Changes and vulnerability of coral reef ecosystem based on field and remote sensing data on Kemujan Island, Karimunjawa Islands, Indonesia

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Abstract. Coral reefs have enormous ecological benefits for marine organisms and human being, therefore needs to be maintained and managed in a sustainable manner. The decline in the quality of coral reef ecosystems on Kemujan Island is largely a result of excessive use of resources. Coral reef condition at Kemujan island of Karimunjawa islands is declining as result of tourism and other anthropogenic activities. The research method used in this study is qualitative. The method used is qualitative with direct observations of coral cover and remote sensing. Directly monitoring was performed using the line transect method. Observation of coral cover using a roll meter along 25 meters was observed every meter to distinguish live coral, dead coral, coral fragments, sand and genera found in the study site. A vast, wide area coverage and efficient based on field observations and satellite data use was inevitable, mainly to determine the vulnerability and sensitivity of coral reefs. The study revealed that decline of life coral cover had decline during last five year 2011–2019 had been monitored using three sets of ASTER data for 2011 found of 69.97 hectares, using Landsat_TM for 2015 decreased to 48.6 hectares and using Sentinel-2A for 2019 futher decline to 18.92 hectares of living coral.

Key Words: ecological vulnerability, sustainable management, marine ecosystem, live coral, coral-cover.

Introduction. Karimunjawa Islands are a group of Islands in the Java Sea with an abundant diversity of biological resources, having various types of ecosystems such as low tropical rain forests, coastal forests, mangrove forests, seagrass ecosystems, and coral reef ecosystems (BTNK 2004). Karimunjawa Islands is located in Jepara Regency, Central Java Province, Indonesia, based on Ministry of Forestry and Plantation Decree No. 78/kpts-II/1999 Karimunjawa Islands are designated as National Park. One of the potential islands for tourism is Kemujan Island. The island has a population of 2,936 inhabitants with a variety of livelihoods, mainly as fisherman. The yearly average rainfall is of 3.0 mm, with temperature range of 30-31ºC. The economic potential of the island is capture fisheries, seaweed cultivation and marine tourism related to coral reefs. Coral reefs are very vulnerable to environmental changes, either to human activities or natural disturbation. Coral reefs are tropical aquatic ecosystems that are important and productive in the aquatic environment (Veron 1986; Indardjo et al 2004).

Coral reef ecosystems are also altered by coral bleaching. Therefore, ongoing management is carried out in order to minimize damage to the coral reef ecosystem. Coral bleaching can also be caused by higher sea surface temperatures. Massive coral bleaching, caused by an increase in average sea surface temperature, has now affected almost every large coral reef ecosystem on earth. Coral bleaching is a stress response that culminates in the loss of the dinoflagellate symbionts from coral (Wilkinson 2000). The condition of coral reef ecosystems on Kemujan Island is largely derived from the excessive use of resources and tourist activities. In addition natural factors also cause a decrease in the condition of coral reefs every year. The threat of coral reefs in Indonesia is almost 95% caused by human activities; 35% is at a high and very high level of threat, with conditions (Burke et al 2011), with very good conditions 6.39%, good 23.40%, sufficient 35.06% and poorly 35.15% (Giyanto et al 2017).

Monitoring for changes of live coral cover based on field and satellite data use need as spatial data base for management of the Karimunjawa Marine National Park. Field observations used Line Transect method for diversity of coral reef species and the status of coral reefs. Field observation was performed for life coral and dead coral at Kemujan Island. Several supporting oceanography variables such as tide ranges, current, waves, sea surface temperature would be measured and discussed. Results would be the status of coral reef vulnerability index for continuous monitoring.

The aim of the present study was to measure the spatial coral cover change based on a multi-temporal satellite data and study on coral vulnerability index based on field oceanographic data.

Material and Method. The study was conducted at Kemujan Island, Karimunjawa Islands, Indonesia in 3rd-10th October 2019, on three field observation locations. Location 1 (Ujung Pandean), location 2 (Kemujan Jetty), location 3 (Batu Pengantin) (Figure 1) with two sampling square on each site based on depth range 2–5 m of reef flat and slopes.

