# The Ecological Resilience of Coral Reefs in Pari Island, Jakarta Province

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**Abstract.** Pari Island located at the Southern part of Thousand Islands Regency in the province of Jakarta, that has experienced environmental damage due to human activities. The objective of this study is to analyse the resilience of the coral reefs in Pari Island. The research was conducted over a period of 8 months, from June 2016 to January 2017. The primary data collection process entailed the utilisation of the LIT (line intercept transect) method for the observation of coral reefs. Secondary data were collected from literature studies related to the environmental conditions. The findings of the study indicated that the coral reef coverage on Pari Island displayed moderate to poor condition. The coral mortality index exhibited a relatively high range, from 0.56 to 0.88. Coral recruitment was observed to be low in the coral reefs of Pari Island. The Porites genus was a dominant feature of the marine ecosystem on Pari Island. In general, the resilience of the coral reefs in Pari Island was moderate to poor. The resistant coral genus was the primary parameter used to determine the resilience of the coral reefs on Pari Island. The coral reefs on Pari Island were classified as part of the resistant category.

## 1 Introduction

The continued existence of coral reefs is threatened by a range of impacts resulting from global climate change and human activity. Coral reefs are highly sensitive to temperature alterations. A 2°C increment in water temperature can precipitate mass mortality among coral reefs [1]. As posited by Trégarot *et al.,* the deterioration of coral reefs can be attributed to three primary factors: global warming, natural disasters, and human activity [2]. However, it is human activity that exerts the most significant impact on the health of these ecosystems.

The natural response of coral reefs to environmental changes and stresses is to survive and demonstrate signs of recovery until a stable community is re-established following damage [3]. The capacity of corals to withstand environmental stress is defined as resilience. According to le Polain de Waroux *et al*, resilience can be conceptualised as the extent of disturbance that can be tolerated before the system undergoes a structural change, whereby the variables and processes that regulate its behaviour are altered [4].

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Pari Island is situated in the northern region of Jakarta Bay. The high level of human activity in the vicinity of Jakarta and greater as well as in Pari Island has the potential to impact the condition of the surrounding marine environment, including the coral reefs. The Jakarta Bay estuary is subject to significant inputs from a multitude of sources, including domestic, industrial, and agricultural activities within the Jakarta, Tangerang, Bogor, and Bekasi regions [5]. Furthermore, the multitude of activities conducted in the vicinity of the bay, including shipping, fishing, aquaculture, and, more recently, reclamation projects, have the potential to impact water quality. Jakarta Bay is currently experiencing elevated levels of eutrophication, accompanied by increased turbidity [6]. Sedimentation represents a significant threat to coral reefs, as the particles can obstruct the polyps of coral, impeding light penetration and, consequently, negatively impacting coral cover [7].

The issue of high human activity has the potential to disrupt the resilience of coral reefs in Pari Island. The resilience of coral reefs can be disrupted and decreased as a result of high human activity in their vicinity. In light of the fact that human activity can pose a significant threat to the survival of coral reef ecosystems, it is imperative that assessments of coral reef resilience be conducted in order to ensure the sustainable utilisation of aquatic resources [8].

The multitude of human activities and inputs from various rivers render Jakarta Bay highly susceptible to pollution, which has the potential to cause significant environmental damage to the bay. As posited by Kunzmann *et al*, Jakarta Bay and the southern Thousand Islands are classified as highly threatened coastal areas, due to overfishing and destructive activities, coastal development, pollution from watersheds, and pollution and damage from the sea [9]. The situation is further exacerbated by the reclamation of Jakarta Bay, which causes sedimentation levels to rise.

The water conditions of Pari Island are typically influenced by those of the surrounding bay. Pari Island is situated in the northern region of Jakarta Bay, approximately 31 km from Muara Angke Harbour in Jakarta. During low tide, the current pattern in the bay exhibits a south-to-north movement with a velocity of 0.25 m/s [10]. Sedimentation represents a pivotal parameter in the resilience of coral reefs; consequently, a number of additional parameters may exert an influence on this resilience. As outlined by Viehman *et al*, there are 61 parameters that affect coral reef resilience, with both positive and negative contributions [11]. Mcleod *et al*, posit that increasing and maintaining coral reef resilience is the sole effective management strategy for addressing disturbances related to climate change [12]. The objective of this study is to analyze the resilience of the coral reefs in Pari Island, with a particular focus on the factors that contribute to their resilience and the potential for future resilience.

## 2 Research method

The research was conducted in the Water of Pari Island, Seribu Island, Jakarta Provine (Figure 1). The observational study was conducted on three occasions: in July 2016, October 2016 and January 2017. Coral reef observations were conducted at four stations on Pari Island (Figure 3). The four stations are as follows: Station 1 (situated to the south of Pari Island), Station 2 (to the west of Pari Island), Station 3 (to the north of Pari Island), and Station 4 (to the east of Pari Island). Coral reef observations were conducted at four stations deemed representative of the condition of coral reefs in the vicinity of Pari Island. The southern station was situated in waters adjacent to Jakarta Bay, with a Marine Protection Area (MPA) designated around the observation point. The western and eastern stations were included in the utilisation zone, where a range of activities, including fishing by local fishermen, were permitted. The northern station was located in the vicinity of Central Island, which had undergone coastal development.

