Coral cover, biomass, and composition of herbivorous reef fishes as indicators of coral reef health in the Padaido Marine Tourism Park, Indonesia

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Abstract. Marine Protected Areas play an essential role in conserving coral reef ecosystems by maintaining biodiversity, sustaining fisheries, and supporting ecosystem resilience. Herbivorous reef fishes are recognized as key ecological indicators because they regulate macroalgal growth and facilitate coral recovery. This study evaluated coral cover, environmental conditions, herbivorous reef fish composition, abundance, and biomass in the Padaido Marine Tourism Park, Indonesia. Field surveys were conducted from August 2021 to June 2022 using the Underwater Photo Transect (UPT) method to assess coral cover and the Underwater Visual Census (UVC) method to quantify herbivorous reef fishes. Environmental parameters, including temperature, pH, salinity, and water transparency, were measured at each sampling station. A total of 84 herbivorous fish individuals representing 26 species from three families (Acanthuridae, Scaridae, and Siganidae) were recorded. Live coral cover ranged from 24.93% to 37.13%, indicating poor to fair reef condition. Herbivorous fish abundance varied from 614.28 to 1,657.14 individuals ha^{-1}, whereas biomass ranged from 14,515.76 to 50,609.04 kg ha^{-1} among stations. Spatial variation in herbivorous fish communities generally corresponded with differences in coral reef condition, highlighting the importance of habitat quality in maintaining reef fish assemblages. The dominance of Acanthuridae, together with the presence of Scaridae and Siganidae, indicates that essential herbivorous functional groups remain within the protected area despite moderate reef degradation. These findings demonstrate that herbivorous reef fish communities provide valuable ecological indicators for evaluating coral reef health and support adaptive zoning, long-term ecological monitoring, and conservation management within the Padaido Marine Tourism Park.

Keywords: Coral reef health; Herbivorous reef fish; Coral cover; Biomass; Marine protected area; Padaido Islands.

1 Introduction

Coral reefs are among the most productive and biologically diverse marine ecosystems, providing essential ecological services such as coastal protection, fisheries production, tourism, and biodiversity conservation. However, these ecosystems are increasingly threatened by climate change, overfishing, coastal development, and other anthropogenic disturbances, leading to declines in coral cover and ecosystem resilience [1–3]. Indonesia, located within the Coral Triangle, supports one of the world's largest coral reef areas and has established numerous Marine Protected Areas (MPAs) to conserve coral reef biodiversity and sustain ecosystem services [4,5].

The condition of coral reefs is commonly assessed using live coral cover, which reflects the health of benthic communities and habitat quality for reef-associated organisms. Nevertheless, coral reef resilience also depends on the presence of herbivorous reef fishes, particularly members of the families Acanthuridae, Scaridae, and Siganidae, which regulate algal growth, facilitate coral recruitment, and maintain ecosystem functioning [6,7]. Although numerous studies have investigated coral reef condition and herbivorous reef fishes independently, information describing their relationship within Marine Protected Areas in eastern Indonesia, particularly in the Padaido Marine Tourism Park, remains limited.

Therefore, this study aimed to evaluate coral reef condition based on live coral cover and to assess the diversity, abundance, and biomass of herbivorous reef fishes at three observation stations within the Padaido Marine Tourism Park. The findings are expected to provide scientific information for evaluating coral reef health and to support adaptive management and conservation planning for Marine Protected Areas in eastern Indonesia.

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2 Research method

2.1 Study Area

This study was conducted from August 2021 to June 2022 in the Padaido Marine Tourism Park (PMTP), Biak Numfor Regency, Papua Province, Indonesia. Field surveys were carried out at four coral reef sampling stations located around Meosmangguandi and Kubori Islands. The stations were selected to represent different reef conditions and levels of anthropogenic disturbance within the conservation area.

Stations 1 and 2 were established on Meosmangguandi Island, with Station 1 located on the northern coast near Meosmangguandi Village and Station 2 on the southern coast near Supraima Village. Stations 3 and 4 were located on the western and eastern coasts of Kubori Island, respectively. Station 1 is situated within a relatively protected area where fishing activities are prohibited and access is limited to research and ecological monitoring. In contrast, Stations 2, 3, and 4 are subject to regular fishing activities by local communities and therefore experience greater anthropogenic pressure.

