Live hard coral coverage and coral diseases distribution in the Ujung Kulon National Park, Banten, Indonesia

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Abstract. The global climate change accompanied with coral diseases outbreaks have been the major key factor of the main issues in Indonesian reefs. However, there is still a lack of studies for the coral diseases in most of the remote reefs across Indonesia. The objective of this study was to provide baseline data for coral health at two different coral reefs within Ujung Kulon National Park in Banten. In terms of percentage cover, Legon Lentah (60.70±5.24%) at the reef crest was found in greatest portion, whilst the lowest percentage cover was found in Citerjun (14.85±6.63%). At the reef slope, the highest percentage coral cover was found in Legon Haji (36.78±4.67%) and the lowest percentage cover was found in Ciapus (3.21±0.93%). Most of the coral observed during this study was infected (85.51% of total colonies). The diseases and compromised health were affected 42 genera, with *Porites* being the highest genera impacted. The damage caused by sedimentation in the reef slope was the most compromised health issues which impacted the corals. Interestingly, the colored band disease on corals was found in the relatively low number of corals. In order to fully understand all the diseases infect the corals, coral health surveys should be conducted on future management. This study provides baseline data on the coral health within the reefs of Ujung Kulon National Park, Banten, Indonesia.

Key Words: environmental disturbances, coral resilience, coral bleaching, diversity, reefs degradation.

Introduction. Coral reefs around the world as essential ecosystems, currently undergoing rapid degradation (Raymundo et al 2009). The degradation of coral reefs has been an important matter to study (Osborne et al 2011). Consequences of the coral reefs degradation are the declining of other reef-associated communities such as reef fish (Madduppa et al 2013; Alvarez-Filip et al 2015; Fahlevy et al 2018). Mortality of corals is increasingly accompanied by a decline in the water quality, and global climate change (Thompson et al 2014) as well as local human activities, including fisheries and tourism that are not environmentally friendly (Sandin et al 2008; Fahlevy et al 2017, 2019). Widespread of coral mortality appears to be associated with climate change and coral disease outbreaks (Harvell et al 2002). Coral diseases are known recognized and have been a key factor in the degradation and threats of reef structures in Indonesian reefs, such as the Belitung (Johan et al 2015), Spermonde, Wakatobi (Muller et al 2012), and Padang Shelf (Johan & Syam 2014). Disease on coral is a natural component which can be found on the reef ecosystem (Couch et al 2014). During outbreaks, the coral disease can affect the main function and structures of coral reefs ecosystem (Kim & Harvell 2004). Many environmental and anthropogenic disturbances are thought to contribute to the onset of the infectious pathogen (Harvell et al 2007). Affected coral may threaten the abundance and diversity of coral reefs (Haapkylä et al 2007). The occurrence of diseases in the marine environment strongly affected the reef ecosystem (Hobbs & Frisch 2010).

Coral health surveys and monitoring are important to provide a review for management and identifying impacts when the diseases occur (Ponti et al 2016). There is an important need in understanding the diseases on coral for management implications

(Raymundo 2010). Marine protected areas (MPAs) are commonly used as a major tool for managing coastal ecosystem (Noble et al 2013). Marine national parks are constitutents of the marine protected areas in Indonesia (Syarif 2009). MPAs are effective to increase the biodiversity and prevent the declining of corals (Selig & Bruno 2010). However, many of previous studies are revealing that coral diseases still occur and have been identified in the national park. There has been comprehensive research on coral disease in the marine national park, such as in the Seribu Islands (Subhan et al 2011), and Sabah (Miller et al 2015) national park. Defining coral diseases sign in the marine environment are important to increase the understanding of disease outbreak (Beeden et al 2012). The idea of assessing for reef health and other signs of diseases of the present study are adopted according to the research framework published by Ponti et al (2016). To identify coral health and diseases, the aims of the present study were to assess the reef health variation at two different coral reef depths and establish the baseline coral disease data-set within Ujung Kulon National Park, Banten, Indonesia. This study is the attempt to improve the baseline data for coral health and diseases in Indonesia.

Material and Method

Study sites. Ujung Kulon National Park is located in the west of Banten province. All surveys were conducted during October 2017. Reef health was determined at ten sites around the Panaitan and Peucang Island (Figure 1; Table 1).

