

Variations in Reef Rugosity and Coral Composition: A Comparative Study of High and Low Wave Energy Sites around Heron Island

Fiona Jeweler

June 14, 2024

Fionajeweler@ucsb.edu

Abstract

Reef rugosity, defined as the structural complexity of coral reefs, is a crucial indicator of reef health and is integral to carbonate budgets, which measure the balance of calcium carbonate production and loss. This study examines reef rugosity and coral composition around Heron Island, comparing high and low wave energy sites. Data collection involved the chain and tape method over sixteen transects, supplemented by underwater photography analyzed using Coral Point Count with Excel extensions (CPCE) software. Our findings indicate that the low wave energy site exhibited slightly higher rugosity (average $R = 1.23$) than the high wave energy site (average $R = 1.18$), though the difference was not statistically significant. Benthic composition analysis revealed that the low energy site had higher percentages of dead coral with algae and lower percentages of sand and macroalgae. Branching corals, which contribute significantly to structural complexity, were more prevalent at the low energy site. This correlation between coral morphology and rugosity highlights the importance of specific coral types in maintaining reef structure. These findings highlight the role of coral morphology in determining reef complexity and suggest that environmental conditions modulate this relationship. This study underscores the importance of maintaining reef rugosity for ecological balance and biodiversity, particularly under the stress of climate change. Future research should explore the contributions of other coral morphologies to reef complexity to inform comprehensive conservation strategies. To improve future studies, we recommend incorporating three-dimensional measurements of rugosity and standardized protocols for coral identification to reduce subjectivity and enhance data accuracy.

Keywords

Rugosity, Carbonate production, Coral composition, Wave energy

Introduction

Reef rugosity, defined as the structural complexity or surface roughness of a coral reef (Dustan et al., 2013), is a crucial component of a carbonate budget. Carbonate budgets measure reef health by focusing on processes that produce and remove carbonate (Dee et al., 2020). High rugosity, characterized by irregular and complex surfaces, typically indicates active calcification processes by corals and coralline algae (Cornwall et al., 2023). These organisms build intricate structures that contribute to a positive carbonate budget by increasing the surface area available for calcifying organisms to colonize, thereby promoting further calcium carbonate production (Mallela, 2018).

On a global scale, reef rugosity significantly impacts biodiversity, habitats, and fisheries. High rugosity creates a variety of niches and microhabitats, which often correlate with increased biodiversity, supporting a wide range of marine species, including fish, invertebrates, and other organisms essential for the ecological balance of reef ecosystems (Gratwick & Speight, 2005). Diverse fish populations, sustained by complex reef structures, serve as vital food sources for millions of people worldwide, particularly in coastal and island communities (Hay, 2013).

Rugose reefs play a crucial role in mitigating climate change impacts by acting as natural breakwaters, reducing wave energy, and protecting coastlines from erosion, storm surges, and flooding, thereby preserving coastal ecosystems (Osorino-Cano et al., 2019). Additionally, the calcification process in reefs produces calcium carbonate, effectively sequestering carbon in the form of reef structures (Cornwall et al., 2021). Therefore, maintaining or enhancing the structural complexity of coral reefs strengthens the natural defenses of coastal ecosystems against the adverse effects of climate change.

Reef rugosity worldwide is facing a decline driven by various factors (Alvarez-Filip et al., 2009), with the Great Barrier Reef particularly vulnerable to multiple stressors. These include bleaching events (Hughes et al., 2017), storms (Connolly & Baird, 2010), predator overpopulation (De'ath et al., 2012), ocean acidification (Cornwall et al., 2021), and overfishing (Kinch et al., 2008). These risks pose significant threats to ecosystem health and biodiversity. The decline in coral reef populations results in habitat loss, diminished species richness, trophic disruptions, reduced ecosystem services, heightened susceptibility to climate change, and decreased carbonate budgets (Sweatman et al., 2011).

The ecological significance of reef rugosity in supporting diverse coral species is well-established, but there are still gaps in understanding how specific coral species contribute to this structural complexity. Identifying how different coral species enhance rugosity can help pinpoint key species essential for maintaining the reef's structural integrity and ecological functions. Moreover, certain coral species exhibit greater resistance to environmental stressors, helping to preserve reef complexity under changing conditions (Hoegh-Guldberg et al., 2017). Understanding the contributions of specific coral species to reef structural complexity is crucial for prioritizing conservation efforts and protecting these keystone species.

