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THE USE OF REMOTE SENSING AND GIS TECHNOLOGY IN SUPPORTING ECOREGION MANAGEMENT

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ABSTRACT

Coastal areas provide great benefits for human lives. In many isolated islands, coastal ecosystem provides food and building materials extracted from coastal vegetation e.g. mangroves. Therefore, it is essential to ensure the sustainability of the coastal ecosystem. This study provides data and a map in supporting the coastal ecoregion management, by using remote sensing satellite imagery, GIS technology, and field observation. Remote sensing and GIS data were obtained from Google Earth and analysed by ArcGIS. The combination of both laboratory and field work were carried out to provide a broad picture of the coastal area in Jefman Island, Raja Ampat, West Papua. The results of this study showed various habitats and vegetation in the Jefman seabed area. It also demonstrates that the abundance and diversity of coral reef and reef fishes are the major community constructing the island, amounting 22% coral cover with 12 families and diversity index 1.20 – 2.52 for reef fish with fish density about 231 ind/50 m^2. Furthermore, other communities such as seagrass, seaweed, and mangrove are also briefly explained, as they also play a greater role in supporting the whole coastal ecological system. Based on map data analysis, we found a particular area that urgently needs to be protected. Remote sensing and GIS technology were found useful to help the manager to design coastal management strategies in the future.

Keywords: coastal area, ecoregion management, GIS, habitat, Jefman Island and remote sensing.

INTRODUCTION

Marine and coastal resources, as the second pillar of Indonesia's maritime axis, bring both economic benefits and environmental sustainability. It is reported by the Indonesia's Central Bureau of Statistic that Indonesia's fisheries' production in 2015 exceeded 14.5 million tonnes, with a total export value of 244.6 million dollars. Indonesia as the main area of marine biodiversity was recorded as the home of 2.122 species of reef fishes, with 1.613 of the total species in Raja Ampat (Allen, 2008). A proper management system is needed to achieve the optimum benefit from this. However, the management system in a different area may be totally different because of the conditions of the environment. Some of the potential locations that are rich in the diversity of species also have poor conditions caused by human activities or natural disasters. These poor and fragile conditions need to be treated differently. Then they can reach stability, re-activating their functions for economic purposes.

The science in remote sensing helps to describe a phenomenon and analyse data without physical contact or direct field observation (Lillesand *et al*., 2014). Meanwhile, GIS is a tool, allowing the combination of various spatial aspects of a project. It benefits a project for a variety of analytical purposes (Meaden & Aguilar-Manjarrez, 2013). Essentially GIS, regarding this study, was used as a tool to support the planning, managing or monitoring of fisheries to bring about improvement and success.

Jefman Island is a small inhabited island in the Raja Ampat archipelago, located to the west of Sorong City, in the West Papua Province, Indonesia. About 1,086 people who come from different races live on the island. Most of them are local, and the rest are sailors

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who came from nearby islands. The island was an air gateway of Sorong City until the Raja Ampat Regency Unfoldment in 2006. Marine transportation activities designed to connect Sorong City and Jefman Island in the past contributed to the environmental degradation of the marine ecosystem. This caused several impacts on the coastal and marine ecosystem of the island. Considering that the condition of the biological communities and the benthic habitat is essential for an ecosystem-based management plan (Buhl-Mortensen *et al*., 2012). Furthermore, it may provide a better understanding when it comes to assessing the impact of human activities on the ecosystem. Thus, producing basic data of the coastal area in Jefman Island is needed to support any management plan in the future.

This study emphasizes providing information about the condition of coastal resources in Jefman Island. The GIS and field observation data will be displayed as a map, which later can help other managers, government, locals or users to create a coastal management system based on the study area.

METHODOLOGY

Study Area

The study was conducted in Jefman Island from June to July 2013. An underwater survey was conducted in seven sites (later we use the terms station 1 to station 7 for marking seven underwater site surveys) to estimate the total diversity and density of coral reefs and reef fishes. Four different sites were also selected for seaweed and seagrass surveys (station A to station D). A benthic community survey was also conducted in station 1 to station 7 and station A to station D. However, due to limited resources, we were not able to calculate the diversity and density of seaweed, seagrass, and benthic species. Underwater photography and sample collections were conducted to identify the species which formed the coastal area ecosystem. Meaningful data can only be produced by selecting the site that is representing the condition of the area. Selected site should cover one community within a unique ecological habitat (Coulloudon *et al*., 1999). Moreover, a transect within the critical area has to be located randomly. Thus, sites that were mentioned above were selected carefully to represent the whole coastal area in Jefman Island. These sites were also selected based on the map produced in pre-study, using remote sensing and GIS (see Fig. 1). Each habitat captured by the baseline map (indicated by the different colour of appearances) was surveyed.

