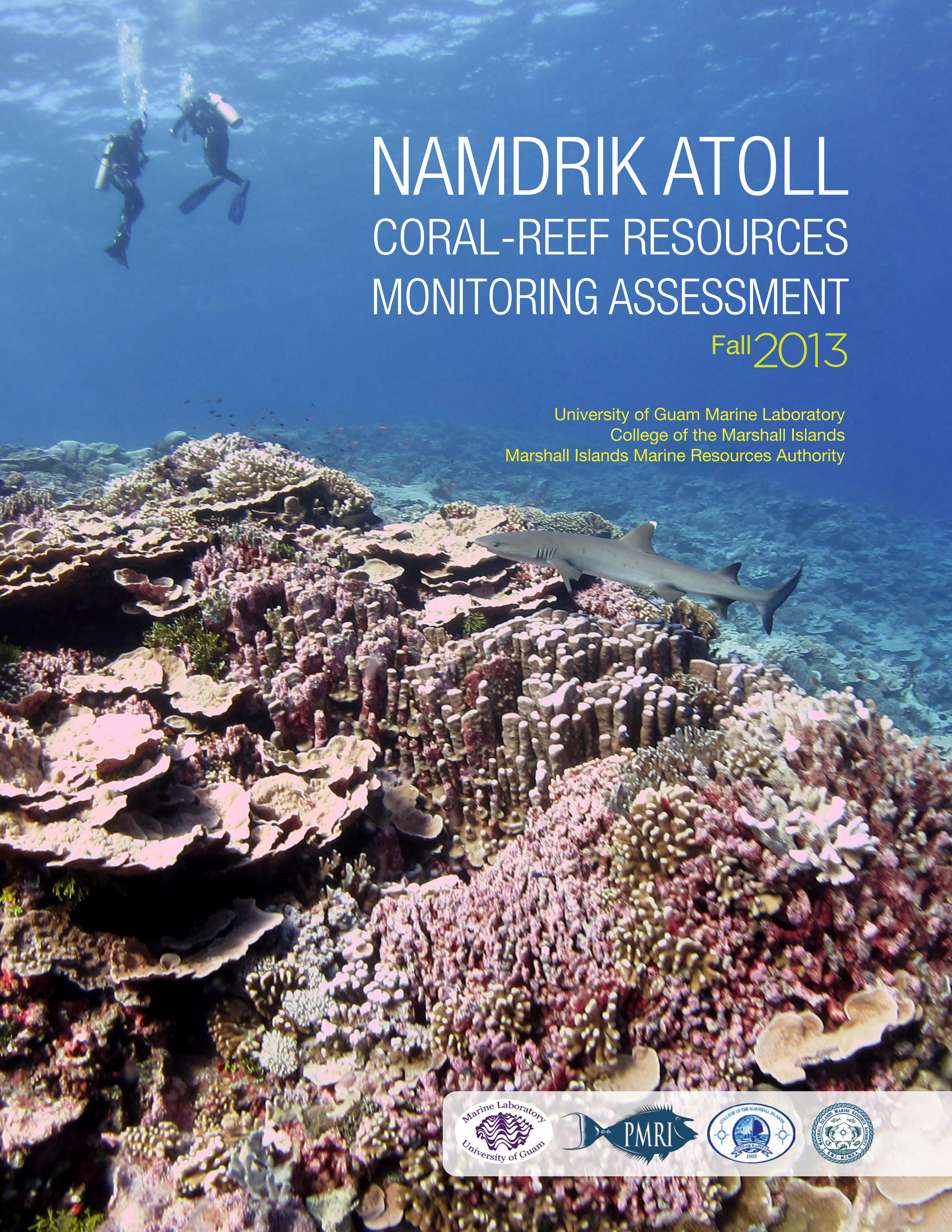

NAMDRIK ATOLL
CORAL-REEF RESOURCES MONITORING ASSESSMENT
Fall 2013

University of Guam Marine Laboratory
College of the Marshall Islands
Marshall Islands Marine Resources Authority

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INTRODUCTION and background

Namdrik Atoll is situated along the chain of atolls that comprises the western Marshall Islands, known as the Ralik Chain (Figure 1). The atoll consists of two islands, Namdrik (south part of the atoll) and Madmad (north). The main community is situated on the southwestern part of Namdrik where a freshwater lens exists. Presently, the community relies heavily upon their marine resources for subsistence, but also income generation to a lesser extent. However, the main source of income continues to be copra production and handicraft sales to the population centers of Kwajalein and Majuro.

Like all RMI atolls, the Namdrik local government has a mandate to manage and protect their marine resources within 5 miles of the atoll (MIMRA Act, 1997). The Iroij, Iroij-drik ro, Alaps and dri-jerbal play key roles in advising the local council on all issues related to the economic development and the well-beings of the atoll residents. However, the mayor and senator of Namdrik have a more hands-on roles in improving the standard of living for Namdrik community, and thus, continuously seek information needed to effectively manage both their marine and terrestrial resources.

Since 2002, coral-reef surveys and community consultations with the Marshall Islands Marine Resources Authority (MIMRA), the College of the Marshall Islands (CMI), and other associated partners have been taking place through the Reimaanlok process. The goal of these surveys and consultations are to assist management planning and conservation area establishment by providing information needed for communities to make informed decisions, and take ownership of their management process.

Scientifically-sound, marine resource assessments form the backbone for resource management discussions and decisions. Similar to many atolls, it is not understood if fishery resources and coral-reef ecosystem condition have been stable on Namdrik because no quantitative studies exist to describe their dynamics through time. Certainly expert fisher opinions can help fill in these knowledge gaps, however the opinions of the fishers can vary with their age and experience. For these reasons, the present efforts on Namdrik have included gathering the input and knowledge of the atoll residents, as well as detailed scientific descriptions of the current coral and fish populations. Together, these sources of information can provide the background needed for establishing (or maintaining) resource management.

Figure 1. Bathymetric map of the Marshall Islands and Namdrik (white square). Lighter colors indicate shallow waters associated with the atolls.

Within this document, we provide a deeper look into the results of a recent marine resource assessment. We first develop a framework to understand the nature and status of Namdrik's marine resources in comparison to two other atolls where similar scientific data exists, Rongelap and Majuro. Rongelap represents a very large atoll that has remained mainly uninhabited since the atomic bomb testing in 1954. While the resettlement process has recently begun on Rongelap, their marine resources depicted a nearly pristine state when surveys were done in 2010, beneficial for drawing comparisons with. On the other hand, Majuro Atoll represents the population center of the RMI where resources are heavily used and influened by human activities, relative to other RMI atolls. Using these two endpoints (i.e., high and low), we first describe the coral reef resources of Namdrik. We next build into a more detailed assessment of individual reefs around Namdrik, and describe the status of marine resources at the eight survey locations visited (Figure 2).

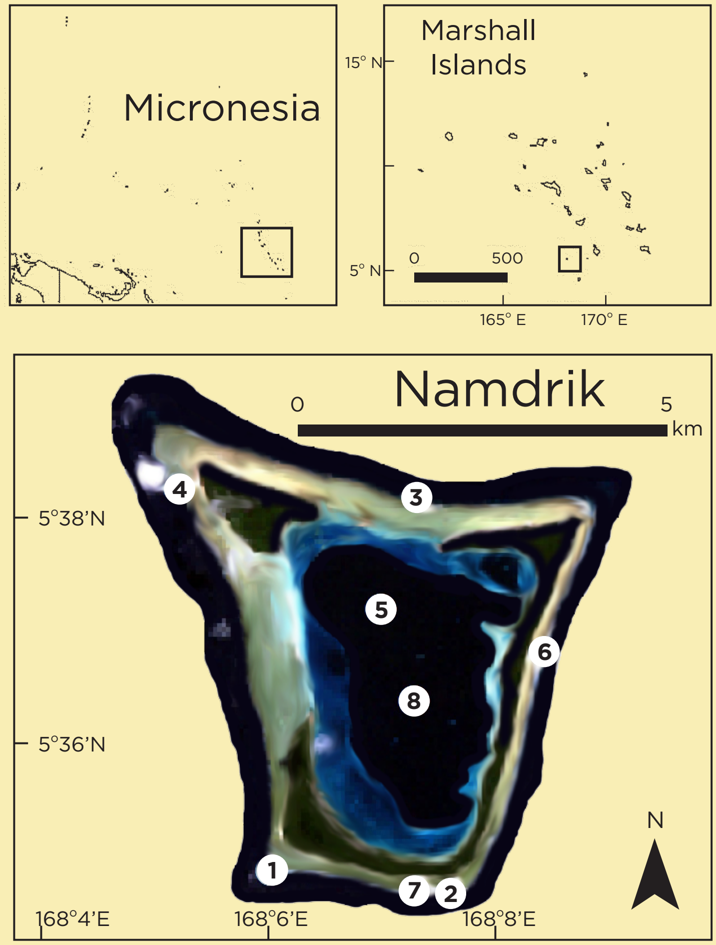


Figure 2. A map of Micronesia showing the Marshall Islands, Namdrik, and the locations of the present marine resource assessment.

