International Journal of Environment and Geosciences 3(1), 44-53 (2019)

Article

The Climate Change Impact on Coral in Weh Island and Aceh Island Indonesia

A. Besse Rimba [a]*, Fusanori Miura [a], Joseph Maina [b], Abd. Rahman As-syakur [c], Stuart Campbell [d]

[a] *Disaster and Prevention Laboratory, Graduate School of Yamaguchi University, Yamaguchi, Japan.; miura@yamaguchi-u.ac.jp (F.M.)*

[b] *Wildlife Conservation Society, Marine Programs, Bronx, NY 10460, USA*

[c] *Center for Remote Sensing and Ocean Sciences (CReSOS), Udayana University, PB Sudirman Street, Denpasar, Bali 80232, Indonesia; ar.assyakur@pplh.unud.ac.id (A.R.A.)*

[d] *Wildlife Conservation Society, Marine Programs, Indonesia*

* *Correspondence: a.besserimba@yahoo.com*

Received: 21 Janury 2018; Accepted: 26 May 2019; Available online: 1 June 2019

Abstract

Climate change is a global phenomenon that affects all aspects of life. Climate change also affects marine life such as coral reefs. This study aims to determine the effect of climate stress on coral in Weh Island and Aceh Island-indonesia. This study combined ground check time series data with time series data of satellite oceans, data is grouped into two categories. They are biodiversity data and climate stress data. The biodiversity data obtained fish data and coral data from in-situ data since 2005 to 2011 and climate data stress data obtained from compilation of satellite ocean data since 1983 to 2011. Biodiversity data includes number species of fish and the genus of coral biodiversity and coral community susceptibility. Climate stress is grouped into three categories. They are radiation, stress reinforcing and reducing stress. Radiation stress factors consists temperature, UV light and doldrums. Stress-reinforcing factors consists sedimentation and eutrophication. Then stress-reducing factors consists temperature variability and tidal amplitude. Base on the research result shows that climate stress has impact on coral condition. Environmental pressure gives significant effect on biodiversity. The climate-change affects indirect impact on the fish and coral reef. Climate change influences the ocean condition. Some of the biodiversity cannot resist due to the ocean condition changes drastically.

Keywords: *Climate change; climate stress; biodiversity; coral community; susceptibility Subject classification codes; include these here if the journal requires them*

1. Introduction

The most productive and biologically diverse ecosystems in the Earth are coral reefs (Odum and Odum, 1955). Coral reef has roles as spawning place, nursery and also as feeding ground for numerous organisms (Maina et al., 2011). Base on the coral reef area statistics by the World Atlas of Coral Reefs, Indonesia is the largest of reef area about 17.95% of total reef in the world (Spalding et al., 2001). Coral reefs are mainly as livelihood for millions of people who engaged in marine fisheries (Graham et al., 2008; Cinner et al., 2012b). Coral reefs become very vulnerable to climate change that led to substantial coral mortality in large scale (Cinner et al., 2012a).

The disturbances on coral causing disruption of marine ecosystems and coral bleaching can occur (Ilhamsyah et al., 2014; Ampou et al., 2017). Bleaching is coral respond to environmental stresses. Stressors are temperature (temperature drops -3ºC to -5 ºC for 5-10 days), solar irradiance (high radiance during the summer months), sub-aerial exposure (coral exposures directly during extreme low tides), sedimentation, fresh water dilution and inorganic nutrients (Buchheim, 1998). Increasing the sea surface

temperatures (SSTs) and hotspots lead to coral bleaching occurs on a large scale (Hoegh-Guldberg, 1999). Hotspots are areas where SST increased to exceed the maximum annual estimates (The highest temperature of the year on average over 10 years) (Goreau and Hayes, 1994). These conditions can be said to be part of the Climate Stress.

The coral bleaching will occur when the increase in SST occurs to 10 weeks or more with hotspots more than 1°C of annual maximum temperature, (Wilkinson et al., 1999). The combination of exposure to ultraviolet light and high SST will lead bleaching. The process will be faster due to coral are not able to withstand the surrounding environment disturbance (Glynn, 1996; Shick et al., 2011).

Based on the field surveys conducted by a team of Wildlife Conservation Society-Marine Indonesia Program (WCS-IP) in May and July 2010 and February 2011, the coral bleaching occurred in Weh Island and Aceh Island. Coral bleaching occurs if the coral could not resist the environmental pressure (Glynn, 1996).