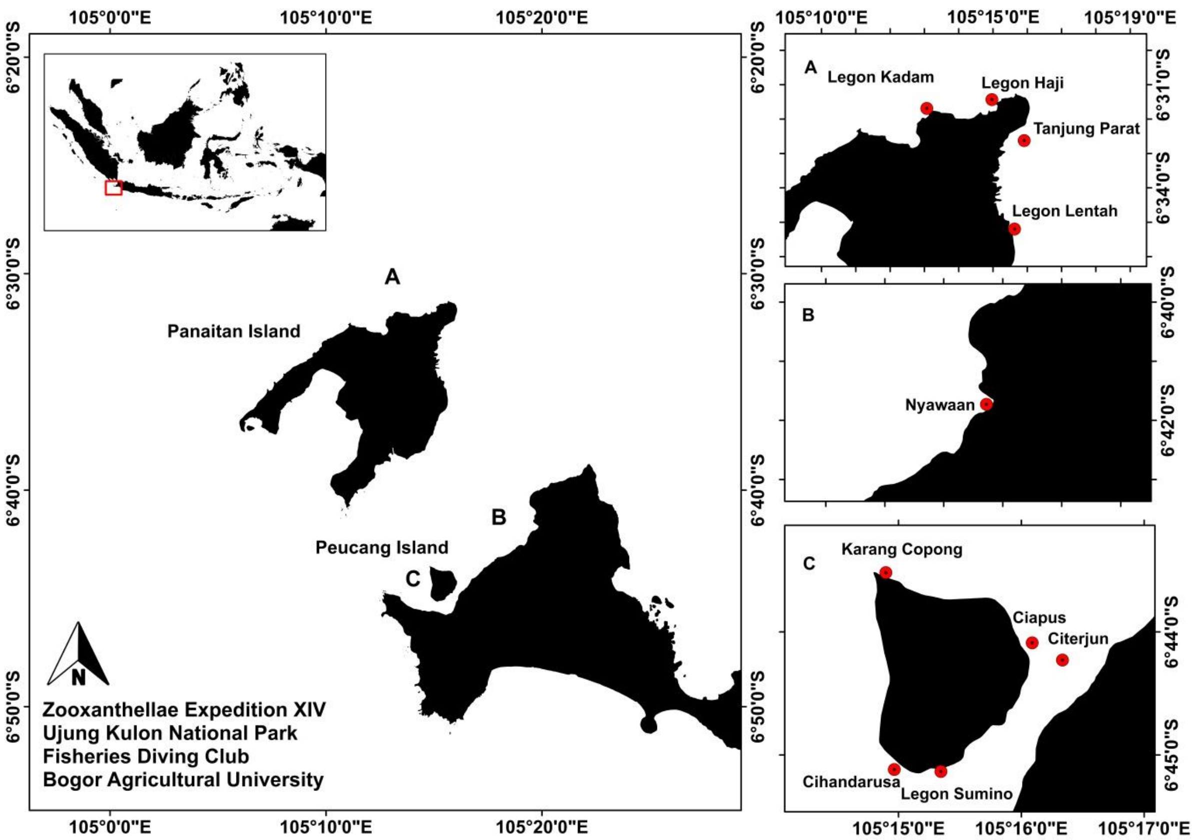

Figure 1. Map of Ujung Kulon National Park, and study sites (A, B, and C).

Panaitan Island is located within the Sunda Straits between Banten and Lampung Province. Peucang and Panaitan Islands was easy to reach by tourist speed boat (Wiyono et al 2018). Along fringing reefs at each location, two different coral reef depths were selected (crest and slope). In the reef crest, the transect was laid in depth around 3-6 m, while in the reef slope the transect was laid around 9-12 m.

Table 1
Geographic coordinates for the ten selected study sites in Ujung Kulon National Park

No.	*Study sites*	*Longitude*	*Latitude*
1	Cihandarusa	105°14' 57.94" E	06°45'07.08" S
2	Ciapus	105°16'05.35" E	06°44'05.35" S
3	Citerjun	105°16'20.14" E	06°44'13.73" S
4	Karang Copong	105°14'53.83" E	06°43'31.11" S
5	Legon Haji	105°14'58.27" E	06°31'26.00" S
6	Legon Kadam	105°13'4.34" E	06°31'41.43" S
7	Legon Lentah	105°15'37.87" E	06°35'12.00" S
8	Legon Sumino	105°15'20.75" E	06°45'08.06" S
9	Nyawaan	105°19 '43.47" E	06°41'43.70" S
10	Tanjung Parat	105°15'54.71" E	06°32'37.50" S

Coral health assessments. Hard coral cover and coral health assessments were carried out at one site around the Ujung Kulon mainland, five sites around Peucang Island, and four sites around Panaitan Island. At each of the 10 selected study sites, percentage of hard coral cover were identified and classified using three replicates of 20 m line intercept transect (English et al 1997) laid on the two different coral reef depths (crest and slope) with a gap of at least 5 m between each transect. Coral health and other signs of diseases were carried out using three replicates 20 x 2 m belt transect along the same transect of hard coral cover. Each scleractinian coral colony was counted and identified to genus level across all transect. To improve the diseases identification, each visible coral disease was close-up photographed. The signs of diseases and other compromised health were categorized and confirmed according to the identification guides by Beeden et al (2008). Coral diseases and the other encountered signs of compromised health are described in Table 2.

Table 2
Category of coral disease and compromised health adopted from Beeden et al (2008), Raymundo et al (2008), and Ponti et al (2016)

Symptom	*Disease or compromised health category*	*Code*
Compromised health	Aggressive overgrowth (e.g. sponges)	AgO
	Sediment damage	SD
Growth anomalies	Enlarged structures	ES
	Invertebrate galls	IG
Health	Health	Healthy
Tissue discoloration - non white	Pigmentation response	PR
Tissue discoloration - white	Bleaching	BL
Tissue loss - non-predation	Focal bleaching	FBL
	Non-focal bleaching (e.g. patches, stripes)	NFBL
	Atramentous necrosis	AtN
	Ulcerative white spots	UWS
	White syndromes	WS
	Yellow band disease	YBD
Tissue loss - predation	Gastropod corallivory (e.g. *Drupella* sp.)	DRU
	Fish bites	FISH

Data analyses. Percentage of the hard coral cover was calculated using English et al (1997). Means and standard errors presented in all data were analyzed from averaged all the total three transects at each depth in all study sites. All data were analyzed using Ms. Excel to obtained percentage of coral cover and mean abundance. Two-Factor with replication analysis of variance (ANOVA) were used to test the significant differences between percentage cover of hard coral, the most common coral diseases and other encountered signs of compromised health between two different coral reef depths and study sites. Prior to multivariate analyses, the most common of coral diseases and compromised health abundance data were standardized. Multivariate analyses were conducted using PRIMER v.7 to visualize the most common coral diseases and compromised health among two different coral reef depths (Clarke et al 2014). Non-metric multidimensional scaling (NMDS) ordination was used from a Bray-Curtis similarity matrix to improve the spread of data (Harter et al 2009).

