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Correlations Between Reef Health and Vertical Zonation on Ushongo Village Reef and Fungu Zinga Reef

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Abstract

While the existence of vertical zonation on coral reefs is well-known, the driving mechanisms and the influence each has is not clear. This study seeks to investigate the influence of reef health on vertical zonation. Reef health is used as a potential factor since it is essentially a broad description of reef diversity. Therefore, a healthy reef which is very diverse is likely to have more and different interspecies interactions than an unhealthy one. This project investigates whether these altered interactions results in different depth distributions of various coral types, categorized broadly by colony shape. Reef health did not seem to significantly affect depth distribution of coral types, although it did influence the species richness of branching and small dome-shaped corals in upper reef sections.

Introduction

Previous research on coral reefs has shown that reefs worldwide tend to exhibit similar general organizational patterns, despite being made up of a remarkably wide variety of species. This organization of coral reefs is expressed largely through the shape of the dominant coral colonies. Although corals are incredibly diverse, most can be placed into a few broad categories according to their shape. Specifically, the most common coral colony shapes include branching, foliose, massive, encrusting, tabular, and small rounded or dome-shaped colonies. Branching corals include those which grow forming usually short branches of similar length. Foliose corals are those which form spiraling colonies where the edges protrude outward and upward from the center. Massive corals form very large colonies several meters across, with some species forming large spheres or domes and others without a well-defined shape. Encrusting colonies impose themselves on others, generally forming a very thin crust (from a few millimeters to a few centimeters thick). Tabular corals are those which forming large, flat plates. Tabular colonies can be differentiated from foliose colonies since they tend to grow only straight outward rather than spiral upward. Small rounded or dome-shaped are those which I identified as portraying this shape and growing up to an estimated half meter across.

Along many reefs, the shallow reef flat tends to end at a reef crest, where it begins to slope downward. Research to the present has shown that reef slopes tend to be organized in a general vertical zonational pattern of coral shapes, where certain types preferentially dominate certain depth ranges along the slope. The most basic zonation pattern on coral reefs is the dominance of branching corals on the upper reef slope and of massive corals on the deeper slope (Wellington 1982a). However, relatively little research has been done on the factors that influence this pattern, aside that it appears to be a function of species larval settlement preference, sunlight availability, and grazing (Wellington 1982b). In a controlled area free of all competition, depth distribution should be dependent solely on species preference and light availability (Baird et al. 2003). However, because coral reefs have such immense biodiversity, interspecific competition is likely to play a significant role in depth distribution of coral, both in regard to grazing by corallivores and spatial competition among benthic species.

If this is true, depth distribution of corals should be influenced by overall reef health, due to the influence of reef health on grazing and species interactions. For instance, fishing will bound to remove several grazing fish species, which then releases coral prey species from predation. These coral species will then be allowed to grow and compete for space for efficiently. Overfished reefs may also have unusually high populations of herbivorous grazing sea urchins, with their predators having been removed. On healthy reefs, it is believed that normal sea urchin populations suppress algal coverage, thus making room for coral to grow. In Jamaica, it has even been observed that the recovery of previously lost sea urchin populations can help to promote reef health and coral recovery in this manner (Idjadi et al. 2010).

However, exceptionally high sea urchin population densities tend to reverse this effect, by suppressing coral larval settlement and resulting in barren areas of reef (O'Leary 2013). As a result of these events, coral species diversity is can be significantly reduced, and certain corals may be forced to settle opportunistic outside their preferred regions of the reef, leading to blurring or loss of the normal organizational patterns observed on healthy reefs.

To learn more about what organizational shifts occur with reef decline, if any, I sought to observe vertical zonation patterns on two different Indian Ocean reefs off Ushongo Village in Tanga, Tanzania: Ushongo Village Reef (UVR) and Fungu Zinga Reef (FZR). The health of UVR and FZR has been largely determined by the differing prevalence of fishing on both. Because of its ease of accessibility from shore, UVR has a long history of fishing, including harmful methods of harvesting such as dynamite and poison fishing. UVR is also shallower, allowing fishermen to stand on the reef, thus directly damaging coral. Fungu Zinga Reef, being much farther offshore, is reached less easily and so has not been abused as significantly and has no known history of dynamite fishing.

Unfortunately, the health of FZR seems to have declined due to increase practice of fishing here in recent years. However, it still seems to portray noticeably greater diversity and abundance of corals and fishes than UVR, and so I still feel comfortable using FZR as my sample healthy reef in comparison to the very unhealthy UVR. That said, I predicted that I would find an overall stronger expression of vertical zonation on FZR than on UVR. In fact, when discussing my project casually with some of the local Ushongo village residents, some referred to UVR as already being "dead." As result, I expected to find very weak organization, if any on UVR among the present live coral coverage.

To test my hypothesis on correlations between reef health and vertical zonation, I observed and compared zonation patterns along the reef slopes of UVR and FZR. Several previous SIT independent study projects (ISPs) have looked into the health of these two reefs and have established the aforementioned health discrepancy. Although there are a number of offshore reefs in the area, I decided to work on UVR and FZR to stay consistent with these past ISPs and because of the known health history.