CORAL-REEF assessment protocols

In order to generate the scientific data needed to characterize the marine resources, standardized protocols were used to assess the coral-reef ecosystem. One of the purposes of using standardized measurements is to ensure their repeatability in the future, and provide a baseline for comparisons to assess change through time.

Island Characteristics and Site Selection

Namdrik is quite small compared to other atolls in the RMI. The lagoon is only 8.55km^2. 600-700 people live on the main island that covers an area of about 2.8km^2. Given the small size of Namdrik, eight coral-reef monitoring locations were established across both outer and inner reefs to assess the marine resources. The survey reefs were selected to represent varying wave exposure, major habitat types, and to include one locally-managed marine protected area (site #5, Figure 2). Collectively, data from these sites provided a representative snapshot of the atoll's marine resources. Each site was identified with a global positioning system and 5 x 50m transects were established to evaluate benthic substrates and coral/fish populations.

Benthic substrates

The abundances of benthic substrates such as corals, crustose coralline algae, and fleshy macroalgal were estimated by taking a series of 0.5 x 0.5 m photographs along the transect lines (Figure 3). In order to estimate the substrate abundances, 5 data points were randomly placed within each photograph, and the substrate under each point was recorded (typically to the genus level). Using this procedure, benthic substrate estimates for each site were calculated based upon 250 data points per transect, and 5 transects per site (1250 data points).

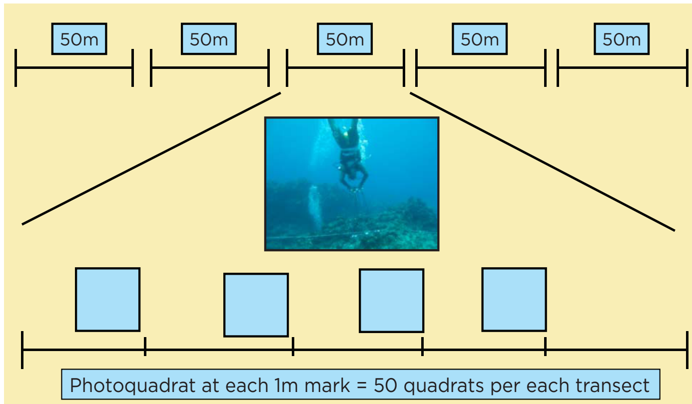


Figure 3. Protocol used for collecting benthic substrate data.

Coral assemblages

A deeper look at the coral assemblages was undertaken by tossing 10 replicate 1m2 quadrats along the 5 x 50m transect lines (Figure 4). Within each quadrat, the species and size of all were recorded to generate information on species richness, colony sizes, and relative abundances.

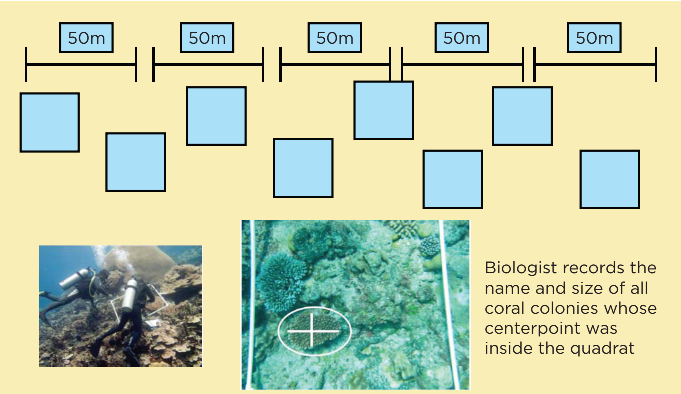


Figure 4. Protocols used to conduct coral population assessment.

Fish assemblages

Fish size and density were estimated using a stationary point count technique. Twelve individual stationary point counts (SPC's) were conducted at equal distances along the 5 x 50m transect lines. During each, the observer identified, counted, and estimated the size of all foodfish within a 5m radius, for a period of 3-minutes. This provided information on the relative sizes and densities of fish. In turn, size and density data were also used to predict biomass (or weight) using size-to-biomass coefficients.

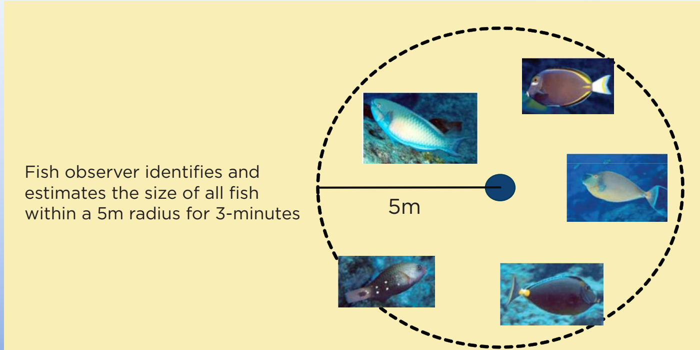


Figure 5. Protocols used to conduct fish population assessments.

COMPARISONS among different atolls

Prior to drawing comparisons between Namdrik, Rongelap, and Majuro, we first introduce one of the consequences of Namdrik's small atoll size. Energy that supports the entire network of coral-reef food webs originates from sunlight that is used as a food source for both corals and marine phytoplankton. In general, the amount of energy that can be delivered to the coral reef ecosystem is a function of the amount of habitat available. The larger the atoll, the more shallow-water habitat available, and the greater the derived energy.

Satellites have recently been used to detect several indicators of primary productivity within coral reef ecosystems. Here, chlorophyll-a images of three different atolls (Namdrik, Majuro, and Rongelap) are shown to provide a perspective of this (Figure 6, blue indicates low productivity, light blue and yellow indicate moderate productivity, and red is highest). The small size of Namdrik, and in particular the small size of the inner atoll waters that are highly productive, results in less net energy being retained within the coral reef ecosystem, naturally.

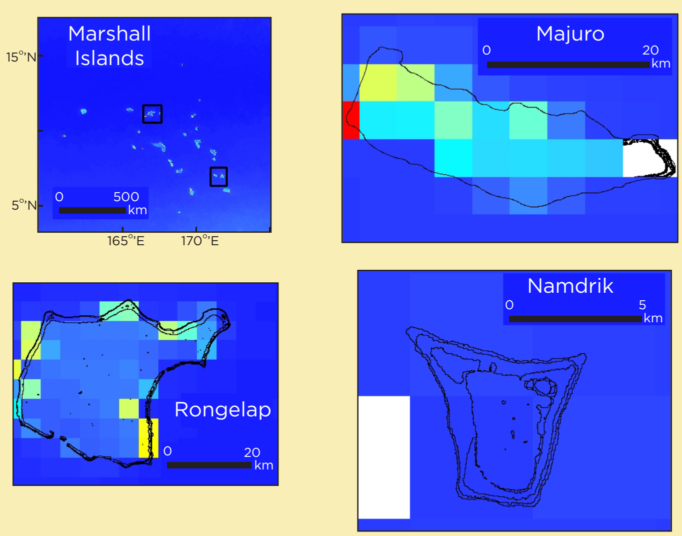


Figure 6. A map of the Marshall Islands, Majuro, Rongelap, and Namdrik showing 10-year, long-term averages of productivity (chlorophyll-a). Lighter blue, green, yellow and red colors indicate higher chlorophyll concentrations, respectively.

Even when considering energy per-unit-area there is a decrease in productivity build-up for smaller atolls because of the decreased proportion of coral-reef habitat where plankton and detritus (ie, major food sources at base of food chain) can exist. In sum, a greater proportion of the outer-reef habitat on Namdrik is influenced by currents and wave energy refraction as compared with larger atolls. This situation has consequences for the fish populations that rely upon phytoplankton and detritus at the base of their food chains. Given less food, we expect to see lower fish populations per unit area than larger atolls such as Rongelap, naturally.

