Coral reef ecosystems condition prediction after tsunami based on previous reef fish community structure and benthic coverage surveillance on Sumur, Banten

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Abstract. Patterns of community structure within coral reefs ecosystems are strongly influenced by a catastrophe such as a tsunami. Sumur is one of the coastal regions affected the most by the Banten Tsunami in December 2018. This research aims to predict coral reef ecosystem conditions after a tsunami based on the reef fish community structure and benthic coverage in the previous month. The research was conducted on every island around Sumur coastal region. Reef fish specimens were sampled using underwater visual census, and benthic coverage was taken with quadrats for Coral Point Count Estimation (CPCe). Overall coral condition assessed by conservation value determined through coral morphology. The highest coral coverage was found in Sumur, Southwest Oar, and North Badul. Nearly all sites have a high diversity reef fish community, with the highest abundance and species richness found in West Umang and North Badul. Badul island, Mangir island, and Cigorondong were categorized as the locations with coral reef ecosystems with the highest stress-tolerators. Most areas with this high stress-tolerator are predominated by coral massive and sub-massive and have higher endurance than other sites. Post-catastrophe, reef fishes will shift to the sites where most coral reef-building has survived, especially reef fishes with territorial behaviour.

Keywords: coral lifeform; coral reef ecosystems; reef fish behavior; tsunami catastrophe

1. Introduction
Coral reefs are essential natural ecosystems on earth, home to thousands of unique and valuable plants and animals [1–4]. More than a quarter of marine species rely heavily on healthy coral reefs [5–7].
Coral reefs are the primary source of food and income, also resources for millions of people through their role in tourism, fisheries, and producing main chemical compounds for medicine [8–10]. Coral reefs provide natural wave barriers to protect coasts and coastlines from storms, tsunamis, and floods through reduced wave action [11–13]. Degradation of the condition of coral reefs in some parts of Indonesia has occurred due to human activities and natural disasters such as coral bleaching, hurricanes, and tsunamis [14–16]. It is feared that the coral reef ecosystem degradation will reduce the diversity of all species of organisms that depend on it.

Sumur was one of the coastal districts which still preserve their ecological richness of kind, especially for the coral reef ecosystems. Sumur represented the utilization area, with most of the utilization comes in the form of tourism and small-scale fisheries activities. Umang, Oar, and Mangir Island are the islands that are mostly dominated by tourism activities. By using boats, anchors, and less decent dive guides, tourism will expose some leverage to the living organism within the area particularly to slow-moving organisms [34–36]. Good management of the local enforcement and human communities is important to maintain the sustainable coastal ecosystems in the utilization zone [16, 34]. On the other hand, Sumur coastal is mostly influenced by runoff from the river alongside the Sumur coast. Runoff cast away sedimentation that affects the open seas and nearest coastal ecosystems. Sedimentation indirectly impacted coral reefs by blocking the sunlight with roil the water and blocking substrate so that zooplankton could not stick [6, 35–38]. Yet, damage due to natural disasters will have fatal effects on all coastal ecosystems at the time of the incident or after. Coastal areas often experience natural disasters due to various natural processes in the ocean [48]. The vulnerability of coastal areas to natural disasters increases in line with the increasing population concentration, which often makes the coastal areas the center of economic activity and densely populated cities [49]. One of the most frequent disasters is the earthquake, followed by tsunamis that often occur around the Pacific Ocean and the Indian Ocean. Considering the history of its occurrence, the area around the Pacific Ocean and the Indian Ocean, which is also known as the Pacific Ring of Fire, often experience tsunami events [17, 19]. This area is located in a location that is geologically being the most active.

A tsunami is one of the natural disasters that often occur in the Ring of Fire. The area around the Ring of Fire has the potential to experience tectonic and volcanic earthquakes. Both types of the earthquake could lead to a tsunami if the earthquake occurs near the coastal area [17–19]. In December 2004, a tsunami devastated the Aceh coastal area was one of the giant tsunamis in Indonesia territory [18, 20, 21]. The tsunami directly impacted the coastal ecosystem, beaches, low dunes, and wetlands induced ecological breakdown, leading to environmental shifting in each ecosystem. Coral reefs as the first barrier of the coastal zone could have various impacts on the coral reef-building itself [17, 20]. The tsunami could break the reef-building directly with the ram power at the moment of the incident occurred.

The earthquake and tsunami that hit the Sumur area, Banten, in December 2018, caused significant land infrastructure damage. This study explains the condition of the pre-tsunami coral reef ecosystem along the coast of Sumur, Banten, and was compiled to provide an overview of coral reefs state in these waters before the disaster; the condition of each observation location can be estimated after being affected by the tsunami.

