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THE EXISTING VALUES OF SMALL ISLAND'S VULNERABILITY INDEX BASED ON EXPOSURE DIMENSION: A CASE STUDY OF KAWE REGIONAL MARINE PROTECTED AREA IN RAJA AMPAT, INDONESIA

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INTRODUCTION

Indonesia is an archipelagic nation consisting of 16,056 islands (UNGEGN, 2017). Most of the islands are relatively small in size and widely spread in the eastern part of Indonesia, concentrated in the heart of the 'Coral Triangle'. The Papuan Bird's Head Seascape (BHS) encompasses over 22.5 million hectares of sea and small islands off the West Papua Province between the latitudes 4°052 S–1°102 N and longitudes 129°142 E–137°472 E (Mangubhai *et al.*, 2012). These small islands, like other small islands over the world, are one of the most vurnerable ecosystems to the impacts of global climate change and sea level fluctuation (Barnett and Adger, 2003). One of the small island groups in the Raja Ampat archipelago, the Kawe Regional Marine Protected Area (KRMPA), is expected to experience these impacts. An assessment of the vulnerability risk of these island ecosystems will provide a resource status that can be used by local and central government to develop sustainable management strategies for small islands.

KRMPA includes the islands of Piai-Sayang, Wayag, Quoy, and Uranie Island. KRMPA is a critical habitat for whales, green turtles (*Chelonia mydas*), hawksbill turtles (*Eretmochelys imbricata*), sharks, and manta rays (*Mobula birostris* and *Mobula alfredi*) (Kahn 2007, Mangubhai *et al.*, 2012). A recent study indicated that Piai-Sayang Island is a mating

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ground and critical habitat for green turtle. This area was declared a turtle protection area in 2012, which has contributed to an increase in the success rate of hatching turtle eggs. Wayag also serves as a birthing ground for sharks and other marine species (Yayasan Penyu Papua, 2014, 2015). In addition to important habitat functions, KRMPA also physically contains exotic and astonishingly beautiful karst islands with some marine lakes and anchianline sites that form the habitat of mutually associated and potentially endemic biota communities (Becking *et al.*, 2014). Among the islands in Wayag there is a channel that connects the sea with the lagoon reef. Due to the fact of small islands ecosystem, even though the marine resources are rich, these also at risk to experience changes due to environmental pressures as the impact of global climate change. The documentation on the impact of climate change on small islands can be visually observed in the change of beach morphology, loss of coastal land area due to sea level rise and the occurrence of coral bleaching due to an increase in sea temperatures.

It is widely considered that the impact of sea level rise will caused some small islands at risk of lost or submerged in the next 10 years (Briguglio, 1995). This concern may occur in KRMPA. Therefore, a comprehensive study of the environmental impacts that provide vulnerable risks due to climate change impacts is needed to guide management and mitigation efforts to minimize these impacts. This is urgently need to be well-studied by accommodating all aspects so that it is in line with the management plans that are being initiated by local governments, local private parties, as well as international parties and communities as owners and users of resources. This study estimates the existing value of small islands vulnerability indexes based on the exposure dimension.

METHODS

Research site

This research was conducted in the small islands within KRMPA which consists of Piai, Sayang, Wayag, Unai/Quoy, Bag and Uranie Islands (Fig. 1), and located quite far from the capital of Raja Ampat Regency. Surveys were conducted over a 6 month period during May until October 2016.