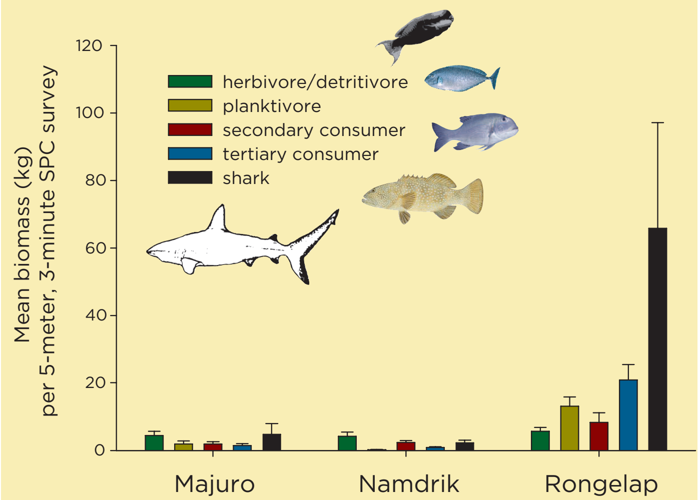
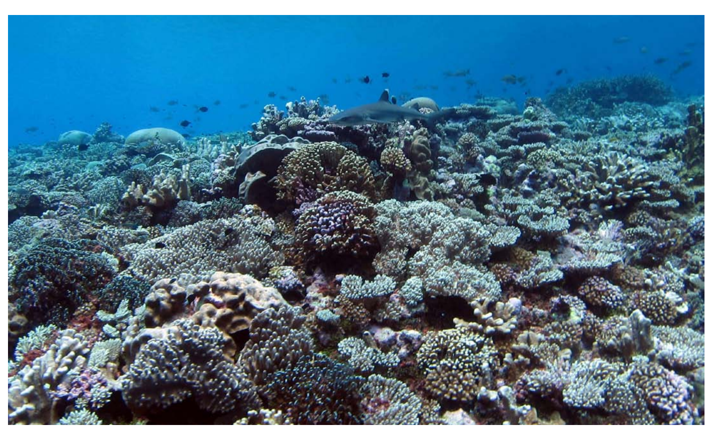


Figure 7. Fish biomass averaged across a suite of representative sites from Majuro, Namdrik, and Rongelap for comparison purposes.

When examining fish populations per unit area for the three atolls, we found that Majuro and Namdrik have similar fish biomass, both disproportionally smaller than Rongelap (Figure 7). This pattern becomes stronger as we move up the food chain from herbivores to predators and sharks. There were also limited abundances of planktivores (plankton eating fish) on Namdrik that is likely due to the small island size and limited productivity described above.



However, when examining the body sizes of fish within each functional group between the atolls a different pattern emerges. For most functional groups, the mean body size of fish was smallest on Majuro where the greatest human pressures exist, larger on Namdrik where a small human population exists, and largest on Rongelap with minimal human presence (Figure 8). Thus, despite a similar biomass of most major fish groups between Namdrik and Majuro, there were fewer, but larger fish on Namdrik. This pattern was strongest for herbivores such as parrotfishes, and weakest for large predators such as groupers. In terms of understanding the entire coral-reef ecosystem, it is important to focus upon the herbivores because they play an essential role in grazing algae and detritus, and maintaining a healthy ecosystem with abundant corals and other calcifying organisms. Larger fish can graze (i.e., clean) a disproportionately larger reef area, and are expected to facilitate improved benthic substrates. The fact that larger predator fish were not found on Namdrik compared with Majuro might be an artifact of both the small size of Namdrik and/or fishing pressure for the larger groupers (desirable foodfish with high economic value).

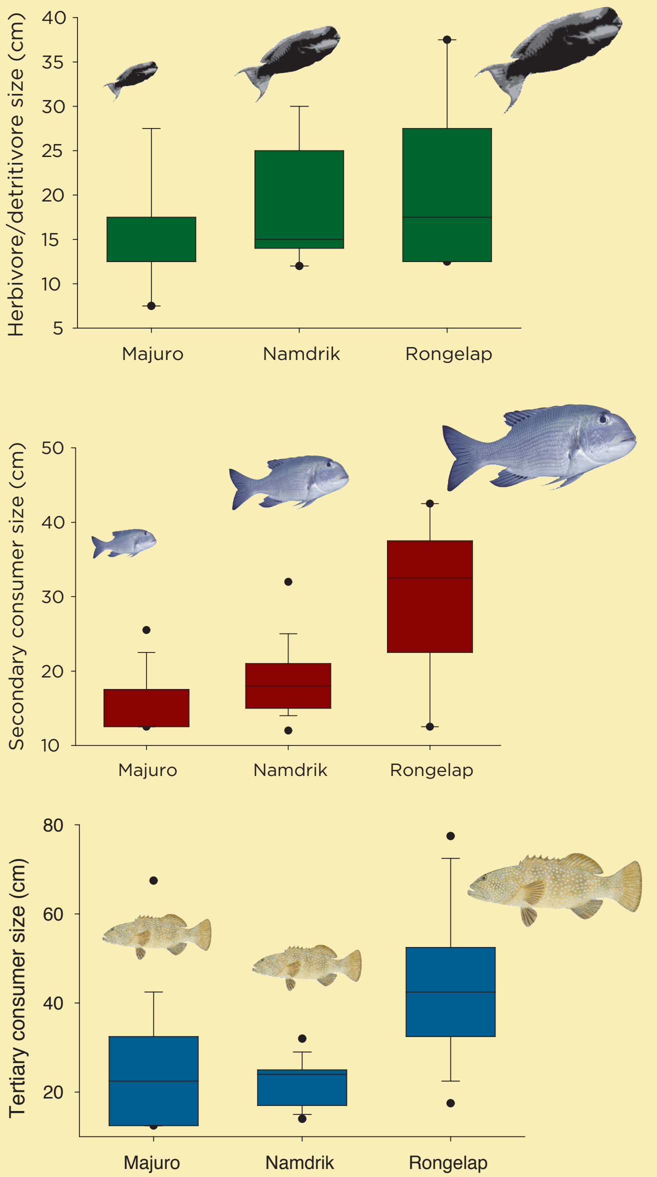
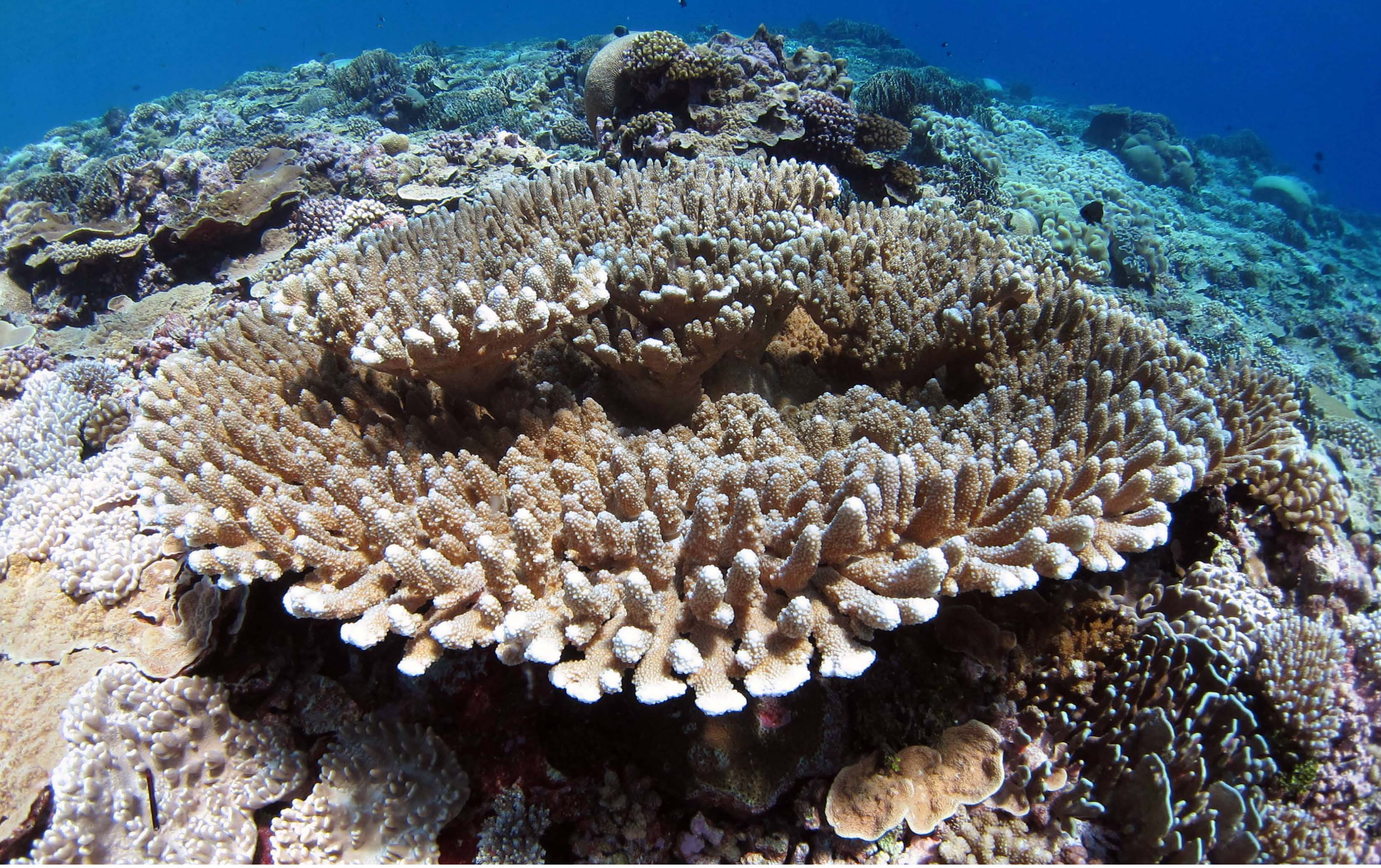


