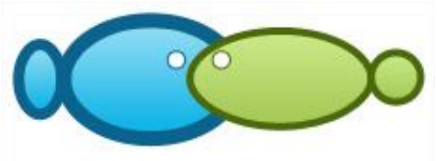

First record of coral reefs in the delta front of Mahakam Delta, East Kalimantan, Indonesia

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Abstract. The water of Mahakam Delta characterized by high turbidity and soft bottom sediment was generally supposed to be as unsuitable environment for coral reef development. However, this study showed that the spread of coral reefs was found in the northern and southern delta front of the Mahakam Delta only about 8.7 km and 11.9 km from the delta, respectively. Observation at the northern area in 2013 resulted in finding six reefs formation (three fringing and three patch) with total area of 41.84 ha, and identifying 21 genera from 13 families of hard corals with averagely poor live coral coverage of LC 21.02% and coral mortality index of CMI 0.25. Meanwhile, in the southern area observed in 2011 and 2013 was found three reef spots, and all were in fringing formation with total area of 32.21 ha. Generic identification in 2011 and 2013 revealed that hard corals consisted in 21 and 22 genera, respectively, or 25 genera in both years, all from the same 12 families. The data analysis of lifeform line intercept transect indicated that the live coral coverage in both years were categorized as fair or moderate with in 2011 and 2013 the LC was 28.12% and 27.76% and CMI was 0.41 and 0.55, respectively.
Key Words: reef formation, reef edge, lifeform line intercept, coral mortality index, live coral coverage.

Introduction. Coral reefs in East Kalimantan are found along coastal waters of East Kalimantan from Berau Sea in Berau District in the north to the coastal water of Tanjung Aru in Paser District in the south. But only coral reefs of Berau Sea (Tomascik et al 1997; Turak 2003), Balikpapan Bay in Penajam Paser Utara District (Tomascik et al 1997) and Tanjung Santan in Kutai Timur District (Tomascik et al 1997) are known to have been reported. Scientific reports on coral reefs in other coastal areas including in the delta front of Mahakam Delta in Kutai Kartanegara District are still unavailable.

Mahakam Delta belongs to the biggest delta in the world covering area of about 1,800 km^2 (Storms et al 2005) and after five years later changed to approximately 1,070 km^2 (Suyatna et al 2010a). The discharge of Mahakam River was estimated to be 1,000–1,500 m^3 sec^{-1} and this flow contained about $8x10^6$ m^3 solids per year with the composition of 70% mud and 30% sand (Allen et al 1979 in Dutrieux 1990). The concentration of total suspended solids in the water column from the apex to the mouth of the delta are ranged from 19.5 to 62 mg L^{-1} at surface, and from 26.5 to 158 mg L^{-1} on the bottom, with a maximum average of 178 mg L^{-1} in the middle part (Creocean 2000). This high concentration of TSS makes the water in the delta very turbid. Thus, the condition of delta or estuary waters was suggested as unsuitable environment for coral reef development (Rogers 1990; Tomascik et al 1997; Fabricius 2005; Golbuu et al 2008; Santodomingo et al 2015). According to Zain et al (2014), no coral reefs and sea grass beds were found in Mahakam Delta. Tomascik et al (1997) described the evidence of coral reefs 75 km from the south and 20 km from the north of the delta located far in Balikpapan Bay and Tanjung Santan, respectively.

Suyatna et al (2010b) identified at least 126 fish species in the Mahakam Delta, and among of them were coral fish species, like *Pterios* sp., *Abudefduf* sp., *Heniochus* sp., *Scolopsis* sp. The Mahakam Delta becomes a feeding ground for coral species as the delta water is actually the habitat for mostly detrivores and prey species such as penaeid

shrimps, and small fishes pepetek as mentioned by the author above. The evidence of coral fish species may indicate the existence of coral reefs not far from the delta. This study describes for the first time in 2011 and 2013 the coral community and status found in the delta front in the southern and northern area not far from the Mahakam Delta.

Material and Method. This study was performed in the delta front water area of the Mahakam Delta, in two Sub-districts i.e. Samboja (representing the southern area) and Muara Badak (representing the northern area), Kutai Kartanegera District, East Kalimantan Province. Eight observation stations were settled in Samboja and 6 stations in Muara Badak. Observation at two stations in Samboja was performed in 2011 and the rest six stations in 2013, while observation at Muara Badak all stations was carried out in 2013. Geographic and coordinate position of the observation station is presented in Figure 1.