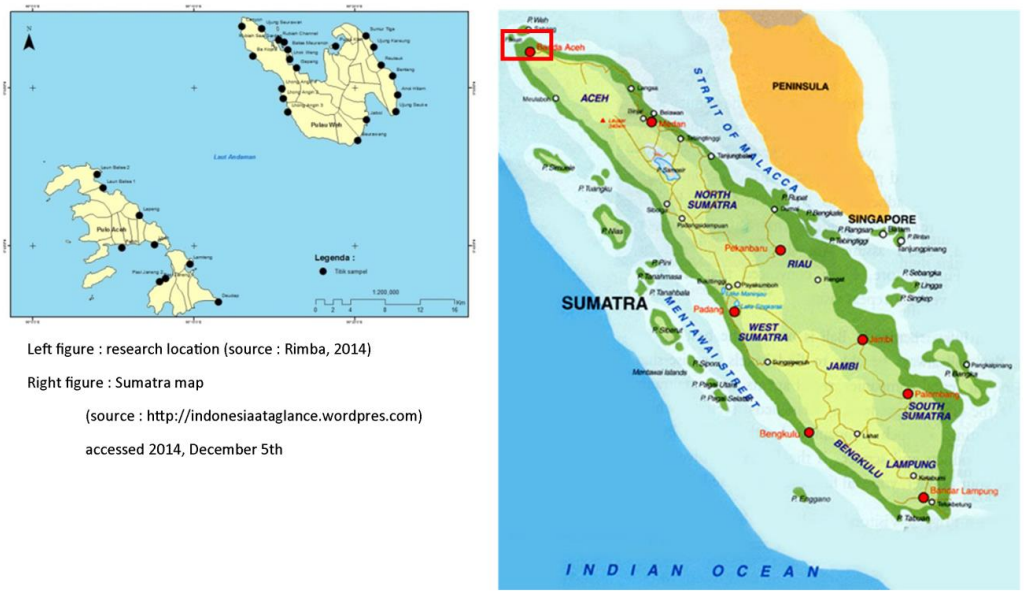
Satellite remote sensing is used monitoring, measuring and mapping phenomenon without direct physical sampling. Ocean features such as large-scale circulation can be visualized by highlighting variations in water color or temperature. These observations can then be used for such activities as ship routing, environmental monitoring of sensitive coastal zones, hazards assessment, and management of fishing fleets. High-resolution coastal images can be used to analyze and map sediment transport, bathymetry, erosion, and aquaculture applications; however, several of these are possible only when the skies are clear. Remote sensing can be applied to identify various environmental stresses to estimate the vulnerability of coral and fish (e.g., Fahlevi et al., 2018). The method can be used that combines some of the satellite data to create a model of environmental pressure.

In this study, we aim to find the relationship between climate stress and its effects on biodiversity of fish and coral. This study is based on field surveys WCS-Marine Indonesia Program in 2010 and 2011 that coral bleaching found in Aceh Island and Weh Island.

2. Material and Method

2.1 Study sites

This study area is located in Weh Island and Aceh Island, administratively located in Aceh province of Indonesia. Geographically, research area is located in 95°0'44.708" - 95°13'3.344"E and 5°35'27.435" - 5°54'31.395" N. The total of study area is 1763.3 km2. Weh Island and Aceh Island spread in Andaman Ocean. In 1982, the area was used as a nature reserve to protect the marine and existing terrestrial ecosystem in this region. The research location can be seen in Figure 1.



Left figure : research location (source : Rimba, 2014)

Right figure : Sumatra map

(source : http://indonesiaataglance.wordpres.com)

accessed 2014, December 5th

Figure 1. Research location

The geology of this islands formed by volcanic processes so that this area is an old volcanic mountains. This research area developed as a tourist area for its natural beauty underwater. Climate of the study area is a wet tropical climate influenced by west monsoon and east monsoon. From November to May, the wind blows from the North West brings much moister and rain to Indonesia; from June to October, the dry wind blows from South-East, it brings few water vapor. The range of temperature in lowland of Indonesia is 23°C to 28 °C all year.

2.2 Data sources and analysis

Sources of data obtained in the two ways, namely the in-situ and satellite imagery. The biodiversity data obtained by in-situ data and the climate stress obtained by the satellite imagery. The biodiversity and climate stress are processed by raster type.

2.1.1. Climate stress

Global sea-level rise is currently increasing at about 2 mm per year. It is about 1-3 mm/year in coastal areas of Asia and is forcasted to accelerate to a rate of about 5 mm per year over the next century (Mackay, 2008).

The stress model was based on oceanographic factors relevant to environmental exposure, including sea surface temperature (SST) rate of rise, SST variability, SST maximum, ocean current and wind speed and direction, chlorophyll concentrations, photosynthetically available radiation and ultra violet light (McClanahan et al., 2011).