Mapping

The mapping of the Jefman seabed objects was conducted by utilising remote sensing and GIS technology. This stage consisted of seven parts: data acquisition, georeferencing (geometric corrections),

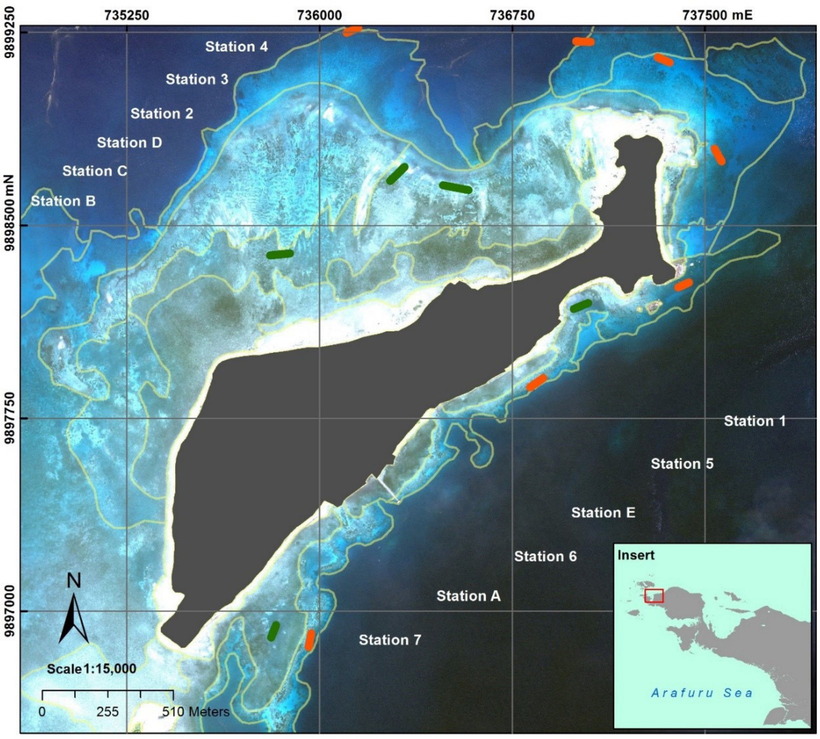

Figure 1. Baseline map of Jefman Island and survey study site. Red dots represent the coral and reef fish survey; green dots represent the seaweed and seagrass survey.

image enhancement, spatial database development, visual interpretation, digitising (raster-to-vector data conversion) and map lay-outing. The data used are QuickBird satellite imagery from Google Earth taken on 29 November 2011. It produced a tentative map of objects on the Jefman seabed that explain the location of existing marine biodiversity, trends and synoptic overview or general description (Fig. 1). The maps produced can also characterise habitat types and a substrate (Kordi & O'Leary, 2016). This information can then be tested later by conducting a field survey.

Field observation

The field observation consists of an underwater and coastal area survey. An underwater survey was conducted using Line Intercept Transects (LIT) and Underwater Fish Visual Census (UFVC) methods to calculate the percentage of reef cover and estimate fish biodiversity (English *et al.*, 1994). These methods utilised five pieces of fifty meters Transects and GPS, with seven spots as observation points surrounding the Jefman Island. Meanwhile, a coastal area survey was conducted to identify seagrass, seaweed, mangrove and benthic communities.

