Detecting and visualizing potential multiple coral reef regimes in Doreri Bay, Manokwari Regency, Indonesia

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Abstract. Impact of local pressures in synergy with effects of global climate change can functionally cause damage to coral reefs and lead to changes in benthic structure often called regime shift. There is an urgent need to anticipate the regime shift as a result of the loss of coral reef resilience. This research aimed to detect and visualize the potential of multiple coral reef regimes in Doreri Bay, Manokwari Regency, Indonesia. Benthic cover data collected by applying underwater photo transect (UPT) method at 5 observation stations. Each station consists of 5-7 sampling sites, bringing the total number of 30 sites. To obtain quantitative data on benthic habitat, data analysis performed on each photo frame by selecting a number of 30 random samples. Descriptive statistics (mean ± SE) were used to compare the cover of six benthic categories within the study area and between stations. In order to detect, visualize and define potential multiple regimes, a combination of exploratory ordination methods was applied, including calculation of the phase shift index (PSI) and multimodality examination, correlation-based PCA, hierarchical cluster analysis, and K-means clustering. The mean percentage of hard coral cover (HC) is the highest compared to other benthic categories at nearly all stations, followed by the abiotic cover (AB) and dead coral cover (DC) respectively. PSI calculation and multimodality test displayed a normal distribution, indicated an absence of multiple regimes. However, the combination of correlation-based PCA and Clustering analysis approach highlighted the existence of three primary reef regimes dominated by live coral, algae and abiotic/dead coral.

Key Words: benthic cover, ecosystem, exploratory ordination, multimodality, phase shift, resilience.

Introduction. Degradation of marine and coastal ecosystems, including coral reefs in many parts of the world today is a global issue that has been the subject of research and management efforts intensively (Douvere 2008; Aswani et al 2012; Anthony et al 2015; Xin et al 2016). Severe reef degradation has taken place over the last fifty years and the main cause is the impact of human activities (Pandolfi et al 2011; Burke et al 2011). In general, the coral reefs exposed to destructive fishing practices, coral mining, and overexploitation of fish herbivores, as well as increased inputs of sediment, nutrients, and pollutants from upland (Hughes et al 2010; Ateweberhan et al 2013). These pressures, in synergy with the effects of climate change such as increasing the sea surface temperature may raise the stress of coral reefs (Semedi & Rahmawan 2016). Furthermore, the synergy of pressures can be functionally cause damage to numerous coral reefs and lowers the threshold from the state dominated by coral to a state that is dominated by algae and other opportunistic species (Folke et al 2004; Norström et al 2009; Obura & Grimsditch 2009; Knudby et al 2014).

Learning from cases of coral reef degradation in various places, resilience-based management (RBM) has now developed as a key concept in the management of coral reefs, which includes two aspects, namely reducing exposure to stress and supports the resilience of the reef system against disturbances (McClanahan et al 2012; Maynard et al

2012; Anthony et al 2015). Resilience-based management of coral reef in a particular area should be supported by a clear understanding of the potential of coral reefs regimes that exist in the area. This is an effort to anticipate the regime shift as a result of the weakening of the resilience of coral reefs (Jouffray et al 2014; Levin & Mollmann 2014).

Detection of potential regimes of the reef systems on a global scale has been carried out by Bruno et al (2009) based on Phase Shift Index (PSI) calculation continued with the test of multimodal patterns in the distribution of frequencies. The results showed that in general reef systems in state-dominated reefs (over 50%), or dominated by algae (over 50%). On a regional scale, Żychaluk et al (2012) applied a stochastic model of semi-parametric data from the reef in the Caribbean, Kenya and the Great Barrier Reef and they found no evidence of bimodality. Jouffray et al (2014) conducted a similar study in the Hawaiian archipelago. Although based on PSI calculation and multimodality test they found no evidence of bimodality, but they have been able to detect the potential of multiple regimes using principle component analysis (PCA) and clustering analysis.

Although at the global and regional scale, the detection of multiple regimes has been successfully applied, this approach has never been applied to support resilience-based management on a local scale, especially in Indonesia. Yet this approach would be very beneficial to support management of coral reefs at a local level since mostly strategic planning and implementation of coral reef management is executed at the level. This research aimed to detect and visualize the potential of multiple regimes of the reef system on a local scale in Doreri Bay, Manokwari Regency, in order to support resilience-based management of coral reefs in the area.

Material and Method

Study area. This research was conducted in Doreri Bay, Manokwari Regency, West Papua Province, Indonesia. Geographically Doreri Bay located at 0°52'43"S - 1°01'29"S and 134°02'06"E - 134°08'03"E. The bay is covering the administration area of three districts in the regency of Manokwari, namely East Manokwari District, West Manokwari District, and South Manokwari District. In these three districts, development activities are concentrated since Manokwari was designated as the capital of West Papua Province in 1999. Based on the analysis of Landsat satellite imagery, Doreri Bay waters has an area of approximately 131.83 km^2 and represents the unity of the five small bays, namely Pasirputih Bay, Sawaibu Bay, Wosi Bay, Sowi Bay and Andai Bay. The bays are the outcome of the rivers and water channels in Doreri Bay area (Figure 1).

Doreri Bay is part of the Papua Bird's Head Seascape (Papua BHS), one of the largest contributor of coral diversity and reef fish and considered as the epicenter of the biological diversity of the shallow waters in tropical areas (Allen & Erdmann 2009). The bay is also recognized as a unique "ecotone" that resembles the transitional boundary between the Cenderawasih Bay in the south and the Pacific Ocean in the north. Preliminary observations of Allen & Erdmann (2008) found that the butterfly fishes (Family Chaetodontidae) in Doreri Bay have different characteristics compared to those in Cenderawasih Bay and the Pacific Ocean. In addition to its function, ecologically, coral reefs in Doreri Bay have functioned well as a source of food and income for local communities over generations. Nevertheless, in line with the policy of local and regional development, the coral reefs in the bay have experienced pressures that threaten the sustainability of its functions (Sabariah et al 2010).