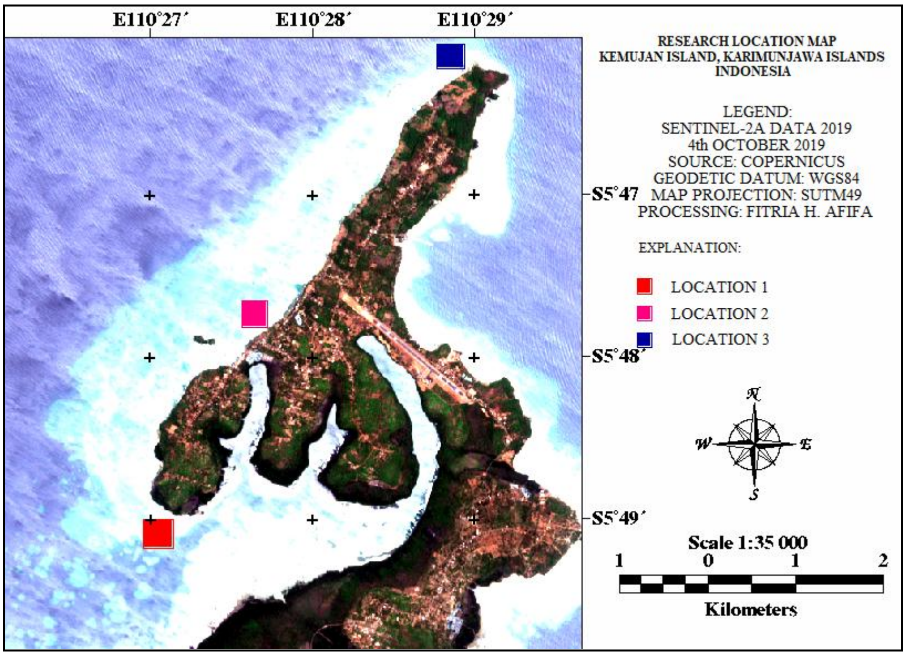

Figure 1. Field sampling location at Kemujan Island.

A line and quadrant transect method had been used for the extent of living corals and the genera that dominated at the study locations (Figure 2). Field observation and measurement was based on Coral Line Transect method after Fachrul (2007). Survey data to describe the structure of coral communities was presented as means of live coral cover, dead coral, sand and presence of associate organism. The steps of the line transect monitoring method were as follows:

1. Selection of locations that represented coral communities on a reef ecosystem.
2. Interval of transect line along 25 m.
3. Transect line started from the coastline to the specified depth, the position of the transect line was parallel to the coastline.
4. Slowly movement along the transect, making record note on the form of growth and if possible genera and species found directly below the rope line.
5. Record data and grouping into live coral, dead coral, sand and coral fragments.

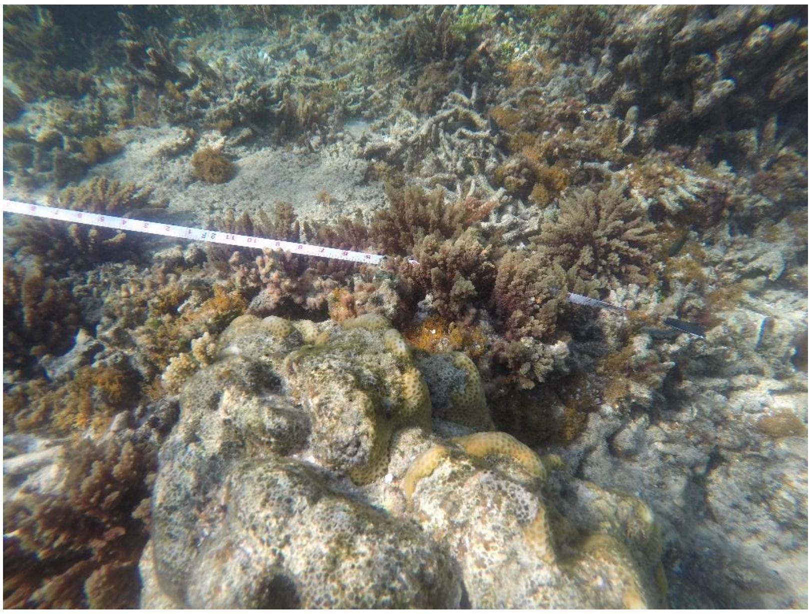

Figure 2. Field monitoring of coral coverage at Kemujan Island.