The Line Intercept Transect is a common method to assess the diversity and percent cover of the coral reef by laying down a transect and recording the length of coral intersect in the transect (Canfield, 1941). It also gives an insight into the other community percentage cover, such as seagrass, seaweed, and other benthic communities. Percent cover is often calculated as below:

$$\%\text{ cover Spp A} = \frac{\text{Total distance Spp A}}{\text{Total line distance}} \text{ x } 100\% \quad \text{............. 1)}$$

The Underwater Fish Visual Census following (English *et al.*, 1994) is used to estimate the density and diversity of reef fish. It is the way to calculate the abundance and diversity of fish by observing the area in 2,5 meters to the left and 2,5 meters to the right (from the transect line) (English *et al.*, 1994). The diversity index of coral reef and reef fish uses the Shannon-Wiener equation, as below:

$$H' = -\sum_{n=1}^{\infty}\left(\frac{ni}{N}\right)\ln\left(\frac{ni}{N}\right) \quad \text{.. 2)}$$

Description:
H' = diversity index
ni = total number of genus
N = total individuals of all genus

As for the indicator, an index value of between 1-0 indicates the low stability of the marine environment, an index of between 1-3 indicates moderate stability and an index value more than 3 indicates a high stability in the ecosystem (Caley *et al.*, 2002).

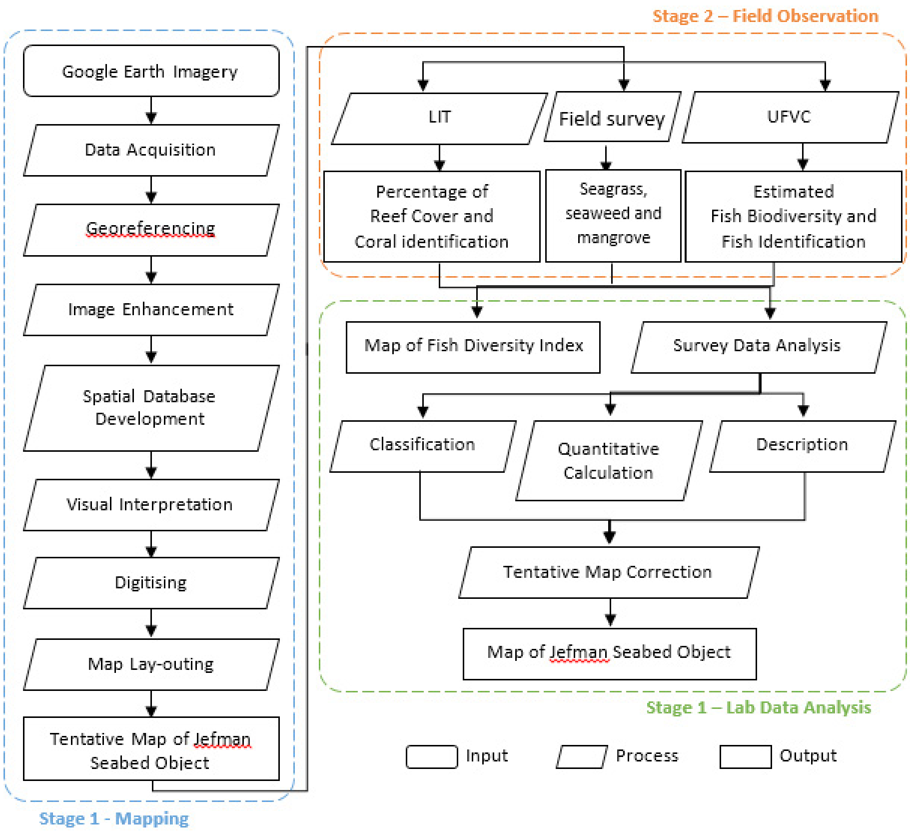

Figure 2. The flow chart of study stages.

Data Analysis

The study was carried out in three stages: mapping of Jefman seabed objects, field observation, and lab data analysis, as is illustrated in Figure 2.

Laboratory data analysis, as the final stage, consisted of two parts, survey data analysis and tentative map correction. Survey data analysis consisted of classification, quantitative calculation and description (complementary explanation) of Jefman coastal resources biodiversity, such as reef fish and coral reef. In addition, tentative map correction used survey data at each sample location as valid input, so that the incorrect data could be corrected. This part generated a corrected map of Jefman Seabed object.

RESULTS AND DISCUSSION

Remote sensing and GIS analysis produced a map explaining the various habitats in the sea and coastal area (Fig. 3). Twelve habitats consisting of different physical and biological structures have formed the Jefman Island coastal area. Firstly, the physical structure as evidence of human settlement was identified, such as road, footpath, airport runway, and dock. The post-colonial heritage was also found. There are 36 bunkers located prominently in the coastal area. These fragile witnesses of war would have been a good object for a historical tourism site as well as for scientists to study the past. For that reasons, this makes Jefman Island unique, and it should be managed carefully. Secondly, a biological structure in this island consists of coral reef, seaweed, seagrass, and mangrove. These physical and biological structures were interpreted using GIS and field survey. Overall, Jefman island seabed is dominantly covered by: seaweed 27%, sandy-seaweed 26%, seaweed-seagrass 22%, sandy-coral 20% and coral 5%.