2.1.2. Coral community susceptibility

The loss of coral reefs in Asia perhaps as high as 88% in the next 30 years due to warming sea-surface temperatures, sea level rise, and other added stresses. By the 1997/98 El Niño event over 34% of Asia's coral reefs were reported to have been lost primarily because response of coral bleaching to high sea-surface temperatures. (Wilkinson, 2004)

Table 1. Sampling Point Group

Group	Sample Point
1	Anoi Itam, Benteng, Reuteuk and Ujung Seuke
2	Ba Kopra, Canyon
3	Batee Meurenon, Rubiah Channel, Rubiah Sea Garden, Ujung Seurawan
4	Beurawang, Jaboi
5	Deudap, Lamteng
6	Lapeng, Leun Balee 1, Leun Balee 2
7	Lhong Angin 1, Lhong Angin2, Lhong Angin3
8	Lhok Weng, Gapang
9	Lhoh, Paloh
10	Pulau Klah
11	Pasi Janeng 1, Pasi Janeng 2
12	Sumur Tiga, Ujung Kareung

The coral community was a weighed measure or index of the hard coral community's response to bleaching for determining the bleaching susceptibility, some of the community resistance to bleaching, which can be influenced by the history of coral bleaching-induced mortality but also other disturbances and recovery from those disturbances (McClanahan et al., 2007). Coral community susceptibility is an advanced analysis of coral bleaching by using in-situ data. Coral community susceptibility is

calculate as the coral taxon's relative abundance multiplied by its bleaching index and summed for all taxa (McClanahan et al., 2007).

2.1.3. Biodiversity metrics

Biodiversity hotspots are used for conservation priorities for marine ecosystems. Recently publication claims to have uncovered new latitudinal gradients in the congeniality of reef communities and new reef hotspots based on functional diversity. Simulation models show that the purported congeniality gradient is a mathematical inevitability of differences in species richness and detectability between vastly different marine ecosystems, namely 'reefs' in tropical, temperate, and polar regions. (Robinson et al., 2014).

Biodiversity metrics apply to evaluate the ecological integrity of aquatic ecosystems (Gallardo et al., 2011). In this study, the number of fish species and coral genus are calculated. Calculating the number of fish species and coral genus were calculated based on the number of transects. The survey data are used in this research starting from 2005 to 2011.

$$Biodiversity\,layer = (Coral + Fish) - (Fish \times Coral) \quad (1)$$

This equation results the map value between 0 and 1, it aggregates two data layers and insures that a pixel value in the output layer is higher than in either layer individually (McClanahan et al., 2011).

