Coral reef condition in Kepulauan Seribu during and after the COVID-19 pandemic (2021-2025)

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Abstract. The COVID-19 pandemic triggered an anthropause phenomenon characterized by a reduction in human activities and interactions with ecosystems, including coastal ecosystems such as coral reefs. This study aims to analyze changes in coral reef conditions in the Seribu Islands during and after the pandemic over the period 2021–2025. Observations were conducted at two stations, namely Barat Pulau Pramuka (BPR) and Selatan Pulau Panggang (SPG), using the Line Intercept Transect (LIT) method at a depth of 3–5 m with three replicates. The results show that the benthic substrate at BPR was dominated by abiotic components, whereas SPG was dominated by hard coral. Hard coral cover at BPR remained in poor condition, showing an increasing trend from 2021 to 2024, followed by a decline in 2025, indicating an unstable recovery pattern. In contrast, SPG did not exhibit clear changes related to the pandemic period, but it remained dominated by hard coral, with the highest cover recorded in 2025 (87.28%). The dominant lifeforms at both stations were submassive, massive, and encrusting. The findings suggest that changes in coral reef conditions were influenced not only by reduced human activities during the pandemic but also by local environmental factors

1 Introduction

Coronavirus Disease 2019 (COVID-19) is an infectious disease caused by the Severe Acute Respiratory Syndrome Coronavirus 2 (SARS-CoV-2). The disease experienced a rapid increase in cases and spread quickly across countries worldwide within a relatively short period [1]. In Indonesia, the first confirmed cases were reported in March 2020. One of the key measures implemented to control the spread of COVID-19 was the Large-Scale Social Restrictions policy (Pembatasan Sosial Berskala Besar, PSBB), or social distancing, which was first enforced in Jakarta on April 10, 2020, and subsequently extended to other cities [2]. The implementation of these measures resulted in widespread restrictions on activities involving public gatherings, including the closure of educational institutions and workplaces, limitations on religious activities that could generate crowds, and the suspension of operations in various locations such as tourism destinations and other activities conducted in public spaces and facilities.

Another phenomenon that emerged during the pandemic is the COVID-19 anthropause, referring to large-scale changes in human activities and their interactions with ecosystems due to the pandemic [3]. Ecosystems worldwide are inherently influenced by human activities across multiple scales, from local to global through alterations in terrestrial, aquatic, and atmospheric systems. Restrictions affecting nearly two-thirds of the global population created a natural experiment to assess the impacts of human activity on various ecosystems [3]. Numerous studies have shown that rapid reductions in human activity can generate positive effects on environmental conditions and wildlife [4].

Lockdown measures have been considered effective in reducing anthropogenic pressure on marine ecosystems. The decline in tourism activities, in particular, is expected to provide significant benefits for coral reef ecosystems by allowing natural recovery processes to occur. In Indonesia, pressures on coral reef ecosystems are generally driven by both anthropogenic and natural factors, which have contributed to the degradation of reef conditions [5]. Several studies

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indicate that coral reef damage in Indonesia is predominantly caused by human activities, such as destructive fishing practices. However, information regarding the extent to which the COVID-19 pandemic has influenced coral reef ecosystem conditions, particularly in areas such as Pramuka Island, remains limited. As a major marine tourism hub in the Kepulauan Seribu Islands, lockdown measures in Pramuka Island led to significant reductions in tourism and other human activities. Therefore, this study aims to assess the impact of changes in human activity during the pandemic on the condition of coral reef ecosystems.

2 Method

2.1 Study sites

This study was conducted during both the pandemic and post-pandemic periods, specifically in September 2020, June 2021, and August 2022–2025, in Kepulauan Seribu. Observations were carried out at two monitoring stations: Dermaga 2 of Pramuka Island/the western part of Pramuka Island (BPR), and the southern waters of Panggang Island (SPG) (**Fig. 1**).