These contrasting environmental and management conditions enabled comparisons of coral reef health, herbivorous reef fish communities, and environmental characteristics across sites with different levels of human disturbance. The geographic distribution of the sampling stations is presented in Figure 1.

2.2 Environmental Parameters

Environmental parameters were measured simultaneously with the coral reef and herbivorous fish surveys to characterize the physicochemical conditions at each sampling station. The measured variables included water temperature (°C), pH, salinity (‰), and water transparency (m). Environmental parameters were measured once at each sampling station and used to describe the general water quality during the study period.

Water temperature was measured *in situ* using a waterproof digital thermometer, while seawater pH was determined using a portable pH meter. Salinity was measured using a handheld refractometer, and water transparency was assessed using a Secchi disk by recording the depth at which the disk disappeared from view. All measurements were conducted during daylight hours before the underwater surveys to ensure consistent environmental conditions among stations.

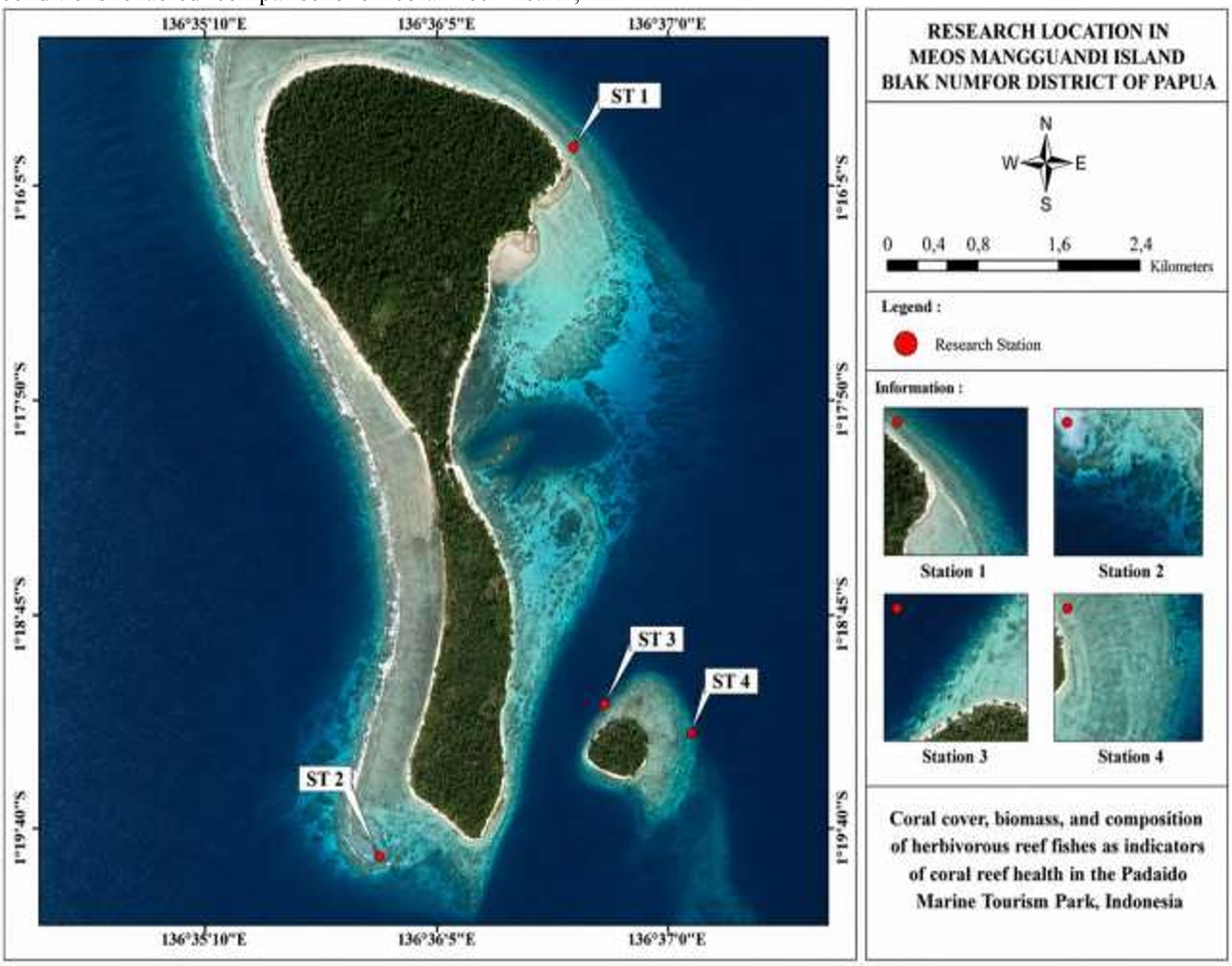

Fig. 1. Map of the four study stations in the Padaido Archipelago. Station 1: 1°16'37" S, 136°36'44" E (north of Meosmangguandi Island); Station 2: 1°19'30" S, 136°35'44" E (south of Meosmangguandi Island); Station 3: 1°18'48" S, 136°36'55" E (west of Kubori Island); Station 4: 1°19'14" S, 136°37'09" E (east of Kubori Island).

2.3 Coral Reef Survey

Coral reef condition was assessed using the Underwater Photo Transect (UPT) method following the protocol developed by the Indonesian Institute of Sciences (LIPI). At each sampling station, a 50-m transect was deployed parallel to the shoreline at a depth of 5–7 m. Underwater photographs of the benthic substrate were taken systematically along the transect using a waterproof digital camera.

The photographs were analyzed using Coral Point Count with Excel Extensions (CPCe) software to estimate the percentage cover of benthic life forms. Live coral cover was calculated as the proportion of points intersecting living hard corals relative to the total observation points. Coral reef condition was classified according to the criteria of the Indonesian Ministry of Environment: poor (<25%), fair (25–49.9%), good (50–74.9%), and excellent (≥75%).

2.4 Herbivorous Reef Fish Survey

