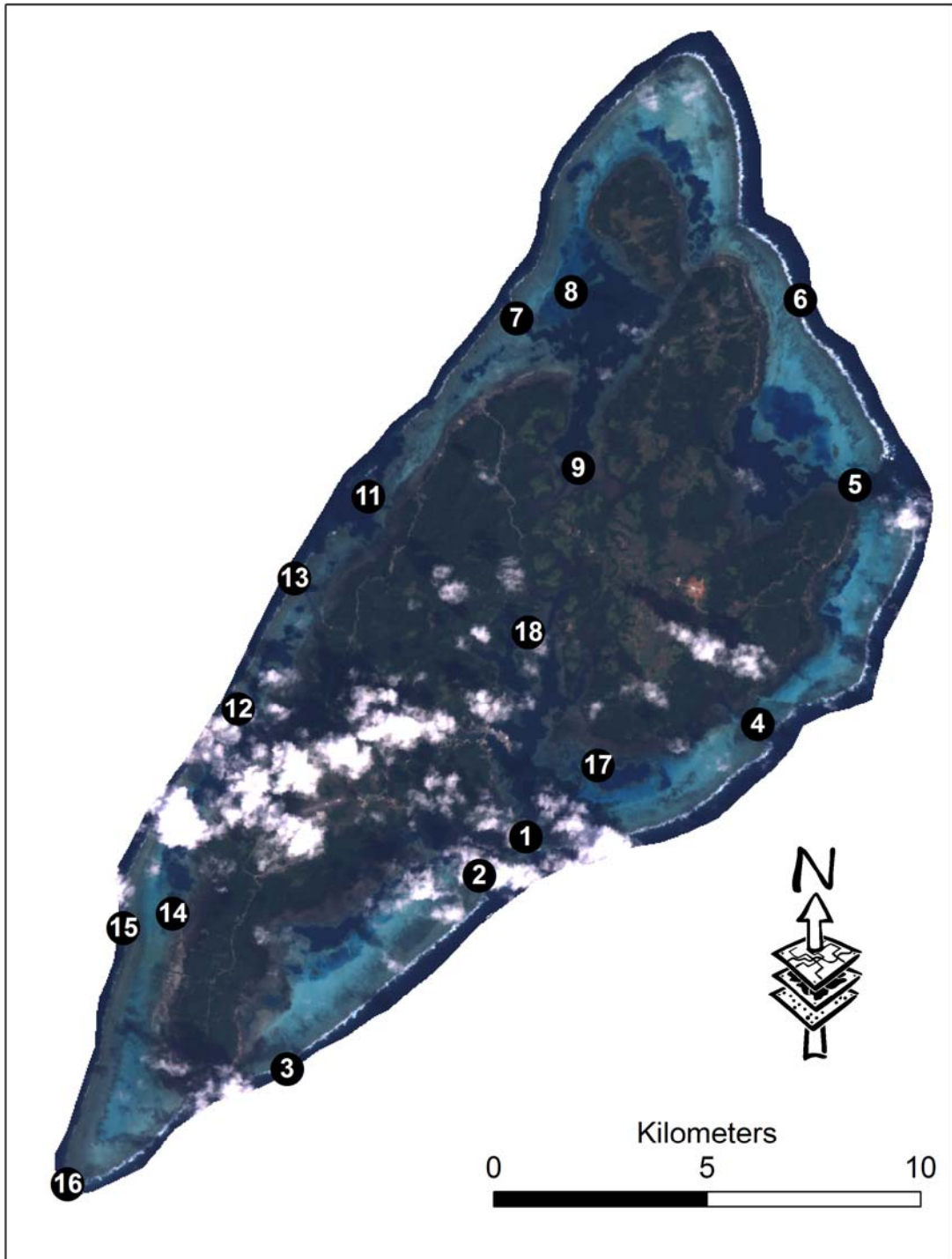


Figure 5. REA sites surveyed on Ngulu Atoll.

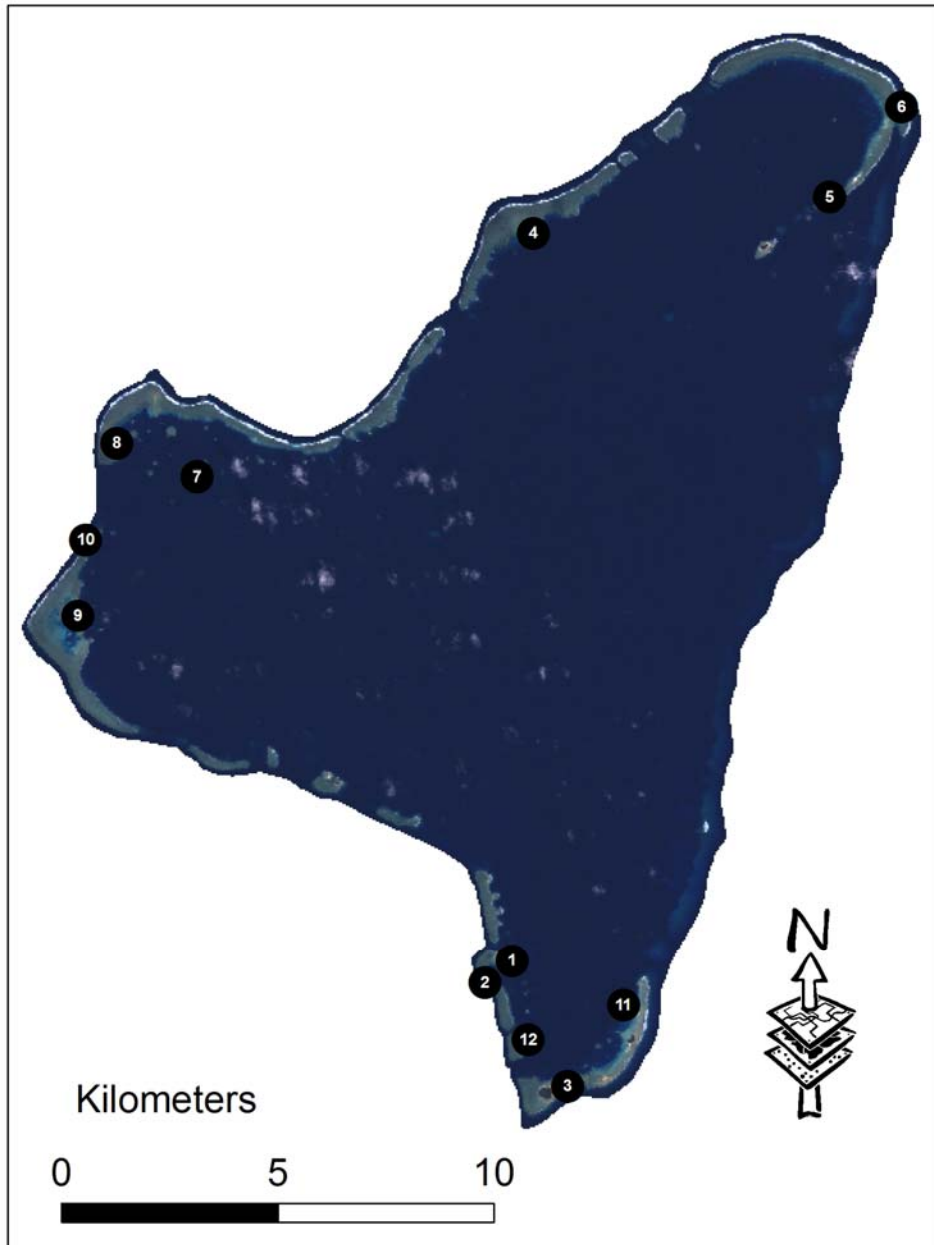
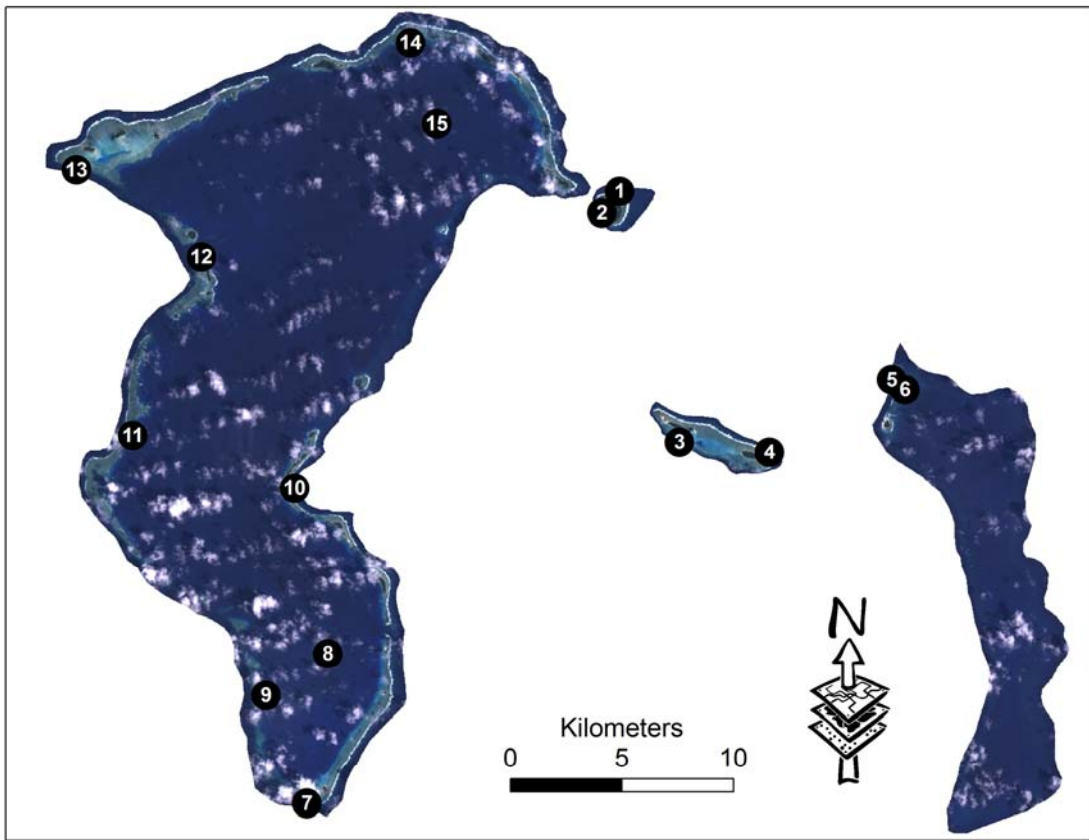


Figure 6. REA sites surveyed on Ulithi Atoll.