Results

Hard coral cover. Hard coral cover in the study sites significantly differed among sites and depths (Table 3). Among all study sites, the percentage of hard coral cover at the reef crest was predominantly higher than at the reef slope (Figure 2a & 2b). However, specific sites at the reef crest were having low coral cover. The highest percentage of coral cover was found in Legon Lentah (60.7±5.24%) at the reef crest and not too different with the percentage cover in Ciapus (60.57±6.23%) and the lowest percentage cover was found in Citerjun (14.85±6.63%). At the reef slope, the highest percentage coral cover was found in Legon Haji (36.78±2.70%) and the lowest percentage cover was found in Ciapus (3.21±0.93%).

Table 3

Repeated-measures ANOVA summaries for percentage of hard coral cover

Variable	*Factor*	*F*	*df*	*p-value*
Hard coral cover	Site	4.49	9	***
	Depth	24.29	1	***
	Site x Depth	5.96	9	***

*p<0.05, **p<0.01, ***p<0.001, n.s. - not significant.

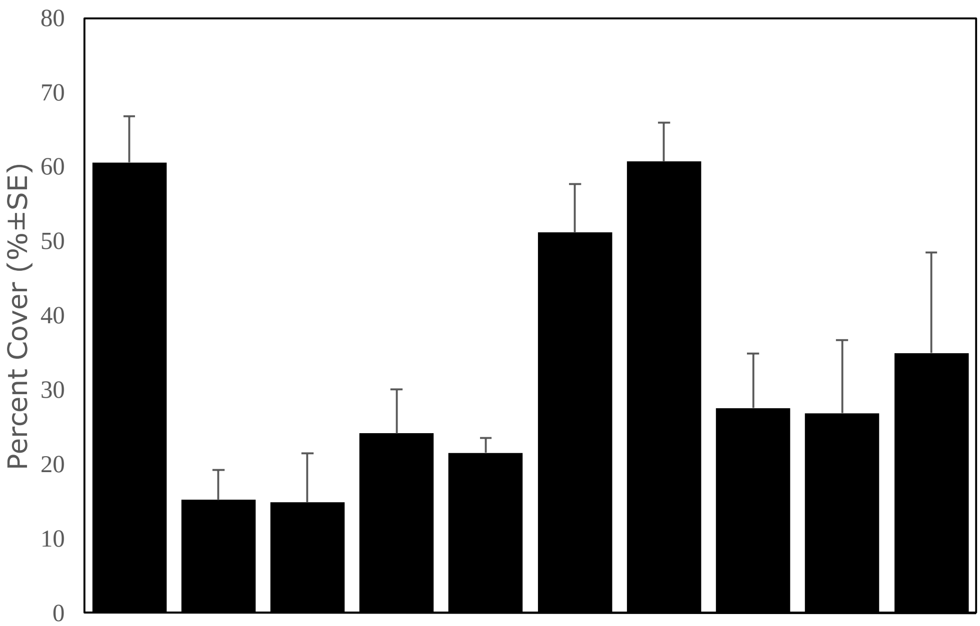

Figure 2a. The relative percentage of hard coral cover (Mean %± SE) at the reef crest.

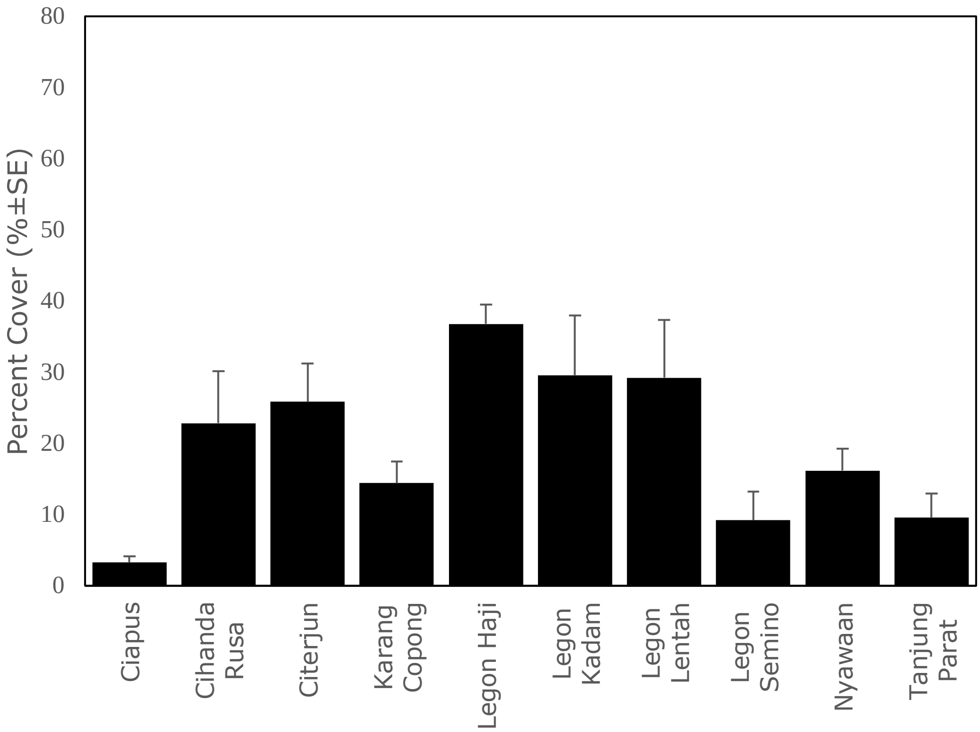

Figure 2b. The relative percentage of hard coral cover (Mean %± SE) at the reef slope.