Coral Reef

The value of the living coral cover is 22% of the total value (Table 1). The value indicates that the condition of the coral reef in Jefman is moderate (Gomez *et al*., 1978). However, detailed calculations in each station vary, with the lowest number about 2.32% of the living coral cover. Physical and biological conditions may become a factor affecting the coral's condition.

It is reported that Jefman has 12 families of coral reef (coral identification following the book of coral reef species (Veron, 2013), dominated by Acroporidae and Poritidae (Table 2). The coral reef-dominated form is branching and massive. It indicates that Jefman's water territory has strong waves and high sedimentation with low-water-visibility (Supriharyono, 1986).

Reef Fish

Based on reef fish identification using the handbook of reef fishes (Allen, 1999), it is reported that Jefman's water territory has 27 numbers of fish families dominated by Pomacentridae and Acanthuridae. The data are presented in Table 3.

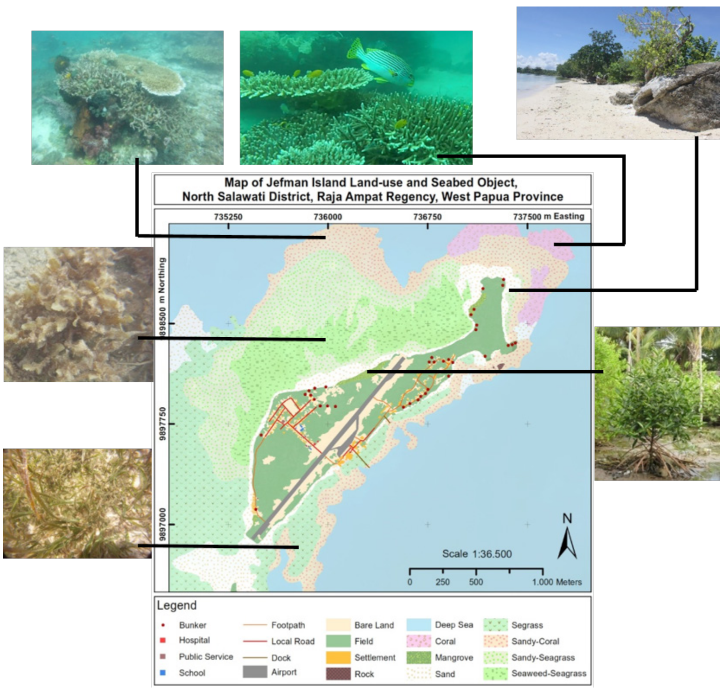

Figure 3. Map of Jefman island land-use and seabed objects.

Table 1. The Percentage cover of coral reef in Jefman's water territory

Percentage cover (%)	Station 1	Station 2	Station 3	Station 4	Station 5	Station 6	Station 7	Total percentage of each habitat (%)
Living coral	24.08	24.24	19.33	33.08	2.32	24.80	26.44	22
Dead coral	21.74	8.72	5.07	14.74	0.00	3.98	11.26	10
Algae	9.96	1.14	6.30	8.70	24.10	11.76	16.66	11
Biotic	32.22	28.48	37.49	17.92	22.18	12.26	5.32	22
Abiotic	12.00	37.42	31.81	25.56	51.40	47.20	40.32	35
Total percentage (%)	100	100	100	100	100	100	100	100

Table 2. Distribution of coral reef in Jefman's water territory

Family	Station 1	Station 2	Station 3	Station 4	Station 5	Station 6	Station 7
Acroporidae	√	√	√	√	√	√	√
Pocilloporidae	√	√	√	√	-	√	-
Poritidae	√	√	√	√	√	√	√
Favidae	√	√	√	√	√	√	√
Fungidae	-	-	-	√	-	√	√
Dendrophylliidae	√	√	√		-	√	√
Agariciidae	-	-	-	√	√	√	√
Euphyllidae	-	-	√	-	-	-	√
Mussidae	-	-	-	√	-	√	-
Oculinidae	-	-		√	-	-	-
Merulinidae	-	-	√	-	-	√	√
Pectinidae	√	-	√	√	-	√	√