Spatial data. The study used Sentinel-2A satellite data of 2019, Landsat8-OLI of 2015 and ASTER of 2011 verified with field survey of coral reef habitats. In general the use of correct wave length of satellite bands used will make accuracy of any analysis or algorithm should be developed (Hartoko et al 2015, 2019).

Coral reefs and other shallow underwater objects can be detected using remote sensing technology based on the analysis of the spectral response characteristics of electromagnetic waves from each band recorded by satellite sensors. Each object has a specific response to electromagnetic radiation. Radiance observed or measured and received reflectance by the sensor is influenced by the nature of the object reflectance at the base and the water above it (Arief 2013). Satellite data processing using multi temporal and spectral classification was applied to measure coral reef cover, changes and delineation of living coral and dead coral. While coral vulnerability index was calculated based on field oceanographic variable and asummed as impact of anthropogenic activities. Cross combination with field data and produce the percentages of vulnerability levels were generated from the index of coral reef vulnerability and changes of coral reef ecosystems at Kemujan Island. The use of remote sensing and spatial technology is one of best alternatives for coral reefs monitoring for wide area and in relatively short time and low cost.

Determination of coral reef vulnerabilty index caused by anthropogenic activity. The measured both physical and biological variables were then valued, weighted and scored for the level of vulnerability. According to Suhery et al (2017), the vulnerability of coral reef ecosystems can be reflected by class of vulnerability index. Vulnerability index is defined as a combination of the degree of exposure to an impact, the sensitivity of an ecosystem or community then in turn to adapt by understand data, mitigation and recovery from the impact and taking advantage of new opportunities created by change (Febrianti et al 2018). The vulnerability index classification is obtained by determining the value of the minimum and the maximum value. The maximum value of vulnerability index 5 indicates high vulnerability, value 3 mederate vulnerability and value of 1 low or no vulnerability. Coral condition value of 5, 3 and 1 to each category weight will generate vulnerability index and coral sensitivity and would be the basis for class category of coral reefs as not vulnerable, vulnerable or very vulnerable (Table 1 & 2).

Table 1
Coral vulnerability and sensitivity category of coral reefs

Vulnerability category	*Class interval*
Low vulnerability	0 – 100
Moderate vulnerability	101 – 250
Very high vulnerability	251– 500

Table 2
Sensitivity category of coral reefs

Sensitivity category	*Class interval*
Low sensitivity	0 – 100
Moderate sensitivity	101 – 250
Very high sensitivity	251– 500

Results and Discussion. Field coral reef observation was used for calculation of coral cover percent. Result of coral cover percent is presented in the Table 3 (location-1 and 2) and Table 4 (location-3); live coral found higher in the slope zone than in reef flat. This is because the depth of the reef flat is much affected by the coastal anthropogenic activities with sand perturbation physical activities of tourists and residents. Slope zones are more dominant in live coral because of the sufficient deep so that the condition of coral reefs was quite good. The average percentage of live coral in location-1, 2 and 3 was found as at medium category. According to the Ministry of the Environment Decree No. 4/2001 concerning the standard criteria for damage to coral reefs as seen from the percentage of live corals is included in the moderate category (25-49.9%). Coral reefs in the Karimunjawa Islands had a diversity of 182 Scleractinian coral species and 23 Non-Scleractinian coral species. Most reef form of coral reefs found in the Karimunjawa islands was a cluster of fringing reefs such as branching coral *Acropora* sp. (BTNK 2004).

Table 3
Percentage of live coral coverage Location-1 (Ujung Pandean) and Location-2 (Kemujan Jetty)

Zone	*1*					*2*				
	LC(%)	*DC(%)*	*CF(%)*	*S(%)*	*Total (%)*	*LC(%)*	*DC(%)*	*CF(%)*	*S(%)*	*Total (%)*
RF(1)	28	32	15	25	100	24	33	20	23	100
RF(2)	28	36	16	20	100	25	37	19	19	100
SL(1)	36	27	12	25	100	35	26	18	21	100
SL(2)	40*	29	11	20	100	38	34	15	13	100
Average	33	31	13.5	22.5	100	30.5	32.5	18	19	100

1 and 2 Sampling location, RF - Reef Flat, SL – Slope, (1) - First sampling, (2) - Second repetition, LC - Live Coral, DC - Dead Coral, CF - Coral Fragments , S - Sand.

