

# The reef health index for coral reefs management in Indonesia

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**Abstract.** The Indonesian coral reef faced significant challenges due to the lack of precise instruments for assessing the health status of corals, which is crucial for ensuring their long-term viability. The reef health index was established by utilizing extensive monitoring data from Indonesia, incorporating metrics such as live coral cover, resilience level, and biomass of the focal reef fish species. In the year 2021, a comprehensive collection of coral reef data was conducted at 22 distinct places within the waters of Indonesia. It is anticipated that the reef health index data will assist stakeholders in effectively and sustainably managing coral reefs. The findings indicate that the reef health index in Indonesia exhibits a range of values from 2 to 7, with 7 being the highest attainable score. Since observations began in 2014, the Indonesian reef health index has maintained a stable value of 5. The available evidence suggests that there is an ongoing occurrence of coral reef degradation in Indonesian waters, as seen by the diminished biomass of the targeted reef fish species. Nevertheless, the potential for recovery of damaged coral reefs exists if the forces that initiate the damage can be mitigated or eradicated.

## 1 Introduction

Indonesia is an archipelagic country that has a coral reef area of about 2.5 million hectares [1]. Indonesia's location in the world's coral triangle area makes it rich in coral species diversity. The main components of coral reefs are hard corals, more commonly referred to as corals. Approximately 69% of the world's corals can be found in Indonesian waters [2].

Coral reefs have economic value for Indonesia. Sadly, Indonesia's coral reefs are under severe pressure from multiple stressors such as soil runoff, sewage and chemical pollution, new diseases, bleaching caused by global warming, and exploitation of fish resources using destructive fishing [3-8]. Therefore, good management of coral reefs is needed to ensure their sustainability. Accurate information about coral reef health is one of the factors needed to be able to manage coral reef ecosystems well. Based on these considerations, the Research Center for Oceanography - Indonesian Institute of Sciences, which has now changed its name to the Research Center for Oceanography - National Research and Innovation Agency, developed a value for the Indonesian coral reef health index [9].

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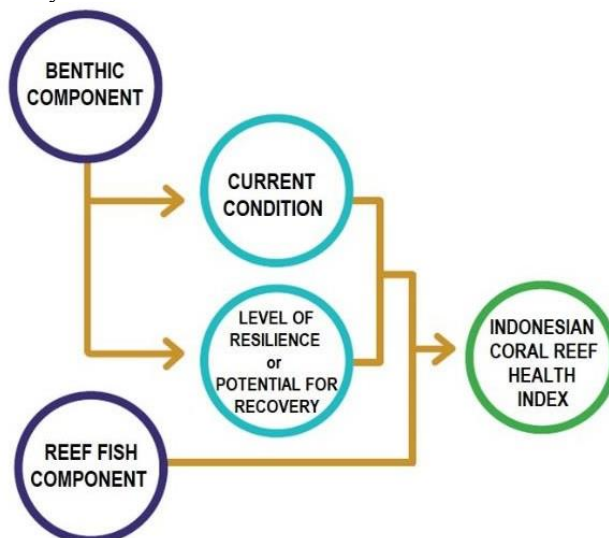
Several publications related to the coral reef index have been developed by previous researchers [10–12]. Some use different variables, and some use many variables to get the index value. The use of many variables may increase the accuracy of a model based on the actual conditions. However, sometimes even more effort is needed, but the increase in accuracy is not proportional to the effort expended [9]. The use of many variables will also be constrained if there are variables that are required but the data is not available. As a result, additional efforts are needed to complete it, including funding and increasing competent human resources in their fields [9]. Based on these considerations, using only available coral reef monitoring data, where field data collection has been carried out in many Indonesian waters in the 2014–2016 period, the Indonesian coral reef health index value was developed. It is hoped that the resulting index value will be more appropriate and relevant to the real conditions of Indonesia itself. The measurement of the coral reef health index value was completed at the end of 2017 [9].