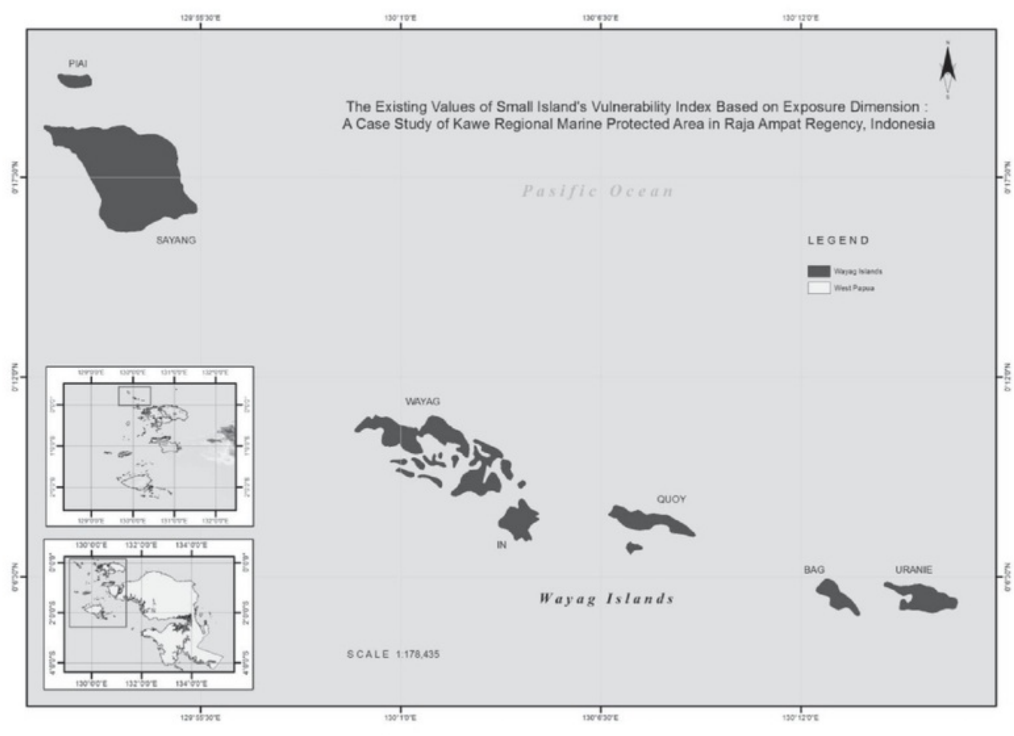

Fig. 1. Map of research site showing small Islands in KRMPA Raja Ampat.

Research Methods

This research used survey methods with direct measurement in the field. Some of the field measurement models are based on the vulnerability index variables (Table 1).

Sea Level Rise (SLR)

Sea level rise is strongly supported by coastal and island morphological data such as elevation and coastal and island slopes. In addition, sea level rise is generally integrated with daily tides on beaches as island. In this study, sea level rise data were obtained by downloading SLR data from altimetry data from www.aviso.sealevel.org. The data is obtained in the form of ASCII data which was extracted using Ocean Data View (ODV) to obtain annual scale increases. This data was then extracted in numerical form to Microsoft Excel for predicting the annual trend of sea level rise at the study site.

Sea Surface Temperature (SST)

Sea surface temperature was downloaded from http://www.oceancolor.gsfc.nasa.gov/cgi/13. In addition, sea surface temperature data were also measured when ground check was performed on the five islands. Temperature data were downloaded from sattellite and were presented in the form of value according to year, date, minute, mean, median and variation of sea surface temperatures. These data the were arranged based on month and year to be further analyzed. Temperature data were also measured *in-situ* when field survey was conducted.

Sand Temperature (ST)

Sand temperature becomes one of the most important indicators in determining hatching success of egg during the incubation period. Sand temperature was measured using logger which is installed only for the first year in the island of Piai. This due to the limitation of avalaible equipment (logger). The measurement of sand temperature in nesting site of Piai Beach was performed in nine (9) selected nests from January to March 2013 (Tapilatu and Ballamu, 2015). Sand temperature data were obtained from temperature data logger buried in the sand on Piai Island. This beach is an index for green turtle nesting to record sand temperature profile. The logger was immersed in 26 green turtle nests with a period of 60-65 days following the hatching period of the turtle nest (Tapilatu and Ballamu, 2015).

Tidal range and potential beach immersion

The inundation rate is one of the impacts of sea level rise on the coastal land or island. The inundation rate is the area of land submerged following the tides or inundation periodically. The inundation rate is strongly influenced by the shape of the beach or the island, if the coastal shape is sloping then the inundation rate tends to be smaller but if the shoreline forms consequently the inundation rate will increase along with the increase of sea level in the coast. In this study the inundation rate was estimated by comparing the shoreline shape of elevation and slope as well as the average daily tides and annual sea level.

Sea turtle nesting and other species foraging habitat

Small islands have ecological functions as nesting habitat and feeding grounds for marine life. To display information related to the ecological functions, it is necessary to inventore the island that served as a habitat and the feeding groundfor turtles, mantas and other marine species. Nesting habitat for sea turtles and feeding habitat for other marine lifes can be identified through the

Table 1. Scale and scoring system of vulnerability index parameters of small islands of KRMPA

Variable	Rank Values					Source
	1	2	3	4	5	
Exposure Dimension						
Sea Level Rise (mm/year)	≤4.99	5-9.99	10-14.0	15-25	≥25	(Stocker *et al.*, 2013; Tahir, 2010; www.alviso.altimetry.fr 2017)
Sea Surface Temperature	<22	24-28	28-33	33-37	>37	(Tahir 2010)
Sand Temperature of Nesting beach	<22	24-28	28-33	33-37	>37	(Fuentes *et al.*, 2011; Tapilatu and Ballamu, 2015)
Tidal distance and Potential Immersion	0-4.9	5-9.9	10-15.9	15.9-19.9	>20	(Runtuboi 2012; Tahir, 2010)
Turtle nesting habitat (Number of nests)	1-2	2-4	4-6	6-8	≥10	(Tapilatu *et al.*, 2017)

monitoring activities within KRMPA. In addition to periodic monitoring within KRMPA, Papua Sea Turtle Foundation has been regularly monitoring number of sea turtle nests in Piai and Sayang islands. Some of the other islands within KRMPA may not be monitored periodically and a ground survey is needed.

Data Analysis

The data obtained were descriptively analyzed and presented. The results were displayed in the form of tables, maps and figures. Each result of the constituent variables of the exposure index was plotted into the constructed scale (Table 1) in order to obtain the rank value. Each variable is then weighted by observing the effect of each variable towards the small island exposure index by using the equation adapted from Briguglio (1995) from the derivative of vulnerability index, i.e.