Herbivorous reef fishes were surveyed using the Underwater Visual Census (UVC) method. Fish observations were conducted along the same 50-m transects used for the coral reef survey. All herbivorous fishes observed within a 5-m belt transect (2.5 m on each side of the transect) were identified to species level, and the number of individuals was recorded.

The total length (cm) of each individual was visually estimated underwater using standard size-class references. Recorded species were subsequently classified into three herbivorous fish families: Acanthuridae, Scaridae, and Siganidae, following the taxonomic references of FishBase and regional reef fish identification guides.

2.5 Biomass Estimation

Herbivorous fish biomass was estimated using the standard length–weight relationship:

$$W=aL^b$$

where W is the estimated body weight (g), L is the total length (cm), and a and b are species-specific length–weight coefficients obtained from FishBase.

The biomass of each individual fish was calculated separately, and total biomass for each sampling station was obtained by summing the biomass of all recorded individuals. Biomass values were standardized and expressed as kilograms per hectare (kg ha^{-1}) to facilitate comparisons among sampling stations.

2.6 Data Analysis

Environmental parameters, live coral cover, herbivorous fish abundance, biomass, and species composition were analyzed descriptively. Herbivorous fish abundance was expressed as individuals per hectare (ind ha^{-1}), whereas biomass was expressed as kilograms per hectare (kg ha^{-1}). Species composition was summarized according to family and the number of individuals recorded at each sampling station.

Because this study employed a descriptive ecological survey with a single observation transect at each sampling station, inferential statistical analyses among stations were not performed. Instead, spatial variation in environmental conditions, coral cover, abundance, biomass, and herbivorous fish composition was presented using tables and figures to describe ecological patterns within the Padaido Marine Tourism Park.

3 Results

3.1 Marine Environmental Parameters

The environmental conditions recorded during the survey indicated relatively similar water quality among the three sampling stations (Table 1). Water temperature ranged from 30.1 to 31.3°C, salinity varied between 31 and 32‰, and water transparency reached 100% at all stations, indicating excellent underwater visibility during data collection. Current velocity ranged from 0.14 to 0.27 m s^{-1}, while water depth varied between 3 and 7 m, representing typical shallow coral reef habitats within the Padaido Marine Tourism Park.

