Distribution and condition of coral reef ecosystem in Tanah Merah Bay, Jayapura, Papua, Indonesia

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Abstract. The coral reef ecosystem in the Tanah Merah Bay (Depapre) is quite large and varied and even relatively pristine. On the one hand, destructive fishing is still common, especially the use of explosives and the use of tuba root anesthesia and even marine tourism activities such as snorkeling and diving that are less professional and the installation of fishing anchors. Ironically, data and information, especially the distribution and condition of corals, are still limited. This study aims to determine the distribution, condition of coral cover and coral damage as initial data and information in sustainable management. The collection of coral reef distribution data uses the Geographic Information System (GIS) method by analyzing SPOT-6 Satellite Imagery. Coral cover and coral damage data gathering used a survey approach with the Point Intercept Transect (PIT) method. The results showed that the distribution of coral spread along the coast of the Tanah Merah Bay region with the highest coral cover in Tanjung Tanah Merah, Tanjung Amay, Tanjung Harlem, Tanjung Sarebo and Amayepa and the lowest at Kwahkebo islands and Tanjung Kuburan Tablasufa. The dominant life form categories are Coral Massive (CM), Coral Branching (CB), Coral Foliose (CF), branching Acropora (ACB) and table Acropora (ACT). Rubble is found to be highest in Amayepa and Tanjung Tanah Merah, Dead Coral/Dead Coral with Alga is found highest at Kwahkebo islands and Amayepa due to use blast fishing. Bleaching was also found in almost all stations due to use of tuba roots.

Key Words: coral cover, destructive fishing, anthropogenic, tourism activities, diving.

Introduction. Tanah Merah Bay or also known as Depapre Bay is one of the areas in the eastern part of the north coast of Papua with the potential of coastal and marine resources that are quite large, varied, and still relatively pristine. The main coastal and marine ecosystems include mangroves, seagrasses, and coral reefs. In addition, there are also some rare and protected biota, such as various types of whales, dolphins and dugongs, and reptiles, including hawksbill turtles (*Eretmochelys imbricata*), green turtles (*Chelonia mydas*) and leatherback turtles (*Dermochelys coriacea*) which are protected species with their nesting areas around Tanjung Tanah Merah and Dormena Village.

Ironically, destructive fishing is still common, such as the use of blast fishing and tuba root anesthesia. Similarly, snorkeling and diving activities that are less professional and placing anchors of fishing boats also cause damage to coral reefs. In addition, turbidity and sedimentation has begun to increase in several locations as a result of the opening of roads on land and the deployment of port construction sites around the waters of Waiya village. Infrastructure development as a consequence of the Tanah Merah Bay area serving as a strategic area to support the development in Papua based on RI Presidential Regulation no. 65 of 2011 concerning the development acceleration of Papua and West Papua.

The coral reef ecosystem resources at Tanah Merah Bay at present, on the one hand, has begun to experience damage especially after becoming a new economic area where the potential of marine and coastal resource pressures will unavoidably increase.

On the other hand, the potential of coral reef ecosystem, in particular, is still relatively not widely studied. Until now there have not been enough data and information available as a reference in efforts to manage sustainable coral reefs. Therefore, we need research that can provide synoptic and spatial data and information. The objective of this study was to determine the distribution and condition of coral ecosystem resources life form in Tanah Merah Bay.

Material and Method

Description of the study sites. This research was conducted in the Tanah Merah Bay region which is geographically located in Depapre District, Jayapura Regency (Figure 1). This research took place from September to December 2017.