Figure 8. Fish body-size distributions for three major function groups across Majuro, Namdrik, and Rongelap. Thin black lines represents the median, boxes indicate the 25th (lower) and 75th (upper) percentiles, error bars indicate the 5th and 95th percentiles, and dots indicate magnitude of outliers.



Patterns in benthic substrate abundances were consistent with those noted for herbivorous fish sizes. Calcifying substrates (corals and crustose coralline algae) comprised a greater proportion of the reef substrate on Rongelap and Namdrik as compared with Majuro (Figure 9). Calcifying substrates are required for reef growth through time, and a threshold of 50% or higher is a general benchmark for sustaining reef development through time. Calcifying substrates are also a good indicator of healthy coral assemblages, and are often associated with both large coral colony sizes and higher diversity.

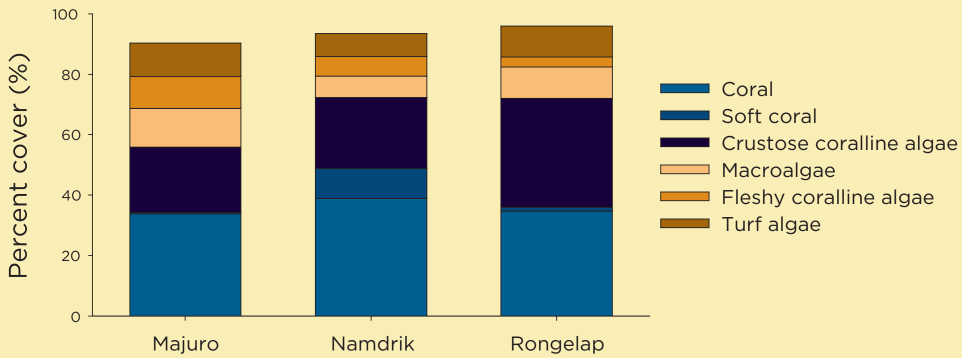


Figure 9. Percent cover of calcifying substrates (blue) as compared with non-calcifying substrates (orange-brown) across study atolls.

Coral colony sizes and diversity were consistent with fish and benthic substrate abundances, suggesting the linked nature of each aspect of the coral-reef ecosystem across RMI atolls. Smallest coral colony size distributions were found on Majuro, while largest were found on Rongelap (Figure 10).

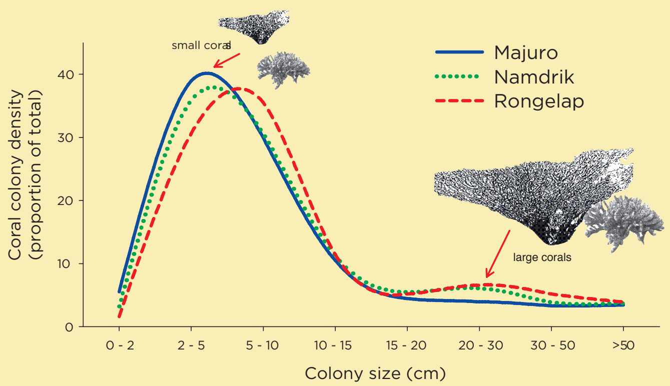


Figure 10. Coral colony-size distributions on the study atolls. Note the secondary, smaller peak in large corals found only on Namdrik and Rongelap that suggests a dominance of corals in terms of percentage cover.

The size distribution of corals on Namdrik was inbetween these two atolls. Interestingly, only Rongelap and Namdrik size class distributions showed a secondary, small peak in the abundances of large coral colonies (>20 cm in diameter). Despite comprising ~10% of the coral assemblage in terms of numeric density, these large corals accounted for a disproportional amount of the percent cover, and provide the vibrant architecture that can be seen from the numerous underwater photos. Coral diversity per survey quadrat also had a steady increase moving along the Majuro-Namdrik-Rongelap gradient (Figure 11). High coral diversity is essential to maximize the ecosystem function of corals. High coral diversity provides for greater habitat complexity for fishes and other invertebrates. High diversity also enhances the resilience of the coral reef, because disturbances do not act equally across all species. For instance, diverse assemblages can buffer against Crown-of-Thorn starfish that have preferences for which corals they prey upon because surviving species will help to maintain the functional role of corals and speed up the recovery process.

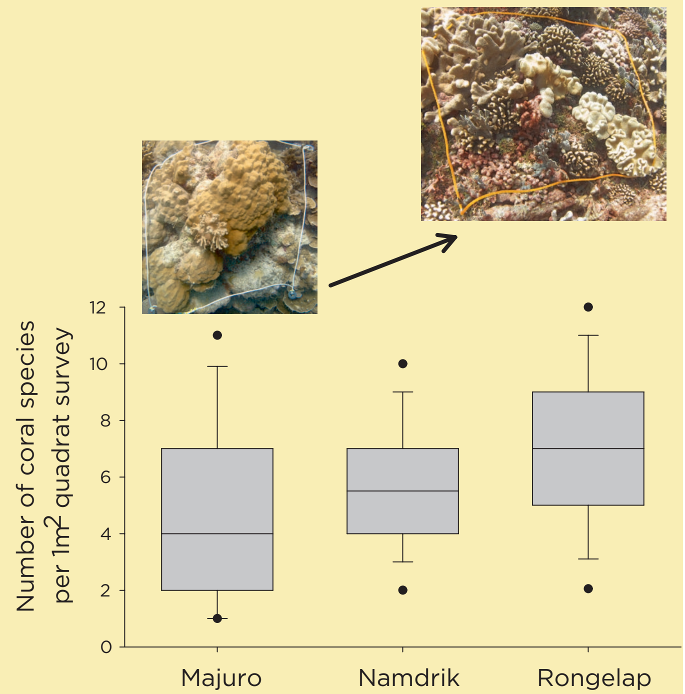


Figure 11. Coral diversity across the study atolls. Thin black lines represents the median, boxes indicate the 25th (lower) and 75th (upper) percentiles, error bars indicate the 5th and 95th percentiles, and dots indicate magnitude of outliers.

NAMDRIK ATOLL
Marine Resources

This second section of the report provides more details about the marine resource assessment specific to Namdrik. Among the eight sites examined on Namdrik, six were located on the outer reef habitats, and two were located within the small protected lagoon waters.

When making general comparisons across the sites it's important to first distinguish between the different habitats that exist, outer and inner reefs (Figure 12). The strongly contrasting physical environments of the outer and inner reefs dictate both the amount of fish and coral resources, and their species-level composition. Similar to previous comparisons between the atolls, data from fish assemblages, benthic substrates, and corals are presented in sequential order for Namdrik, then these data are synthesized to assess reef "condition".