Study Site

Data collection was collected on two different coral reefs: Ushongo Village Reef (UVR) and on Fungu Zinga Reef (FZR). Both of these reefs are located offshore of Ushongo Village in Tanga, Tanzania on the Indian Ocean Coast. Both reefs are exposed to fairly strong influence by oceanic tides and currents on a daily basis. During my studies, the prevailing winds and currents came from the same Southeasterly direction almost every single day, being very light in the mornings and growing stronger throughout the day.

The tidal difference is roughly 2-3 meters from high to low tide, with a complete tidal cycle—for example one low tide to the next—being approximately 12.5 hours. Near low tides, the highest coral structures are exposed at the surface, although this seemed to occur only rarely or not at all around the reef crests. Data was collected as close to mid-tide as possible each day in order to maintain consistent depth measurements. Mid-tide was chosen because at low tides the water was often too shallow to snorkel on the reef, with much of the coral being very close to the surface, especially on UVR. At high tides, the currents often appeared stronger and visibility was poorer, particularly on UVR as well.

Ushongo Village Reef:

UVR is a patch reef located directly offshore of Ushongo Village, roughly 500 meters from the beach at the close edge and extending one to two hundred meters across. It is rather easily accessed by small boats and kayaks and could even be swam to. The reef exists as a large reef flat, with slopes around most of the perimeter. At mid tides, the reef crest was generally around the 2m mark around most of the reef, and the slope extended to around 5m in most places, though sometimes only 3m. On several days, the visibility was very poor due to suspended sediment, and it could be difficult to see the bottom clearly at 5m depth. The reef flat contains large areas of dead coral and seaweed, but most of the reef slope area was covered by live coral. After having been told by local residents that the reef was considered near dead, seeing live coral covering most of the slopes gave me some renewed hope for finding vertical zonation patterns.

At the base of the 5m slopes, sandy bottom extends outward from the reef forming a flat seafloor. This sandy bottom is mostly dominated by seagrass beds surrounding the reef. These seagrass beds generally begin around 5m from the base of the reef slope, with very little coral noticed growing separated from the main reef structure. In some areas, such as the North edge of the reef, there was only a very gradual slope, along which a seagrass bed extends onto the reef flat with no discernable reef crest present.

Being so easily accessible from the village, UVR has been heavily and unsustainably fished for many years, including some particularly harmful practices such as dynamite fishing and poisoning. In addition, one local mentioned that large predators such as sharks had been killed and apparently entirely removed from the reef over the years by the fishermen as an attempt to maintain fish stocks on the reef. Also, because the reef is so shallow at low tides, it was common to see fishermen standing on and walking around the reef to catch and spear fish each day, further damaging the coral present.

Because my project deals with vertical zonation, special attention was paid to the reef slopes, with the reef flat being largely ignored. As stated earlier, the slope generally stretched from the 2-5m depth range at mid-tide, with slopes ranging from near-vertical drop-offs to being much more gradual.

Fungu Zinga Reef:

FZR is a fringing reef surrounding the Fungu Zinga sandbar island, roughly 5-6 km offshore of Ushongo Village. The reef stretches at least around the Southwest, West and North edges of the island, but the Eastern side of the island was not visited and so not observed. The island nearly disappears at high tide but reaches around 3m elevation and about 200m dry sand across at low tide. The reef exists as several patches surrounding the island, with distance from the island beach varying with the tides. The most significant and complete reef areas seen are located to the Southwest and North of the island, with areas of sandy bottom and some short seagrass beds between the reef areas. The North area of the reef is especially well-covered with live coral, has a very clear reef slope, and is where most of the FZR data collection was performed.

Like on UVR, the reef crest is generally found around the 2m mark at mid tide. However, the slope at FZR is a much larger feature, with the base reaching around 10m depth in most areas. At the base, sandy bottom is present and stretches beyond the reef, continuing into the deeper water but more gradual than the reef slope. The reef slope contained most live coral coverage and had noticeably higher fish abundance and diversity. Some coral patches were observed growing on the sandy bottom beyond the reef slope, but these were excluded from the study and only the main slope itself was studied. Visibility was much better here than on UVR. It was generally quite easy to float at the surface and see clearly to nearly 15m depth.

As the health of UVR has declined due to overuse, many fishermen have resorted to fishing on FZR, leading to currently declining health according to the locals. However, practices such as dynamite fishing and poisoning have not been practiced here as on UVR, although large predators including sharks have been largely removed from this reef as well. Only a single shark (whitetip reef shark) was observed here during data collection. Despite declining health, FZR contains noticeably greater live coral coverage than UVR.

Methods

Data collection consisted essentially of recording depth measurements of coral along 10m transects set on the reef slopes. Transects were made from 10m lengths of rope with weights tied to either end. Weights were simply water bottles which had been found on the beach and filled with sand. UVR was reached by kayak, with an anchor made from multiple sand-filled bottles. FZR was reached by a motor-driven sailboat crewed by two local fishermen. Transects were distributed randomly and opportunistically on the reef slopes around the reef perimeter.

On UVR, one end of the transect was placed at the base of the slope and was run up the slope and over the reef crest. Because the slope is only 5m vertically, the excess of the 10m transect was run along the reef slope. On FZR, the 10m transect covered the entire area in most cases, due to the much larger size of the slope. When the entire length of the reef slope covered more than 10m, the transect was placed so that the ends were roughly equidistant from the slope's crest and base respectively. Because, of differences in slope length, not all transects covered all depth ranges, so some ranges—especially the upper and lower intervals—are not represented in all transects. Transects were rested as gently as possible on the reef to avoid damage to coral.

