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PATTERNS OF RUGOSITY ON CORAL REEFS AROUND LAE-LAE, SAMALONA, BARRANG LOMPO AND KAPOPOSANG ISLANDS

A. M. AGUNG PRATAMA ABDURRACHMAN[1], ESTRADIVARI[2,3], GUNAWAN SYAFRUDDIN[1], JAMALUDDIN JOMPA[4], SEBASTIAN C. A. FERSE[2,3] AND ROHANI AMBO-RAPPE[4]*

[1]Marine Science Study Program, Faculty of Marine Science and Fisheries, Hasanuddin University, 90245 Makassar, South Sulawesi, Indonesia. [2]Department of Ecology, Leibniz Centre for Tropical Marine Research (ZMT), 28359 Bremen, Germany. [3]Department of Marine Ecology, Faculty of Biology and Chemistry, University of Bremen, 28359 Bremen, Germany. [4]Marine Science Department, Faculty of Marine Science and Fisheries, Hasanuddin University, 90245 Makassar, South Sulawesi, Indonesia.

**Corresponding author: rohani.amborappe@mar-sci.unhas.ac.id*
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Abstract: Corals have many growth forms, creating many nooks and crannies which provide specialized places for marine organisms to shelter, live, and breed. Reef rugosity is a simple surface roughness measurement; a high rugosity value will support fish communities. This research measured the differences in reef rugosities in four islands in Spermonde Archipelago, Indonesia based on their distance from the mainland and the reef depth. Observation sites were Lae-Lae (LL; inshore zone), Samalona and Barrang Lompo (SA and BL; inner mid-shelf zone), and Kapoposang (KP; outer zone). At each station, rugosity was measured on the reef slope in two depth zones: 3-5 m shallow and 6-10 m deep using chains. The rugosity index at shallow reefs was increasing towards outer zones (Lae-Lae: 0.143 ± 0.015; Kapoposang: 0.655 ± 0.133), which means shallow reefs further from the Sulawesi mainland have more complex structures. There are differences between sites (P-value: 0.0000641) namely LL-BL sites (0.0001675), SA-BL (0.0001873), LL-KP (0.0016070), and SA-KP (0.0018514). At deeper depths, the rugosity was varied with Kapoposang having a higher value (0.451 ± 0.207). The inshore-offshore rugosity patterns in the four sampled islands are likely linked to anthropogenic pressures from the mainland of Sulawesi.

Keywords: Coral reefs, marine biota, reef fish, rugosity.

Introduction

A threatened coral reef ecosystem requires active attention to rehabilitate its physical, structural, and biological functions (Williams *et al*., 2019; Idris *et al*., 2020). The most spectacular, diverse, and economically valuable marine ecosystems are coral reefs, which are home to a diverse range of organisms (Nugraha *et al*., 2020; El-Naggar, 2021), providing living space or habitats for both benthic and pelagic marine biota (Levin *et al.,* 2016). Habitat diversity also makes a substantial contribution to the high biodiversity in coral reef ecosystems. From a geomorphological point of view, coral reefs are generally divided into three zones: The reef flat, reef crest, and reef slope (Blanchon, 2011). Rugosity is a simple way to represent the form and structural complexity of any given seabed cover, including coral reefs. In general, coral reef habitats with branching coral lifeforms will have a higher rugosity (structural complexity) than that covered with encrusting corals (Hill & Wilkinson, 2004). Coral reef ecosystems near the mainland will have a lower value (Teichberg *et al.,* 2018). Rugosity varies within and among the three reef zones, depending on the structural properties of the coral colonies growing in each zone. There is a strong relationship between rugosity and fish density and biomass (Graham & Nash, 2013). Zone characteristics and depth will affect abundance and diversity, in slope zones it is usually associated with abundant and diverse reef fish communities (Darling *et al*., 2017).

