

Spatial assessment of relative resilience potential to support management of coral reef ecosystem in Doreri Bay area, Manokwari Regency, Indonesia

T F Pattiasina^{1,2}, A Sartimbul², B Semedi², E Y Herawati², D D Pelasula³, M Krey¹, Mulyadi⁴

¹Faculty of Fisheries and Marine Science, University of Papua, Manokwari 98314, Indonesia

²Postgraduate Program, Faculty of Fisheries and Marine Science, University of Brawijaya, Malang 65145, Indonesia

³Research Center for Deep Sea, Indonesian Institute of Science, Ambon 97233, Indonesia

⁴Teluk Cenderawasih National Park, Manokwari 98312, Indonesia

E-mail: th.pattiasina@unipa.ac.id

Abstract. The assessment of ecological resilience is a new approach to support coral reef management, especially in addressing anthropogenic stresses and anticipating the impacts of climate change. This study applies advanced scientific approaches to spatially assess the relative resilience potential and to determine management actions on coral reef ecosystems in Doreri Bay, Manokwari Regency, Indonesia. The combination of underwater photo transect (UPT) method, belt transect, Aqua MODIS satellite data processing, interview, observation and laboratory analysis were applied to collect 11 resilience indicators data, consist of 7 process indicators and 4 stress/pressure indicators. The relative resilience potential and stress were analyzed through several stages including data compilation, normalization, scale setting, and calculation of resilience and stress value, site ranking and site categorization. Furthermore, the relative resilience potential, relative stress values, and the value of individual indicators were queried using criteria to determine target sites and appropriate management actions. The results indicate a spatial variation of the relative resilience potential of coral reefs, where sites with high resilience potential values are located near local community settlements, particularly around Lemon Island and Mansinam Island. Efforts to reduce pollutant sources from land are necessary on sites located near river estuaries and densely populated settlements. Most of the sites meet the criteria for fisheries management/enforcement. Efforts to manage fisheries and law enforcement need to be done on sites at the reefs of Sawaibu and around Raimuti Island.

1. Introduction

Coral reefs are among the richest ecosystems with very high productivity compared to other ecosystems on earth. These ecosystems have important functions both ecologically and economically. In some places, coral reefs even have important cultural values for local communities (Burke et al., 2011; Cinner et al., 2012; Cinner et al., 2013; Weijerman et al., 2015). Nevertheless, in line with the increase in the world population and the increase in development activities that are generally concentrated in coastal areas, the threat to coral reef resources is an important issue today. The combination and sometimes synergies between local pressures and climate change have led to a sharp decline in the percentage of



coral cover from about 60% in the past fifty years, to about 20% in current conditions (Hughes et al. 2010; Ateweberhan et al. 2013). In order to prevent further degradation and ensure the sustainability of the world's coral reef systems, serious management efforts need to be undertaken.

The survival of coral reefs is highly dependent on resilience, which is the capacity of coral reefs to survive and recover from degradation and ensure the availability of ecosystem goods and services (Marshall and Schuttenberg, 2006; Mumby et al., 2007; Maynard et al., 2012). If disturbances occur on coral reefs and resilience is at a low level, vulnerability will increase, then there will be a shift from coral-dominated status to a status dominated by algae or other opportunistic organisms (Folke et al., 2004; Norström et al. 2009; Obura and Grimsditch, 2009; Knudby et al., 2014).

Resilience status of coral reef ecosystems is usually measured and monitored using an indicator of abundance or coral cover from important taxonomic groups, whereas those indicators are not sufficient enough to describe resilience. The spectacular decline of coral reefs in many places in the Caribbean is an example of ecological shock, because of the mistake in using only coral abundance as an indicator of resilience. Therefore, experts attempt to assess the development of measures of other indicators to monitor important processes related to coral reef resilience (Hughes et al., 2010; Graham et al., 2013). The development of the concept of assessing the potential for coral reef ecosystem resilience was initiated by Salm et al. (2001). This concept was built in response to a serious coral bleaching event in 1998. This is based on the idea that coral reefs have physical and ecological characteristics that enable some coral reefs to survive or recover from disturbance.

Referring to the above concept Obura and Grimsditch (2009) introduced a guide to the assessment of coral reef ecosystem resilience covering 61 indicators of resilience. However, these guidelines are still constrained in their application, especially in developing countries as they require adequate resources. In order to overcome these constraints, McClanahan et al. (2012) conducted studies to determine important resilience indicators based on three approaches: 1) expert judgment or response to the importance of an indicator compared to other indicators (perceived importance), 2) scientific evidence, and 3) feasibility of each indicator. The results are 11 key indicators affecting coral reef resistance and recovery from local impacts and climate change. Furthermore, their test results support the concept that while high ecological complexity, few but relatively strong indicator variables can affect the dynamics of the ecosystem. Using the framework recommended by McClanahan et al. (2012), coral reef resilience assessments has been implemented by Maynard et al. (2015) in the Commonwealth of the Northern Mariana Islands (CNMI) region.

Although it has been successfully implemented in the CNMI region, this advanced method has never been implemented in Indonesia, especially in new development areas such as Papua region, where the pressure from development activities is quite intense. The rapidly increasing development in Papuaduring the special autonomy era has created chronic pressures on coral reef ecosystems, whereas local communities are still dependent on the services of the ecosystems. In order to support the management of coral reef ecosystems in the region, the assessment of resilience is an urgent need to be implemented. This study aims to spatially assess the relative resilience potential of coral reefs and to identify target areas and management actions in Doreri Bay area, Manokwari Regency, West Papua Province, Indonesia.

2. Study area

Geographically, Doreri Bay is located at the position of 0° 52'43"S - 1° 01' 29" S and 134° 08'06"E - 134° 04'03" E, and is administratively a part of Manokwari District, West Papua Province. Doreri Bay is also part of the Bird's Head Seascape (BHS) region, which has been recognized as one of the largest contributors to the diversity of shallow marine biology in the tropics (Allen and Erdman, 2009). The bay is also thought to be a unique "ecotone" that resembles the transitional boundary between the Gulf of Cenderawasih in the south and the Pacific Ocean. Based on preliminary observations of Allen and Eidman (2008), the butterflyfishes (Chaetodontidae) in Doreri Bay have different characteristics with those in Cenderawasih Bay in the south and the Pacific Ocean in the north. In addition to its ecological uniqueness, coral reef fishery in Doreri Bay serves as a source of food and also a source of income for

local communities. Nevertheless, the urgent need for the expansion of Manokwari city as a consequence of the development of the region has caused coral reef ecosystems in Doreri Bay to experience pressure that threatens the sustainability of the ecosystems.

