Distribution and condition of coral reef resources using satellite image data on Labengki Island, Southeast Sulawesi (Indonesia)

[1]Suharta A. Husen, [2]La Sara, [2]Andi Irwan Nur, [3]Muslim Tadjuddah

[1] Faculty of Fisheries and Marine Science, Muhammadiyah University, Kendari, Southeast Sulawesi, Indonesia; [2] Department of Aquatic Resources Management, Faculty of Fishery and Marine Science, Halu Oleo University, Kendari 93232, Southeast Sulawesi, Indonesia; [3] Department of Fish Capture, Faculty of Fishery and Marine Science, Halu Oleo University, Kendari 93232, Southeast Sulawesi, Indonesia. Corresponding author: La Sara, lasara_unhalu@yahoo.com

Abstract. The purposes of this study were to identify and to estimate the condition of coral reef ecosystems using satellite imagery SPOT 5 to be used as the basis of formulation resource management policy of coral reef ecosystems. This study was conducted in the shallow sea waters of Labengki Island, Southeast Sulawesi. The methods were *unsupervised* and *supervised classification* using *lyzenga algorithm*, to calculate the extent and condition of coral reef ecosystems through remote sensing without contact directly with the objects in shallow water. This method used infrared waves. The classification was determined based on the observer's subjectivity and the dominance of the substrate in the sea bottom. The analysis showed that the resources in these waters were grouped into five classes, namely live coral (LC) covering an area of 20,178 hectares, damaged coral (DC) covering an area of 83,699 hectares, seagrass (SG) covering an area of 27,834 hectares, mixed coral (MC) covering an area of 57.03 hectares and rock (R) covering an area of 21,245 hectares. A comprehensive estimation of the area of coral reef ecosystems in south and southeast of the research locations were 60.53% (in good condition), and 9.50% (in poor condition). Whereas in east, northeast and north research locations were 11.31% (in damaged condition), 28.15% (in moderate condition), and 13.59% (in damaged condition) respectively. The data showed that the overall condition of the coral reef ecosystem in these waters was classified as damaged.

Key Words: coral reef distribution, coral reef condition, satellite images, Labengki island, estimation of coral reef potential.

Introduction. The total of small islands in Indonesia is 17,504, and the coastline of 95,181 km have large fisheries resources, tourism potential and environmental services that have not been optimally utilized, mostly from coral reef ecosystems (Hidayah et al 2016). These resources lie in territorial waters and exclusive economic zones (EEZ), each of which has an area of about 5.9 million km^2. Indonesia's total marine area is about 2.1% of the Earth surface and 14% of the world's total coastline (Adisoemarto 2004). The characteristics of most small islands in Indonesia are remote, isolated, and vulnerable to natural disasters (Susilawaty et al 2015).

One of the marine resources that have economic and social prospects is a coral reef ecosystem in which the species diversity exceeds another marine ecosystem. A coral reef ecosystem is an essential ecosystem in tropical regions and has many ecological, physical, economic, and social functions (Hilmi et al 2012; Prasetya et al 2014; Awak et al 2016). Physical balance among other organisms will form three-dimensional biogenic structures of coral reefs, i.e. high biodiversity, heterogeneity, and the resilience of the social and economic systems (Dikou 2010). The coral reef ecosystem is an assemblage of various organisms interacting with its physical environment so it forms several functions as sources of food production, spawning and feeding ground for various marine species (Titlyanov et al 2018). Besides, the coral reef provides valuable benefits such as fisheries, ecological goods and services, and recreational activities for many human communities (Gholoum et al 2012). Marine resources exploitations as happened in the Coral Triangle pose challenges for biogeographers and resource managers, because the coral reef has many functions, especially the economic and social function. Therefore, these resources face a severe threat due to intensive exploitation on a large scale (Carpenter et al 2011). Substantial shifts in the abundance and composition of coral communities happen due to bleaching, excessive fishing pressure, and water quality degradation (Magris et al 2015). In order to maintain the sustainability of this valuable coral reef ecosystem is required a formulation of effective management which specifically is based on understanding of physical, chemical, and biological data of spatial variability. Those data have to be taken and monitored regularly on monthly basis (Thys et al 2016).