Results and Discussion

Large-scale differences in the modern coral assemblages from each island were detected (Figure 7). This trend is a suggested result of the variation in driving environmental variables. Ngulu and Ulithi had a greater similarity in coral composition compared with Yap (Figure 7). One site (site 8, Ngulu, Figure 4), had closer affinities with Ulithi coral assemblages than Ngulu's, and was unique to Ngulu, further discussed below. Regional comparisons show that coral cover varied from 23% on Ngulu, to 29% on Yap, and 53% on Ulithi (Figure 8), however this trend follows closely with the percentage of outer reefs that were surveyed, being highest for Ulithi. More interesting, two measures of community evenness indicated that Ngulu's coral cover was more evenly spread out among different species, followed by Ulithi and then Yap (Figure 8). It has been shown that selective environments (high wave exposure or pollution for example) tend to reduce evenness (Loya 1972, Tomascik and Sander 1987, Adjeroud and Salvat 1996, Houk et al. 2005), and the relatively high population on Yap may be associated with higher levels of land-based pollution compared with the two atolls. Measures of community evenness are independent of species richness, the later being the total number of species observed. Species richness is usually highest on large islands with many different habitats (Cornell and Karlson 1996).

Figure 6. Multi-dimensional scaling plot showing the differences in coral assemblages between Yap (crosses), Ngulu (open diamonds), and Ulithi (diamonds with crosses).

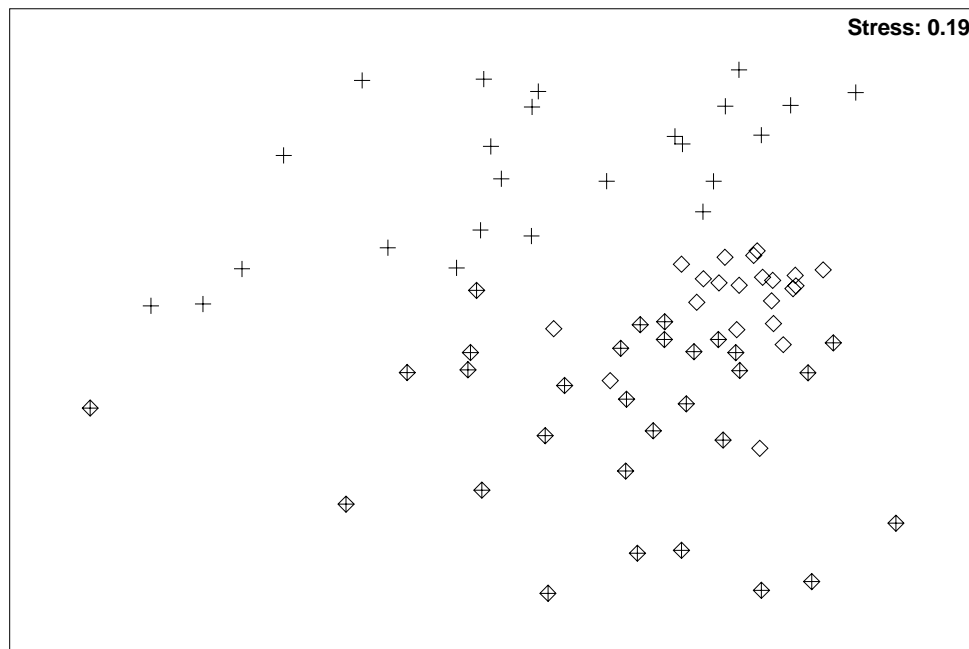


Figure 7. A comparison of coral cover and two measures of community evenness (SE bars) from Yap, Ngulu, and Ulithi. Margalef's d-statistic and Fishers α were used to estimate coral community evenness.

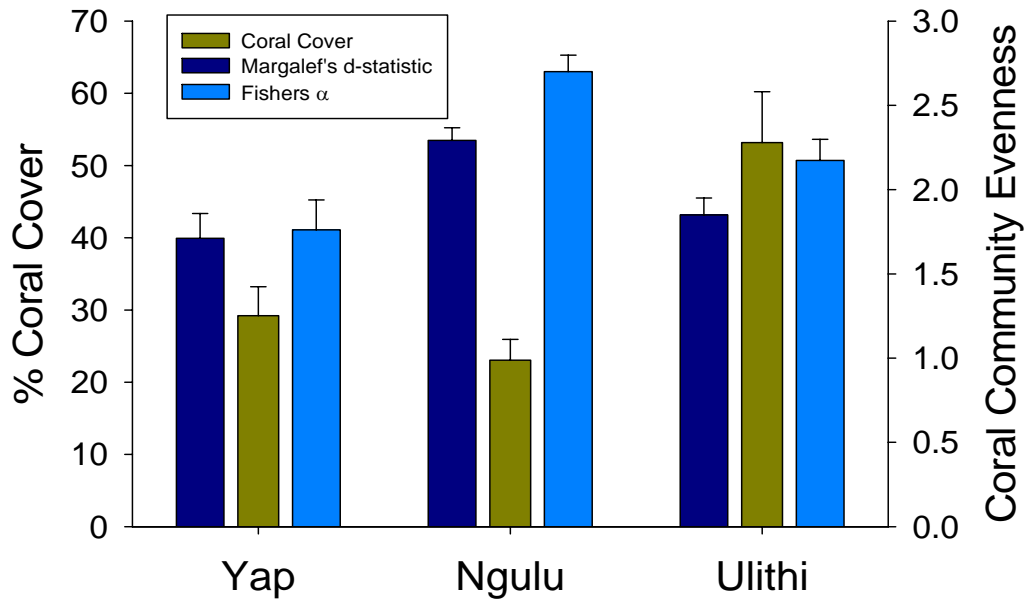


Figure 8a. Multi-dimensional scaling plot showing the differences in 8 – 10 meter depth coral assemblages on Yap between channels (crosses), inner reefs (open diamonds), and outer reefs (diamonds with crosses). Yap-1 is labeled because it represents an outlier channel site.

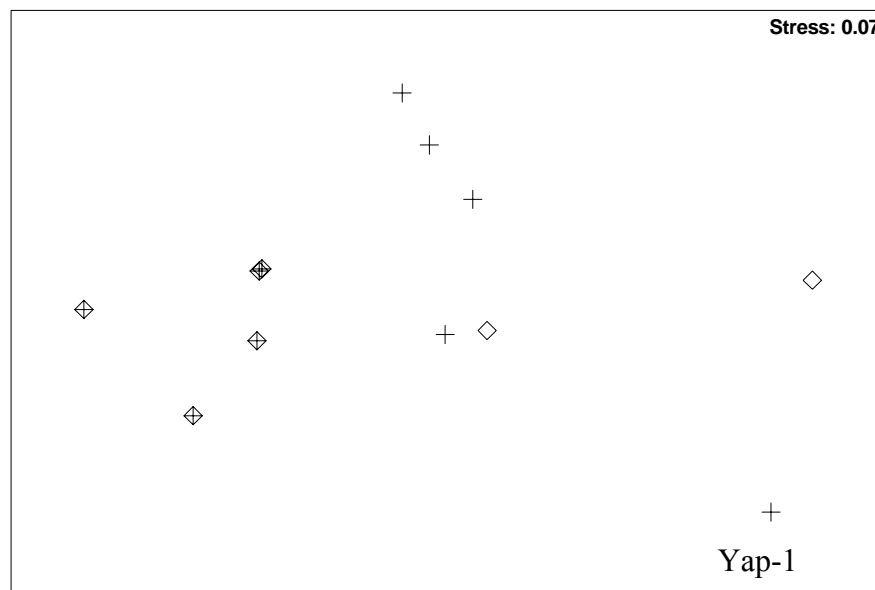
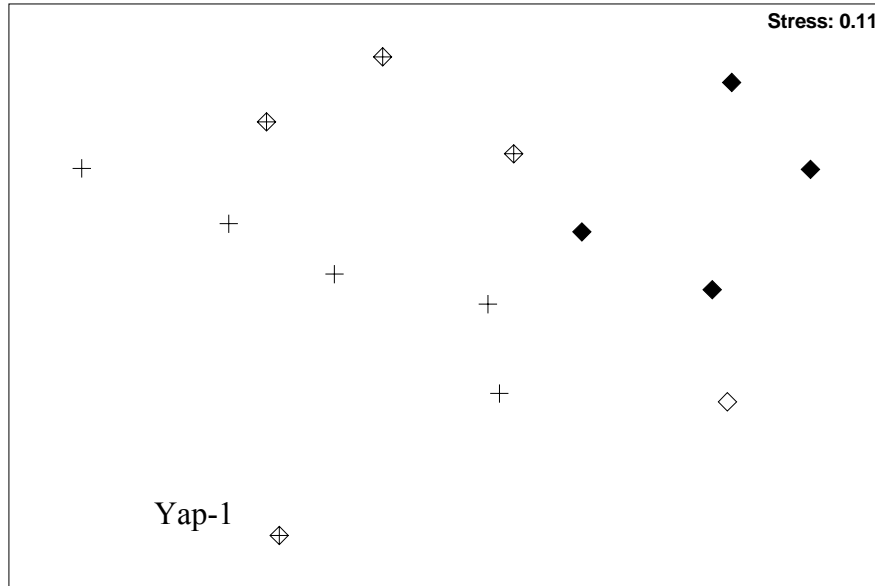


Figure 8b. Multi-dimensional scaling plot showing the differences in 1 – 3 meter depth coral assemblages on Yap between varying exposure: low (crosses), medium (diamonds with crosses), moderate (filled diamonds), and high (open diamonds). Yap-1 is labeled because it represents an outlier medium-exposure site.



Yap Island –

CORALS

‘Reef type’ best explained the differences in deeper modern coral assemblages of Yap (Figure 9a), while exposure did not show any clear trends when analyzed for all sites combined. At the 8 – 10 meter depth, the outer reefs had the greatest evenness of many common reef-building genera: *Acropora*, *Isopora*, *Hydnophora*, *Echinopora*, *Cyphastrea*, and *Goniastrea* (Figures 9a and 10a). In contrast, *Porites* abundance increased where low exposures existed, in the channels and inner reefs, and high coral cover was often found (Figure 9a and 10a). These results suggest the environment associated with the deeper, outer reefs is favorable for coral diversity and evenness, while the inner reefs and channels have the potential to hold mono-stands of *Porites* and *Montipora*, slower growing communities that take longer to recover from disturbances (Golbuu et al. 2007). Channel and inner reef assemblages had the greatest variation in species abundances, cover, and evenness, a probable cause of varying proximity to, and magnitude of, land-based disturbances. **Channel sites 4, 5, and 11 are where assemblages showed the highest cover, evenness, and species richness, and represent areas deserving the greatest management consideration.** Only one inner reef had live corals growing at the 8 – 10 meter depth, typical of turbid inshore reefs, and thus no management suggestions are offered. In contrast to the channels and inner reefs, there is no evidence that suggests the outer reefs show any influence to land-based pollution, rather large-scale disturbances may exert the greatest degree of control upon these assemblages. **Cover and evenness**

Figure 9b. Percent coral cover (SE bars) of the most dominant genera found at the 1 – 3 meter depth for Yap within differing wave exposure regimes.