As such, our study sought to examine the reef rugosity and coral communities surrounding Heron Island. Specifically, we focused on assessing reef rugosity at both high and low wave energy sites around the island and investigated the correlation between reef structural complexity and the composition of benthic coral communities. Given the limited existing documentation of reef rugosity around Heron Island, this study stands to significantly contribute to monitoring changes in the reef's structural complexity.

Questions

Are there variations in reef rugosity between the high and low wave energy sides of Heron Island?

Is there a correlation between reef rugosity and benthic coral composition?

Methods and Experimental Design

Study Site and Time

For the purpose of this study, the north and south sides of Heron Island, where our investigation took place, will be designated as the high and low energy sites, respectively. Positioned at the southern tip of the Great Barrier Reef, Heron Island experiences distinct environmental influences. The north side, exposed to prevailing northward trade winds, encounters elevated wave energies, while the south side is characterized by comparatively lower wave energies (Dee, 2020). These unique environmental conditions shape the reef ecosystems differently at each site, fostering a diverse array of coral species. Our study focused on the outer reefs of both locations, where the abundance and diversity of corals provided a robust dataset for

analysis. Refer to Figure 1 for visual representations of the low and high wave energy sites selected for this study.

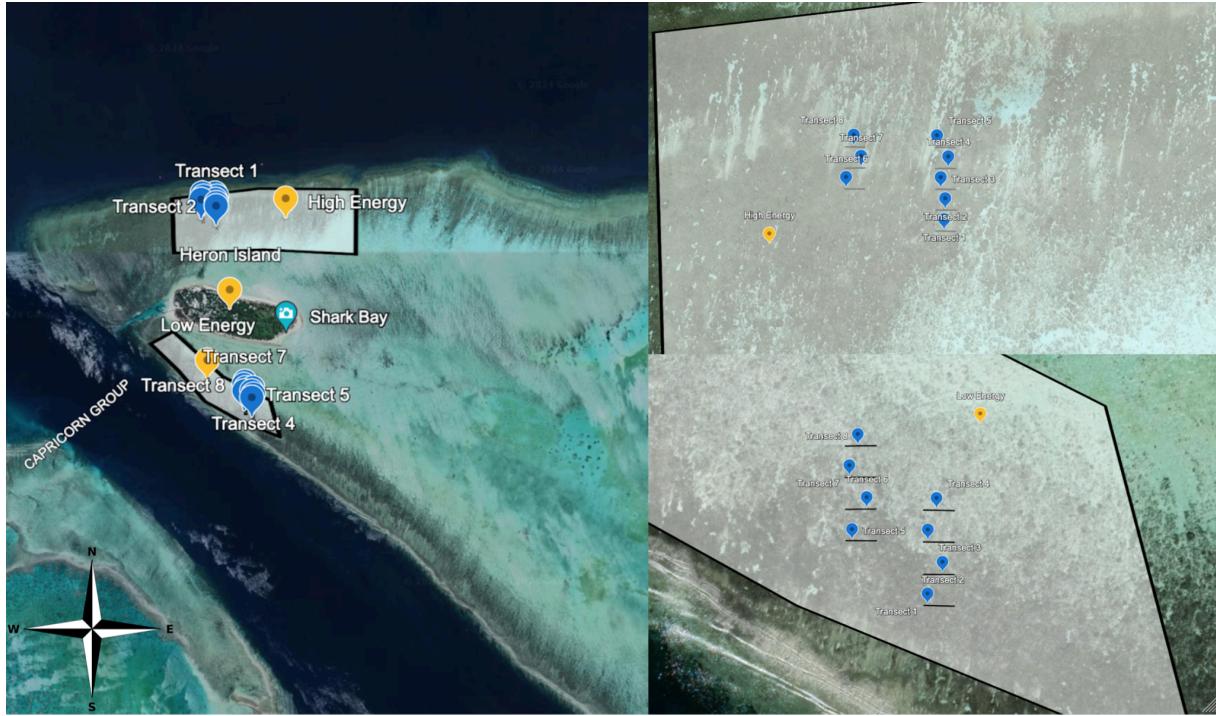


Figure one: Map of Heron Island outer reefs, delineating the locations where transects were laid

To ensure methodological consistency, data collection was conducted exclusively during high tide over a span of three days from approximately 7:30 am to 9:20 am. This tidal condition not only safeguarded our team and the delicate coral ecosystems from harm but also provided optimal depth for capturing comprehensive photographic documentation. On the initial day, transects were laid out on the low wave energy side of the island; however, due to prevailing currents, only five were completed. The remaining three transects were surveyed two days later. Subsequently, on the second day, all eight transects on the high wave energy side of the island were successfully completed. Weather conditions were favorable all three days, with low winds and high sun.