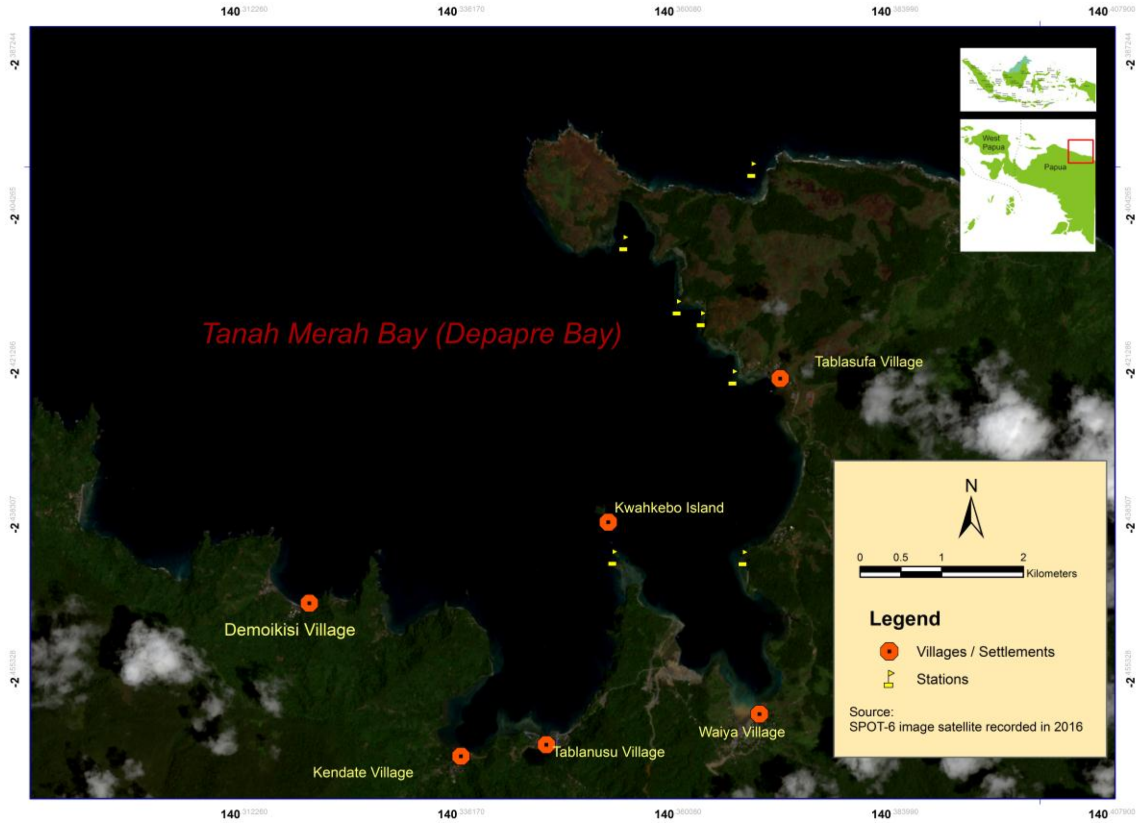

Figure 1. The location of Tanjung Tanah Merah, station of data collection and the coral reef ecosystem in Tanjung Tanah Merah, Papua, Indonesia.

Category and data source. There are two data categories in this study, namely primary and secondary data. The primary data were obtained from field surveys and Satelite Image analysis, while the secondary data were obtained from the literature review, documents and reports from the institution that are relevant to the study topic.

Data collection technique. Life form data collection was carried out through surveys. Data on the distribution and extent of the coral reef areas were obtained by processing the data analysis of SPOT-6 image satellite recorded in 2016 by Pustekdata Lapan. Station determination (Table 1) to collect coral data was determined based on the results of the Rapid Reef Assessment (RRA) survey. The aim of RRA survey was to find out, in general, the extent of benthic species and the habitat shape in the areas of reef top, reef edge and reef flat. This technique was also used in determining transect points and the locations of detailed studies using Global Positioning System (GPS). After the RRA survey was carried out, it was followed by taking coral cover estimation using Point Intercept Transect (PIT) (Santavy et al 2012). PIT method was used because it is fast, efficient and provides a good estimate for the cover of benthic communities (Hill & Wilkinson 2004).