Coral reefs support more than 1/3 of (Darling *et al*., 2017) marine species as well as provide coastal protection and support the welfare, food, and economic security of millions of people (Hoegh-Guldberg *et al.*, 2019). Physical, biological, and anthropogenic processes affect the condition of coral reefs (Cinner *et al.*, 2016; Hoegh-Guldberg *et al.*, 2019). There is an ongoing increase in the degradation of coral reef conditions due to human activities, with deleterious effects on the biotic communities associated with coral reefs as well as on human beings (Burke *et al*., 2011; Wilkinson, 2020). Overfishing using environmentally unfriendly methods is one of the behaviours that change the reef condition, including the percentage of coral cover and the rugosity of the coral reefs used as fishing grounds (Kleypas & Eakin, 2007; Foo *et al.*, 2021).

The Spermonde Archipelago in South Sulawesi, Indonesia comprises 120 small, coral-fringed islands (Kench & Mann, 2017) which have been divided into four zones based on the distribution of coral reefs and the distance from the Sulawesi mainland: The inner zone, middle inner zone, middle outer zone, and outer zone (Troelstra *et al*., 1996; Renema & Troelstra, 2001; Janen *et al.,* 2017). This zonation of the Spermonde Archipelago has been based on the premise that distance from the mainland is a proxy for the intensity of anthropogenic pressures and terrestrial influences, which are generally higher closer to the mainland coast, with multiple indicators that water quality is better further offshore. A study by Teichberg *et al.* (2018) shows that coral rugosity between 2012 and 2014 in the Spermonde Archipelago followed this pattern, with a more complex benthic structure found further from the mainland of Sulawesi.

Anthropogenic pressures and terrestrial influences have remained high on South Sulawesi's mainland coast over the last decade. The construction of the Center of Indonesia, a soon-to-be Makassar landmark built on a reclamation site, added to the already high pressures on coral reefs. The objective of this study was to measure the rugosity of coral reefs in different zones and depths in the Spermonde Archipelago, South Sulawesi, Indonesia. The study is intended to provide up-to-date information on the structural complexity of coral reef ecosystems and qualitatively observe its changes over time.

Materials and Methods

This study was conducted around four islands in three zones of the Spermonde Archipelago (Figure 1): Lae-Lae (inner zone), Samalona and Barrang Lompo (middle inner zone), and Kapoposang (outer zone). Lae-Lae is an island in the inner zone while Samalona is an island in the middle inner zone. Barrang Lompo, in the middle inner zone of the Spermonde Archipelago has a very high human population density, with the majority of the inhabitants making a living from fisheries, including the collection of sea cucumbers. This island is also the administrative capital of Kepulauan Sangkarang District and Hasanuddin University has a marine station and hatchery, which are used for research and as a centre for student fieldwork. Kapoposang is one of the outermost islands of the Spermonde Archipelago (outer zone); this island has been designated as a priority area for the conservation of marine flora and fauna under the Decree of the Minister for Marine Affairs and Fisheries on the Management and Zonation Plan (2014-2034) for the Kapoposang Islands and Surrounding Waters Recreational Park in South Sulawesi Province. However, fishermen coming to Kapoposang Island from outside the park often still fish using explosives.

Data were collected from July to September 2021 using a transect method. The transects were laid on coral reefs off the north-western side of each island (except Kapoposang, where the northwest consists of a steep drop-off starting at around 3 m water depth and the north-eastern side was used instead) so that the sites were facing away from the Sulawesi mainland coast. The Spermonde Archipelago is influenced by the Indonesian Throughflow, with water masses moving from north to south; this influence is especially strong along the western side of the archipelago and on each island. Based on the results of a study of the destructive fishing