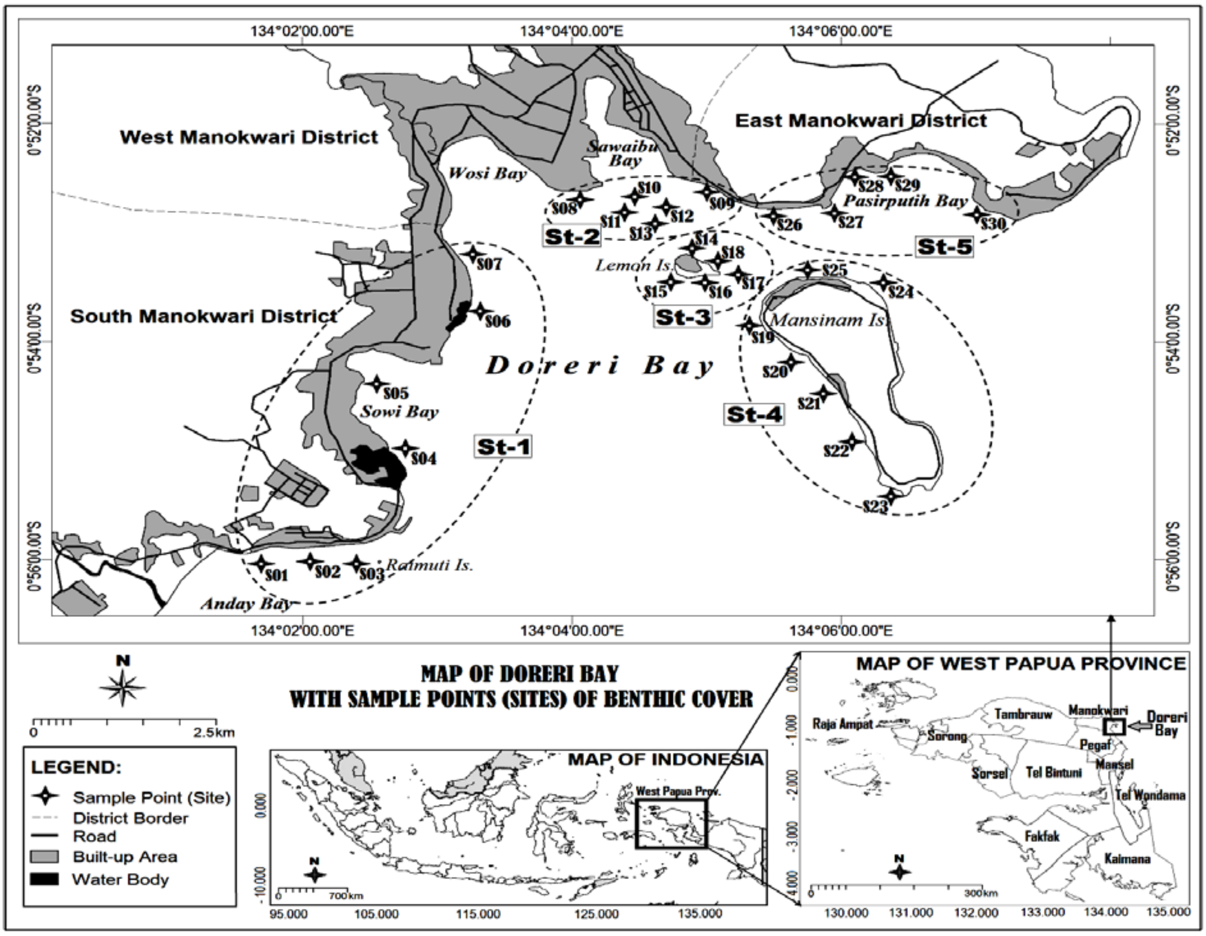

Figure 1. Map of the study area showing the location of Doreri Bay and the location of sampling sites. Within the bay, 5 locations that represent the overall condition of coral reefs were determined as observation stations (St-1 to St-5). Dot circle showing the group of sites at each observation station.

Data collection. Sampling stations and sites for the benthic cover data collection were determined based on preliminary analysis of coral reefs distribution in Doreri Bay using Landsat 8 OLI image, path/row 106/061 recorded in August 2015 as well as the preliminary survey results. Five sampling stations considered as the representation of coral reefs in the entire study area, including: 1) the western part of Doreri bay, 2) Reef flat in front of Sawaibu Bay (a small bay in Doreri Bay area, 3) Lemon Island, 4) Mansinam Island, and 5) the eastern part of Doreri bay. Each station consists of 5-7 sampling sites, bringing the total number of 30 sites (see Figure 1). Data were collected in the field at the end of March until the beginning of April 2016. Table 1 shows the list of sampling stations and sites in the study area with location and geographic coordinates of each site.

Benthic cover data collected by applying underwater photo transect (UPT) method (Alquezar & Boyd 2007; Kohler & Gill 2006), using Canon G1X camera with a resolution of 14.3 megapixels and covered by a housing. Photos were taken using a frame made of 1-inch diameter PVC pipe, frame size 1 x 1 m (1 m^2), with a distance of about 130 cm from the substrate. The camera was placed on a holder made of square-shaped PVC pipe, which was connected to each side of the frame with four rods PVC pipe. 50-meter transect line was laid parallel to the shoreline at depths between 5-10 m. Photographs were taken at an angle perpendicular to the substrate, which the first frame starting from the "0 cm" to "100 cm", frame 2 "100 cm" to "200 cm", and so on until the 50^{th} frame at the end of each transect. Frame with odd numbers placed on the left of the line, while the even-numbered on the right. Illustration of UPT method for benthic cover data collection is presented in Figure 2.