Table 4
Percentage of Coral Coverage Site 3 (Batu Pengantin)

Zone	*3*				
	LC (%)	*DC (%)*	*CF (%)*	*S (%)*	*Total (%)*
RF(1)	40	24	16	20	100
RF(2)	38	22	18	22	100
SL(1)	43	25	17	15	100
SL(2)	45	23	18	14	100
Average	41.5	23.5	17.25	17.75	100

3 - Sampling site, RF - Reef Flat, SL – Slope, (1) - First repetition, (2) - Second repetition, LC - Live Coral, DC - Dead Coral, CF - Coral Fragments, S – Sand.

Coral genera found at Kemujan Island were *Acropora* sp., *Astrepora* sp., *Pocillopora* sp., *Seriatopora* sp., *Stylophora* sp., *Favia* sp., *Goniopora* sp. Some of these genera have various forms of growth of branching, dense (massive), crust (encrusting), table (tabulate) and sheets (foliaceous). *Acropora* sp. was the most dominant genus in all three study sites. Supriharyono (2007) reported that *Acropora* sp. is fast-growing coral species and highly tolerant to seawater temperature changes. The fast growing *Acropora* sp. genus continues to dominate at Kemujan Island in suitable environmental conditions. Overall genera found at Kemujan Island are presented in Table 5.

Table 5

Coral Genera in Kemujan Island locations

Genus	*Location-1*	*Location-2*	*Location-3*
Acropora sp.	✓	✓	✓
Astrepora sp.	✓	✓	✓
Pocillopora sp.		✓	✓
Seriatopora sp.	✓	✓	✓
Stylophora sp.			✓
Favia sp.	✓	✓	✓
Goniopora sp.	✓		

Remote sensing monitoring of coral reefs. The results of satellite image processing compare 3 different years with a distance every 4 years. The image data used are 2011 using ASTER satellite imagery, 2015 imagery data uses Landsat 8 OLI, and 2019 uses Sentinel-2A satellite imagery data. The use of different satellite data will give different resolution. The results of ASTER image data processing for 2011 had three class of coral cover. ASTER data spatial analysis found coral reef cover (Figure 3) area of living coral of 67.29 hectares at location-2 and 3. While life coral cover at location-1 was 2.67 hectares; ASTER satellite data processing used Band 4,3,1 with 15 meter pixel resolution.

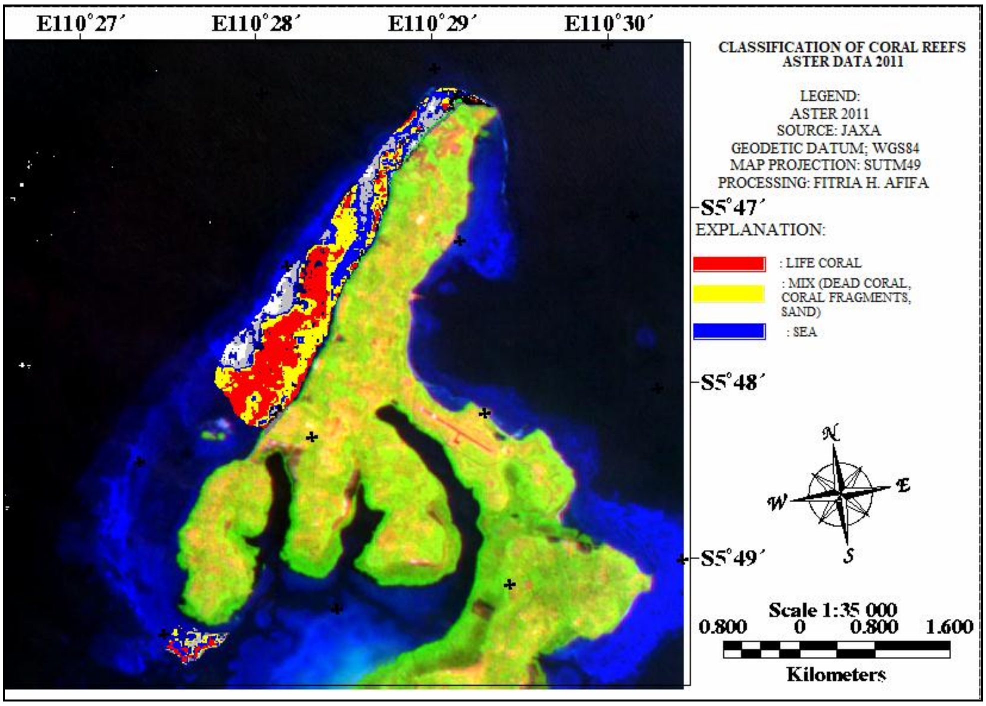

Figure 3. Classification of live coral cover using ASTER data 2011.