*Vulnerable =(Exposure * Sensitivity / (Adaptation capacity)*

$$(VI = \frac{E * S}{CA}).$$

The weight and scoring values of the variables of each dimension were standardized by the formula below,

$$SV = \left(\frac{xij - \min xij}{\max xij - \min xij}\right)$$

where SV is the standardized variable.

RESULTS

The exposed nature of the KRMPA location makes the small islands of this region very dynamic and changing based on the seasons (Table 2). The west season is well-known for its strong wind and high waves, so the erosion process is very real on small islands, different things are shown when the east season or the shady season occurs.

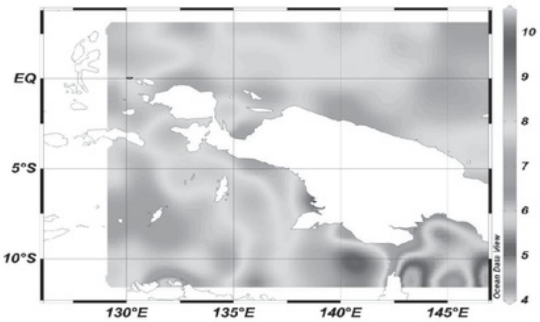

Fig. 2. Sea level rise in Papua and Raja Ampat coastal area

Exposure Dimension

Sea Level Rise (SLR) of Small Island

Sea level rise is one of the impacts of ongoing climate change both on a global scale and on a local scale in coastal areas. Sea level rise is expected to increase significantly in the next few years (Fig. 2-3).

Sea Surface Temperature (SST)

Distribution of sea surface temperature (SST) in KRMPA varied in monthly and yearly profiles (Fig.4). In 2009, the lowest temperature was detected in August (29.3°C), while the highest in September (30.2°C). In 2010, the lowest temperature was in February (28.7°C), while the highest in October (30.6°C). In 2011, the lowest temperature was in August (29.0°C), while the highest was in May (30.3°C). In 2012, the lowest temperature was between January and February (29.4°C),and the highest was in May (30.4°C). In 2013, the lowest temperature was in February (29.0°C), while the highest was in June (30.5°C). Then in 2014, the lowest temperature was in February (28.8°C), while the highest in June (30.5°C). In 2015, the lowest temperature was in February (29.3°C), while the highest in June (30.4°C), and in 2016, the lowest was in February (29.8°C), and the highest was in May (31.5°C).

Table 2. Characteristics of small islands in KRMPA

Island	Size of area (Ha)	Beach width (m)	High tide (m)	Slope/tilt (m)	Elevation (m)	Tidal type
Piai	41.23	24	13.36	2.4	1.02	Semi-diurnal
Sayang	2535.0	64	18.65	1.2	1.20	Semi-diurnal
Wayag	608.8	17.8	14.27	2.3	2.2	Semi-diurnal
Unai	242.2	16.2	12.8	2.5	3.13	Semi-diurnal
In	132.6	15.4	10.54	1.5	3.37	Semi-diurnal
Bag	55.0	8	6.89	2.7	3.95	Semi-diurnal
Uranie	47.4	16	12.3	2.4	4.76	Semi-diurnal

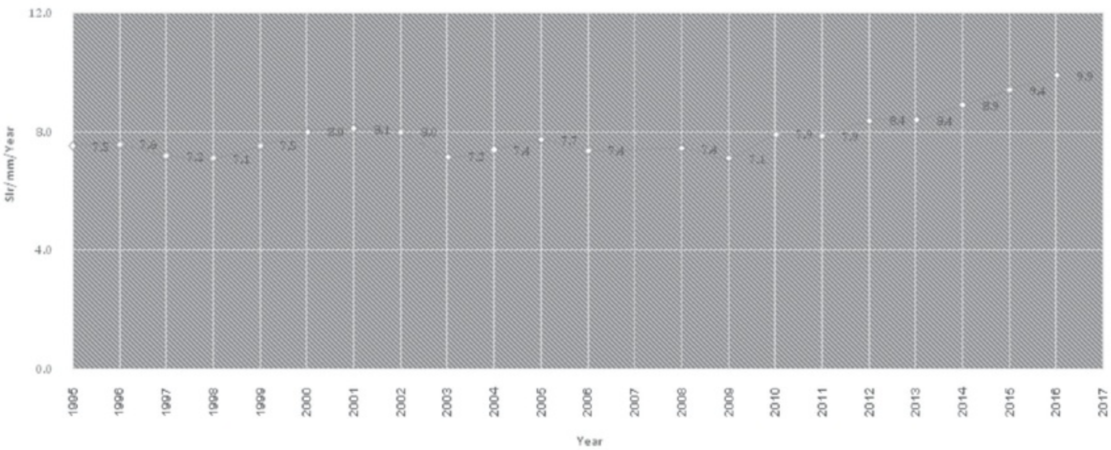

Fig. 3. Trends of sea level rise in the North Coast of Raja Ampat

In 2010, the lowest sea level temperatures seen in February and the highest temperatures seen in October. The sea surface temperature in 2011 represented the highest trend in November and the lowest trend in August. Moreover, in 2012 sea surface temperatures showed the highest temperatures exist in November and the lowest temperatures in March. Furthermore, profiles of sea surface temperatures revealed high temperatures in February 2013 and 2014 and low temperature in June for 2013 and in May for 2014. The overall sea surface temperature in KRMPA in the 8-year period showed an increase trend or constant (Fig. 5). The relative sea surface temperature is clustered at 29°C from 2009 to 2014 while an increase of 1°C was observed in the period between 2015-2016.