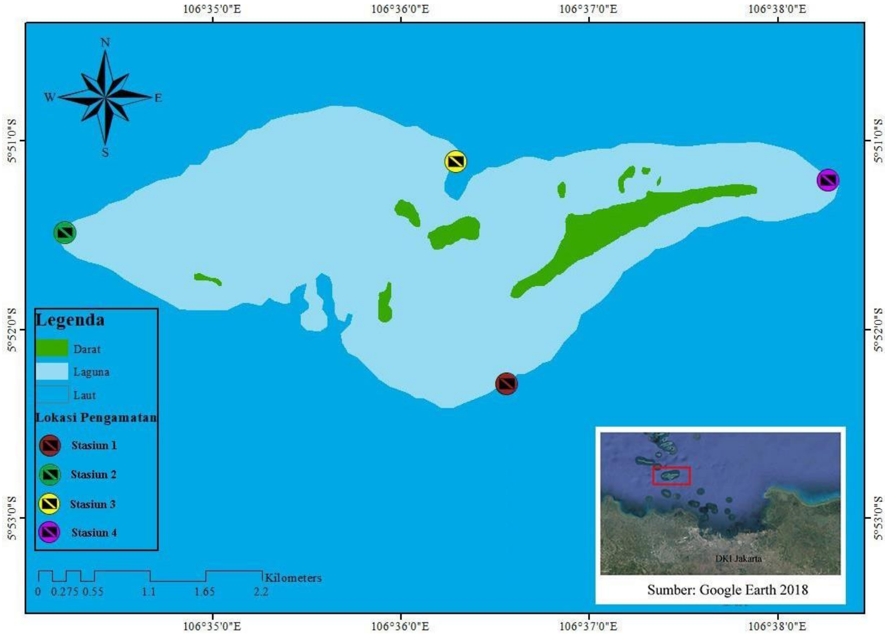


**Fig. 1**. Research location on Pari Island (Source: SHP Indo, WGS84 datum).

### 2.1 Data collection

The data collection process was conducted in two distinct phases. The initial phase entailed field observations, which constituted the primary data set. The secondary data set was subsequently collected through other means. The primary data collected was the percentage of bottom substrate cover, while the secondary data comprised total suspended solid (TSS) distribution data and current distribution. The observation of bottom substrate cover was conducted utilising diving apparatus and data collection instruments, including 100-metre line transects, slats, and underwater cameras. TSS data were obtained from Landsat 8 images downloaded from the Earth Explorer website (earthexplorer.gov.us.gs). These were then processed with ENVI 5 and ArcGIS 10.2 software to obtain TSS distribution values. The current distribution data for Pari Island were obtained through a literature study.

In this study, the method employed was the observation of the bottom substrate cover utilising the line-intercept transect (LIT) technique with transect video. The LIT method was conducted at two depths: 3 and 10 metres. The data collection procedure commenced with the deployment of the line transect along a 100-metre length, and then proceeded with the observation of the first 20 metres, interspersed with a 20-metre interval, until the full 100 metres were reached. The observations were recorded according to the substrate category (Table 1) and the length of the category [13]. Figure 2 illustrated the method of collecting data on bottom substrate cover.

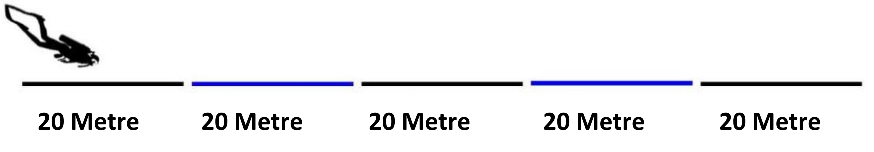


**Fig. 2.** Illustration of bottom substrate cover observation.

Coral reef observations were also conducted using the video transect method, as illustrated in Figure 3. The observations were compiled by swimming at a depth of approximately one metre above the transect, following the length of the observation transect. The camera was positioned directly downward, facing the transect [35]. The resulting transect video was then analysed with the assistance of the Indo-Pacific Coral Finder identification book [].

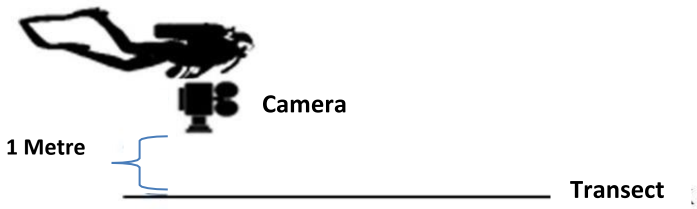


**Fig. 3.** Illustration of observation with video transect.

**Table 1**. Substrate category (Urbina-Barreto *et al*, 2021)

| Category | Type | Code | Decription |
|---|---|---|---|
| Dead Coral | - | DC | Newly dead coral, white in colour |
| Dead Coral with Alga | - | DCA | Dead coral covered with algae |
| Hard Coral | - | HC | Hard coral |
| Other Fauna | Soft Coral | SC | Corals with soft bodies |
| | Sponge | SP | Example: Aaptos aaptos |
| | Zoanthids | ZO | Example: Palythoa tubercolusa |
| | Others | OT | Anemone, sea cucumber, gorgonian, clam |
| Algae | Alga Assemblage | AA | Consisting of more than one type of algae |
| | Coralline Algae | CA | Algae that have a lime structure |
| | Halimeda | HA | Algae of the genus Halimeda |
| | Macroalgae | MA | Large-sized algae |
| | Turf Agae | TA | Resembling fine grasses |
| Abiotic | Sand | S | Sand |
| | Rubble | R | Scattered coral fragments |
| | Silt | SI | Mud |
| | Water | WA | Water columns / crevices with a depth of more than 50 cm |
| | Rock | RCK | Rock coral |
| | | DDD | Data not recorded or missing |