3. Materials and methods

3.1. Resilience and stress indicators

The indicators used in the assessment of coral reef ecosystem resilience are indicators recommended by McClanahan et al. (2012), and belong to two groups according to Maynard et al. (2015), namely: 1) indicators of resilience processes, including variability of sea water temperature, coral diversity, resistant coral species, coral recruitment, macroalgae cover, biomass of herbivorous fish and functional diversity of herbivorous fish; 2) anthropogenic stress/pressure indicators, which includes nutrient level, sedimentation, physical impact and fishing pressure.

3.2. Data collection

Data of resilience and stress indicators was collected directly in the field and through computer analysis (desktop analysis). Sampling stations were determined on the basis of representation in order to illustrate the overall condition of coral reefs in Doreri Bay. A total of 30 sampling sites for the entire study area were determined according to the distribution patterns of coral reefs based on an initial analysis of Landsat 8 OLI recorded in 2016 and preliminary survey results. The sites distributed at the coral reefs located in the western part of Doreri Bay, in front of Sawaibu Bay, around Lemon Island, around Mansinam Island, and in the eastern part of Doreri Bay. The map of study area showing the location of sampling sites is shown in Figure 1.

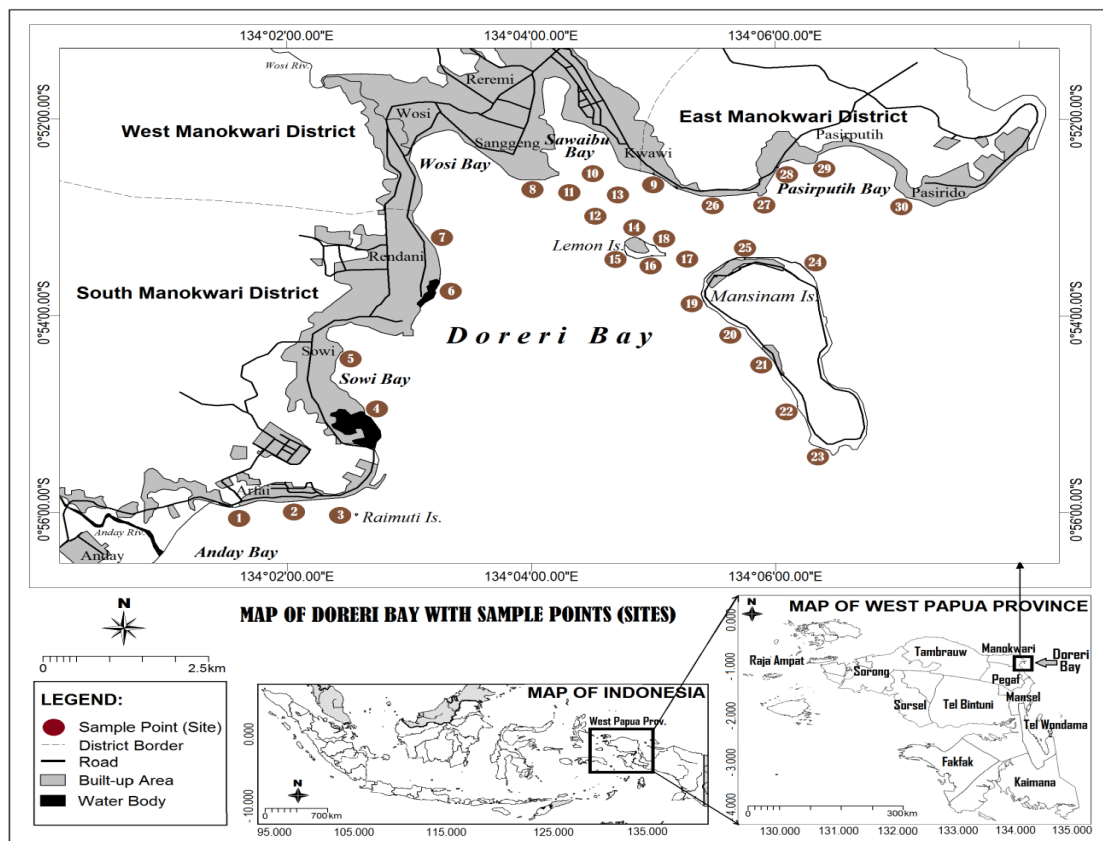


Figure 1. Map of the study area showing the location of Doreri Bay and the sampling sites within the bay. A total of 30 sampling sites were determined according to the distribution patterns of coral reefs in the entire study area.

The underwater photo transect method (Alquezar and Boyd, 2007; Kohler and Gill, 2006) was applied to collect data on coral diversity indicators, resistant coral species, coral recruitment, macroalgae cover and physical impact. Meanwhile, the belt transect method (Jupiter and Egli, 2011) was applied to collect biomass data and functional diversity of herbivorous fish, while interviews and observations to collect data on fishing pressure. Data on temperature variability, nutrient level, and sedimentation/turbidity were collected through satellite image analysis and geographic information system analysis. Methods applied for measuring indicators of ecological resilience is presented in Table 1.

Table 1. Methods applied for measuring indicators of ecological resilience. A total of 11 indicators including 7 indicators of resilience processes (denoted by*) and 4 stress indicators (denoted by**) were measured through field survey, satellite image and GIS analysis.