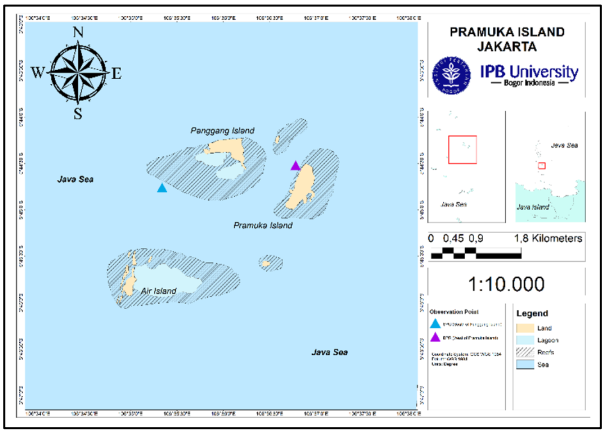


Fig 1. Research location map

2.2 Data Collection

Coral reef observations were conducted using a modified Line Intercept Transect (LIT) method [6]. At each site, a 75 m measuring tape was deployed parallel to the shoreline at depths of 3–5 m. Observations were conducted in three replicates, each consisting of a 20 m observation section separated by a 5 m interval. Data collection was carried out by divers swimming along the transect line while recording the types of benthic substrates encountered. Substrate categories followed the classification of English *et al.* [6], including hard coral (HC), dead coral (DC), dead coral with algae (DCA), abiotic components, and other fauna. For hard corals, lifeform categories were recorded to describe reef morphology, and identification was conducted to the genus level. All identified genera were subsequently verified using the World Register of Marine Species (WoRMS, 2024).

2.3 Data Analysis

The data analysis employed was based on the percentage cover of benthic substrates. The percentage cover of each lifeform and substrate category was calculated using a formula adapted from English *et al.* [6], as follows:

$$\%\ \text{Cover} = \frac{\text{Total length category}}{\text{Transect length}} \times 100\% \qquad (1)$$

Based on the Decree of the state minister for the Environment, KepMenLH No. 4 Tahun 2001, the condition of coral reef ecosystems is determined using standard criteria for coral reef damage, which are based on the percentage cover of live hard coral. The classification of coral reef condition according to live hard coral cover is presented in Table 1.

Table 1. Standard criteria for coral reef damage

Category		Percentage of Living Coral (%)
Damage	Poor	0 – 24,9
	Moderate	25 – 49,9
Good	Good	50 – 74,9
	Very Good	75 - 100

3 Result and discussion

3.1 Benthic substrate cover

The composition of benthic substrate cover at both observation stations during the 2021–2025 period shows interannual variation with distinct patterns at each location (**Fig. 2**). At the western part of Pramuka Island (BPR), benthic substrate cover throughout 2021–2025 was dominated by abiotic components, with the highest abiotic cover recorded in 2025 (72.77%) and the lowest in 2024 (42.25%). In contrast, the southern part of Panggang Island (SPG) was consistently dominated by hard coral cover across all observation years, with the highest value in 2025 (87.28%) and the lowest in 2022 (41.73%). Other substrate categories, such as soft coral, algae, other biota, and dead coral with algae (DCA), exhibited relatively lower proportions, each contributing less than 33%. Overall, these differences in substrate composition reflect variations in benthic habitat conditions that influence coral growth and persistence [7].