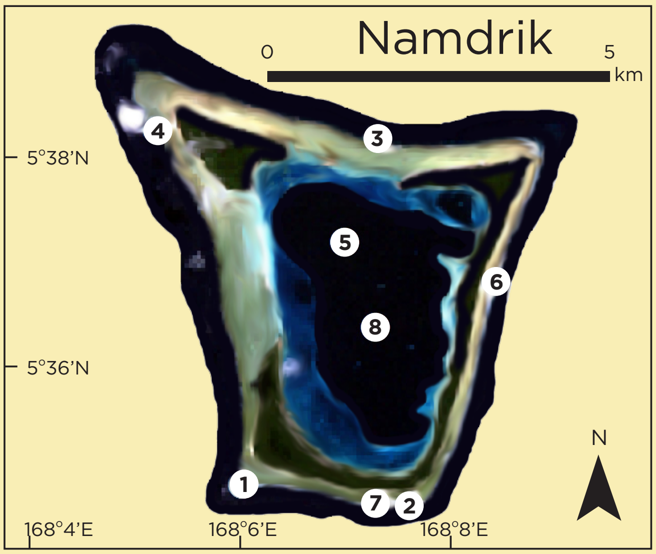


Figure 12. A map of the Marshall Islands and Namdrik highlighting the sites where marine resource assessments were conducted.

The greatest fish biomass was found on the northwest coast on the leeward side of the atoll (site 4, Figure 13). Fish at this site were comprised mainly of herbivores, however larger consumers such as snappers, groupers, and jacks were also found in relatively high abundance. Beyond biomass, the fish populations were also largest in body-size at this site (Figure 14), suggesting its importance as both a fishing ground and replenishing future fish stocks. Sharks were more commonly seen on the highly-exposed northern coast, constituting nearly 50% of the observed assemblage biomass (site 3). Yet, shark occurrences on the SPC transect surveys were rare in comparison to Rongelap, but when present, they always constitute a disproportional amount of the biomass given their large body sizes. Equal levels of fish biomass were observed at the remaining sites.

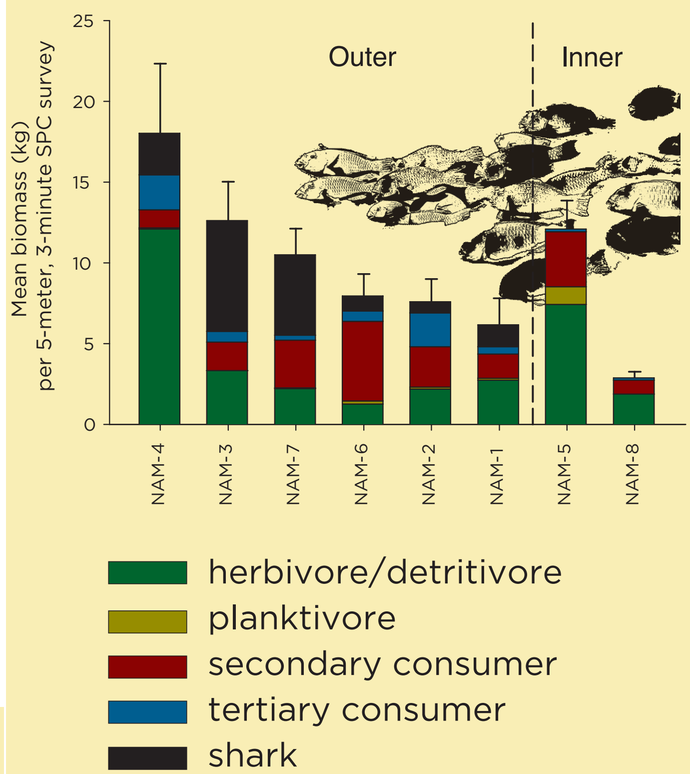
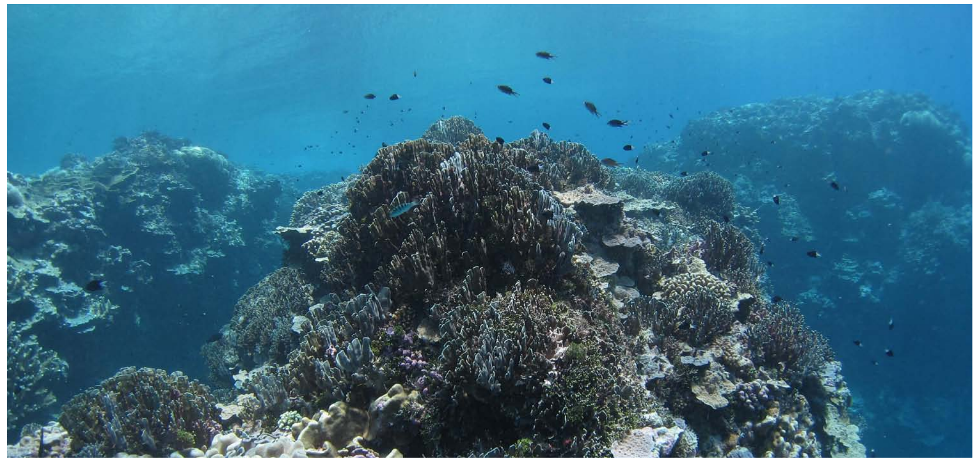


Figure 13. Fish biomass across Namdrik survey sites for five major functional groups.



Fish sizes were also largest on the northwest and northern coastlines (Figure 14). The one exception to this was site 7, a centralized reef on the southern side of the atoll. This reef is situated in a favorable location for fishing access (leeward southern side of the atoll, away from the points where currents are strongest), perhaps contributing to the relatively small fish sizes found there.

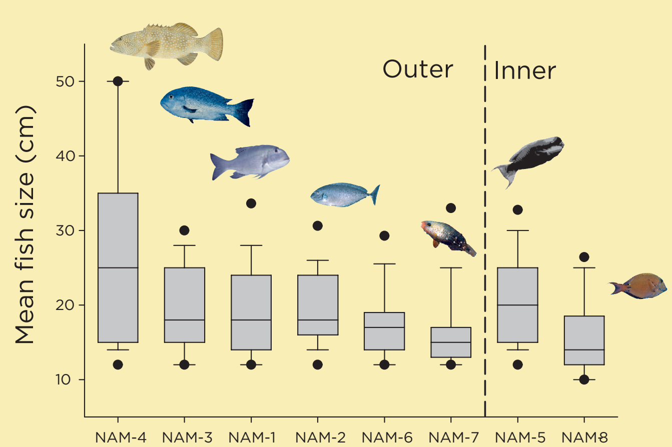


Figure 14. Fish body-size distributions on Namdrik for all species combined, except sharks. Thin black lines represents the median, boxes indicate the 25th (lower) and 75th (upper) percentiles, error bars indicate the 5th and 95th percentiles, and dots indicate magnitude of outliers.

Sites inside the atoll were very different from each other in terms of fish populations. Clearly fish resources were higher at the northern inner atoll reef (site 5) compared with the patch reef near the main human population (site 8). The Northern patch reef was under local management, whereby limited fishing occurred in these waters.

Benthic substrates on Namdrik were consistently dominated by calcifying coral and crustose corralline algae growth for the outer reefs. The majority of sites had over 80% coverage by calcifying organisms, suggesting healthy benthic substrates conducive for persistent reef growth. The reef on the northwestern coast was exceptional to these overall trends where lower (~60%) calcifying substrate coverage existed (site 4). This was unexpected given the high fish biomass and larger fish sizes, however, this situation is thought to be attributed to the unique location and physical environment (leeward reef protected from highest wave exposure). Both this site, and the other wave sheltered outer reef on the south coast (site 7) had the greatest coverage of macroalgae. Because of their accessibility throughout much of the year for fishing, and their productivity build-up given low wave exposure, these reefs are expected to offer the greatest amount of nutrients and detritus for macroalgal growth. These sites are desirable candidates for future monitoring because productivity, macroalgal growth, and fish biomass are linked components of the coral-reef ecosystem. Given their accessibility and naturally high fish biomass, these reefs may be most sensitive to fishing pressure. The inner atoll reefs were very distinct from each other, whereby the locally managed reef in the northern atoll had >50% calcifying substrates but the patch reef near the village had <40%.