Indicator	Methods
Sea surface temperature variability *	Monthly sea surface temperature data from the AquaMODIS satellite period 2002-2017 was obtained from the NEO NASA website. Maximum monthly mean (MMM) was calculated for each pixel. MMM is the month in years with the highest average temperature during the period. The month with the MMM, together with the month before and the following month is defined as a 12-week warm period (summer). Variability was calculated as a standard deviation from that warm temperature period (Maynard et al., 2015; Sartimbul et al., 2010).
Coral diversity *	A list of genera/species was made, then coral diversity was calculated based on the Simpson diversity index for each site, with a range of values from 0 to 1. The higher the value (close to 1), the higher the coral diversity.
Resistant coral species *	Each genera/species was assigned a susceptibility value of 1-5 (Marshall and Schuttenberg, 2006; McClanahan et al., 2007, Maynard et al., 2015). Genera/species with a susceptibility value between 1-2 were classified as resistant to bleaching. The proportion (%) of resistant coral species was calculated for each site.
Coral recruitment *	Juvenile corals (recruits) are coral with geometric mean size <4 cm. The juvenile coral density (recruit/m ²) was calculated for each site, ie the total number of juveniles divided by the observed area.
Macroalgal cover *	Macroalgae cover was calculated as the percentage (%) of the points categorized as macroalgae of the entire points of the benthic cover on each site.
Funct. groups of herbivorous fish *	Herbivorous fish were divided into four functional groups: large excavators, browsers, grazer/detritivore and small excavators (Green and Bellwood, 2009). The functional group richness of herbivorous fishes was calculated as the number of functional groups present.
Biomass of herbivorous fish *	The average length of the fish size class was applied in the long-weight relationship formula (L-W), ie $W = a \times L^b$, with a and b obtained from FishBase (Froese & Pauly, 2009). The L-W conversion requires a fork length parameter. The conversion factor of total length to fork length (TL-FL) was also taken from FishBase. For each site, "herbivorous biomass" was calculated as the total weight estimate of all herbivorous fish, divided by the area (kg/100 m ²).
Physical impact **	The physical effects of human activities and natural phenomena were identified from the coral conditions seen in the photo frames. The proportion (%) of damaged/dead coral was calculated for each site.
Fishing pressure **	Based on observations and interviews with local fishermen, it is known that access is the driver of fishing pressure. The multiplication of the standardized values of coastal distance and distance from the fisherman's settlement is the proxy of fishing pressure.
Pollution/nutrient **	The multiplication of the standardized value of the distance and the area of the nearest/adjacent watershed to the site is a proxy for pollution/nutrient at each site.
Sedimentation **	Composite water sampling was done from bottom to the surface as many as three replicates for each site. Turbidity was measured using a turbidity meter, and the turbidity value (NTU) for each site is the average of all three replications.

3.3. Data analysis

3.3.1. Assessment of relative resilience potential and relative stress.

Assessment of resilience potential includes several stages: data compilation, normalization, uni-directional scale setting, scale setting in accordance with perceived importance, calculation of average resilience value of each site, calculation of relative resilience value, site ranking and site classification based on value Relative resilience (Maynard et al., 2015). Once compiled, all resilient indicator data is

normalized by dividing the value of each indicator from each site to the maximum value of the indicator among all sites. The next step is to set the uni-directional scale for macroalgae cover indicators, as high macroalgae cover scores indicate low resilience conditions. Normalized result values of the macroalgae cover variable are subtracted from the value of "1" (1 - n). Normalized values are then scaled according to the perceived importance of each indicator (in McClanahan et al., 2012). The perceived value of each indicator is divided by the lowest perceived importance (the functional group of herbivorous fish = 11.00) to obtain scaling multipliers. Furthermore, the normalized value of each indicator is multiplied by the scaling multiplier value and averaged to obtain the crude resilience value. The raw resilience values for each site are then normalized, which is divided by the highest crude resilience value to obtain a standard range from 0 - 1. These values are the final score of resilience for each site.

After calculating the final resilience value of each site, the next process is to rank sites based on the final resilience value of each site. Site ranking is done by sorting the data in the table, where the data is compiled from the highest to the lowest. The ranking of the previous process has not been able to give a clear picture of which sites are high, medium or low resilient. It is, therefore, necessary to group the site so that it is easy to understand how many sites have low, medium or high resilience. Grouping sites are done by calculating the average value (avg) and standard deviation (sd) from the relative resilience value of the entire site. Furthermore, the grouping is done based on the following criteria: High Resilience (value > avg + 1 sd); Medium-high Resilience (value > avg and < avg + 1 sd); Medium-low Resilience (value < avg and > avg - 1 sd); Low Resilience (value < avg - 1 sd). The stresses/pressures of human activities were assessed using the same method as the assessment of relative resilience potential. Stress on a given site was expressed relative to the site with the most severe stress due to human activity. High scores indicate high-stress levels and vice versa.

3.3.2. Identifying target locations and management actions. The resilience potential values, values of each resilient indicator and stress indicator values were tested by criteria for identifying targeted locations for management actions (Maynard et al., 2015). The identification criteria are related to the following management objectives: 1) Conservation; 2) Reduction of pollution sources from the land; 3) Fisheries management and law enforcement; 4) Monitoring bleaching and recovery support; 5) Coral reef restoration/translocation of corals; 6) tourism development. The query name and criteria used to suggest targets for different types of management actions presented in Table 2.

Table 2. Criteria for queries used to suggest targets for different types of management actions on each site (Maynard et al., 2015).

Query Name	Criteria
Conservation (C)	<i>Sites have high or low resilience potential; currently outside established no-take MPAs</i>
Land-based Source Pollution Reduction (L)	<i>Sites have above-average resilience potential & land-based sources of pollution</i>
Fishery Management and Enforcement (F)	<i>Sites have above-average resilience potential & fishing access or below-average herbivore AFG biomass & above-average fishing access or both</i>
Bleaching Monitoring and Supporting Recovery (B)	<i>Sites have low bleaching resistance & low herbivore AFG biomass</i>
Reef Restoration/Coral Translocation (R)	<i>Sites have above-average resilience potential & low coral diversity or coral cover.</i>
Tourism Outreach and Stewardship (T)	<i>Sites have above-average coral diversity, fish species richness, and fish biomass</i>

4. Results and discussion

4.1. Relative Resilience Potential

The assessment results based on the seven indicators of the resilience process indicate that the relative resilience potential of the reefs varies spatially. The value of the resilience potential between two sites may differ significantly even though they are adjacent to one another. The average value of resilience potential of 30 sites is 0.70 (± 0.12 sd). Resilience potential values ≥ 0.83 were classified as High Resilience Potential, values ≥ 0.70 and < 0.83 were classified as Medium-High, values < 0.70 and > 0.57 were classified as Medium-Low, and values ≤ 0.57 were classified as Low Resilience Potential. Among the 30 sites surveyed, 6 sites (20.0%) were classified as relatively high resilience potential, 8 sites (26.7%) were classified as Medium-high, 11 sites (36.7%) were classified as Medium-low, and 5 sites (16.7%) were classified as Low. The highest relative resilience potential value was found at site S19 (Mansinam Island Cemetery), whereas the lowest value was found at site S07 (Rendani Settlement).