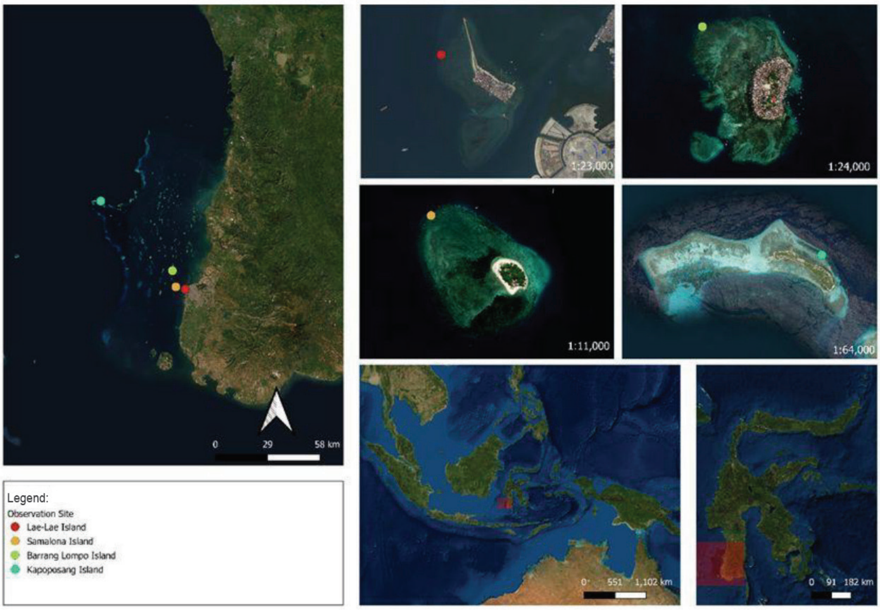

Figure 1: Map showing the coral reef rugosity observation sites in the Spermonde Archipelago

practices of fishermen from the Spermonde islands, the destructive activity was conducted in some areas of Spermonde such as in the outer area of Spermonde, the middle area of Spermonde, TWAL Kapoposang, Tanakeke Islands, Langkai, and Lanyukang Islands (DFW, 2003).

Rugosity was measured on the reef slope zone at two depths: 3-5 m and 6-10 m below the sea surface. A chain 22.4 m long was laid in a straight line following the contours of the coral reef surface and the distance between the ends of the chain was measured with a tape measure (Figure 2). Rugosity measurements were made along 50 m line transects following a method adapted from the Chain Intercept Transect (CIT) method for evaluating coral reef rugosity (Hill & Wilkinson, 2004). On each site, there were three replicates with a distance of 10 m between the transects. The same observer also noted the most dominant benthic group and coral lifeform in each transect qualitatively.

The rugosity index (C) was calculated as $C = 1 - d/l$, where d is the horizontal distance between the ends of the chain following the coral reef surface and l is the length of the chain when fully extended in a straight line (22.4 m) as a divider of the chain length when stretched on the surface of coral reefs (Risk, 1972; Aronson & Precht, 1995; Knudby *et al.,* 2007). The coral reef rugosity (C) values were then grouped into four categories: (1) Low rugosity, $C < 0.25$, (2) fair rugosity, $C = 0.25\text{-}0.50$, (3) good rugosity, $C = 0.51\text{-}0.75$, and (4) high rugosity, $C > 0.75$ (Aronson & Precht, 1995). Data were analyzed using the One Way-ANOVA parametric test. If the results of the analysis show a significant difference ($p < 0.05$), then a post hoc test (pairwise comparison) will be carried out using the Tukey test to see which groups are significantly different.

Results and Discussion

Rugosity varied greatly between sites and depths. At shallow reefs (3-5 m depth), Figure 3 shows that the mean coral reef rugosity was 0.143 ± 0.015 at the Lae-Lae Island site, in the low category. The mean rugosity was in the high category at Barrang Lompo Island (0.854 ± 0.083). There is a clear inshore-offshore coral rugosity gradient (Figure 3), with islands closer to the mainland having almost flat structural