Monitoring the coral reef condition can be done directly or indirectly (Awak et al 2016; Spalding et al 2017) in order to estimate and map the coral reefs (Spalding et al 2017). Outlining the potential value of coral reef ecosystems can be conducted through (1) an integrative and multi-disciplinary approach during extensive field observations, (2) collecting optical remote sensing data sets (satellite and air-based products), (3) modelling tools to enable observation and improve field observations to understand the changing process of coral reefs, (4) habitat maps developed at an appropriate scale in regulating the correct system (Brock et al 2009; Rivero et al 2016). The approach for optimizing the spatial placement of management areas is based on maximizing objective functions that combine ecological, social, and economic criteria (Christensen et al 2009).

The marine ecosystem modeling can be used to identify the benefits of marine protected areas for coral reef ecosystems (Varkey et al 2012). According to Ladys et al (2012), to examine the condition of the beach, which is influenced by the human activity and the natural factors, remote sensing technique can be used. According to Papakonstantinou et al (2016), remote sensing plays a vital role in coastal observation because it is one of the most valuable tools that is used to detect and monitor coastal areas. Decision making is also benefited with the tool to identify and map coral reef features using satellite imagery. It can provide accurate information about the estimations and the current conditions for decision-makers for management and sustainable use of marine resources (Gholoum et al 2012).

Southeast Sulawesi has 124 named and unnamed islands. One of the islands is Labengki Island covering 948 ha (9.48 km^2). It consists of Labengki Besar and Labengki Kecil. The population is 471 people with a density of 49.68 people per km^2 (Badan Pusat Statistik 2017). This islands is a conservation area with a wide surface, based on interpretation of Landsat imageries, around 81.8 ha (Dit. KKJI 2013; Kusumawardhani 2016). The island has a beautiful panorama and high biodiversity to become a potential tourism destination. This study is the start to collect biophysical data of coral reefs in the Labengki islands waters with the promising social and economic resource to be the basis of its management.

Material and Method

Description of the study sites. This research was carried out from May to July 2017 in the waters of the Labengki Islands (Labengki Besar Island and Labengki Kecil Island), Southeast Sulawesi (Figure 1). These waters were chosen as research locations because: (1) these location had the economic potential of coral reef ecosystem resources; (2) the fisheries potential in this region has a role as community income; (3) the damage to the coral reef ecosystem in these waters seemed to be caused by the use of environmentally unfriendly fishing gear. Research variables consisted of: (1) coral type; and (2) estimation of coral reef ecosystems based on the territorial distribution of the islands (Figure 1).