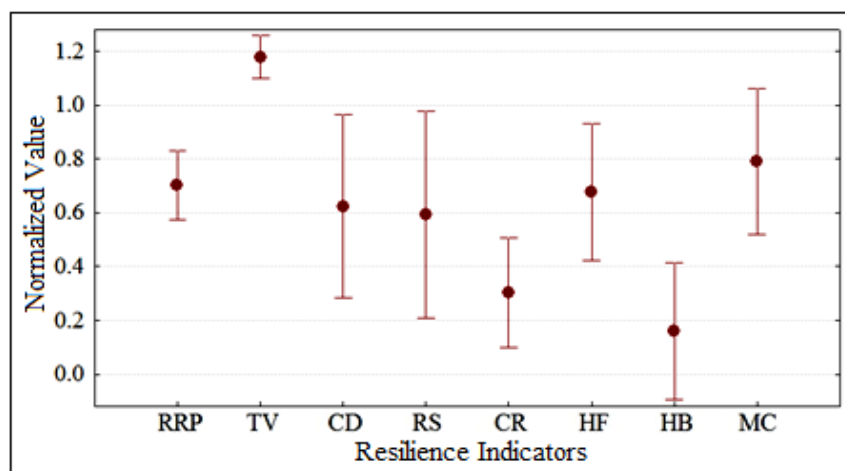


Figure 2. Distribution of normalized values of relative resilience potential (RRP) and resilience indicator values: temperature variability (TV), coral diversity (CD), resistant species (RS), coral recruitment (CR), functional group of herbivorous fish (HF), herbivorous fish biomass (HB) and macroalgae cover (MC). Black circle shape represent average value, while tail equal to “1 sd”.

Generally, sites with relatively high resilience potential values are located near local people's settlements, particularly around Lemon Island and the northern part of Mansinam Island, including sites S19 (Mansinam Island Cemetery), S25 (North Mansinam Island), S15 (Southwest Lemon Island), S12 (South Reef Flat), S29 (Pasirputih Cape), and S16 (South Lemon). These sites generally have high values on indicators of functional groups of herbivorous fish and herbivorous fish biomass. In addition, on these sites, the value of the macroalgae cover indicator and the coral recruitment indicator are constantly low compared to the other six indicators of resilience processes. Even the values of the coral recruitment indicator at the S15 site (Southwest Lemon Island) and site S16 (South Lemon Island) are low, although both sites belong to a high resilience potential class.

Sites that have the relatively low value of resilience potential are located at the south of Mansinam Island and western side of Doreri Bay. In addition to site S07 which has the lowest relative resilience potential value, there are four other sites that have relatively low resilience potential value ie, site S21 (Mansinam Mariculture), S22 (Southwest Mansinam Island), S02 (Arfai-Raimuti), and S23 (Mangewa Cape). Of the five sites, three sites are located in the southwest and south of Mansinam Island, while the other two sites are located on the western side of Doreri Bay. Unlike sites with high resilience potential, the five sites have generally low values in all resilience indicators, particularly functional groups of herbivorous fish, coral diversity, and coral recruitment. Map showing the relative resilience potential of 30 sites presented in Figure 3.