2. Material and methods

2.1. Study sites
Five small islands along the Sumur coast were selected as the sampling sites (figure 1). Each island was sampled twice in the opposite direction for data representation. Area of Sumur, Banten is exposed to runoff from several river flows resulting in high turbidity of water near the mainland but suffered the least impact from the tsunami. On the other hand, Badul, Mangir, and Oar Islands are located closest to the tsunami epicenter compared to Sumur and Umang Islands.
2.2. Data collection and data analysis

Coral reef ecosystem observation was conducted in November 2018, exactly one month before the tsunami hit the coast of Sumur, Banten. Coral reefs data were collected using the Underwater Photograph Transect (UPT) method [22]. Genus and lifeform identification used coral identification guideline by English et al. [27] The photos were analyzed using computer software to obtain quantitative data (ImageJ; CPCe; PhotoQuad) [23–26]. Reef fish communities were assessed using Underwater Visual Census (UVCs) [27]. Reef fish species identification used guidelines by Kuiter and Tonozuka [28] and was grouped in 4 classes (herbivorous, coralivorous, carnivorous, planktivorous, and omnivorous) based on the predation type.

A conservation value was built to predict the value of tsunami impact on the coral reef ecosystem in each site [29] by classifying coral reefs based on triangular (ternary) diagrams of hard coral percent coverage composition. Classification of conservation value are categorized as 1) Ruderals (r) which characterized by rapid growth and high fragility, for example, Acropora corals, Heliopora, and Millepora; 2) Competitors (K) are characterized with a more slow coral recruit and grow than Acropora (Non-Acropora like Coral Foliose, Coral Encrusting, and Coral Mushroom); 3) Stress-tolerators (S) characterized by slow growth and are very tolerant of a high level of stress such as high sedimentation or eutrophication, for example, Coral Massive and Coral Sub Massive; 4) Mixed Coral Lifeforms which contained an equal proportion of three classes of coral mentioned before. The conservation class (CC) was divided into four classes that CC 1 was reef area dominated (≥ 50%) by the Stress-tolerators class, CC 2 was dominated with Competitors class, CC 3 was dominated with Ruderals coral, and CC 4 was approximately equal of all coral classes.

![Figure 1. Coral reef ecosystem observation location along Sumur, Banten coast.](image)

Principal Component Analysis (PCA) was built to compare the location, reef fishes, and coral reefs conditions. This analysis aimed to eliminate the main similarities among sites and evaluate the
differences in community structure patterns among observation locations [30, 31]. PCA was calculated to compare observed area with coral lifeform and reef fish trophic level variables. A non-metric multidimensional scaling (nMDS) analysis was calculated based on Bray-Curtis dissimilarity quadratic matrix transformed data. nMDS was used to analyze reef fishes and coral reefs assemblage composition among observation locations based on reef fish trophic level, benthic coverage, and coral lifeform. Quadratic transformation reduces divergence between uncommon and abundant classes by abundant downweighting classes relative to uncommon classes. These analyses were performed in PRIMER-E v.7.0, and a significance level of 0.05 was considered [32, 33].

3. Results

3.1. Coral reefs ecosystem community structure

The average percentage of coverage was 37.60 ± 17.75% (figure 2A). The highest hard coral percentage of coverage was in Sumur (60.07%), and the lowest is Southwest Mangir (4.87%). On the other hand, the average value of abiotic was 35.62 ± 20.37%, and the highest was Southwest Mangir (75.81%), while the lowest was West Oar (12.40%). The average value of dead coral with algae was 16.45 ± 9.62%, and the highest was Southwest Oar (36.47%), while the lowest was West Umang (4.47%). Other components have a low average value, such as dead coral 0.01 ± 0.03%, soft coral 7.97 ± 20.81%, sponges 0.99 ± 1.20%, and other categorize 1.35 ± 2.16%. The status of coral condition was moderate about coral reef damaged criteria. The most dominant lifeform is Coral Massive (CM) (31.83%), and the least lifeform is Acropora Encrusting (ACE)(0.19%) (figure 2B). Acropora Branching (ACB) and Coral Mushroom (CMR) percentages are found to be highest in West Umang (13.70% and 20.54%), while CM is in South Badul (71.14%), Coral Branching (CB) is in North Mangir (44.88%), and Coral Sub-massive (CS) is in Cemara (82.37%). The highest percentage of Acropora Tabulate (ACT) (8.95%) and Coral Foliose (CF) (53.16%) is found in West Sumur. In Northwest Oar, ACE and Coral Encrusting (CE) have the highest percentage (1.29% and 39.29%, respectively), while in Southwest Oar, the highest percentage is found in Coral Heliopora (CHL) (9.45%) and Coral Millepora (CME) (30.99%)