Data Collection

Overall, we implemented a total of sixteen transects using the chain and tape method (CT method) across both the high and low wave energy sites. These transects were evenly distributed, with eight situated at North Beach and an additional eight positioned at South Beach.

Each transect spanned a length of 20 meters, affording us a thorough examination of both areas. Aligned parallel to both the shoreline and one another, the first transect at each site was randomly positioned, with subsequent transects spaced approximately 20 meters apart.

The transect was carefully laid across the substrate and meticulously tensioned to prevent any sagging that might affect our measurements. To secure the zero meter end of the tape measure, we utilized coral fragments, while the opposite end was firmly held in position by our team. Additionally, a 5.4-meter beaded chain was placed over both the initial and terminal sections of each transect, allowing us to derive two rugosity values per transect. Unfortunately, by the second day, our chain had shortened to 4.6 meters; however, we continued the measurements using the same methodology.

At every meter of each transect, we captured underwater photos, amounting to a total of 320 images. These photographs were taken from approximately 0.7 meters above the transect using an Olympus Tough TG-6 4.5 millimeter GPS camera. These photographs allowed us to later analyze the area around our transects and determine the coral and substrate composition with which we could compare our rugosity values with.

Process

We inputted both the contoured chain length and straight chain length values into a Microsoft Excel spreadsheet, where they were used to calculate the rugosity index (R) using the following formula:

$$R = \frac{\text{Tape chain length}}{\text{Beaded chain length}}$$

This rugosity index acted as a proxy for assessing reef structural complexity. An R value of one indicates a flat surface with no structural complexity (where the chain's tape length is equal to the beaded chain length).

We analyzed the photos we captured using the Coral Point Count with Excel extensions (CPCE) program. This software serves as a valuable tool for assessing coral cover from transect photographs (Kohler & Gill, 2006). It distributes a specified number of spatially random points across a transect image, which are then user-identified in terms of the features they overlay. Coverage statistics are subsequently calculated, with results automatically exported to Excel spreadsheets. In our study, the software was utilized to help us calculate the percent composition of contributing coral morphologies, dead coral fragments, macroalgae, rubble and sand in our

rugosity data. The program selected twenty random points in each photo, and once they were carefully analyzed, each point was labeled using our predetermined coded keywords. After labeling all twenty photos from each transect, we consolidated the data into a single Microsoft Excel file to facilitate the analysis of percent benthic cover composition. This process was repeated for all sixteen transects.

Statistical Analysis

Analysis and visualization of our data were performed using RStudio version 4.3.3. For comparative analysis between high and low energy rugosity, a t-test was conducted (Fig. 2). Additionally, to assess differences in benthic and live coral cover percentages across high and low wave energy sites, an ANOVA test was employed (Fig. 3 and Fig. 4). The ANOVA graphs were generated in R utilizing ggplot2.

Results

Calculations

Although not found to be statistically significant ($T = 0.96036$, $df = 30$, $P = 0.3446$), when comparing rugosity values (R) we found that the low wave energy site had a higher rugosity than the high wave energy site (Fig. 2). The low energy site was found to have a R value of approximately 1.23, while the high energy site had a R value of approximately 1.18. While the high wave energy site showcased two notably high R values (1.508 and 1.543), these are considered outliers.