Randomization of transect placement was performed by anchoring the kayak or boat in a new spot each day and setting up a transect along the slope in the area of complete coral coverage nearest the boat. On days where multiple transects were observed, the transect was lifted and carried to a new area by swimming. Collection of depth measurements was performed by snorkeling and recording depth measurements of coral colonies in an underwater field notebook.

Originally, depth measurements were taken to the nearest centimeter. An air-filled, sealed bottle was used as a float to which the 0cm end of a measuring tape was attached. After being positioned directly above the desired point to be measured, the other end of the measuring tape was carried down while diving to record depth of coral colonies. Since measurement to the nearest centimeter was possible, the depth ranges of larger colonies were recorded. Corals observed were identified to the species level if possible and later placed into the aforementioned categories: branching, foliose, massive, encrusting, tabular, and rounded-dome-shaped.

Unfortunately, the measuring tape used was not salt-water resistant and broken beyond repair due to rust on the sixth day in the field. As a result, depth was then recorded in 1m intervals. To do this, a 10m rope was knotted at each meter and tied to a bottle float at one end and a stone at the other end. The stone was used as the 0m end of the line and was lowered so that when a knot was exactly on the surface, the depth of the stone in meters was equal to the number of knots to the surface. After being positioned directly above the top of each transect, the stone was slowly lowered as the knots were counted, then moved along the transect and gently set down on the point of the transect at the nearest exact-meter depth. Coral species between the transect end and meter interval were identified by diving down for close observation. The stone was then gently lifted and moved farther down the transect until it could be set at the next meter interval. Rather than mark each meter interval simultaneously, data was simply recorded at each interval between the stone's current and last positions before moving the stone again.

Data was recorded as the species observed along the transect in each 1m depth range, such as between 1-2m, 2-3m, etc. Since the transect was rested on the slope, species were recorded only if the transect line passed directly over the colony. In addition, only live coral colonies were recorded. If species could not be identified in the field, notes were taken on the colony to be identified later as best as possible using a guidebook. Even if multiple colonies of the same species appeared with a single depth interval, each species was only recorded once per interval as being present there. However, each species was recorded for all intervals it appeared in along the transect. Depth intervals were only observed if they fell within the 10m transect length. In two cases at FZR, the transect stretched from the crest to deeper than 10m depth. Because the measuring rope was only 10m long, and coral observed deeper but still along the transect was recorded simply as being in the 10+m interval.

After, field data was collected, species were split into the six categories by shape. The average number of species per category found in each depth interval was calculated for all transects. For each depth interval, the number of species per type were counted and added for all transects, then divided by the number of transects in which that depth interval is represented. The average numbers of species per category per interval were then averaged together for each reef to obtain an average trend in observed species richness on each reef, with the results in Figure 1.

In addition, counts were taken for each time a coral type was represented in an interval than averaged to obtain the percentage of times in which that category appeared in that depth range. Here, species was not considered, but merely the presence of a coral type in an interval was. The results for this method are portrayed in Figure 2. Strength of vertical zonation was judged based on the general trends of species richness along transects and the average number of appearances each. In addition, a Simpson's Diversity Index was calculated for each coral type on each reef using the number of intervals each species appeared in.

Results

Over twelve days in the field, a total of fifteen transects were studied between UVR and FZR. Eight of these days were spent at UVR, where six transects were studied. The days worked in the field at UVR were not consecutive, due to bad weather on several days. At FZR, nine transects were studied over four consecutive days. While bad weather prevented work in the field several days throughout the allotted three-week timespan, improved work efficiency in the field allowed for making up for time lost to bad weather and coordinating trips to FZR with the local fishermen.

A total of eighteen distinct coral species were observed on UVR, while twenty six were observed on FZR. All coral types except tabular were observed on UVR, while every type was recorded at least once on FZR. Some species could not be identified with confident, and so were simply left recorded as distinct unknown species within their shape category.

On both reefs, branching, rounded, and massive corals were the leaders in abundance and species richness. Encrusting and foliose corals appeared relatively consistently throughout most transects but were scattered and less common. Tabular corals were present on the reef and observed outside transects, but they were rather scarce and scattered. The only one which appeared on a transect was on FZR T6 in the 9-10m range. Since all data was collected at mid tides, no coral at the reef crests was observed in the upper 1m of the water column. In addition, no coral was observed deeper than 5m at UVR, and any coral deeper than 10m at FZR was labeled simply as 10+. It is estimated that no coral beyond 10m along a transect was any deeper than 12m, although this could not be exactly measured.

Figure 1 below shows the average number of species from each category that was found in each depth interval. Figure 1a portrays the results from UVR, while figure 1b portrays the results from FZR. Smoothed trendlines were fitted to the graphs to interpolate and show general patterns in each type's depth distribution.