The number of reef fish species is 125 species belonging to 23 families with an abundance reaching 300 ± individuals/250m2 in one location. Pomacentridae is the most frequently found, with 28 species recorded. Furthermore, the family with the most common species is Labridae, with 22 species recorded, followed by the Chaetodontidae family with 19 species recorded. While the Apogonidae, Ephippidae, Gramistidae, Haemulidae, Lethrinidae, Mullidae, Muraenidae, Phempherididae, and Zanclidae Families are one species for each family.

Badul Island is the highest reef fish species and abundance compared to other locations (figure 3). The most common Families at Badul Island are Pomacentridae, i.e., 13 species, 9 species of Chaetodontidae, 7 species of Labridae, and Scaridae for each family. The highest number of reef fish is in Umang Island (199 individuals/250m2 at East Umang and 270 individuals/250m2 at West Umang (figure 5A). The number of species in Umang Island is 13 species of Pomacentridae, 10 species of Labridae, 7 species of Chaetodontidae and Scaridae. Mangir Island has the smallest abundance of reef fish that is only 41 species of reef fish were recorded. Pomacentridae and Chaetodontidae are the most species richness with 8 species of reef fish.

The herbivores reef fish are the highest number of individuals for each location where the number recorded was 608 ± individuals/250m2. South Badul had the highest abundance of herbivore reef fish (106 individuals/250m2), while the Sumur and Southwest Mangir had the lowest abundance of herbivore reef fish (3 individuals/250m2 and 5 individuals/250m2), Carnivorous reef fish were mostly found in North Badul (67 individuals/250m2 and the coast of Cemara (63 individuals/250m2) (figure 4). North Badul Island was the highest planktivore reef fish, namely 125 individuals/250m2, while Sumur was the lowest number of planktivore reef fish (15 individuals/250m2). Despite having a relatively small individual abundance, this fish class is often used as an indicator for assessing coral reef ecosystems' health. North Mangir and North Badul are the highest abundance of corallivore reef.
fish, namely 24 individuals/250m². Southwest Mangir was as the lowest abundance of corallivore reef fish (7 individuals/250m²).

Figure 2. Coral reef condition in Sumur, Banten based on (A) benthic substrate percent coverage and (B) coral morphology percent coverage.

Figure 3. Assessment of (A) abundance and (B) species richness of reef fish assemblages at each observation location.
3.2. Patterns of community structure and conservation value

The best comparison between both variables can be seen in nMDS (figure 5) at a site level, which clearly shows that Sumur sites are separate from the rest of the sites. On the reef-fish trophic classes variable (figure 5A), Sumur and Southwest Mangir are separated from the other sites because Sumur has a low abundance on each trophic class even though Sumur has all five classes at its sites. While Southwest Mangir only has three classes, which more abundant only on omnivore classes. Figure 5B, which is based on coral lifeform, occurred specific agglomeration. West Umang and Cigorondong have proximity on higher coverage of coral foliose and coral massive, which only these two sites that have abundant coral foliose. Cemara and North Mangir are grouped by high coral sub-massive coverage with a lower percentage on other coral lifeforms. North Badul is also included as abundant coral foliose site, but on the other side, North Badul has a general abundance of the other coral lifeform. The similarity between both variables is that Sumur is separated from the other groups because Sumur has a poor condition of the coral reef ecosystem resulting from the mainland's activities.

**Figure 4.** Reef fish abundance based on trophic classes at each observation location.

**Figure 5.** Non-metric multidimensional scaling (nMDS) plot of (A) fish communities based on trophic classes and (B) coral lifeform at every observation location for perceiving pattern of coral reef ecosystems.
Figure 6. Principal Component Analysis (PCA) of the coral reef ecosystem based on trophic classes of reef fish communities compared with coral lifeform at each observation location. The blue arrow signifies the variable which most affected at every quadrant.

