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Mapping coral cover using Sentinel-2A in Karimunjawa, Indonesia

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Abstract. *Satya ED, Sabdono A, Wijayanti DP, Helmi M, Widiaratih R. Suryoputro, AAD, Handoyo, G, Puryajati, AD. 2023. Mapping coral cover using Sentinel-2A in Karimunjawa, Indonesia. Biodiversitas 24: 827-836.* Coral reefs in the Karimunjawa National Park (KNP) have their own charm, especially for snorkeling and divers, it can be seen from the number of tourist visits which tends to increase every year, except for 2020 to 2021 due to the COVID-19 pandemic. This study aims to determine the impact of tourism on coral reef cover in KNP, with islands selected as representatives of high, medium and low level of tourist visits using Sentinel-2A. Comparison of Sentinel-2A coral cover area in 2020 with previous research which used Landsat 8 data in 2018 showed decrease in coral cover area by 16.5% and an increase in sand area by 24.1% for island of high tourist visits. It can be seen that tourism activities have significant impact on coral cover area, especially snorkeling and diving activities that are intentional or not potentially damaging to coral reefs. Sentinel-2A's ability to detect coral area is reliable, since field data is needed as input for data processing to identification locations in detail as needed. Coral area in 2020 using Sentinel-2A obtained for Menjangan Besar Island and Menjangan Kecil, Sintok Island, Tengah Island and Seruni Island were 1.88 km^2, 0.303 km^2, 0.318 km^2, 0.237 km^2 respectively.

Keywords: Coral cover, KNP, level tourist visiting, sand cover, Sentinel-2A

INTRODUCTION

Karimunjawa National Park (KNP) is an iconic tourist destination in the northern part of Central Java, Indonesia which is visited by tourists due to its underwater beauty, one of which is its coral reefs (Wijayanto et al. 2021). Therefore, the most dominant types of tourism activities carried out by tourists when visiting KNP are snorkeling, diving, enjoying the sunset and white sand, fishing etc. This marine tourism has had a significant economic impact (Spalding et al. 2017), it can be seen from social changes, namely the shift in the work of the surrounding community from original fishermen to current boat operators and tour guides, moreover there has been an increase in the economy through motor and car rentals, homestays, as well as increased demand for sea-based food products (Ramadhan et al. 2022).

The Karimunjawa National Park Agency (KNPA) who manages KNP has distinguish it into 9 zoning systems, namely the core zone, jungle zone, marine protection zone, land utilization zone, marine tourism utilization zone, marine cultivation zone, historical cultural religious zone, rehabilitation zone, and traditional fishing zone. The existence of marine tourism utilization zones creates its own concerns (Li and Chen 2022), if underwater tourism does not pay much attention to ecotourism or environmental sustainability, there will be pressure and adverse impacts on coral reef ecosystems (Krieger and Chadwick 2013; Toyoshima and Nadaoka 2015; Soares et al. 2021).

The coral reefs in KNP have their own charm, especially for snorkeling and divers, which can be seen from the number of tourist visits which tend to increase every year except for 2020 to 2021 due to the covid19 pandemic resulting in the temporary closure of KNP. Because diving and snorkeling have the potential to harm coral reefs intentionally or unintentionally with the fins hitting or stepping on coral reefs, breaking of coral reefs, especially the branching type, was shown by Kismartini and Yusuf (2015) to cause 10% per year damage to coral reefs in KNP (Hannak et al. 2011). These damaged coral reefs will be more vulnerable to death due to damage to the coral skeleton, susceptibility to disease, increased predation (De et al. 2020).

Coral reefs are not only a support for recreational functions, but have a far more crucial ecological role, namely in the provision of food, health, and coastal protection. However, they are vulnerable to damage due to environmental disturbances (Hayati et al. 2020; Burke and Spalding 2022). The protection and management of coral reefs is not only important for the coral reef habitat itself, but also for local communities who are highly dependent on it as a natural resource (Eastwood et al. 2017; Eddy et al. 2021). According to the above discussion, it is necessary to conserve the coral reefs in KNP as one of the efforts to monitor the condition of coral reefs continually.

This study aims to determine the area of coral reef cover in KNP with selected islands as representatives of high, medium and low levels of tourist visits and to investigate the impact of marine tourism activities (Figure 1). The area of coral reef cover was obtained using remote sensing due to the technology capability to detect the presence of coral cover effectively and efficiently (Yamano et al. 2020; Wicaksono et al. 2021). Landsat imagery was extensively used in earlier studies on the area of coral cover in KNP, including work by Irawan et al. (2017) using Landsat 5, 7, and 8, and by Azka et al. (2019) using Landsat 8. Along with the development of technology in the field of remote sensing, the aspect of resolution such as spatial, temporal, spectral and radiometric, and the application of its use are also growing. There is still limited study use of Sentinel-2A for coral cover in KNP. This condition encourages the research to use Sentinel-2A since it has a better spatial resolution of 10 meters, so the expected results can be having higher accuracy (Phiri et al. 2020). Sentinel-2A has the ability to detect the seabed so it is widely used to detect the presence of sufficient macrobenthos (Oiry and Barrill´e 2021), seagrass beds (Fauzan et al. 2021), and benthic habitats (Lizcano-Sandoval et al. 2022) with reliable and accurate (Peng et al. 2022). Due to the fact that Sentinel-2A data is currently not widely accessible or is not open to the public (Sudmanns et al. 2020), it is still challenging to examine changes in coral cover from the previous year. For this reason, the focus of this study is on reporting coral cover area results for 2020.

MATERIALS AND METHODS

The research area in Karimunjawa National Park (KNP), Central Java, Indonesia covers islands that represent the level of tourist visits approach by number of tourist and ships used based on the Association of Indonesian Tour Guides (HPI/Himpunan Pramuwisata Indonesia 2021), which the time series data recorded the number of daily tourist visits and ships used from November 2018-March 2020. Generally, tourism activities are dominated by snorkeling and diving activities compared to other tourism activities such as sunset trips, fishing and others. Tourists tend to visit during the holiday and summer season namely from June-December 2020 (Bursa et al. 2022), while the tourist arrivals start to decrease slightly with the strong winds and the rains brought by the West Monsoon enters which is not conducive for shipping, snorkeling and diving activities (Figure 2). The same pattern was observed for the type of maritime tourism, with ships employed for the activities of diving, snorkeling and other activities including fishing and sunset cruises (Figure 3). In addition to having a good impact on the local community's economy, marine activities like snorkeling and diving also have negative impact on coral reef (Au et al. 2014; Rouphael and Inglis 2001; Shokri et al. 2021). Other activities that are not directly visible, such as the incorrect anchoring of ship also stresses coral reefs and contribute in escalation of the coral damage (Davis 1977; Forrester 2020).