Occurrences of coral diseases. A total of 2,327 coral colonies from 52 genera of hard coral at all study sites and two different reef depths were counted. Coral diseases and compromised health were encountered on 1,990 (85.51%) colonies from 42 hard coral genera, with the highest mean of abundance colonies being affected was *Porites* (65.50±7.61 ind 40 m^{-2}), followed by *Montipora* (16.33±2.91 Ind 40 m^{-2}), *Favites* (11.67±0.87 ind 40 m^{-2}), *Coeloseris* (11±1.21 ind 40 m^{-2}), and *Favia* (8.17±1.43 ind 40 m^{-2}; Figure 3). The most frequently encountered diseases and other compromised health types were at the Legon Kadam and Legon Haji, while the less common was at the Citerjun (Table 4). The signs of compromised health caused by the aggressive overgrowth of sponges (AgO), sediment damage (SD), and invertebrate galls (IG) were found at all study sites. Growth anomalies of hard coral by enlarge structure (ES) was the most uncommon signs of diseases found (Table 4). In addition the total number of colonies scleractinian coral affected by ES only four colonies at all transects. Yellow band diseases (YBD) occurrences on coral during the present study were found only on Fungiidae group (Figure 4E). Mean abundances and the total number of occurrences of coral diseases and compromised health at two different coral reef depths were depicted in Figure 5.

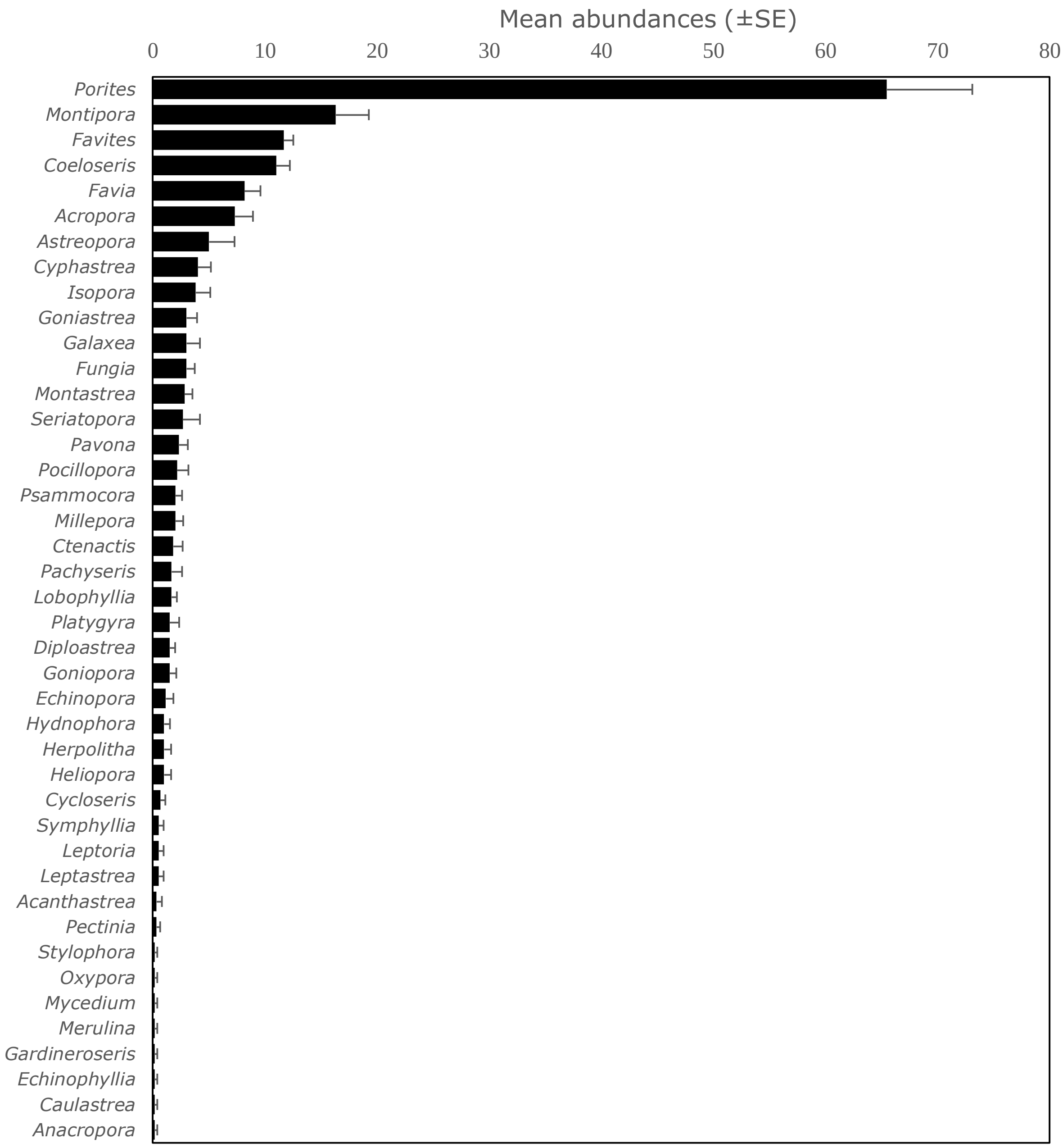

Figure 3. Overall mean abundances (ind 40 m^{-2} ±SE) of each coral genus affected in all study sites and depths.