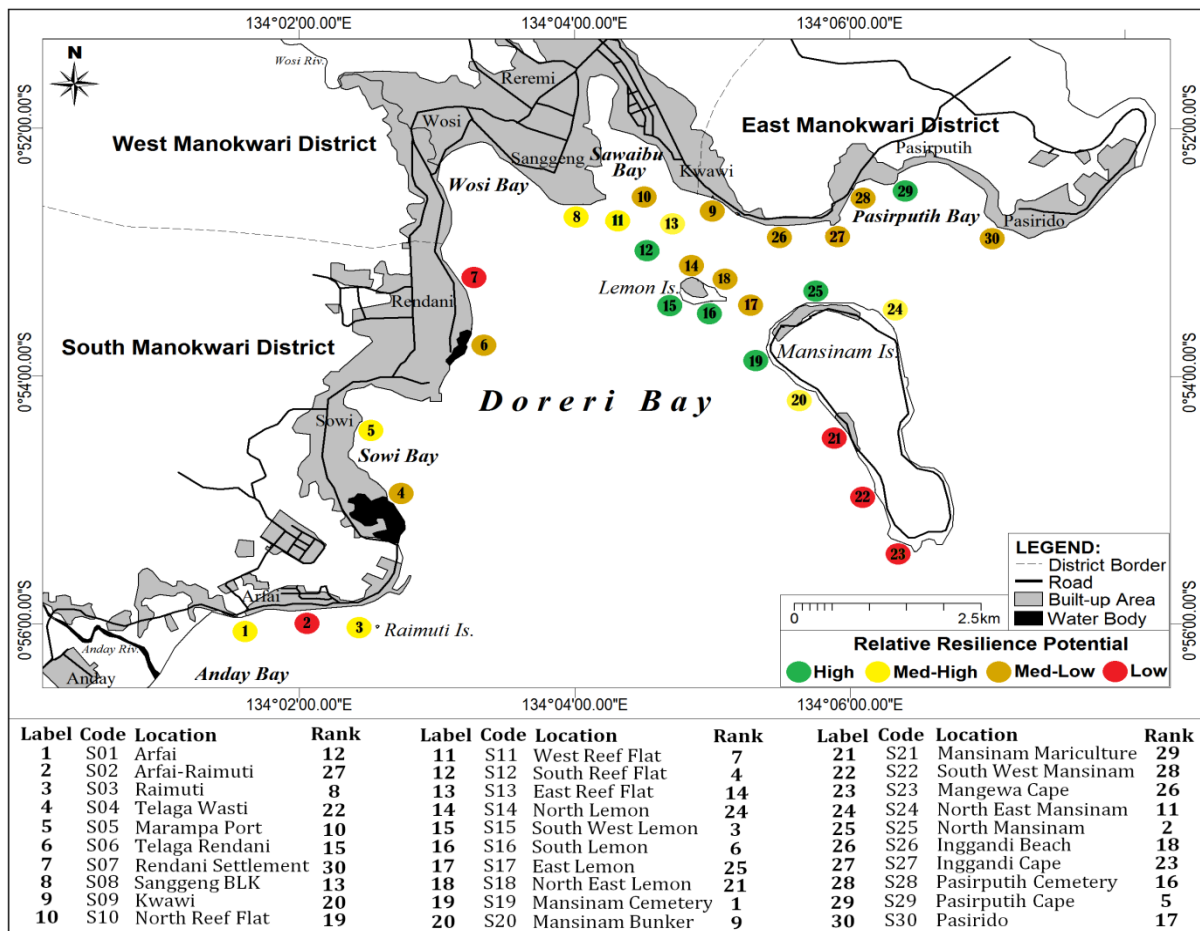


Figure 3. Map showing the relative resilience potential of 30 sites, where 6 sites (20.0%) classified as relatively high, 8 sites (26.7%) Medium-high, 11 sites (36.7%) Medium-low, and 5 sites (16.7%) Low. The highest value found at site S19 (Mansinam Island Cemetery), while the lowest one found at site S07 (Rendani Settlement).

The number of sites classified in the Medium-Lower class is more than the number of sites in other classes. Sites in the Medium-Lower class generally spread from the Pasirputih Bay to the Sawaibu Bay as well as north of Lemon Island. The other two sites are located on the western side of Doreri Bay, in Telaga Wasti and Telaga Rendani. The value of resilience indicators from these sites is generally low, especially the value of functional herbivorous groups and variability of sea surface temperatures, while the macroalgae cover value is quite high. Meanwhile, the sites classified into the Medium-High class are located on the western side of Doreri Bay, particularly at the Arfai-Raimuti Island locations, reef flats in Sawaibu Bay, and Mansinam Island. The values of the resilience indicators of the sites in this class are generally varied, but the values of recruitment indicators of corals are constantly high, and the values of macroalgae cover indicators are generally low.

The results described above indicate that there is a linkage between herbivorous fish indicators (functional group and biomass), macroalgae cover and resilience potential of coral reefs. The traditional understanding of coral reef ecosystems has focused on three groups of organisms namely coral, algae and fish. Coral and algae are the main benthic producers, but both compete with each other in exploiting space (Pawlik et al., 2016). Herbivores are key processes that support coral reef survival by inhibiting the development of macroalgae which can impact on the living, growth and survival of corals (Heenan and Williams, 2013). Furthermore, increased herbivorous fish have the potential to reduce the competition of algae to corals (Bawole et al., 2014; Bonaldo and Hay, 2014, Stender et al., 2014). Thus,

an important thing to support the sustainable management of coral reef ecosystems is a clear understanding of the role by certain types of herbivores in limiting the development of algae as well as supporting coral under certain environmental conditions (Adam et al., 2015).

4.2. Relative Anthropogenic Stress

Based on the calculation of relative anthropogenic stress value from 30 sites based on four stress indicators, the relative stress average value is 0.56 (± 0.18 sd). The stress values ≥ 0.74 were classified as High, the values ≥ 0.56 and < 0.74 were classified as Medium-high, the values < 0.56 and > 0.38 were classified as Medium-Low, and the values ≤ 0.38 were classified as Low. A total of 6 sites (20.0%) were classified as relatively high stress, 7 sites (23.3%) were classified as Medium-high stress, 14 sites (46.7%) were classified as Medium-low stress, and 3 sites (10.0%) were classified as Low Stress. The highest relative stress was found on site S01 (Arfai), whereas the lowest relative stress was found on site S11 (West Reef Flat). Map showing the relative anthropogenic stress of 30 sites presented in Figure 4.