Figure 1

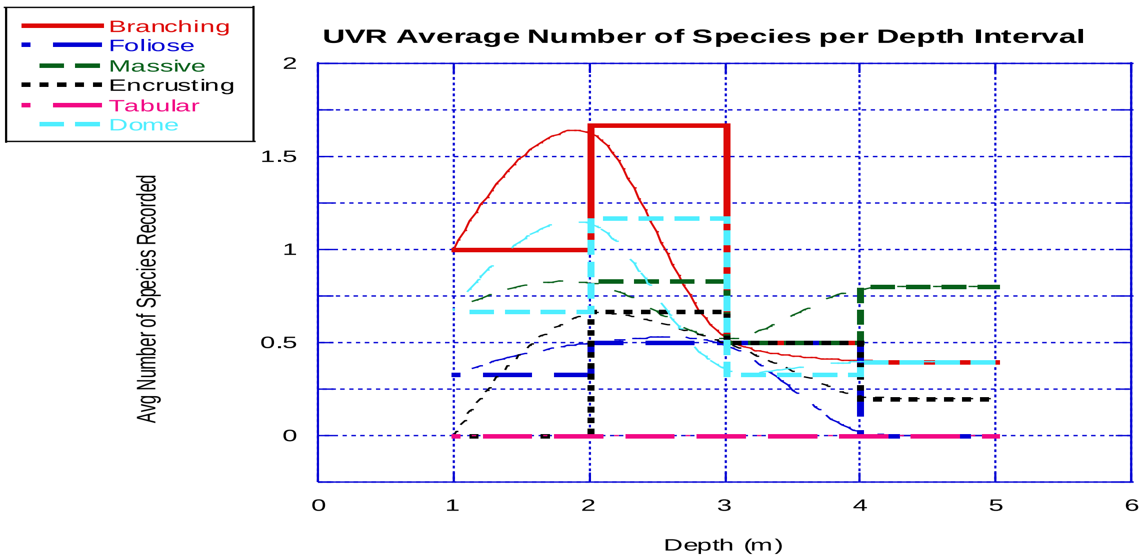

Figure 1a.

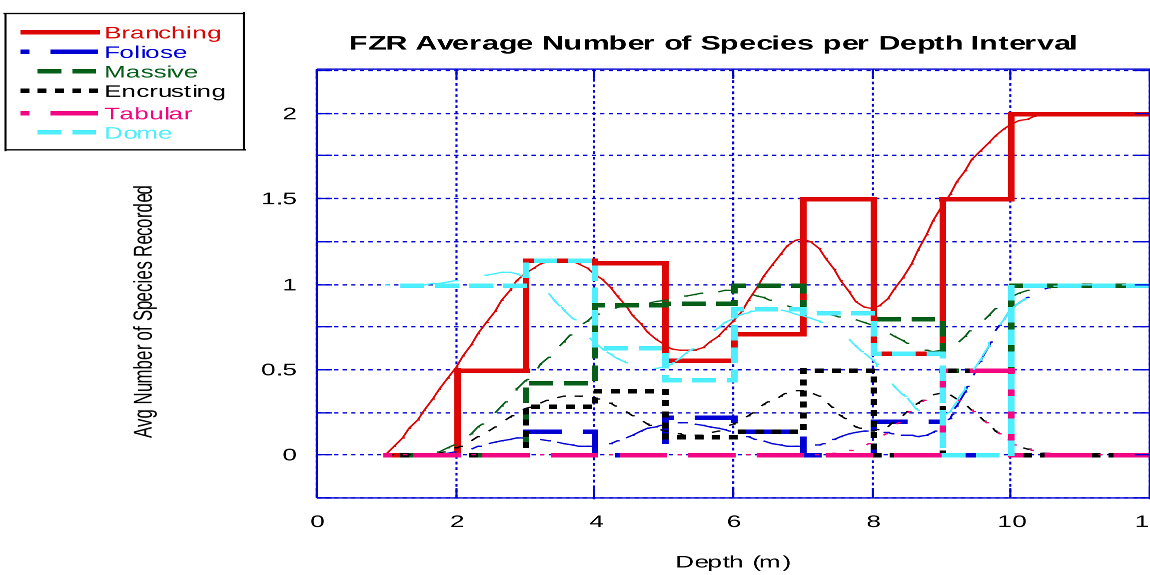

Figure 1b.

On UVR, branching corals generally had the highest species richness in the 1-3m depth range on UVR, followed by dome-shaped corals. However, between 3 and 4 meters, these two types decline, causing massive corals to lead in species richness in the 4-5m range, the deepest interval observed on UVR. Encrusting and foliose corals followed similar trends to branching and dome-shaped corals, increasing until the 2-3m interval, then declining until the slope's base.

On FZR, dome shaped corals led in species richness in the 1-3m range and tied with branching corals in the 3-4m interval. From 4m onward, dome-shaped corals decline in species richness but remain between 0.5-0.75 species per interval until declining to 0 at the 9-10m range and rising back to 1 deeper than 10m. Massive corals remain low in species richness until 3m depth but remain consistent until the base. Branching corals show the most interesting trend with peaks at 3-5m, 7-8m, and 10+m and lows at 1-2m, 5-6m, and 8-9m. At the low points in branching coral diversity, massive corals take the lead, but branching corals lead in species richness from 4-5m, 7-8m, and 9+m. Similar to UVR, encrusting and foliose corals remain consistently low throughout most depth intervals, except for a spike in foliose corals deeper than 10m.

Figure 2 removes the number of species from the calculation, dealing simply with how often each coral type appeared in a given depth interval. This model follows a similar pattern to that shown in Figure 1, with branching corals present most often until 3m and massive corals present most often after.