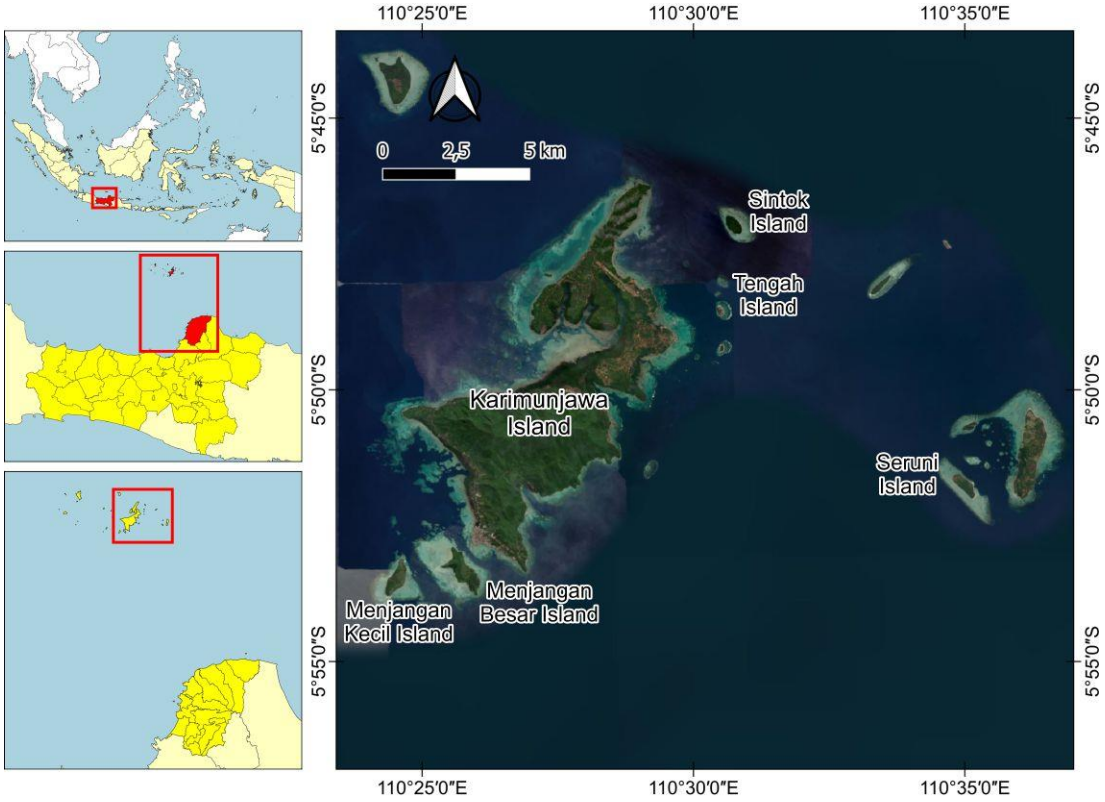

Figure 1. Research location in Karimunjawa National Park (KNP), Central Java, Indonesia

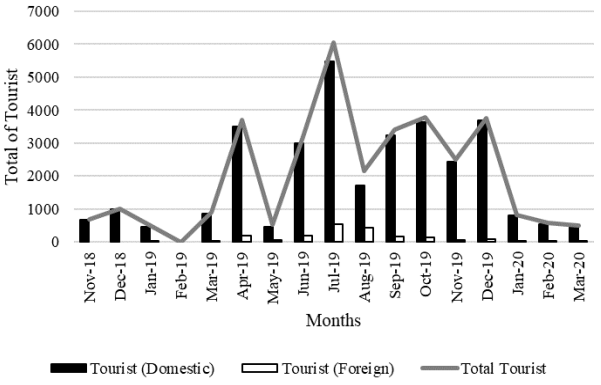

Figure 2. Number of tourists visits (domestic and foreign) in Karimunjawa National Park, Central Java, Indonesia from Nov 2018-March 2020 (HPI 2021)

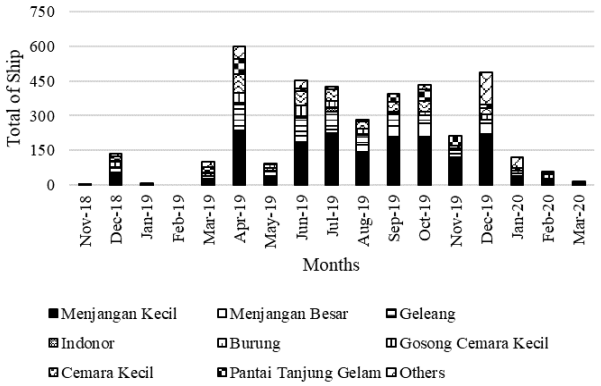

Figure 4. Tourist destinations in western area of Karimunjawa National Park, Central Java, Indonesia (HPI 2021)

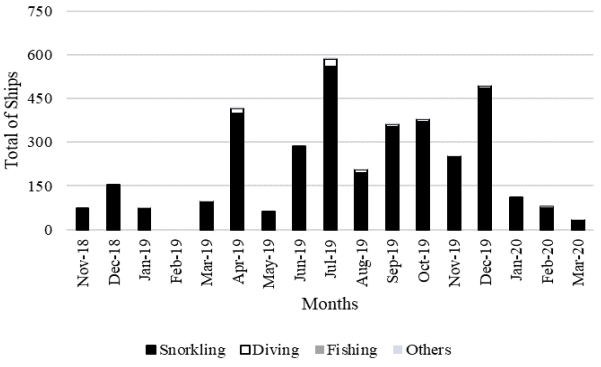

Figure 3. The number of ships used for serve tourists activities from domestic and foreign tourist in Karimunjawa National Park, Central Java, Indonesia from Nov 2018-March 2020 (HPI 2021)

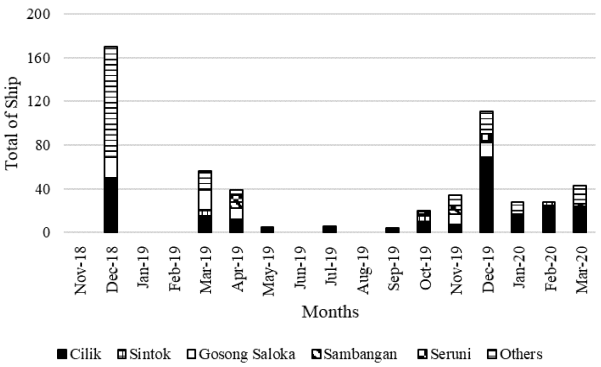

Figure 5. Tourist destinations in eastern area of Karimunjawa National Park, Central Java, Indonesia (HPI 2021)

The tourist visit data furthermore is detailed to the specific island of tourist destination. When the east monsoon occurs between June and August, tourists have a tendency to visit the islands in the western area of KNP (Figure 4); but, when the west monsoon occurs between December and February, tourist visits tend to decrease in the western area and instead they visit the eastern area of KNP (Figure 5). This condition is triggered especially in the western area of KNP when rains and high waves reaching height up to 2 m, hampers shipping and marine activity, while eastern area still have lower wave height due to hinderance of the incoming waves by Karimunjawa Island (Muskananfola et al. 2021). Based on the total amount of tourist visits (Figures 4 and 5), the islands represented with high tourist visits were Menjangan Kecil and Menjangan Besar Islands, while the islands with moderate visits were represented by Sintok and Tengah Islands, while the those with low visits were represented by Seruni Island which is outside the KNP Area. It was also noticed that the high tourist visit destinations were located in western area of KNP, while the medium and low level visit destinations were in the eastern area of KNP.