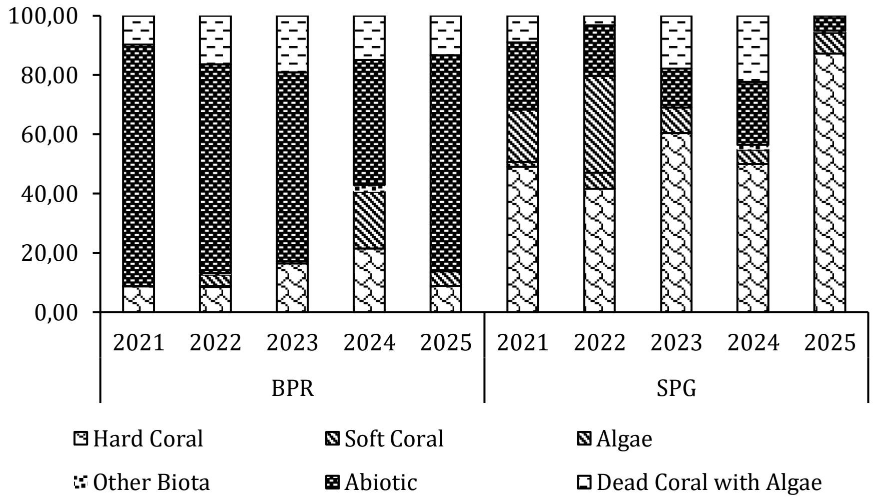


Fig 2. Benthic substrate cover at BPR and SPG sites from 2021 to 2025

The high proportion of abiotic substrate at BPR can be associated with its location near Dermaga 2 of Pramuka Island, where physical disturbances such as vessel traffic, anchoring, and water movement may lead to unstable substrates such as rubble and sand. Intensive local disturbances of this nature are often key limiting factors for coral reef resilience, sometimes exceeding the influence of global climate change in certain regions. Such conditions are less conducive to coral recruitment, as they hinder larval settlement on suitable substrates. The increase in hard coral cover observed from 2021 to 2024, followed by a decline in 2025, suggests that recovery processes at BPR are unstable. In contrast, fluctuations in hard coral cover at SPG appear relatively more stable, with a significant increase observed in 2025, indicating a higher ecosystem resilience capacity. Given that the observed patterns do not show a consistent increase during the period of reduced human activity, these findings suggest that the impact of the COVID-19 pandemic on changes in benthic substrate cover at the study sites is likely limited or no significant [3].

3.2 Hard coral cover

Hard coral cover at the two observation stations exhibited interannual fluctuations (**Fig. 3**). Referring to the Indonesian coral reef damage criteria established under KepMenLH No. 4 Tahun 2001, live coral cover at the western part of Pramuka Island (BPR) consistently fell within the poor category, with values recorded at 8.72% (2021), 8.53% (2022), 16.50% (2023), 21.52% (2024), and 8.87% (2025). In contrast, the southern part of Panggang Island (SPG) showed more favorable conditions, with moderate categories in 2021 (49.00%), 2022 (41.73%), and 2024 (49.92%), a good category in 2023 (60.42%), and an excellent category in 2025 (87.28%). At BPR, hard coral cover increased gradually from 2021 to 2024, followed by a decline in 2025, indicating an unstable recovery pattern. Meanwhile, SPG exhibited a more fluctuating trend.

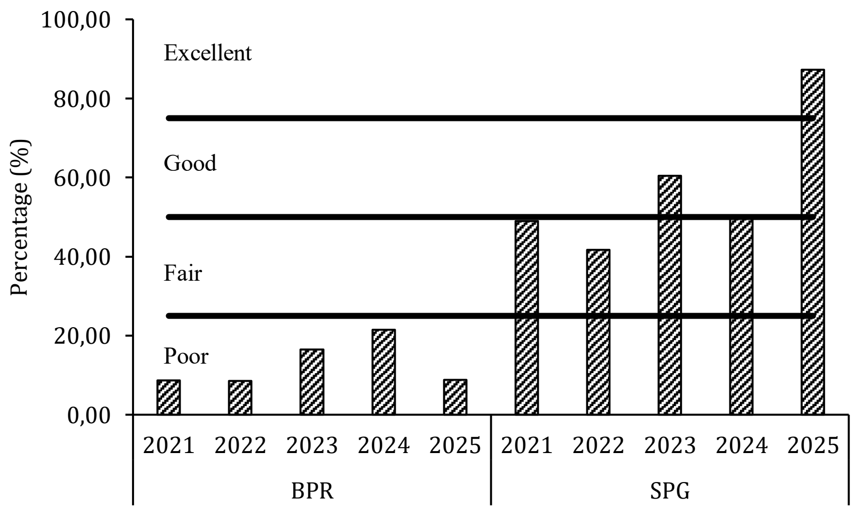
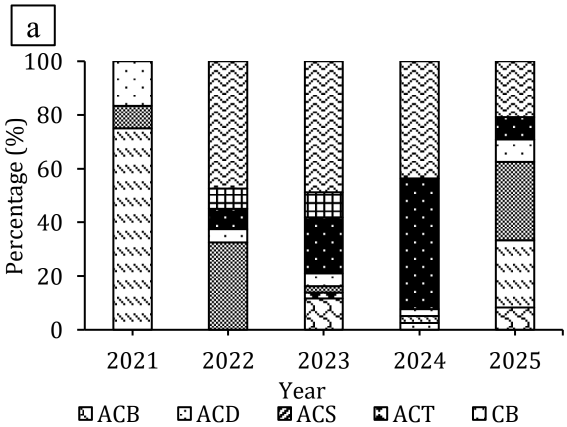