Figure 2 below shows how frequently each coral type appeared in each depth interval. If multiple species were present, this was excluded, and each category simply was counted as being present in the interval. This count was then divided by the number of times the interval was observed. Smoothed trendlines have been fitted to show general trends in distribution.

Figure 2

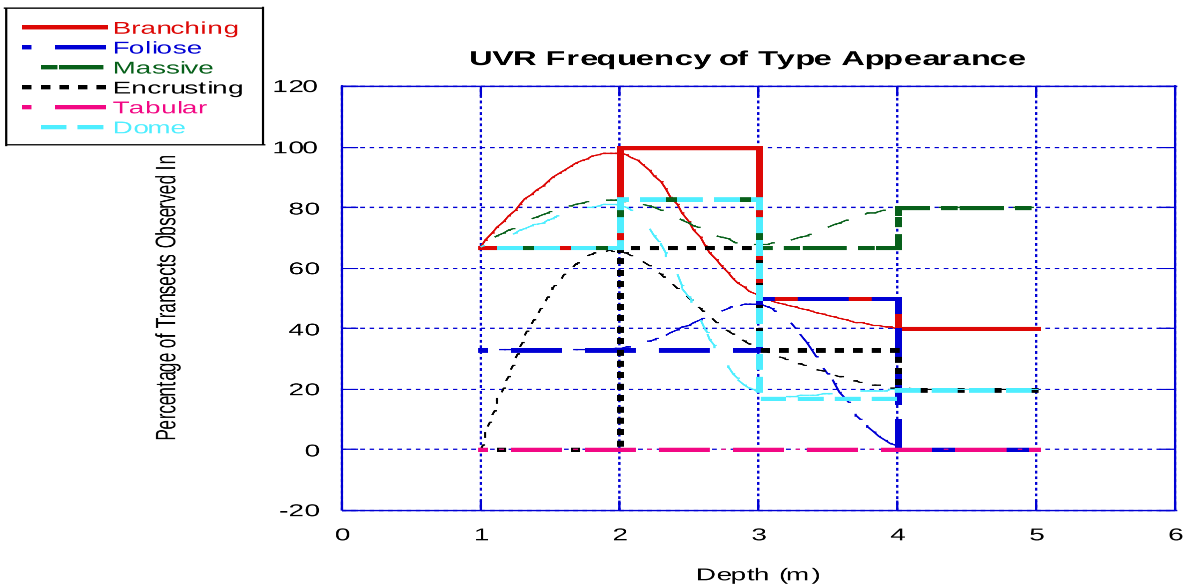

Figure 2a

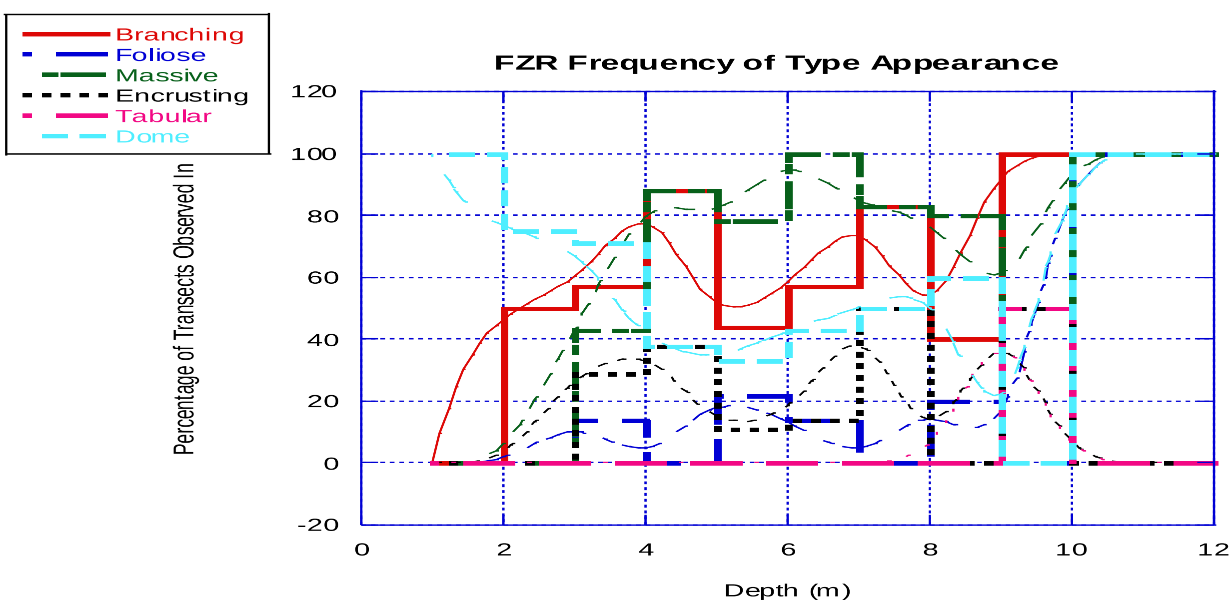

Figure 2b

Figure 2b also portrays fairly similar trends to Figure 1b, with dome-shaped corals being the most commonly present type from 1-4m. However, in this model, branching corals are never the leading type, except at 9-10m. Figure 2b shows a transition in the 4-5m interval, during which massive corals begin to be seen more frequently than either dome or branching. Here, like in figure 2a, massive corals remain the most frequently observed for most depth intervals after this transition, except at 9-10m.