Table 4

Diseases and compromised health status at the study sites

Sites	*AgO*	*AtN*	*BL*	*DRU*	*ES*	*FBL*	*FISH*	*FISH+IG*	*IG*	*NFBL*	*PR*	*SD*	*SD+AgO*	*SD+IG*	*UWS*	*WS*	*YBD*	*Total*
Ciapus	+		+	+					+			+	+	+	+			143
Cihandarusa	+	+			+		+	+	+	+	+	+		+	+	+		144
Citerjun	+		+			+			+			+	+				+	181
Kar. Copong	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+		108
Leg. Haji	+	+	+	+		+	+	+	+	+	+	+	+	+	+	+		330
Leg. Kadam	+	+	+	+		+	+	+	+	+	+	+	+	+	+	+		338
Leg. Lentah	+	+	+	+		+	+	+	+		+	+	+	+	+	+	+	279
Leg. Sumino	+	+	+				+	+	+			+			+	+	+	79
Nyawaan	+	+	+		+	+			+		+	+		+	+	+	+	170
Tanj. Parat	+		+				+		+	+		+		+	+	+	+	218

Figure 4. Examples of coral diseases and compromised health found in corals in the study sites. Focal bleached colonies of *Favites* (A), invertebrate galls in *Porites* (B), sediment damage in *Favia* (C), predation by *Drupella* sp. (D), yellow band diseases in *Ctenactis* (E), and white syndromes in *Acropora* (F).

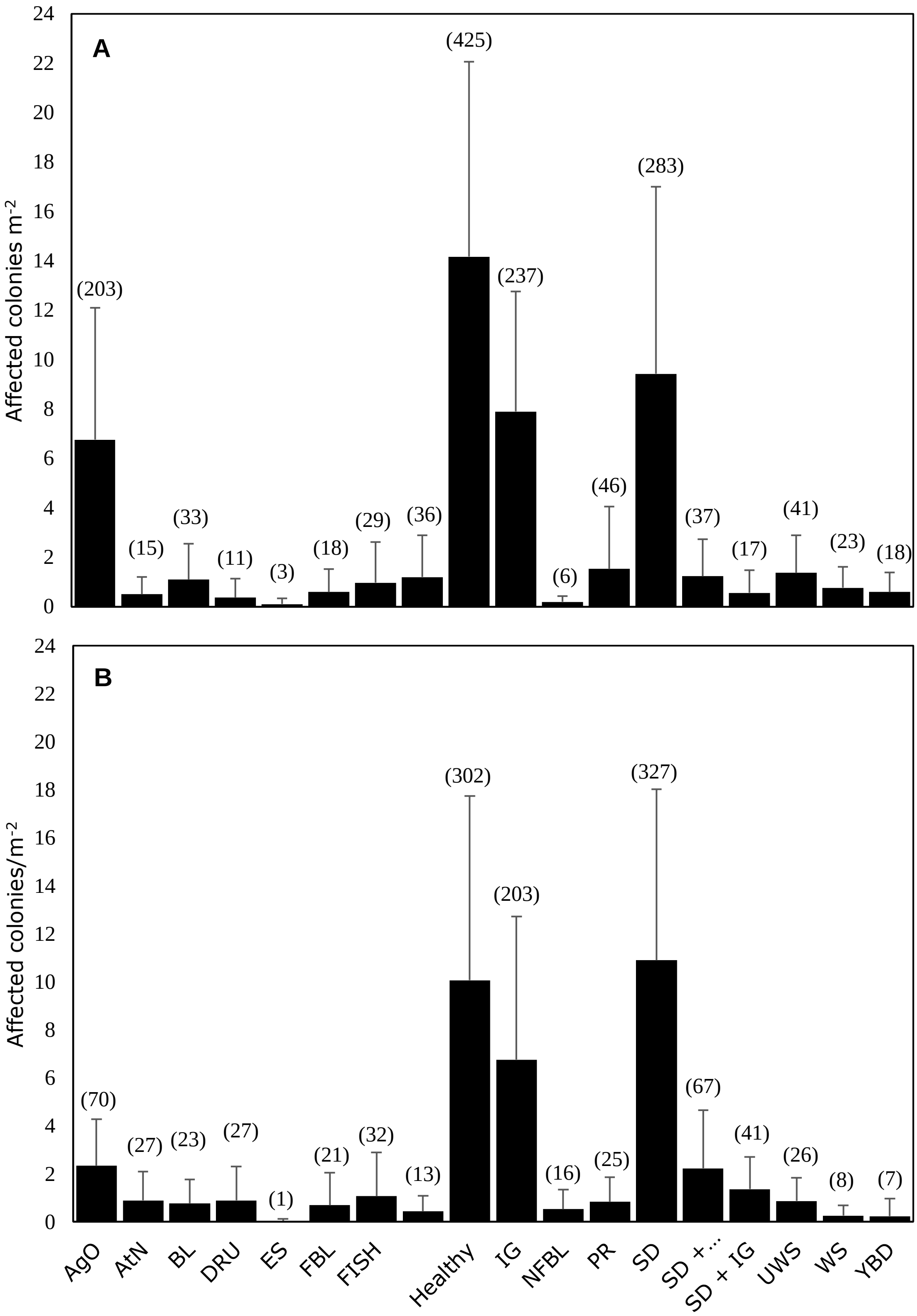

Figure 5. Overall mean abundances of coral diseases and compromised health (Mean ± SE) at the (A) reef crest and (B) reef slope in the study sites. In brackets is the total number of occurrences.