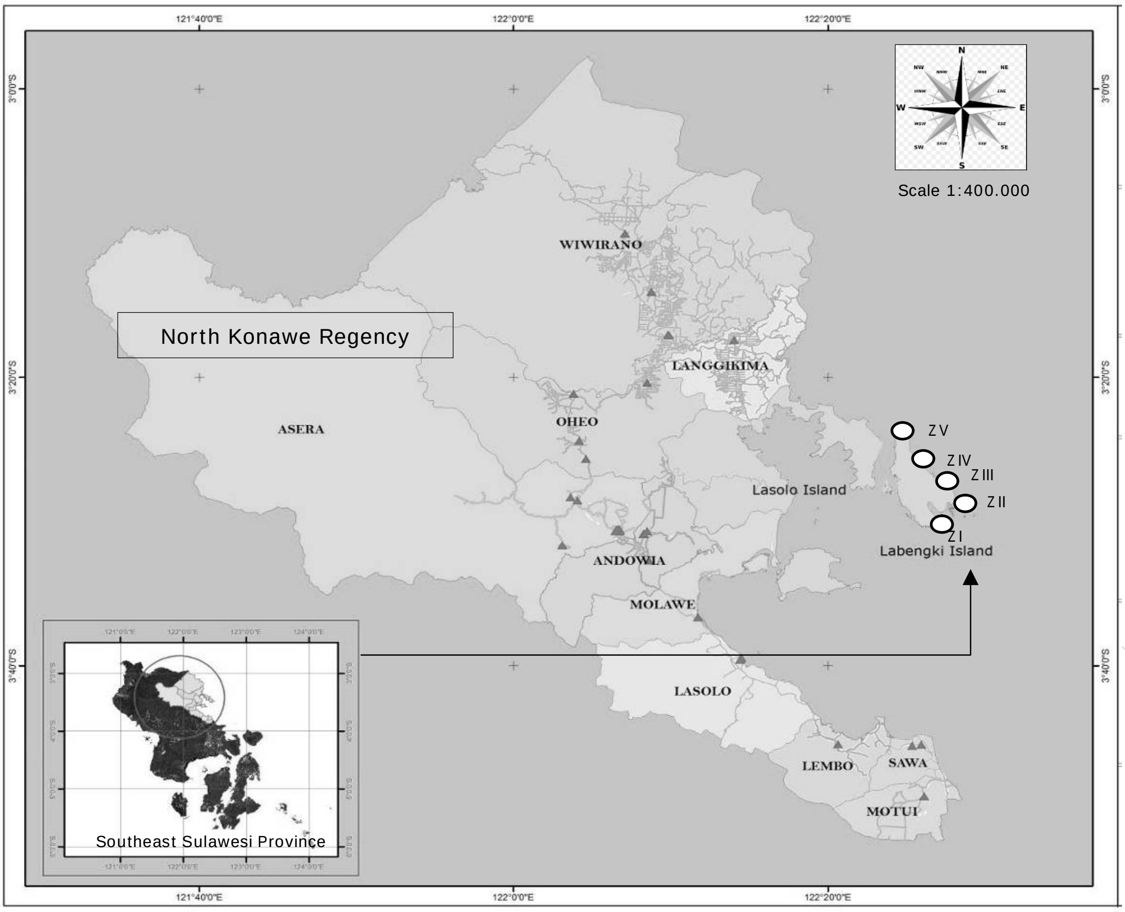


Figure 1. Map of research locations in the waters of the Labengki Islands of Southeast Sulawesi.

Data collection. The primary data in this study was the results of the processed satellite imageries and the ecosystem data of coral reefs (*in situ*) in five research zones on the islands. The SPOT 5 satellite imageries data obtained was processed by several stages: (1) geometric correction; (2) images mosaicking; (3) sharpening of satellite images (enhancement); (4) cropping the satellite images and distributed it to several zones; (5) separating land objects and water objects (landmarks); (6) classification; (7) lyzenga algorithm formulation; (8) multi-spectral classification; and (9) field testing/unsupervised classification.

The first and second zones were in the south and southeast, the third and fourth zones in the east and northeast and the last zone in the south of the island. The zones were divided to estimate the cover and condition of coral reefs based on the results of data processing with *lyzenga* analysis.

Furthermore, an accuracy test (error matrix for map accuracy assessment) was conducted with the category of mortality index in each zone and visual interpretation of image analysis results based on composite colors. Then, the results of the classification information data for each zone were estimated (Ampou et al 2011). The result of accuracy map processed was adjusted with area object computed and further inserted into diagonal form (Table 1) until it attains 81.48% (Baja et al 2002). Error matrix is a class cross tabulation which is allocated by map and reference data (FAO 2016).

Table 1
Error matrix for map accuracy assessment of each component in coral ecosystem in Labengki Islands of Southeast Sulawesi

Class	*LC*	*DC*	*SG*	*MA*	*MC*
Live coral (LC)	*				
Damaged coral (DC)		*			
Seagrass (SG)			*		
Macro algae (MA)				*	
Mixed coral (MC)					*

User accuracy (%) = 100 - error of commission (%); procedure result accuracy (%) = 100 -error of commission (%)

The data of coral reef ecosystem were collected along line transect using point intercept transect (PIT) method. In each zone, a 50 m roll transect was spread along the coral colony parallel to the coastline by following the contour depth. Observations were made at the water depth station, which were 3 and 10 m with three replications. Measurements were made with accuracy approaching cm, coral colonies of known species were immediately recorded (Manuputy & Djuwariah 2009):

$$ni = \frac{li}{L} \times 100$$

where n_i = cover component of each item i, i = 1, 2, 3, ... , n (%); l_i = number component of each item i, i = 1, 2, 3, ..., n; L = length of transect total/component total (cm).

Percent of coral cover was one of the indicators used to assess the condition of the coral reef. The assessment included the percentage of live and broken coral cover, which was recorded on the line transect (Table 2).