Figure 7. The r-K-S ternary diagram of coral morphology at observation location.
Badul Island, East Umang, and Southwest Oar are mostly separated by carnivore trophic class, coral millepora, heliopore, encrusting, and acropora encrusting (figure 6). Coral massive generally affects Cigorondong, Northwest Oar, and Southwest Mangir. Sumur groups themselves by acropora branching, tubulate, and coral foliose variable. Cemara, North Mangir, and West Umang are sites with the most variable that affects them, among them are planktivore, herbivore, omnivore, and corallivore from reef fish trophic classes also coral sub-massive, branching, and mushroom from coral lifeform. CC1 (Badul Island, Cemara, Cigorondong, and Southwest Mangir) and four locations on CC 2 (Umang Island, West Umang, and North Mangir), one location of CC 4 (Southwest Oar). CC1 is mostly dominated by coral massive that have the most robust lifeform than the others. There are no CC 3, which have the faintest condition, which meant that Sumur was adapted to the high exposure of open seas from the Hindia Ocean. Southwest Oar depicts the most diverse coral lifeform with the absence of dominance of one of coral lifeform.

4. Discussion

4.1. Community structure and ecological pattern of coral reef ecosystem

During this study, surveys were conducted, which represented the assessment alongside the coastal coral reef ecosystems of Sumur, Banten. Sumur was one of the coastal which still preserve their ecological richness of kind, especially for the coral reef ecosystems. Sumur represented the utilization area, with most of the utilization comes in the form of tourism and small-scale fisheries activities. Umang, Oar, and Mangir are the islands that are mostly dominated by tourism activities. By using boats, anchors, and less decent dive guides, tourism will expose some leverage to the living organism within the area particularly to slow-moving organisms [34–36]. Good management of the local enforcement and human communities is important to maintain the sustainable coastal ecosystems in the utilization zone [16, 34]. On the other hand, Sumur coastal is mostly influenced by runoff from the river alongside the Sumur coast. Runoff cast away sedimentation that affects the open seas and nearest coastal ecosystems. Sedimentation indirectly impacted coral reefs by blocking the sunlight with roll the water and blocking substrate so that zooplankton could not stick [6, 35–38]. Yet, damage due to natural disasters will have fatal effects on all coastal ecosystems at the time of the incident or after.

This study around Sumur coast has decent coverage of hard coral besides West Umang and Southwest Mangir. West Umang and Southwest Mangir are located imminently to the mainland in which they have high turbidity water. Southwest Mangir is directly affected by runoff from the river. In the rainy season, the impact of runoff will spread farther and broader toward the coral reefs ecosystem [39, 40]. High traffic activity and mooring by tourism boats on West Umang suppressed the coral coverage, which was replaced by soft coral. Soft coral blooming adversely affects hard coral among the same sites. Some research shows that soft-bodied cnidarians or soft corals competitively impair many hard corals on the tropical coral reef ecosystem [41, 42]. Sumur, which is located near the mainland, instead possessed high hard coral coverage. Observation showed the water around Sumur Island has high turbidity with greenish water; however, many old coral colonies grow and adapt to this condition. Coral foliose and massive are mostly found in Sumur, with certain recent coral as encrusting form.

Coral reef ecosystems along Sumur, Banten coastline hold various types of stony coral lifeform. Different coral lifeform can provide various places for fish to itinerate [43, 44]. Reef-building with complex crevice or rugosity will escalated reef fish abundance and species richness [45, 46]. Diverse food availability around the coral reef ecosystem will attract various reef fish for dwelling inside [44, 47]. Badul Island, in both the north and south side, has the highest abundance with various species of reef fish which Badul Islands have high coral massive coverage. Old coral massive with a complex reef-building structure could provide shelter for various reef fish species with a territorial and crepuscular or nocturnal habit, which can not be necessarily provided by the other types of coral morphology. The abundance and species richness of reef fish communities along Sumur, Banten
coastline have the same proportion, indicated the tight possibility of reef fish species dominance. The existence of dominant species in a reef fish community structure can be assessed by the possibility of loss in one of the trophic pyramids. Sumur and Southwest Mangir have the lowest composition of reef fishes contributed by poor water condition, unavailability of various types of food, and low rugosity on both observation locations.

nMDS and PCA denote that several observation locations are grouped by similar coral lifeform and reef fish trophic class composition. The adjacent observation location has a similarity of coral reef ecosystem composition. Cemara and Uman Island are grouped by some of the trophic classes of reef fish. Both locations are on the north side of Sumur, Banten coastline. Umang, Badul, and Oar Island are spatially located far from the mainland than the other islands. Sumur, Mangir, and Cigorondong Island separated from other islands due to their unique and different conditions. Sumur has good coverage of coral coverage but a poor appearance of reef fish. Mangir has an excellent coral reef ecosystem on the open seawhile Mangir facing the mainland is directly impacted by runoff and poor coral reef ecosystem condition. Cigorondong is located far to the south of Sumur, Banten coast and has a poor benthic substrate and reef fish species.