Sandy Beach Temperature (SBT)

The results show the variation of monthly sand temperature (Fig. 6).

Inundation Rate (IR)

Piai Island has the largest inundation value approximately 4.05 m, followed by Wayag Islands group of 1.80 m, Sayang Island of 1.72 m and Bag Island of 1.18 m where the inundation takes place when high tides occur (Fig. 7).

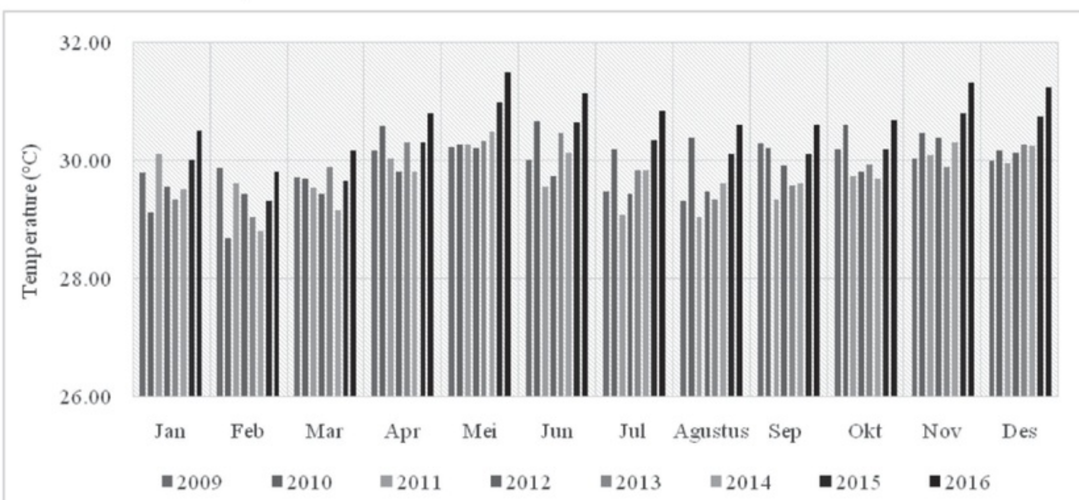

Fig. 4. Distribution of sea surface temperatures during the period between 2009-2016 (Aqua Modiv, 2016).

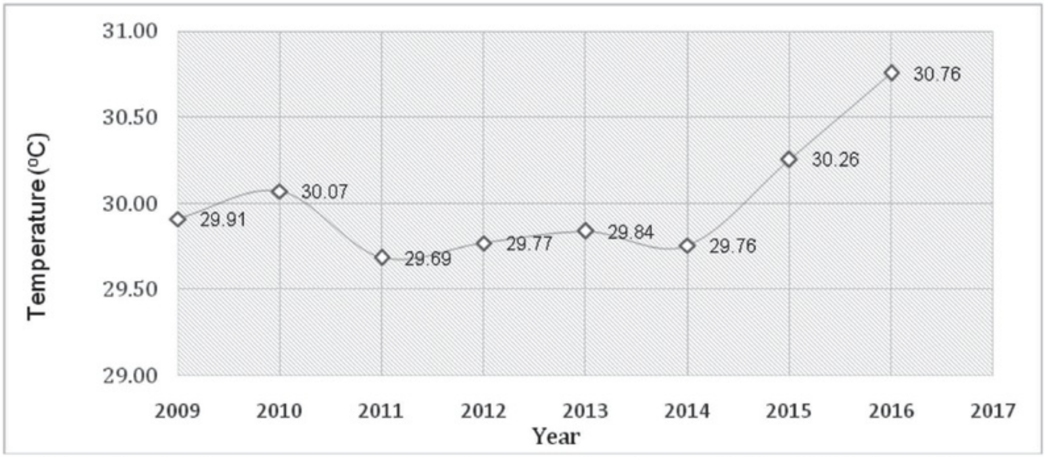

Fig. 5. Trends of sea surface temperature in the period of time between 2009 and 2016 (Aviso, 2016)