Coral assemblages across Namdrik were dominated in numeric density by small colonies, but fewer, large

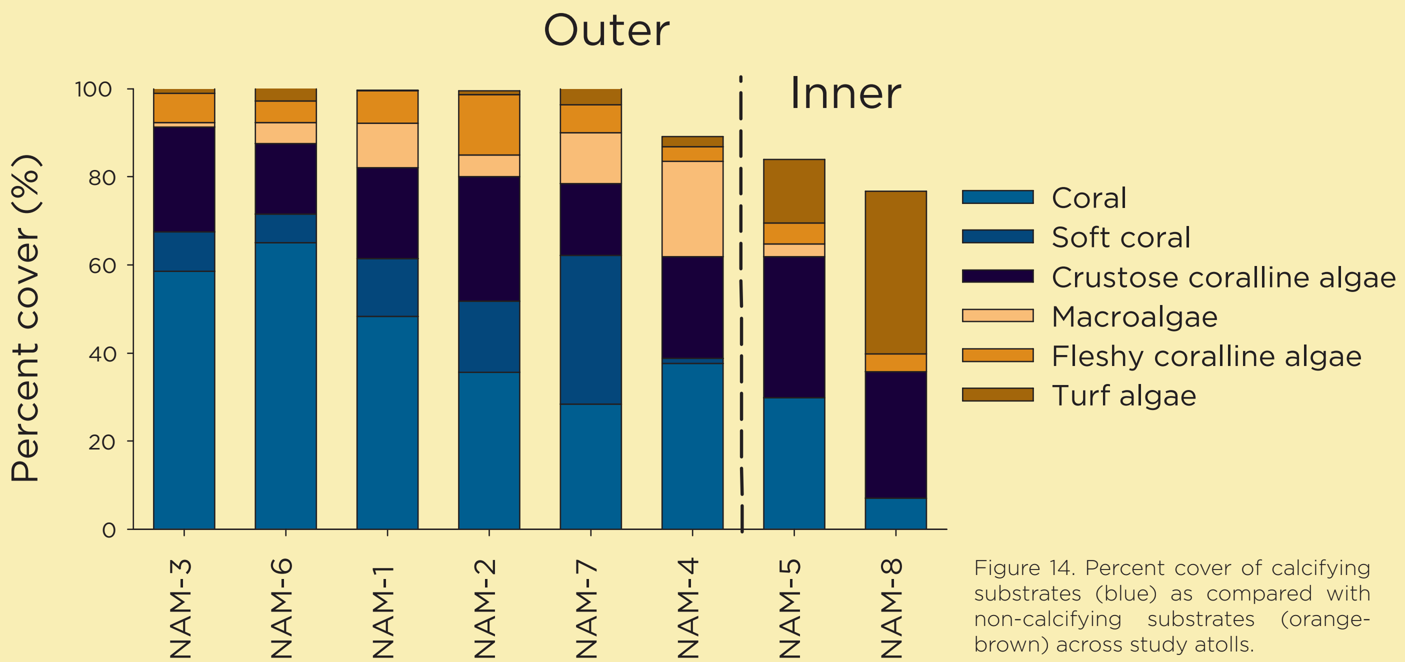
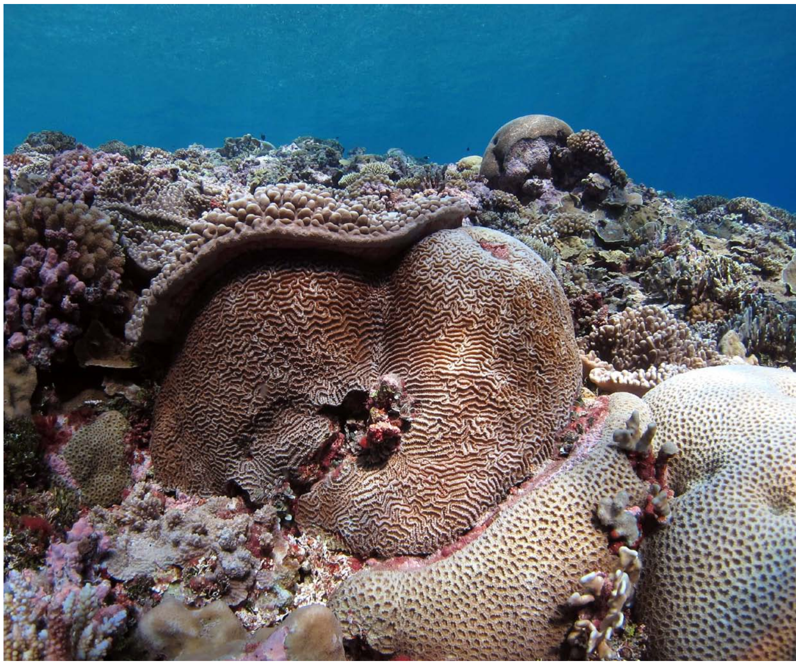


Figure 14. Percent cover of calcifying substrates (blue) as compared with non-calcifying substrates (orange-brown) across study atolls.

colonies made up the bulk of the percent coverage and provided for high habitat complexity (Figure 15). The largest corals were found on the southern coast, where large *Isopora* and *Acropora* stands were frequently observed. Lush coral growth was also found along the eastern coast despite high wave exposure. A greater dominance of small colonies was apparent along the northern reefs where wave exposure was highest. Interestingly, the unique leeward assemblage on the northwestern coast had the smallest mean colony size (and the greatest range of small-to-large corals). The dominance of small colonies may be associated with benthic substrates that were increasingly covered with macroalgae, a competitor for space on the reef that can impede coral growth. Continued monitoring should keep coral colony size distributions in mind as often they are sensitive indicators of phase shifts on reefs, or transitions to less desirable states. For example, after disturbance events, colony size distributions shift markedly, and their recovery is critical for maintaining habitat complexity. On the inner atoll reefs fresh feeding scars from the Crown-of-Thorn starfish existed, and many of the large colonies associated with the locally managed inner atoll reef were dead. This certainly served to distinguish between inner and outer atoll colony sizes (Figure 15), but interestingly, didn't mask the consistent pattern whereby the reef currently under traditional management had larger corals and more complex habitat development.

Coral diversity appeared to be driven by high wave exposure that exists on the north coastline, preventing the growth of large coral colonies, and thus maximizing the number of species that existed (Figure 16). Elsewhere, coral diversity was mainly consistent, with the northwest atoll having the lowest number of species within each survey quadrat (site 4). Species diversity can be influenced both by natural environments as well as human influences. Comparisons of diversity are best interpreted for the same reef through time, or for reefs within similar physical environments. High diversity was also found along the protected southern coast, at reefs in closest proximity to the points where currents are strongest. Lastly, the locally-managed inner atoll reef held substantially more diverse coral assemblages compared with the patch reef closer to the human population.



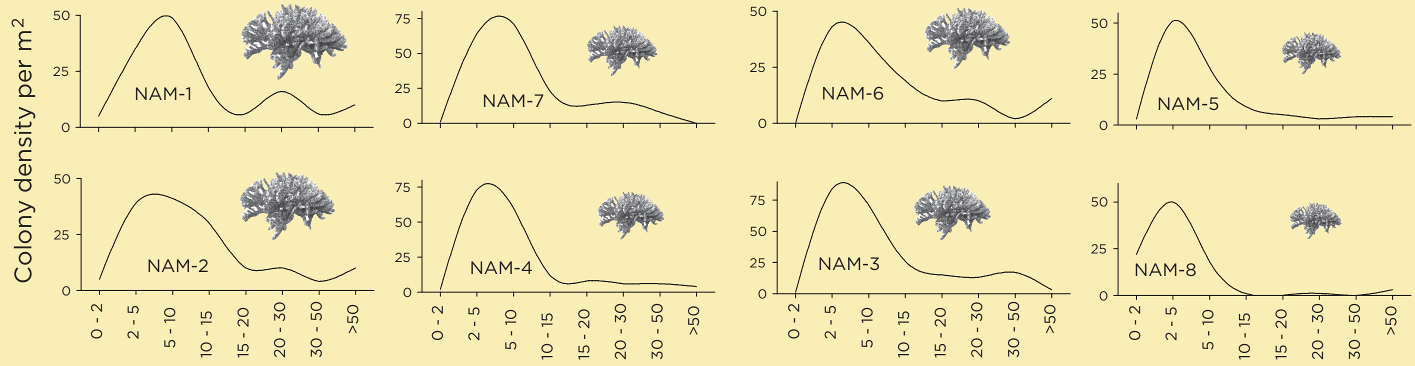


Figure 15. Coral colony-size distribution across Namdrik survey sites.