Table 3. Distribution of reef fish in Jefman's water territory

Family	Station 1	Station 2	Station 3	Station 4	Station 5	Station 6	Station 7
Chaetodontidae	√	√	√	√	√	√	√
Haemulidae	-	√	√	√	√	√	-
Scaridae	√	√	√	√	√	√	-
Pomacentridae	√	√	√	√	√	√	√
Acanthuridae	√	√	√	√	√	√	√
Holocentridae	√	-	√	√	-	√	√
Labridae	-	√	√	√	√	√	√
Scorpaenidae	-	-	√	-	-	√	-
Pomacanthidae	√	√	√	√	-	√	√
Ephippidae	-	√	√	-	-	√	-
Blenniidae	√	-	√	-	√	-	√
Mullidae	√	-	-	√	-	-	√
Zanclidae	√	√	√	-	-	√	-
Batrachodidae	√	-	-	-	-	-	-
Balistidae	√	√	√	-	√	√	-
Plesiopidae	√	√	√	-	-	√	-
Syngnathidae	-	√	√	-	-	-	-
Muraenidae	-	-	√	-	-	-	-
Tetraodontidae	-	-	√	-	-	-	-
Carangidae	-	-	-	√	-	-	-
Plesiopidae	-	-	-	√	-	-	-
Clupeidae	-	-	-	-	√	-	-
Apogonidae	-	-	-	-	-	-	√
Caesionidae	√	√	√	√	-	-	-
Lutjanidae	√	√	√	√	-	√	-
Serranidae	-	-	√	√	√	√	√
Siganidae	√	√	√	√	√	√	-

Symbol √ is presenting the particular reef fish's family in the site

Table 4. Biological parameter of reef fish community in Jefman Island

Parameter	Station 1	Station 2	Station 3	Station 4	Station 5	Station 6	Station 7
Number of fish family	15	15	21	15	11	16.00	10.00
Density (ind/m^2)	0.80	0.85	1.30	0.93	0.72	0.68	1.20
Diversity	1.94	1.71	2.52	1.91	1.20	1.89	1.39
Dominance	0.24	0.31	0.12	0.26	0.48	0.27	0.43

The diversity index (H') ranges between 1.20 and 2.52. It explains that Jefman has moderate diversity in reef fish. The diversity index also explains about the stability in reef fish abundance and whether its condition is good enough to support fish lives. The condition of the environment, foods, and predators are factors that define the value of reef fish abundance (Caley *et al*., 2002).

The abundance value of reef fish in Jefman is 231 ind/50 m^2. A group of major fish has the highest number with 89% of the total value, target fish have 6%, and indicator fish have 5% of the total value. The low abundance value of indicator fish is dominated by Chaetodontidae which shows that the health and condition of the coral reef in Jefman are poor. Moreover, these fish may have a positive correlation with the abundance and distribution of the coral reef because they are corallivores that simply depend for their life on coral for their food (Hourigan *et al*., 1988).

Mangrove

The mangrove area located in Jefman Island covered less than 1 hectare, which spreads differently into three main areas of the island. It is only the West, South, and North part of the island that is covered by mangrove. The areas also have different conditions and species of mangrove.

In the West, mangrove grows on a mud-substrate and a stony-base along the coastal area. *Sonneratia alba, Rhizophora mucronata*, and *Rhizophora apiculate* were found and grown separately in the colony (mangrove identification using the handbook of mangrove introduction in Indonesia (Noor *et al*., 1999)).

In the North, the condition of the area was probably the same as for the mangrove community in the West. Nevertheless, *Sonneratia alba* was the only species which inhabited the area. Furthermore, the southern area was inhabited by *Sonneratia alba* and *Rhizophora stylosa* which grow on a mud-substrate base. The area was different from the other two, instead of facing directly to the sea it is located about 500 metres from the coastline of the main island, next to the settlement area.