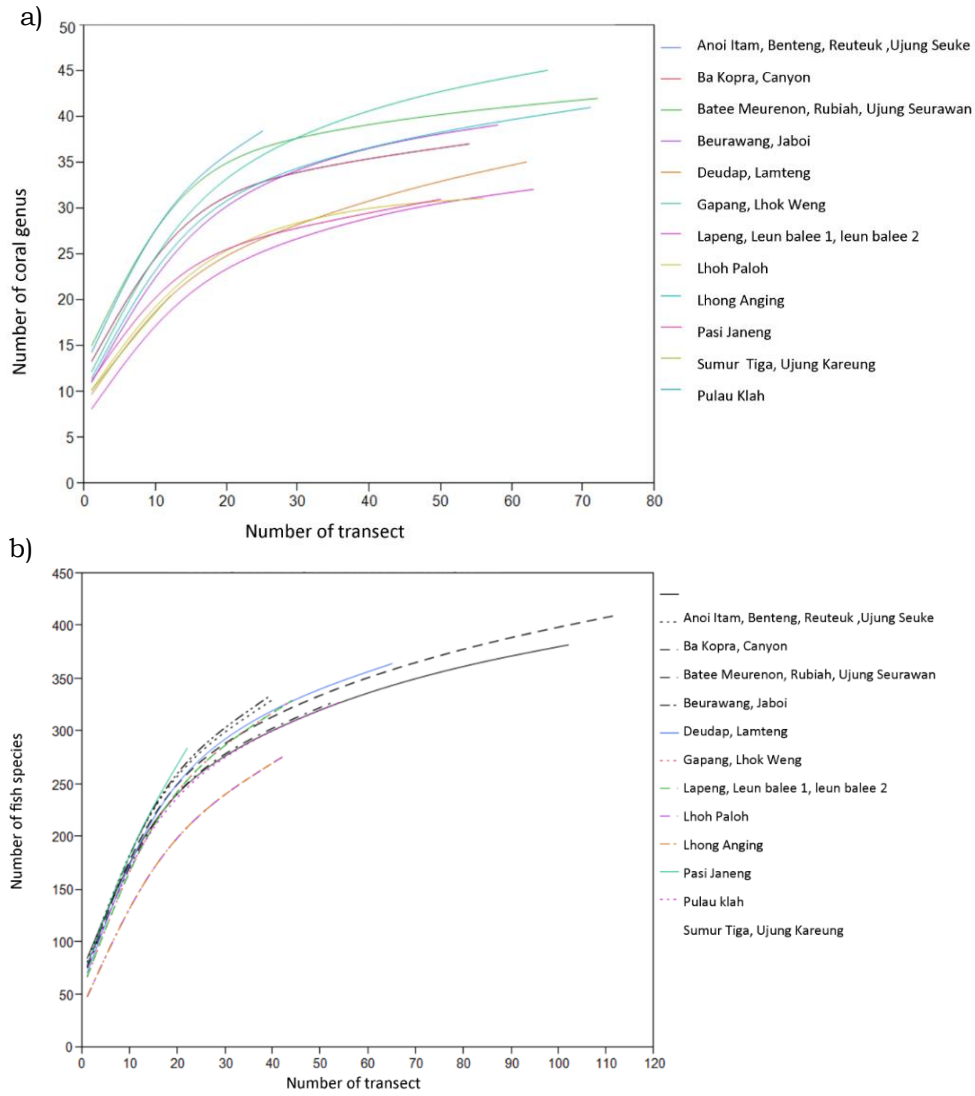


Figure 2. Number of (a) coral genus and (b) fish species in transect

2.1.4. Data analysis and mapping

All data exported to raster type the re-scale. All data have range 0 to 1. O means low and 1 means high. There are 29 sample locations. The sample points were grouped into 12 groups based on the conservation management (Table 1).

3. Result

3.1 Biodiversity

The possibility for increasing or reduction significantly of the biodiversity of fish species and coral genus is small, although this ecosystem affected by catastrophes such as the tsunami in Aceh in 2004. It is caused by the continuity of connectivity in the ocean which always supplies the larvae for the coral reef ecosystem.

In the Figure 2(a) and 2(b) show the number of coral genus and coral fish species. The more of transect numbers are used to estimate the diversity. The more accuracy of coral genus and coral fish species is higher. In this study, the number of transects that used is as much as possible transects. These transects are expected to describe not only the diversity of coral fish species and coral genus but also representing all the sample points. Based on the Figure 2(a), it increased drastically to 10th transect. After the 10th transect, the graph pattern is constant. While for the Figure 2(b), the number of coral fish species increases in each transect. This graph was made by using EstimateS 8.2 software. It is a free software application for Windows and Macintosh operating systems that computes a variety of biodiversity statistics, estimators, and indices based on biotic sampling data (Colwell, 2013).