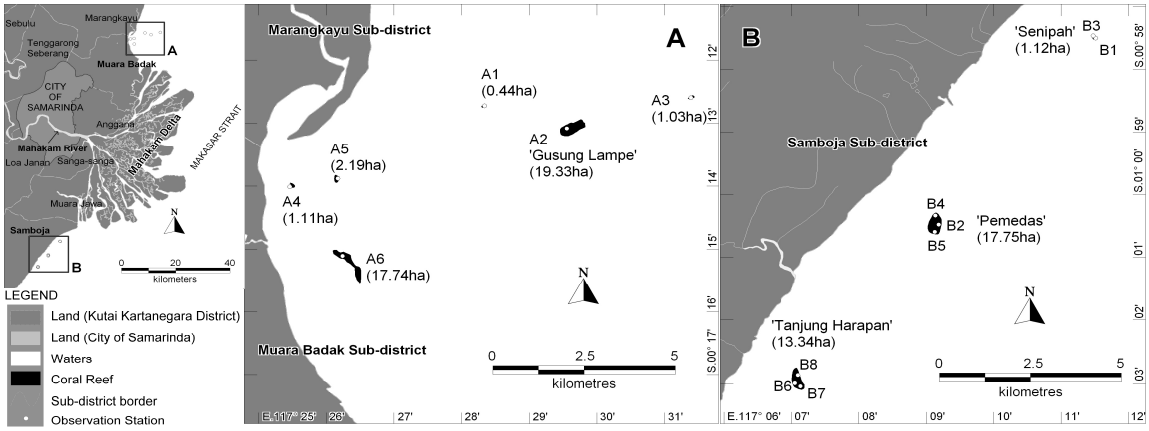

Figure 1. Observation stations and coral reefs distribution in the northern (A) and southern (B) area of Mahakam Delta.

Lifeform line intercept transect method was applied in order to obtain data on coral condition. Fifty meter long measuring tape was deployed to the reef profile. The length of a lifeform category of each coral colony or benthic organism that crossed by transect line was measured (English et al 1994). Percent cover of corals was calculated using formula (Gomez & Yap 1988; English et al 1994; Gomez et al 1994) as follows:

$$Percent\,Cover\,\alpha = \frac{total\ length\ of\ \ lifeform\ \alpha}{length\ of\ \ transect} x100$$

α = a category of lifeform

Percent cover of hard corals (HC) is the total of both coverage of lifeform Acropora and Non-Acropora. Live coral coverage (LC) is the total of hard coral and soft coral coverage (LC = HC + SC). Refer to Jompa & Pet-Soede (2002) and Hill & Wilkinson (2004) coral coverage condition can be classified into following categories: LC <25% as poor/bad, LC 25% - <50% as fair/moderate, LC 50% - <75% as good, and LC ≥75% as excellent.

Coral mortality index (CMI or MI) or hard coral mortality index (HCM) is a ratio between standing dead corals to the total cover of both hard and dead corals (Gomez et al 1994; Fox et al 2001; Metillo 2005; Sadhukhan & Raghunathan 2011). The value of CMI indicates the change of corals from live to dead l. If CMI ≈ 0 means that no significant changes of the live corals, if CMI = 1 means there is a change of live corals to dead corals, and if CMI >0.33, the mortality index is considered to be high and the reef is classified as ill (Sadhukhan & Raghunathan 2011).

Because studies on coral reefs in this area are lacking, the scientific information about reef distribution is almost unavailable and thus spotting reef area through the common satellite image encountered difficulty. The high water turbidity of Mahakam Delta was another handicap making impossible to spot the reefs visually from the

surface. However, since acoustic returns from seabed are able to identify seabed characteristics such as substrate type and density (Allen et al 1976; Lawrence & Bates 2001; Kagesten 2008; Elia et al 2009), Garmin GPSMap 585 echosounder was used to distinguish between the soft and hard bottom substrate type (Garmin 2011). The spotted area of hard substrate bottom was further cross-checked by scuba diving to determine whether it was coral reefs or not, or it was a transition between hard and soft bottom substrate which further considered as reef edge. Identification of hard coral category was done until genus level in-situ (Kelley 2009) and/or ex-situ (Veron 2000; Veron & Stafford-Smith 2002).