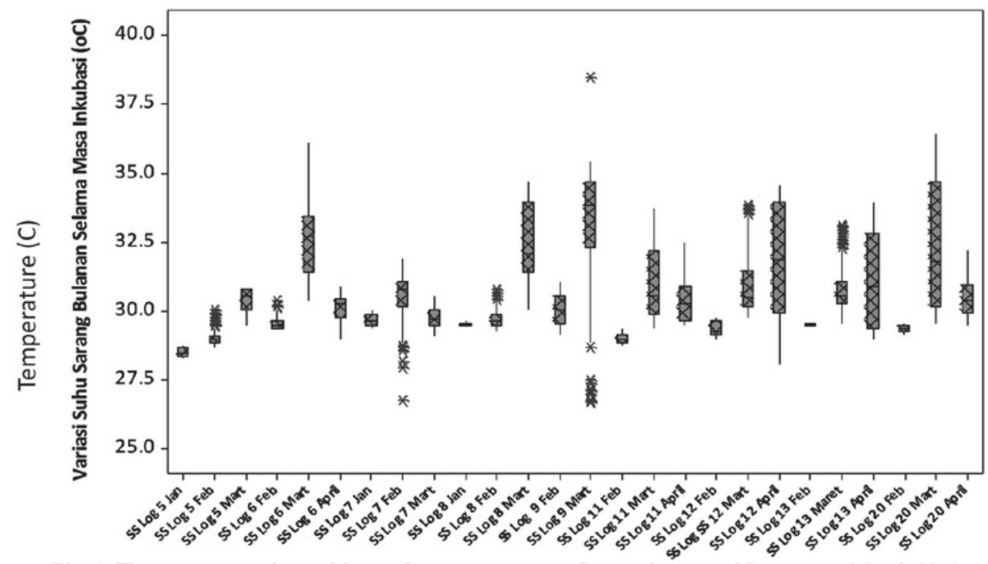

Fig. 6. The variations of monthly sand temperatures on Piai in the period January to March 2013 (Yayasan Penyu Papua 2015).

Important habitats for marine life (turtles and mantas)

It was identified that small islands in KRMPA are important habitat for a variety of marine lifes including sea turtle and manta (Table 3).

Scoring and weight of exposure vunerability index

As a preliminary stage in Table 2, we obtained scores and weights of each of the constituent variables that will produce the vulnerability index values which obtained from each variable annotation by taking the mean values (Table 4).

The most significant of the index value was the weighted value of the sea surface temperature (SST) variable. This value will be better if supported by the value of the proportion of each variable in each island. The result of the estimated projection displayed the significance of the variable to the value of exposure (Fig. 8).

The proportion value of the constituent variables of the exposure index indicates different percentages. On the sea level rise, the highest percentage was on the island of Quoy/Unai (21%), followed by Bag and Uranie Islands (19%), Wayag Islands (16%), and Piai Island (14%). Sea level rise has a close association with coastal inundation rate or opportunity loss of coastal land area. Although it has the lowest percentage value but Piai Island is at risk of having a high rate of inundation because it has a narrow beach width supported by a coastal morphological form with a rather steep slope and an elevation of 1.2 m.

The proportion of sea surface temperature variables showed the highest value in Wayag Islanda (25%), Piai and Sayang Islands (22%), Quoy/Unai Island (21%), Bag and Uranie Islands (19%). Sea surface temperature variable indicates the condition of global temperature changes that occur in the coast, particularly on the small islands in

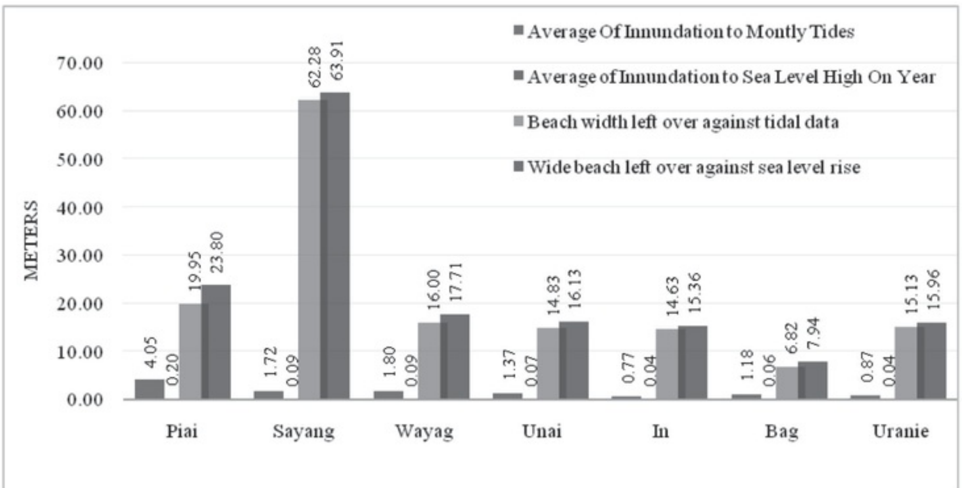

Fig. 7. Monthly and annual average of inundation based on tidal and sea level rise

Table 3. Number of nest and presence of manta rays on small islands within KRMPA

Island	Sum of nest per season (2016)	Manta rays	Description
Piai	568	present	Index beach
Sayang	112	found	Index beach
Wayag	25	found	Non index beach & alternative beach
Quoy (Unai)	15	found	Non index beach & alternative beach
In	8	found	Non index beach & alternative beach
Bag	17	found	Non index beach & alternative beach
Uranie	9	found	Non index beach & alternative beach

Source: Yayasan Penyu Papua (2014, 2015)

Table 4. Score and weight value from composed variable to exposure index.