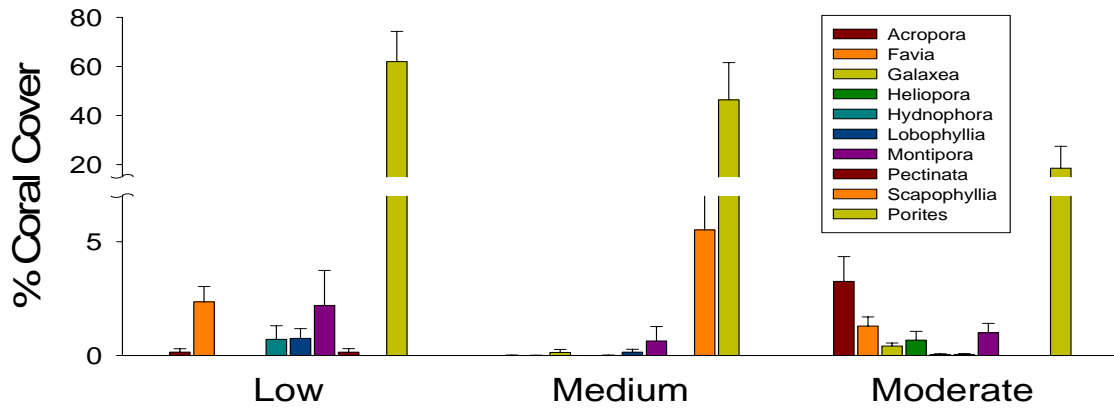


Figure 10a. Percent coral cover (SE bars) and evenness at each Yap site for 8 – 10 meter coral assemblages in differing reef types.

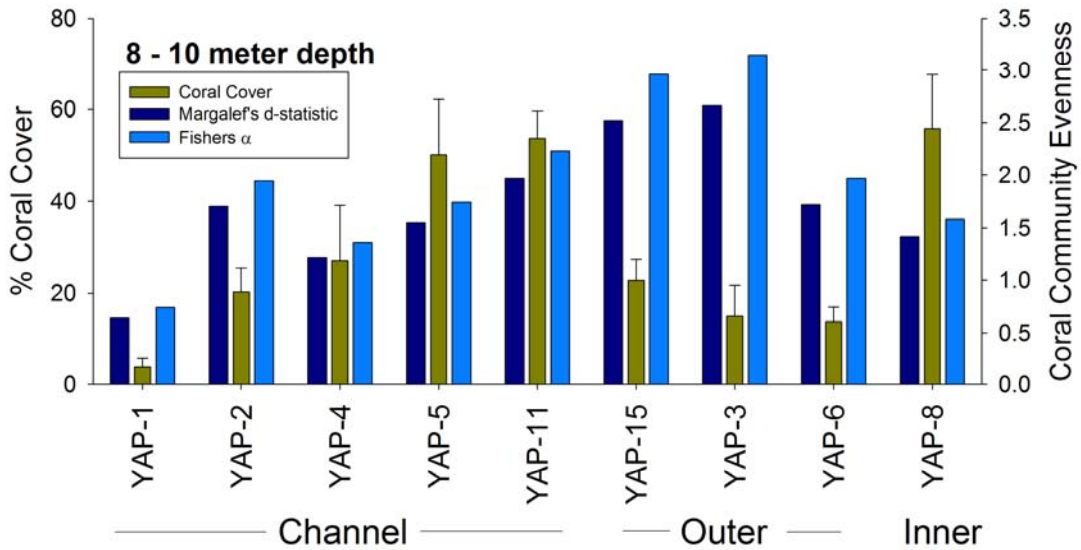
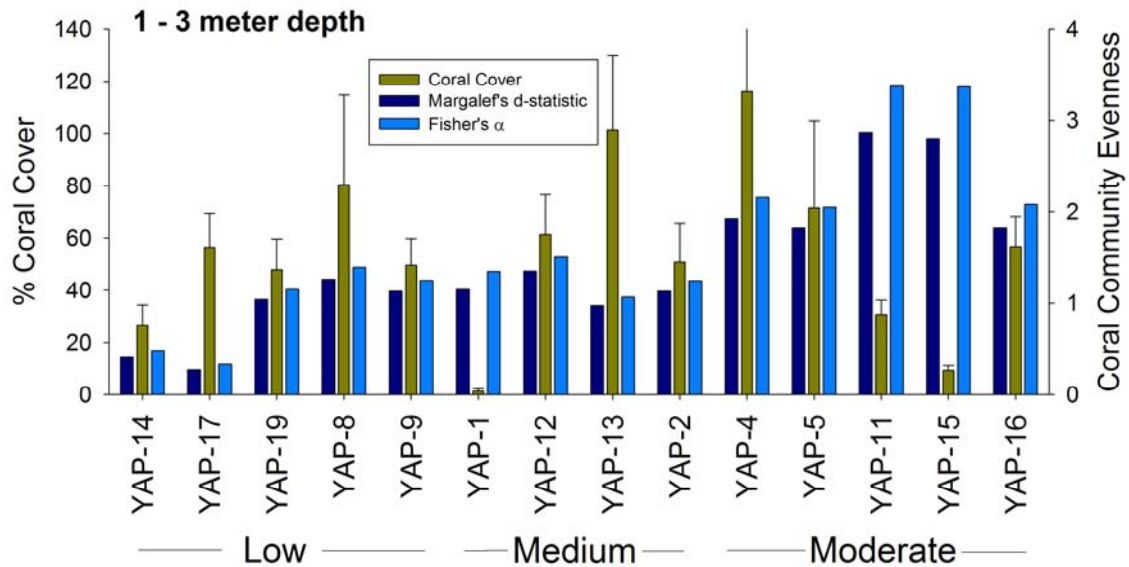


Figure 10b. Percent coral cover (SE bars) and evenness at each Yap site for 1 – 3 meter coral assemblages at different exposures.



MACROINVERTEBRATE ABUNDANCES

Crinoids, sea urchins, clams, sea cucumbers, and ‘other edible shells’ were the dominant macroinvertebrates found on Yap (Figures 11 and 12). Depth, ‘reef type’, and exposure all influenced macroinvertebrate abundances. At the 8 – 10 m depth the channel sites had the greatest abundances of crinoids (suspension feeders), the outer reefs had the most urchins, and the inner reefs and channels had the most sea cucumbers (Figure 12a). Clams (all species grouped together) were in relatively low abundances compared with the atolls, averaging less than 1 individual per 5-minute swim at both depths surveyed (Figure 12a-b). No octopus was encountered during the quantitative surveys at either depth, and only one lobster was counted. Trochus were abundant in shallow waters with medium to moderate exposure (Figure 12b), mainly the outer channels and reefs. **Site 7 held the greatest diversity and abundances of macroinvertebrates compared with all others and thus is recommended for enhanced management consideration.**

Figure 11. Relative macroinvertebrate abundances at all shallow (1 – 3 m) sites on Yap.

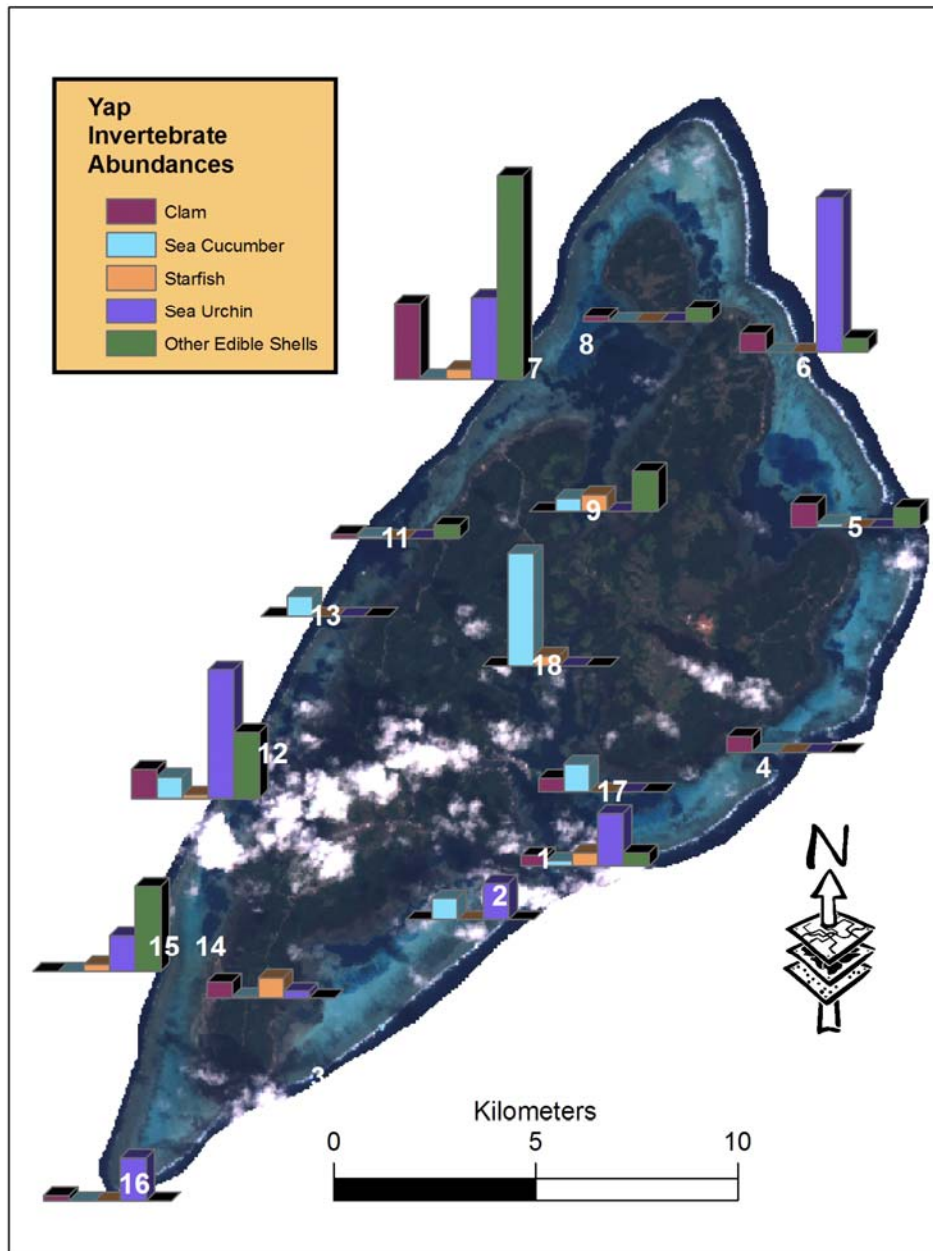


Figure 12a. Macroinvertebrate abundances for 8 – 10 m depth Yap sites in differing reef types.