Table 1

The sampling stations and sites in the study area with geographic coordinates. The sites ranging from the west to the east side of Doreri Bay

Station	*Site code*	*Location*	*Latitude*	*Longitude*
Station 1 (7 sites) West of Doreri Bay	S01	Arfai	134.02844	-0.93302
	S02	Arfai-Raimuti	134.03289	-0.93235
	S03	Raimuti	134.03970	-0.93282
	S04	Telaga Wasti	134.04510	-0.91637
	S05	Marampa Port	134.04058	-0.90538
	S06	Telaga Rendani	134.05218	-0.89735
	S07	Rendani Settlement	134.05353	-0.88852
Station 2 (6 sites) Sawaibu Reef Flat	S08	Sanggeng BLK	134.06944	-0.87672
	S09	Kwawi	134.08360	-0.87591
	S10	North Reef Flat	134.07611	-0.87713
	S11	West Reef Flat	134.07504	-0.87868
	S12	South Reef Flat	134.07800	-0.87901
	S13	East Reef Flat	134.07713	-0.88050
Station 3 (5 sites) Lemon Island	S14	North Lemon	134.08158	-0.88562
	S15	South West Lemon	134.07915	-0.88960
	S16	South Lemon	134.08245	-0.88946
	S17	East Lemon	134.08562	-0.88906
	S18	North East Lemon	134.08454	-0.88724
Station 4 (7 sites) Mansinam Island	S19	Mansinam Cemetery	134.08852	-0.89540
	S20	Mansinam Bunker	134.09196	-0.89978
	S21	Mansinam Mariculture	134.09857	-0.90727
	S22	South West Mansinam	134.10241	-0.91650
	S23	Mangewa Cape	134.10648	-0.92286
	S24	North East Mansinam	134.10101	-0.88884
	S25	North Mansinam	134.09583	-0.88869
Station 5 (5 sites) East of Doreri Bay	S26	Inggandi Beach	134.09272	-0.87937
	S27	Inggandi Cape	134.09716	-0.87922
	S28	Pasirputih Cemetery	134.09997	-0.87449
	S29	Pasirputih Cape	134.10456	-0.87478
	S30	Pasirido	134.11832	-0.88041

The photos were analyzed using Coral Point Count with Excel Extensions (CPCe) software version 4.1 (Kohler & Gill 2006). To obtain quantitative data on benthic habitat, data analysis performed on each frame by selecting the random samples. This technique was used to determine the number of random points. The population is all biota and substrate in the photo frame, while the samples are 30 points chosen randomly on the photo by software CPCe. According to Giyanto et al (2010), a number of 30 random points is representative for estimating the percentage cover of the category and the substrate. The data recorded was substrate and biota located right on the 30 random points. Benthic cover data is the percentage cover of benthic habitat category, which is obtained based on the formula for the calculation of benthic categories cover (Giyanto et al 2010; Giyanto et al 2014):

$$\text{Category Cover (\%)} = \frac{\text{Number of Category Points}}{\text{Number of Random Points}} \times 100\ \%$$

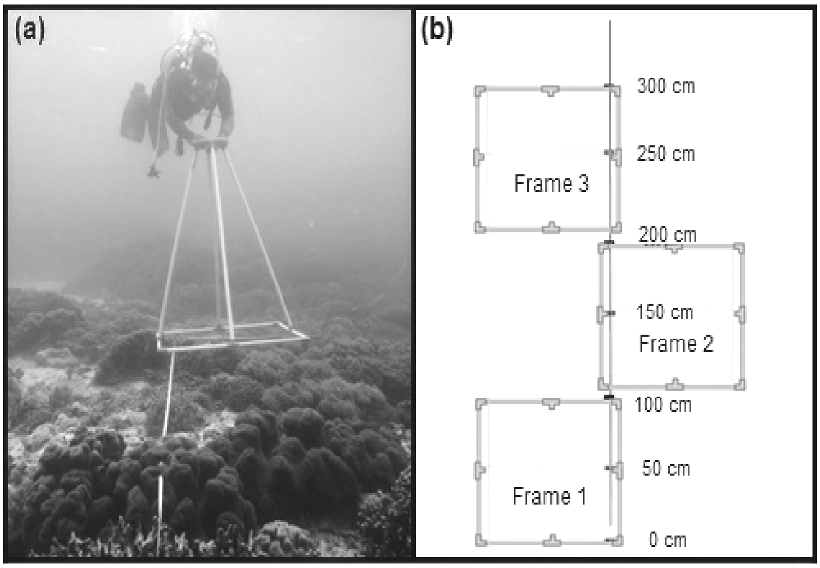

Figure 2. Illustration of UPT method applied in benthic cover data collection. Photos were taken at an angle perpendicular with a distance of about 130 cm from the substrate (a). Frame 1 starting from the "0 cm" to "100 cm", frame 2 "100 cm" to "200 cm", and so on until the 50th frame at the end of each transect (b).

Statistical analysis. We used descriptive statistics (mean±SE) to compare the percentage cover among six benthic categories in the study area and to compare the percentage cover of benthic categories between observation stations. Then, we calculated the phase shift index (PSI) and multimodality examination graphically, which is carried out using a graph in the frequency distribution of live coral and algae cover data (Bruno et al 2009). In essence, PSI is the first component of the principal component analysis (PCA) based on the cover of live coral and algae (macroalgae and turf algae). The purpose of applying PSI calculation and multimodality test is to detect potential multiple regimes in the coral reef system, particularly the existence of algae regime as a common phenomenon following coral degradation.

After calculation of PSI and multimodality test, we applied a combination of exploratory ordination methods using the data of six categories of benthic cover for the same purpose that is to detect, visualize and define potential multiple regimes (Jouffray et al 2014). The categories of benthic cover used were hard coral (HC), dead coral (DC), turf algae (TA), macroalgae (MA), other fauna (OT) and abiotic (AB). The first step is to apply the correlation-based PCA using benthic cover data of all categories. The second step is to apply a hierarchical cluster analysis to cover benthic variable using Euclidian distance matrix similar to the PCA analysis. Finally, based on the number of significant clusters obtained from the hierarchical cluster analysis, the K-means clustering applied to categorize the sites.

Results

Benthic cover composition. The benthic community in Doreri Bay is in relatively good shape with moderately high percentage of hard coral cover (46.75±4.23%, N=30, Figure 3). However, the mean coral cover in the study area is greater than across the entire Bird's Head Seascape, which is about 28.7% in 2015 (Glew et al 2015). The mean percentage of hard coral cover (HC) is the highest compared to other benthic categories in the study area. Besides hard coral, abiotic cover (AB) is also quite prominent in the study area, followed by the dead coral cover (DC). The mean percentage of abiotic cover is 32.27±3.37% (N=30), while dead coral cover is 10.93±1.89% (N=30). Other benthic categories, namely macroalgae (MA), other fauna (OT) and turf algae (TA), mostly have the low mean percentage of cover. Turf algae have the lowest mean percentage of cover among the six benthic categories which is 3.02±0.64% (N=30).