Table 2
The categorization of basic components of coral reef ecosystems based on coral lifeforms and codes

Type	*Category*	*Code*
Hard coral	Dead coral	DC
	Dead coral with algae	DCA
Acropora	Branching	ACB
	Encrusting	ACE
	Submassive	ACS
	Digitate	ACD
	Tabulate	ACT
Non-Acropora	Branching	CB
	Encrusting	CE
	Feliose	CF
	Massive	CM
	Submassive	CS
	Mushroom	CMR
	Millepora	CME
	Heliopora	CHL
Other fauna	Soft coral	SC
	Sponges	SP
	Zoanthids (Platyhoa, Protopalythoa)	ZO
	Others (ascidians, Anemones, Thorny coral, Tridacna)	OT
Abiotic:	Sand	S
	Rubble	R
	Silt	SI
	Water	WA
	Rocks	RCK

Source: English et al (1994).

Results

Image processing. The results of lyzenga analysis on SPOT 5 satellite imageries showed several groups, namely: 1) live coral; 2) damaged coral; 3) mixed; 4) rock; 5) seagrass bed (Table 3), and furthermore the classification image is spatially illustrated (Figure 2).

Table 3

Distribution of ecosystem conditions on Labengki Island, Southeast Sulawesi

Ecosystem type	*Area (ha)*	*Percentage (%)*
Rock	21.2	10.1
Mixed coral	57.1	27.2
Damaged	83.7	39.8
Live	20.2	9.6
Seagrass	27.8	13.3
Total area	210.0	100

The results showed that the largest classification area in these waters was the damaged coral (39.8%), followed by mixed coral (27.2%). Live coral had the smallest area (9.6%), while rock and seagrass areas were 10.1% and 13.3% respectively.

The next process was combining the colours from the image classification results, so each class can be determined.

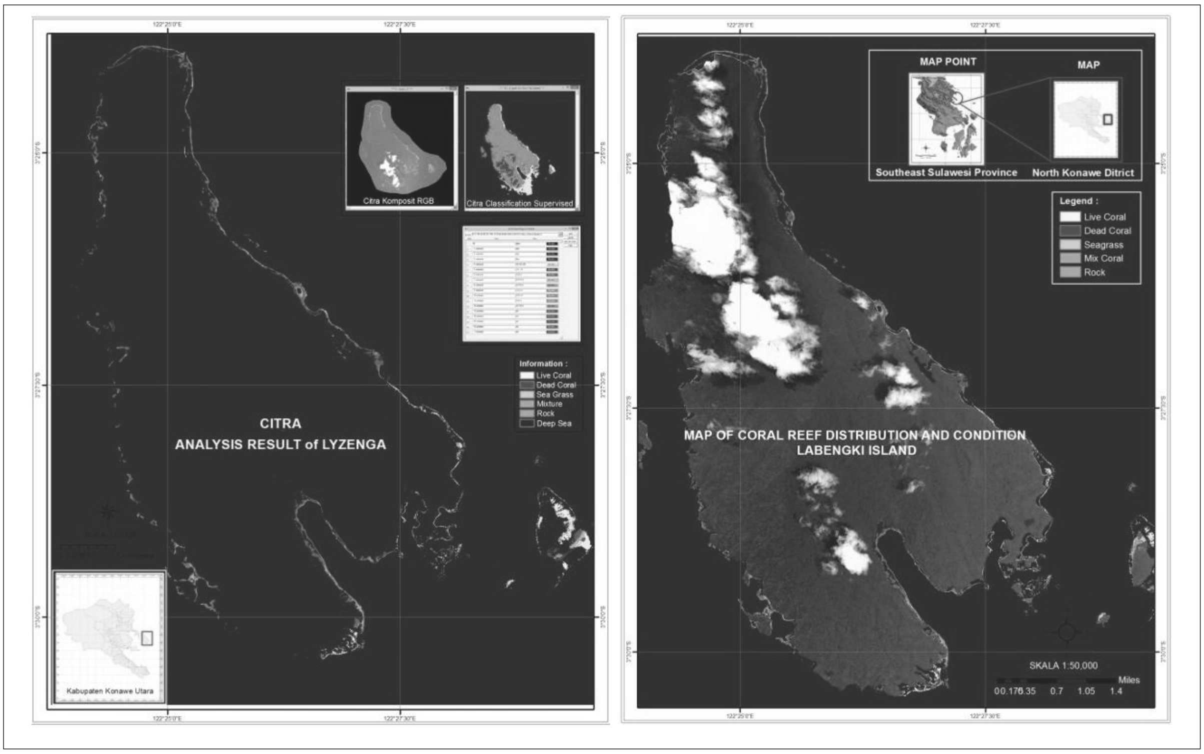


Figure 2. Image distribution of shallow-water ecosystem based on the *Lyzenga* analysis results.