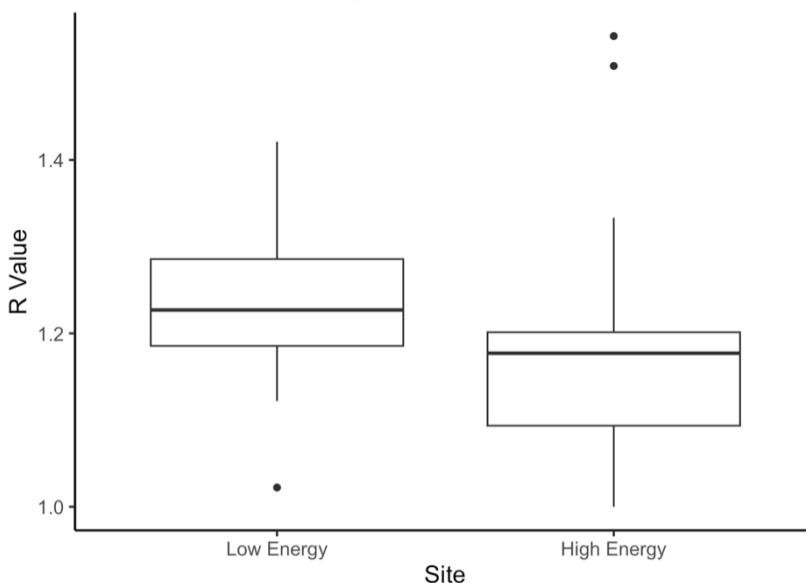


Figure 2: This box plot compares the rugosity values (R) measured from the low and wave sites. Error bars represent +/- standard errors and dots represent outliers. The P-value is 0.3446.

Image Analysis

In terms of benthic cover composition, dead coral with algae was about 23.1% higher at the low energy site ($F = 9.939$, $df = 4$, $P = 0.0079578$; Fig. 3), whereas sand was about 20.6% lower at the low energy site ($P = 0.0288609$). Macroalgae was found to be about 21.6% lower at the low energy site ($P = 0.0175492$). Percent cover of both live coral ($P = 0.9973127$) and rubble ($P = 0.9999250$) were not found to have statistically significant differences between the high and low wave energy sites (Fig. 3).

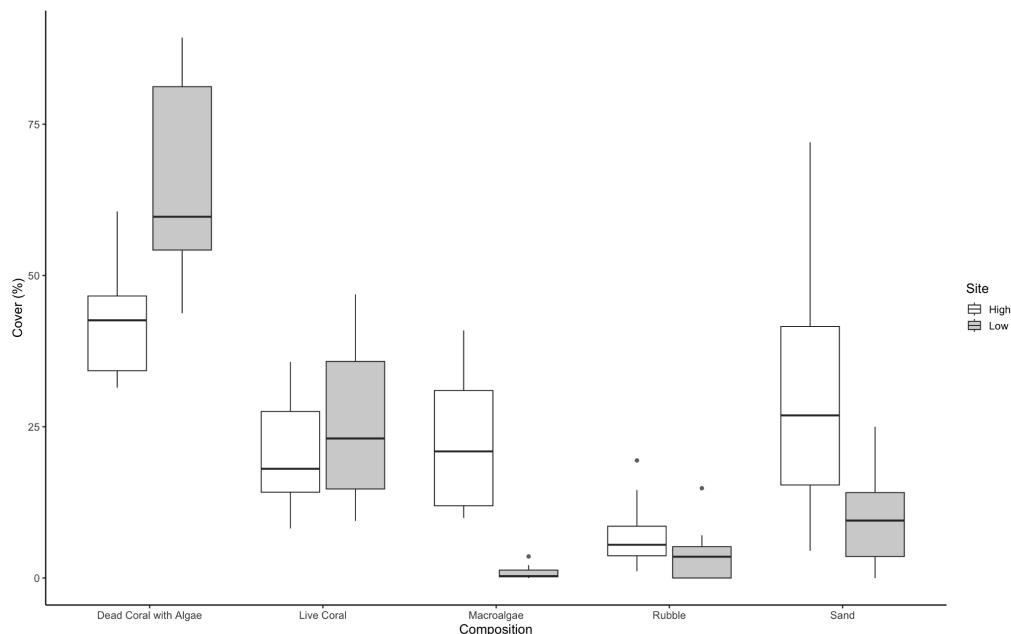


Figure 3: This box plot compares the percent cover of coral community compositions of dead coral with algae (left), live coral (second to left), macroalgae (middle), rubble (second to right) and sand (right). Error bars represent +/- Standard Error and dots represent outliers. The P-Value is <0.1.