Spatial and depth pattern. The infected colonies found at more than five study sites were chosen to be the most common of coral diseases and compromised health. Overall, in the present study, there are 13 different types of the most of common coral disease and compromised health. Among the 42 genera of hard corals, the effect from sediment

(SD) was the most frequently affecting the hard coral genera (Table 5) with the significant difference of abundance between sites.

Table 5

Diseases and compromised health affecting each coral genus

Genus	AgO	AtN	BL	DRU	ES	FBL	FISH	FISH+IG	IG	NFBL	PR	SD	SD+AgO	SD+IG	UWS	WS	YBD	Total
Acanthastrea												+			+			2
Acropora	+	+	+	+				+	+	+	+	+	+			+		107
Anacropora												+						4
Astreopora	+		+			+			+	+	+	+	+		+	+		46
Caulastrea												+						1
Coeloseris	+		+	+		+	+	+	+	+		+	+	+	+			143
Ctenactis		+										+			+		+	16
Cycloseris												+			+		+	6
Cyphastrea	+	+	+	+			+		+			+			+			42
Diploastrea	+	+										+		+		+		10
Echinophyllia	+																	1
Echinopora									+			+	+			+		18
Favia	+	+	+	+	+	+	+		+	+	+	+		+	+			61
Favites	+	+	+			+	+	+	+	+	+	+	+	+	+	+		109
Fungia	+		+							+		+					+	34
Galaxea	+								+			+	+	+	+			32
Gardineroseris												+						1
Goniastrea	+		+			+			+			+	+	+		+		32
Goniopora	+									+	+	+			+			15
Heliopora	+								+			+						17
Herpolitha			+									+			+		+	8
Hydnophora	+								+			+	+					7
Isopora	+		+	+					+			+	+		+			43
Leptastrea										+		+						3
Leptoria												+						5
Lobophyllia	+								+		+	+		+		+		11
Merulina													+					1
Millepora	+				+				+	+	+	+						31
Montastrea			+						+	+	+	+		+		+		22
Montipora	+	+	+			+	+		+	+	+	+	+	+	+	+		297
Mycedium																+		2
Oxypora												+						4
Pachyseris	+		+						+			+	+			+		13
Pavona	+		+						+				+	+				25
Pectinia												+						3
Platygyra			+						+			+			+	+		11
Pocillopora	+	+	+	+					+			+	+	+				22
Porites	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+		1017
Psammocora	+						+		+			+	+	+				21
Seriatopora	+											+	+					155
Stylophora												+						1
Symphyllia									+			+						4

In addition, the effect of sites on SD was different between sites and depths (Table 6). No significant differences between WS and UWS were found across sites or depths (Table 6). The combination of sediment damage and invertebrate galls (SD+IG) affected 13 coral genera, was significantly different across sites and depths (Table 5). Aggressive overgrowth (AgO) from sponges affected 24 genera (Table 4) of hard coral with the significant difference in abundance between sites and depths (Table 6). A total of 71 colonies (Figure 5) of the pigmentation response (PR) signs found in the present study was not significantly different across the depths (Table 6), which appear to be like inflammation on the coral surface but it's not a signs of disease (Beeden et al 2008).

Table 6

Site and depths effect on the distribution of the most common coral diseases and compromised health

Code	*Site*		*Depth*		*Site x Depth*	
	F	*P-value*	*F*	*P-value*	*F*	*P-value*
AgO	2.61	*	8.03	*	1.43	n.s.
AtN	2.41	*	1.22	n.s.	2.54	*
BL	0.98	n.s.	0.43	n.s.	2.18	*
FBL	3.09	*	0.06	n.s.	2.56	*
IG	14.45	**	0.66	n.s.	0.83	n.s.
SD	7.01	**	0.55	n.s.	6.33	**
SD+AgO	4.85	**	2.26	n.s.	2.48	*
SD+IG	2.36	*	4.20	*	4.20	**
UWS	1.44	n.s.	0.87	n.s.	1.57	n.s.
WS	1.99	n.s.	3.13	n.s.	0.90	n.s.
PR	3.26	*	0.94	n.s.	1.46	n.s.
FISH	3.47	*	0.03	n.s.	4.41	*
FISH+IG	2.73	n.s.	2.92	n.s.	3.29	*

Summary of ANOVA Two-factor with replication. (* $p<0.05$, ** $p<0.001$, n.s - not significant).

The coral communities based on the most common coral diseases and compromised health highlight that the reef slope more clustered than reef crest in composition among reef types (Figure 6).