With the increase in monitoring data, the calculation of the coral reef health index value needs to be updated to find out the current conditions. Therefore, the purpose of this study is not only to determine the coral reef health index in each location but also to determine the overall Indonesian coral reef health index value based on the benthic and fish component datasets in 2021. The latest information on the value of the Indonesian coral reef health index is expected to assist stakeholders in better coral reef management.

## 2 Metodology

### 2.1. Formulation

The coral reef health index value is calculated using a formula developed by [9], which involves a combination of benthic components and coral reef fish components (Figure 1). The benthic component consists of the current condition and the level of resilience or potential for recovery.



**Fig 1.** Components used in calculating the coral reef health index [9]

The parameters of the current condition were approached based on the value of live coral cover (LiveCoral-LC), which was distinguished by 3 criteria as follows:

Low :  $LC < 19\%$   
Moderate :  $19\% \leq LC \leq 35\%$   
High :  $LC > 35\%$

The potential of recovery or resilience level was calculated from the combination of the values of the macroalgae cover (Fleshy Seaweed-FS), dead coral (Rubble-R), and live coral (Live Coral-LC). The combination values were then categorized into 2 categories below:

Low :  $FS \geq 3\%$  or  
 $(R > 60\% \text{ and } LC \leq 5\%)$   
High :  $FS < 3\%$  or  
 $R \leq 60\% \text{ or } LC > 5\%$

The coral reef fish component was approached based on the biomass value of the target fish from seven families (carnivorous fish from the Serranidae, Lutjanidae, Lethrinidae, and Haemulidae; and herbivorous fish from the Siganidae, Scaridae, and Acanthuridae), with the following criteria:

Low : biomass  $< 970$  kg/ha  
Moderate :  $970 \text{ kg/ha} \leq \text{biomass} \leq 1940$  kg/ha  
High : (biomassa  $> 1940$  kg/ha).

Furthermore, based on these criteria, the index value can be determined, as shown in Figure 2. The index value ranges from 1 to 10. The higher the index value, the healthier the coral reef condition.

## 2.2. Data sampling

The calculation of the coral reef index is carried out by utilizing coral reef health monitoring data belonging to the Research Center for Oceanography. The data variables needed are live coral cover (LC in%), fleshy seaweed cover (FS in%), coral rubble cover (R in%), and biomass of reef fish from seven selected families (biomass in kg h-1).

Coverage percentage data for LC, FS, and R were obtained based on field data taken using the underwater photo transect (UPT) method and analyzed using CPCe [13]. Technical implementation of the UPT method and analysis with CPCe in detail can be seen in [14, 15]. The latest data on coral reef monitoring carried out by the Research Center for Oceanography is data for 2021, which is spread throughout Indonesia's coral reef waters (table 1). Meanwhile, data for reef fish biomass was collected using the UVC method and focused on the 7 selected families whose technical implementation is in [14, 17].

The latest coral reef monitoring data belonging to the Research Center for Oceanographic was taken at 22 locations in 2021. The 22 locations are spread throughout Indonesia's coral reefs (table 1).

No.	Benthic		Fish	Reef health index (RHI)
	Live coral cover	potential for recovery	Reef fish	
1.	High	High	High	10
2.	Moderate	High	High	9
3.	High	High	Moderate	8
4.	High	Low	High	8
5.	Moderate	High	Moderate	7
6.	Low	High	High	7
7.	High	High	Low	6
8.	High	Low	Moderate	6
9.	Moderate	Low	High	6
10.	Moderate	High	Low	5
11.	Low	High	Moderate	5
12.	Low	Low	High	5
13.	High	Low	Low	4
14.	Moderate	Low	Moderate	4
15.	Low	High	Low	3
16.	Low	Low	Moderate	3
17.	Moderate	Low	Low	2
18.	Low	Low	Low	1