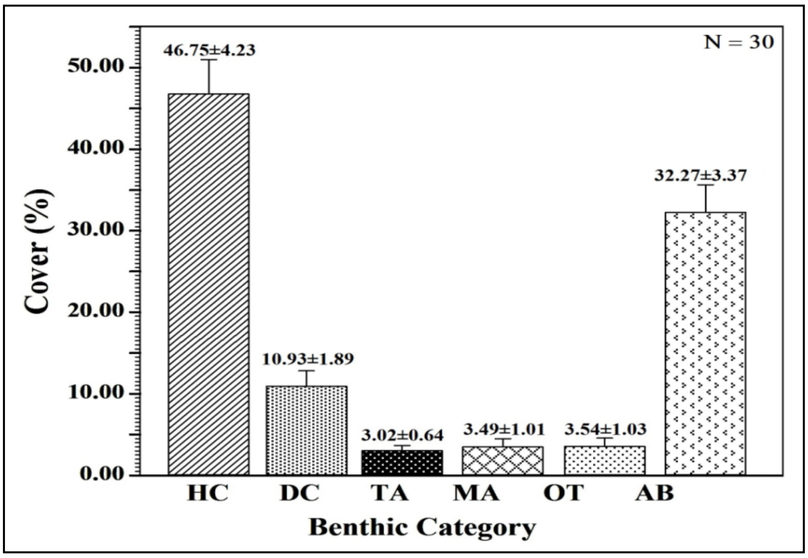

Figure 3. The cover of six benthic categories in the study area. Bar indicates mean percentage of cover (±SE), calculated by pooling the percentage cover of hard coral (HC), turf algae (TA), macroalgae (MA), other fauna (OT), dead coral (DC) and abiotic (AB) at all sites in the study area. In general, hard coral has the highest percent cover, followed by abiotic and dead coral.

The mean percentage of the hard coral cover is the highest compared to other benthic categories at all stations (Table 2). The highest mean percentage of hard coral cover found at Station 5 (East of Doreri Bay) where at that station macroalgae and turf algae also found in the highest cover. In contrast, dead coral and other fauna found to have the lowest cover at the station. Meanwhile, the lowest mean percentage of hard coral cover found at Station 1 (West of Doreri Bay). The highest cover of dead coral and abiotic found at Station 4 (Mansinam Island), while turf algae and macroalgae found to have the lowest cover at the station. The highest cover of other fauna found at Station 3 (Lemon Island), while the lowest one found at Station 5.

Table 2

The mean percentage cover of six benthic categories at each observation station

Station	*No. site*	*Mean cover of benthic categories (%)*					
		HC	*DC*	*TA*	*MA*	*OT*	*AB*
Station 1 (West of Doreri Bay)	7	#39.39	19.71	2.67	1.45	6.86	29.92
Station 2 (Sawaibu Reef Flat)	6	53.01	10.64	3.88	1.43	2.98	28.05
Station 3 (Lemon Island)	5	43.25	11.20	2.92	1.77	*8.80	32.06
Station 4 (Mansinam Island)	7	40.90	*21.19	#1.70	#0.65	3.35	*32.22
Station 5 (East of Doreri Bay)	5	*60.76	#2.08	*6.72	*5.96	#2.40	#22.08

The mean percentage cover calculated by pooling the percent cover of each benthic category at all sites per station. Numbers with * symbol indicate the highest percentage cover of each benthic category, while numbers with # symbol indicate the lowest one.

Detection and visualization of potential reef regimes. Shifting of reef state dominated by coral to the state dominated by algae has been seen as a common phenomenon throughout the tropics. Although according to the results of previous studies, there are also other alternatives such as soft corals, sponges, starfish, and corallimorpharians. In order to detect whether multiple regimes are present in the reef system, particularly in the relationship between corals and algae, we have calculated the phase shift index (PSI). Based on the calculation, the value of the PSI is in the range between -1.74 (coral dominance) and 2.09 (algae dominance). Furthermore, the results of multimodality test that uses a frequency distribution of corals and algae at 30 sampling sites clearly show the absence of multiple regimes (Figure 4).

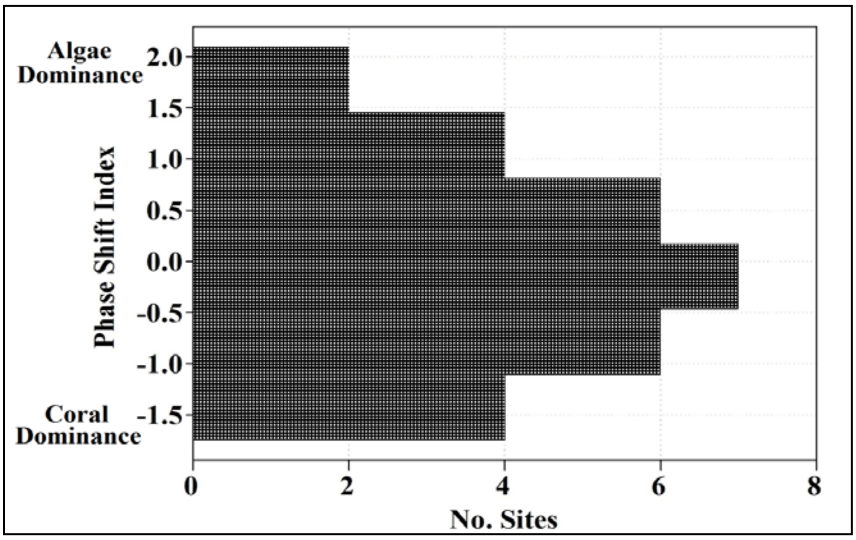

Figure 4. Count histogram of the phase shift index (PSI) of 30 sites in Doreri Bay. The value of the PSI is in the range between -1.74 (coral dominance) and 2.09 (algae dominance). The graph does not show any indication of bimodality.

Although multimodality test showed the absence of multiple regimes, on the other hand, correlation-based principal component analysis (PCA) results indicate the potential of the multiple regimes of coral reefs in Doreri Bay (Table 3). The correlation-based PCA shows that there are two components affect benthic cover in the study area. The first component described a gradient from hard coral cover (HC) at the negative score to dead coral cover (DC) and abiotic (AB) at the positive score. On the other side, the second component described the variability of turf algae (TA), macroalgae (MA) and other fauna (OT) at the negative score. It is similar to the result found by Bawole et al (2014) throughout their study in Cenderawasih Bay, a greater bay located at south of Doreri Bay, although the benthic variables used is a little different.