For percent cover of each live coral morphology, branching coral composition was found to be significantly higher at the low wave energy site in comparison to the high energy site ($F = 4.306$, $df = 5$, $P = 0.0013373$; Fig. 4). On the eight high wave energy transects, branching corals averaged 62.89% of the total live coral cover. In contrast, on the eight low wave energy transects,

branching corals averaged 90.15% of the total live coral cover (Fig. 4). All other coral morphologies identified within our site (encrusting, foliose, massive, submissive, and tabulate) were not found to have significant differences between high and low energy wave sites, and did not significantly contribute to the overall percent cover of the reef (Fig. 4).

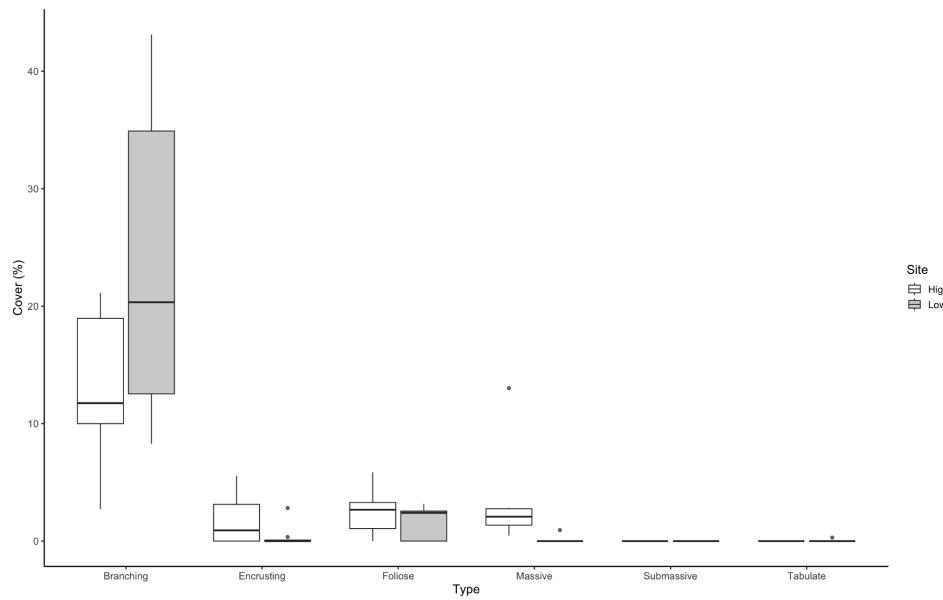


Figure 4: This box plot compares the percent cover of live coral compositions of branching (left), encrusting (second to left), foliose (third to left), massive (third to right), submissive (second to right), and tabulate (right). Error bars represent +/- Standard Error and dots represent outliers.

The P-Value is <0.1.

Comparison

When comparing coral composition to rugosity, a trend emerged. Given that branching coral was the most abundant coral morphology, it was used for this analysis. At the high wave energy site, the relationship between the proportion of branching to non-branching corals and the average R value for each transect showed a slight positive correlation (Fig. 5). This indicates that as the proportion of branching corals increases on the high wave energy side of the island, rugosity also tends to increase, albeit weakly. In contrast, at the low wave energy site, no relationship was observed between the proportion of branching to non-branching corals and the average R value for each transect (Fig. 5), indicating that changes in branching coral composition on the low energy side of the island do not have a clear impact on rugosity.