Observations were made using a 10 m meter parallel to the reef flat at a depth of about 3-5 m and 10-13 m with 3 repetitions. Stations were determined based on consideration of representation, security, comfort, and safety in data collection (Giyanto et al 2014). Therefore, stations were generally located in areas that are relatively protected from large waves (Figure 1). Data collection of the aquatic environment parameters such as dissolved oxygen, current, water transparency, pH, salinity, and temperature was done in situ at the same station with coral data collection.

Table 1

Location of the observation stations

Location / Station	*Coordinate*	
	E	*S*
Kwahkebo island	$140^0$21'10.636"	$2^0$26'34.83"
Tanjung Sarebo	$140^0$21'36.151"	$2^0$24'55.50"
Tanjung Tanah Merah	$140^0$21'15.012"	$2^0$24'30.01"
Tanjung Harlem	$140^0$21'45.734"	$2^0$25'0.163"
Amayepa	$140^0$22'5.8335"	$2^0$24'0.902"
Tanjung Amay	$140^0$21’30.013"	$2^0$26'30.00"
Tanjung Kuburan Tablasufa	140°21'47.00"	2°25'23.00"

Data analysis. The detection of coral reefs used SPOT-6 Image Satellite, which has been widely used in identifying coral habitats and shallow waters (Arief 2012; Arief 2013). In general, data on the distribution of coral reef habitats was obtained through two stages, namely pre-processing stage (radiometric and geometry correction, masking and cropping, composite image, and image sharpening) and interpretation. The main process in the image interpretation digitally done was the image classification (Suyarso 2014).

Description of benthic categories used the category of level 2 (Facon et al 2016), namely Algal assemblage (AA), branching *Acropora* (ACB), digitate *Acropora* (ACD), *Acropora* encrusting (ACE), submassive *Acropora* (ACS), table *Acropora* (ACT), Coralline algae (CA), coral branching (CB), encrusting (CE), foliose (CF), *Heliopora* (CHL), massive (CM), Millepora (CME), mushroom(CMR), submassive (CS), *Tubipora* (CTU), Dead coral (DC), Recently killed coral (RCK, Dead coral with algae (DCA), Fleshy macroalgae (FMA), *Halimeda* (HA), Nutrient indicator algae (NIA), Others (OT), Rubble (R), Rock (RCK), Sand (S), Soft coral (SC), Silt (SI), Sponges (SP), Turf algae (TA), Water (WA), and Zoanthids (ZO). The percentage of live coral cover was obtained by the following equation (Facon et al 2016):

Percent cover = 100 × Number of points where the category is recorded/Total number of points on the transect

The benthic category cover values, especially life form, and the percentage criteria were obtained from the above equation, categorized by referring to Minister of Environment Decree No. 04/2001; Gomez & Yap (1988), namely the percentages of 0-24.9% (poor), 25-49.9% (fair), 50-74.9% (good), and 75-100% (excellent). Furthermore, the coral cover data are displayed spatially on a 1:250,000 scale map with the help of ArcMap 10.5 software.

Results

Aquatic environment conditions. The measurement results of each parameter are presented in Table 2. The values displayed are the results of the calculation of the average repetition at each station location.

Table 2

The condition of aquatic parameters

Location/Station	*Dissolved oxygen (mg/L)*	*Current (m/s)*	*Water transparency (%)*	*pH*	*Salinity (ppt)*	*Temp (^oC)*
Kwahkebo Island	5.25	0.24	100	8.0	31.35	30
Tanjung Sarebo	5.24	0.24	100	7.3	32.04	31
Tanjung Tanah Merah	5.24	0.24	100	8.5	32.00	30
Tanjung Harlem	5.25	0.24	100	8.5	32.00	31
Amayepa	5.25	0.28	100	8.5	32.35	29
Tanjung Amay	5.25	0.26	100	8.5	31.20	30
Tanjung Kuburan Tablasufa	5.24	0.20	100	8.5	32.04	30

Distribution of coral reef ecosystem. The coral reef ecosystems around the Tanah Merah Bay area spread along the coast from Tanjung Tanah Merah (Depapre District) to Bukisi Village, Bukisi District (Figure 2).