No	Composed Variables		*Exposure Dimension of Ranking Value of Small Island*						Weight
			Piai	Sayang	Wayag	Quoy/Unai	Bag	Uranie	
1	Sea Level Rise	SLR	2	2	2	2	2	2	0.2
2	Sea Surface Temperature	SST	3	3	2	2	3	3	0.1
3	Sand Temperature	ST	3	3	3	2	2	2	0.2
4	Inundation Rate	IR	2	3	3	2	2	2	0.2
5	Turtle Nesting site and Manta Ray Habitat NsHb	5	5	4	3	3	3	0.2	

Source : Primary data, 2017.

KRMPA. Changes in global temperatures can impact natural ecological processes. For example, coral bleaching during which corals eject symbiotic zooxanthellae due to increased water temperatures. This can eventually result in death of the coral colonies.

Furthermore, coastal inundation rate in the six islands shows the highest proportion on the island of Quoy (Unai) of 21.1%, Uranie Island by 19%, Wayag Island has a proportion of 16.7% and Piai and Sayang Islands is 14.85%. The estimation of the coastal inundation on the small islands of Kawe Regional Marine Protected Area has a correlation with sea level rise as well as tidal. Beach inundation is also at risk of eliminating coastal land area which also has some ecological functions, one of them as

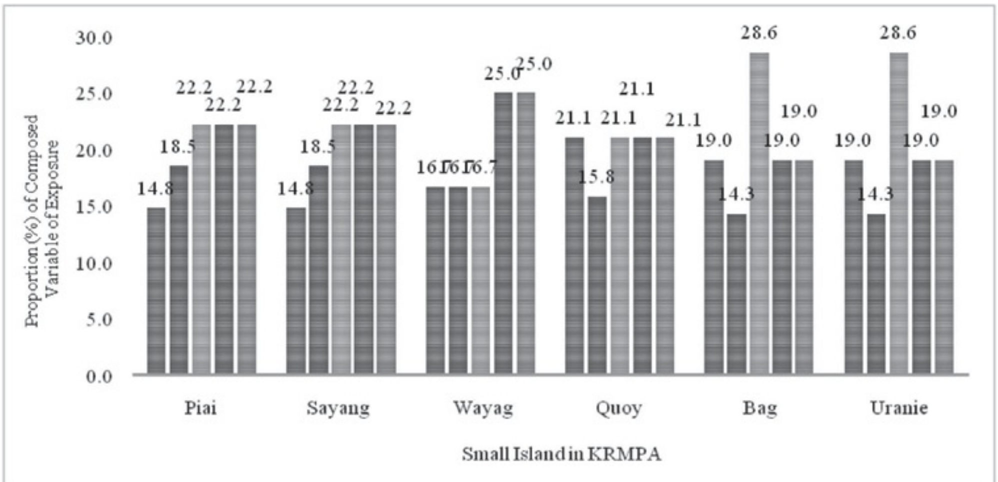

Fig. 8. Proportion of composedvariable of exposure vulnerability index to small islands in KRMPA.

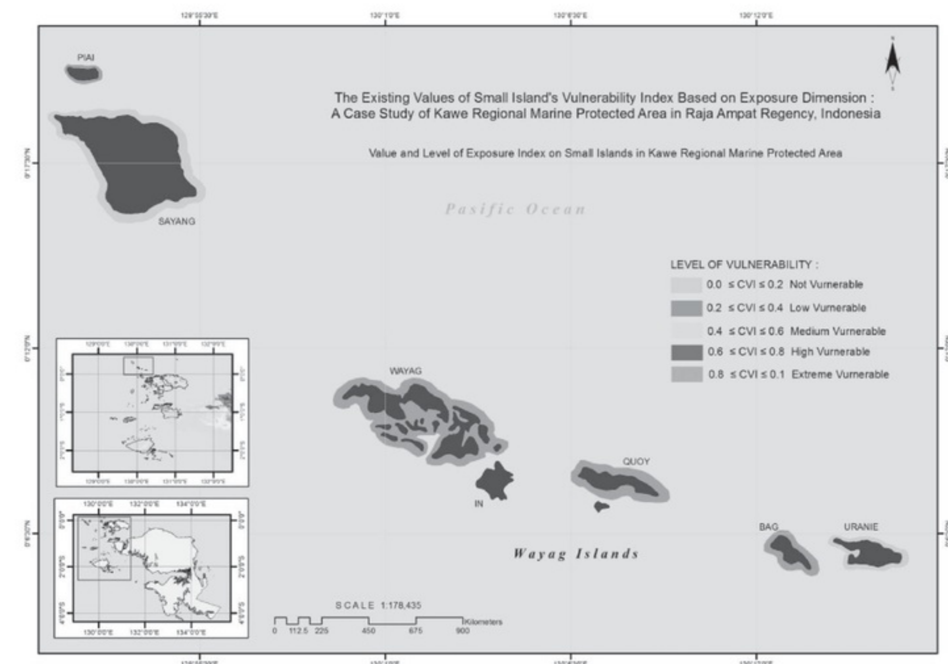

Fig. 9. Mapping and flying diagram of value and level of exposure index on small islands in KRMPA.

turtle nesting habitat. The proportion of spawning habitat and manta habitat shows that Piai and Sayang Islands provide proportion of 18.5%, Wayag Island is 16.7%, Quoi Island is 15.8% and Bag Uranie Island is 14.3%.