Analysis for 2015 using Landsat8-OLI data into three classes is presented in Figure 4. The extent of coral cover of 67.29 hectares in 2011 had decrease to 46.17 hectares in 2015 representing location-2 and 3 and in the second sampling area live coral cover had reduced to 2.43 hectares representing location 1. Total of live coral cover at location-1 and 2 was 48.6 hectares. Processing used Landsat8_OLI satellite images using Band 4,3,2 with 30 meters satellite image resolution.

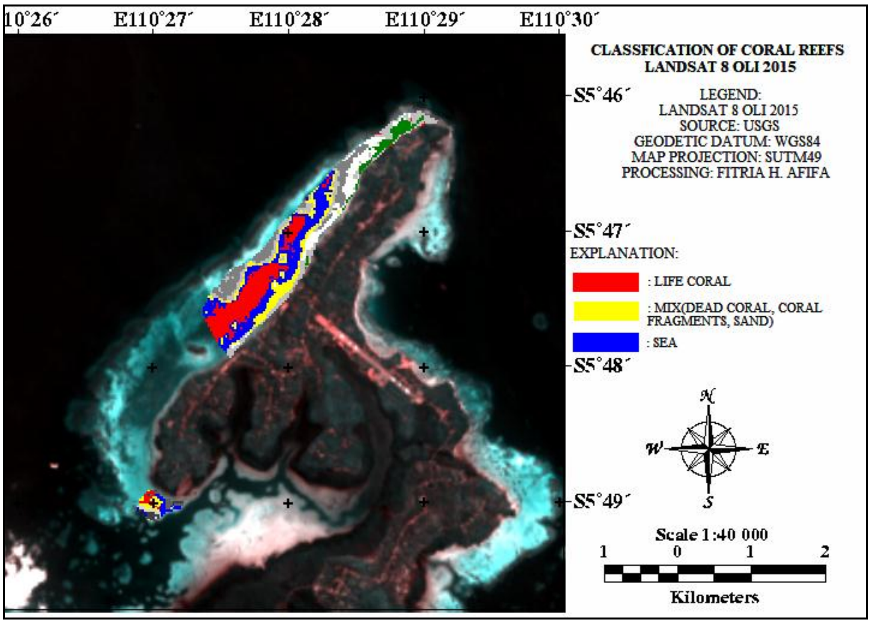

Figure 4. Classification of live coral cover using Landsat8-OLI data 2015.

Analysis using Sentinel-2A for 2019 is presented in Figure 5; overall of live coral cover was significantly reduced from 2011 (67.29 hectares), 2015 (46.17 hectares) to 18.92 hectares in locations-2 and 3 in field observation and in the second location live coral cover was decrease to 2.07 hectares representing location-1 and total of live coral cover at location-1 and 2 was 21 hectares. Overall changes of live coral are presented in Figure 6.