Coral cover area was obtained from processing of Sentinel-2A satellite imagery for each island obtained from the European Space Agency (ESA) via the Copernicus Open Access Hub website (https://scihub.copernicus.eu/), accessed on 27th March 2021. The Sentinel-2A uses Level-2A Multi Spectral Instrument (MSI) sensor which records spectral channels B2 (490 nm), B3 (560 nm), B4 (665 nm) and B8 (842 nm) at a spatial resolution of 10 meters and temporal resolution of 2-3 days (Elders et al. 2022). Sentinel-2A which provides level 2 imagery with atmospheric correction (Warren et al. 2019; Chraibi et al. 2022) was processed using the SNAP application. Sea bed map was produced using the Sen2Coral method with the Lyzenga formula, namely $Xi = \ln (Ri-Ri^{deep})$ (Hedley et al. 2018). Furthermore, the process of identifying the seabed map was carried out using the supervised method, with input of field data to identify the desired coral and sand areas. There were 26 verification points as input from the field survey as many as 26 points on April 12th, 2021, which were divided into 9 verification points for Menjangan Besar Island and Menjangan Kecil Islands, 7 verification points for Tengah Island, 5 verification points for Sintok Island, and 5 for Seruni Island of verification points (Table 1). These verification points were marked as area with coral, sand and seagrass. After identifying the area they were classified and digitized to calculate the cover of coral and sand area.

Table 1. Verification points for supervised satellite Sentinel-2A (12th April 2021)

No.	Latitude	Longitude	Remarks
Menjangan Besar, Menjangan Kecil and Karimunjawa Islands			
1	5.88456	110.40854	Coral
2	5.8939	110.41589	Coral
3	5.89043	110.43816	Coral
4	5.5324	110.26049	Sand
5	5.52909	110.25747	Sand
6	5.52867	110.25706	Sand
7	5.52684	110.25749	Sand
8	5.53129	110.26255	Sand
9	5.53041	110.26398	Seagrass
Tengah Island			
1	5.48641	110.30.447	Coral
2	5.48662	110.3074	Sand
3	5.4832	110.30648	Sand
4	5.48351	110.30384	Sand
5	5.48726	110.30543	Coral
6	5.48483	110.30753	Sand
7	5.48308	110.30479	Coral
Sintok Island			
1	5.46898	110.30494	Coral
2	5.47206	110.3065	Sand
3	5.47296	110.3101	Coral
4	5.46835	110.31099	Sand
5	5.46564	110.30534	Sand
Seruni Island			
1	5.51372	110.34791	Coral
2	5.5166	110.35145	Sand
3	5.51883	110.35364	Sand
4	5.51847	110.34698	Sand
5	5.51701	110.35158	Seagrass

Table 2. Coral and sand cover area in 2020 from Sentinel-2A

Level of tourist visit with approach of number ships used	Island	Area 2020 (km^2)	
		Coral	Sand
High	Menjangan Besar & Menjangan Kecil	1.87	2.84
Medium	Sintok	0.30	0.37
Medium	Tengah	0.32	-
Low	Seruni	0.24	0.94

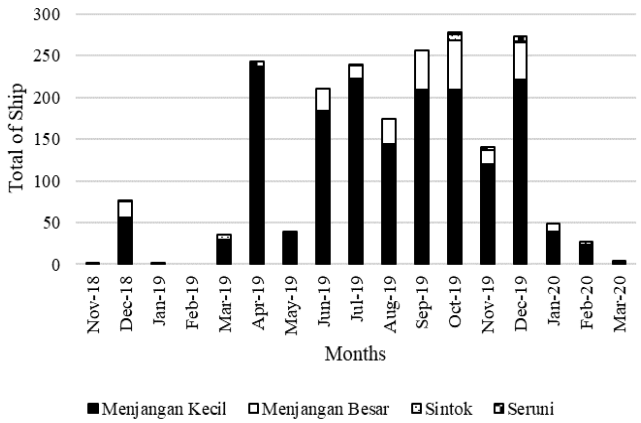

Figure 6. Tourist destination based on level of tourist visits with the approach of number of ships used in Karimunjawa National Park, Central Java, Indonesia (HPI 2021)

RESULTS AND DISCUSSION

Tourist visit data

The study estimated the number of tourists visiting the study area by approach using the number of ships used for snorkeling and diving as an indicator due to the more tourist come, the more ships used. Each tourist ship estimated can carry about 5-15 passengers (Rajan et al. 2011). The study found that the most popular islands for tourist visits were Menjangan Kecil Island and Menjangan Besar Island, located in the western area of KNP, with a decrease in the number of tourists visiting Sintok Island (medium level visits) and Seruni Island (low level visits) located in the eastern part of KNP. This data provides an approximation of the level of tourist visits in each island and can be useful for managing the area and understanding the impact of tourism on the coral reefs.

Coral and sand cover

The study utilized Sentinel-2A satellite data and the Lyzenga formula (Nimalan et al. 2021) to classify seabed pixels and measure the area of coral and sand cover in the study area. Field data was used as input for the classification process. The study was conducted on different islands and the data was collected on different dates, with high tourist visit islands being captured on June 27th 2020 and medium and low tourist visit islands being captured on December 20th 2020. The results of the coral and sand cover for each island were recorded and presented in Table 2 and Figure 7. This method provides a reliable and accurate means of monitoring coral and sand cover in islands and understanding the impact of human activities on these habitats.

In general, the highest coral and sand cover areas of 1.87 km^2 and 2.84 km^2 were found on Menjangan Besar and Menjangan Kecil Island, respectively. Followed by islands with moderate levels of tourist visits, namely Sintok Island with an area of coral and sand cover of 0.30 km^2 and 0.37 km^2, these results are not much different from Tengah Island with a coral cover area of 0.32 km^2. In particular, Tengah Island did not have area of sand, but was dominated by dense coral cover.

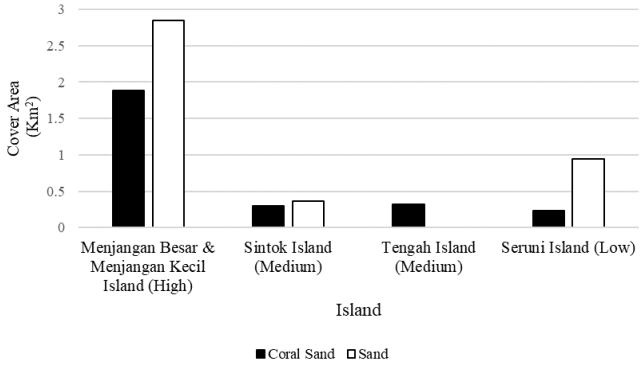

Figure 7. Cover area of coral and sand based on tourist visit of high (Menjangan Besar and Menjangan Kecil Island) processing on 27 June 2020, medium (Sintok and Tengah Island), and low (Seruni Island) on 20th December 2020 based on Sentinel-2A processing

Furthermore, for the low coral cover area represented by Seruni Island, the coral and sand cover areas were 0.24 km^2 and 0.94 km^2 respectively. The pattern obtained for coral area had positive relationship with the level of tourist visits, that is, the wider the area of coral cover, the higher the level of tourist visits. However, impact of increased tourism activity on coral rich areas studied by Andersson (2007) and Liu et al. (2012) showed decrease in the area of coral cover with increasing tourist visits. Moreover, the higher incoming tourist interpret to increasing boating activities and increased anchoring, which impact the coral degradation (Edinger et al. 1998; Small and Oxenford 2022). In light of the fact that the coral cover area is the main magnetism for tourists, so that ecotourism must be promoted in order to ensure the survival of coral biodiversity, and it is now even more crucial to regularly check state of coral health (Hu et al. 2022).