Seagrass and seaweed

Seagrass vegetation in Jefman Island is dominated by five species, such as *Enhalus acoroides*, *Thalassia hemprichii*, *Halophila ovalis*, *Cymodocea rotundata*, and *Syringodium isoetifolium*. They grow densely, covering all areas around the coastal region. A mixed combination of seagrass and seaweed habitats were found in the north area of the island (Fig. 2). Seaweed species that were found in the associated area consist of several species, such as *Dictyota sp*., *Padina sp*.,

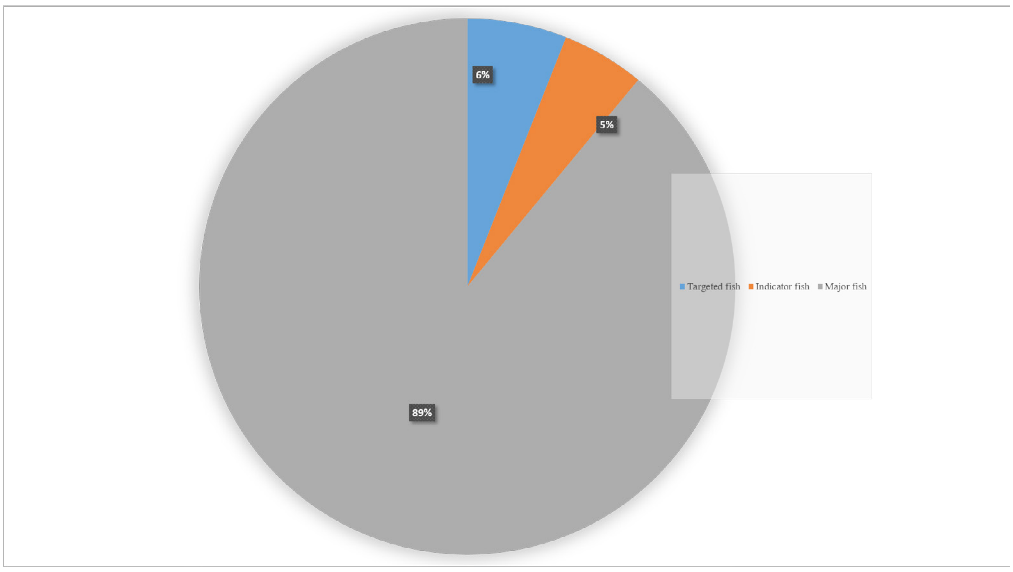

Figure 4. The abundance value of reef fish in Jefman's water territory.

Halimeda sp., Sargassum sp., Caulerpa sp., Codium sp., Gigartina sp., and Ulva sp.

Benthic community

The benthic community in Jefman Island is predominantly formed by invertebrate species. Its distribution is spread around the coastal area, in the coral reef habitat below 15 metres depth; the part affected by low-tide waves. The dominant species of invertebrate found on the island are listed below (Table 5).

The coastal area of this small remote island is formed by coastal-marine communities that are considered necessary to maintain the ecological stability and sustainability of its natural resources. The island has an intermediate level of coral health with an average of 22% living coral cover. However, other studies may have argued that living coral cover would not be able to explain the health of the coral reef ecosystem because every place has got authentic physical conditions that may contribute to this value. For instance, the available area for corals to support their recruitment may be distinct from the large area of the reef. Others argued that the macrofaunal community may be more relevant in assessing the health of the coral reef ecosystem (Coker *et al*., 2014; Connell *et al*., 1997; Gomez *et al*., 1994; Gomez *et al*., 1978). Furthermore, studies explaining the conditions of the coral reef ecosystem within a certain period of time and within a particular area are more likely to provide better information when it comes to determining the health of the coral reef.

The existence of a particular community species may have been influenced by other communities who live in the same ecosystem (Ray & McCormick-Ray, 2009). This was shown by the living coral cover value that may contribute to the distribution of reef fish density and diversity in this island. An average value of reef fish density (from station 1 to station 7) is high in the areas where the living coral cover is also high. Furthermore, Pomacentridae was reported as a territory-dominating reef fish in Jefman. Also, reef coral branching is the main habitat for Pomacentridae which has a significant relationship with the density of Acropora sp. (Öhman & Rajasuriya, 1998) and is the highest reef community with a living coral cover value of about 8.44%. Supported by other studies, the richness value of several reef fishes such as Chaetodontidae, Pomacentridae, Labridae, Scaridae.