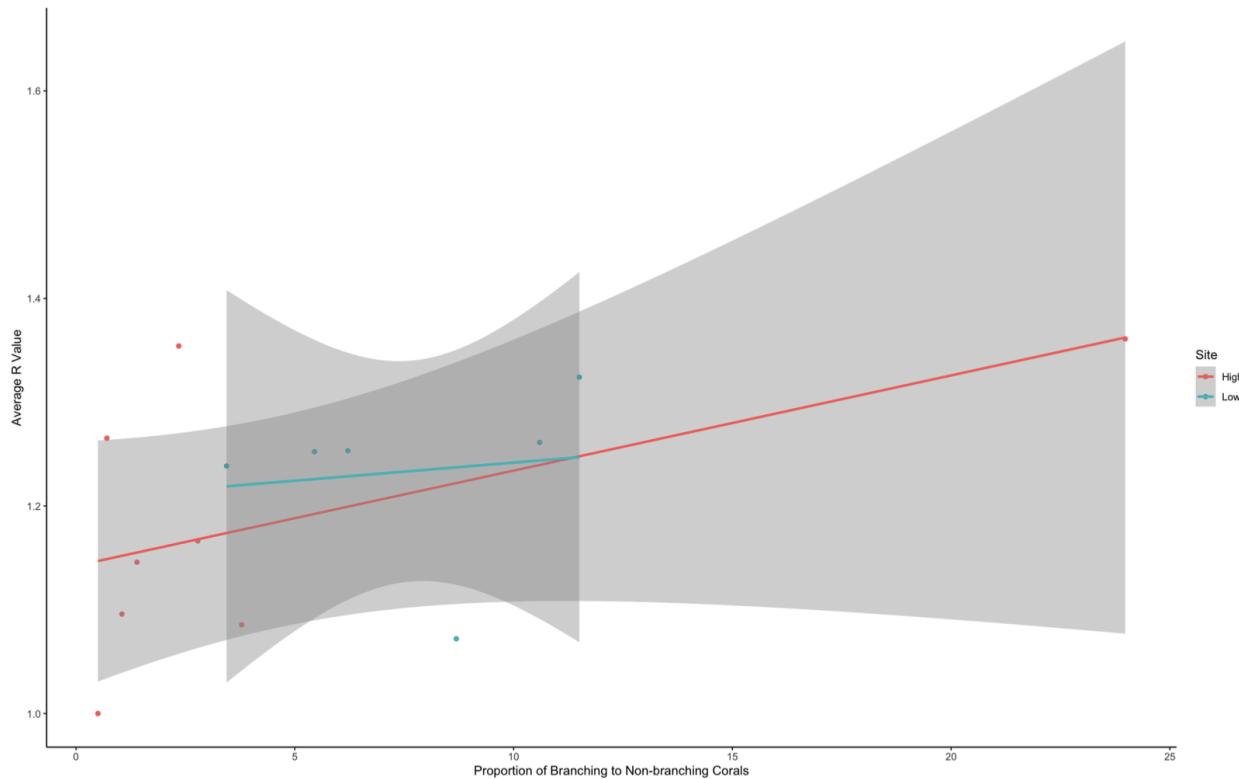


Figure 5: This scatter plot shows the relationship between the proportion of branching to non-branching corals and the average of the two R values obtained for each transect. The red and blue lines are the fitted trendlines for the high and low wave energy site values, respectively. The shaded areas around the trend lines indicate the confidence intervals. The “Average R Value” refers to the average of the two R values obtained at each transect.

Discussion

After a comprehensive analysis utilizing both imaging and statistical methods of the reef rugosity and coral communities around Heron Island, our findings indicate variations in reef rugosity between the high and low wave energy sides of the island. Additionally, we identified correlations between reef rugosity and benthic coral composition.

Our data confirms that reef rugosity varies between the high and low wave energy sides of the island, though not as significantly as anticipated, as indicated by the statistically non-significant p-value. The higher rugosity observed on the low wave energy side was expected, given that the southern end of the island is more sheltered from winds, storms, and other disturbances. This protection enables corals in these areas to develop greater structural

complexity (Graham & Nash, 2012). The low and high wave energy sites yielded average rugosity values of 1.18 and 1.23, respectively (Fig. 2), which can be compared to the average rugosity values of 1.15 (south side) and 1.35 (north side) obtained from a previous study conducted on Heron Island (Brown et al., 2021).

The high percentage of dead coral with algae as benthic cover at both sites (Fig. 3) is consistent with recent and frequent disturbances brought on by climate change, such as bleaching events (Done et al., 2007). Dead coral can significantly contribute to rugosity by retaining complex topography and dimensions, sometimes better than live or non-coral substrate (Engleman et al., 2023), which could have impacted the variations in rugosity values between the sites. On the high wave energy site, sand made up almost as much of the benthic cover as dead coral with algae, whereas dead coral with algae was significantly more prevalent than sand on the low wave energy site (Fig. 3). This indicates that more frequent disturbances from waves and wind on the high energy side may be preventing coral colonies from establishing, thus impacting carbonate budgets (Mallela, 2018).