Table 3

Correlation of the variables with the first two factors

Variable	*PC1*	*PC2*
Hard coral (HC)	-0.9368	0.2590
Dead coral (DC)	0.7068	0.2463
Turf algae (TA)	-0.0084	-0.7956
Macroalgae (MA)	-0.3528	-0.6193
Other fauna (OT)	0.3505	-0.5094
Abiotic (AB)	0.7770	0.0281

PC1 described a gradient from hard coral cover at the negative score, to dead coral cover and abiotic at the positive score. PC2 described the variability of turf algae, macroalgae and other fauna at the negative score.

Six variables were plotted as vectors into a PCA diagram of benthic cover variables (Figure 5). The diagram showed that Component 1 (PC1) explained 37.14% of the total variance and Component 2 (PC2) describes 23.41% of the total variance. Therefore, those two components explain 60.55% of the total variance of six benthic variables data. The diagram also visualizes the correlation between variables, where the angle between two variables indicates the correlation between those two variables. The smaller the angle between two variable vectors the stronger the correlation. The diagram shows that turf algae cover has a strong correlation with other fauna cover and macroalgae cover, while dead coral cover has a strong correlation with abiotic cover. On the other hand, hard coral cover has a weak correlation with other variables.

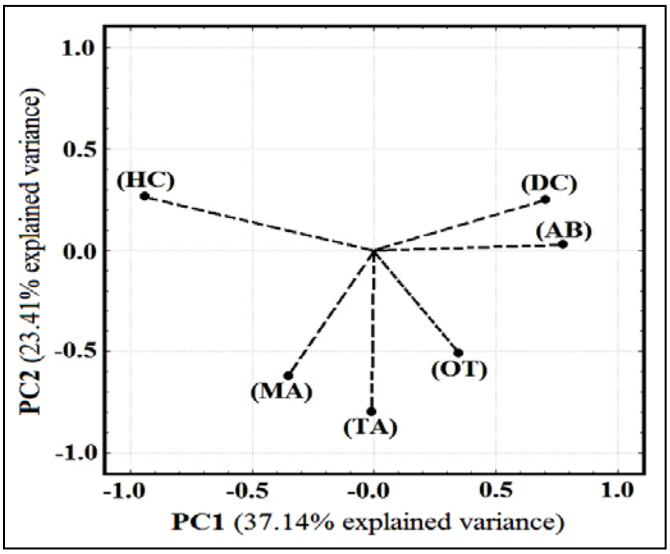

Figure 5. Principle Component Analysis (PCA) diagram of benthic cover variables. Six variables are plotted as vectors. The smaller the angle between two variable vectors the stronger the correlation. Turf algae cover (TA) has a strong correlation with the other fauna cover (OT) and macroalgae cover (MA), while dead coral cover (DC) has a strong correlation with abiotic cover (AB). Hard coral cover (HC) has a weak correlation with other variables.

Categorization of sites into potential reef regimes. The results of hierarchical cluster analysis provided a visual picture in which the cover of benthic variables grouped into three clusters (Figure 6). Turf algae cover closely associated with the other fauna cover (soft coral, sponge, and zoanthid). It is clearly showed through cluster dendrogram that those two variables are also associated with macroalgae cover. Therefore, turf algae, macroalgae, and other fauna are grouped into one cluster. Dead coral is closely associated with abiotic components (rubble, sand, and rock). Those two variables are grouped into another cluster. On the other side, hard coral alone is categorized into a separate cluster.

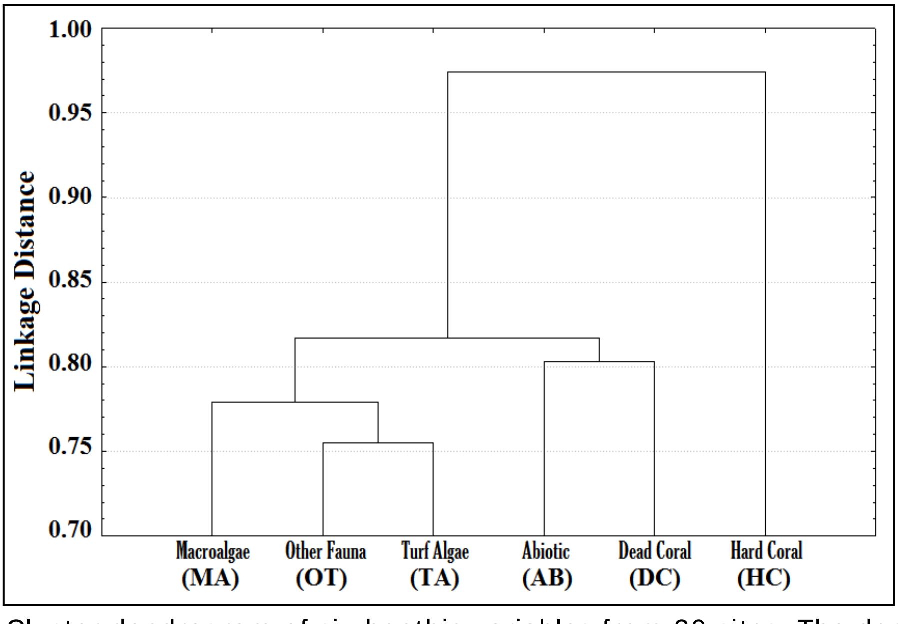

Figure 6. Cluster dendrogram of six benthic variables from 30 sites. The dendrogram shows a visual picture in which the benthic cover variables grouped into three clusters.

K-means clustering categorized all of these sites into three clusters to obtain a picture of how many sites are classified into a particular reef regime (Table 4). The results showed that a number of 9 sites (30%) were categorized as the living coral regime, other 9 sites (30%) were categorized as algae regime, while a number of 12 sites (40%) were categorized as abiotic/dead coral regime. The results in Table 4 indicate that three sites in Station 5 categorized into live coral regime, one site categorized into algae regime, and one site categorized into abiotic/dead coral regime. Categorization of the sites in at Station 1 and Station 4 are similar, where four sites of those stations categorized into abiotic/dead coral regime, while two sites categorized into algae regime and only one site categorized into live coral regime. Three of five sites of Station 2 categorized into live coral regime, two sites categorized into algae regime, while one site categorized into abiotic/dead coral regime. Only one site of Station 3 is categorized into live coral regime, while two sites are categorized into algae regime and two other sites are categorized into abiotic/dead coral regime.