Table 5. Benthic community in Jefman Island

Phylum	Class	Genus	Species
Mollusca	Gastropod	Lambis	Lambis sp.
		Strombus	Strombus sp.
		Turbo	Turbo marmoruta
		Cassis	Cassis cornuta
		Cyprea	C.tigris
			C. annulus
		Nerita	Nerita sp
		Trochus	Trochus sp
		Conidoe	Conidoe sp
		Murex	Murex sp.
		Conus	Conus sp.
	Bivalve	Meretrix	Meretrix sp.
		Anadara	Anadara granosa
		Tridacna	Tridacna sp.
Echinodermata	Crinoid	Nemaster	Nemaster rubiginosa
	Astreroids	Protoreaster	Protoreaster nodosus
	Holothuroids	Holothuria	Holothuria edulis
			Holothuria scabra
		Stichopus	Stichopus chloronotus
			Stichopus noctivagus
		Theolata	Thelenota ananas
		Bohadschia	Bohadschia tenuissima
		Actinopyga	Actinopyga sp.

Acanthuridae and Gobiidae have a positive relationship with the increase of living coral cover (Bell & Galzin, 1984).

However, if we look closely at the analysis between living coral cover and reef fish abundance among seven stations (Fig. 5) the graph shows that there is neither a linear nor an exponential relationship between the two parameters. The analysis model shows a negative correlation between the living coral cover and fish abundance. Whereas, the determinant value explains that is only 30% variation of fish abundance variable that could be explained by the condition of living coral cover. Furthermore, one area presented a negative correlation in comparison to the positive correlation presented by six other stations (see red dots in Fig. 5). This inconsistency may give us an understanding of how complex an ecological system is in a particular area.

Moreover, there may be other factors contributing to the relationship between living coral cover and reef fish abundance. Other studies showed that the abundance of fish decreases in the area where the living coral cover is high, and suggest that habitat heterogeneity may play a greater role in its relationship to the living coral cover (Weiler , unpublished work).

In determining the condition of the coral reef ecosystem explained above, we use Chaetodontidae as an indicator to explain the health of the coral reef. Unlike the living coral cover which gave us an intermediate level of coral health, the abundance of Chaetodontidae as an indicator fish (Fig. 4) Indicates that the coral reef condition in Jefman Island is poor. Chaetodontidae may become an indicator of coral health because coral is their source of food. The prime feeding preference of Chaetodontidae is various corals species from *Acropora sp*., *Montipora*., and *Pocillopora sp*. (Hourigan *et al*. 1988; Neudecker 1979; Reese, 1975).

By using spatial data modification on the diversity value, we produced a map explaining the rich diversity of reef fish in Jefman's water territory. The light colour indicates the low value of fish diversity and the dark colour represents the area where fish abundance is high (Fig. 6). Station 5 (Fig. 5, yellow dot) which is near the light area (where reef fish density and the living coral cover is at the lowest point) is the area nearest to the Sorong Island (the main island in West Papua Regency). This huge island is densely populated, and land based human activities may have influenced the water condition in the nearby coastal area.

Furthermore, the endemic fish of Raja Ampat (*Hemiscyllium freycineti*) was found in the area during the study. *Hemiscyllium freycineti* is one of the protected-species that is listed by IUCN. Thus, we suggest managing this area and establishing it as priority protected, in order to maintain the biodiversity of marine communities.

Other coastal communities that form Jefman Island are seagrass and seaweed with the highest percentage that is: 75% of the total coastal habitat (with the proportion; seaweed 27%, sandy-seaweed 26%, and seaweed-seagrass 22%). These two habitats are critical to support the juvenile nurseries of many species. Their abundance also varies, depending on sediment depth, nutrients, light availability and circulation (Ray & McCormick-Ray, 2009).