4.2. Ecological shifting of coral reef ecosystems after tsunami
Coastal areas often experience natural disasters due to various natural processes that occur in the ocean [48]. The vulnerability of coastal areas to natural disasters is increasing in line with the increasing population concentration, which often makes the coastal areas the center of economic activity and densely populated cities [49]. One of the most frequent disasters is the earthquake, followed by tsunamis that often occur around the Pacific Ocean and the Indian Ocean. Taking into account the history of its occurrence, the area around the Pacific Ocean and the Indian Ocean, which is also known as the Pacific Ring of Fire, often experience tsunami events [17, 19]. This area is located in a location that is geologically being the most active. Tsunami will directly impact coral reefs as the first barrier of the coastal zone and could have various kinds of impact on the coral reef-building itself [17, 20]. The tsunami could break the reef-building directly with the ram power at the moment of the incident occurred. Post tsunami, coral reefs would impact by rubble coverage and construction or litter debris that could smother the surviving living coral [19, 21]. Post-tsunami, coral reef ecosystems take a long time to recover, leading to coral bleaching and ecological shifting from living coral organisms into algae coverage.

Conservation value along Sumur, Banten coastal area, signifies the coral reef ecosystem in CC 1 and CC 2. Mainly on each observation location, robust lifeforms will be found such as coral massive, sub-massive, foliose, and encrusting. The slow growth of coral reef-building has an advantage in endurance to resist external disturbance, down to a natural disaster level. [29, 50] exhibit that location with tough coral reef-building from class 1 or 2 conservation value could withstand longer against tsunami, from before to after the incident. Nevertheless, the tsunami impact may vary on the location of the tsunami that occurred. Location among CC 2 probably cannot survive the tsunami, so it is possible that ecological shifting happens with the movement of the living organisms to the CC 1 location. The ecological pattern showed that every observation location that is grouped due to closeness to one of the variables has CC 1 sites each of group. After the tsunami, the coral reef ecosystem condition will generally shift to the CC 1 location with a proximate variable to the impacted location. Living organisms that survive after the tsunami in Umang Island will devolve to the closest island or Cemara. The organism that still exists on Mangir or Sumur after the tsunami will shift to Badul Island because both islands have a similar coral reef ecosystem composition. Oar island’s existence organism will be devolved to Cigorondong, located far from the center of the tsunami. Ecological shifting along Sumur, Banten coastline was a form of adaptation for living organisms like reef fish, which could swim away if their territory is damaged due to natural disaster.

Reef fishes can change their territory if the coral reef ecosystem condition is affected by disturbance, both from external or internal [51]. Planktivorous, omnivorous, and herbivorous will survive quickly based on food availability in the environment. However, those groups can not survive
tsunami power because most trophic classes consist of small reef fishes. Carnivorous can last during or after the tsunamis because of their large-sized bodies and food availability in the environment. Coralivorous is the type of reef fish that will be most affected due to their small-sized bodies and difficulty in feeding in the environment after the tsunami. However, the existence of a coral reef ecosystem with CC 1 criteria will improve coral reefs' recovery along the coastline of Sumur, Banten by starting from locations with CC 1 criteria.

Recovery of coral reef ecosystems after catastrophe should be started from the mainlands and human resources. Coastal cleaning up will save the Banten coast beach and will reduce damage to the survived coral reefs. Reconstruction of coral reef ecosystems is the best way to rehabilitate after tsunamis because the coral reef condition will shift to horrible condition. Post tsunami, coral reefs would impact by rubble coverage and construction or litter debris that could smother the surviving living coral [19, 21]. Post-tsunami, coral reef ecosystems take a long time to recover, leading to coral bleaching and ecological shifting from living coral organisms into algae coverage.

5. Conclusion

Sumur, Banten coastal zone was dominated with robust coral reef-building from coral massive and sub-massive, which can survive tsunami and impact catastrophe. Most living organisms that could move away from the decayed coral reef ecosystem will shift into CC 1 categorized coral reef location. Coral reefs will change to rubble, algae, and litter debris coverage while reef fishes will change to large-bodied size in the ecosystems. It is necessary to rehabilitate and reconstructed the coral reef ecosystem and debris from the mainlands.

My suggestion: This study explains that the lifeform of massive and submassive coral can recover and defend by the tsunami. Moreover, slow coral growth and recruitment is a natural process of restoring benthic structures on the coast. On the other hand, this study proves that coral’s fast growth does not survive the high stresses and pressures. The recovery time, recruitment, and restoration of the coral’s benthic structure after the tsunami would be future research to understand the level of post-disaster recovery.

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