Overall, the measured environmental parameters were within the tolerance range commonly reported for tropical coral reef ecosystems, providing suitable conditions for coral growth and reef-associated fishes.

Table 1. Environmental parameters measured at each sampling station.

No.	Parameter	Station 1	Station 2	Station 3	Station 4
1	Temperature (°C)	29.7	29.3	30.0	29.9
2	pH	8.40	7.84	7.21	7.58
3	Salinity (‰)	31.5	31.5	31.5	31.5
4	Brightness (m)	5	6	10	10

3.2 Coral Reef Cover

The Line Intercept Transect (LIT) survey revealed spatial variation in live coral cover among the three sampling stations (Figure 2). Station 3 exhibited the highest percentage of live coral cover (47.20%), followed by Station 2 (43.80%) and Station 1 (38.50%).

According to the Indonesian coral reef health classification, all stations were categorized as having moderate coral cover, although Station 3 showed relatively better reef condition than the other surveyed sites. Dead coral, coral rubble, and abiotic substrates constituted a considerable proportion of the benthic community at all stations, indicating variation in benthic composition throughout the conservation area.

3.3 Composition of Herbivorous Reef Fish

A total of 26 herbivorous reef fish species belonging to three families were recorded during the underwater visual census surveys (Table 2). The recorded families comprised Acanthuridae, Scaridae, and Siganidae.

The family Acanthuridae contributed the greatest number of species and individuals observed across all sampling stations. Scaridae represented the second most diverse family, whereas Siganidae consisted of fewer species but was consistently recorded at all stations. The occurrence of these three herbivorous fish families indicates the presence of the principal functional groups responsible for grazing and macroalgal control within the reef ecosystem.

Table 2. Species composition and abundance of herbivorous reef fishes recorded at the four sampling stations.

No.	Family	Species	Station 1	Station 2	Station 3	Station 4
1		*Acanthurus lineatus*	+	+	+	+
2		*Acanthurus mataiioides*	+	+	+	+
3		*Acanthurus nubilus*	+	+	+	+
4		*Acanthurus nigricans*	+	+	+	+
5		*Acanthurus olivaceus*	+	+	+	+
6	Acanthuridae	*Acanthurus pyroferus*	+	+	+	+
7		*Acanthurus triostegus*	-	+	+	+
8		*Ctenochaetus binotatus*	+	+	+	+
9		*Naso lituratus*	+	+	-	+
10		*Naso unicornis*	+	+	+	+
11		*Zebrasoma* sp.	+	+	-	-
12		*Acanthurus nubilus*	-	-	+	-
13		*Chlorurus bleekeri*	+	+	+	+
14		*Chlorurus hockeri*	+	+	+	+
15		*Chlorurus sordidus*	+	-	+	+
16		*Chlorurus microrhinos*	+	-	+	+
17	Scaridae	*Scarus frenatus*	+	+	+	+
18		*Scarus ghobban*	+	+	+	+
19		*Scarus niger*	+	+	+	+
20		*Scarus psittacus*	+	+	+	+
21		*Scarus schlegeli*	+	-	-	+
22		*Scarus tricolor*	+	-	+	+
23		*Siganus doliatus*	+	-	-	+
24	Siganidae	*Siganus puellus*	+	-	-	+
25		*Siganus vulpinus*	+	-	-	+
26		*Siganus stellatus*	-	-	+	-

3.4 Herbivorous Fish Biomass

Herbivorous reef fish abundance and biomass varied among the three sampling stations (Figure 2). Station 3 supported the highest abundance and biomass of herbivorous fishes, whereas Station 1 recorded the lowest values. Station 2 showed intermediate abundance and biomass between the other two stations.

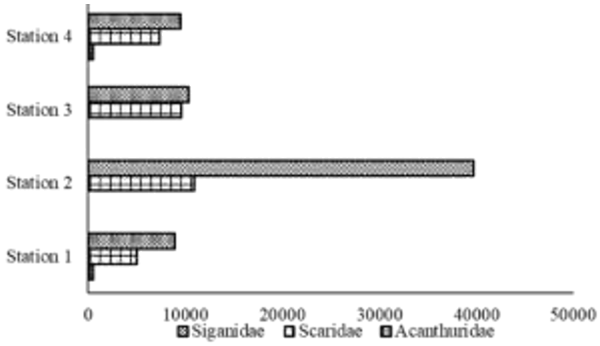

Fig. 2 Composition of herbivorous fish in the Padaido Water Tourism Park.