Table 4

Site clustering based on K-means clustering analysis

Cluster 1 Live coral regime)			*Cluster 2 (Abiotic/Dead coral regime)*			*Cluster 3 (Algae regime)*		
Site	*Location*	*Station*	*Site*	*Location*	*Station*	*Site*	*Location*	*Station*
S03	Raimuti	St-1	S01	Arfai	St-1	S02	Arfai-Raimuti	St-1
S08	Sanggeng BLK	St-2	S04	Telaga Wasti	St-1	S05	Marampa Port	St-1
S09	Kwawi	St-2	S06	Telaga Rendani	St-1	S10	North Reef Flat	St-2
S11	West Reef Flat	St-2	S07	Rendani Settl.	St-1	S12	South Reef Flat	St-2
S16	South Lemon	St-3	S13	East Reef Flat	St-2	S15	SW Lemon	St-3
S19	Mansinam Cem.	St-4	S14	North Lemon	St-3	S18	NE Lemon	St-3
S28	Pasirputih Cem.	St-5	S17	East Lemon	St-3	S20	Mansinam Bunk	St-4
S29	Pasirputih Cape	St-5	S21	Mansinam Mari.	St-4	S25	North Mansinam	St-4
S30	Pasirido	St-5	S22	SW Mansinam	St-4	S27	Inggandi Cape	St-5
			S23	Mangewa Cape	St-4			
			S24	NE Mansinam	St-4			
			S26	Inggandi Beach	St-5			
Total 9 sites (30%)			Total 12 sites (40%)			Total 9 sites (30%)		

A number of 9 sites (30%) were categorized as the living coral regime, other 9 sites (30%) were categorized as algae regime, while 12 sites (40%) were categorized as abiotic/dead coral regime.

Discussion. Regime shift concept has been applied in various studies related to other subjects. Sartimbul et al (2007), for example observed water temperature anomalies at the Awashima Island, Japan, and defined regime shift as a major shift of water temperature from cold years with positive PDO (pacific decadal oscillation) to warm years with negative PDO. On the other hand, the term regime shift, also known as phase shift in coral reef studies is used to describe a major shift from coral-dominated state to an alternate assemblage typically characterized by over abundances of algae or other opportunistic species (Hughes et al 2007; Bruno et al 2009; Norström et al 2009; Joufrray et al 2014). Detection of the multiple regimes is a relevant effort to anticipate the possibility of regime or phase shift from coral-dominated state to undesirable state.

The approach combination of statistical exploration used in this study proved to be able to give a clear picture of the existence of coral reef regimes in Doreri Bay. Furthermore, the results show that the application of the PSI calculation alone is not sufficient enough to detect the presence of multiple regimes. The same results were found in studies by Bruno et al (2009) and Jouffray et al (2014) who applied the calculation of PSI and multimodality test on a wider scale. Yet another approach implementation through a combination of correlation-based PCA and cluster analysis, as suggested by Jouffray et al (2014) proved to be able to detect the presence of multiple regimes. Three regimes dominated by different categories of benthic cover, namely live coral, algae and abiotic/dead coral could be detected by the combination approach.

Multimodality test that focused on the relationship of coral and algae did not show any indication of bimodality. However, the results of the analysis of benthic cover percentage, PCA and cluster analysis in this study have provided an early warning of the presence of algae which leads to competition with coral. Based on K-means clustering, at least two sites of each station categorized into algae regime. It corresponds to the real conditions in the field, where on those sites we found the damaged reefs and algae have taken over space previously filled by coral. Even in some sites turf algae has covered the body of dead corals (Figure 7). This is presumably due to the lack of control over algae by herbivores.

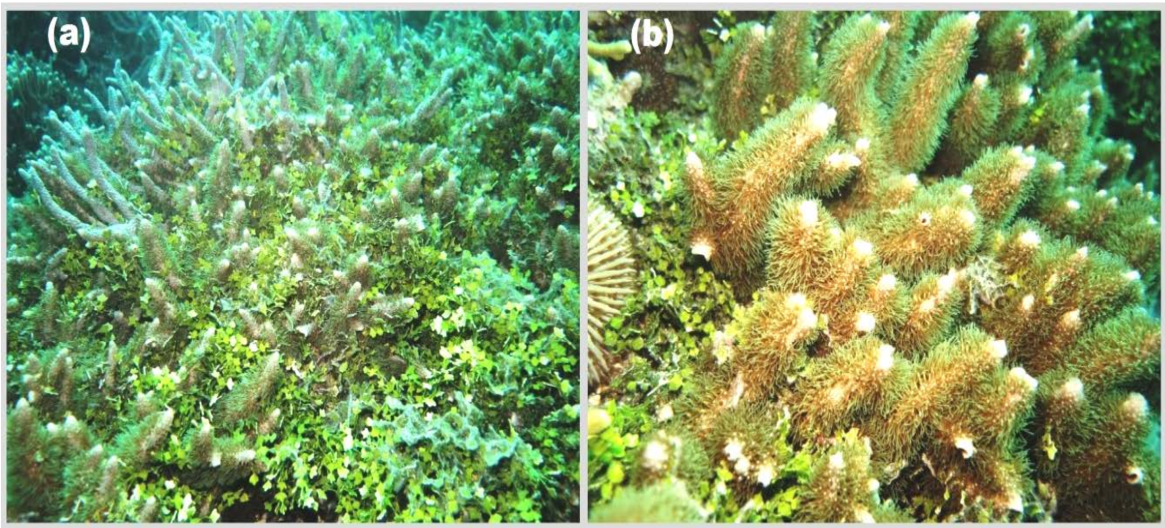

Figure 7. Pictures showing a competition for space between coral and algae. The pictures show an example of the coral damage occurred at site 21 (Station 4) categorized into algae regime. Algae have taken over space previously filled by coral (a). Close up picture show clearly a condition where turf algae have covered the bodies of dead corals (b).