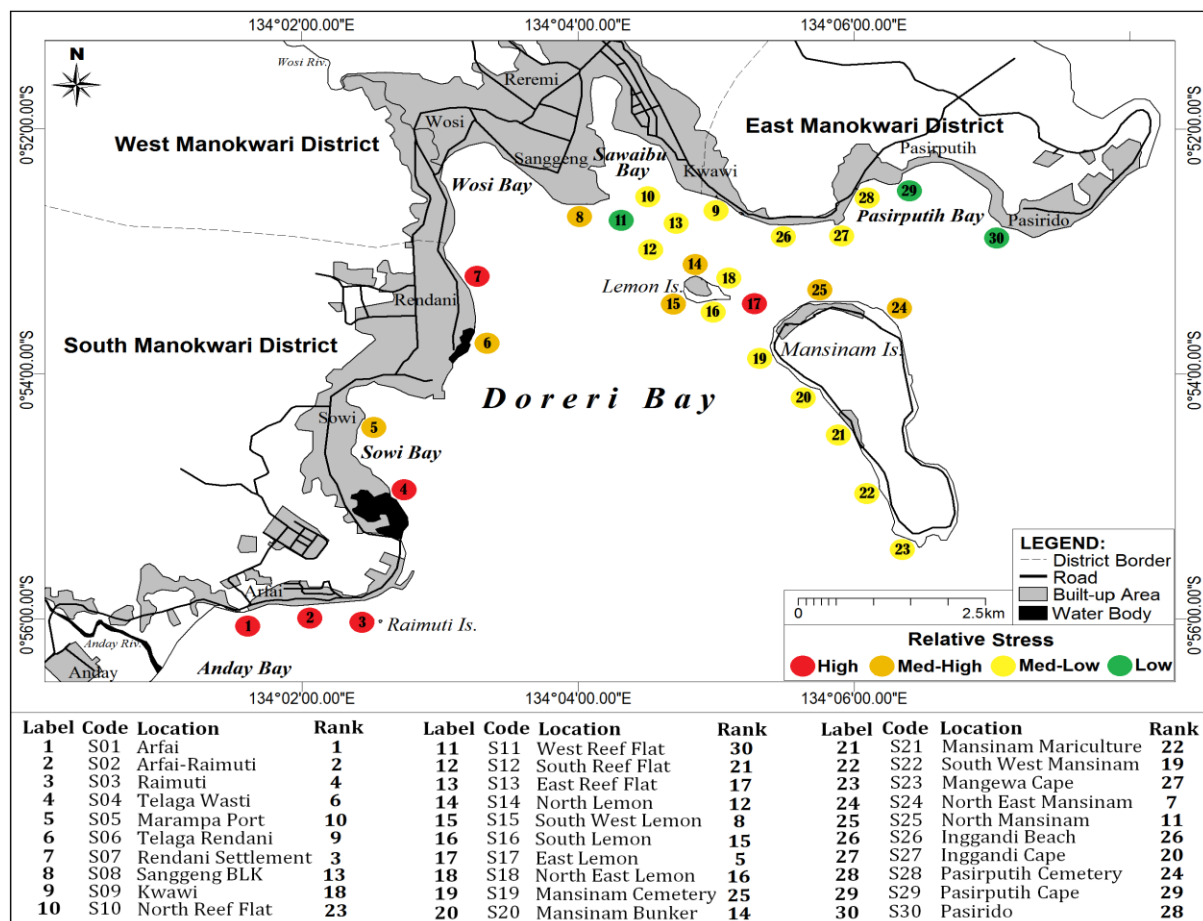


Figure 4. Map showing the relative anthropogenic stress of 30 sites, where of 6 sites (20.0%) were classified as relatively high stress, 7 sites (23.3%) Medium-high, 14 sites (46.7%) Medium-low, and 3 sites (10.0%) Low stress. The highest relative stress value found at site S01 (Arfai), while the lowest one found at site S11 (West Reef Flat).

In general, the relative stress of coral reefs varies spatially among all sites in the study area. However, sites that are classified into relatively high-stress classes are generally located on the western side of Doreri Bay. Sites that have relatively high-stress values are Arfai and Raimuti Island (S01, S02, and S03), Telaga Rendani (S04) and settlements in Rendani (S07). Two other sites located between these

sites, including Marampa Port (S05) and Telaga Rendani (S06) also have a high stress and classified in the class of Medium-high stress. On the other hand, sites belonging to other classes are located in the middle to the east of Doreri Bay, starting from Sawaibu Bay, Mansinam Island, Lemon Island to Pasirputih Bay. The relative stress value of sites on the western side of Doreri Bay is associated with the generally high value of sedimentation indicator, in addition to the high nutrient/ pollution value, especially the sites in Arfai and Raimuti Island. This relates to the location of these sites, which are relatively close to the river estuaries, where in the upper land there has been conversion from forest to settlement.

Maina et al. (2013) suggests that increased sediment and poor water quality reduce the ability of corals to withstand thermal stress, as well as reduce the ability to recover when experiencing bleaching events. Coastal reef systems generally experience an increase in sediment supply as a result of forest conversion in the upper land. Goatley et al. (2016) also point out that corals near the coast will experience the impact of sediment transport from the mainland, whereas corals far from mainland sedimentary sources will experience in-situ sedimentation disturbances due to physical, biological and chemical processes. In addition to sedimentation problems, nutrification due to human activity often leads not only to the increase of inorganic nutrients such as ammonia, nitrate and phosphate but also to the ratio of the concentrations of these nutrients in the waters. In certain types of phytoplankton the growth becomes chemically unbalanced because the availability of certain nutrient types decreases from the cell's need. This condition is known as nutrient deficiency and results in disturbing effects, such as reduced efficiency of photosynthesis of the symbiotic algae in coral (Wiedenmann et al., 2012).

4.3. *Targets Locations for Management Actions*

The final value of resilience, resilience indicator values and stress indicators have been queried with six criteria for determining appropriate management actions for each site. The number of sites that meet the fisheries management criteria is 19 sites, and the number is the highest compared to the other five criteria. These sites are scattered almost in all parts of Doreri Bay, from the west side to the east side of the bay. The number of sites that meet the criteria for bleaching monitoring and recovery support is 12 sites that are also scattered in almost all parts of Doreri Bay. Meanwhile, a number of 7 sites meet the criteria for the reduction of sources of pollution from the upper land, 5 sites meet the criteria for conservation, 4 sites meet the criteria for tourism development, and there was only 1 site that meets the criteria for coral restoration or coral translocation. The site meets the criteria for coral reef restoration is site S16, located in the southern part of Lemon Island. Map showing the result of queries to identify targets for different management actions presented in Figure 5.

The identification of target locations and management actions indicates that fisheries management needs to be implemented on most sites. It aims to reduce mortality of herbivorous fish as a result of fishing activities. Based on the results of their research on the Hawai'i islands, Weijerman et al. (2013) found a strong association between fish biomass and capture mortality. The high mortality of capture results in changes in fish communities, where there is a decrease in the number of large fish and biomass of piscivores. Further changes in reef fish communities have an effect on the relationship between corals and macroalgae. The results of the study by Stender et al. (2014) in Pelekane Bay shows that coastal access restrictions, efforts to tighten fishing rules, increased oversight of both legal and illegal fishing activities have had an impact on decreasing fishing pressure, and ultimately recovery of coral and reef fish conditions.