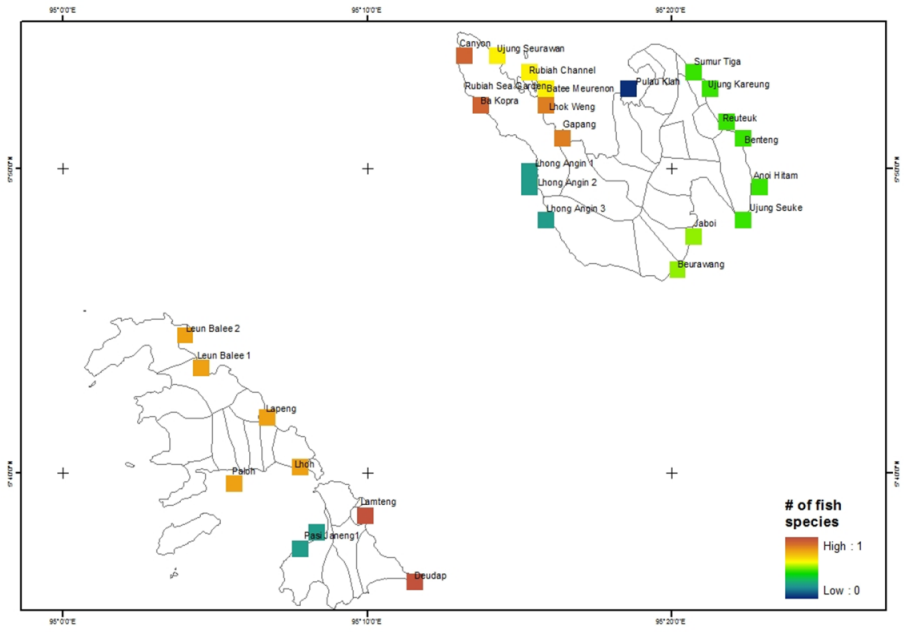


Figure 3. Number of Fish Species

The location is very decisive condition by the biodiversity of fish and coral genus at the side which located in the western end of Weh Island, the condition of biodiversity is quite diverse. This is due to the good water circulation from the Indian Ocean as supporting factors a high diversity of fish and coral genus. Increasingly entering into the Bay Sabang, nutrient availability and water circulation reduced, so that Klah Island which located in that the area is protected from the influence of wind and currents. The lack of influence of the ocean caused a lack of diversity of fish and coral genus in the sample point Klah Island and the east coast compared to the west coast of Weh Island. While Aceh Island was affected by Tsunami 2004, this island is dominated by sand substrate which causing big damage due to sand debris. However, oceanographic circulation in this region is very good, thus helping the recovery process. Current conditions, coral reefs began to improve.

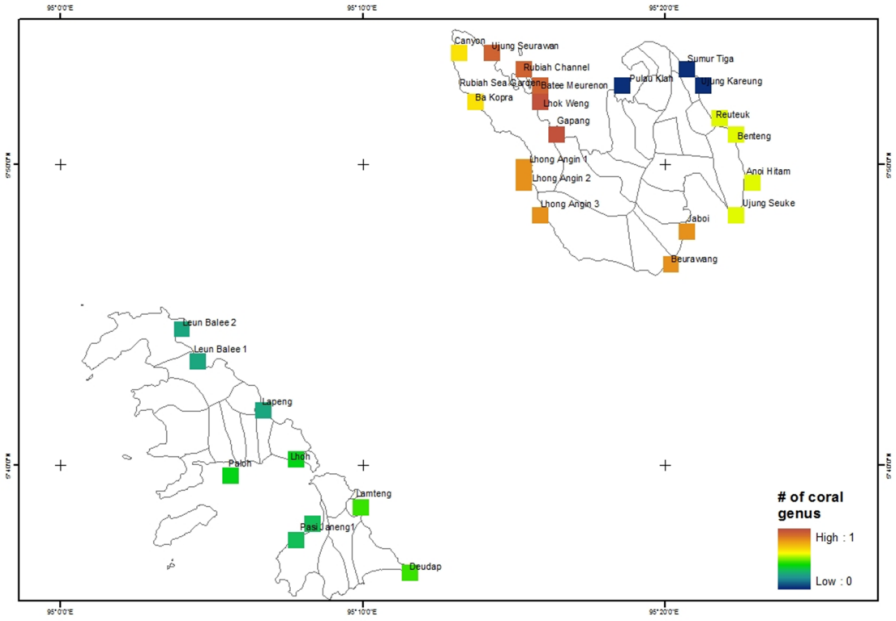


Figure 4. Number of Coral and Fish Diversity

In Figure 2(a) shows the sample point of Gapang and Lhokweng has higher coral genus in transect 40. Lhong Anging is always in the lower in all transects. While fish graph, the number of fish species is same for all sample points except in Pasi Janeng. As show in Figure 2(a), the lowest number of coral genus in Weh Island is located in Klah Island, Ujung Kareung and Sumur Tiga. The highest number of coral genus is located in sample point of Ujung Seurawang, Rubiah Channel, Batee Meuron, Lhok weng and Gapang. Aceh Island has moderate the number of coral genus comparing with other sample points.