Considered to be a marine tourism utilization zone, the Menjangan Besar Island and Menjangan Kecil Island were the most popular tourist destinations because they still have high coral densities, a rich diversity of coral genus, and excellent coral cover (Januardi et al. 2016). The waters of KNP have a good level of brightness and clarity, so that coral reefs at a depth of 8 meters are still clearly visible from the surface. Figure 8 displays the results of Sentinel-2A processing for the area of coral and sand cover for the islands of Menjangan Besar Island and Menjangan Kecil Island, which cover an area of 1.87 km^2 and 2.84 km^2, respectively, in 2020.

The coral and sand coverage of Sintok Island, which is characterized by medium tourist activity, was quantified using Sentinel-2A imagery with a coverage area of 0.30 km^2 and 0.37 km^2, as depicted in Figure 9. The coral coverage area on Tengah Island was found to be 0.32 km^2, as illustrated in Figure 10. Tengah Island is designated for marine utilization, while Sintok Island is divided into two zones, with the northern part designated as a marine protection zone and the southern part as a marine utilization zone. Tengah Island is a popular spot for snorkeling and diving, due to its high coral density and diversity, as reported by Kusuma et al. (2018), who observed that shallow waters have a higher coral density than deep waters, but the number of lifeforms in the shallow sea is lower than in the deep sea. A similar pattern was also found on Sintok Island, according to Widhiatmoko et al. (2020), who reported that live coral coverage in shallow waters is higher than in deep waters. However, the limited availability of satellite data from previous studies for coral and sand coverage in Sintok and Tengah Island hinders the ability to measure changes in coral and sand coverage. The presence of a resort on Tengah Island may also contribute to stress on coral reef habitats through nutrient, sediment, and chemical pollutant inputs (Cowburn et al. 2018).

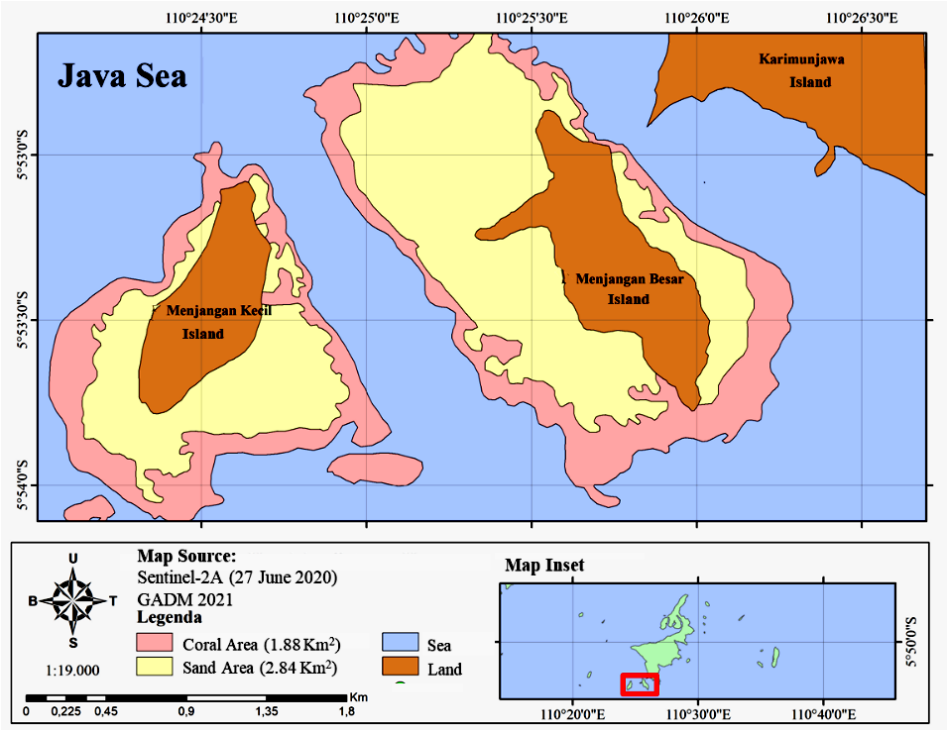

Figure 8. Cover area of coral and sand based on high level tourist visit (Menjangan Besar dan Menjangan Kecil Island) from Sentinel-2A imagery processed on 27 June 2020 (source: https://scihub.copernicus.eu)

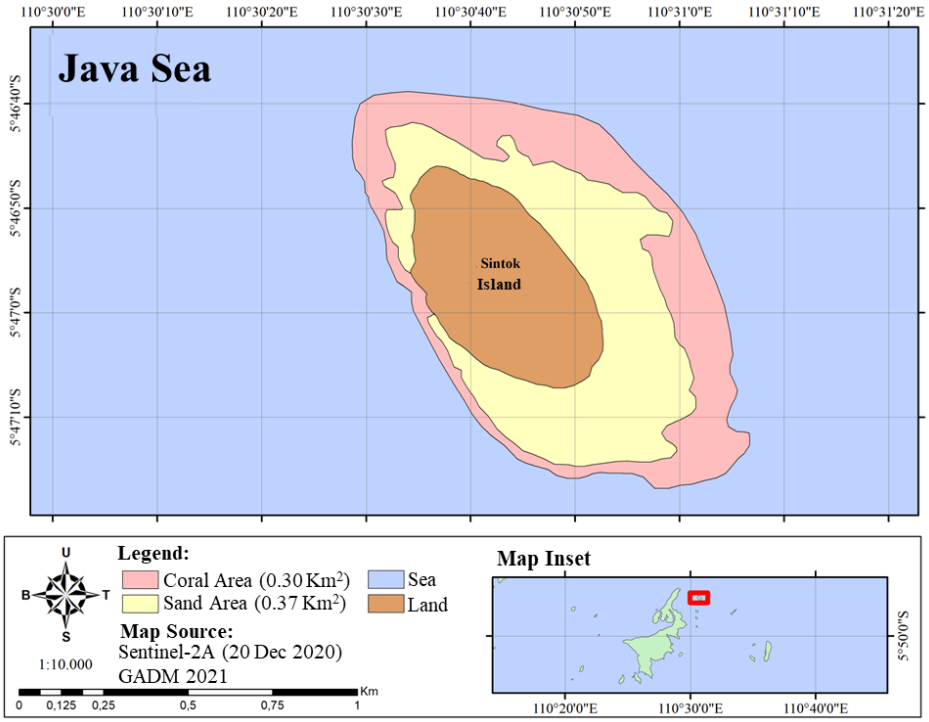

Figure 9. Cover area of coral and sand based on medium level tourist visit (Sintok Island) from Sentinel-2A imagery processed on 20 December 2020 (source: https://scihub.copernicus.eu)