Results and Discussion. Six reef spots were found in the water of Muara Badak. Each reef spot represented one observation station. Reef formations in this area were classified in fringing and patch reefs. Reefs at observation station A1, A2, and A3 were formation of patch reefs, located about 3.3-8.9 km from the shoreline with A3 as the furthest station. Reefs at station A4, A5, and A6 were included as fringing reef formation, positioned about 0.7-2.0 km from shoreline with A4 as the nearest station. Referring to the position of Mahakam Delta, these reefs were located about 8.7-13.6 km measured from the outer island of northern Mahakam Delta with A6 as the nearest station.

Among those six reef spots, only reef at station A2 has already been named locally as Gusung Lampe ('gusung' or 'gosong' is an Indonesian term for sandbar, sandbank or patch reef). The coral grew well until the water depth of ±5m, but below it the coral coverage depleted greatly due to siltation or softened bottom substrate. All reef area from station A1 to A6 was 0.44 ha, 19.33 ha, 1.03 ha, 1.11 ha, 2.19 ha and 17.74 ha, respectively, with a total reef area of 41.84 ha.

In Samboja at the southern delta front, three reef spots were found. Station B1 and B3 represented reef spots known as reefs of "Senipah"; station B2, B4, and B5 as reefs of "Pemedas"; and station B6, B7 and B8 as reefs of "Tanjung Harapan". "Senipah", "Pemedas", and "Tanjung Harapan" actually are the name of places where the reefs located. All three reefs in this area were in fringing reef formation, found about 2 km (Senipah), 1.7 km (Pemedas) and 1.5 km (Tanjung Harapan) from shoreline. The distance of reefs measured from the outer island of southern Mahakam Delta consecutively was 11.9 km, 17.8 km, and 23.7 km. Reefs grew in 2-3 m deep flat seabed. Reef area in Senipah, Pamedas, and Tanjung Harapan was recorded as wide as 1.12 ha, 17.75 ha, and 32.21 ha, respectively.

Thirty eight coral genera from 11 families of hard coral category were identified from Muara Badak. During survey in 2011 and 2013 in Samboja were identified 21 genera from 11 families and 22 genera from 12 families respectively, from that numbers only 25 genera came from 12 families was known. Diploastreidae was the only family observed in 2013, while the same 11 families were also found in the previous survey in 2011 (Table 1).

The station A1, the nearest patch reef to the shoreline was categorized as fair/moderate (HC 25.3% and LC 27.5%). The hard coral coverage mostly came from genus of *Echinopora*. However, neither hard nor soft corals were observed dominant in this reef coverage, but mushroom anemone *Rhodactis* from order Corallimorpharia predominated instead which was categorized into others (OT). Corallimorpharian has been known causing phase shift phenomenon and predominating the reef e.g. in Red Sea and Palmyra Atoll (Langmead & Chadwick-Furman 1999; Work et al 2008; Norstrom et al 2009). Various reasons have been proposed to explain this phenomenon including the increase of human disturbance, pollution, or changes in coral reef biota that serve a major ecological function such as depletion of grazers (Work et al 2008).

Table 1

The Genera of corals in Muara Badak (2013) and Samboja (2011 and 2013)