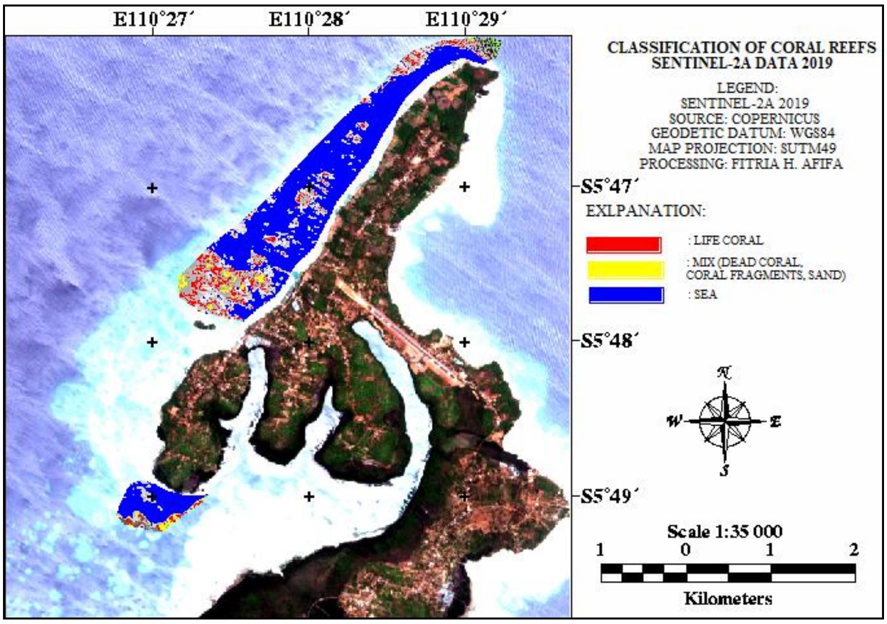

Figure 5. Classification of live coral covers using Sentinel-2A data 2019.

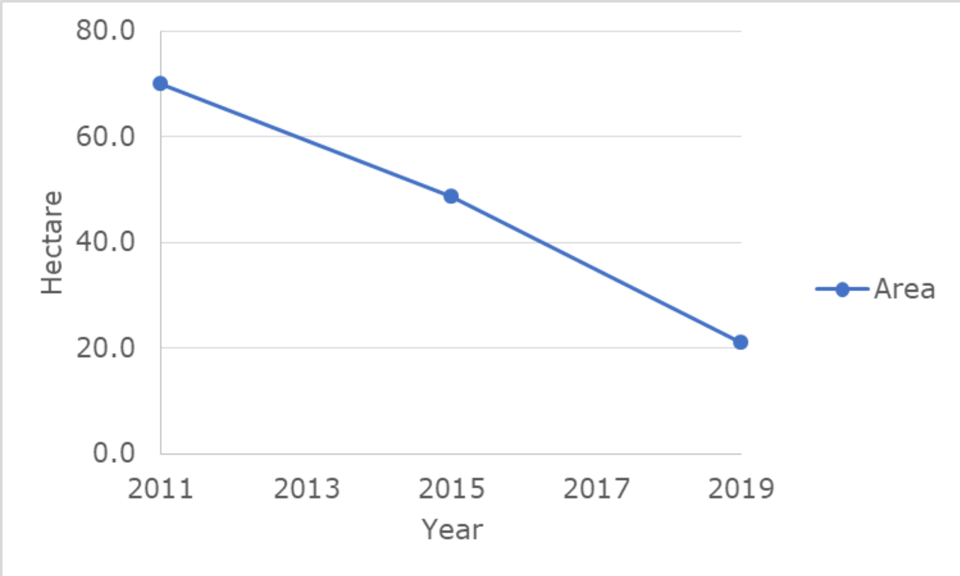

Figure 6. Changes of live coral cover at Kemujan Island.

Coral reef vulnerability and sensitivity index. Coral reef is an ecosystem of organisms which live at the bottom of seawater with capability to deposit limestone ($CaCO_3$) to withstand the waves of the sea. Dominant live organisms are coral animals that have a large amount of limestone skeleton deposit and algae (Khairunisa et al 2012). The score of vulnerability and sensitivity index of coral reefs was calculated based on field variables measurement then calculated based on predetermined values (5, 3, 1) and weights (in percent). Vulnerability index for Kemujan Island at the three locations based on oceanographic variables for location-1, 2 and 3 was moderate vulnerability index with score of 220 and in the range of 101-250 and for location-3 score of vulnerability index was 160. The result of sensitivity index for the three locations has the same value of 220 in the category of moderate sensitivity with score range of 101-250 (Table 2). The score calculation can be used as base reference for future management concerning condition of coral reefs. Based on live coral cover and vulnerability index from 2011, 2015 and 2019 had decreased significantly so there is a need of better coral reef ecosystem management for sustainable life coral existence of the area.