## 2.2 Data Analyst

### *2.2.1 Percentage cover*

The data set pertaining to the composition of the substrate at the bottom level comprised several parameters, including the percentage cover of hard coral, the genus in question, the level of resistance, and other variables. The percentage of hard coral cover was a commonly used metric for assessing the condition of coral reefs. According to the Decree of the Minister of Environment No. 04 of 2001, the quality standard criteria for the percentage of coral reef cover were outlined in Table 2. The following formula, adapted from (Urbina-Barreto *et al*, 2021), was applied for calculating the percentage of substrate cover:

$$\text{Percentage Cover} = \frac{length\ catergory\ (cm)}{6000} \text{x } 100\% \qquad (1)$$

**Table 2.** Quality standard criteria for percentage coral reef cover.

| Live coral cover category | Percentage live coral cover (%) |
|---|---|
| Bad | 0 – 24,9 |
| Medium | 25 – 49,9 |
| Good | 50 – 74,9 |
| Very Good | 75 – 100 |

### *2.2.2 Coral Mortality index*

The Coral Mortality Index (CMI) was a metric that quantifies the extent of coral mortality in each body of water. The CMI assumed a value between 0 and 1, with higher values indicating a greater prevalence of coral mortality. The mathematical formulation of the CMI was provided below, as derived by [14]:

$$Moratality\ Index = \frac{\text{\% Dead Coral}}{\text{\% Dead Coral+\% life Coral}} \qquad (2)$$

### *2.2.3 Number of recruits*

The number of recruits was calculated based on the number of recruit colony sizes observed along the transect. Recruitment colonies were defined as coral colonies measuring less than 10 cm in diameter. According to Garnett and nothwood, colonies of this size could be considered representative of the recruitment process, providing insight into the phenomenon through an examination of the incremental growth in the group [15].

### *2.2.4 Distribution of coral size classes*

The distribution of coral size classes provided a means of assessing the condition of coral reefs. The approach adopted in this study was based on the findings of Bernard *et al* [16]. According to this research, the distribution of coral size classes can be used to gain insights into the current condition of coral reefs with regard to factors such as coral colonies, recruitment, historical trends and others.

### *2.2.5 Coral reef resilience*

The resilience of coral reefs was evaluated based on observations of predetermined parameters, subsequently assigning a score and weighting the results obtained for each parameter. The assessment of coral reef resilience was based on seven parameters, encompassing resistant corals, hard coral cover, coral diversity, coral recruitment, coral size class distribution, macroalgae, and TSS (Table 3). The scoring system employed for the assessment of coral reef resilience was adapted from the methodology proposed by Bernard *et al* [16], while the weighting system was derived from the findings of McClanahan *et al* [17].

**Table 3**. Key parameters of coral reef resilience.

| No | Paramatre | Unit | Bobot | Score | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | **1** | **2** | **3** | **4** | **5** |
| 1 | Resistant coral genus | % | 0,19 | <6,1 | >6,1-9,3 | >9,3-12,5 | >12,5-15,6 | >15,6 |
| 2 | Coral cover hard | % | 0,11 | <19,15 | >19,15-38,35 | >38,35-57,55 | >57,55-76,75 | >76,75 |
| 3 | Genus Richness | - | 0,15 | 1-10 | 11-18 | 19-27 | 28-35 | 36-44 |
| 4 | Recrturtment of | Colony | 0,14 | 0-5 | 6 -10 | 11-15 | 16-20 | 21-25 |
| 5 | Class Distribution Coral size | - | 0,12 | 1-2 | 3-4 | 5-6 | 7-8 | >9 |
| 6 | Macroalgae | % | 0,14 | >2,41 | >1,91-2,41 | >1,42-1,91 | >0,92-1,42 | <0,92 |
| 7 | TSS | mg/l | 0,15 | >20 | >15-20 | >10-15 | >5-10 | <5 |

Sumber: Simarangkir [18], KLH No.51 [19]

The values obtained for the coral reef condition parameter were then compared with the parameters set out in Table 3 in order to determine the score. The following formula was then used to determine the value of coral reef resilience:

$$R= \sum( B \text{ x } S ) \quad (3)$$

Note:
B = Bobot, S = Score
R = Resilience point, If
R= 1,00-1,80 (Very Bad); 1,80-2,60 (Bad); 2,60-3,40 (Medium); 3,40-4,20 (Good); dan 4,20-5,00 (Excellent)

# 3 Result and discussion

The waters of Pari Island were distinguished by their singular characteristics, which were shaped by the island's geographical location. Geographically, Pari Island constituted a single member of a cluster of diminutive islands collectively known as the Thousand Islands. The Pari Island cluster comprised three significant ecosystems of tropical coastal areas: mangroves (11.5 ha), seagrasses (375.8 ha), and coral reefs (235.7 ha) [20]. The overall condition of Pari Island was discussed in the subsequent sub-chapters of the results.

## 3.1 Percentage cover of substrate categories and mortality index (MI)

The succeeding paragraphs presented the results of the percentage cover of substrate categories, as illustrated in Figure 4. Abiotic substrate categories, dead coral with algae, and hard coral were among the nine categories exhibiting a high percentage. Conversely, there were substrate categories of sponge, soft coral, macroalgae, dead coral, and others with low percentages.