No	Family	Genus	Muara Badak	Samboja	
			2013	2011	2013
1	Acroporidae	*Acropora*	v	v	v
2	Acroporidae	*Alveopora*	v	v	
3	Acroporidae	*Astreopora*	v		
4	Acroporidae	*Montipora*	v	v	v
5	Agariciidae	*Leptoseris*	v	v	v
6	Agariciidae	*Pavona*	v	v	v
7	Dendrophylliidae	*Turbinaria*	v	v	v
8	Diploastreidae	*Diploastrea*	v		v
9	Euphyllidae	*Euphyllia*	v		
10	Euphyllidae	*Galaxea*	v	v	v
11	Euphyllidae	*Nemenzophyllia*	v		
12	Euphyllidae	*Physogyra*	v		
13	Faviidae *	*Leptastrea*		v	v
14	Fungiidae	*Ctenactis*	v		
15	Fungiidae	*Cycloseris*	v		v
16	Fungiidae	*Fungia*	v		
17	Fungiidae	*Heliofungia*	v		
18	Fungiidae	*Herpolitha*	v		
19	Fungiidae	*Lithophyllon*		v	
20	Fungiidae	*Podabacia*	v		
21	Lobophylliidae	*Acanthastrea*	v		v
22	Lobophylliidae	*Lobophyllia*	v		
23	Lobophylliidae	*Oxypora*	v		
24	Lobophylliidae	*Symphyllia*	v	v	v
25	Merulinidae	*Cyphastrea*	v		
26	Merulinidae	*Echinopora*	v	v	v
27	Merulinidae	*Dipsastraea*	v	v	v
28	Merulinidae	*Favites*	v		v
29	Merulinidae	*Goniastrea*	v		
30	Merulinidae	*Hydnophora*	v	v	v
31	Merulinidae	*Leptoria*	v		
32	Merulinidae	*Merulina*		v	v
33	Merulinidae	*Phymastrea* **	v		
34	Merulinidae	*Mycedium*	v		
35	Merulinidae	*Oulophyllia*		v	
36	Merulinidae	*Pectinia*		v	v
37	Merulinidae	*Platygyra*	v	v	v
38	Milleporidae	*Millepora*	v		
39	Pocilloporidae	*Pocillopora*	v		
40	Pocilloporidae	*Seriatopora*	v		
41	Pocilloporidae	*Stylophora*	v	v	v
42	Poritidae	*Goniopora*	v	v	v
43	Poritidae	*Porites*	v	v	v

No	Family	Genus	Muara Badak	Samboja	
			2013	2011	2013
44	Siderastreidae	*Pseudosiderastrea*		v	v

The use of Euphyllidae (with i only one) refers to the International Commission on Zoological Nomenclature 2011. Genera classification used refers to Budd et al (2012), except the *incertae sedis* (*) follows the previous reference (Veron 2000). (**) The latest name, the previous name was Montastraea.

Station A2 had the best condition among other observed stations in this area. It was categorized into good condition with HC 59.7% and LC 61.8%. Reef represented by this station was the largest reef spot, located about 5.7 km seaward from shoreline. The coral community growth was optimum along the patch reef edge at deep of 2-5 m. The hard corals were predominated by genera of *Porites* and *Montipora*. The station A3 was the furthest reef spot from the shoreline, and categorized as poor/bad coral condition, with hard coral coverage of 13.0%. Despite these reefs located in relatively clear sea water due to the far distance from turbidity sources, refer to the data in Table 2, this reef spot was characterized by large coverage of rubble (R 53.9%). According to local fishers, the reef was damaged due to blast fishing practices and according to Fox & Caldwell (2006) and England (2014) cause negative impact on the reefs community and alter the reef structure physically by creating expanses unstable coral rubble and by shattering the coral skeletons.

Referring to Table 3, the coral reefs of Muara Badak were overall categorized into poor/bad condition with hard coral coverage 20.05% and live coral coverage 21.02%. The patch reefs tended to have better condition than the fringing reefs formation.

The fringing reef formation in Muara Badak at station A4, A5 and A6, all were categorized into poor/bad coverage condition with LC of 10.7%, 4.5%, and 8.6% respectively. The low coverage of hard corals in this spots was considered to be influenced by high turbidity or siltation resulting in soft bottom sediment (indicated by high value of SI coverage as seen in Table 2), which in turn covered benthic communities or disturbed larval settlement/recruitment (Fabricius 2005; Erftemeijer et al 2012). *Porites* was observed as the dominant hard coral or the most tolerant coral to stress/disturbance in these three reef spots. *Porites*, especially the massive form, commonly was found tolerant to high turbidity environment (Tomascik et al 1997; Toda et al 2007; Golbuu et al 2008; Safuan et al 2016).

In general the hard coral mortality index at Muara Badak area in average was 0.22 meaning no significant change of live coral. This healthy reef condition was mainly shown by station A1 and A2, but ill reef condition was shown by reefs at station A3, A4 and A6. Reefs at station A4 and A6 located near shore grew at turbid waters and soft bottom sediment. Mackinnon et al (2000) described that the fringing reefs that formed near the shore were vulnerable to pollution and siltation. High volume of mud in shore substrate led to limiting the coral development in very slow growth or even causing the absence of coral in the area. Turbidity and sedimentation also elevate the levels of coral disease and higher levels of other compromised health indicators at high sediment plume exposure sites (Pollock et al 2016).