Changes in coral reef areas. It is widely understand that coral reef is one of marine ecosystems which have a high level of biodiversity and its ecosystem provides many benefits for marine life and even for humans through coral reef fish resources. Coral reef ecosystems can be damaged easily with common anthropogenic activities and no proper protection that increase life coral vulnerability. Alamsyah et al (2019) reported that major anthropogenic threats to the damage of coral reef ecosystem are such as coastal community waste disposal, increased pollution and destructive fishing practices. Status of Coral Reefs of the World in 2004 report estimates that around 20% of the world's coral reefs have been damaged and show no chance of recovery in the near future, 24% of the world's coral reefs are very close to the risk of destruction due to human pressure and 26% are in category of threatened for the long run. Until 20 years ago, it seemed that the biggest threats to coral reefs were chronic human disruption to land-use change and poor watershed management, waste disposal, coral mining and destructive fishing. Even more in recent years the global climate has changed drastically, leading to mass coral bleaching events and frequent coral death, on the other hand also ocean acidification of sea water is likely to be the biggest threat to the safety of coral reefs. Natural disturbances have affected coral reefs for thousands of years earlier than human-caused disturbances (Edwards & Gomez 2007). Anthropogenic coral damage caused by tourism activities requires higher special attention for coral reefs ecosystem restoration or experienced physical coral damage (Salim 2012).

Some potential coral reef ecosystems in Indonesia had experienced extensive coral cover decline. One of the declines had occurred in Kemujan Island, Karimunjawa islands. Monitoring of coral cover changes can be carried out by direct field survey or indirect measurement with the use of satellite as have been done for Kemujan Island for the past five years namely 2011 using ASTER, 2015 using Landsat8-OLI and 2019 using Sentinel-2A. Changes and decline of live corals was significant from 2011 live coral cover was 69.97 hectares decrease in 2015 to 48.60 hectares and in 2019 further decreased to 21.00 hectares. Live coral cover decline is assumed due to several factors, both natural factors and human activities around the waters of Kemujan Island. Nurhidayat et al (2019) reported that coral damage is caused by several factors such as human activity, both directly and indirectly. According to Akhmad et al (2018), factors that are directly related to coral reef morphology are depth, size and shape of coral colonies. While factors related to ecology are different species with different regenerations which can affect the extent of dead surface colonies. Partial coral mortality is also related to the dynamics of live corals, by means of reducing colonies and energy for growth and reproduction. Naturally, by means of segregation (fusion or fragmentation) the coral colony would be able to form a new colony as survival adaptability of physical damaged colony or damage cause by algal turf (Dikou & Van Woesik 2006; Febrianti et al 2013). Damage to coral reefs in Indonesia was indicated mainly as a result of human activities (Supriharyono 2007). Here can be mentioned fishing practices that are not environmentally friendly, such as bombing and the use of poisons. Coral and beach sand mining also contributes to the exploitation of reef ecosystem. Coral destruction is a concern for the extinction of marine life on small islands and disruption of the ecological balance which in turn affects the decline in fish populations. Only about 7% of coral reefs are still in very good condition and 61% has been damaged. Coral cover was further reduced for the eastern part of Indonesia; the percentage of coral cover in very good condition was 9.80%, in good condition 35.29%, in moderate condition 25.49% and 29.42% in damaged condition (Indarjo et al 2004).

ASTER satellite imagery sensing. Indirect observation consisted of remote sensing technology using satellite imagery. Remote sensing basically uses electromagnetic waves to obtain information from an object. According to Rini & Jajang (2019), each object has a response in absorbing, reflecting or emitting certain electromagnetic wavelengths, so that each object can be distinguished based on its spectral response. The satellite imagery used to analyze changes in area in 2011 was the ASTER satellite image from a Japanese and American collaboration project. ASTER imagery is a satellite image of earth resources that is often utilized for physical studies. The ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer) image was launched on December 18, 1999, produced by a Japanese and American collaborative project to monitor the earth's surface regarding natural resources. This sensor observes the earth's surface from an altitude of 705 km with band frequencies: Visible and Near Infrared (VNIR), Short Wave Infrared (SWIR) and Thermal Infrared (TIR) (Puspitarini & Retnadi 2011). ASTER satellite images have 14 bands; in the present observation the bands used were 4, 3, 1 where each band has a different wavelength. Band-1 was used because it penetrates water, bands-3 and 4 for vegetation. ASTER satellite image ASTER image has a spatial resolution of 15 meters. Landsat8-OLI satellite data which is collaboration of NASA and USGS used in this study for analysis of spatial coral cover in 2015 has a spatial resolution of 30 meters. Meaning that Landsat8_OLI data has less spatial resolution or less spatial accuracy compared to ASTER satellites which has 15 meter spatial resolution. The Landsat8_OLI satellite data used 4, 3, 2 bands. For fundamental understanding of the use of satellite data for coastal habitat such as coral, magrove, seagrass or phytolankton biomass should be used the corect satellite bands for measurement accuracy. The use of band 2 and 3 has ability for seawater column penetration, while band 4 for live coral chlorophyll-a or coastal vegetation (Hartoko et al 2013, 2015).