DISCUSSIONS

KRMPA is considered to have abundant natural resources in small islands and surrounding coastal areas. Conservation International Indonesia (2015) stated that the coast surrounding Kawe Regional Marine Protected Area has important ecological functions as habitat for species such as green and hawksbill turtles, manta rays, and various species of shark. In addition, several underwater caves that are connected to form a canal are also found in this location. Sayang-Wayag Island is recognized as the most important area for turtles that make these two beaches as nesting sites that have been designated as index beach and have been the center for monitoring for 3 years (Yayasan Penyu Papua, 2014, 2015). Furthermore, it was also reported by Conservation International Indonesia (2015); Lewis *et al*. (2015) that the Wayag Islands are a nursery ground for sharks and other species.

KRMPA has six islands - Sayang, Piai Island, Wayag, Bag Island, Uranie and Quoy/Unai. These islands are physically very open to environmental influences because they have positions that are in the north and are directly exposed to the Pacific Ocean from the Pacific Ocean. One of runoff received by small islands comes from sea level rise. It was found that 70% of coastal areas of the world have experienced sea level rise and 20% of coastal areas have been lost due to the impact of this sea level rise (Stocker *et al*., 2013). Temporary and continuous sea level rise is also predicted to occur on small islands in Papua region. Coastal areas of Papua that are geographically bordering the Pacific Ocean will certainly receive impact of sea level rise. The altimetry data reveal that the trend of sea level rise in Papua Island generally follow the linear pattern which every year has increased although on a relatively low scale. Poloczanska *et al*., (2009) estimated a rise in sea level using IPCC projection in 2010 and will reach 18-59 cm in 2100 and potentially continue to increase between 10 to 20 cm due to increased water period as a result of melting ice masses in the northern hemisphere. Furthermore, data from IPCC (2015) states that the average sea level rise (SLR) in the world ranges from 0.4 to 0.8 m/year. With such an increase model there will be several coastal areas submerged within a certain time range, but will also have an impact on the loss of the coastal land area.

Fig. 4 shows the spatial and temporal patterns of sea surface temperature distribution, weekly in the period of September 2014 (http://apdrc.soest.hawaii.edu). The average temperature of the northern coastal area of Raja Ampat including KRMPA is 30.3 °C. This fact was well-supported by the results of *in-situ* field measurements in September 2016. The average sea surface temperature reached 30.7 °C in west season (December-February) and east season (June-August), the first transitional season in April and the second transitional season in October. The distribution of annual sea surface temperature shows fluctuating properties, where the distribution of sea surface temperature in 6 years (2009-2016) has a downward trend although tolerance is still at 29°C. This fact can be attributed to the current La Niña and El Niño phenomena that are happening globally. The influence of these phenomenona is enough to affect the local climate at the study site. By considering the average temperatures that tend to warm (29°C) then it is predicted that in the year 2009-2016, El Niño phenomenon will contribute a significant influence in the coast of Indonesia, including in Papua. This finding is confirmed by the research of Hamuna *et al*. (2015) which stated that the coast of Papua such as Jayapura is likely to warm with the temperature range of 28-29°C. A similar situation fact is assumed to occur in KRMPA. In addition, Savitria *et al*. (2014) confirmed that sea surface temperature in the northern coast of Papua is likely to warm and it is predicted to have similarity with annual and monthly sea surface temperature variations in the southern Pacific Ocean. The warm temperatures is influenced by *Indonesian* Through Flow (ITF) flowing from north to south of Indonesia, while in the middle of the year some regions of Indonesia experience the rainy season so that the region of Maluku and parts of Papua crossed by cooler *Indonesian* Through Flow (ITF) contributing to the warm of sea surface temperature (Hamuna *et al*. 2015).

The variation of monthly nest temperature of the green turtle shows fluctuations in each nest with temperature variations of 29-32 °C in the period of January to March 2013. The results indicate an increase in nest temperature in all observation samples that occurred in March 2013. Moreover, the temperature drop was seen in the nest in January. The decrease in nest temperature is highly dependent on changes in air temperature that is connected to global temperatures. January is the beginning of the year and classified as a transitional season so that the high intensity of rainfall that causes a decrease in air temperature which affects the decrease in nest temperature. Different conditions are indicated by the nest temperature variation in March. The high temperature in the nest is thought to be due to the high intensity of the sun interspersed with the global temperature rise affecting global temperatures and climate so that air temperature have a tendency to increase along with the increase of sand temperature (Hays *et al*. 2001).