To determine the error rate of image data processing, field testing using an error matrix resulting from classifying training set pixel method was conducted by comparing *in situ* data in each research zone. The accuracy test result was 0.81 (81.48%); thus, the level of accuracy was 80%, meaning that the analysis can be trusted and continued to estimation (Table 4).

Table 4

Error matrix resulting from classifying training set pixel

Class	*LC*	*DC*	*SG*	*MC*	*R*	*Total*	*Error C**
Live coral (LC)	9	2	1	-	-	12	0.75
Damaged coral (DC)	-	7	1	-	-	8	0.88
Seagrass (SG)	-	-	10	1	-	11	0.91
Mixed coral (MC)	1	2	1	10	-	14	0.71
Rock (R)	-	1	-	-	8	9	0.89
Total	10	12	13	11	8	54	-
Error C**	0.90	0.58	0.77	0.91	1.00		0.81
			Accuracy				81.48%

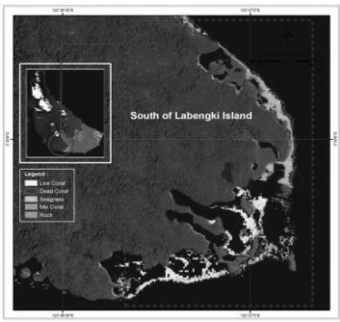
User accuracy (%) = 100 - error of commission (%); procedure result accuracy (%) = 100 - error of commission (%).

The estimation of the most live coral cover was in the south of z1 (6.9 ha), and the most damaged coral cover area was in the z5 (33.7 ha) (Table 5 and Figure 3).

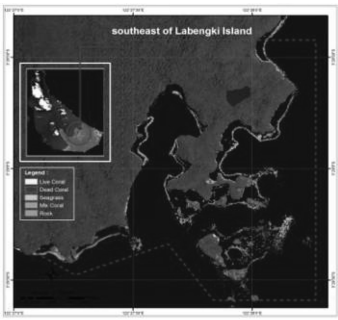
Table 5

Estimated coverage (ha) of coral reef ecosystem conditions

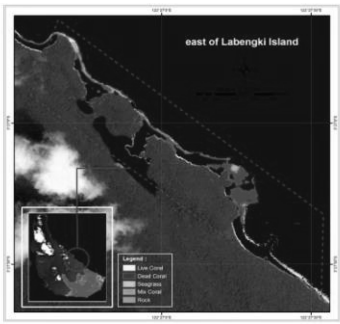
Research zone	*Live coral (LC)*	*Damaged coral (DC)*	*Seagrass (SG)*	*Mixed coral (MC)*	*Rock (R)*
South (z1)	6.9	4.5	6.7	8.1	8.9
Southeast (z2)	1.7	16.2	0.6	3.9	6.5
East (z3)	2.5	19.6	3.8	12.7	2.2
Northeast (z4)	3.8	9.7	5.2	14.1	0.4
North (z5)	5.3	33.7	11.6	18.3	3.2
Total	20.2	83.7	27.9	57.1	21.2



(a) South zone

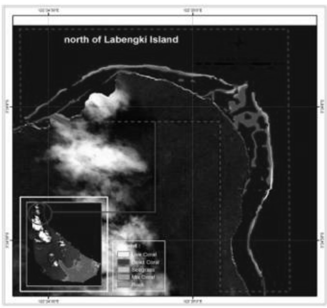


(b) Southeast



(c) East zone

(d) Northeast zone



(e) North zone

Figure 3. Estimated coral reefs condition in each zone in Labengi Island of Southeast Sulawesi.

Coral reef cover. The field observation discovered some types of coral, namely Acropora consisting of some lifeforms: Acropora type palmata and Formoza (ACB), Digitata type

(ACD), Humulis, Digitifera, Gemmifera, and encrusting types (ACE), and Acropora type of Alifers, Coneata, Dead Coral Algae (DCA), and Dead Coral (DC) type (Figure 4).