The results shown in Figure 2 are differ from those in Figure 2 due to variations in the diversity index of each coral type. This also explains the high species richness of branching corals in deeper FZR, despite lower frequency compared to massive corals. Branching corals had Simpson's Indices of Diversity of 0.7516 and 0.8263 on UVR and FZR respectively. Dome-shaped corals also had a high Simpson's Index of Diversity on both reefs: 0.7949 on UVR and 0.7756 on FZR. Massive corals, however, had the lowest Simpson's Diversity Index of these three dominant types, with 0.4190 on UVR and 0.2084 on FZR.

Discussion

According to the data, both reefs did portray fairly similar patterns of vertical zonation. Generally, branching species dominated to upper half of UVR while massive corals dominated the lower half. While observed in the species richness model, this distinction is highlighted in the frequency model in figure 2a. Meanwhile, FZR did have a slightly more complex pattern of vertical zonation, where dome-shaped then branching corals led in species richness in the upper and upper-mid reef respectively before massive coral begins to lead below 5m. Interestingly, Figure 2b indicates somewhat lower relative dominance of branching corals along most of the slope, with them only leading in frequency of appearance at 9-10m and matching with massive corals at 4-5 and 7-8m. Figure 2b shows all types except tabular corals converging at 100% frequency at 10+m. However, this is somewhat misleading, since this depth interval was only observed along one transect, so any type that was present in that particular location is listed as present in 100% of the 10+m areas studied.

Interestingly, as described previously some coral patches were seen in deeper water several meters from the slope base. While not studied as part of this project, it was noticed that these patches tended to have more large tabular corals than observed on the slopes. If this is true, it may be that large tabular corals add another level of zonation to the deep reef, although this is not confirmed in this study.

One interesting feature of the graphs is that species richness of branching corals is significantly higher in the upper 1-3m of UVR than on FZR. It may be that this is the result of branching corals having the greatest capacity to settle and grow quickly. Therefore, intense grazing of the reef flat by sea urchins on UVR may actually promote diversity in branching corals.

One important note recorded in the meta-data of this study is that massive corals, particularly *Pavona clavus*, tended to make up especially large regions of reef slopes below 3m on UVR and 4m on FZR. Along many transects, this species forms the bulk of the reef slope foundation, with other types such as branching and dome colonies present in deeper water generally growing off of or in gaps in massive *P. clavus* sheets. This is emphasized by the general lack of diversity in massive corals as indicated by their low observed Simpson's Index of Diversity. On each transect only a single massive coral species was ever observed in a given depth interval. As a result, massive corals, as their name suggests, typically covered consistently much greater areas with a single species or colony than several colonies of other coral types on FZR. This is observed in Figures 1b and 2b, where branching corals often had high species richness in the deep reef but did not appear as frequently as massive corals. Therefore, this study finds that massive corals did indeed dominate the reef slopes below 4-5m on FZR.

Conclusion

Generally, despite being less healthy and diverse and having a much smaller reef slope, UVR did portray the originally expect features of vertical zonation, with branching corals tending to dominate that upper half of the reef slope and massive corals dominating the lower half. FZR, the healthier reef, portrayed 3 distinct levels of zonation, with small dome-shaped colonies dominating the upper reef slope, branching corals somewhat deeper, and massive corals becoming prevalent below 4-5m.

While FZR exhibited this third layer of zonation, compared to UVR's two, it is believed that this is simply due to the small size of and depth gradient of UVR's reef slope, since the two layers were already compressed into a total 4m depth gradient (1-5m). In addition, dome-shaped corals tied with branching corals in appearance frequency in the 1-2m interval on UVR and was second to branching in species richness. It may be possible that dome-shaped colonies could dominate upper reef sections of larger unhealthy reefs where competition for space is less limited by overall slope area.

Therefore, overall health reef health does not seem to significantly affect depth distribution of coral types. However, this conclusion would be strengthened greatly by performing a repeat of this study on two reefs of more comparable size, since it cannot be ascertained in this study how vertical zonation on UVR is affected simply by the slope size.

Furthermore, the only coral types significantly in any way were branching and dome-shaped corals in the upper 1-3m depth. On UVR, branching corals were significantly more diverse in this range than on FZR, and dome-shaped corals were significantly less diverse in the 1-2m interval on UVR than FZR. One hypothesis for this difference is that higher sea urchin density on the UVR reef flat promotes species richness of branching corals, which tend to grow the fastest and so would be best able to fill in bare patches left by urchin grazing. This may allow branching corals to outcompete dome-shaped corals in the upper reef areas of unhealthy reefs with high urchin populations.

Despite this, the general pattern of branching corals dominating upper reefs and massive corals dominating lower reefs alone cannot be declared an indicator of reef health at this time, although more complex patterns of vertical zonation with more than these two layers may serve this role on larger reef slopes.

Ethics

This study was conducted entirely in the field, with no formal social participation involved. Some casual conversations with local residents took place, but these were generally initiated by residents who were simply curious about the project. Therefore, any information used from such conversations was simply used as general knowledge since it was not formally collected data. One person, Mwindadi, spoke very good English and organized trips to FZR with local fishermen. Two fishermen boated me and my snorkel partners to FZR and were compensated.