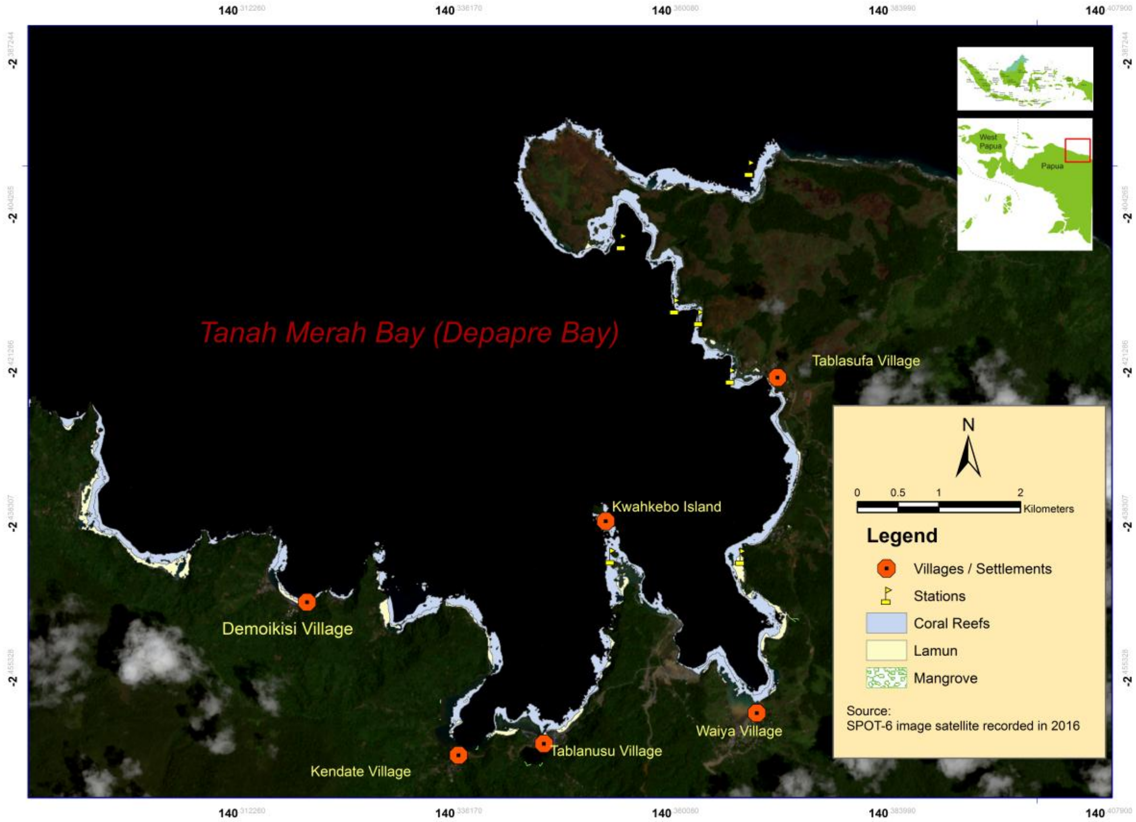

Figure 2. Distribution of coral reef ecosystem in Tanah Merah Bay, Papua, Indonesia.

Condition of coral reef ecosystem. Coral conditions were obtained from the comparison between the percentage of live coral cover and abiotic components consisting of sand, rubble and dead coral. The highest conditions of coral cover in the Tanah Merah Bay area were found at Tanjung Tanah Merah station at 68.00%, Tanjung Amay at 64.33%, and Tanjung Harlem at 63.67%, Tanjung Sarebo at 60.00%, and Amayepa at 57.33%, each of which can be categorized as "good". The lowest is at Kwahkebo Island station at 46.33% and Tanjung Kuburan Tablasufa at 46.00%, each of which is categorized as "fair" (Table 3).