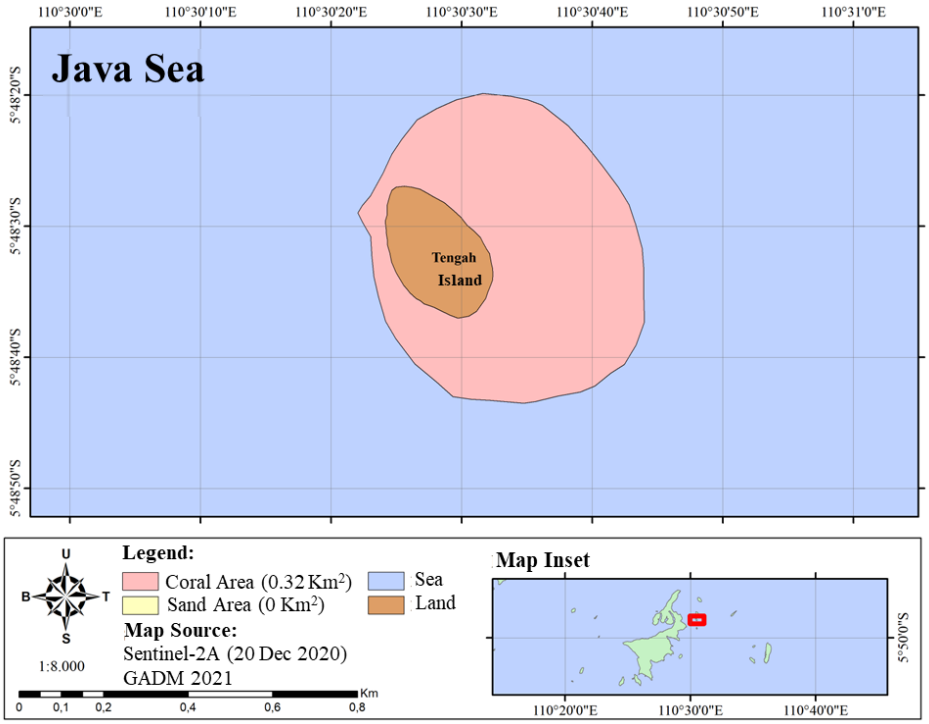

Figure 10. Cover area of coral and sand based on medium level tourist visit (Tengah Island) from Sentinel-2A imagery processed on 20 December 2020 (source: https://scihub.copernicus.eu)

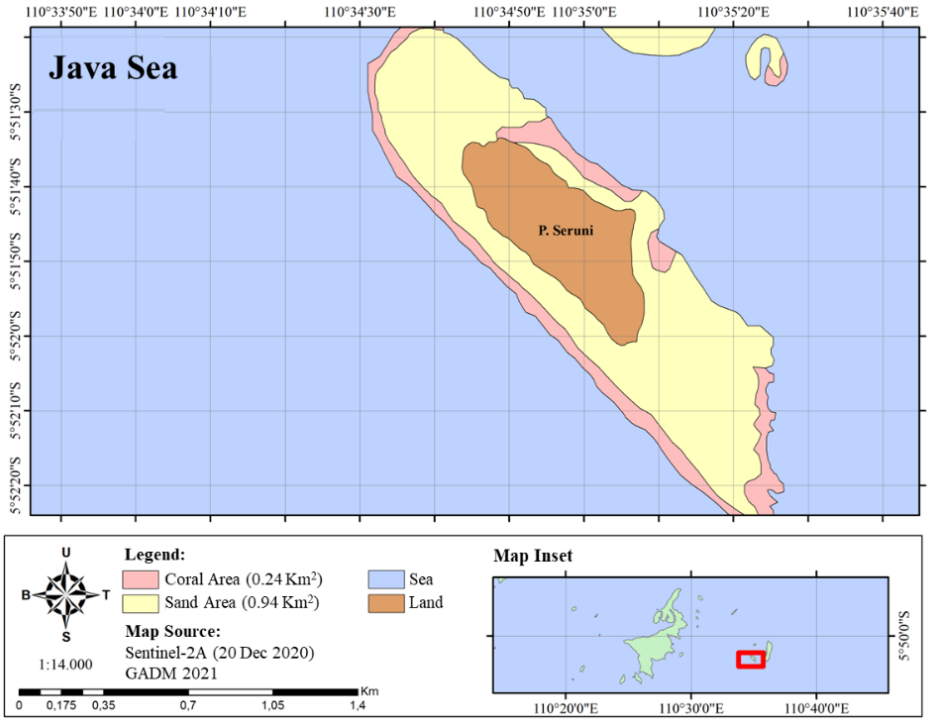

Figure 11. Cover area of coral and sand based on low level tourist visit (Seruni Island) from Sentinel-2A imagery processed on 20 December 2020 (source: https://scihub.copernicus.eu)

The coral and sand coverage of Seruni Island, which is characterized by low tourist activity levels, was determined using Sentinel-2A imagery with a coverage area of 0.24 km^2 and 0.94 km^2 as depicted in Figure 11. A study by Munasik et al. (2021) found that the coral coverage and diversity of coral species on Seruni Island were lower compared to other islands within marine protection and utilization zones. Seruni Island, located on the easternmost perimeter and outside of the KNP region, has a smaller coral coverage area in comparison to Menjangan Besar Island, Menjangan Kecil Island, Tengah Island, and Sintok Island, which are semi-enclosed islands in proximity to Karimunjawa Island. The limited availability of data on coral and sand coverage from previous studies and the constraints of Sentinel-2A data make it challenging to discern changes in coral and sand coverage on Seruni Island. Additionally, the presence of marine floating cages on the island may impact nutrient enrichment, however, the coral habitats remain in a healthy state (Sabdono et al. 2019).

The changes in coral and sand coverage on islands with low and medium levels of tourist activity cannot be accurately determined due to a lack of satellite data. However, changes in coral and sand coverage on islands with high levels of tourist activity, namely Menjangan Besar Island and Menjangan Kecil Island, can be observed. Table 3 illustrates the changes in coral and sand coverage from 2014-2020 in detail. Previous research by Azka et al. (2019) using Landsat 8 imagery was used to compare the coral and sand coverage in the years 2014-2018 to the coverage in 2020 using Sentinel-2A imagery in this study. Overall, the coral coverage on Menjangan Besar Island and Menjangan Kecil Island fluctuated, with an increase in 2015, 2017, and 2018 and a decrease in 2016 and 2020. Azka et al. (2019) found that the coral and sand coverage on Menjangan Besar Island and Menajangan Kecil Island was 2.19 km^2 and 2.16 km^2 respectively in 2018 using Landsat 8 imagery, while Sentinel-2A imagery in this study found the coverage to be 1.88 km^2 and 2.84 km^2 respectively in 2020. This data shows a decrease in coral coverage by 16% or 0.31 km^2 and an increase in sand coverage by 24% or 0.69 km^2 from 2018 to 2020 (Figure 12). This pattern is consistent with research by Januardi et al. (2016) who found a decrease in coral coverage on Menjangan Besar Island by 7.92 Ha from 2013-2015 using Landsat 8 imagery and research by Ilham et al. (2018) who found a decrease in coral coverage on Menjangan Kecil Island by 14.1 Ha from 2013-2017 using Landsat 7 imagery. The results of this study show the importance of monitoring coral cover continuously as an effort to preserve coral reefs, especially in areas with high tourist visits to get better information for decision maker as a tool of management and policy (Zakai and Chadwick-Furman 2002).

The findings of this study suggest that islands with higher levels of tourist activity experience a greater decline in coral coverage. This is particularly evident on Menjangan Kecil Island, due to the high pressure of un-ecotourism behavior. According to data from HPI, Menjangan Kecil Island was the most visited island by tourists from November 2018 to March 2020. The decline in coral coverage results in an increase in the area of sand.