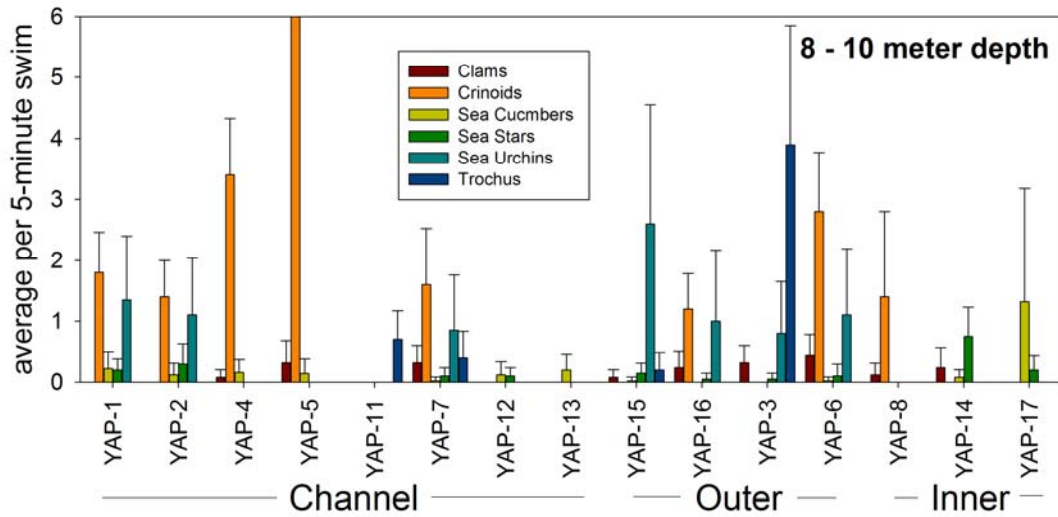
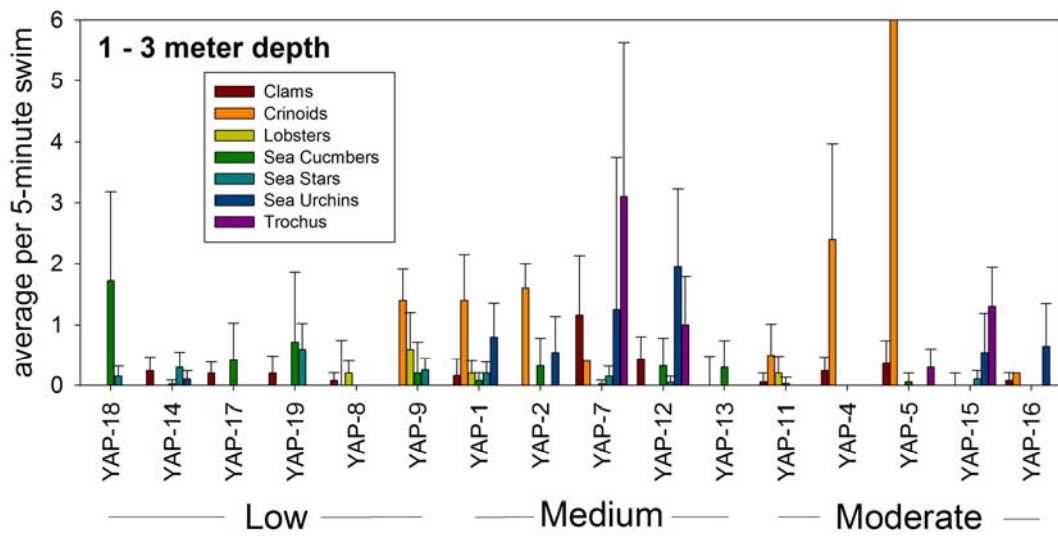


Figure 12b. Macroinvertebrate abundances for 1 – 3 m depth Yap sites varying in wave exposure reef types.



Ngulu Atoll –

CORALS

Similar to Yap Island, ‘reef type’ best explained the differences in 8 - 10 m depth, modern coral assemblages of Ngulu Atoll (Figure 13a), while no such trends were eminent for exposure. *Porites* were most abundant on the inner sand reefs and visually created the structure that identifies these unique habitats on Ngulu (Figure 14b). *Heliopora* were the only other corals that had greater than 1% coverage on the inner sand reefs, while other common reef-building genera were mostly absent due to a lack of a true reef substrate for colonization. There was a steady increase in the abundance of many genera along an inner reef – channel – outer reef gradient, except *Porites* which showed an opposite, declining trend along this gradient (Figure 14b). Outer reefs represent the only ‘reef type’ where *Acropora* were common at the 8 – 10 m depth, where several species were well represented: *A. c.f. surculosa*, *A. digitifera*, *A. palifera*, *A. nassuta*, *A. paniculata*, *A. granulosa*, and *A. secale*. Coral community composition in the channels was intermediate between the inner and outer reefs as surveys were conducted while drifting from the inner to the outer reef through the channels. **Coral coverage and evenness estimates suggest that sites 7, 8, 10, and 5 are areas for special management concern (Figure 15a). Sites 7, 8, and 10 are all representative of the western-central section of Ngulu, suggesting management should focus upon this biologically-enriched, geographic region.**

Wave exposure best explained the differences in shallow assemblages of Ngulu (Figure 13b), while ‘reef type’ was less influential because shallow assemblages were not well differentiated between inner, outer, and channel reefs. At extremely low exposures shallow communities are dominated by *Porites* and *Heliopora* (Figure 14a), whose abundance declines sharply when moving towards locations with higher exposure. Site 6 was unique because it represents the only high exposure site surveyed on Ngulu, and at this regime many corals had a decreased colony size (*Acropora*) or near absence (*Goniastrea*, *Leptastrea*, *Heliopora*, and *Stylophora*). Medium exposure localities held relatively high abundances of dominant corals compared with low and high exposures. **Sites 7, 8, and 10 had the greatest coverage, while evenness was similar among shallow coral assemblages within each wave exposure regime (Figure 15b), again suggesting the central-western geographic region should be given high management consideration.**

Figure 13a. Multi-dimensional scaling plot showing the differences in 8 – 10 meter depth coral assemblages on Ngulu between channels (crosses), outer reefs (diamonds with crosses), inner reefs (filled diamonds), and inner sand reefs (x's). NGU-2 is labeled because it represents an outlier outer reef site.

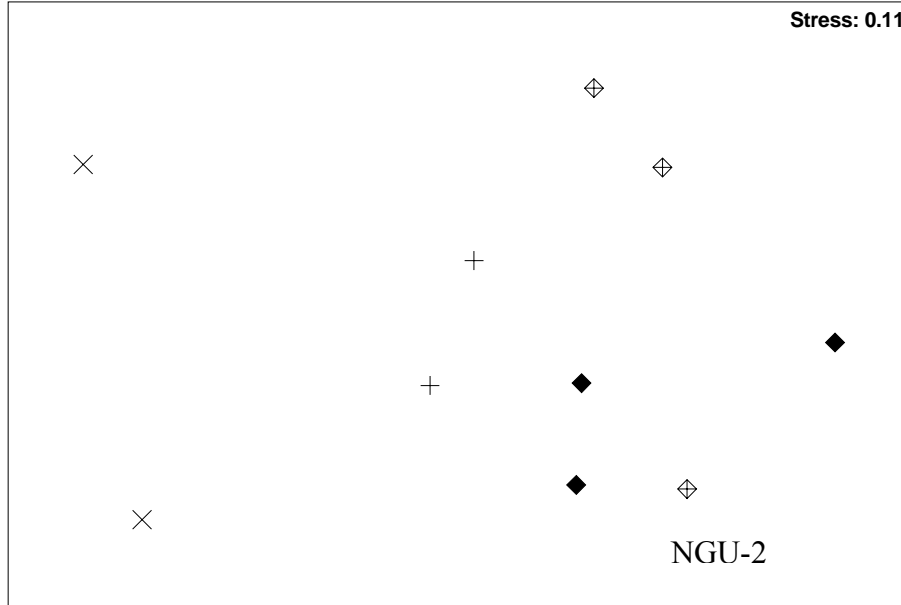


Figure 13b. Multi-dimensional scaling plot showing the differences in 1 – 3 meter depth coral assemblages on Ngulu between varying exposure: low (x's), medium (filled diamonds), moderate (diamonds), and high (crosses).

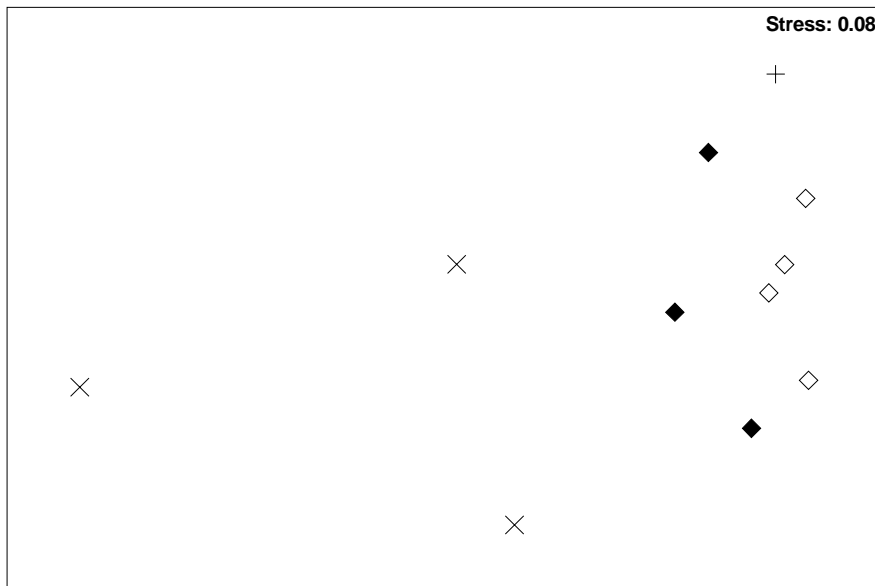


Figure 14a. Percent coral cover (SE bars) of the most dominant genera found at the 1 – 3 meter depth at Ngulu within differing wave exposure regimes.