Table 3

Percentage of coral cover per station

Location/Station	Live coral (%)		Component average (%)	Category (%)*
	Depth 3-5 m	*Depth 10-13 m*		
Kwahkebo Island	44.67	48.00	46.33	fair
Tanjung Sarebo	49.33	70.67	60.00	good
Tanjung Tanah Merah	64.67	71.33	68.00	good
Tanjung Harlem	58.67	68.67	63.67	good
Amayepa	45.33	69.33	57.33	good
Tanjung Amay	62.67	66.00	64.33	good
Tanjung Kuburan Tablasufa	36.00	57.33	46.67	fair

*Gomez & Yap (1988); Minister of Environment Decree (2001); Source: Result of Primary Data Source, 2017.

The percentage of life forms found at all locations/stations is presented in Table 4.

Table 4

Percentage of life form at all station

Location/Station	Percentage of life form (%)													
	ACB	*ACT*	*ACE*	*ACS*	*ACD*	*CA*	*CB*	*CE*	*CF*	*CM*	*CME*	*CMR*	*CS*	*CTU*
Kwahkebo island	0.17	0.17	4.17	2.17	1.83	0.50	4.50	2.50	1.17	3.67	0.50	1.00	0.67	-
Tanjung Sarebo	3.33	1.17	2.00	1.17	1.33	1.50	7.00	2.33	2.50	4.00	0.33	2.00	0.33	0.67
Tanjung Tanah Merah	5.83	4.00	1.67	1.67	3.17	0.83	4.33	1.33	1.83	5.33	0.17	2.50	0.67	0.67
Tanjung Harlem	1.17	0.67	1.50	0.33	0.50	1.67	6.00	1.50	6.67	9.17	1.33	0.67	0.67	-
Amayepa	5.50	4.67	0.67	0.67	2.00	0.50	4.50	1.50	2.17	3.67	0.83	2.00	-	-
Tanjung Amay	0.33	1.00	2.50	1.00	0.50	1.83	3.00	1.17	4.83	11.33	1.83	0.33	2.50	-
Tanjung Kuburan Tablasufa	-	1.17	1.00	0.50	1.00	1.00	2.67	2.00	2.17	10.00	0.50	0.50	0.83	-

Branching (ACB); Tabulate (ACT); Encrusting (ACE); Submassive (ACS); Digitate (ACD); Coralline Algae (CA); Coral Branching (CB); Encrusting (CE); Foliose (CF); *Heliopora* (CHL); Massive (CM); Millepora (CME); Mushroom (CMR); Submassive (CS); *Tubipora* (CTU); not found (-).
Source: Result of Primary Data Analysis, 2017.

The highest rubble average was found in Amayepa at 14.67%, Tanjung Sarebo 12.67%, and Tanjung Tanah Merah 10.67%. The average dead coral with algae was found in Kwahkebo Island at 8.67% and Amayepa 8.00% (Table 5).

Table 5

The percentage of rubble and dead coral / dead coral with algae

Location / Station	Rubble (%)		Dead coral /dead coral with Algae (%)		Average of rubble (%)	Average of dead coral /dead coral with algae (%)
	Depth 3-5 m	Depth 10-13 m	Depth 3-5 m	Depth 10-13 m		
Kwahkebo island	8.67	4.67	6.00	11.33	6.67	8.67
Tanjung Sarebo	16.00	9.33	4.00	3.36	12.67	3.68
Tanjung Tanah Merah	12.67	8.67	4.67	5.33	10.67	5.00
Tanjung Harlem	5.33	8.67	7.33	4.00	7.00	5.67
Amayepa	20.67	8.67	11.33	4.67	14.67	8.00
Tanjung Amay	4.67	3.33	4.67	1.37	4.00	3.02
Tanjung Kuburan Tablasufa	2.00	5.33	6.67	6.00	3.67	6.33

Source: Result of primary data analysis, 2017.