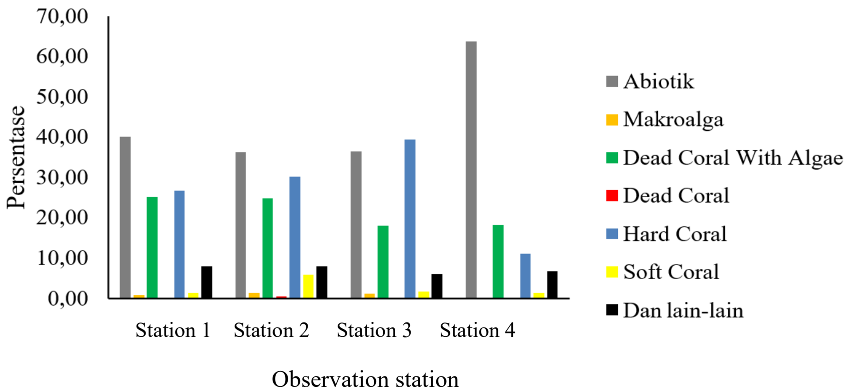


**Fig. 4.** Percentage cover of substrate categories.

Abiotic substrate encompassed a category of substrate that was ubiquitous across the majority of observation stations. The most prevalent form of abiotic substrate identified in this study was broken coral. The ranking of stations, from highest to lowest, in terms of the proportion of abiotic substrates, was as follows: Station 4, Station 1, Station 3, and Station 2 (Figure 4).

The overall percentage of hard coral cover in this study was not a dominant feature. However, when the percentage of hard coral cover was compared with the percentage of macroalgae and dead coral with algae, which were competitors of coral reefs, it can be seen that the percentage of hard corals on Pari Island still dominates, with the exception of Station 4. The order of stations with the highest to lowest percentage of hard coral cover was as follows: Station 3, Station 2, Station 1, and Station 4 (Figure 4). The mortality index (IM) value in this study was high due to the prevalence of broken corals in the substrate of Pari Island waters. Overall, the mortality index value at a depth of 10 metres was greater than the depth of 3 metres. The order of stations with the highest to lowest mortality index values were Station 4, Station 1, Station 2, and Station 3. The coral mortality index (IM) value in this study was presented in Figure 5.

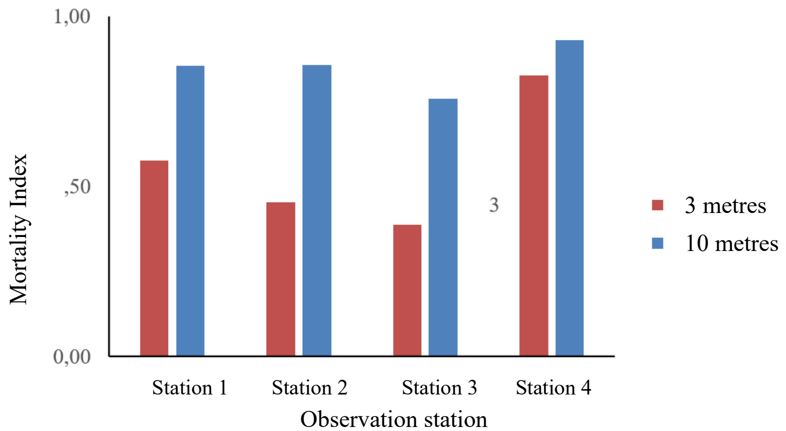


**Fig. 5**. The mortality index in 3 and 6 metres.

The mean percentage of coral reef cover was 26.86%, which fallen within the moderate category as defined by the Minister of Environment Decree No. 4 of 2001. Furthermore, the mortality index value in this study was notably elevated, with all stations exhibiting a mortality index value of approximately 1, on average. Station 4 exhibited the most adverse condition of the coral reefs, based on the values of coral reef cover and mortality index.

## 3.2 Genus richness

The genus was identified at four stations, with a total of 43 genera identified across all stations. The range of genera identified at each station was between 16 and 26. The results obtained from the 10 most commonly found genera indicated that the genus Porites sp., a genus of resistant coral, was the most dominant genus in the waters of Pari Island. The genus Tubipora sp., a rare genus, was found at Station 2 and in the following figure 6.

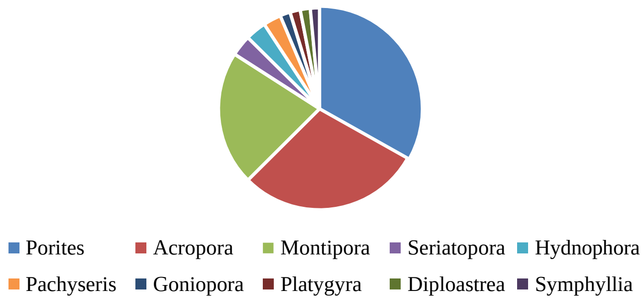


**Fig. 6.** illustrated the 10 most common genera found in this study.

## 3.3 Resistant coral genus

A genus of coral that exhibited heightened resilience to fluctuations in temperature and other environmental stressors that precipitate coral mortality was herein referred to as a "resistant coral genus." Some coral genera, including Porites sp. (massive, non-branching), Pavona sp., and Astreopora sp., exhibited a higher level of resistance compared to other genera [16]. The genus Porites sp. was identified as the most resistant overall. Station 2 exhibited the highest percentage of this genus, while Station 4 demonstrated the lowest and could be found in the figure 8.