Sentinel-2A satellite was launched in 2015 launched as part of the Copernicus European Space Agency (ESA) program. The satellite carries various high resolution multispectral imager images with 13 spectral bands. The satellite will conduct terrestrial observations in support of services such as forest monitoring, detection of land cover changes, and natural disaster management as well as for coastal and marine use (Putri et al 2018). Sentinel-2A satellite data has 13 bands and in the analysis of the present study we used the 4, 3, 2 bands combination. The bands has almost the same functionality as other satellites where bands 2 and 3 can penetrate seawater, while band 4 for vegetation monitoring by means of chlorophyll-a reflectance. ASTER had 15 meter spatial resolution and Landsat8 had 30 meter spatial resolution and Sentinel-2A satellite has 10 meters. Different spatial resolution will have different result of spatial accuracy in the division of coral reef class (Hartoko & Latifah 2019). Coral reef vulnerability and sensitivity was classified based on field survey data. Further study for coral reef class spatial modelling used cell-based modeling, which is spatial data processing technique in raster-based Geographic Information Systems (GIS) in combination of field and numeric data of satellite. The results of cell-based spatial modeling in the form of a comprehensive thematic map will be used as a basis for determining the coral reef coolness index due to anthropogenic activity (Widyayanto et al 2009).

Vulnerability and sensitivity of coral reef. Kemujan Island of Karimunjawa Islands is a semi-enclosed seawater surrounded by a group of large and small islands, with coral reefs scattered in all the islands that can protect from wave disruption. Coral reefs are very important and productive tropical aquatic ecosystems in aquatic environments. Indonesia is one of the countries with the highest coral reef resources in the world. Basically, damage to coral reefs is caused by natural and human factors. According to Uar et al (2016), damages are caused by natural variables such as increase of sea water temperatures, hurricanes, global climate change, earthquakes, volcanic eruptions, predators and diseases. The impact of damage caused by humans is usually fishing activities that are not environmentally friendly, or activities that cause environmental pollution. The condition of coral reefs is vulnerable and sensitive to environmental changes, and thus results in decrease of live coral cover as vast monitoring results by processing satellite images in Kemujan Island from 2011, 2015 and 2019. Such coral reef declining conditions with more anthropogenic impact in Kemujan Island had indicate the need of serious consideration and action plan in the coming years to otherwise diminish of coral reefs with ability to very slow natural recovery. According to Febrianti et al (2018), coral reefs basically have natural recovering ability when coastal environmental conditions get worsen. Such process requires a long period of time and coral reef recovery requires a good environmental recovery process. Damage caused to coral reefs due to typhoons, storms and human activities has the potential to recover capability depends on proper coastal management. Recovery only occurs when the added pressure due to anthropogenic activities is limited (Westmacott 2000; Wilkinson 2000).

Conclusions. The results of the present study indicate that the condition of coral reef ecosystems is included in the moderate vulnerable category. Vulnerable coral reefs cause changes in the area every year, the need for good zoning so that coral reefs are maintained and be able to recover slowly. Changes of live coral cover for the last five years in 2011, 2015 and 2019 based on satellite data for 2011 using ASTER satellite revealed area of 69.97 hectares of live coral, 2015 using Landsat8 satellite found live coral decreased to 48.6 hectares and for 2019 using Sentinel-2A satellite data live coral cover was reduced to 18.92 hectares.

Acknowledgements. The authors would like to thank the Karimunjawa National Park Office for the field survey permit. Also thanks to USGS for the use of ASTER, Landsat8-OLI and ESA Copernicus for Sentinel-2A and all parties involved in the research.

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Received: 19 March 2020. Accepted: 20 April 2020. Published online: 26 April 2020.
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How to cite this article:
Afifa F. H., Hartoko A., Purnomo P. W., 2020 Changes and vulnerability of coral reef ecosystem based on field and remote sensing data on Kemujan Island, Karimunjawa Islands, Indonesia. AACL Bioflux 13(2):1016-1026.