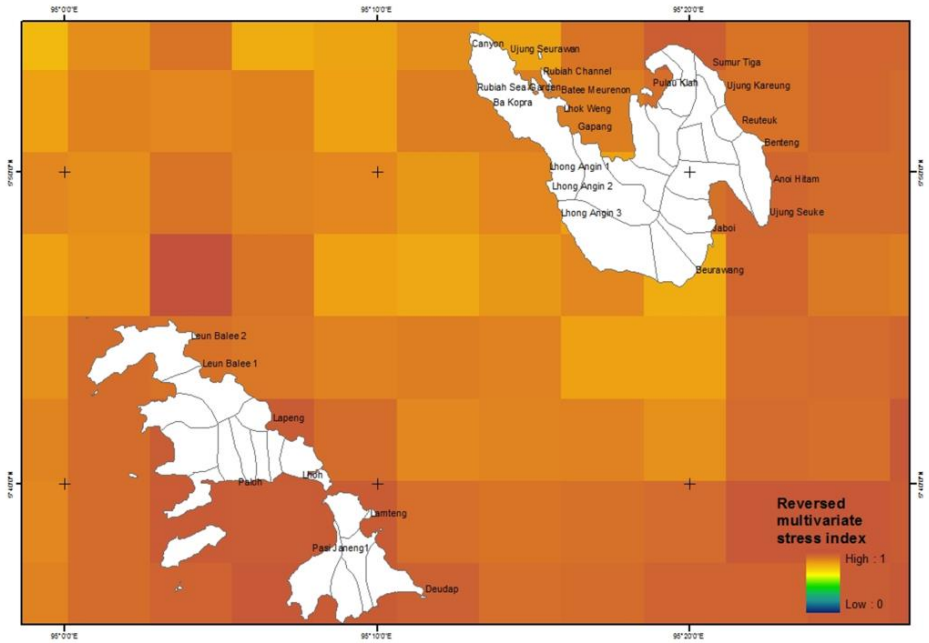


Figure 5. Multivariate stress (climate stress) model

Figure 3 is the number of fish species map, the lowest number of fish species is in Klah Island and the highest is in Ba Copra, Canyon, Lamteng and Deudap. Meanwhile, Figure 4 is the biodiversity of coral genus and fish species, in this map shows generally all the sample points have same high diversity.

Figure 2, 3 and 4 show the condition of sample points. All maps are done by re-scale where the highest score is 1 and the lowest score is 0. By re-scale processing, the result of each sample point can be compared.

3.2 Climate stress

The climate stress modeling can be seen in Figure 5, where the study area has high pressure from the environment. Climate stress is a model that combines the radiation, reducing and reinforcing to produce the spread of climate stress map.

3.3 Coral community susceptibility

Disturbance to coral communities can be seen in Figure 6, the highest disturbance of coral community susceptibility is in Canyon. The resistance of coral genus to environmental pressure is different; the same pressure from environment but different response from coral. This is due to differences in the composition of the coral. Areas with more susceptible corals will be severely affected by climate stress, while areas with more resistant coral will be resilient to climate stress.

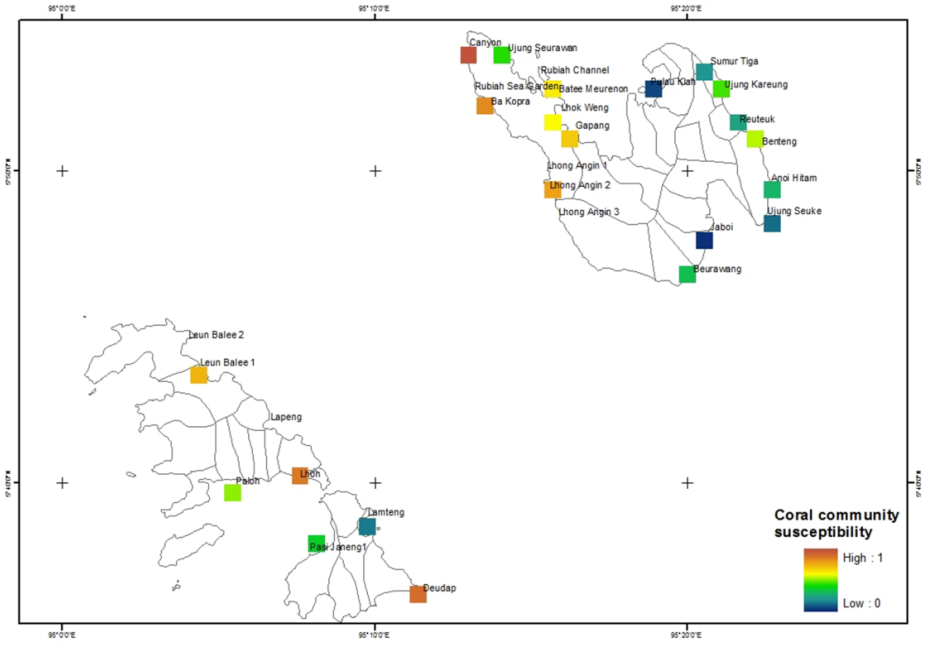


Figure 6. Coral Community Susceptibility

The analysis between coral community susceptibility and climate stress can be seen in Figure 6. The susceptibility is calculated by coral genus composition which susceptible to the temperature changing or other environment pressures. The area that has many susceptible corals has higher impact to the climate stress comparing areas that have many resilient corals.

3.4 Correlation among biodiversity, climate stress and coral community susceptibility

Figure 7 is the final result of this study. This map obtained from all maps. Based on the Figure 4, the climate stress, coral community susceptibility and biodiversity have moderate value.