Fig 3. Hard coral cover at BPR and SPG sites from 2021 to 2025

Coral reefs that have experienced degradation retain the capacity for recovery. Surviving coral communities at disturbed sites can undergo recovery phases by reorganizing into new community structures [8]. The increase in hard coral cover observed at BPR between 2021 and 2024 may be associated with reduced anthropogenic pressure during the COVID-19 pandemic. Nevertheless, because similar trends were not consistently observed across sites and years, the overall contribution of pandemic-related restrictions to coral reef recovery remains uncertain. BPR is located near residential areas and serves as a tourism site, where human activities are typically intensive. However, these activities declined significantly during the pandemic. In the fisheries and marine sector, the pandemic led to a sharp decline in seafood demand, with export demand decreasing by approximately 30–40%, resulting in reduced fishing activity [9]. Similarly, ecotourism activities, including tour guiding and other commercial operations, also declined, indicating a reduction in human disturbances in coastal waters. Conversely, the fluctuations observed at SPG suggest that changes in hard coral cover varied among observation years. Such variations are common in coral reef ecosystems and may reflect differences in local environmental conditions over time.

3.3 Lifeform composition

The results of this study reveal variation in the dominant coral growth forms at the two observation stations across different years (**Fig. 4**). A total of ten coral lifeforms were identified, namely Acropora Coral Branching (ACB), Acropora Coral Digitate (ACD), Acropora Coral Submassive (ACS), Acropora Coral Tabulate (ACT), Coral Branching (CB), Coral Encrusting (CE), Coral Foliose (CF), Coral Massive (CM), Coral Mushroom (CMR), and Coral Submassive (CS). Certain coral lifeforms tend to dominate specific habitats, largely influenced by prevailing environmental conditions.



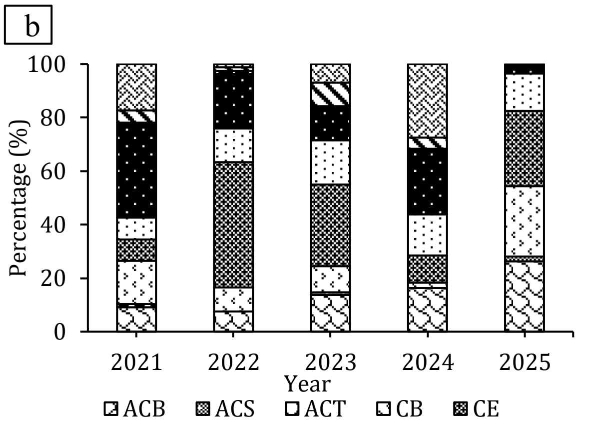


Fig 4. Composition of coral life forms at (A) BPR and (B) SPG sites from 2020 to 2025.