All other ethical concerns dealt with careful practice on the reefs. Transects were always lowered, set, and removed as gently as possible, and care was taken to ensure that lines did not become entangled on the coral. Unfortunately, one transect was lost at sea on the first day of attempted data collection. From this point on, a floating bottle was tied to the transects so that they could be spotted from the surface and found again in case left for any reason. Minimal sunscreen was worn to prevent unnecessary pollution to the reef as well.

Limitations and Biases

Perhaps the most glaring limitation was proper identification of coral species. I had very little experience doing this previously and was using a guidebook twenty years old. Fortunately, this limitation is offset by the focus of this project on coral shape/type rather than species. This allowed some species to simply be recorded as unknown branching, etc. and still be useful to the project. Also, some species can grow in different forms, with some forming either encrusting or branching colonies for instance. As a result, there was some personal uncertainty and bias in deciding which category each type should be placed in.

The other glaring limitation was the difference in size of the reef slope on both reefs. FZR had a slope double the size of that of UVR, a reef flat with greater live-coral coverage, and coral patches even deeper than the main reef slope. Therefore, it is unclear which of the differences observed on the two reefs are resultant merely of the size discrepancy.

Also, with the larger slope of FZR, the slope covered different gradients and so different areas depending on the location. Because of this, the 10m transect did not always cover the same depth intervals on all transects, meaning not all intervals are represented equally.

Another important limitation was the presence of storms, which made field data collection impossible on some days. This made the already limited 3.5-week timespan even more so. Also, visibility was often very poor on UVR, often being difficult to see the slope base clearly at just 5m depth. Even the worst days of visibility on FZR were always better on UVR.

After the measuring tape broke, depths could no longer be recorded exactly, forcing a shift in the project to establish intervals instead. Accuracy in depth measurements was sometimes also thrown off by currents causing the tape/line to bend or shift while lowering.

Another setback was that the reefs were too large to map out as originally intended. Instead, transects were laid out randomly, usually simply where the kayak or boat was anchored. When multiple transects were recorded in a single day, the transect line was lifted and moved to a new spot while swimming. New locations were selected as randomly as possible, with attempts made to move sufficiently far according to personal judgement, in order to cover as much reef area as possible. In doing so, spots were selected randomly, with as little attention to coral present as possible to remove potential bias.

Logistically, the transect lines were narrow, and coral was only recorded if the line passed directly over the colony. While this maintained consistency, it also meant that the vast majority of coral on both reefs was not directly surveyed.

Lastly, coral reefs tend to be very complex systems, with a great deal of competition among and within species. As a result, there are likely many factors, biotic and abiotic, influencing the organization of reefs, of which a proper understanding requires much more than one month of data collection.

Recommendations

If a repeat of this study is conducted, it is strongly recommended that is be performed on two reefs of more comparable size than UVR and FZR, preferably both on the scale of FZR. Unfortunately, this would likely require a reef that has yet to be studied by SIT students, and it would likely be more expensive, since the "new" reef would likely be farther offshore and less readily accessible than UVR.

Another interesting idea would be to look more closely into coverage area of the different coral types. This may be a better proxy for local dominance of a coral type than species richness and may shed light on interactions between types.

One idea considered in retrospect would certainly be to interview fishermen formally early in the ISP period to find out more details regarding fishing practices and especially which species, if any, are particularly targeted. A study investigating which fish species—especially grazers and indicator species—are targeted and which are present on a reef would be great to expand upon the understanding of just how fishing practices influence food web dynamics and reef composition. Such a study could also focus on looking into which grazing species are present and in what abundance compared to which coral species are present.

Another interesting study could involve sea urchin density in relation to benthic species composition and coverage. This would tell which species, if any, are more vulnerable to urchin grazing.

References

Baird, A. H., R. C. Babcock, and C. P. Mundy. "Habitat selection by larvae influences the depth distribution of six common coral species." Marine Ecology Progress Series 252 (2003): 289-293.

Idjadi, Joshua A., R. Nicholas Haring, and William F. Precht. "Recovery of the sea urchin Diadema antillarum promotes scleractinian coral growth and survivorship on shallow Jamaican reefs." *Marine Ecology Progress Series* 403 (2010): 91-100.

O'Leary, Jennifer K., et al. "Fish and sea urchin grazing opens settlement space equally but urchins reduce survival of coral recruits." Marine Ecology Progress Series 493 (2013): 165-177.

Phamdo, Eric H. "Accessibility and Coral Reef Health: A Comparative Analysis of Accessibility and Coral Health of Shallow Reefs in Pangani District, Tanga, Tanzania." SIT ISP (2010).

Richmond, Matthew D. *A Guide to the Seashores of Eastern Africa and the Western Indian Ocean islands*. Sida/Department for Research Cooperation, SAREC (1997).

Wellington, Gerard M. "An experimental analysis of the effects of light and zooplankton on coral zonation." Oecologia 52.3 (1982): 311-320.

Wellington, Gerard M. "Depth zonation of corals in the Gulf of Panama: control and facilitation by resident reef fishes." Ecological Monographs 52.3 (1982): 223-241.