Table 3. Cover area of coral and sand in Menjangan Besar and Menjangan Kecil Island from Landsat 8 during 2014-2018 (Azka et al. 2019) and Sentinel-2A (2020)

Cover area	Cover area of coral and sand (km^2)					
	2014	**2015**	**2016**	**2017**	**2018**	**2020**
Coral	2.00	2.19	1.63	1.89	2.19	1.88
Sand	1.93	2.11	2.36	2.54	2.16	2.84

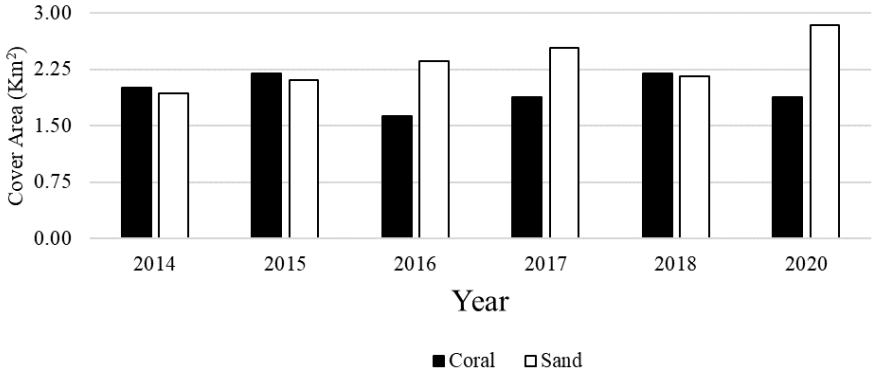

Figure 12. Cover area of coral and sand in Menjangan Besar and Menjangan Kecil Island from Landsat 8 during 2014-2018 (Azka et al. 2019) and Sentinel-2A (2020)

This is because as living corals die, over time they degrade and shrink, resembling a sand-like shape. This decline in coral coverage is caused by the transformation to other habitats and is consistent with previous research. Biondi et al. (2014) found that the decline in coral coverage on Menjangan Besar Island and Menjangan Kecil Island was due to the high level of snorkeling activities, which can be seen in the large number of new coral fractures and scratches on coral reefs caused by collisions with fins and inappropriate anchoring practices (Saphier and Hoffmann 2005; Kininmonth et al. 2014; Webler and Jakubowski 2016; Broad et al. 2022). Additionally, Lamb et al. (2014) found that coral reefs in areas with high diving intensity have a higher prevalence of coral death. Furthermore, coral damage can also be caused by natural factors such as high waves, sedimentation, alga overgrowth, feeding scars from Drupella snails, and climate change (Hein et al. 2015; Januardi et al. 2016; Carter et al. 2020). To maintain coral biodiversity in areas with high tourist density, possible solution is to provide education such as briefings before snorkeling or diving in smaller groups, regarding buoyancy control and other ecotourism behaviors to minimize damage (Barker and Robert 2004; Uyarra and Côté 2007; Toyoshima and Nadaoka 2015). Furthermore, another option such as KNPA provides appointed routes for diving and snorkeling based on their expertise (Rangel et al. 2015). This option becomes powerful solutions for reef conservation area to reduce coral reef damage strictly by allowing the certifying training course as permit for divers and snorkelers around determined coral reefs (Camp and Fraser 2012; Pineiro-Corbeira et al. 2020; Allen et al. 2022).

This study has demonstrated that Sentinel-2A imagery is reliable and effective in identifying coral and sand cover areas in the waters of Karimunjawa. This is supported by the fact that Sentinel-2A imagery requires field data for input, which helps to accurately classify the desired area. The findings show that there is a significant impact on coral and sand cover areas in KNP, particularly in areas with high levels of tourist visits such as Menjangan Besar and Menjangan Kecil Island. These areas have seen a decrease in coral cover by 16% or 0.31 km^2 and an increase in sand cover by 24.1% or 0.69 km^2, likely due to the destruction of live coral, which has led to changes in habitats. These findings highlight the need to continuously monitor coral and sand cover areas, particularly in areas with high tourist density. Additionally, conservation education for diving and snorkeling should be implemented as a management tool to reduce the pressure on coral reefs. This can include limiting the number of divers and snorkelers, mandatory guided tours, training programs for safe diving and snorkeling, and the use of artificial coral reefs or designated routes for diving and snorkeling. Furthermore, certifying training course for the behavior of divers and snorkelers around coral reefs, could also be a good solution for reef conservation.

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REFERENCES

Allen ME, Loomis DK, Vaske J. 2022. Norm power of scuba diving and snorkeling behaviors in the Florida Keys. Ocean Coast Manag 228: 106300. DOI: 10.1016/j.ocecoaman.2022.106300.

Andersson JEC. 2007. The recreational cost of coral bleaching -A stated and revealed preference study of international tourists. Ecol Econ 62: 704-715. DOI: 10.1016/j.ecolecon.2006.09.001.

Au ACS, Zhang L, Chung SS, Qiu JW. 2014. Diving associated coral breakage in Hong Kong: Differential susceptibility to damage. Mar Pollut Bull 85: 789-796. DOI: 10.1016/j.marpolbul.2014.01.024.

Azka LM, Mustafa LD, Mas'udia PE. 2019. Coral reef area analysis based on satellite imagery data processing using the lyzenga algorithm. J JARTEL 8 (1): 13-19. DOI: 10.33795/jartel.v8i1.150. [Indonesian]

Barker NHL, Roberts CM. 2004. Scuba diver behaviour and the management of diving impacts on coral reefs. Biol Conserv 120: 481-489. DOI: 10.1016/j.biocon.2004.03.021.

Biondi I, Munasik M, Koesoemadji K. 2014. Kondisi terumbu karang pada lokasi wisata snorkeling di Kepulauan Karimunjawa, Jawa Tengah. J Mar Res 3 (3): 194-201. DOI: 10.14710/jmr.v3i3.5990.

Broad A, Rees M, Knott N, Swadling D, Hammond M, Ingleton T, Morris B, Davis AR. 2022. Anchor scour from shipping and the defaunation of rocky reefs: A quantitative assessment. Sci Total Environ 863: 160717. DOI: 10.1016/j.scitotenv.2022.160717.

Burke L, Spalding M. 2022. Shoreline protection by the world's coral reefs: Mapping the benefits to people, assets, and infrastructure. Mar Policy 146: 105311. DOI: 10.1016/j.marpol.2022.105311.

Bursa B, Mailer M, Axhausen KW. 2022. Travel behavior on vacation: transport mode choice of tourists at destinations. Transportation Res Part A: Policy Pract 166: 234-261. DOI: 10.1016/j.tra.2022.09.018.

Camp E, Fraser D. 2012. Influence of conservation education dive briefings as a management tool on the timing and nature of recreational SCUBA diving impacts on coral reefs. Ocean Coast Manag 61: 30-37. DOI: 10.1016/j.ocecoaman.2012.02.002.

Carter AL, Wilson AM, Bello M, Hoyos-Padilla EM, Inall ME, Ketchum JT, Schurer A, Tudhope AW. 2020. Assessing opportunities to support coral reef climate change refugia in MPAs: A case study at the Revillagigedo Archipelago. Mar Pol 112: 103769. DOI: 10.1016/j.marpol.2019.103769.

Chraibi E, Boissieu FD, Barbier N, Luque S, Féret J. 2022. Stability in time and consistency between atmospheric corrections: Assessing the reliability of Sentinel-2 products for biodiversity monitoring in tropical forests. Intl J Appl Earth Observation Geoinformation 112: 102884. DOI: 10.1016/j.jag.2022.102884.