Discussion

Aquatic environment conditions. Oxygen is less soluble at high temperatures. At the same time, the respiration rate depends on dissolved oxygen from most microbes, macrofauna, and algae which increases significantly. The temperature increase exacerbates low oxygen stress and allows the expansion of anoxic zones, especially in areas of high organic waste input and poor circulation basins (Goreau & Hayes 2008). Based on the measurement results, dissolved oxygen at the study location ranged from 5.24 to 5.25 mg/L.

Transportation Agency of Jayapura Regency's (2006) stated that the most dominant currents in Tanah Merah Bay were tidal currents, which ranged between 0.06-0.28 m/s at high tide, and 0.05-0.25 m/s at low tide. Meanwhile, at full moon time (high tide) it ranged 0.11-0.33 m/s and 0.11-0.31 m/s at low tide. The current speed at the research station varied in the range of 0.20-0.28 m/s. The highest current speed observed at Amayepa station was allegedly due to direct contact with the Pacific Ocean. Amayepa Station was the only station outside the Tanah Merah Bay area (Figure 1). Measurements in this study were carried out at low tide along with data collection of coral and reef fish. Data collection on coral and reef fish was very possible when the waters were relatively calm, i.e. at low tide.

The movement of water or water flow is very influential for coral growth because the movement of water for aquatic organisms is related to the supply of oxygen (Osinga et al 2011), and food (Sebens et al 1998). The process of hydrodynamics (current and turbulence) affects coral growth, reducing the level of attack of coral-eating biota (Lenihan et al 2015). Although corals have a mechanism for cleaning sediment deposition, excessive sediment deposition will affect coral growth (Roy & Smith 1971). The results of current measurements at the study location ranged between 0.20 and 0.28 m/s. The current range is still ideal for coral growth.

Water transparency is very closely related to light penetration, which is very important for zooxanthellae and coral animals, especially in the photosynthesis process (Rogers et al 2001). The value of water transparency that was obtained is 100%, meaning that the light could still penetrate to the bottom. The value of water transparency is ideal for coral growth because the value of water brightness that is suitable for coral growth set by the Ministry of Environment in 2004 is >5 m. The brightness condition of the waters in the Tanah Merah Bay area is ideal to support the excellent growth of coral (Nybakken 1997), because the light can enter the bottom of the waters, especially at a depth of 10-13 m. Such conditions are very good for zooxanthellae which are symbiotic with coral animals to carry out photosynthesis well.

The pH range set by the Ministry of Environment of the Republic of Indonesia (2004) is 7-8.5. The degree of acidity (pH) of water describes the concentration of hydrogen ions in a certain area of waters (Rogers et al 2001). pH is closely related to carbon dioxide concentration and alkalinity. The pH at the study location was in the range of 7.5-8.5, where a relatively ideal condition for coral growth is 7.5-8.4 (Rogers et al 2001). The results of pH measurements by Jayapura Regency's of Transportation Agency (2006) in the waters around the port construction showed that the pH had a range of 6.7-7.8. The effects of more acidic water on marine invertebrates can vary between stages of life (Kurihara 2008).

Salinity describes the concentration of the total ions present in a certain area of waters with the main ions being composed of sodium, potassium, magnesium, chloride, sulfate, and bicarbonate. The ideal salinity value for coral reefs is around 25-40 ppt (Wilkinson & Buddemeier 1994). Corals are very sensitive to salinity, which determines the spread of coral reefs (Goreau & Hayes 2008). Even short-term exposure to salinity below 30 ppt reduces coral tolerance to increased temperatures, and this effect is further aggravated by exposure to high light intensity (Coles & Jokiel 1978). Changes in salinity can lead to photosynthesis and zooxanthellae respiration of *Stylophora pistillata* corals (Ferrier-Pages et al 1999). The most vulnerable species are branching Acropora and table Acropora (True 2012).