In addition to nesting beaches located around KRMPA, the coast is also a habitat for some manta rays. As stated by Lewis *et al*. (2015) that the lagoons of Wayag are a nursery ground for manta rays because of the calm lagoons and good food reserves for the manta growth process. Turtle nesting habitats are usually found on open beaches and away from human access. At the research site, it is known one beach of turtle nesting site index that has become the base-camp of several conservation agencies such as Piai island beaches. Piai is a turtle nesting site index that has been monitored the last 10 years to estimate and protect turtle populations in Papua (Tapilatu and Ballamu, 2015; Yayasan Penyu Papua, 2014, 2015). In addition to Piai Island, several turtles trails and turtle nests are also found in Sayang Island and Wayag Islands, Quoy Island, Bag Island and Uranie Island.

The results of the exposure index estimate within the scope of the vulnerability index indicate that the small islands in KRMPA will be exposed to external influences with a range from low to extreme levels (Fig. 9). Then the overall value of exposure index for KRMPA is 0.51, fall within the medium scale which means that KRMPA having small islands is at medium risk to the environmental change.

Piai and Sayang Islands have the most extreme and high levels of risk, because of the geographical location that is directly exposed to the Pacific ocean and the opportunity to be exposed to climate change both the global climate that comes from the Pacific Ocean but also the local climate. The local and global climate changes that occur contribute local changes, mainly on the islands and their constituent habitats such as beaches and others. For example, Piai Island in the west season will experience heavy wave erosion along the coast. Some of the inland areas will have reduce shoreline and the indication of loss of coastal areas will be continuously occurring. Furthermore, Sayang island is an adjacent island to Piai island, has a very large land area (Table 2) and is at risk of exposure to the external influences from the Pacific ocean. However, when compared with Piai Island, this island tends to resilience due to the form of a large island and is composed of a sloping beach so that the indication of inundation and the loss of land area is very low.

Uranie Island is at the medium level of vulnerability exposure index. This is due to the small size of the island with the form of steep beach on the west side while the east, south and north form rocky shoreline. The island's morphological form is particularly at risk for changes in both the waves and shade seasons, especially in sandy parts that undergo accretion and erosion processes. The island's openness also provides an indication that local climate influences are capable of providing physical changes to the island that could lead to ecological degradation, especially for island habitats, both on shore and in coast.

Bag, Quoy and Wayag islands are found to have low levels of exposure vulnerability index. This is due to low island effectiveness with the form of islands that tend to be protected so that the influence of external factors is very small. The low effectiveness of these islands is indicated by unrecorded ecological data on Quoy, Unai and Bag islands, while the Wayag slands are known as one of the Raja Ampat tourist icons although with some ecosystem data such as coral reefs and other marine biota.

The most remarkable result to emerge from this study is that the vulnerable indication of small islands in KRMPA from exposure dimension is very of high risk. This is supported by global and local climate changes that occur continuously, which are predicted to have a considerable influence on the existence of small island islands in KRMPA which is geographically very exposed to the influence of the Pacific ocean. As McCarthy *et al*. (2001) points out, the value of vulnerability is generally a description of the exposure, sensitivity and adaptive capacity of an entity or island. Relatively high vulnerability values are thought to be the effect of island positions that are exposed to environmental disturbances (Turvey, 2007), and also because of the isolation of the island (Campbell, 2006). Further Turvey (2007) states that vulnerability also affects the process of adaptation of the island to environmental changes that occur. The present value of the vulnerability exposure index may increase with increasing levels of vurnerability but may also decrease depending on the effectiveness and ability of the island to accommodate the impact of the oncoming environment. The existence of these small islands requires management attention so as to minimize the vulnerability of the island. The vulnerability of the island certainly contributes to affect the island-forming ecosystem, especially marine ecosystems such as coral reefs, sea-grass and others that have ecological functions. One thing that can be done to minimize the vulnerability of small islands is to increase the natural adaptive capacity of the system (Smit and Pilifosova, 2003) by protecting the existence of coastal ecosystems, such as coral reefs, mangroves and seagrass beds so as to increase adaptive capacity of the small islands.

CONCLUSION

In conclusion, the existing value of vulnerability exposure index on small islands in KRMPA is in the range of 0.1 to 0.9, with the information level from the low level to the extreme level. Piai Island has a very high exposure vulnerability index and this situation puts pressure on the island and its habitat. Sayang and Uranie islands are at the value of vulnerability exposure indexes of 0.65 and 0.50 which are at medium level. Indications of these levels and values mean that the island also tends to be exposed externally but still have considerable resilience. The other three islands (Wayag, Quoy and Bag) have low susceptibility exposure index values of 0.1 to 0.4 due to the islands' protection factor so that very low external influences are likely to occur in this island.

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THE EXISTING VALUES OF SMALL ISLAND'S VULNERABILITY INDEX BASED ON EXPOSURE DIMENSION: A CASE STUDY OF KAWE REGIONAL MARINE PROTECTED AREA IN RAJA AMPAT, INDONESIA

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