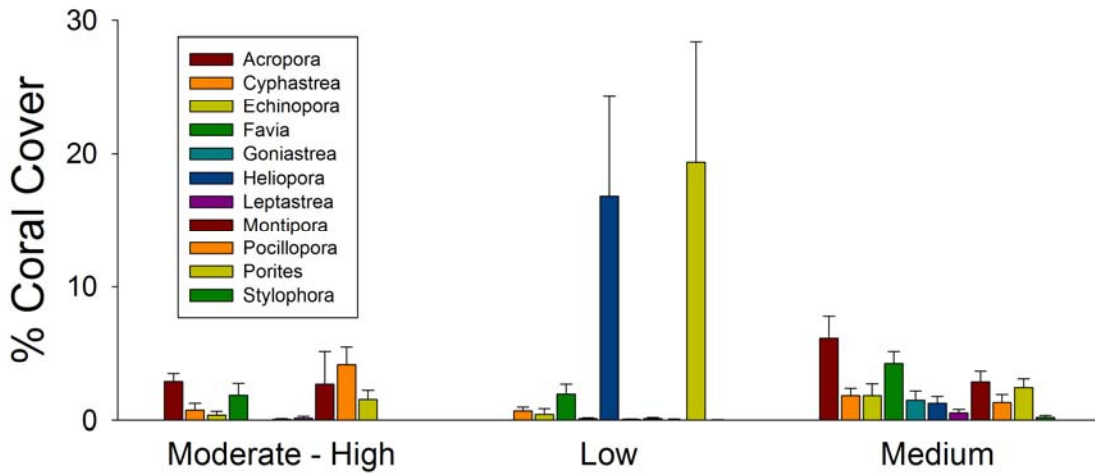


Figure 14b. Percent coral cover (SE bars) of the most dominant genera found at the 8 – 10 meter depth at Ngulu within three different reef types: outer, inner, and channel.

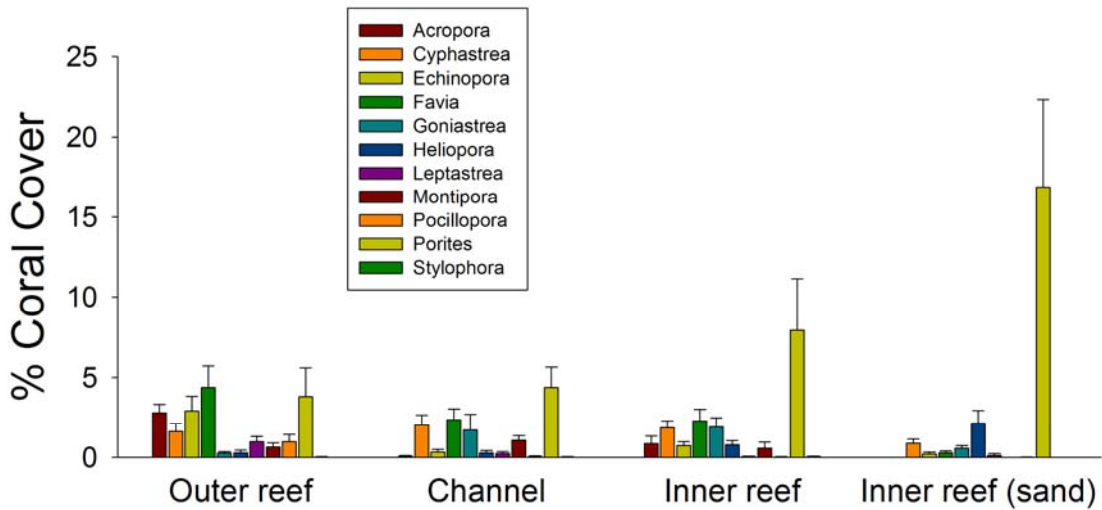


Figure 15a. Percent coral cover (SE bars) and evenness at each Ngulu site for 8 – 10 meter coral assemblages in differing reef types.

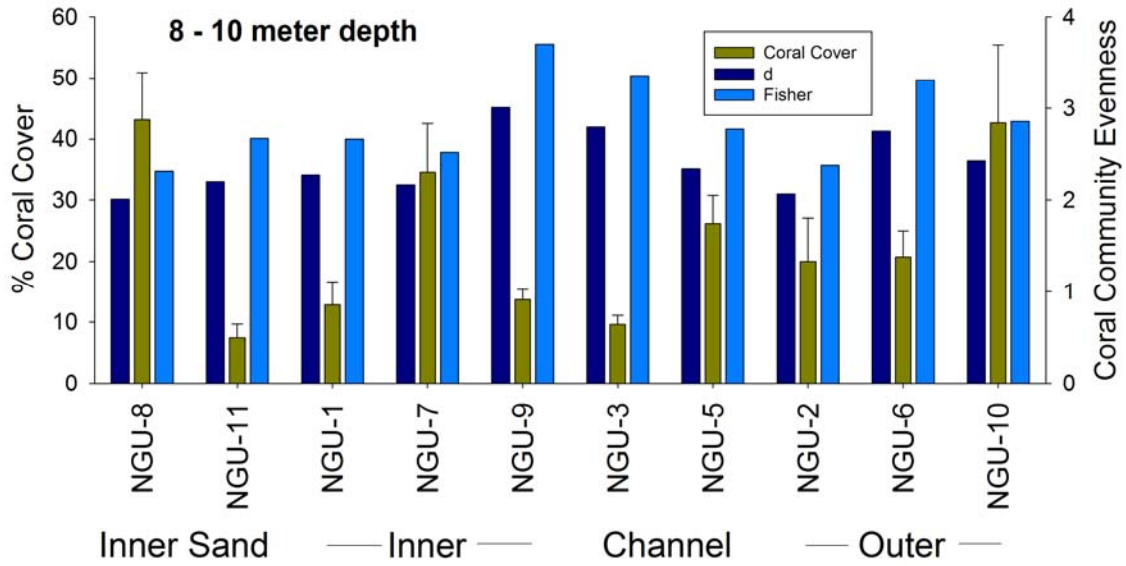
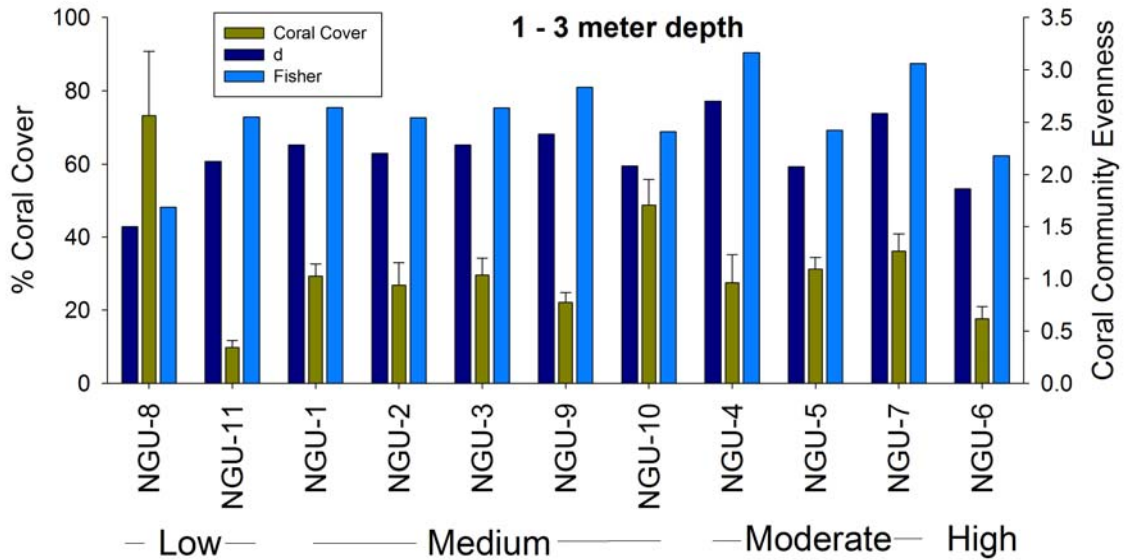


Figure 15b. Percent coral cover (SE bars) and evenness at each Ngulu site for 1 – 3 meter coral assemblages at different exposures.



MACROINVERTEBRATE ABUNDANCES

Crinoids, sea urchins, clams, sea cucumbers, and ‘other edible shells’ were the dominant macroinvertebrates found on Ngulu (Figures 16 and 17). Notably, clam abundances were much higher than on Yap where they were absent during many surveys, while lobster abundances followed a similar trend to a lesser degree, being found but not abundant. Both shallow and deep depths supported high clam abundances at all sites (average = 6.3 individuals per 5-minute, min=2, max = 15). At both depths sea-cucumbers were only abundant on inner reefs, reaching highest abundances on the uncommon sand-dominated reefs. **Because the majority of these reefs reside within the western-central geographic region, further support for high management concerns are confirmed.** Site 4 had an relatively high abundance of trochus and other edible shells compared with all others at the 1-3 meter depth (Figure 16a and 17a). **If the local community places a high dependence upon these resources, enhanced management consideration should be given for site 4.** High abundance were also found at site 6, however the high exposure may serve to limit access to harvesting. Most other invertebrate groups reached their highest abundances in at the 1-3 m depth where medium-moderate exposure existed (Figure 17a). These habitats may be ideal for urchins and sea-stars. **The notable absence of Actinopyga sea-cucumbers, typically common in shallow waters of moderate wave energy, is not understood or reconciled, but noted.**

Figure 16a. Relative macroinvertebrate abundances at all shallow (1 – 3 m) sites on Ngulu.

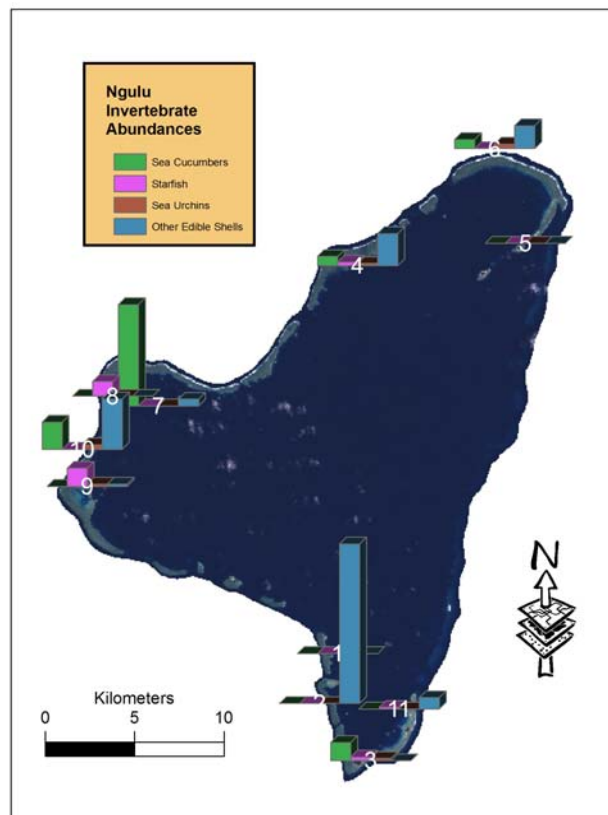


Figure 16b. Relative clam and crinoid abundances at all shallow (1 – 3 m) sites on Ngulu.