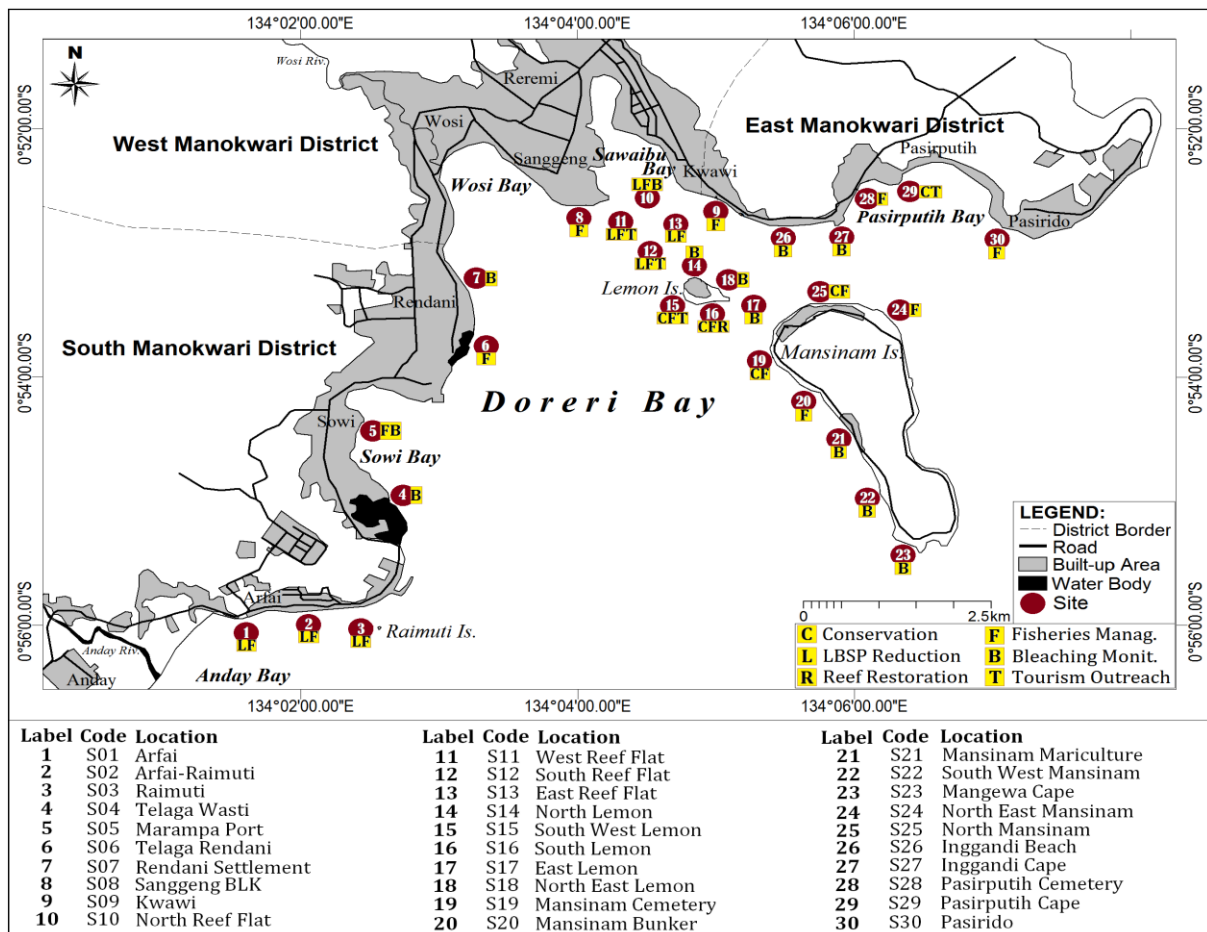


Figure 5. Map showing the result of queries to identify targets for different management actions. A number of 19 sites meet the criteria for fisheries management, 12 sites for bleaching monitoring/recovery, 7 sites for reduction of pollution from the land, 5 sites for conservation, 4 sites for tourism development, and only 1 site for coral restoration/translocation.

5. Conclusion

The resilience potential and pressure on coral reefs varies spatially. Sites with high resilience potential values are mainly located near local community settlements, particularly around Lemon Island and Mansinam Island. Sites with high-stress values are mainly located on the west side of the bay, particularly in Arfai and around Raimuti Island. In order to reduce stress, local scale management of sedimentation from the upper land is a relevant effort. Most of the sites meet the criteria for fisheries management/enforcement and bleaching monitoring which will contribute to the resilience of coral reef ecosystem in the bay.

Acknowledgement

This work is a part of dissertation research of the corresponding author. We would like to express our special gratitude and thanks to the Ministry of Research, Technology and Higher Education of the Republic of Indonesia (Kemendikbud), Education Offices of West Papua Province (Dinas Pendidikan Provinsi Papua Barat), and the Government of Raja Ampat Regency (Pemerintah Kabupaten Raja Ampat) for the financial support. We are indebted to the Bentara Papua Foundation, Fisheries Science Laboratory and Marine Sciences Laboratory of Papua University for the diving equipment, water sampling equipment and water sample analysis. Finally, We are grateful to

SCEEPAAR 7000 Diving Team (Rimer Biloro, Syafril, Rizky Karamoy, Ruland Tanati and Freddy Daan) for their hardworking during data collection in the field.