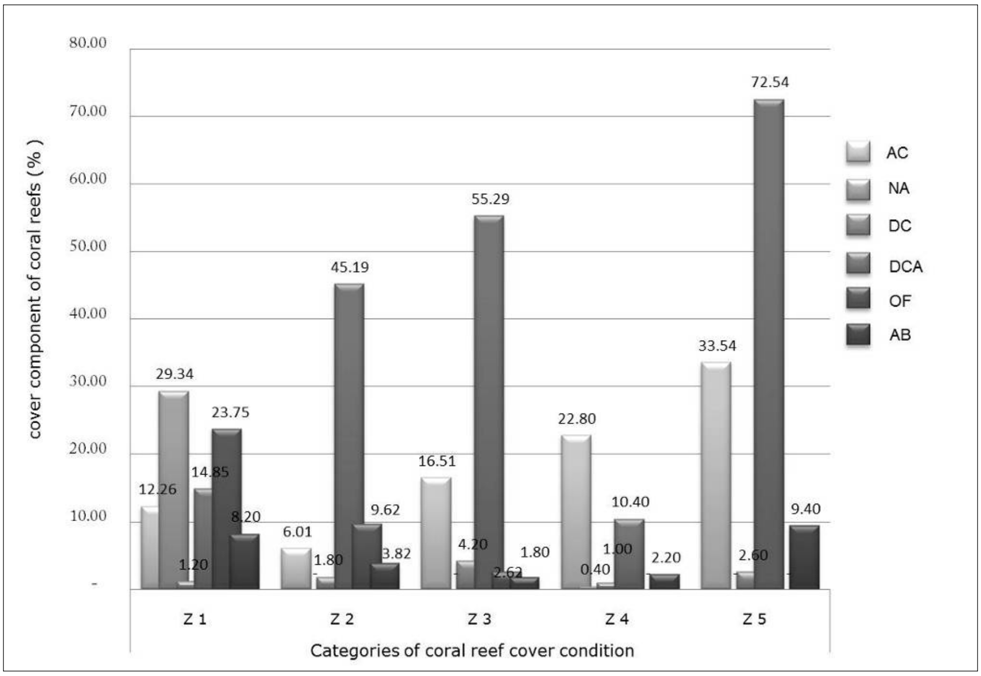


Figure 4. Categories of coral reef cover conditions in each study zone in Labengki Islands of Southeast Sulawesi.

The largest percentage of Acropora component (AC) cover was in zone 5 (33.5%), while the largest percentage of non-Acropora (NA) cover is in the first zone (29.3%). The highest percentage of damaged coral (DC) cover was in the third zone (4.2%), and the damaged coral overgrown with algae (DCA) cover was in the fifth zone (72.5%). Furthermore, the highest biotic (OF) cover was in the first zone (23.7%), and the abiotic (AB) cover was in the last zone (9.4%).

Discussion. Satellite image data processing is a way of manipulating data into an expected output. Some research concerning the impact of damaged coral reef ecosystem in shallow water can be seen in Table 6.

Table 6

Researches related to the estimation of the condition of coral reef cover

Location	*Cause of damage*	*(%) damage*	*Source*
Pandan Bay, East Kutai	Destructive fishing	2.1-67.8%	Syahrir et al (2015)
Southern of Misool Waters	Waves and ocean currents	36.7-70.7%	Prasetya et al (2014)
Owi Island, Biak, Papua	Reef fish exploitation	11-30%	Awak et al (2016)
Payar Island, North Malaka Strait, Malaysia	Wave, current and sedimentation	22.6% 0.49-3.33%	Abdullah et al (2016)
Taman Wisata Alam Laut Lasolo	No information available	Does not extensive information on coral reef	Kusumawardhani (2016); Dir. KKJI (2013)
Labengki Islands, North Konawe	Bomb fishing	39.8%	Present study

Field monitoring was conducted to combine multiple classes; five classes of the cover components of the shallow water in these islands were formed. Although, there was live coral cover in this area, overall condition of the coral reef ecosystem was in the damaged category. The marine object-oriented approach was conducted based on image classification by showing the potential inventory of coral reef resources (Benfield et al 2007). Referring to area, Labengki Islands which is located in the coastal conservation of area of Lasolo Bay has a coral reef area of ±81.8 ha (Dir. KKJI 2013; Kusumawardhani 2016). This study is not in line with what found earlier in which the area of coral reef in Labengki Island is ±103.87 ha. Main difference between earlier and later study is likely to rely on the different uses of image satellite.