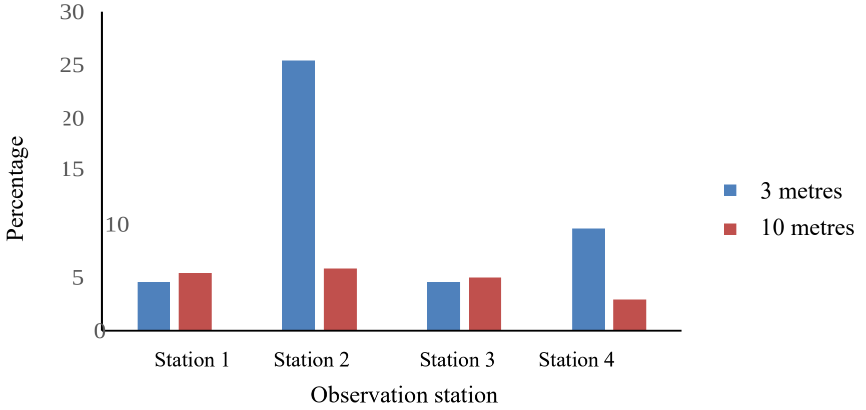


**Fig. 7.** Illustrated the percentage of resistant coral genus across all stations.

## 3.4 Colony size class frequency

The distribution of colony size classes may be indicative of the condition of coral reefs in a given area. The highest frequency was observed in the size class of 21-40 cm. Based on the frequency distribution, the condition of coral reefs at Station 1 and Station 2 was superior to that of other stations. The condition of coral reefs at Station 4 indicated that there was excessive exploitation of nature, as evidenced by the presence of four size classes that were not filled. Figure 8 depicted the frequency distribution of coral colony classes.

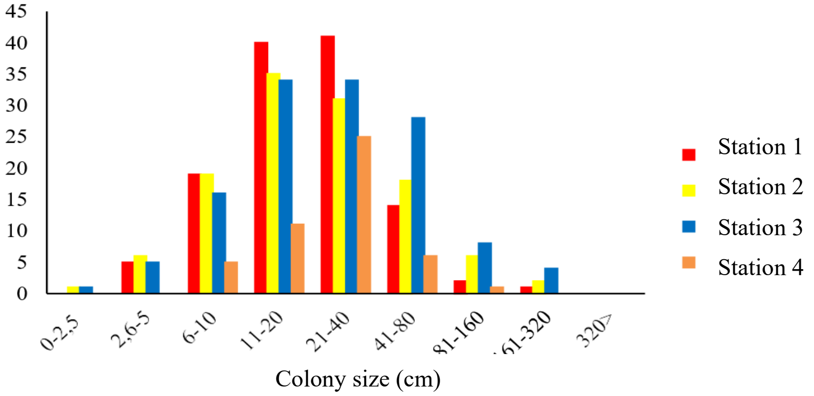


**Fig. 8**. Coral colony class frequency.

## 3.5 Coral recruitment

The recruitment phase was characterised by the appearance of coral colonies measuring ≤10 cm in size. The highest coral recruitment was observed at Station 2, while the lowest coral recruitment was recorded at Station 3. Based on the data obtained, the recruitment observed on Pari Island was markedly low. The genus Porites sp., Acropora sp., and Montipora sp. represented the most frequently occurring genus in the recruited colonies. Figure 9 illustrated the frequency of recruitment obtained from two depths.

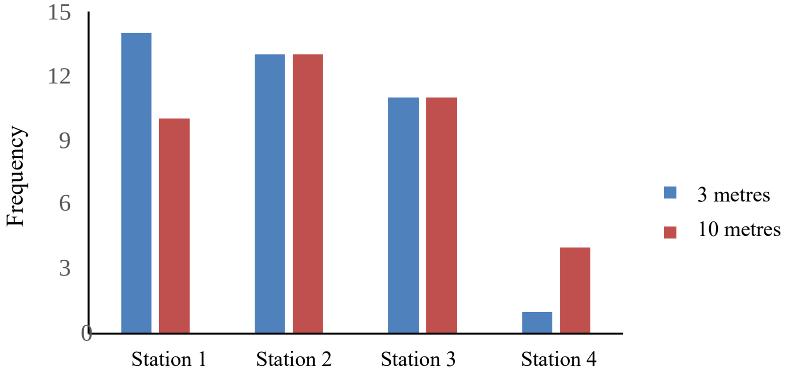


**Fig. 9**. Frequency of coral recruitment.

### 3.6 Season Alteration

The study was conducted over three seasons: the eastern, transitional, and western seasons. July 2016 was included in the eastern season, October 2016 was included in the transitional season leading up to the rainy season, and finally, January 2017 was included in the western season (BMKG 2016) [21]. Based on observations, the condition of the coral reefs on Pari Island did not undergo any changes in quality standard category as a result of seasonal changes. This was in contrast to the resistant coral genus, where changed in the percentage of cover can affect the resilience of coral reefs.

The genus of resistant corals underwent a transformation over time, with changes occurring exclusively between October and January. When compared to the alterations in the percentage of resistant coral genus, Station 1 exhibited a more pronounced decline than Station 2. Station 1 witnessed a reduction in the resistant genus by 7.92%, representing the most significant percentage decreased during the observation period. The alterations in the percentage of resistant coral genus based on observation time were presented in Figure 10.