**Figure 2.** Calculation of coral reef health index value [9]

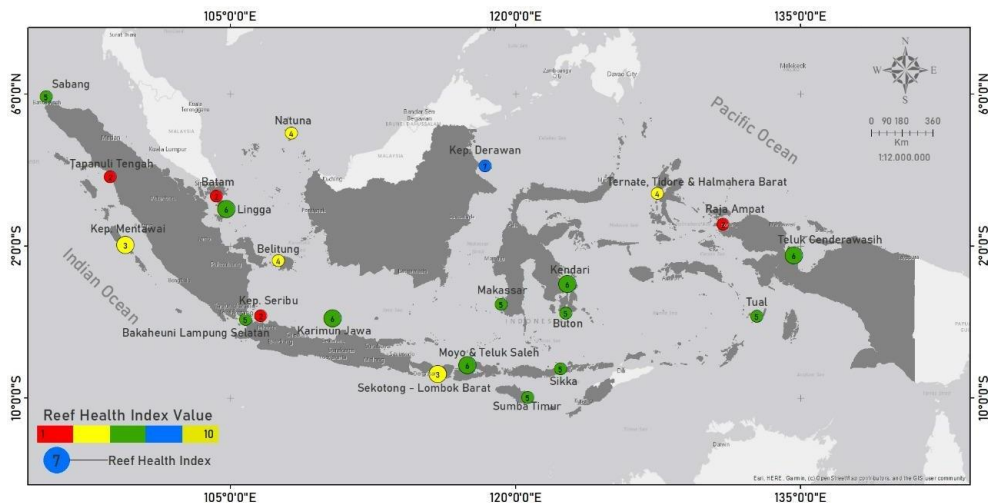
**Table 1.** Location and number of stations for coral reef monitoring in 2021

No	Location	Province	Number of station
1	Bakauheni - Lampung Selatan	Lampung	10
2	Batam	Kepulauan Riau	19
3	Belitung	Bangka Belitung	11
4	Buton	Sulawesi Tenggara	15
5	Karimun Jawa	Jawa Tengah	10
6	Kendari	Sulawesi Tenggara	9

7	Kepulauan Derawan	Kalimantan Timur	11
8	Kepulauan Mentawai	Sumatera Barat	9
9	Kepulauan Seribu	DKI Jakarta	14
10	KKPN TNP Laut Sawu (Sumba Timur)	Nusa Tenggara Timur	10
11	Lingga	Kepulauan Riau	12
12	Makassar	Sulawesi Selatan	13
13	Moyo dan sekitarnya	Nusa Tenggara Barat	32
14	Natuna	Kepulauan Riau	19
15	Raja Ampat	Papua Barat	12
16	Sabang	Nanggroe Aceh Darussalam	12
17	Sekotong - Lombok Barat	Nusa Tenggara Barat	12
18	Sikka	Nusa Tenggara Timur	13
19	Tapanuli Tengah	Sumatera Utara	13
20	Teluk Cenderawasih	Papua	12
21	Ternate, Tidore dan Halmahera Barat	Maluku Utara	14
22	Tual	Maluku	10
Total stations			379

### 3 Results and Discussion

The coral reef health index (RHI) of Indonesia exhibited spatial variability among monitoring sites in the year 2021. The observed values fall within the range of 2 to 7, with a maximum possible value of 10 (see Figure 3). The stations that recorded the lowest levels (RHI = 2) were Central Tapanuli, Batam, Kepulauan Seribu (Thousand Islands), and Raja Ampat. On the other hand, the Derawan Islands in East Kalimantan exhibited the highest index values (RHI = 7).



**Fig. 3.** Indonesia's coral reef health index (RHI) in 2021 at each monitoring location

The observation locations in Central Tapanuli were located around the coastal areas of Hajoran-Sitardas, as well as Mursala Island and its surroundings. The observation locations in Batam were placed around Petong Island, Pulang Abang Besar, Abang Kecil Island, Pangelap Island, and several islands around Karas Island. For the location of the Thousand Islands, observations were made at several stations from Pari Island to West Penjaliran Island in the northern part of the Thousand Islands. Observations in Raja Ampat were carried out at stations around Batanta Island and Salawati Island.