Spreading of algae at reef system in Doreri Bay should be anticipated earlier given that algae are the main competitor to the corals. According to Pawlik et al (2016), corals and algae are benthic primary producers, but both competed in utilizing the space on the reefs. Goatley et al (2016) suggested that macroalgae is one of the important indicators to assess the health condition of corals, and also a benchmark of the resilience of coral reefs in a given location. Decreasing in coral cover and increasing in algae cover is the most common measure of coral reef health, and so far this condition becomes the final point of degradation. Once these signs are apparent, then the coral reefs have been degraded and damage has occurred. Research of Bonaldo & Hay (2014) showed evidence of the potential destructive interaction between the dynamics of macroalgae and corals on the reef. Great vulnerability of some coral species on contact with macroalgae can decrease the resilience of coral in the area dominated by macroalgae. When macroalgae increases in tropical reefs, macroalgae competition could lead to feedback which can suppress the resilience of coral, inhibits the recovery of coral and support the stability of a field of algae in habitats that are initially available for the reef.

Phase shift from the state dominated by coral to the state dominated by algae, is closely related to the control of herbivores. Until now, the understanding of coral reef ecosystems has generally focused on the relationship between coral, algae and herbivores. Mumby et al (2007) have created a simulation model that describes the phase shift event of reef systems in the Caribbean. The model suggests that coral reefs in the Caribbean did not indicate a stable state of algal-domination when grazing activities by parotfish and grazing urchin Diadema reached a level of 42% of the coral reefs in every six months. But then, the state dominated by algae emerged when the populations of urchin Diadema declined sharply due to the mass mortality in 1983, and the grazing activities was only dominated by parotfish. Furthermore, the decline of coral provided space for colonization of macroalgae. When the maximum grazing capability has been achieved, then later, the addition of extensive grazing areas will reduce the mean intensity of grazing. As a result, the probability of macroalgae to develop increased.

In addition to the presence of algae and competition relationship with the corals, another aspect that needs serious attention is the coral damage due to the impact of human activity. The lowest percentage of the live coral cover was found at Station 1, and based on the results of K-means cluster analysis, four of six sites in the station was categorized into abiotic and dead coral regime. This is consistent with observations in the field, where the pressure of human activities, especially fishing and collecting of marine biota in this location is quite high. The access to the use of fish and other reef resources are relatively more freely at Station 1. This opens up opportunities for the practice of fishing and the collection of other sea products are irresponsible and damaging the living coral. Mellin et al (2016) suggest that the damage of coral reef is not only seen in the reef structure but further the interference will affect reef fish that depend on corals for shelter, for food or habitat for recruitment. If this condition is allowed to continue, then the severe damage will occur, and further, the coral reef ecosystem services to local communities will not be able to sustain.

Humans and coral reefs ecosystems have a relationship where humans depend on the services provided by ecosystems. However, the services provided by an ecosystem are highly dependent on the treatment of humans to the ecosystem. To overcome the problem of coral damage due to the impact of human activities, control of the activities of utilization of fish and other reef resources is urgent. According to Shlesinger & Loya (2016) even in situations where it seems the future of coral reefs is uncertain, the trend of degradation of the local reefs caused by human activities that harm can be reduced. Furthermore, Sharma et al (2016) suggest that in ecosystem management, an approach that involves the participation of local community should be involved in the management strategy. Recognition of the culture, beliefs, traditional ecological knowledge and capacity of local community organizations is imperative. Bawole et al (2013) stated that each location has unique culture, socioeconomic, and local knowledge necessary for evaluation, design, and implementation activities in order to achieve successful coral reef management strategy.

Conclusions. The present study has proven the success of the combination of exploratory statistical techniques to detect and visualize multiple coral reef regimes in Doreri Bay, Manokwari Regency. The results of this study have provided an early indication and early warning to anticipate the possibility of regime shifts in coral reef systems. However, the analysis in this study is based on a snapshot of data in 2016, so it cannot give a historical overview of the development of each regime. Therefore, further study is needed to explore the issue. In addition, to obtain a clearer picture of the reef system's ability to survive and recover from local pressures and the impact of climate change, it is necessary to estimate the resilience of coral reef ecosystems based on indicators appropriated to the local context.

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References

Allen G. R., Erdmann 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.

Allen G. R., Erdmann M. V., 2009 Reef fishes of the Bird's Head Peninsula, West Papua, Indonesia. Check List 5(3):587-628.

Alquezar R., Boyd W., 2007 Development of rapid, cost effective coral survey techniques: tools for management and conservation planning. Journal of Coastal Conservation 11:105-119.

Anthony K. R. N., Marshall P. A., Abdulla A., Gooch M., Graham N. A. J., Green A., Heron S. F., 2015 Operationalizing resilience for adaptive coral reef management under global environmental change. Global Change Biology 21:48-61.

Aswani S., Christie P., Muthiga N. A., Mahon R., Primavera J. H., Cramer L. A., Barbier E. B., Granek E. F., Kennedy C. J., Wolanski E., Hacker S., 2012 The way forward with ecosystem-based management in tropical contexts: reconciling with existing management systems. Marine Policy 36(1):1-10.

Ateweberhan M., Feary D. A., Keshavmurthy S., Chen A., Schleyer M. H., Sheppard C. R. C., 2013 Climate change impacts on coral reefs: synergies with local effects, possibilities for acclimation, and management implications. Marine Pollution Bulletin 74:526-539.

Bawole R., Pattiasina T. F., Kawulur E. I. J. J., 2014 Coral-fish association and its spatial distribution in Cenderawasih Bay National Park Papua, Indonesia. AACL Bioflux 7(4):248-254.

Bawole R., Rumere V., Mudjirahayu, Pattiasina T. F., 2013 Performance of coral reef management within marine protected areas: Integrating ecological, sosioeconomic, technological and institutional dimensions. Jurnal Manajemen Hutan Tropika 19(1):63-73.

Bonaldo R. M., Hay M. E., 2014 Seaweed-coral interactions: variance in seaweed allelopathy, coral susceptibility, and potential effects on coral resilience. PLoS ONE 9(1): e85786. https://doi.org/10.1371/journal.pone.0085786

Bruno J., Sweatman H., Precht W., Selig E., Schutte G., Hill C., Carolina N., 2009 Assessing evidence of phase shifts from coral to macroalgal dominance on coral reefs. Ecology 90:1478-1484.