Based on the correlation variable in Table 2, the coral had correlation between radiation (low), reducing (very low), reinforcing (very low), climate stress (low), coral susceptibility (moderate). The fish had correlation between reinforcing (low) climate stress (very low), coral (strong). The biodiversity has correlation to reinforcing (low), climate stress (low). The correlations are mostly low due to the climate stress data that used is

global data, the biodiversity is local data. The climate stress data has small resolution of spatial.

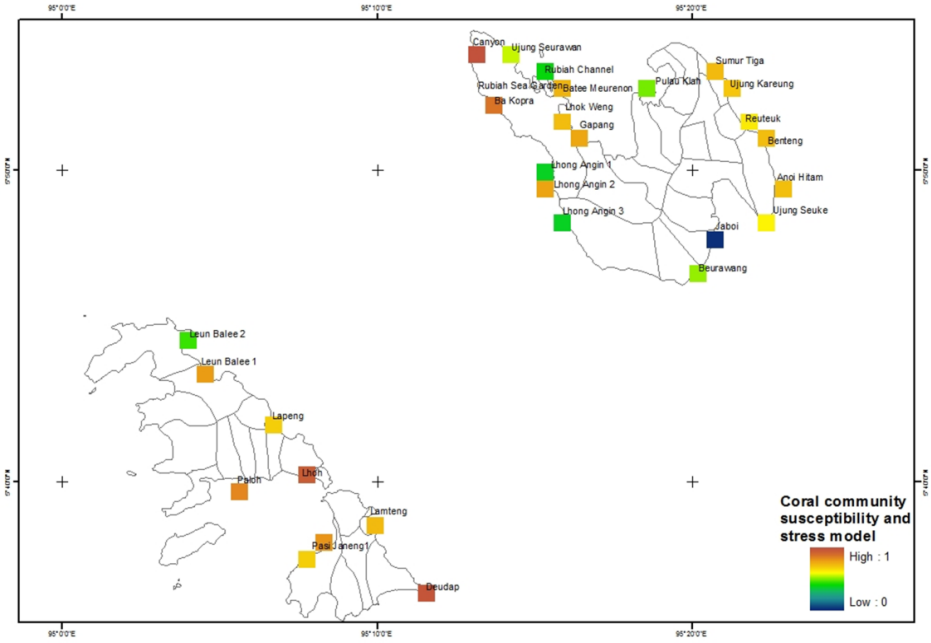


Figure 7. Biodiversity, Coral Community Susceptibility and climate stress

Table 2. Correlation between variable

Variable	Correlation
radiation x coral	-0.30088
reducing x coral	-0.14763
reinforcing x fish	0.299701
reinforcing x coral	0.131310348
reinforcing x biodiversity	0.295294
radiation and reducing x coral	-0.37059 1
climate stress x coral	-0.35742 1
climate stress x biodiversity	0.10159
climate stress x fish	-0.06107
coral x fish	0.648822
coral x coral susceptibility	0.454338

4. Conclusion

1. The amount of fish species and coral genus increase significantly by increasing number of transect.
2. The same condition of environmental affected different response of the coral. If the area has more coral susceptible, the area has high impact of climate stress comparing with the area which has high resistant coral. The resistance coral is more resilient to climate stress.
3. The climate stress has impact to the coral genus but for the fish species has very low impact.

5. Acknowledgments

In the end of this research, we would to say thank you very much to Wildlife Conservation Society who support all data in this research and Yamaguchi University.

References

Ampou, E. E., Johan, O., Menkès, C. E., Niño, F., Birol, F., Ouillon, S., & Andréfouët, S. (2017). Coral mortality induced by the 2015–2016 El-Niño in Indonesia: the effect of rapid sea level fall. *Biogeosciences*, **14**(4), 817-826.

Buchheim, J. (1998). *Coral reef bleaching*. [online] Odyssey Expeditions- Marine Biology Learning Center Publications, (https://www.marinebiology.org/coralbleaching.htm), [diakses: 4 Maret 2019]

Cinner, J. E., McClanahan, T. R., Graham, N. A. J., Daw, T. M., Maina, J., Stead, S. M., Wamukota, A., Brown, K., & Bodin, Ö. (2012a). Vulnerability of coastal communities to key impacts of climate change on coral reef fisheries. *Global Environmental Change*, **22**(1), 12-20.