Corals of station A3, at several colonies were observed to suffer from bleaching, and based on the information from local fishermen, this station frequently became a target area for illegal/destructive fishing, such as cyanide and blast fishing practices as mentioned earlier. Burke et al (2011) suggested that poison fishing was destructive to corals, and cyanide might bleach corals and kill polyps. However, it was still inconclusive due to insufficient scientific information for this area. Mous et al (2000) stated that the cyanide fishery for food fish may not be as threatening to Indonesia's coral reefs as is sometimes assumed, especially not as compared to other threats such as blast fishing or coral bleaching caused by global climate change.

Table 2

Percent cover of lifeform per observation station in Muara Badak and Samboja

Specification		*Muara Badak Sub-district*						*Samboja Sub-district*							
		2013						*2011*			*2013*				
		A1	*A2*	*A3*	*A4*	*A5*	*A6*	*B1*	*B2*	*B3*	*B4*	*B5*	*B6*	*B7*	*B8*
Dead coral	DC		2.2	6.4				11.0	9.1		10.2	7.6			
	DCA	4.7	2.6	2.2	13.8		7.9	6.3	6.7	29.6	5.6	6.8	35.4	78.9	21.2
Acropora	ACB	1.0	1.6	0.3							2.6	5.4			
	ACT		6.9	1.9					1.2						
	ACE														
	ACS										3.2	10.0			
	ACD										2.0	1.4			
Non Acropora	CB		10.2	0.4				0.0	1.0		8.6				
	CE	19.1	11.7	1.4	4.9	0.5	1.0	9.5	13.1	5.1	8.6	18.8	13.0	5.5	6.8
	CF		16.1			0.5		0.1	2.3		2.8		9.8	1.4	1.0
	CM	4.0	8.6	6.1	5.8	3.5	6.1	6.9	9.0	0.5	7.8		21.6	4.2	16.5
	CS	0.4	2.2	2.4				1.9	2.9						
	CMR	0.8	2.4	0.5									0.4		
	CME														
	CHL								0.8						
Other fauna	SC	2.2	2.1				1.5	4.0	3.7		0.6		7.6	1.4	
	SP	3.2	1.3	1.1	4.6	1.0	2.0	1.1	3.5		1.4				
	AA	5.8		0.3					0.0						
	CA														
	HA				11.7		1.0	1.4	0.1						
	MA	1.8			8.2		1.5								
	TA														
	ZO														
	OT	25.4	1.2	0.4	3.2		1.5	4.5	4.4	15.8			3.0	0.6	
Abiotic	S	13.9	4.4	15.0			6.5	1.2	3.3	30.3	33.2	34.8	9.2	8.0	40.4
	R	10.9	20.3	53.9	5.6			2.9	1.1	18.7	2.4				14.1
	RCK			6.5		45.5			1.6		11.0	15.2			
	SI	6.8	6.2	1.2	42.2	49.0	71.0	49.3	36.4						
	WA														
	DDD														

Table 3

Percent Cover of Hard Coral (HC), Live Coral (LC), Coral Mortality Index (CMI), Category of Coral Condition, And Coordinate of Observation Station

Station		*HC*	*LC*	*Condition category*	*CMI*	*Coordinate*
Muara Badak (2013)	A1	25.30	27.50	Fair/Moderate	0.16	S.0° 12' 43.4" E.117° 28' 20.4"
	A2	59.70	61.80	Good	0.07	S.0° 13' 04.9" E.117° 29' 33.4"
	A3	13.00	13.00	Poor/Bad	0.40	S.0° 12' 35.7" E.117° 31' 23.5"
	A4	10.70	10.70	Poor/Bad	0.56	S.0° 14' 00.8" E.117° 25' 27.8"
	A5	4.50	4.50	Poor/Bad	0.00	S.0° 13' 52.8" E.117° 26' 10.4"
	A6	7.10	8.60	Poor/Bad	0.53	S.0° 15' 06.3" E.117° 26' 14.5"
	Av.	20.05	21.02	Poor/Bad	0.25	
Samboja (2011)	B1	18.40	22.39	Poor/Bad	0.48	S.0° 57' 30.1" E.117° 11' 30.8"
	B2	30.19	33.84	Fair/Moderate	0.34	S.1° 00' 28.6" E.117° 09' 11.1"
	Av.	24.30	28.12	Fair/Moderate	0.41	
Samboja (2013)	B3	5.64	5.64	Poor/Bad	0.84	S.0° 57' 27.9" E.117° 11' 28.6"
	B4	35.60	36.20	Fair/Moderate	0.31	S.1° 00' 19.8" E.117° 09' 08.2"
	B5	35.60	35.60	Fair/Moderate	0.29	S.1° 00' 35.6" E.117° 09' 07.6"
	B6	44.74	52.34	Good	0.44	S.1° 02' 59.7" E.117° 07' 03.0"
	B7	11.08	12.50	Poor/Bad	0.88	S.1° 03' 02.6" E.117° 07' 08.0"
	B8	24.30	24.30	Poor/Bad	0.47	S.1° 02' 52.5" E.117° 07' 05.8"
	Av.	26.16	27.76	Fair/Moderate	0.55	