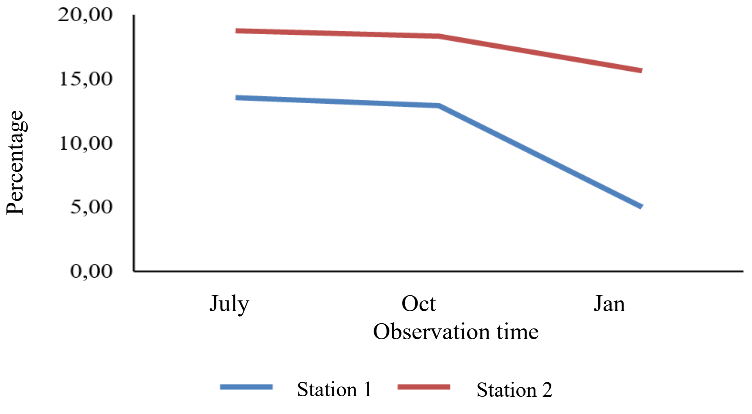


**Fig. 10.** Change in percentage of resistant genus.

### 3.7 Total suspended solids

The total suspended solids (TSS) concentration was included among the environmental factors affecting coral reefs, as the magnitude of the TSS concentration can influence the survival of these ecosystems. Rangel-Buitrago *et al*, asserted that sediment waste was detrimental to marine life, as it can cause turbidity that obstructed the gills or filter elements of filter-feeding animals [22]. Overall, TSS concentrations at all stations exhibited comparable values, ranging from 28.50 to 29.09 mg/L. However, during field observations, notable differences in turbidity were observed between each station. Table 4 presented a summary of TSS concentrations.

**Table 4**. TSS concentration.

| Parametre | Site 1 | Site 2 | Site 3 | Site 4 |
|---|---|---|---|---|
| TSS (mg/L) | 29,09 | 28,79 | 29,03 | 28,5 |

### 3.8 Current Distribution

The prevailing pattern on Pari Island was predominantly influenced by tidal movements.

(Aunillah *et al,* posit that Pari Island exhibited elliptical current movement as a consequence of tidal factors, with the island's tidal type characterised by a single daily tide [23]. This indicated that there was a single tidal movement per day, characterised by an ebb and a flood. Figure 11 illustrated the current pattern of Pari Island during high tide, while Figure 12 depicted the current pattern during low tide. It can be observed that the dominant current direction shifts towards the southwest and northeast.

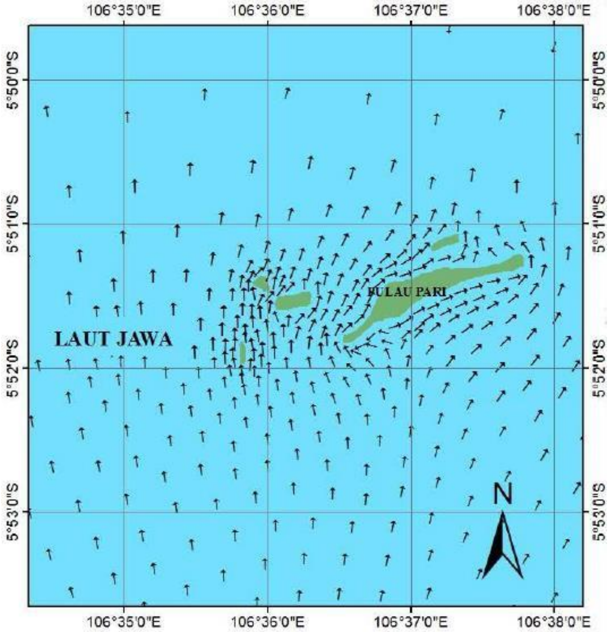


**Fig. 11.** Current patterns at high tide [21].

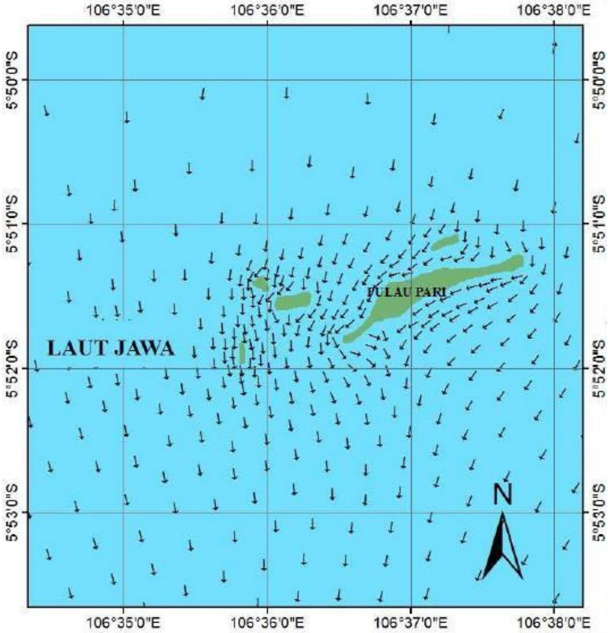


**Fig. 12**. Flow patterns at low tide [21]

### 3.9 Percentage of macroalgae cover

Macroalgal temporal observations were conducted at Stations 1 and 2. The percentage of macroalgae observed from July to October was found to be between 3.08 and 5.43%. Furthermore, there were fluctuations in January, with the percentage of macroalgae decreasing to around 0.18-1.08%. As Simarangkir noted, although the percentage of macroalgae was small, every 0.5% change in macroalgae cover can affect the resilience of coral reefs [18]. The changes in the percentage of macroalgae based on observation time are presented in Figure 13.