Cinner, J. E., McClanahan, T. R., MacNeil, M. A., Graham, N. A., Daw, T. M., Mukminin, A., Feary, D. A., Rabearisoa, A. L., Wamukota, A., Jiddawi, N., & Campbell, S. J. (2012b). Comanagement of coral reef social-ecological systems. Proceedings of the National Academy of Sciences, 109(14), 5219-5222.

Colwell, R. K. (2013). About Estimates. [online] Estimates Statistical Estimation of Species Richness and Shared Species from Samples, (http://viceroy.eeb.uconn.edu/estimates/EstimateSPages/AboutEstimateS.htm), [accessed: 5th December 2014].

Fahlevi, A. R., Osawa, T., & Arthana, I. W. (2018). Coral Reef and Shallow Water Benthic Identification Using Landsat 7 ETM+ Satellite Data in Nusa Penida District. *International Journal of Environment and Geosciences*, **2**(1), 17-34.

Gallardo, B., Gascón, S., Quintana, X., & Comín, F. A. (2011). How to choose a biodiversity indicator–Redundancy and complementarity of biodiversity metrics in a freshwater ecosystem. *Ecological indicators*, **11**(5), 1177-1184.

Glynn, P. W. (1996). Coral reef bleaching: facts, hypotheses and implications. *Global change biology*, **2**(6), 495-509.

Goreau, T. J., & Hayes, R. L. (1994). Coral bleaching and ocean" hot spots". *Ambio-Journal of Human Environment Research and Management*, **23**(3), 176-180.

Graham, N. A. J., McClanahan, T. R., MacNeil, M. A., Wilson, S. K., Polunin, N. V. C., Jennings, S., Chabanet, P., Clark, S., Spalding, M. D., Letourneur, Y., Bigot, L., Galzin, R., Ohman, M. C., Garpe, K. C., Edwards, A. J., Sheppard, C. R. C. (2008). Climate warming, Marine Protected Areas and the ocean-scale integrity of coral reef ecosystems. *PLoS One*, **3**(8), 1-9.

Hoegh-Guldberg, O. (1999). Climate change, coral bleaching and the future of the world's coral reefs. *Marine and freshwater research*, **50**(8), 839-866.

Ilhamsyah, Y., Fadli, N., Setiawan, I., & Haridhi, H. A. (2014). coral reef bleaching in Weh Island, Indonesia, a natural climate variability or global climate change impact?. *Aquaculture, Aquarium, Conservation & Legislation*, **7**(6), 508-515.

Mackay, A. (2008). Climate change 2007: impacts, adaptation and vulnerability. Contribution of Working Group II to the fourth assessment report of the Intergovernmental Panel on Climate Change. *Journal of Environmental Quality*, **37**(6), 2407.

Maina, J., McClanahan, T. R., Venus, V., Ateweberhan, M., & Madin, J. (2011). Global gradients of coral exposure to environmental stresses and implications for local management. *PLoS One*, **6**(8), 1-14.

McClanahan, T. R., Maina, J. M., & Muthiga, N. A. (2011). Associations between climate stress and coral reef diversity in the western Indian Ocean. *Global Change Biology*, **17**(6), 2023-2032.

McClanahan, T. R., Ateweberhan, M., Graham, N. A. J., Wilson, S. K., Sebastián, C. R., Guillaume, M. M., & Bruggemann, J. H. (2007). Western Indian Ocean coral communities: bleaching responses and susceptibility to extinction. *Marine Ecology Progress Series*, **337**, 1-13.

Odum, H. T., & Odum, E. P. (1955). Trophic structure and productivity of a windward coral reef community on Eniwetok Atoll. *Ecological monographs*, **25**(3), 291-320.

Robinson, J. P., White, E. R., Wiwchar, L. D., Claar, D. C., Suraci, J. P., & Baum, J. K. (2014). The limitations of diversity metrics in directing global marine conservation. *Marine Policy*, **48**, 123-125.

Shick, J. M., Iglic, K., Wells, M. L., Trick, C. G., Doyle, J., & Dunlap, W. C. (2011). Responses to iron limitation in two colonies of Stylophora pistillata exposed to high temperature: Implications for coral bleaching. *Limnology and Oceanography*, **56**(3), 813-828.

Spalding, M. D., Ravilious, C., & Green, E. P. (2001). *World atlas of coral reefs*. Berkeley, USA: University of California Press.

Wilkinson, C. R. (1999). Global and local threats to coral reef functioning and existence: review and predictions. *Marine and Freshwater Research*, **50**(8), 867-878.

Wilkinson, C. (2004). *Status of Coral Reefs of the World: 2004, Volume 1*. Queensland, Australia: Australian Institute of Marine Science.