Cowburn B, Moritz C, Birrell C, Grimsditch G, Abdulla A. 2018. Can luxury and environmental sustainability co-exist? Assessing the environmental impact of resort tourism on coral reefs in the Maldives. Ocean Coast Manag 158: 120-127. DOI: 10.1016/j.ocecoaman.2018.03.025.

Davis GE. 1977. Anchor damage to a coral reef on the coast of Florida. Biol Conserv 11: 29-34. DOI: 10.1016/0006-3207(77)90024-6.

De K, Nanajkar M, Mote S, Ingolea B. 2020. Coral damage by recreational diving activities in a Marine Protected Area of India: Unaccountability leading to 'tragedy of the not so commons'. Mar Pollut Bull 155: 111190. DOI: 10.1016/j.marpolbul.2020.111190.

Eastwood EK, Clary DG, Melnick DJ. 2017. Coral reef health and management on the verge of a tourism boom: A case study from Miches, Dominican Republic. Ocean Coast Manag 138: 192-204. DOI: 10.1016/j.ocecoaman.2017.01.023.

Eddy TD, Lam VW, Reygondeau G, Cisneros-Montemayor AM, Greer K, Palomares ML, Bruno JF, Ota Y, Cheung WW. 2021. Global decline in capacity of coral reefs to provide ecosystem services. One Earth 4: 1278-1285. DOI: 10.1016/j.oneear.2021.08.016.

Edinger EN, Jompa J, Limmon GV, Widjatmoko W, Risk MJ. 1998. Reef degradation and coral biodiversity in Indonesia: Effects of land-based pollution, destructive fishing practices and changes over time. Mar Pollut Bull 36 (8): 617-630. DOI: 10.1016/S0025-326X(98)00047-2.

Elders A, Carroll, ML, Neigh CSR, D'Agostino AL, Ksoll C, Wooten MR, Brown ME. 2022. Estimating crop type and yield of small holder fields in Burkina Faso using multi-day Sentinel-2. Remote Sens Appl Soc Environ 27: 100820. DOI: 10.1016/j.rsase.2022.100820.

Fauzan MA, Wicaksono P, Hartono. 2021. Characterizing Derawan seagrass cover change with time-series Sentinel-2 images. Reg Stud Mar Sci 48: 102048. DOI: 10.1016/j.rsma.2021.102048.

Forrester GE. 2020. The influence of boat moorings on anchoring and potential anchor damage to coral reefs. Ocean Coast Manag 198: 105354. DOI: 10.1016/j.ocecoaman.2020.105354.

Hannak JS, Kompatscher S, Stachowitsch M, Herler J. 2011. Snorkelling and trampling in shallow-water fringing reefs: Risk assessment and proposed management strategy. J Environ Manag 92: 2723-2733. DOI: 10.1016/j.jenvman.2011.06.012.

Hayati Y, Adrianto L, Krisanti M, Pranowo WS, Kurniawan F. 2020. Magnitudes and tourist perception of marine debris on small tourism island: Assessment of Tidung Island, Jakarta, Indonesia. Mar Pollut Bull 158: 111393. DOI: 10.1016/j.marpolbul.2020.111393.

Hedley JD, Roelfsema C, Brando V, Giardino C, Kutser T, Phinn S. 2018. Coral reef applications of Sentinel-2: Coverage, characteristics, bathymetry and benthic mapping with comparison to Landsat 8. Remote Sens Environ 216: 598-614. DOI: 10.1016/j.rse.2018.07.014.

Hein MY, Lamb JB, Scott C, Willis BL. 2015. Assessing baseline levels of coral health in a newly established marine protected area in a global scuba diving hotspot. Mar Environ Res 103: 56-65. DOI: 10.1016/j.marenvres.2014.11.008.

Hu W, Zheng X, Li Y, Du J, Lv Y, Su S, Xiao B, Ye X, Jiang Q, Tan H, Liao B. 2022. High vulnerability and a big conservation gap: Mapping the vulnerability of coastal scleractinian corals in South China. Sci Total Environ 847: 157363. DOI: 10.1016/j.scitotenv.2022.157363.

Ilham M, Supriharyono S, Widyorini N. 2018. Analysis of Changes in the Area of Coral Reefs Using Remote Sensing Data from Landsat Imagery 7 Etm+ and 8 Oil in the Waters of Menjangan Kecil Island, Karimunjawa (Jepara). Manag Aquat Resour J 7 (1): 157-163. DOI: 10.14710/marj.v7i1.22536. [Indonesian]

Irawan J, Sasmito B, Suprayogi A. 2017. Mapping the Distribution of Coral Reefs Using the Lyzenga Algorithm Temporally Using Landsat 5 7 and 8 Imagery (Study Case: Karimunjawa Island). J Geodesy Undip 6 (2): 56- 61. [Indonesian]

Januardi R, Hartoko A, Purnomo PW. 2016. Habitat analysis and changes in coral reef area on Menjangan Besar Island, Karimunjawa Islands using satellite imagery. Manag Aquat Resour J 5 (4): 302-310. DOI: 10.14710/marj.v5i4.14435. [Indonesian]

Kininmonth S, Lemm S, Malone C, Hatley T. 2014. Spatial vulnerability assessment of anchor damage within the Great Barrier Reef World Heritage Area, Australia. Ocean Coast Manag 100: 20-31. DOI: 10.1016/j.ocecoaman.2014.07.003.

Kismartini, Yusuf M. 2015. Stakeholders analysis: Managing coastal policy implementation in Rembang District. Procedia Environ Sci 23: 338-345. DOI: 10.1016/j.proenv.2015.01.049.

Krieger JR, Chadwick NE. 2013. Recreational diving impacts and the use of pre-dive briefings as a management strategy on Florida coral reefs. J Coast Conserv 17 (1): 179-189. DOI: 10.1007/s11852-012-0229-9.

Kusuma AB, Ardli ER, Prabowo RE. 2018. The diversity of stony coral and the tendency to bleach based on lifeform in the Tengah Patch-Reef of Karimunjawa Islands. Scr Biol 5 (1): 13-18. DOI: 10.20884/1.sb.2018.5.1.416.

Lamb JB, True JD, Piromvaragorn S, Willis BL. 2014. Scuba diving damage and intensity of tourist activities increases coral disease prevalence. Biol Conserv 178: 88-96. DOI: 10.1016/j.biocon.2014.06.027.

Li T, Chen Y. 2022. The obstacle to building a mutual regulation system: Exploring people's intervention intention toward tourists' deviant behavior. Ann Tour Res 93: 103377. DOI: 10.1016/j.annals.2022.103377.

Liu PJ, Meng PJ, Liu LL, Wang JT, Leu MY. 2012. Impacts of human activities on coral reef ecosystems of southern Taiwan: A long-term study. Mar Pollut Bull 64: 1129-1135. DOI: 10.1016/j.marpolbul.2012.03.031.

Lizcano-Sandoval L, Anastasiou C, Montes E, Raulerson G, Sherwood E, Muller-Karger FE. 2022. Seagrass distribution, areal cover, and changes (1990-2021) in coastal waters off West-Central Florida, USA. Estuar Coast Shelf Sci 279: 108134. DOI: 10.1016/j.ecss.2022.108134.