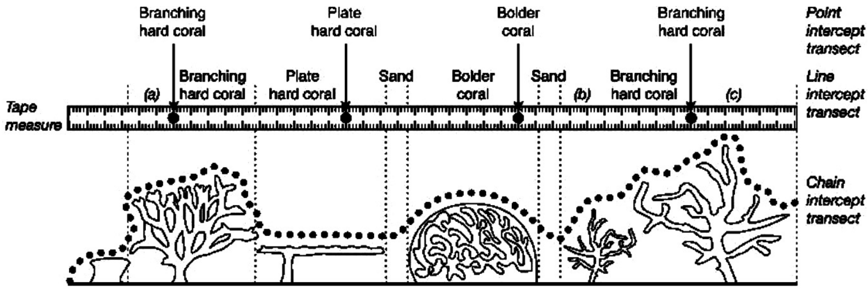

Figure 2: Sketch illustrating the rugosity measurement method using a chain (Hill & Wilkinson, 2004)

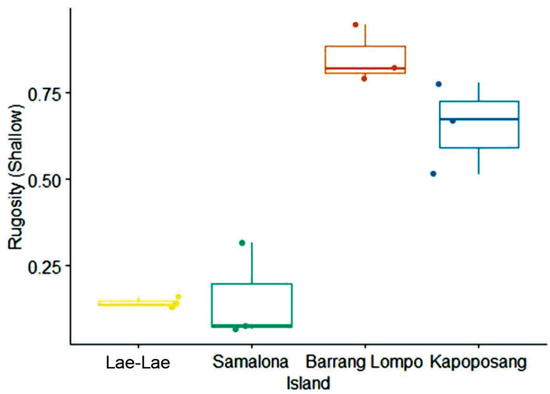

Figure 3: Mean coral reef rugosity at 3-5 m depth at the study sites around four islands in the Spermonde Archipelago. Error bars indicate the standard error: Lae-Lae = 0.083, Samalona = 0.133, Barrang Lompo = 0.015, and Kapoposang = 0.142

complexity and islands further from the mainland having a more complex 3D benthic structure.

At the 6-10 m depth, turbidity was very high in the waters around Lae-Lae Island, with low visibility, so, it was not possible to collect rugosity data. At the Samalona Island site, the coral reef rugosity was fair (0.215 ± 0.029) while rugosity was high at both the Barrang Lompo Island (0.349 ± 0.101 and Kapoposang Island (0.451 ± 0.207) sites (Figure 4).

Differences in rugosity can arise due to differences in coral reef development and growth, oceanographic conditions, and external disturbances due to human activities (Kench & Mann, 2017; Foo *et al.*, 2021). As the island nearest to the Sulawesi mainland, Lae-Lae is affected by waste, nutrients, and sediments from land-based anthropogenic activities, particularly from Makassar, the capital city of South Sulawesi Province. The decrease in environmental parameters (Chl-a, POC, and turbidity) is clearly visible closer to the shoreline (Sawall *et al.*, 2011). The decreased water quality badly affected the benthic community, including coral reefs close to the mainland of the Spermonde (Plass-Johnson *et al.*, 2018). The coastal reclamation being undertaken as part of the development of Makassar as a waterfront city is one source of sedimentation which has affected coral growth on reefs around the small islands nearby (Mosriula *et al.,* 2018). The influence of coastal cities (Teichberg *et al.,* 2018) and the disposal of domestic waste and sewage into marine waters can lead to the degradation of coral reef ecosystems (Lachs *et al.*, 2019). The low rugosity on coral reefs around Lae-Lae Island can be seen as an indicator of the high level of degradation experienced by these reefs,

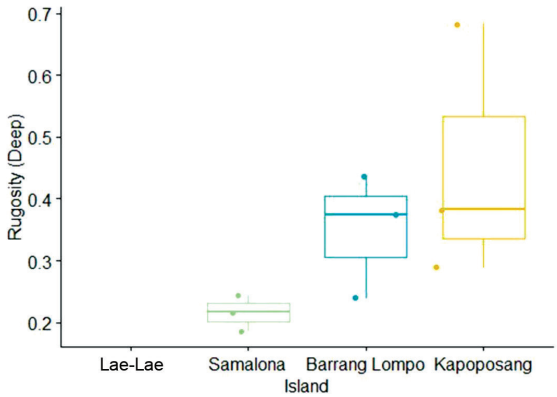

Figure 4: Mean coral reef rugosity at 6-10 m depth at the study sites around four islands in the Spermonde Archipelago. Error bars indicate the standard error: Samalona = 0.029, Barrang Lompo = 0.101, and Kapoposang = 0.207

where anthropogenic factors associated with the proximity of the island to Makassar City on the nearby mainland are thought to be the principal cause of this degradation. Other studies on the coral reefs of the Spermonde Archipelago report a negative correlation between live coral cover and distance from the Makassar City mainland (Faizal *et al.*, 2020). Conversely, live coral cover has been found to increase further from the mainland (Teichberg *et al.*, 2018).