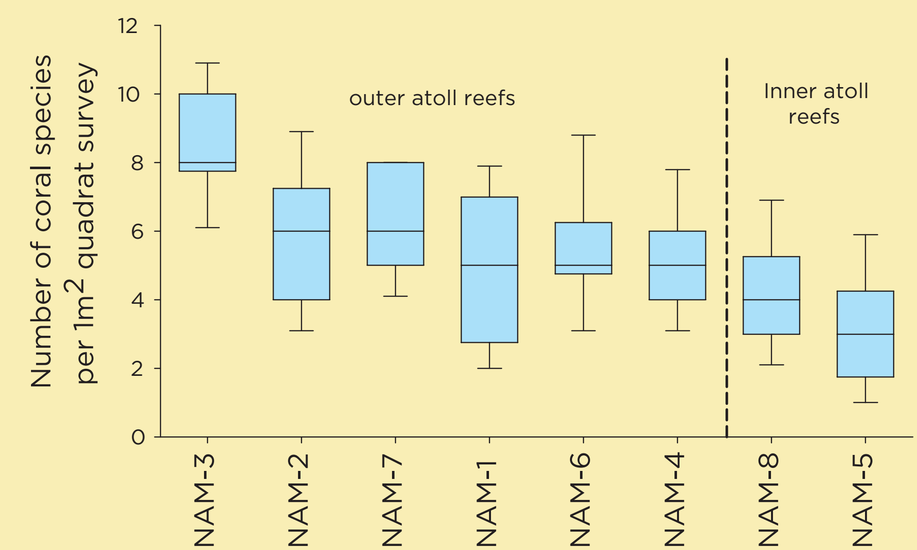
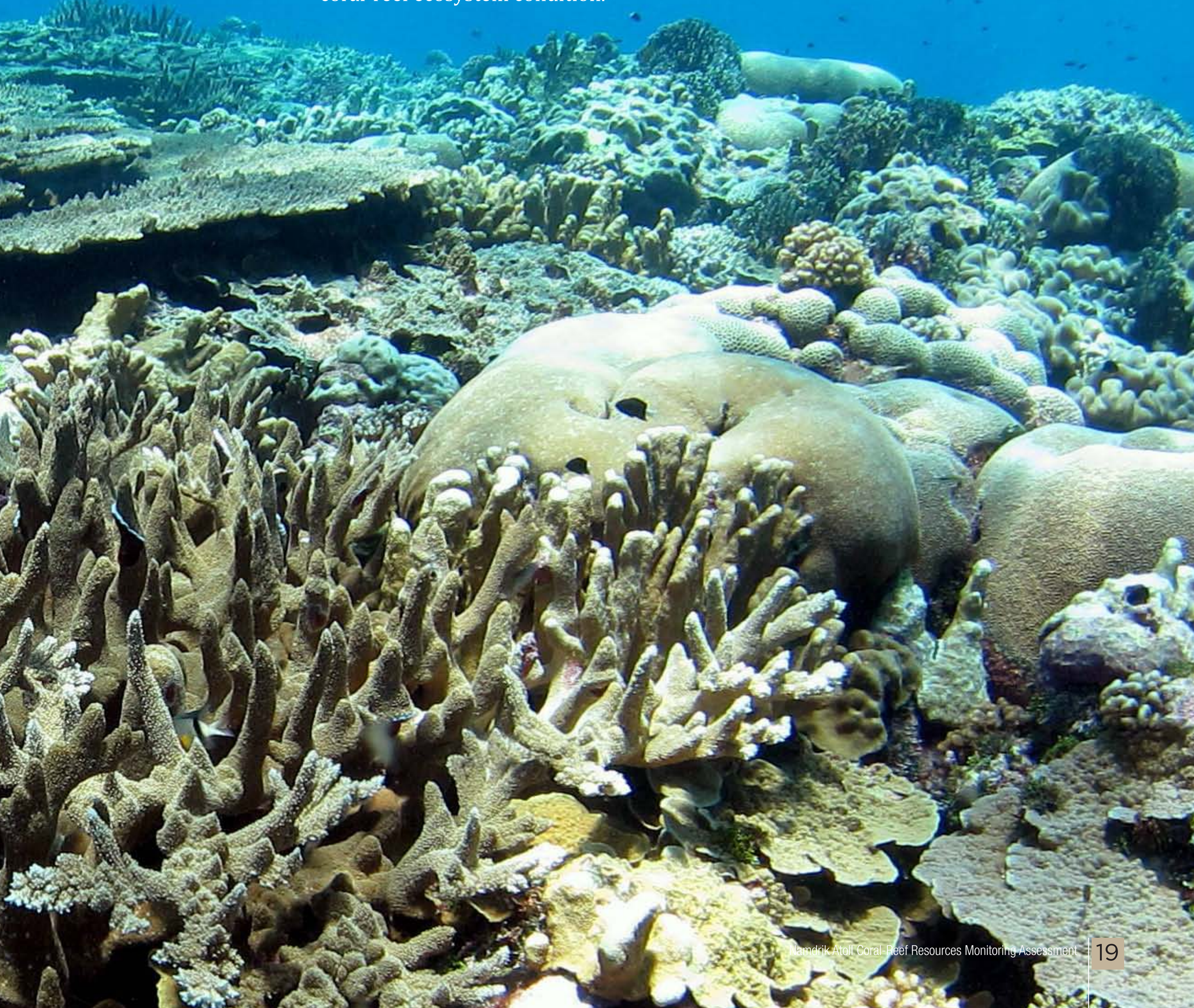


Figure 16. Coral diversity across Namdrik. Thin black lines represents the median, boxes indicate the 25th (lower) and 75th (upper) percentiles, and error bars indicate 5th and 95th percentiles.

Namdrik Atoll Coral-Reef Ecosystem Condition

Coral-reef condition on Namdrik was estimated by considering the three components of the marine resource survey assessments equally. Fish biomass and body-size data were standardized and combined to provide an indicator of the fishery resources. Benthic substrates were evaluated by taking the percent cover of all calcifying substrates (i.e., corals, crustose coralline algae, and soft corals) and dividing that by all non-calcifying substrates (i.e., algae). The resultant ratio provided a measure of benthic substrate quality. Last, coral colony sizes and species diversity data were standardized and combined to provide an indicator of the coral resources. In this sense, equal weighting was given to the corals, fishes, and benthic substrates. Together, the mean scores from these three categories were taken and used as an overall indicator of coral-reef ecosystem condition.



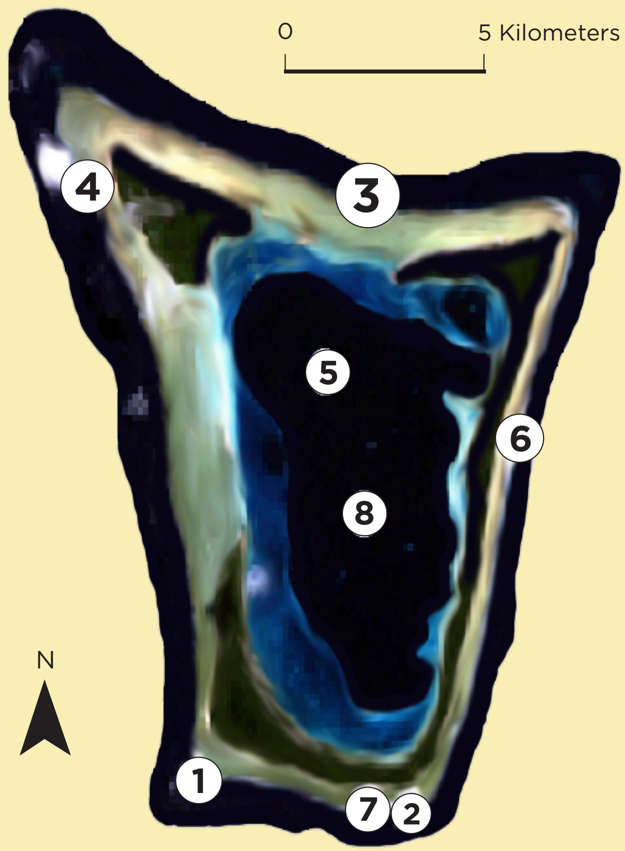


Figure 17. A map of Namdrik with site-symbols scaled proportionally in size with coral-reef condition score. Condition was evaluated by considering three major components of the ecosystem: fish resources, coral populations, and benthic substrates (see text). Larger symbols indicate better condition.