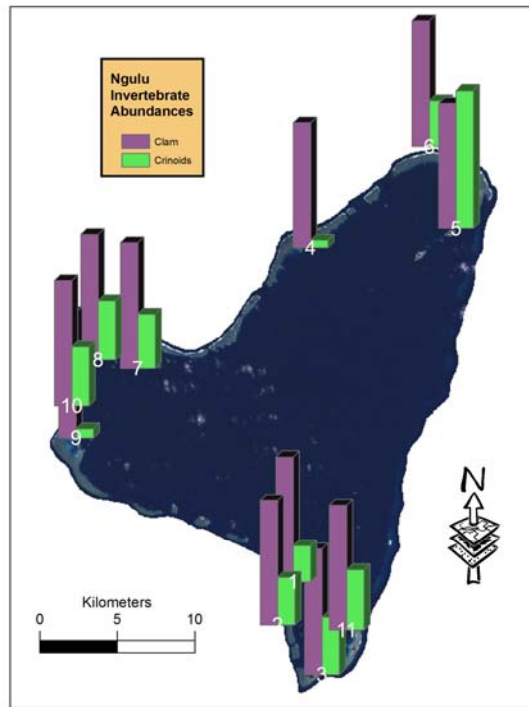


Figure 17a. Macroinvertebrate abundances for 1 – 3 m depth Ngulu sites at varying wave exposures.

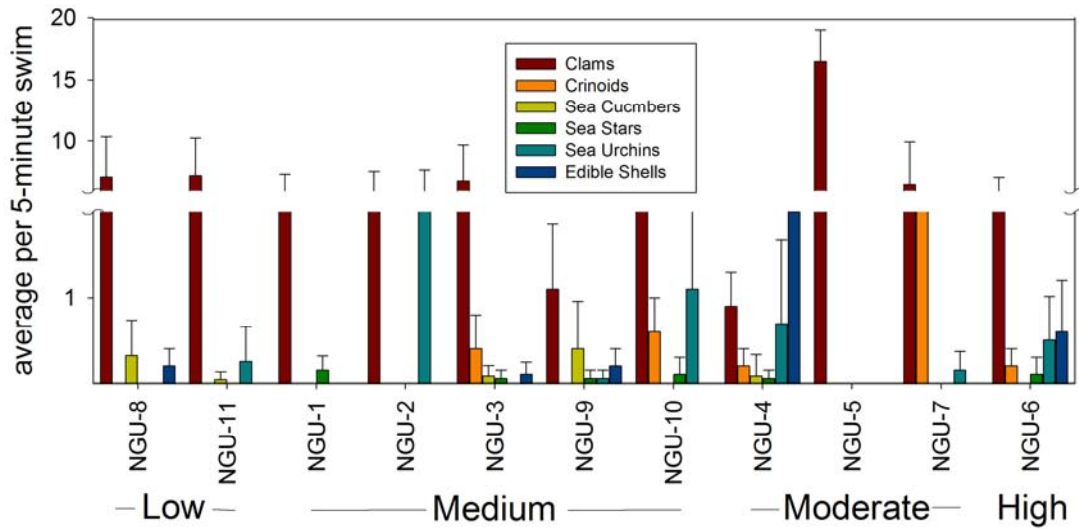
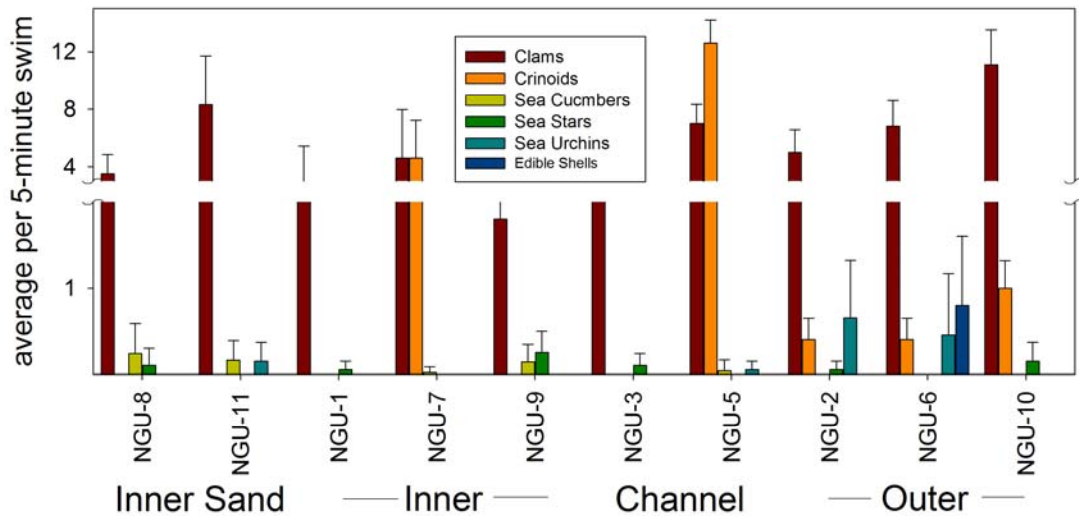


Figure 17b. Macroinvertebrate abundances for 8 – 10 m depth Ngulu sites in differing reef types.



Ulithi Atoll –

CORALS

Two unique features of Ulithi's modern coral assemblages are the increased abundance of *Pocillopora* on the outer exposed reefs, and large stands of foliose *Montipora* on the inner reefs, as compared with Yap or Ngulu. Similarly described, 'Reef type' best explained the large-scale differences in coral communities on Ulithi at the 8 – 10 m depth (Figure 18), however only inner (patch reefs included) and outer reefs were represented in survey sites, while channel sites were poorly represented. *Porites* were most abundant on inner reefs where they accounted for 30% of the coral coverage on average (Figure 19). Foliose *Montipora*, *Heliopora*, *Psammacora*, *Stylophora*, and *Acropora palifera* corals were also abundant on inner reefs compared with outer. An increase in the amount of reef-framework found on the outer reefs allowed higher abundances of *Pocillopora*, corymbose *Acropora*, encrusting *Montipora*, and *Favia*. Coral coverage varied greatly at all sites with no apparent differences between 'reef type', however evenness was consistently higher on outer reefs (Figure 20a). Coverage estimates greater than 100% occurred at two inner reef sites where mono-stands of *Porites* and *Montipora* led to the measurement of colonies that exceeded the quadrat size (.25 m²). **Sites 13, 12, 3, 5, and 7 all have relatively high coverage and evenness estimates, while site 6 represents a unique *Acropora palifera* community not seen elsewhere. Unlike Ngulu, no single geographic region is indicated for special management concern, rather strategies may best benefit from a spatially-representative approach.**

Unlike Yap and Ngulu, shallow assemblages were not strongly influenced by wave exposure. While there may have been some bias introduced due to a differing observer recording coral data on Ulithi, the results suggest that other influential drivers of coral

assemblages exist on Ulithi. The recent impacts of typhoon Sudal may have altered the coral community structure, especially in shallow waters, but no before data exist to quantify change. **Coral cover and evenness were high at sites 5 and 6, confirming that this locality holds large populations of many corals that may serve as one notable source of larvae. The results also indicate that site 13 on the western side of the main atoll holds a relatively high diversity of tabulate Acropora species, encrusting Montipora, and massive Favia, indicators of good source population for reef-building corals.**

Figure 18. Multi-dimensional scaling plot showing the differences in 8 – 10 meter depth coral assemblages on Ulithi between inner (crosses), outer reefs (filled triangles). ULI-6 is labeled because it represents an outlier inner-reef.

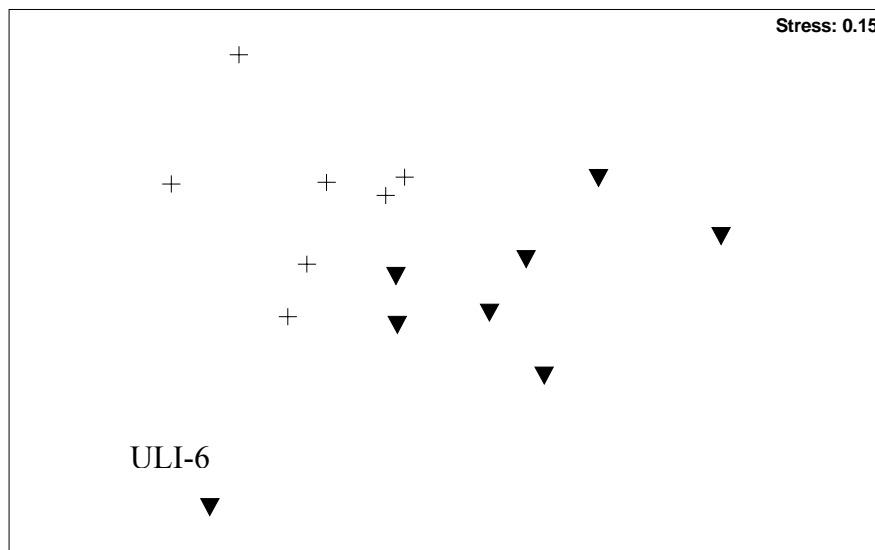


Figure 19. Percent coral cover (SE bars) of the most dominant genera found at the 8 – 10 meter depth at Ulithi within two different reef types: outer and inner.

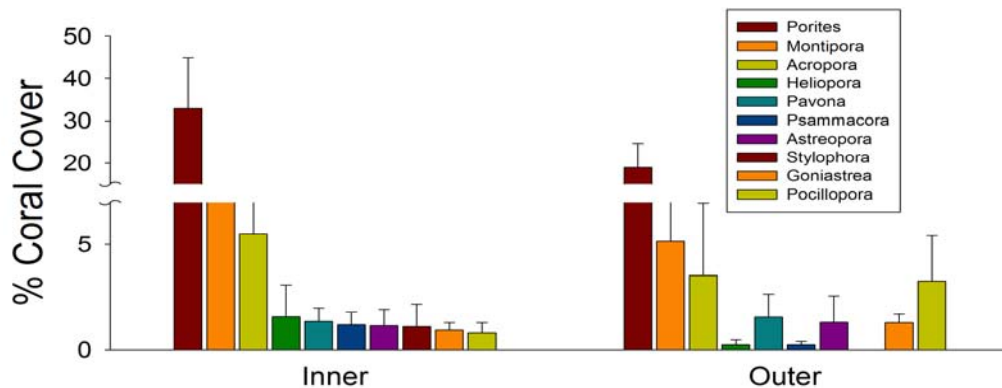


Figure 20a. Percent coral cover (SE bars) and evenness at each Ulithi site for 8 – 10 meter coral assemblages in differing reef types.