At the BPR observation station (western Pramuka Island), branching coral lifeforms strongly dominated in 2021, accounting for 75% of the total composition. Branching corals are characterized by rapid growth and recovery rates compared to other coral growth forms [10]. Their high growth rates contribute to increased coral cover and enhance habitat structural complexity (**Fig. 5**). However, despite their fast growth, branching corals are generally more vulnerable to disturbances such as bleaching, disease, and predation [11]. The implementation of lockdown measures during that year may have contributed to the high dominance of branching forms, as reduced human activity likely minimized physical disturbances, allowing fast-growing coral types to expand more effectively.

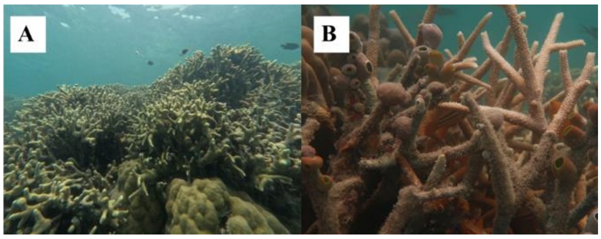


Fig 5. Branching coral growth forms observed at the study site (A–B).

The dominant composition of coral growth forms shifted in subsequent years, with a sharp decline in branching corals, followed by the dominance of submassive, massive, and encrusting forms. The prevalence of these growth forms is largely influenced by their colony characteristics, which tend to be more adaptable to environmental changes (**Fig. 6**). Submassive corals can persist on sandy substrates with relatively low calcium carbonate content. Their robust colony structure enables them to withstand strong currents and wave action [12]. Similarly, massive corals exhibit a high tolerance to extreme environmental conditions and are commonly found in areas with a high proportion of degraded coral cover [13]. These corals are generally more resilient than other growth forms, supported by their solid skeletal structure, which provides resistance to hydrodynamic forces, as well as their strong capacity to adapt to temperature fluctuations [14]. In addition, encrusting corals contribute to substrate stabilization by adhering tightly to reef surfaces, allowing them to persist under physically dynamic conditions. Collectively, the dominance of these growth forms indicates a shift toward more stress-tolerant coral communities, reflecting environmental pressures that favor resilient rather than fast-growing species.

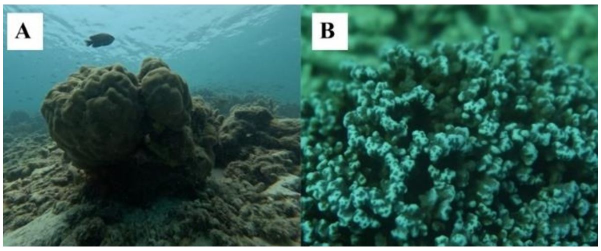


Fig 6. Coral growth forms observed at the study site, showing (A) massive and (B) submassive forms.

At the SPG observation station (southern Panggang Island), the dominant coral growth form throughout the 2021–2025 period was encrusting coral (**Fig. 7**). Notably high proportions of encrusting corals were recorded in 2022 (46.84%), 2023 (30.39%), and 2025 (28.07%). Encrusting corals exhibit a lateral growth strategy that allows colonies to spread across available substrates, as well as an overgrowth capability that enables them to cover other organisms, thereby enhancing their competitive advantage for space [15]. The SPG station, located in a coastal area with relatively high anthropogenic activity, likely experiences increased competition for space among benthic organisms. Under such conditions, spatial competition (biological interaction) plays a crucial role in determining community dominance patterns [15].

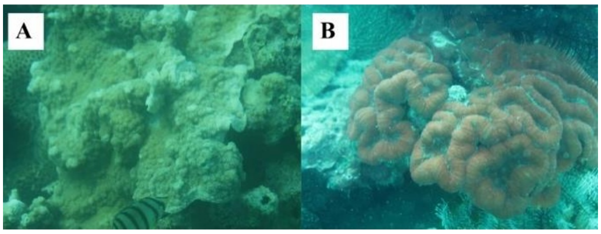


Fig 7. Encrusting coral growth forms observed at the study site (A–B).

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