Burke L., Reytar K., Spalding M., Perry A., 2011 Reefs at risk revisited. World Resources Institute, Washington DC, 114 p.

Douvere F., 2008 The importance of marine spatial planning in advancing ecosystem-based sea use management. Marine Policy 32:762-771.

Folke C., Carpenter S., Walker B., Scheffer M., Elmqvist T., Gunderson L., Holling C. S., 2004 Regime shifts, resilience, and biodiversity in ecosystem management. Annual Review of Ecology, Evolution, and Systematics 35:557-581.

Giyanto, Iskandar B. H., Soedharma D., Suharsono, 2010 Eficiency and accuracy in underwater photo analysis to assess the condition of coral reef. Oseanologi dan Limnologi di Indonesia 36(1):111-130.

Giyanto, Manuputty A. E. W., Abrar M., Siringoringo R. M., 2014 Coral reef monitoring. In: Manual book for coral reef monitoring. Suharsono, Sumadhiharga O. K. (eds), pp. 8-31, CRITC COREMAP CTI LIPI.

Glew L., Ahmadia G. N., Fox H. E., Mascia M. B., Mohebalian P., Pakiding F., Estradivari, Hidayat N. I., Pada D. N., Purwanto, 2015 State of the Bird's Head Seascape MPA network report. World Wildlife Fund, Conservation International, Rare, The Nature Conservancy, and Universitas Papua, Washington D.C., United States, Jakarta, Indonesia, and Manokwari, Indonesia.

Goatley C. H. R., Bonaldo R. M., Fox R. J., Bellwood D. R., 2016 Sediments and herbivory as sensitive indicators of coral reef degradation. Ecology and Society 21(1):29.

Hughes T. P., Rodrigues M. J., Bellwood D. R., Ceccarelli D., Hoegh-Guldberg O., Mccook L., Moltschaniwskyj N., Pratchett M. S., Steneck R. S., Willis B., 2007 Phase shifts,

herbivory, and the resilience of coral reefs to climate change. Current Biology 17: 360-365.
Hughes T. P., Graham N. A. J., Jackson J. B. C., Mumby P. J., Steneck R. S., 2010 Rising to the challenge of sustaining coral reef resilience. Trends in Ecology and Evolution 25(11):633-642.
Jouffray J., Nystro M., Norstrom A. V., Williams I. D., Wedding L. M., Kittinger J. N., Williams G. J., 2014 Identifying multiple coral reef regimes and their drivers across the Hawaiian archipelago. Philosophical Transactions of the Royal Society of London B: Biological Sciences 370:20130268. http://dx.doi.org/10.1098/rstb.2013.0268
Knudby A., Pittman S. J., Maina J., Rowlands G., 2014 Remote sensing and modeling of coral reef resilience. In: Remote sensing and modeling: advances in coastal and marine resources. Finkl C. W., Makowski C. (eds), pp. 103-134, Springer International Publishing Switzerland.
Kohler K. E., 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.
Levin P. S., Mollmann C., 2014 Marine ecosystem regime shifts: challenges and opportunities for ecosystem-based management. Philosophical Transactions of the Royal Society of London B: Biological Sciences 370(1659):20130275.
Maynard J., Mckagan S., Johnson S., Houk P., 2012 Coral reef resilience to climate change in Saipan, CNMI; field-based assessments and implications for vulnerability and future management. NOAA Coral Reef Initiative, 56 p.
McClanahan T. R., Donner S. D., Maynard J. A., MacNeil M. A., Graham N. A. J., Maina J., 2012 Prioritizing key resilience indicators to support coral reef management in a changing climate. PLoS ONE 7(8):e42884.
Mellin C., MacNeil M. A., Chela A. J., Emslie M. J., Calej M. J., 2016 Marine protected areas increase resilience among coral reef communities. Ecology Letters 19(6):629–637.
Mumby P. J., Hastings A., Edwards H. J., 2007 Thresholds and the resilience of Caribbean coral reefs. Nature 450(7166):98-101.
Norström A. V., Nyström M., Lokrantz J., Folke C., 2009 Alternative states on coral reefs: beyond coral-macroalgal phase shifts. Marine Ecology Progress Series 376:293-306.
Obura D., Grimsditch G., 2009 Resilience assessment of coral reefs: Assessment protocol for coral reefs, focusing on coral bleaching and thermal stress. IUCN, Switzerland, 69 p.
Pandolfi J. M., Connolly S. R., Marshall D. J., Cohen A. L., 2011 Projecting coral reef futures under global warming and ocean acidification. Science 333:418–422.
Pawlik J. R., Burkepile D. E., Thurber R. V., 2016 A Vicious circle? Altered carbon and nutrient cycling may explain the low resilience of Caribbean coral reefs. BioScience 66(6):470-476.
Sabariah V., Pattiasina T. F., Parenden D., Zainuddin F., 2010 Doreri Bay' water condition, resource biodiversity and its utilization by coastal people in Manokwari. Jurnal Perikanan dan Kelautan 6(1):1-14.
Sartimbul A., Nakata H., Hayashi I., 2007 Recent change in water temperature and its effect on fisheries catch of bottom gillnets in a coastal region of the Tsushima warm water current. La Mer 45:1-13.
Semedi B., Rahmawan F., 2016 Estimation of stress level of coral reefs bleaching using night-time satellite data: A case study on Indonesian tropical waters. Nature Environment and Pollution Technology 15(1):297-300.
Sharma G., Hundsdorfer B., Singh K. K., 2016 Comparative analysis on the socio-ecological and economic potentials of traditional agroforestry systems in the Sikkim Himalaya. Tropical Ecology 57(4):751-764.
Shlesinger T., Loya Y., 2016 Recruitment, mortality, and resilience potential of scleractinian corals at Eilat, Red Sea. Coral Reefs 35(4):1357-1368.
Xin L. H., Adzis K. A. A., Hyde J., Cob Z. C., 2016 Growth performance of *Acropora formosa* in natural reefs and coral nurseries for reef restoration. AACL Bioflux 9(5):1090-1100.

Żychaluk K., Bruno J., Clancy D., McClanahan T., Spencer M., 2012 Data-driven models for regional coral-reef dynamics. Ecology Letters 15:151–158.

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