Samalona is an island with a relatively sparse human population; however, this island is used as a tourism destination, especially for day trips and as a diving site. Tourist data released by the Makassar City Government show that the number of visitors to Samalona Island was 20,000 in 2019 (Statistics of Makassar, 2021). Tourism that is not environmentally friendly will reduce reef cover (Parenden *et al.*, 2021). Recreational activities in the marine environment such as snorkelling and scuba diving can result in physical damage, including direct physical contact between visitors and the coral reef (Hasler & Ott, 2008). Anchor damage is a major concern, leading to an ongoing decline in coral reef conditions; in particular, dive boats often anchor in the coral reef zone as there are no permanent moorings at dive spots (Siriwong *et al.*, 2018). The contribution of tourism that is not environmentally friendly will reduce the condition of reef cover (Parenden *et al.*, 2021). This study revealed coral reef rugosity at Samalona Island between the two depth zones of 3-5 m shallow and 6-10 m deep. Rugosity levels were low on the coral reefs at 3-5 m depth but even lower rugosity value was measured at 6-10 m. The lower rugosity at the deeper depths where most scuba diving activities take place is an indication that dive tourism is one of the causes of coral reef degradation at this site.

The majority of people living on Barrang Lompo Island are dependent on fishing for their livelihoods, with many men working on sea cucumber fishing boats or trawlers. Barrang Lompo is a major centre for the sea cucumber or *teripang* fishery and trade (Schwerdtner Máñez & Ferse, 2010). Sea cucumbers are the main target of fishing boats originating from Barrang Lompo Island but some divers accidentally find and take other products (lobsters and some gastropods) for additional income (Yusuf *et al.*, 2017). Sea cucumber fishing grounds are far from Barrang Lompo Island, so, this fishery does not have a major direct impact on the waters and coral reefs around the island. However, fishermen on Barrang Lompo Island have been intensely fishing using bombs since 1990 (Zaelany, 2019). Moreover, this densely populated island is the Sangkarrang District capital and has accumulated a huge number of marine debris (Sur *et al.*, 2018). Therefore, this island has been the site of a waste management programme involving the local community and building awareness and understanding regarding the impacts of waste on the health of the marine environment. From this study, we found the coral rugosity was higher at the 3-5 m depth than at the 6-10 m depth off the island. There were large colonies of massive corals at 3-5 m depth which likely raised the rugosity value (Andi M.A. Pratama, pers. observation).

Kapoposang Island is one of the outermost islands in the Spermonde Archipelago, in the zone furthest offshore. Due to the distance from the Sulawesi mainland, there is little impact from the input of terrestrial waste, with clear waters conducive to coral reef ecosystems. Offshore locations and good coral reef conditions have a positive influence on rugosity (Smallhorn-West *et al.,* 2020). These factors likely explain the high rugosity at the Kapoposang Island site. At the deeper (3-5 m) transect, the coral community was dominated by branching lifeforms (Andi M. A. Pratama, pers. observation), resulting in a higher rugosity than the shallower (6-10 m) transect. Branching corals tend to have a high complexity of form (Knudby & LeDrew, 2007). The waters around Kapoposang Island have been designated as a Marine Tourism Park, with four zones: Core, sustainable fisheries, utilization, and rehabilitation zones (Arifin *et al.*, 2019). The establishment of marine protected areas is a strategy to conserve and improve coral reef health (Hargreaves-Allen *et al.*, 2017). The zonation plan limits the activities that can be carried out in each zone, including fishing and can thereby directly reduce the damage to the coral reef ecosystem. Since the Park was declared, the coral reef condition has not declined further and indeed, there has been some improvement in the core zone; however, the results have not been as good as expected, with indications that the park management is still far from optimal (Arifin *et al.*, 2020). To increase live coral cover, coral transplantation programmes have been implemented around Kapoposang Island (Ulfah *et al.*, 2020). In turn, an increase in hard coral cover should lead to an increase in rugosity (Bozec *et al.*, 2015).