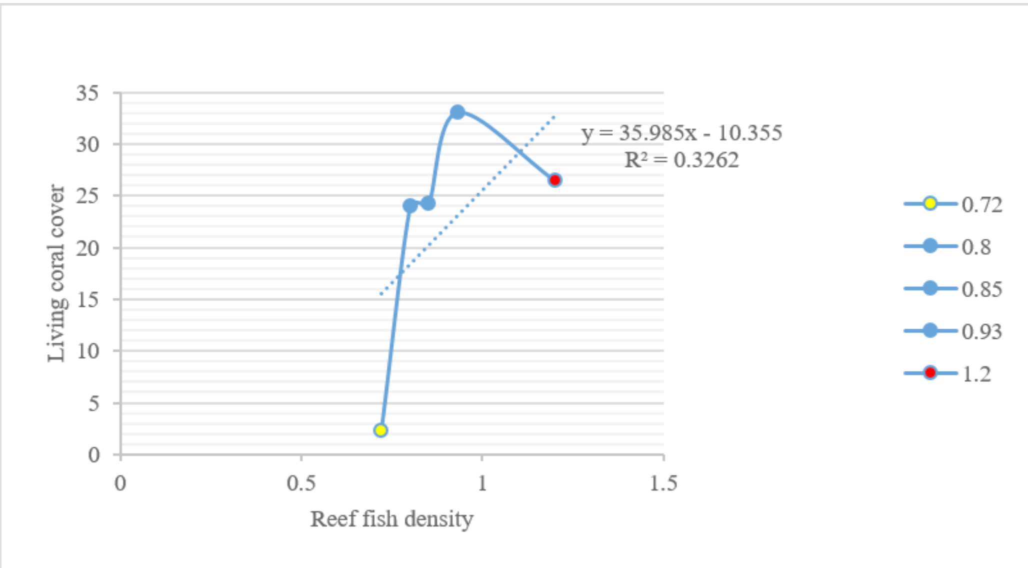

Figure 5. Analysis of reef fish density and living coral cover value in Jefman's water territory.

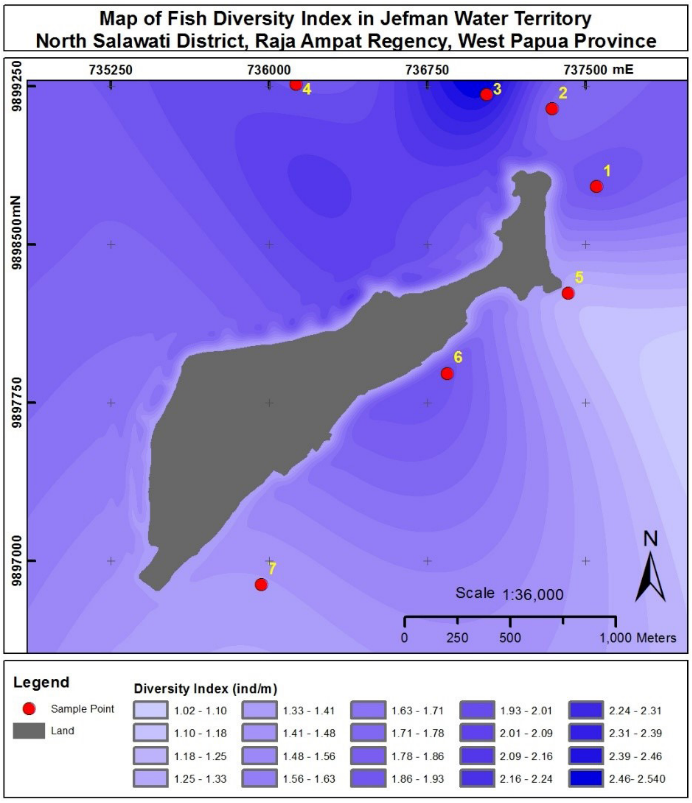

Figure 6. Spatial distribution of fish diversity index in Jefman's water territory.

Another habitat that is considered the smallest area of them all is mangrove. We suggest that planting more mangroves is possible to do in the mangrove area at the North and West of the island, as the water circulation and substrate are considered suitable there. Moreover, to protect the coral reef ecosystem in the northern part of the island, planting mangrove is extremely necessary to support the stability of the coral reef ecosystem. It may well increase the biomass of the coral reef communities such as reef fish (Mumby *et al*., 2004). The species of mangrove which can possibly be planted is *Sonneratia alba*, as this species is considered to have salinity-tolerance.

CONCLUSION

The Jefman Island seabed area is dominantly covered by; seaweed 27%, sandy-seaweed 26%, seaweed-seagrass 22%, sandy-coral 20% and coral 5%. It has a moderate diversity of reef fish, while the health and condition of the coral reef are poor. This study is important to determine management planning in the future, as we found one particular place urgently needs to be protected (the area that is facing the Sorong Island). Furthermore, planting mangroves could be the best option for maintaining coastal ecosystem stability and increasing the biodiversity of the coastal-marine species in Jefman Island.

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