Coral reef distribution is limited by coral distribution, which is generally related to physiological processes, especially in terms of food and reproduction. Thus, the temperature will limit both through ecological interaction processes, where the energy needs of coral reefs progressively become less competitive against the dominance of certain organisms such as macroalgae (Veron 1995; Szmant 2002). Temperature is also a variable that plays an important role in controlling the horizontal distribution of coral reefs (Veron 1995). The effects of warmer and more acidic water in marine invertebrates can vary between stages of life (Kurihara 2008). Temperature affects the sticking of the sponge, and some species will increase at higher temperatures (Duckworth et al 2012), while the temperature increase has negative effects on the growth and survival of corals (Hoegh-Guldberg et al 2007).

The ideal temperature for coral growth is in the ranges of 23-30^{o}C (Wilkinson & Buddemeier 1994), but each colony or type of coral has a certain resistance in adapting temperature fluctuations (Duckworth et al 2012). The range of surface temperatures at the observation station was 29-31^{o}C. The same temperature range was also reported by Transportation Agency of Jayapura Regency (2006), namely 29-31^{o}C. The average annual temperature in Jayapura and its surrounding waters in Hamuna et al (2015) tend to decrease with a range of 25-31^{o}C. Furthermore, it is stated that spatially, offshore waters or far from the coast have higher sea surface temperatures compared to waters near the coast. Temporally, the average value of sea surface temperature tends to be higher in the east season until the east-west transition season; however, it is lower in the west season until the west-east transition season due to high-intensity rainfall.

Distribution of coral reef ecosystem. Based on the results of SPOT 6 image analysis, the area of coral reef ecosystem in the Depapre Bay region is around 335.75 ha. The largest areas are around Tanjung Tanah Merah, Tanjung Harlem, and Tanjung Sarebo. The locations of the ecosystems are relatively wide and protected in certain seasons, especially the east monsoon. Meanwhile, in other locations such as the island of Kwahkebo, Kampung Tablanusu, and Kendate directly face the Pacific Ocean, which is characterized by a steep beach or cliff. There are several small rivers that do not flow throughout the year to Tanah Merah bay so that the beaches are sandy and rocky. The only major river is in Bukisi District, which is to the left of the bay. Thus the sedimentation carried by the river flow was almost non-existent. Currently, sediment material has entered the waters, especially in the Waiya village due to the opening of the road as a port supporting route, especially during the rainy season. The sediment inflow has recently been suspected to cause coral damage around the site (Acevedo et al 1989). The sediment increase in the waters will ultimately reduce dissolved oxygen which affects colony life form, coral cover, animal composition of coral inhabitants and recruitment coral pattern (Pastorok & Bilyard 1985).

Condition of coral reef ecosystem. Overall, the cover percentage obtained was higher than that recorded by Marine and Fisheries Agency of Jayapura Regency's (2015), which was an average of 39.09% using RRAS method and 42.38% using Line Intercept Transect (LIT) method. Based on the depth at each station, coral cover is generally higher at a depth of 10-13 m. The high coral cover especially in Tanjung Tanah Merah is thought to be due to the ideal water conditions for coral growth (Table 1), and it is in a relatively protected position from waves that fluctuate in certain seasons compared to other stations. Meanwhile, the low coral cover on the islands of Kwahkebo and Tanjung Kuburan Tablasufa is allegedly due to the relatively stationary physical position of the waves coming in both the East and West seasons because it is located in the middle of the bay and relatively acts as a barrier for the inner area of the bay and gets pressure from the mainland that is close to the source of sedimentation carried by the river that carries material from the terrestrial that begins to open. This is in line with the research of Roberts et al (2017) concerning terrestrial degradation of coral reef health. Kwahkebo Island is administratively located in the territory of the Tablanusu village government, and it is a catchment area of Tabla tribe. Kwahkebo Island is located between Waiya village (also known as Tabla Wauna village) and Tablanusu village, which are adjacent to the port construction site (Figure 1).