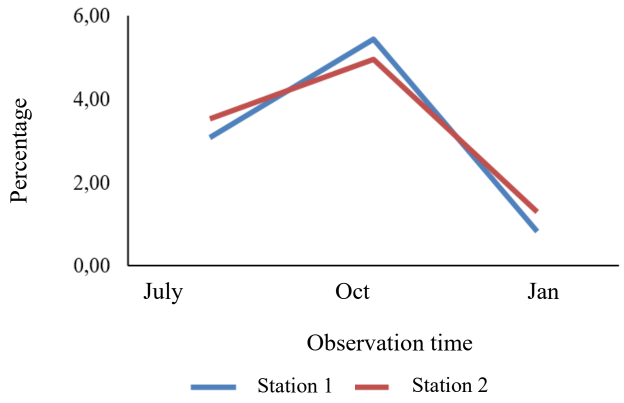


**Fig. 13**. Percentage change in macroalgae.

### 3.10 Resilience in numbers

The data obtained indicated that certain parameter values contributed positively and negatively to coral reef resilience. It can be observed that the parameters with low scores in terms of coral reef resilience were recruitment and sedimentation. Conversely, macroalgae had a high score in this regard. The calculation of Pari Island coral reef resilience, with weights and scores presented in Table 5.

**Table 5**. Spatial resilience index of Pari Island.

| **Parametre** | **Bobot** | **Site 1** | | **Site 2** | | **Site 3** | | **Site 4** | |
|---|---|---|---|---|---|---|---|---|---|
| | | **Score** | **B x S** | **Score** | **B x S** | **Score** | **B x S** | **Score** | **B x S** |
| Resistant coral genus | 0,19 | 2,00 | 0,37 | 5,00 | 0,94 | 2,00 | 0,37 | 3,00 | 0,56 |
| Hard coral cover | 0,11 | 2,00 | 0,23 | 2,00 | 0,23 | 3,00 | 0,34 | 1,00 | 0,11 |
| Genus Richness | 0,15 | 3,00 | 0,45 | 3,00 | 0,45 | 3,00 | 0,45 | 2,00 | 0,30 |
| Coral recruitment | 0,14 | 1,00 | 0,14 | 1,00 | 0,14 | 1,00 | 0,14 | 1,00 | 0,14 |
| Coral size class distribution | 0,12 | 4,00 | 0,48 | 5,00 | 0,48 | 5,00 | 0,48 | 5,00 | 0,36 |
| Macroalgae | 0,14 | 5,00 | 0,69 | 4,00 | 0,55 | 4,00 | 0,55 | 5,00 | 0,69 |
| TSS | 0,15 | 1,00 | 0,15 | 1,00 | 0,15 | 1,00 | 0,15 | 1,00 | 0,15 |
| **Sum** | **1,00** | **2,52 (Bad)** | | **2,94 (Medium)** | | **2,49 (Bad)** | | **2,32 (Medium)** | |

Note : *B* = Weight; *S* = Score

### 3.11 Spatial resilience

The spatial determination of coral reef resilience was obtained based on the results of calculations using the coral reef resilience index. The overall resilience value of Pari Island was divided into two categories: moderate resilience and poor resilience. The area west of Pari Island was characterised by low resilience, while the southern, northern and eastern regions of the island were included in the poor resilience category. Figure 14 presented a map of the coral reef resilience of Pari Island.

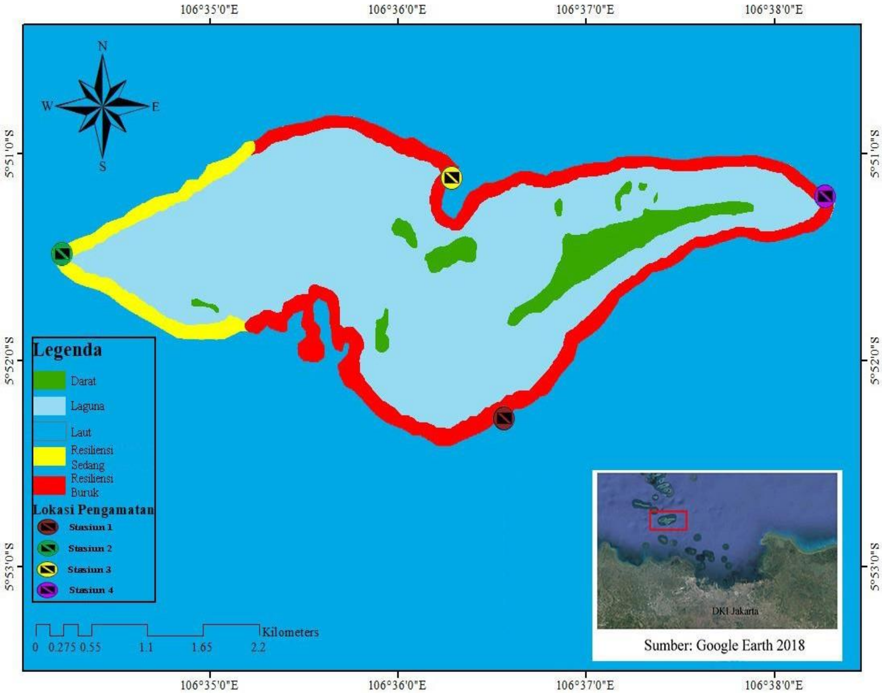


**Fig. 14.** Resilience of Pari Island coral reefs.

## 4 Discussion

The physical condition of the waters surrounding Pari Island was characterised by the prevalence of coral break substrates. This suggested that damage to the coral reefs had been caused by human activities. As posited by Good and Bahr, human activity was the primary driver of coral reef degradation worldwide [24]. This assertion aligned with the findings of Boström-Einarsson *et al*, which indicated that the deterioration of coral reefs on Pari Island was inextricably linked to historical human activities, including the extensive use of fishing gear that caused significant damage to these ecosystems, the deployment of explosives, and the introduction of potassium poison, which collectively have contributed to the current state of these reefs [25].