The coral-reef ecosystem condition assessment found that the highest resource values currently exist for the most wave exposed, northern reefs (Figure 17, Table 1). This was an artifact of high scores across all ecosystem components, fish, corals, and benthic substrates. Elsewhere, most of the reefs appeared to have high ecosystem values that were not substantially different from each other (sites 4, 6, 1, and 7). However, the individual components of the ecosystem differed markedly, and should be considered. For instance the northwestern reef (site 4) had among the highest scores for fish and corals, but the lowest for benthic substrates. This suggests the site may be naturally rich in resources given its physical attributes, yet fishing pressure or other human influences may be limiting grazing potential and/or facilitating macroalgae growth. In sum, although healthy fishery and coral resources were found here in comparison to other reefs, they likely have been even more impressive in the past, and their shift through time may be linked with the benthic substrates.

Reefs on the eastern coastline had similar inconsistencies with ecosystem component scores. Here, fish and coral resources were among the lowest, yet high values existed for benthic substrates. This situation may be due to the eastern wave exposure flushing macroalgal growth, promoting crustose coralline algal growth, and limiting large coral colony development. The low fish resource

Site	Reeftype	Fish Resources (ranks)	Benthic Substrates (ranks)	Coral Assemblages (ranks)	Ecosystem Condition (scores and ranks)
NAM-1	Outer	4	3	4	0.72 (4)
NAM-2	Outer	3	4	6	0.48 (6)
NAM-3	Outer	2	1	1	2.01 (1)
NAM-4	Outer	1	6	2	1.33 (2)
NAM-6	Outer	6	2	5	0.78 (3)
NAM-7	Outer	5	5	3	0.68 (5)
NAM-5	Inner	1	1	1	1.47 (1)
NAM-8	Inner	2	2	2	0.53 (2)

Table 1. Coral-reef condition rankings for each ecosystem component, and overall raw scores with corresponding ranks in parentheses.

scores were thought to be less of an artifact of wave exposure and more attributed to human influence given the proximity to the main village.

The remaining two sites on the southern coastline had more consistent values for each component. This situation of moderate overall scores may be an artifact of enhanced accessability due to lower wave exposure along the southern coastline. Along the southern coast, site 2 was unique in that a major reef collapse existed, removing much of the reef slope and leaving only a steep wall for coral growth. This natural event was most likely the cause of the lowest ecosystem condition score.

Ecosystem condition was expectedly higher for the locally managed inner reef in comparison to the patch reef near the human center. This pattern was consistent across all components.

CONCLUSIONS and Recommendations

This report has taken a comparative approach towards describing the status of the marine resources on Namdrik. Initial comparisons at the atoll level suggested that healthy coral-reef ecosystems and fish populations currently exist on Namdrik compared with Majuro, where human impacts are higher. Yet, comparisons with Rongelap, a more pristine atoll, suggested that human footprints exist, and the obvious question is to what extent. The presence of healthy ecosystems on Namdrik was supported by the dominance of calcifying substrates, coral assemblages with large colonies forming complex habitats, high local diversity, and large sizes of many functional fish groups. While the overall trends are positive for Namdrik, comparisons across sites found a gradient in ecosystem condition, with many sites on the leeward and more accessible southern side of the atoll having lower than expected fish resources. These finding for the basis for management recommendations.

Given the small size of Namdrik, it seems ideals of both locally-managed protected areas with fishing is limited, as well as locally-derived policies to address fishing techniques and catches become refined and/or established. For instance, setting aside portions of the inner atoll lagoon as no-take protection zones are encouraged because they are easier to enforce, and can provide a greater payoff due to high productivity in the lagoon waters. This process is currently ongoing, but might best be expanded to include 2-3 reef areas that are easily observed by a local 'management team'. The minimum size of each protected area should be at least 500 m x 500 m (0.25 km2), but larger areas will be more effective for protecting fish species that have larger range sizes (i.e., larger predator fish). In contrast, the outer reefs on the western and southern side of the island (i.e., the leeward side) are more ideal for localized fishing policies. Informal communication with many Namdrik fishermen described that many traditional forms of fisheries management exist. These are centered upon fish spawning cycles, catch limits, and fishing intensity. Fish size-at-capture and quota policies represent common approaches taken, as well as protecting key spawning times when fish tend to aggregate and become more vulnerable to over exploitation. Last, continued monitoring on 3-5 year intervals is necessary to augment local management, providing a benchmark to assess whether or not policies are working, and if they might need to be changed.

Monitoring is essential for understanding growth and death cycles on coral reefs (Figure 18). It is through growth and death cycles that we can best realize whether reefs are properly managed, and predict their

fate through time. If localized stressors become too strong the cycle is disturbed, and reefs will take longer than expected to recovery, or may never recover to states dominated by calcifying substrates. Managing localized stressors is now more imperative than ever because climate change is expected to increase the frequency of disturbances that impact reefs, placing a greater need for a speedy recovery processes. Therefore, keeping reefs in a state where they can rapidly recover is the best way to embrace the future.

In March, 2012, the Namdrik Atoll Local Resource Committee was awarded the prestigious United Nations Equator Prize for innovative approaches towards managing their resources. This leadership was exemplified by the present status of the marine resources. However, maintaining coral-reef resources in their healthy state will require continued attention to maintaining and adapting management to modern economic demands and a changing climate.

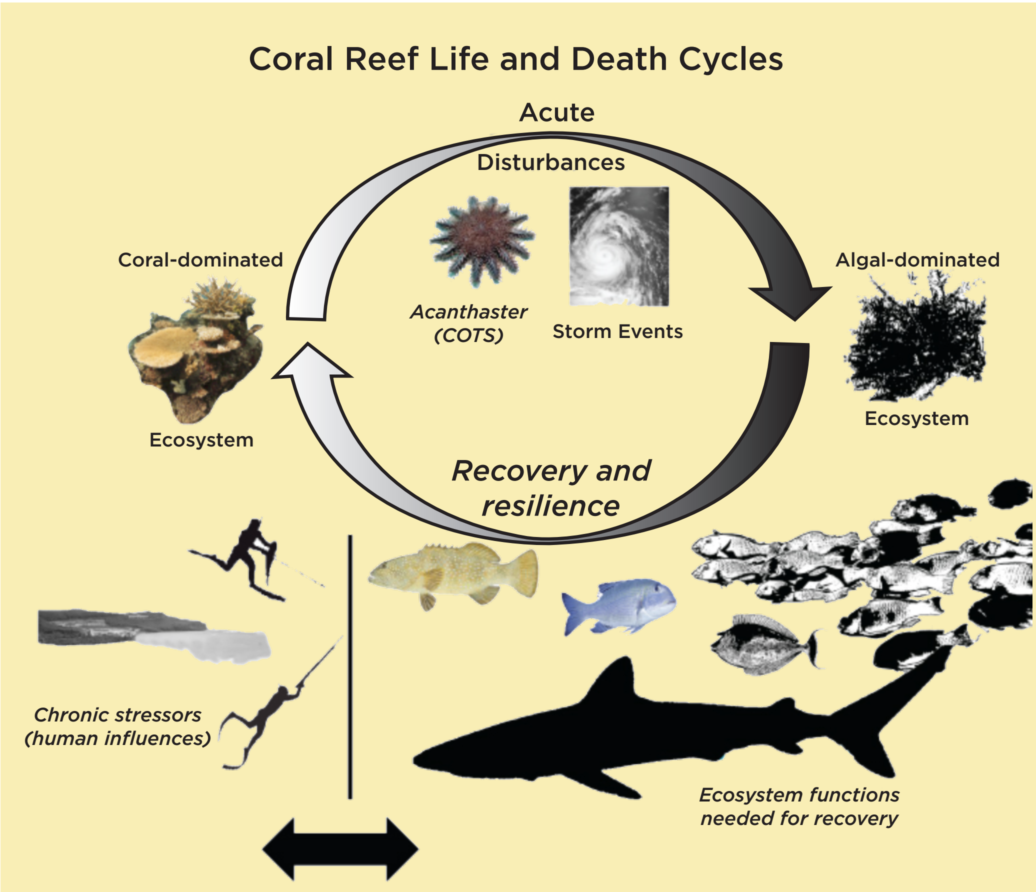


Figure 18. Life and death cycles on coral reefs. While we have less influence over disturbance events on coral reefs, we can keep localized stressor in check as to promote recovery of coral-dominated ecosystems into the future. Where each atoll society draws their line (i.e., the black vertical line in the figure) will ultimately depend upon how they manage their resources.