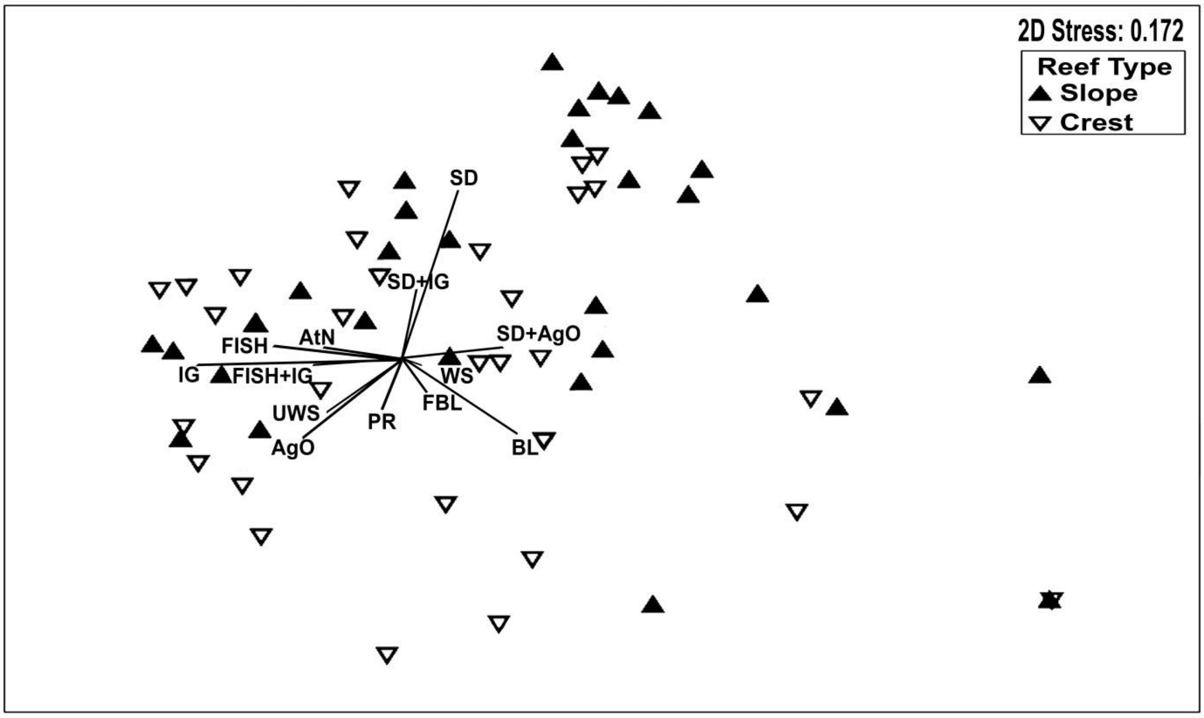

Figure 6. Non-metric MDS plot of the most common coral diseases and compromised health at Ujung Kulon National Park, showing among pattern of association based on abundance. Vectors represent the contribution of the most common coral diseases to the observed variation among sites.

Discussion. During the present study, surveys were conducted which represents the assessment at two different coral reef depths (crest and slope) around the national park. National parks as a part of marine protected areas (MPAs) are viewed to protect the existing natural resources from the degradation (Chirico et al 2017). The terrestrial part of the Ujung Kulon National Park was more intensively studied than their littoral habitat. Tourism and fishing activities were commonly found around the Ujung Kulon National Park. Those activities were giving some impact on the living organism within the area (Putri et al 2012). These surveys on corals are important for the future management of the reef environment and improving on coral reefs data in the National Park. Interestingly, the hard coral cover during this present study found that reef crest was higher with 60.70% coverage in the Legon Lentah. Based on the study sites condition, most of the abiotic component at study sites around the reef crest and slope was dominated by sands. The condition of site and depth at all study sites explained the variation in coral cover. The effect of light intensity (Schutter et al 2008) and turbidity (Anthony & Connolly 2004) might be an important factor influencing the coral community. Light limitation caused by sedimentation was also the major problem. The intensity of light in shallow reefs improved coral growth (Veal et al 2010). The previous study in Seribu islands National Park by Fahlevy et al (2017), stated that the effect of sites and depths was also affecting the coral structures and composition. Water turbidity due to sedimentation was limiting the light intensity to the deeper reefs. Touristic activities around the Panaitan Islands also contribute to the degradation of coral cover within the area. Well-managed tourism should improve the social, economy, and environmental condition within the area (Diedrich 2007). However, the implementation of the regulation within the national park was not well managed; therefore, direct contact by tourist, anchor damage on coral was still intense without solutions. Good management implementation by the local enforcement and communities are important to reveal the effectiveness of marine protected areas (Mora et al 2006).