References

- [1] Adam T C, Burkepile D E, Ruttenberg B I and Paddock M J 2015 Herbivory and the resilience of Caribbean coral reefs: knowledge gaps and implications for management *Marine Ecology Progress Series* **520** 1-20.
- [2] Allen G R and Eidman M 2008 Natural resources in Cenderawasih Bay, Papua. A statement in stadium generale for Fisheries and Marine Science, The State University of Papua Manokwari, Indonesia.
- [3] Allen G R and Erdmann M V 2009 Reef fishes of the bird's head peninsula, West Papua, Indonesia *Check List* **5**(3) 587-628.
- [4] Alquezar R and Boyd W 2007 Development of rapid, cost effective coral survey techniques: tools for management and conservation planning *Journal of Coastal Conservation* **11**(2) 105-119.
- [5] Ateweberhan M, Feary D A, Keshavmurthy S, Chen A, Schleyer M H and Sheppard C R 2013 Climate change impacts on coral reefs: synergies with local effects, possibilities for acclimation, and management implications *Marine pollution bulletin* **74**(2)526-539.
- [6] Bawole R, Pattiasina T F and Kawulur E I J 2014 Coral-fish association and its spatial distribution in Cenderawasih Bay National Park Papua, Indonesia. *Aquaculture, Aquarium, Conservation & Legislation-International Journal of the Bioflux Society (AAFL Bioflux)*, **7**(4) 248-254.
- [7] Bonaldo R MandHay M E 2014 Seaweed-coral interactions: variance in seaweed allelopathy, coral susceptibility, and potential effects on coral resilience *PLoS One* **9**(1)e 85786.
- [8] Burke L, Reyntar K, Spalding M and Perry A 2011 *Reefs at risk revisited* World Resources Institute Washington DC.
- [9] Cinner J E, Huchery C, Darling E S, Humphries A T, Graham N A, Hicks C C, Marshall N and McClanahan T R 2013 Evaluating social and ecological vulnerability of coral reef fisheries to climate change *PLoS One* **8**(9)e 74321.
- [10] Cinner J E, McClanahan T R, Graham N A J, Daw T M, Maina J, Stead S M, Wamukota A, Brown K and Bodin Ö 2012 Vulnerability of coastal communities to key impacts of climate change on coral reef fisheries *Global Environmental Change* **22**(1) 12-20.
- [11] Folke C, Carpenter S, Walker B, Scheffer M, Elmqvist T, Gunderson L and Holling C S 2004 Regime shifts, resilience, and biodiversity in ecosystem management *Annual review of ecology, evolution, and systematics* **35** 557-581.
- [12] Froese R and Pauly D 2009 Fishbase Version World Wide Web Electronic Publication Retrieved from <http://www.fishbase.org> (February 2016).
- [13] Goatley C H R, Bonaldo R M, Fox R J and Bellwood D R 2016 Sediments and herbivory as sensitive indicators of coral reef degradation *Ecology and Society* **21**(1) 29.
- [14] Graham N A, Bellwood D R, Cinner J E, Hughes T P, Norström A V and Nyström M 2013 Managing resilience to reverse phase shifts in coral reefs *Frontiers in Ecology and the Environment* **11**(10)541-548.
- [15] Green A L and Bellwood D R 2009 Monitoring functional groups of herbivorous reef fishes as indicators of coral reef resilience: a practical guide for coral reef managers in the Asia Pacific region (No. 7) IUCN.
- [16] Heenan A and Williams I D 2013 Monitoring herbivorous fishes as indicators of coral reef resilience in American Samoa *PloS one* **8**(11)e79604.
- [17] Hughes T P, Graham N A, Jackson J B, Mumby P J and Steneck R S 2010 Rising to the challenge of sustaining coral reef resilience *Trends in ecology & evolution* **25**(11) 633-642.
- [18] Jupiter S and Egli D P 2011 Ecosystem-based management in Fiji: successes and challenges after five years of implementation *Journal of Marine Biology* **2011**1-14.
- [19] Knudby A, Pittman S J, Maina J, and Rowlands G 2014 Remote sensing and modeling In Finkl, C W and Makowski C eds. 2014 *Remote sensing and modeling: Advances in coastal and*

- marine resources* **9** Springer International Publishing Switzerland.
- [20] Kohler K E and Gill S M 2006 Coral point count with excel extensions (CPCe): A Visual Basic program for the determination of coral and substrate coverage using random point count methodology *Computers & Geosciences* **32**(9) 1259-1269.
- [21] Maina J, De Moel H, Zinke J, Madin J, McClanahan T and Vermaat J E 2013 Human deforestation outweighs future climate change impacts of sedimentation on coral reefs *Nature communications* **4** 1-4.
- [22] Marshall P A and Schuttenberg H Z 2006 A reef manager's guide to coral bleaching. *Great Barrier Reef Marine Park Authority Australia*.
- [23] Maynard J, Mckagan S, Johnson S and Houk P 2012 Coral Reef Resilience to Climate Change in Saipan, CNMI, Field-based Assessments, and Implications for Vulnerability and Future Management. Commonwealth of the Northern Mariana Islands, Division of Environmental Quality.
- [24] Maynard J A, Mckagan S, Raymundo L, Johnson S, Ahmadi G N, Johnston L, Houk P, Williams G J, Kendall M, Heron S F and Van Hooonk R 2015 Assessing relative resilience potential of coral reefs to inform management *Biological Conservation* **192** 109-119.
- [25] McClanahan T R, Ateweberhan M, Graham N A J, Wilson S K, Sebastián C R, Guillaume M M M and Bruggemann J H 2007 Western Indian Ocean coral communities: bleaching responses and susceptibility to extinction *Marine Ecology Progress Series* **337** 1-13.
- [26] McClanahan T R, Donner S D, Maynard J A, MacNeil M A, Graham N A, Maina J, Baker A C, Beger M, Campbell S J, Darling E S and Eakin C M 2012 Prioritizing key resilience indicators to support coral reef management in a changing climate *PloS One* **7**(8) e42884.
- [27] Mumby P J, Hastings A and Edwards H J 2007 Thresholds and the resilience of Caribbean coral reefs *Nature* **450**(7166) 98-101.
- [28] Norström AV, Nyström M, Lokrantz J and Folke C 2009 Alternative states on coral reefs: beyond coral - macroalgal phase shifts *Marine ecology progress series* **376** 295-306.
- [29] Obura D and Grimsditch G 2009 Resilience assessment of coral reefs: assessment protocol for coral reefs, focusing on coral bleaching and thermal stress Gland: IUCN.
- [30] Pawlik J R, Burkepile D E and Thurber R V 2016 A Vicious circle ? Altered carbon and nutrient cycling may explain the low resilience of Caribbean coral reefs *BioScience* **biw** 047.
- [31] Salm R V, Smith S E and Llewellyn G 2001 Mitigating the impact of coral bleaching through marine protected area design *Coral bleaching: Causes, consequences and response University of Rhode Island: USA* 81-88.
- [32] Sartimbul A, Nakata H, Rohadi E, Yusuf B and Kadarisman H P 2010 Variations in chlorophyll-a concentration and the impact on *Sardinella lemuru* catches in Bali Strait, Indonesia. *Progress in Oceanography* **87**(1) 168-174.
- [33] Stender Y, Jokiel P L and Rodgers K S 2014 Thirty years of coral reef change in relation to coastal construction and increased sedimentation at Pelekane Bay, Hawai'i *PeerJ* **2**e300.
- [34] Weijerman M, Fulton E A and Parrish F A 2013 Comparison of coral reef ecosystems along a fishing pressure gradient. *PloS One* **8**(5) e63797.
- [35] Weijerman M, Fulton E A, Janssen A B, Kuiper J J, Leemans R, Robson B J, van de Leemput I A and Mooij W M 2015 How models can support ecosystem-based management of coral reefs *Progress In Oceanography* **138** 559-570.

Reproduced with permission of copyright owner. Further reproduction prohibited without permission.