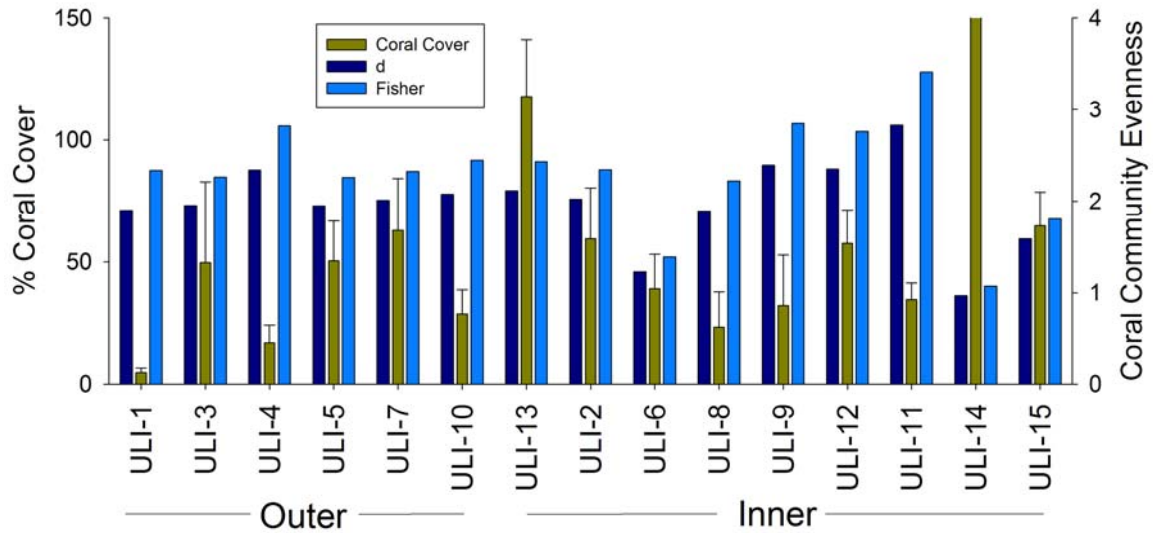
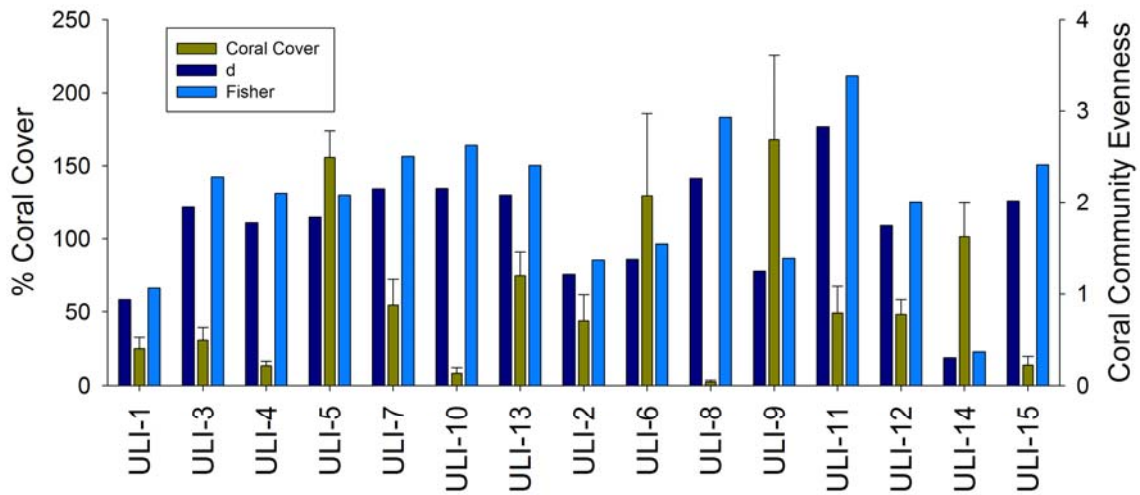


Figure 20b. Percent coral cover (SE bars) and evenness at each Ulithi site for 1 – 3 meter coral assemblages.



MACROINVERTEBRATE ABUNDANCES

With the exception of the sea urchin *Echinostrephus aciculatus* which ubiquitously present (Figure 22), the only common macroinvertebrates on Ulithi were clams and sea cucumbers (Figure 21). Notably, there were few edible shells such as *Trochus* and *Lambis* compared with Yap and Ngulu, however, two sea cucumbers, *Holothuria whitmaei* and *TheLENOTA ananas* were found in high abundances. These trends may be a result of large-scale environmental differences (amount of sandy habitat available, differing larval input due to regional ocean circulation patterns, etc.), and selective harvesting over time. **On relative terms, sites 13 and 5 had the highest clam abundances suggesting the presence of influential reproductive populations, and thus deserve management consideration.** Sea cucumbers were found in higher abundances at the 8 – 10 meter depth, where sites 1, 15, 12, and 8 had relatively large populations (Figure 22b). **If there is a desire to manage this irregularly distributed resource harvest quotas or gear restrictions may be a better option than establishing marine protected areas.**

Figure 21. Relative macroinvertebrate abundances at all shallow (1 – 3 m) sites on Ulithi.

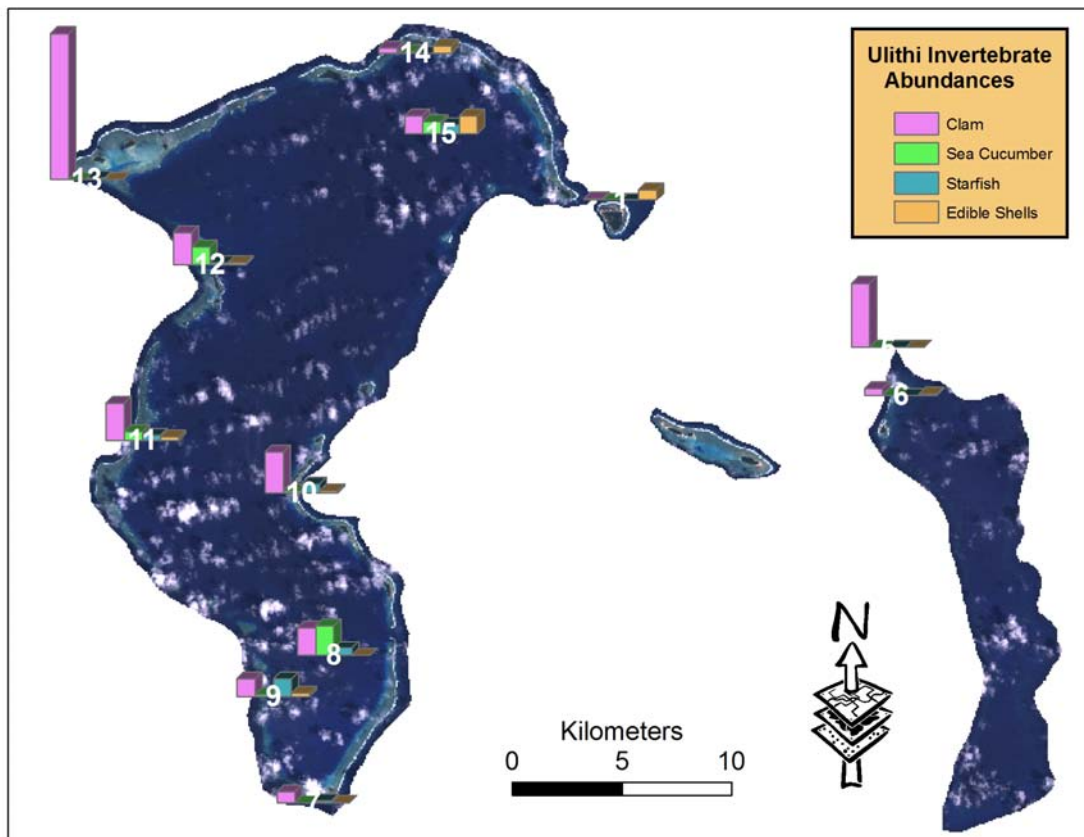


Figure 22a. Macroinvertebrate abundances for 8 – 10 m depth Ulithi sites in differing reef types.

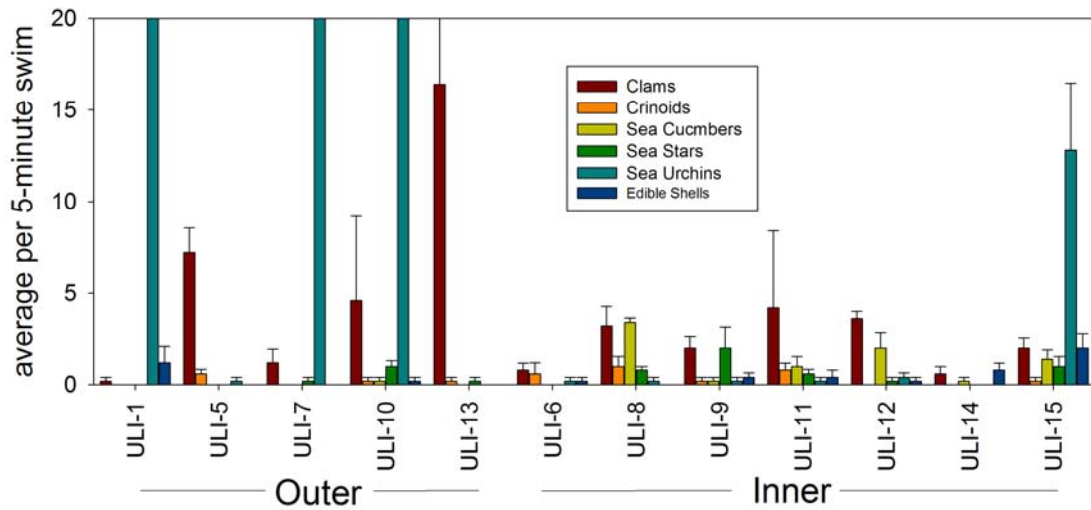
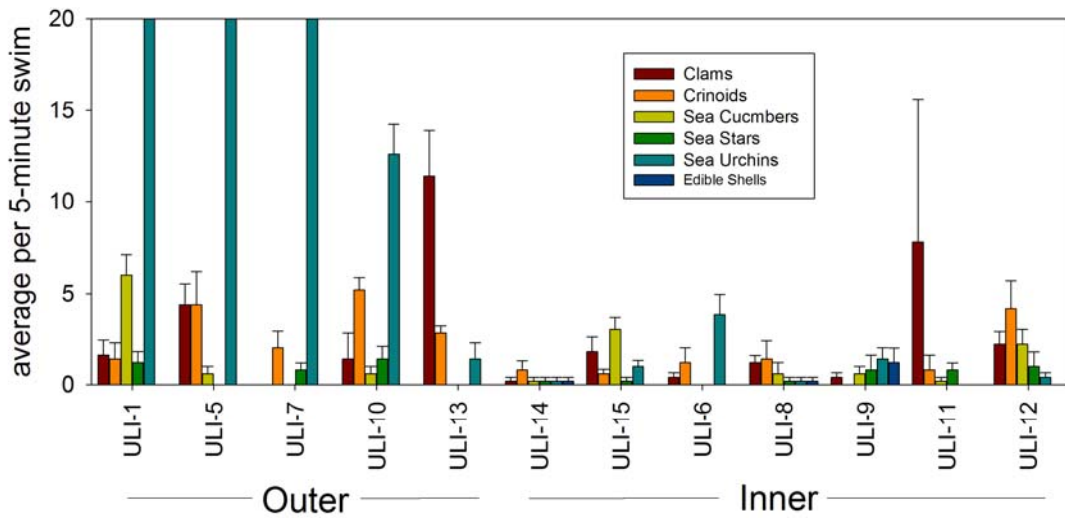