Based on Syahrir et al (2015), coral reefs tend to develop well in water depths of 0 to 7 m. The results of this study show that coral reef damage occurred at a depth of 6-10 m with a total area of 83.7 ha with the highest level of damage being in the northern zone covering 33.7 ha (Table 5). This shows that damaged coral in Labengki waters is an ideal place for coral growth. This damage is caused by illegal fishing (bomb) and the influence of water waves directly. The results of the study of Prasetya et al (2014) and Abdulllah et al (2016) show that coral reefs in semi-open areas will decrease in growth because they are influenced by currents and waves of sea water.

The result of the coral reef cover was tested using the accuracy test, and several classification matrix errors were revealed, including (1) in the live coral class, there was a 12% error point (9% live coral, 2% damaged coral and 1% seagrass); (2) in the damaged coral class, there was 8% error points (7% damaged coral and 1% seagrass); (3) in the seagrass class, there were 11% error points (10% seagrass and 1% mixed coral); 4) in the mixed reef class, there were 14% error points (live coral 1%, damaged coral 2%, seagrass 1% and mixed coral 10%); (5) in the rock class, there were 9% error points (1% broken coral and 8% rock). Thus, the accuracy-test value was 0.81 or 81.48%. Baja et al (2002) explained that the accuracy value above 80% is correct, and the estimation of the study can be continued. Meanwhile, a result of research by Awak et al (2016) showed that by obtaining an accuracy value of 67% matrix in aquatic bottom habitats such as live coral, damaged coral, seagrass, mixed reef and rock, this research can be continued to determine the impact of the damage.

The fault matrix is the class tabulation label allocated by the map and the individual class accuracy into the diagonal matrix containing the data point as the actual means of conformity between the classification and the observation (Dadhich et al 2012; FAO 2016). Rwanga & Ndambuki (2017) explained that the error matrix table can be used as a parameter of the accuracy of the results of satellite imagery through a comparison between the number of rows (data fields) and columns (satellite images) divided by the number of pixels that indicate errors in each classification.

Remote sensing can be used to predict and estimate changes in habitat and biodiversity of coral reef in the long term in different zones (Guzman et al 2004; Arias-Gonzales et al 2010; Huang & Klemas 2012). Remote sensing can also be used to accurately predict the existence of habitat and fish stocks by combining and analyzing using other satellite data (Purkis et al 2008; Nurdin et al 2015). Remote sensing can also be used to collect information, map the type of coral reef substrate, ensure its sustainability and protect from the effects of damage by humans (Knudby et al 2007; Jones et al 2011).

Conclusions. The live coral cover on this island was 20.2 ha (9.6%) and the damaged coral was 83.7 ha (39.8%). Consequently, the condition of the coral reef ecosystem on the island was in the damaged category. The damage on the coral reef ecosystems occurred due to the use of non-environmental friendly fishing gear. Currently, the island has been turned to a tourist destination by the government and the community; however, this activity has the potential to damage the coral reef ecosystem. Uncontrolled tourism is a threat to the coral reef ecosystem. Therefore, a policy regulation for marine management is needed for the sustainability of coral reef ecosystems and biodiversity.

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Authors:
Suharta Amijaya Husen, Faculty of Fisheries and Marine Science, Muhammadiyah University, Kendari, 93118 Kendari, Southeast Sulawesi, Indonesia, e-mail: arta.analyst@gmail.com
La Sara, Department of Aquatic Resources Management, Faculty of Fishery and Marine Science, Halu Oleo University, the 2nd floor, Kampus Bumi Tridharma, 93232 Kendari, Southeast Sulawesi, Indonesia, e-mail: lasara-unhalu@yahoo.com
Andi Irwan Nur, Department of Aquatic Resources Management, Faculty of Fishery and Marine Science, Halu Oleo University, Kampus Bumi Tridharma, 93232 Kendari, Southeast Sulawesi, Indonesia, e-mail: ainina3@gmail.com
Muslim Tadjuddah, Department of Fish Capture, Faculty of Fishery and Marine Science, Halu Oleo University, Kampus Bumi Tridharma, 93232 Kendari, Southeast Sulawesi, Indonesia, e-mail: muslim22jan@gmail.com

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