Sediment damage was the most common of compromised health affecting the corals (Figure 4C), and this compromised health was found at all study sites. The damage caused by sediment was commonly found in the reef slope, suggesting the sedimentation was higher in the deeper reefs. These results may be due to the effect of terrestrial runoff and the strong currents from the Sunda strait within the Ujung Kulon National Park. Sedimentation under the area of coral reefs was a major problem on coral depletion (Crabbe & Smith 2005). Terrestrial runoff was also leading the changes of water quality parameters in the coastal area (Fabricius 2005) and increasing the growth rate of algae (Liñán-Cabello et al 2016). In addition, terrestrial runoff also increasing the prevalence of coral diseases. The previous study in Madagascar (Sheridan et al 2014) and Hawai (Shore-Maggio et al 2018), reveal significant results of white syndrome prevalence on specific corals that found in the greatest portion at the reefs located near the terrestrial runoff. The present study detects that white syndrome was also infecting the corals in the Ujung Kulon National Park (Figure 4F). Nonetheless, the occurrence of white syndrome in Ujung Kulon National Park was not significant different among all study sites and depths (Table 6). These results reveal that the most abundant of white syndrome found was affecting in *Montipora* corals (73 colonies), followed by Porites (18 colonies), and the other genera were found below 10 colonies. Generally, white syndrome was associated with the bacterial pathogen and environmental condition (Hobbs & Frisch 2010). The second most common of compromised health was invertebrate galls. It was also observed mostly on the depth of reef crest. Galls were caused by the invertebrate within the reefs area. The occurrence of the invertebrate living on hard corals is a common thing (Hoeksema & van der Meij 2013). There are different types of symbiotic relationships between hard coral as the host and the living invertebrates within the corals (van Tienderen & van der Meij 2016). It was said that hard corals also reliant on their existences (Stella et al 2011). Some invertebrate taxa also protect the corals from coral-predatory (Rouzé et al 2014) and slowing the infection of coral diseases (Pollock et al 2013). However, specific crabs were considered parasites (Shima et al 2010). Leray et al (2015) stated the species of *Hapalocarcinus* sp. (gall crab) and *Dendropoma* sp. (vermetid snails) were considered harming the corals. This present study confirms that the galls were mostly caused by crabs, mollusks (*Pedum* sp.), and polychaetes (Figure 4B).

Apart from the existences of coral-feeding fish, the existence of the invertebrates living on corals is also one of the reason fish-bite scar occurrences on hard corals surface. Specific species from decapod are a potential prey for reef fish (Simon-Blecher & Achituv 1997). Those reef fishes were praying the invertebrates living on coral, therefore, it was also injured the coral surfaces. Aside of damaging the coral skeleton, the effect of fish bites caused by corallivores fishes was considered to be the vectors for coral diseases (Ponti et al 2016). In this study, the majority of fish bites identified were found in massive *Porites* (77.27% of colonies). In addition, *Porites* was the most impacted coral by diseases. The present study was mostly found *Porites* impacted by diseases in reef crest. Although the number of colonies in the reef crest was slightly higher than in reef slope, it still suggests that *Porites* in the depth of reef crest are more susceptible to the variation of diseases (Haapkylä et al 2007). The sign of compromised health impacted on coral was the aggressive overgrowth of sponges. The overgrowing of coral-killing sponges on healthy coral was observed mostly in the reef crest and the impacted coral caused by aggressive overgrowth associated with sediment was mostly found in the depth of reef slope. Most of the coral-killing sponges species found during the present study overgrowing the variety of corals were *Chalinula nematifera* and other species from coral-killing sponge groups. The other species of coral-killing sponges affecting the large number of corals in Indonesia was *Terpios hoshinota* (Madduppa et al 2015; Elliott et al 2016). The outbreaks of the coral-killing sponges *T. hoshinota* are a major concern on a global scale (van der Ent et al 2016). The presence of *C. nematifera* within the study sites also has major importance during the outbreaks, therefore quantitative assessments are needed in order to track the severity of these sponge (Ponti et al 2016).

Most of the corals observed during the prrsent study were infected by diseases and were of compromised health. Interestingly, tissue loss caused by non-predation on corals was found in relatively low number of corals. Compare to the other previous study on coral diseases occurrence in different region in Indonesia which reveal the black band diseases, brown band diseases, and skeletal eroding band (Haapkylä et al 2007; Haapkylä et al 2009), the colored band diseases found during this study was only yellow band diseases in the Fungiidae groups. The yellow band diseases found during this study was characterized by the pale yellow color within the colony (Figure 4E). However, this study does not explain whether yellow band diseases that infected the coral are Arabian yellow band diseases (AYBD), Pacific-Yellow band diseases (PYBD), or Caribbean yellow band diseases (CYBD). Johan et al (2017) explained there were different characteristics of yellow band diseases infected the corals, such as CYBD, AYBD, and PYBD were only known to infect the specific species of corals. However, a similar study on the coral disease at the other national park conducted in Seribu Islands National Park (Subhan et al 2011) reveals the yellow band diseases impacted several mushroom corals, such as Sandalolitha, Ctenactis, Fungia, Herpolitha, and Heliofungia. Although it was at a different geographical location, it would be useful information that those corals genera were also affected by the yellow band diseases.

Similar to the colored band diseases found during this study, bleaching was found in relatively low number of corals. Hughes et al (2017) explained the coral bleaching contributed to the reef degradation. Bleaching has mostly impacted the coral in the reef crest and the temperature supposed to be higher at the shallow reef. Symbiotic dinoflagellate algae within the corals were expelled from the polyps during the increasing of the sea temperatures and caused the bleaching on coral (Wilson et al 2012). In order to fully understand all the diseases impact the corals, coral health study should be conducted within all the area of the Ujung Kulon National Park.

Conclusions. The baseline data of coral health from this study shows that the diseases were more impacted in the reef crest. Low diseases may be reflection of the areas due to the low percentage cover of hard coral structures. Although, the number of the diseases found in the reef slope was lower, specific diseases and compromised health were still found in great portion at reef slope, such as the sediment damage and invertebrate galls.

The present study suggests some coral degradation in the Ujung Kulon National Park have been linked to the touristic activities and environmental condition (e.g. light intensity, turbidity, currents). Determine whether the coral colonies are impacted or are in healthy condition in order to select the transplant species are important for transplantation activities. This baseline survey of coral health will be used for future studies in order to manage the reefs area within Ujung Kulon National Park.

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