Figure 22b. Macroinvertebrate abundances for 8 – 10 m depth Ulithi sites in differing reef types.



Summary and Conclusions

The results presented here provide a contemporary snapshot of the coral-reef assemblages on Yap, Ngulu, and Ulithi, Federated States of Micronesia. Quantitative data were used to identify patterns between the environment and coral reef assemblages, and building from this base, identify where ecologically-rich sites exist on the three islands. Our findings highlight sites that are appropriate for enhanced management consideration based upon modern coral and invertebrate assemblages (Figures 23 – 25).

Most influentially, depth-stratified, quantitative data provide a baseline for Yap's local marine monitoring program to assess change over time resultant from natural and human disturbances, and to assess the effectiveness of management strategies. It is strongly recommended that these sites, or a subset of inner, channel, and outer reef sites continues to be monitored. One notable limitation of this REA is our inability to understand resiliency. Continued monitoring after future disturbances will provide insight into resiliency, whereby the sites that are least impacted or that rebound quickly deserve high management consideration.

Figure 23. Yap Island with sites deserving special concern for management highlighted in red. A star (site 4) indicates the presence of a unique, species-rich coral assemblage.

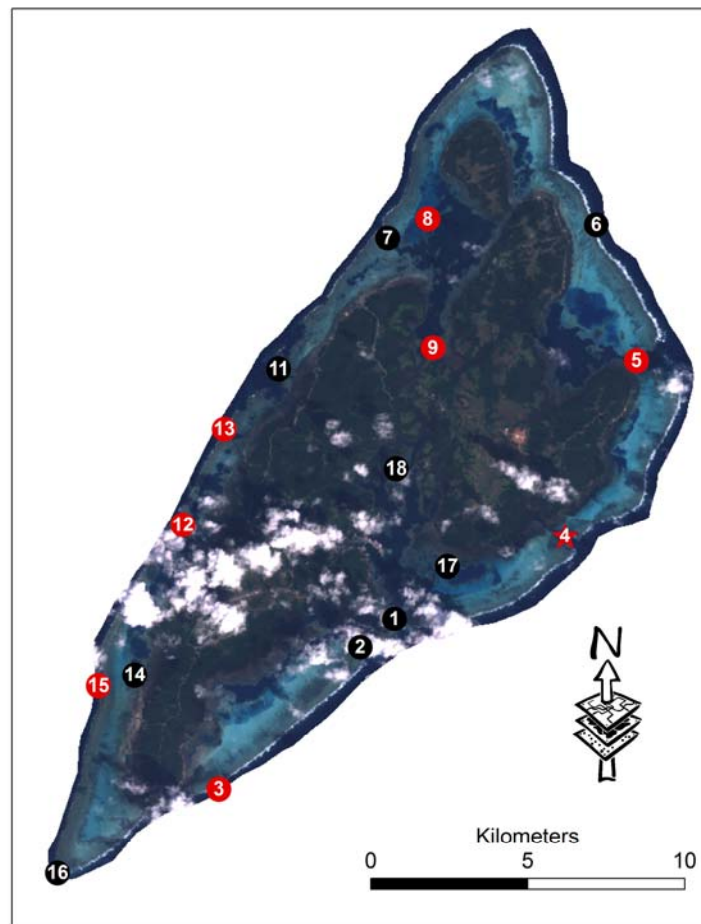
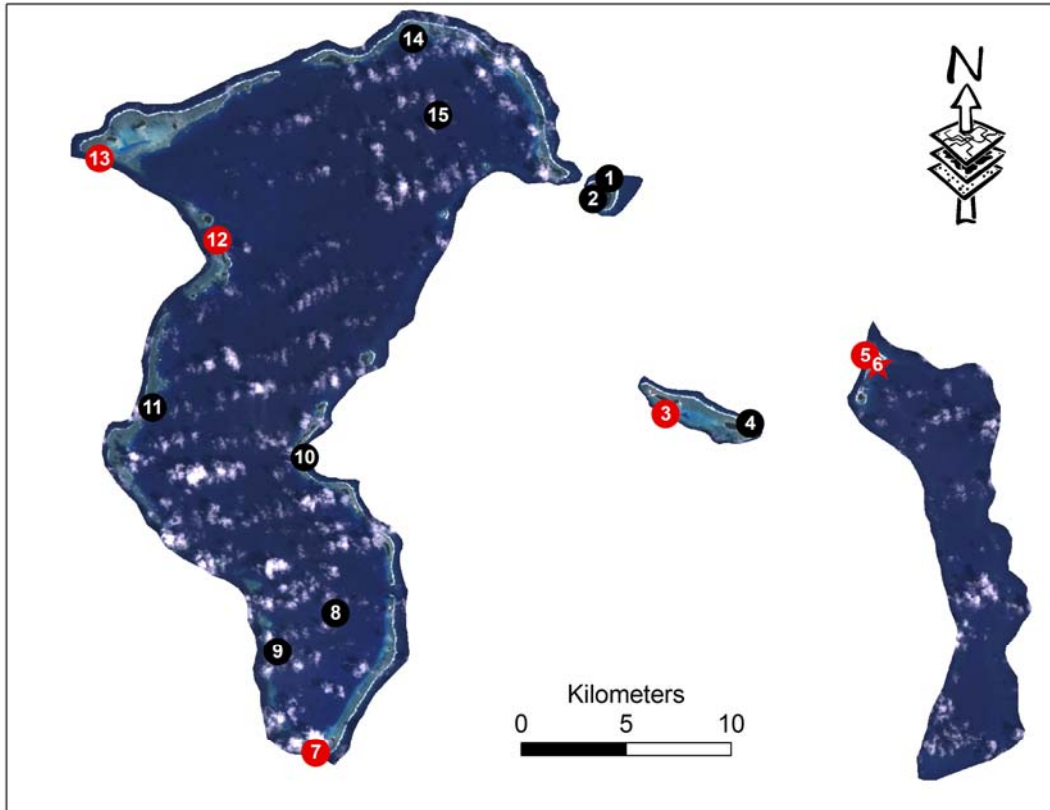


Figure 24. Ngulu Atoll with sites deserving special concern for management highlighted in red. Stars (sites 7, 8, and 10) indicate the presence of high coral cover and evenness in the western side of the atoll.



Figure 25. *Ulithi Atoll with sites deserving special concern for management highlighted in red. The star (site 6) indicates the presence of a unique *Acropora palifera* coral assemblage.*



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References Cited

- Bonjean F, Lagerloef GSE. 2003. Diagnostic model and analysis of the surface currents in the tropical Pacific Ocean. *Journal of Physical Oceanography* 32(10):2938-2954.
- Charpy-Roubaud CJ, Charpy L, Cremoux JL. 1990. Nutrient budget of the lagoonal waters in an open central South Pacific atoll (Tikehau, Tuamotu, French Polynesia). *Marine Biology* 107(1):67-73.
- Charpy L. 2001. Phosphorus supply for atoll biological productivity. *Coral Reefs* 20(4):357-360.
- Clarke KR, Warwick RM. 2001. Change in marine communities an approach to statistical analysis and interpretation. Primer-E Ltd. Plymouth Marine Laboratory, United Kingdom.
- Cornell HV, Karlson RH. 1996. Species richness of reef-building corals determined by local and regional processes. *Journal of Animal Ecology* 65(2):233-241.
- Done T, Turak E, Wakeford M, DeVantier L, McDonald A, Fisk D. Decadal changes in turbid-water coral communities at Pandora Reef: loss of resilience or too soon to tell? *Coral Reefs*:1-17.
- Golbuu Y, Victor S, Penland L, Idip D, Emaurois C, Okaji K, Yukihiro H, Iwase A, van Woesik R. 2007. Palau's coral reefs show differential habitat recovery following the 1998-bleaching event. *Coral Reefs* 26(2):319-332.
- Houk PaJS. 2004. Marine and water quality monitoring plan for the Commonwealth of the Northern Mariana Islands. Division of Environmental Quality and Coastal Resources Management Office, Saipan, CNMI.
- Houk PC. 2006. Spatial distribution of coral reef communities and reef growth in the Commonwealth of the Northern Mariana Islands. *Dissertation*: Florida Institute of Technology.
- Montaggioni LF. 2005. History of Indo-Pacific coral reef systems since the last glaciation: Development patterns and controlling factors. *Earth Science Reviews* 71:1-75.
- Randall RH RS, Irish EE, Wilkins SC, Smith BD, Amesbury SS. 1988. A marine survey of the Obyan-Naftan reef area, Saipan, Mariana Islands. University of Guam Marine Laboratory, Tech. Rept. 90:62 pp.

Storlazzi CD, Brown EK, Field ME, Rodgers K, Jokiel PL. 2005. A model for wave control on coral breakage and species distribution in the Hawaiian Islands. *Coral Reefs* 24(1):43-55.

van Woesik R, Done TJ. 1997. Coral communities and reef growth in the southern Great Barrier Reef. *Coral Reefs* 16(2):103-115.

Webb KL, DuPaul WD, Wiebe W, Sottile W, Johannes RE. 1975. Enewetak (Eniwetok) Atoll: aspects of the nitrogen cycle on a coral reef. *Limnology and Oceanography* 20(2):198-210.