Estimated herbivorous fish abundance ranged from 614.28 to 1,657.14 individuals ha^{-1}. The highest abundance was recorded at Station 2, followed by Station 1, Station 3, and Station 4.

Estimated biomass ranged from 14,515.76 to 50,609.04 kg ha^{-1}. Station 2 recorded the highest biomass (50,609.04 kg ha^{-1}), whereas the lowest biomass was observed at Station 1 (14,515.76 kg ha^{-1}). Biomass values at Stations 3 and 4 were 19,979.20 kg ha^{-1} and 17,437.13 kg ha^{-1}, respectively.

The spatial distribution of herbivorous fish abundance and biomass among the four sampling stations is presented in Figure 2.

4 Discussion

4.1 Environmental Conditions

The environmental parameters recorded during the study indicated that water quality was generally suitable for the growth of coral reefs and associated reef fishes. Water temperature (30.1–31.3°C), salinity (31–32‰), water transparency (100%), current velocity (0.14–0.27 m s^{-1}), and water depth (3–7 m) were all within the range commonly reported for healthy tropical coral reef ecosystems [8]. These environmental conditions provide a favorable habitat for coral growth, photosynthetic activity of symbiotic zooxanthellae, and the survival of reef-associated organisms.

Although slight variations in temperature and current velocity were observed among sampling stations, these differences were relatively small and were unlikely to substantially influence the distribution of coral reef communities. Instead, local ecological factors such as benthic habitat condition, reef structural complexity, and biological interactions are likely to play a greater role in determining coral reef condition and the distribution of herbivorous reef fishes within the study area [4,9].

High water transparency observed at all stations indicates low sediment input during the survey period, allowing sufficient light penetration for coral photosynthesis. Adequate light availability is essential for maintaining coral productivity because reef-building corals rely on their symbiotic algae to meet a large proportion of their energy requirements [7,10]. Collectively, these findings suggest that the physical and chemical characteristics of the surveyed waters remain generally favorable for sustaining coral reef ecosystems within the Padaido Marine Tourism Park.

4.2 Coral Reef Condition

The present study revealed that live coral cover at the three sampling stations ranged from 38.5% to 47.2%, indicating that the coral reefs within the Padaido Marine Tourism Park were generally in moderate condition according to the Indonesian coral reef health classification [9,11]. Although living corals remained the dominant benthic component, the presence of dead coral, coral rubble, and abiotic substrates suggests that the reef ecosystem has experienced ecological disturbances that may have reduced habitat quality.

Coral reef condition is strongly influenced by both natural and anthropogenic factors, including climate variability, sedimentation, destructive fishing practices, and coastal activities. These disturbances can reduce live coral cover, alter benthic community composition, and ultimately decrease the structural complexity of reef habitats [4,7,10]. Habitat complexity is particularly important because it provides shelter, feeding areas, and nursery habitats for numerous reef-associated organisms, thereby supporting high levels of marine biodiversity [9].

Among the surveyed sites, Station 3 exhibited the highest live coral cover, indicating relatively better habitat quality than Stations 1 and 2. This spatial variation suggests that coral reef condition within the conservation area is heterogeneous and may reflect differences in local environmental conditions and historical disturbance levels. Similar spatial variability has been reported in many tropical coral reef ecosystems, where reef condition differs even within the same marine protected area because of variations in exposure, substrate characteristics, and human activities [12].

Although the observed coral cover was categorized as moderate, maintaining and improving reef condition remains essential for sustaining ecosystem resilience. Healthy coral reefs provide the structural foundation that supports reef fish communities, promotes coral recruitment, and enhances ecosystem recovery following disturbances. Therefore, effective conservation measures and continuous ecological monitoring are required to prevent further degradation and maintain the ecological integrity of the Padaido Marine Tourism Park [10,13].