Munasik, Romadhoni AA, Helmi M. 2021. Comparison of Spatial Patterns of Coral Reef Conditions in Karimunjawa National Park. Mar J 14 (2): 175-184. DOI: 10.21107/jk.v14i2.11436. [Indonesian]

Muskananfola MR, Erzad AF, Hartoko A. 2021. Hydro-oceanographic characteristics and sedimentation in the waters of Kemujan Island, Karimunjawa, Indonesia. AACL Bioflux 14 (5): 2866-2877.

Nimalan K, Thanikachalam M, Usha T. 2021. Development of spectral library for coral reef benthic compositions in Gulf of Mannar. Reg Stud Mar Sci 47: 101978. DOI: 10.1016/j.rsma.2021.101978.

Oiry S, Barill´e L. 2021. Using sentinel-2 satellite imagery to develop microphytobenthos-based water quality indices in estuaries. Ecol Indicators 121: 107184. DOI: 10.1016/j.ecolind.2020.107184.

Peng Y, Sengupta D, Duan Y, Chen C, Tian B. 2022. Accurate mapping of Chinese coastal aquaculture ponds using biophysical parameters based on Sentinel-2 time series images. Mar Poll Bull 181: 113901. DOI: 10.1016/j.marpolbul.2022.113901.

Phiri D, Simwanda M, Salekin S, Nyirenda VR, Murayama Y, Ranagalage M. 2020. Sentinel-2 Data for Land Cover/Use Mapping: A Review Remote Sens 12 (14): 2291. DOI: 10.3390/rs12142291.

Piñeiro-Corbeira C, Barreiro R, Olmedo M, Cruz-Modino RDL. 2020. Recreational snorkeling activities to enhance seascape enjoyment and environmental education in the Islas Atlánticas de Galicia National Park (Spain). J Environ Manag 272: 111065. DOI: 10.1016/j.jenvman.2020.111065.

Rajan B, Varghese VM, Pradeepkumar AP. 2011. Recreational boat carrying capacity of Vembanad Lake Ecosystem, Kerala, South India. Environ Res Eng Manag 56 (2): 11-19. DOI: 10.5755/j01.erem.56.2.270.

Ramadhan A, Salim WA, Argo TA, Prihatiningsih P. 2022. The human dimension dilemma in marine spatial planning. Mar Policy 146: 105297. DOI: 10.1016/j.marpol.2022.105297.

Rangel MO, Pita CB, Gonçalves JMS, Oliveira F, Costa C, Erzini K. 2015. Eco-touristic snorkelling routes at Marinha beach (Algarve): Environmental education and human impacts. Mar Policy 60: 62-69. DOI: 10.1016/j.marpol.2015.05.017.

Rouphael AB, Inglis GL. 2001. "Take only photographs and leave only footprint'?: An experimental study of the impacts of underwater photographer on coral reef dive site. Biol Conserv 100: 281-287. DOI: 10.1016/S0006-3207(01)00032-5.

Sabdono A, Radjasa OK, Trianto A, Sarjito, Munasik, Wijayanti DP. 2019. Preliminary study of the effect of nutrient enrichment, released by marine floating cages, on the coral disease outbreak in Karimunjawa, Indonesia. Reg Stud Mar Sci 30: 100704. DOI: 10.1016/j.rsma.2019.100704.

Saphier AD, Hoffmann TC. 2005. Forecasting models to quantify three anthropogenic stresses on coral reefs from marine recreation: Anchor damage, diver contact and copper emission from antifouling paint. Mar Pollut Bull 51: 590-598. DOI: 10.1016/j.marpolbul.2005.02.033.

Shokri MR, Mohammadi M. 2021. Effects of recreational SCUBA diving on coral reefs with an emphasis on tourism suitability index and carrying capacity of reefs in Kish Island, the northern Persian Gulf. Reg Stud Mar Sci 45: 101813. DOI: 10.1016/j.rsma.2021.101813.

Small M, Oxenford HA. 2022. Impacts of cruise ship anchoring during COVID-19: Management failures and lessons learnt. Ocean Coast Manag 229: 106332. DOI: 10.1016/j.ocecoaman.2022.106332.

Soares MO, Rossi S, Gurgel AR, Lucas CC, Tavares TC, Diniz B, Feitosa CV, Rabelo EF, Pereira PH, de Kikuchi RK, Leão ZM. 2021. Impacts of a changing environment on marginal coral reefs in the Tropical Southwestern Atlantic. Ocean Coast Manag 210: 105692. DOI: 10.1016/j.ocecoaman.2021.105692.

Spalding M, Burke L, Wood SA, Ashpole J, Hutchison J, Ermgassen PZ. 2017. Mapping the global value and distribution of coral reef tourism. Mar Policy 82: 104-113. DOI: 10.1016/j.marpol.2017.05.014.

Sudmanns M, Tiede D, Augustin H, Lang S. 2020. Assessing global Sentinel-2 coverage dynamics and data availability for operational Earth observation (EO) applications using the EO-Compass. Intl J Digital Earth 13 (7): 768-784. DOI: 10.1080/17538947.2019.1572799.

Toyoshima J, Nadaoka K. 2015. Importance of environmental briefing and buoyancy control on reducing negative impacts of SCUBA diving on coral reefs. Ocean Coast Manag 116: 20-26. DOI: 10.1016/j.ocecoaman.2015.06.018.

Uyarra MC, Côté IM. 2007. The quest for cryptic creatures: Impacts of species-focused recreational diving on corals. Biol Conserv 136: 77-84. DOI: 10.1016/j.biocon.2006.11.006.

Warren MA, Simis SG, Martinez-Vicente V, Poser K, Bresciani M, Alikas K, Spyrakos E, Giardino C, Ansper A. 2019. Assessment of atmospheric correction algorithms for the Sentinel-2A MultiSpectral Imager over coastal and inland waters. Remote Sens Environ 225: 267-289. DOI: 10.1016/j.rse.2019.03.018.

Webler T, Jakubowski K. 2016. Mitigating damaging behaviors of snorkelers to coral reefs in Puerto Rico through a pre-trip media-based intervention. Biol Conserv 197: 223-228. DOI: 10.1016/j.biocon.2016.03.012.

Wicaksono P, Wulandari SA, Lazuardi W, Munir M. 2021. Sentinel-2 images deliver possibilities for accurate and consistent multi-temporal benthic habitat maps in optically shallow water. Remote Sens Appl: Soc Environ 23: 100572. DOI: 10.1016/j.rsase.2021.100572.

Widhiatmoko MC, Endrawati H, Taufiq NSPJ. 2020. Potensi ekosistem terumbu karang untuk pengembangan ekowisata di Pulau Sintok Taman Nasional Karimunjawa. J Mar Res 9 (4): 374-385. DOI: 10.14710/jmr.v9i4.27801. [Indonesian]

Wijayanto A, Munasik, Farasara FP, Fadlilah YN, Windiyana AN, Meiliana S, Haryanti D. 2021. Coral reef coverage and reef fish abundance in Menyawakan Island, Karimunjawa. IOP Conf Ser Earth Environ Sci 750: 012057. DOI: 10.1088/1755-1315/750/1/012057.

Yamano H, Sakuma A, Harii S. 2020. Coral-spawn slicks: Reflectance spectra and detection using optical satellite data. Remote Sens Environ 251: 112058. DOI: 10.1016/j.rse.2020.112058.

Zakai D, Chadwick-Furman NE. 2002. Impacts of intensive recreational diving on reef corals at Eilat, northern Red Sea. Biol Conserv 105: 179-187. DOI: 10.1016/S0006-3207(01)00181-1.