Appendix A: UVR Transect Results

Depth (m)	T1	T2	T3
1 to 2	Pavona clavus		Pocillopora verrucosa
			Montipora aequituberculata
			Leptastrea purpurea
2 to 3	Montipora aequituberculata	Montipora digitata	Montipora digitata
	Echinopora lamaellosa	Leptastrea purpurea	Montipora aequituberculata
	Pocillopora verrucosa	Pocillopora verrucosa	Leptastrea purpurea
	Fungia scutaria	Pavona clavus	Echinopora gemmacea
	Favia favus		Pavona clavus
	Pavona clavus		
	Leptastrea purpurea		
	Echinopora gemmacea		
3 to 4	Echinopora gemmacea	Pavona clavus	Pavona clavus
	Montastrea curta		
	Montipora aequituberculata		
	Platygyra daedalea		
4 to 5		Pavona clavus	Pavona clavus
			Montipora digitata

Depth (m)	T4	T5	T6
1 to 2			Hydnophora exesa Pocillopora verrucosa Unknown branching-1 Platygyra daedalea
2 to 3	Montipora digitata Pocillopora verrucosa	Montipora digitata Pavona clavus Pocillopora verrucosa Leptastrea purpurea Echinopora gemmacea	Hydnophora exesa Platygyra daedalea Pocillopora verrucosa Unknown branching-2 Unknown crust-1
3 to 4	Montipora digitata Hydnophora exesa	Pavona clavus Montipora aequituberculata Acropora vallida	Echinopora lamellosa Echinopora gemmacea Unknown branching-2 Unknown crust-2
4 to 5	Hydophora exesa	Pavona clavus	Echinopora gemmacea Acropora vallida Unknown Dome-1 Platygyra daedalea

Appendix B: FZR Transect Results

Depth (m)	T1	T2a	T2b
1 to 2		Leptastrea purpurea	
2 to 3		Leptastrea purpurea Fungia scutaria	
3 to 4	Pavona clavus Fungia scutaria Unknown Dome-2	Fungia scutaria Acropora vallida Echinopora lamellosa Unknown branching-3 Favia stelligera Montipora digitata	
4 to 5	Pavona clavus	Acropora vallida Pavona clavus Stylophora pistillata	
5 to 6	Pavona clavus Fungia scutaria	Pavona clavus Fungia scutaria Halomitra pileus	Pavona clavus Unknown branching-3
6 to 7	Pavona clavus Montipora digitata		Pavona clavus

7 to 8	Echinopora gemmacea Pavona clavus Platygyra daedalea Favia abdita Montipora digitata	Pavona clavus
8 to 9		Pavona clavus
9 to 10		Pavona clavus Unknown branching-3
10+		Pavona clavus Unknown branching-3 Acropora vallida Fungia scutaria Echinopora lamellosa

Depth (m)	T3	T4	T5
1 to 2			
2 to 3		Leptastrea purpurea Acropora vallida	
3 to 4	Pavona clavus	Montipora digitata Platygyra daedalea	
4 to 5	Pavona clavus Unknown branching-3 Unknown crust-3	Montipora digitata Fungia scutaria Pavona clavus Unknown crust-3 Halomitra pileus	Favia stelligera
5 to 6	Pavona clavus	Pavona clavus	Favia stelligera Echinopora lamellosa
6 to 7	Pavona clavus Unknown branching-3 Fungia scutaria	Pavona clavus	Favia stelligera Echinopora lamellosa Pavona clavus Platygyra daedalea
7 to 8	Pavona clavus Unknown branching-3 Fungia scutaria		Stylophora pistillata Echinopora gemmacea Acropora vallida

		Unknown branching-4
8 to 9	Pavona clavus	Unknown branching-4 Echinopora lamellosa Unknown branching-5 Platygyra daedalea
9 to 10		
10+		

Depth (m)	T6	T7	T8
1 to 2			
2 to 3	Montipora digitata	Leptastrea purpurea	
3 to 4	Montipora digitata	Leptastrea purpurea	Echinopora gemmacea
		Platygyra daedalea	Favia stelligera
		Unknown crust-4	Montipora digitata
		Fungia scutaria	Platygyra daedalea
		Pavona clavus	
4 to 5	Montipora digitata	Unknown branching-4	Platygyra daedalea
	Pavona clavus	Leptastrea purpurea	Unknown branching-4
		Unknown branching-6	Hydnophora exesa
		Pavona clavus	Echinopora gemmacea
		Fungia scutaria	
5 to 6	Montipora digitata	Pavona clavus	Platygyra daedalea
	Pavona clavus		Unknown branching-1
			Montipora digitata
			Palthoa natalensis
			Turbinaria Mesenterina
6 to 7	Pavona clavus		Hydnophora exesa
			Unknown branching-1
			Montipora digitata
			Echinophora gemmacea
			Fungia scutaria
			Unknown dome-1
			Favia favus
			Leptastrea purpurea
7 to 8	Pavona clavus		Unknown crust-5
	Montipora digitata		Montipora digitata
			Leptastrea purpurea

		Hydnophora exesa
		Unknown branching-5
		Unknown branching-4
		Acropora vallida
8 to 9	Pavona clavus	Acropora vallida
	Platygyra daedalea	Hydnophora exesa
		Platygyra daedalea
9 to 10		Montipora digitata
		Echinopora gemmacea
		Unknown branching-5
		Pavona varians
10+		