The dominant life forms were found in the study locations, namely the types of Coral Massive (CM), Coral Branching (CB), Coral Foliose (CF), branching Acropora (ACB) and table Acropora (ACT). Acropora dominates stations that are on the outside, namely Amayepa, and Tanjung Tanah Merah. The Coral Massive (CM) dominates the inside section of the stations in the Tanah Merah Bay region, namely in Tanjung Amay and Tanjung Kuburan Tablasufa (Table 3). The dominance of Acropora genus shows that the water quality in the station is still good, because Acropora is very susceptible to anthropogenic influences, especially sedimentation (True 2012). Soft coral was only found at Kwahkebo station at 7.67%. The high life form of soft coral is highly correlated with water quality parameters, especially sedimentation (Baum et al 2016). Hard coral is more important because of its capacity as a reef builder (Cuadrado et al 2016). Therefore, if soft coral grows faster, the hard coral will lose in competition for food and space so that the coral cover becomes low (Atrigenio & Alino 1996).

The causes of damage to coral reefs in the Tanah Merah Bay region can be classified into two categories: natural and anthropogenic (human), while in terms of scale, they are classified into local and regional scales. Anthropogenic damage is generally caused by destructive fishing and sedimentation activities due to port infrastructure development around Waiya and Tablanusu villages which are categorized as local causes. The causes of damage of local scale are relatively easy to manage, compared to regional ones. The highest rubble was found at Amayepa station at 14.67%, Tanjung Sarebo 12.67%, and Tanjung Tanah Merah 10.67%. Dead Coral (DC), and Dead Coral with Algae (DCA) were found to be the highest at Kwahkebo island station at 8.67% and at Amayepa station 8.00%.

The high level of rubble and dead coral/dead coral with algae indicates that coral damage has occurred. The high rubble at the three stations was thought to be due to the explosive use that is still rampant in the Tanah Merah Bay area, where the three stations are relatively far from the settlement and the officer control (Figure 2). Signs of coral damage due to explosive are evident at each station in the form of new and old faults. Blast fishing is still often done by fishermen, both local fishermen and outside fishermen, such as fishermen from Jayapura City (Figure 3).

Figure 3. Rubble due to the use of explosives (blast fishing) at Tanjung Sarebo (original).

The raw material for blast fishing comes from remnants of World War II gun powder which is still widely found in the Tanah Merah area. The impact of blast fishing, even though it does not affect coral recruitment, (Sawal et al 2013), can physically reduce coral cover (Pauly et al 1989). Perhaps the most damaging of destructive fishing practice is dynamite or blast fishing (Mous et al 2000). The practice of anesthesia using tuba roots or known as Seido in the Tefraa language is still common among the local fishermen even in fishing when the opening of Tiaitiki is still considered non-destructive because it only makes the fish faint. Tiaitiki is a local wisdom of Tefraa/Tabla tribe community, namely with an "area closure" system at a certain time (Yarisetou 2009). Tuba root is the sap from vines called *Derris elliptica* which is often found in the Tanah Merah Bay region. Coral bleaching due to the use of tuba roots is found in several stations, including at the stations of Tanjung Tanah Merah, Tanjung Harlem and Tanjung Sarebo (Figure 4).

Figure 4. Coral bleaching due to use tuba root at Tanjung Harlem (original).

Conclusions. The highest cover coral covers are respectively found at the stations of Tanjung Tanah Merah, Tanjung Harlem, and Tanjung Sarebo. The lowest coral covers are found at the stations of Kwahkebo Island and Tanjung Kuburan Tablasufa. The high percentage of coral cover in Tanjung Tanah Merah, Tanjung Harlem, and Tanjung Sarebo is allegedly due to the relatively ideal water conditions for coral growth. Meanwhile, the low coral cover on Kwahkebo Island and Tanjung Kuburan Tablasufais is suspected to have been subjected to physical wave pressure both in the East and West monsoon as well as sedimentation pressure carried by the river flow during the rainy season in form of materials from the upland which begins to open. Anthropogenic damage which caused rubble was highest at the stations of Amayepa, Tanjung Sarebo, and Tanjung Tanah Merah. Meanwhile, Dead Coral (DC) cover and Dead Coral with Algae (DCA) were found to be highest at the stations of Kwahkebo Island and Amayepa.

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