Global climate change is affecting and will have an increasing effect on the condition of coral reef ecosystems. Rising seawater temperatures, ocean acidification, and increased severity and/or frequency of tropical storms all cause damage to coral reef ecosystems (Harley *et al.*, 2006; Hoegh-Guldberg, 2011) and can reduce the rugosity of coral reefs (Bozec *et al.*, 2015). Significant damage to coral reefs in the Spermonde Archipelago due to elevated seawater temperatures was recorded in June-August 2016 (Mosriula *et al.*, 2018). Other causes of damage to coral reefs in the Spermonde Archipelago include the use of explosives to catch fish and ship grounding (Williams *et al.*, 2019). Storms can significantly reduce coral reef cover, depending on the intensity of the storm that occurs (Gardner *et al.*, 2005). In addition, waste disposal and marine debris are an ongoing problem for the people living in the Spermonde Archipelago, affecting both the biotic and abiotic components of the marine environment (Sur *et al.*, 2018; Sawalman *et al.*, 2021).

Coral reef complexity is highly dependent on the amount of hard substrate (Gratwicke & Speight, 2005). Complex formations with high rugosity will provide many niches and refuges for reef fishes. Rugosity is an important ecological variable (Knudby & LeDrew, 2007). Rugosity levels and trends ensure the availability of habitat for coral reef-associated flora and fauna in the future (Bozec *et al.,* 2015). A decline in rugosity will have an impact on fish abundance and the biodiversity of coral reef ecosystems (Alvarez-Filip *et al.*, 2011; González-Rivero *et al.*, 2017). High rugosity will also provide living spaces for microscopic algae, macroalgae, scleractinian corals, gorgonians, sponges, and many other animals (Gratwicke & Speight, 2005). A very strong correlation between coral reef rugosity and the total abundance of corallivorous fishes has been reported (Rafly *et al.*, 2020). Another study found that reef-associated fish density was highest in areas with high rugosity, although density was not correlated with live coral cover (Nugraha *et al.*, 2020). Higher rugosity can have a greater influence on reef fish diversity (Walker *et al.*, 2009) than in areas with generally low rugosity (Gratwicke & Speight, 2005). Nonetheless, rugosity values can be very complex and variable at all spatial scales, so, a single measurement cannot be considered as comprehensive (Knudby & LeDrew, 2007). Additional measurements from different parts of the reefs are thus recommended. Rugosity is only one part of the interconnected habitat, so, it is very important to maintain the condition of the marine environment.

Conclusion

Coral reef rugosity is closely related to the coral reef condition. While coral reefs can become degraded (as reflected in the lower live coral cover) due to natural disasters such as severe storms, tsunamis, and coastal abrasion, the causes of coral reef degradation include many anthropogenic factors including the use of environmentally unfriendly fishing methods, waste disposal, coral and sand mining, and even beach and dive tourism. Coral reef rugosity influences the abundance of coral reef-associated fishes. In this study, the rugosity was lower in coral reefs closer to the Sulawesi mainland coast than those further offshore and the rugosity values reflected the coral reef condition. These data support the assumption that anthropogenic pressures and climate change impacts marine ecosystems, especially coral reefs, and will result in reduced rugosity that will have a deleterious impact on coral reef-associated marine organisms. Therefore, rugosity should be considered a key parameter and it is important to include rugosity when assessing the health of coral reef ecosystems.

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Conflict of Interest Statement

The authors declare that they have no conflict of interest.

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