The sedimentation in Pari Island as a whole was deemed to be in contravention of the quality standard for marine biota as set out in Decree of the Minister of Environment No. 51 of 2004 [19]. It was hypothesised that this was due to the influence of seasonal factors and human activities. As postulated by Try and Kusumah, seasonal factors have the potential to influence water conditions [26]. During the rainy season, for instance, there was often an increase in TSS values. Furthermore, Lu *et al*, posited that currents and waves also influenced the distribution of sediment in the water [27]. Good and Bahr, elucidated that urbanisation in coastal areas can exacerbate sedimentation in the water, which subsequently endangered coral reefs. The condition of Jakarta Bay waters wss categorised as highly threatened [24].

The reefs of Pari Island were collectively experiencing a decline in coral recruitment (Figure 10), due to the unfavourable water conditions that prevail in the vicinity of the island. The elevated sedimentation levels in the vicinity of Pari Island had been identified as a significant impediment to the coral recruitment process. As posited by Wibowo *et al*, a decline in coral recruitment had been observed on Pari Island, attributed to the diminished survival rate of coral larvae following attachment to the substrate [28]. As posited by Browne *et al*, coral mortality might result from a deficiency in light intensity, which impeded the photosynthetic capabilities of zooxanthellae algae [29]. Additionally, high sedimentation rates had been identified as a contributing factor to reduced coral species richness, coral cover, growth rates, and recruitment rates, as postulated by Rodriguez-Ruano *et al* [30].

Macroalgae was a marine biota whose life was directly influenced by current conditions. This was due to the fact that the magnitude of current density could lift and sweep macroalgae that are attached to the substrate. As Johansen noted, wind and current speed exert a significant influence on coral reef habitats, particularly in shallow areas [31]. The body of macroalgae was often referred to as 'tallus' due to its lack of roots, which were a defining feature of higher plants. However, macroalgae could adhere to holdfasts, which were structures that resemble roots. Nevertheless, the adhesion of macroalgae to the substrate was inherently weak, rendering them susceptible to being washed away by strong currents [32].

The overall resilience of coral reefs on Pari Island was determined by three main parameters: resistant coral genus, hard coral cover, and genus richness. These three parameters provided an overview of the problems at each station. According to McClanahan *et al*, the resistant genus parameter was an important aspect in determining the ability of corals to survive disturbance [17]. The hard coral cover parameter could describe the magnitude of human disturbance, and the genus richness parameter was related to biological aspects.

Station 1 (situated to the south of Pari Island) constituted a Marine Protected Area (MPL) that was frequently utilised for tourism-related activities. The expansion of such activities had the potential to inflict direct harm upon coral reefs, including those belonging to the genus that was resistant. This was evidenced by the decline in the percentage of resistant genus in the region (Figure 10), as these species were unable to survive in the presence of direct human-induced damage. As posited by Bartelet *et al*, the utilisation of coral reef ecosystems as tourist destinations could result in damage to the coral reefs themselves [33]. Furthermore, as postulated by Rodriguez-Ruano *et al*, the resistant genus was a genus that was capable of withstanding temperature increases, but was unable to survive direct damage from human activities [30]

A comparative analysis of resilience values revealed that Station 4 (situated to the east of Pari Island) exhibited the lowest resilience value among the other areas under consideration. The low percentage of coral cover and genus richness in the area resulted in a low resilience value. Rodriguez-Ruano *et al*, posited that the percentage of coral cover parameter was of great consequence for the resilience of coral reefs, as it served as an indicator of the quality of the habitat [30]. Simarangkir, asserts that genus richness was of paramount importance in ensuring the survival of coral reef ecosystems, as an increase in temperature allowed for the proliferation of numerous coral species [18].

The coral reef cover at Station 3 (north of Pari Island) was the most extensive of all the areas under consideration, yet this did not guarantee high resilience. This was due to the low cover of resistant genus in the area. As McClanahan *et al*, had demonstrated, parameters related to the ability to survive environmental disturbances, such as the presence of resistant genus, are of great importance [17]. This was because the ability to survive the death of corals due to environmental disturbances was a key factor in determining the resilience of an area.

The implementation of resilience-based coral reef management strategies on Pari Island was guided by the objective of maintaining areas that have been identified as having high resilience values, while simultaneously increasing the extent of areas that have been determined to have low resilience values. One method of maintaining and increasing resilience was to expand the APL area from the south of Pari Island to the west of the island. Furthermore, the transplantation of corals in the southern region of Pari Island, which was designated as an APL area, can be employed as a means of enhancing resilience in the region. As elucidated by Rodriguez-Ruano *et al*, the reduction or elimination of pressure could serve as a crucial factor in increasing coral survival [30]. Additionally, as posited by Firmansyah *et al*, the implementation of a zoning system in coral reef management could yield favourable outcomes for the surrounding coral reefs [34].

## 5 Conclusion

The overall resilience of the coral reef ecosystem on Pari Island was found to be poor, with the exception of the western region which resilience state/level was medium. The low hard coral cover on the island was a primary factor contributing to this poor resilience. The resilience of the coral reef ecosystem on Pari Island was primarily determined by the presence of resistant coral genera.

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