4.3 Realtionship between cora cover and Herbivorous Reef Fish

The present study demonstrated a positive spatial association between live coral cover and the abundance and biomass of herbivorous reef fishes across the three sampling stations. Station 3, which exhibited the highest live coral cover, also supported the greatest herbivorous fish abundance and biomass, whereas Station 1 recorded the lowest values for these ecological indicators. Although no statistical correlation analysis was performed, this pattern suggests that reef habitats with better coral condition tend to support more developed herbivorous fish communities.

Live coral cover contributes directly to habitat quality by increasing reef structural complexity and providing shelter, feeding grounds, and nursery habitats for reef-associated organisms. Structurally complex reefs generally support greater fish abundance and biomass because they offer a wider range of ecological niches and reduce predation risk [4,9]. Consequently, variations in coral cover are commonly reflected in differences in herbivorous fish community structure among reef habitats.

The dominance of Acanthuridae, followed by Scaridae and Siganidae, indicates that essential herbivory processes remain active within the Padaido Marine Tourism Park. These herbivorous fishes perform complementary ecological functions by grazing algal turfs, removing macroalgae, and maintaining suitable substrates for coral recruitment. Such functional diversity helps prevent macroalgal overgrowth and supports ecological processes that enhance coral reef resilience [5,6,13–15].

The observed relationship between coral cover and herbivorous reef fish communities has important implications for coral reef conservation. Protecting areas with relatively high coral cover is expected to maintain ecosystem functions and preserve key herbivorous fish populations, while degraded reefs may benefit from management strategies that reduce fishing pressure and strengthen long-term ecological monitoring. Maintaining both healthy coral habitats and diverse herbivorous fish assemblages is therefore essential for improving the resilience and long-term sustainability of coral reef ecosystems within the Padaido Marine Tourism Park.

4.4 Management Implications

The findings of this study provide important scientific information for the adaptive management of the Padaido Marine Tourism Park. Spatial variation in live coral cover, herbivorous reef fish abundance, and biomass indicates that ecological conditions differ among reef sites within the protected area. Therefore, management strategies should be tailored to site-specific ecological characteristics rather than applying uniform conservation measures throughout the marine protected area.

Reef sites with relatively higher live coral cover and greater herbivorous fish biomass should be prioritized for conservation because they function as important habitats for reef-associated organisms and contribute to maintaining key ecological processes. Protecting these areas through effective enforcement of marine protected area regulations and minimizing anthropogenic disturbances can help preserve coral reef resilience and sustain ecosystem services [4,10,12].

Conversely, reef sites with lower coral cover and reduced herbivorous fish biomass require greater management attention. Conservation efforts in these areas should emphasize reducing fishing pressure on herbivorous fishes, preventing destructive human activities, and implementing long-term ecological monitoring to evaluate changes in reef condition over time. Maintaining healthy herbivorous fish populations is widely recognized as an effective strategy for controlling macroalgal growth and supporting coral reef recovery following disturbances [13–15].

Overall, integrating periodic assessments of coral cover, herbivorous fish diversity, abundance, and biomass into routine monitoring programs will provide valuable ecological indicators for evaluating management effectiveness within the Padaido Marine Tourism Park. Such information can support evidence-based decision-making, adaptive conservation planning, and the long-term sustainability of coral reef ecosystems in eastern Indonesia.

5 Conclusion

This study demonstrated that coral reefs within the Padaido Marine Tourism Park were generally in moderate condition, with live coral cover ranging from 38.5% to 47.2% across the three sampling stations. A total of 26 herbivorous reef fish species belonging to the families Acanthuridae, Scaridae, and Siganidae were recorded, with Acanthuridae contributing the highest abundance and biomass. Spatial variation in herbivorous fish communities generally followed the pattern of live coral cover, indicating that reef sites with relatively better coral condition supported higher herbivorous fish abundance and biomass.

The findings highlight the ecological importance of maintaining both healthy coral reef habitats and herbivorous fish populations to sustain coral reef resilience within the Padaido Marine Tourism Park. Continuous ecological monitoring and adaptive management are therefore essential to protect reef ecosystem functions and support the long-term conservation of coral reef biodiversity in eastern Indonesia.

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