Branching coral was the dominant live coral morphology at both sites, although the low wave energy site had a significantly higher benthic composition of branching coral than the high wave energy site (Fig. 4). Branching corals have been shown to have the highest fractal dimensions compared to other coral morphologies (Zawada et al., 2019), explaining the higher rugosity value on the low wave energy site. This demonstrates how the proportion of certain coral morphologies influences rugosity and, consequently, carbonate budgets (Mallela, 2018).

The positive correlation between the proportion of branching to non-branching corals and average R values for the high wave energy site (Fig. 5) highlight the relationship between branching coral morphologies and rugosity. Branching coral populations are less established on the high wave energy site due to wave and wind influences, so increasing the amount of branching coral positively impacts rugosity. On the other hand, since branching coral populations are better established on the low wave energy site, increasing the amount of branching coral does not significantly impact rugosity. This finding suggests that while coral composition does affect rugosity to some extent, the strength and nature of this relationship can vary depending on environmental conditions.

Our findings are crucial for understanding how environmental conditions and specific coral species contribute to reef structural complexity and carbonate budgets. In light of recent

bleaching events on Heron Island (Fordyce et al., 2021), this study is particularly valuable for monitoring changes in the reef's structural complexity. Given that climate change heightens the exposure and vulnerability of corals, with branching corals being particularly at risk (McClanahan, 2022), this research can inform future conservation efforts aimed at prioritizing and protecting these vulnerable species. Branching corals, known for their rich biodiversity and contributions to reef health (Muir & Pichon, 2019), underscore the urgency of protective measures. Furthermore, additional research is needed to investigate how other coral morphologies contribute to reef structural complexity, which will also aid in developing comprehensive conservation strategies.

Sources of Error

In our study, several factors introduced potential errors into our data. Inconsistent distances of photos from corals across transects and challenging currents impacted measurement and analysis accuracy. Limited time led to conducting only five transects in a day on the high wave energy site, potentially affecting data reliability due to shifting tides that impacted rubble placement and sand dispersal. Breakage of beads on the rugosity chain necessitated remeasurement, while subjective coral morphology identification introduced biases. To improve future experiments, we suggest incorporating three-dimensional rugosity measurements and minimizing subjective biases through standardized protocols.

Acknowledgements

I extend my deepest respect and recognition to the First Nations People of the Sea Country, where this study was conducted. I acknowledge the Traditional Owners of the land on which I conducted this experiment, and would like to pay my respects to Elders past and present. I'm grateful for the help and continued support I received from my group members, tutors, and professor, Nicola Browne.

References

- Alvarez-Filip, L., Dulvy, N.K., Gill, J.A., Côté, I.M. and Watkinson, A.R., 2009. Flattening of Caribbean coral reefs: region-wide declines in architectural complexity. Proceedings of the Royal Society B: Biological Sciences, 276(1669), pp.3019-3025.

Brown, K.T., Bender-Champ, D., Achlatis, M., van Der Zande, R.M., Kubicek, A., Martin, S.B., Castro-Sanguino, C., Dove, S.G. and Hoegh-Guldberg, O., 2021. Habitat-specific biogenic production and erosion influences net framework and sediment coral reef carbonate budgets. *Limnology and Oceanography*, 66(2), pp.349-365.

Connolly, S.R. and Baird, A.H., 2010. Estimating dispersal potential for marine larvae: dynamic models applied to scleractinian corals. *Ecology*, 91(12), pp.3572-3583.

Cornwall, C.E., Carlot, J., Branson, O., Courtney, T.A., Harvey, B.P., Perry, C.T., Andersson, A.J., Diaz-Pulido, G., Johnson, M.D., Kennedy, E. and Krieger, E.C., 2023. Crustose coralline algae can contribute more than corals to coral reef carbonate production. *Communications Earth & Environment*, 4(1), p.105.

Cornwall, C.E., Comeau, S., Kornder, N.A., Perry, C.T., van Hooidonk, R., DeCarlo, T.M., Pratchett, M.S., Anderson, K.D., Browne, N., Carpenter, R. and Diaz-Pulido, G., 2021. Global declines in coral reef calcium carbonate production under ocean acidification and warming. *Proceedings of the National Academy of Sciences*, 118(21), p.e2015265118.

Dee, S., Cuttler, M., O'Leary, M., Hacker, J. and Browne, N., 2020. The complexity of calculating an accurate carbonate budget. *Coral Reefs*, 39(6), pp.1525-1534.