The low coral reef health index in the Central Tapanuli location can be attributed to the inadequate condition of coral reefs on neighbouring small islands, including Silabulabu Island and Silaban Island. The geographical positioning of Batam was influenced by the state of the coral reef ecosystem surrounding Karas Besar Island and Galang Island. The Thousand Island RHI was impacted by the state of coral reef ecosystems situated in its vicinity. The Thousand Islands archipelago has been influenced by the state of coral reef ecosystems located within the Kepulauan Seribu region, specifically on Sebaru Besar Island, Belanda Island, Bira Besar Island, and Pamagaran Island. Poor conditions of coral reef ecosystems were observed in the vicinity of minor islands in Raja Ampat, including Warir Island, Jefman Island, and Waipelet Island, which are situated near the Salawati region.

The RHI values of 2 were indicative of a moderate level of coral cover, a limited potential for recovery, and a low biomass of targeted fish. An elevated FS cover (>3%) or a sequence of low coral cover followed by a high R cover (>60%) may both contribute to the poor recovery potential.

The occurrence of high levels of macroalgae (FS) cover is typically observed in bodies of water that are contaminated, primarily as a result of waste discharge, which contributes to elevated nutrient levels in the water. The augmentation of nitrogen levels will expedite the proliferation of algae, encompassing FS. Furthermore, in the event of a diminished population of herbivorous fish, the regulation of algae proliferation is compromised. The rapid proliferation of algae is a hindrance to the growth of coral. Corals are anticipated to see a decline in their competitive ability to occupy space within the reef ecosystem. Hence, the significance of herbivorous fish within coral reef ecosystems is quite pronounced. According to earlier studies [18–20], the overexploitation of herbivorous fish is to blame for the excessive proliferation of algae.

A sequence of low coral cover and high rubble cover is frequently the consequence of a significant storm that destroys coral or destructive fishing employing bombs. The utilization of explosive devices will result in the fragmentation of coral colonies, leading to their subsequent demise. Due to the unstable nature of R as a substrate, coral larvae cannot endure and develop into mature corals. The broken-down dead coral can be effortlessly flipped by strong currents and waves, burying juvenile corals in the process.

Despite the elevated RHI of the Derawan Islands, vigilance remains warranted, particularly in coral reef ecosystems in close proximity to the Kalimantan mainland. Human activities occurring on the mainland have the potential to impact the waters surrounding Derawan Island due to its geographical proximity to the river estuary in Kalimantan. This is evident from the comparatively reduced live coral cover on Panjang Island, the most distant island from the Kalimantan mainland, in comparison to other islands.

The coral reef index of Indonesia in 2021 has been determined to be 5 on a scale of 10, indicating its global value. The value in question has been consistent over the years, as determined by the analysis of annual monitoring data held by the Research Centre for Oceanography since 2014. The findings indicate that the live coral cover (LC) in Indonesia falls within the "moderate" range ( $19\% < LC < 35\%$ ). Moreover, it demonstrates a significant possibility for recovery, as indicated by the low presence of fleshy seaweed cover (<3%) and rubble cover (<60%). Additionally, the target fish biomass is rather low, measuring below

970 kg/ha. In comparison, the average coral cover was lower than recorded in Malaysia (40.63%) [16].

Based on this figure, it may be inferred that the prevalence of coral reef damage in Indonesian waters remains significant, as seen by the diminished biomass of the targeted reef fish species. The potential for repairing damage to coral reefs remains contingent upon the reduction or elimination of the causative elements.

## Conclusion

The coral reef health index in Indonesia for the year 2021 exhibits a range of values, spanning from 2 to 7 out of a maximum score of 10, across different monitoring locations. In general, the coral reef index of Indonesia in the year 2021 remains constant at a value of 5, which has been unchanged since 2014. Ongoing coral reef degradation persists in Indonesian waters, as evidenced by the diminished biomass of the targeted reef fish species. Nevertheless, the possibility for recovery of coral reefs damaged by many circumstances exists, provided that these triggering events are mitigated or eradicated.

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