Live coral coverage in Samboja area varied from poor/bad to good as shown in Table 3. In general, both data in 2011 and 2013 indicated that the condition of coverage was categorized fair/moderate with LC 28.12% and 27.76%, respectively. Reefs of Senipah at station B1 and B3 had the lowest coral coverage among other reef spots in this area and were categorized into poor/bad condition. Reefs of Pemedas represented by station B2, B4 and B5 showed similar condition and were categorized into fair/moderate condition. Station B6 in reefs of Tanjung Harapan, was the only station having good category of coral coverage, while at station B7 and B8 the corals had poor/bad coverage.

Massive and encrusting life forms were commonly observed in reefs of Samboja area with *Porites* and *Montipora* as predominant genera. Nevertheless, in reefs of Pemedas at station B4 and B5, *Acropora*, *Montipora,* and *Porites* was the common observed genera. In general all three reefs in Samboja area were classified as ill with CMI values of 0.41 (2011) and 0.55 (2013). CMI value obtained at station B7 and B3 was 0.88 (the highest) and 0.84, respectively. At all stations in reefs of Senipah (B1 and B3) and Tanjung Harapan (B6, B7, and B8), CMI values were above 0.33 and classified as ill. However, reefs of Pemedas at station B4 and B5 were considered as healthy reefs indicated by consecutive CMI values of 0.31 and 0.29. But reef at station B2 was classified ill since the CMI value was recorded 0.34, slightly above the 'healthy' limit.

The modern Mahakam has two active fluvial distributary systems directed northeast and southeast (Storms et al 2005). The northeast distributary is Muara Berau that flows to the north and southeast distributary is Muara Jawa that flows to the south (Nursigit et al 2013). The distributaries were contributed by a high water discharge coming from one of the largest rivers in Indonesia namely Mahakam River, carrying tones of terrigenous sediments into coastal water (Tomascik et al 1997). Thus, the bottom sediment or substrate is characterized by mud or high silt and clay contents (Allen et al 1976; Allen & Chambers 1998; Storms et al 2005).

Turbidity and sediment loads from northeast distributary system will be delivered into the water of Muara Badak Sub-district, while from southeast distributary system will affect coral reefs in the water of Samboja Sub-district. Turbid water and

sedimentation/siltation was obviously observed to affect the coral reef existence and condition in both Sub-districts, particularly on the fringing reefs. Smith et al (2008) suggested that near shore coral reefs were displaying signs of declining health, representing the cumulative impacts from variety of natural and anthropogenic disturbances. However, how the coral might be able to survive or to adapt toward the effect of continuing turbidity and sedimentation/siltation, as well as to other natural and anthropogenic disturbances, has not fully understood yet since more studies in this area are still required.

Conclusions. At northern delta front of Mahakam Delta, which is administratively included in Muara Badak Sub-district, coral reefs are distributed in six reef spots (three in fringing and three in patch formation), in the total area of 41.84 ha, with coral coverage of LC 21.02% (poor/bad category) and CMI value of 0.25. Thirty eight genera from 13 families of hard corals were identified from this area.

At southern delta front of Mahakam Delta which administratively belongs to Samboja Sub-district, three reef spots were observed, and all in fringing formation with total area of 32.21 ha. Data in 2011 showed that coral coverage (LC) in this area averaged 28.12% (fair/moderate category) with CMI value of 0.41. But data in 2013 showed the coral coverage (LC) in this area was recorded 27.76% (fair/moderate category) with CMI value 0.55. Twenty five genera of hard corals were identified from both years, 21 genera identified in 2011 and 22 genera in 2013, all were included into the same 12 families.

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