De'Ath, G., Fabricius, K.E., Sweatman, H. and Puotinen, M., 2012. The 27-year decline of coral cover on the Great Barrier Reef and its causes. *Proceedings of the National Academy of Sciences*, 109(44), pp.17995-17999.

Done, T., Turak, E., Wakeford, M., DeVantier, L., McDonald, A. and Fisk, D., 2007. Decadal changes in turbid-water coral communities at Pandora Reef: loss of resilience or too soon to tell?. *Coral reefs*, 26, pp.789-805.

Dustan, P., Doherty, O. and Pardede, S., 2013. Digital reef rugosity estimates coral reef habitat complexity. *PloS one*, 8(2), p.e57386.

Engleman, A., Cox, K. and Brooke, S., 2023. Dead but not forgotten: complexity of *Acropora palmata* colonies increases with greater composition of dead coral. *PeerJ*, 11, p.e16101.

Fordyce, A.J., Ainsworth, T.D., Page, C.E., Bergman, J.L., Lantz, C.A. and Leggat, W., 2021. Microalgal blooms in the skeletons of bleached corals during the 2020 bleaching event on Heron Island, Australia. *Marine and Freshwater Research*, 72(11), pp.1689-1694.

Graham, N.A. and Nash, K.L., 2013. The importance of structural complexity in coral reef ecosystems. *Coral reefs*, 32, pp.315-326.

Gratwicke, B. and Speight, M.R., 2005. The relationship between fish species richness, abundance and habitat complexity in a range of shallow tropical marine habitats. *Journal of fish biology*, 66(3), pp.650-667.

Hay, J.E., 2013. Small island developing states: coastal systems, global change and sustainability. *Sustainability Science*, 8, pp.309-326.

Hoegh-Guldberg, O., Poloczanska, E.S., Skirving, W. and Dove, S., 2017. Coral reef ecosystems under climate change and ocean acidification. *Frontiers in Marine Science*, 4, p.158.

Hughes, T.P., Kerry, J.T., Álvarez-Noriega, M., Álvarez-Romero, J.G., Anderson, K.D., Baird, A.H., Babcock, R.C., Beger, M., Bellwood, D.R., Berkelmans, R. and Bridge, T.C., 2017. Global warming and recurrent mass bleaching of corals. *Nature*, 543(7645), pp.373-377.

Kinch, J., Purcell, S., Uthicke, S. and Friedman, K., 2008. Population status, fisheries and trade of sea cucumbers in the Western Central Pacific. *Sea cucumbers. A global review of fisheries and trade*. FAO Fisheries and Aquaculture Technical Paper, 516, pp.7-55.

Kohler, K.E. and S.M. Gill, 2006. Coral Point Count with Excel extensions (CPCE): A Visual Basic program for the determination of coral and substrate coverage using random point count methodology. *Computers and Geosciences*, 32(9), pp.1259-1269, DOI:10.1016/j.cageo.2005.11.009.

Mallela, J., 2018. The influence of micro-topography and external bioerosion on coral-reef-building organisms: recruitment, community composition and carbonate production over time. *Coral Reefs*, 37(1), pp.227-237.

McClanahan, T.R., 2022. Coral responses to climate change exposure. *Environmental Research Letters*, 17(7), p.073001.

Muir, P.R. and Pichon, M., 2019. Biodiversity of reef-building, scleractinian corals. *Mesophotic coral ecosystems*, pp.589-620.

Osorio-Cano, J.D., Alcérreca-Huerta, J.C., Mariño-Tapia, I., Osorio, A.F., Acevedo-Ramírez, C., Enriquez, C., Costa, M., Pereira, P., Mendoza, E., Escudero, M. and Astorga-Moar, A., 2019. Effects of roughness loss on reef hydrodynamics and coastal protection: approaches in Latin America. *Estuaries and coasts*, 42, pp.1742-1760.

Sweatman, H., Delean, S. and Syms, C., 2011. Assessing loss of coral cover on Australia's Great Barrier Reef over two decades, with implications for longer-term trends. *Coral reefs*, 30, pp.521-531.

Zawada, K.J., Dornelas, M. and Madin, J.S., 2019. Quantifying coral morphology. *Coral Reefs*, 38(6), pp.1281-1292.