Coral mortality and bioerosion index for assessing environmental stress effects: a study case of the Indonesian Tropical Reef in Banda-Neira Conservation Park

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Abstract. Periodic monitoring of ecological conditions is a demand in coral reef conservation. Identification of coral and environmental conditions is needed to evaluate conservation effectiveness. Most conservation studies in developing countries usually use the live coral cover index to access coral reef health condition. However, this method does not calculate the ecological impact of environmental stress on coral reef community, such as coral mortality or coral bioerosion. This paper presents a simple mortality-bioerosion index to assess the health condition of coral reef. The index was developed from a study of environmental stress on the tropical coral community in Indonesian Banda-Neira Conservation Park. Coral cover (three 30 m line intercept transects) and water quality parameters including clarity, pH, DO (dissolved oxygen), salinity, phosphate, nitrate, and ammonia were analyzed *in situ*, and statistical correlations between these parameter were determined by multivariate analysis. The results of this study showed that coral communities were degraded, with inorganic nitrogen eutrophication as the major factor. The simple proposed index proves to be reliable in classifying the ecological condition of tropical coral reef environment. Classification is noted as very poor and poor (an environment with low light intensity and inorganic nitrogen eutrophication), good (an environment with slight pressure from eutrophication), and excellent (an environment with adequate water clarity, dissolved oxygen, and pH).
Key Words: coral index, coral reef, eutrophication, sewage pollution, tropic.

Introduction. The Indonesian archipelago is a well-known hotspot region for coral reef organisms. The central region of Indonesia and the southern Philippines are rich with corals, fish, molluscs, and crustaceans (Roberts et al 2002). Indonesian coral reef is a 51020 km^2 region that consists of 2122 fish species that represent 54.4% of the total reef fish fauna of the Indo-West and Central Pacific (IWCP) region (Allen 2008). However, unsustainable exploitation of Indonesian marine resources and anthropogenic pressures have risen over the last decade, and, as a consequence, coral reefs have degraded dramatically (Siry 2011). Acute stress factors (coral mining and destructive fishing activities) and environmental stress factors (sewage pollution and sedimentation) have been causing considerable coral reef damage (Edinger et al 1998; Szmant 2002; Caras & Pasternak 2009; Haapkylä et al 2009). Previous findings show that coral community and diversity in Indonesian coral reef region (Seribu Island, Karimunjawa Island, and Wakatobi Island) are degrading and driven by eutrophication and sedimentation (Baum et al 2015; Januar et al 2015a; Januar et al 2015b). The Indonesian government announced the CTI (Coral Triangle Initiative) program to address these issues. Its goal is to establish Marine Protected Areas (MPAs) and form a network with the surrounding countries (Malaysia, Papua New Guinea, the Solomon Islands and Timor-Leste) to address the effects of climate change and anthropogenic pressures (Clifton 2009).

Periodic monitoring is needed in managing marine conservation. The current status of coral health and environmental conditions is important to evaluate the conservation effectiveness. Indonesian authorities currently use the live coral cover index (below 25% -

poor; 25-50% - moderate; 50-75% - good; 75-100% - excellent) that refers to Gomes & Yap (1998) as an official guide for assessing coral reef health in conservation areas (Manuputty & Djuwariah 2009). Recent coral reef studies in Indonesian regions (marine protected areas in North Sulawesi, Kalimantan, Riau, Aceh, and Central Java Province) used the live coral cover index (Yunandar 2011; Tuhumena et al 2013; Purbayanto et al 2014; Sulisyati et al 2014; Purbani et al 2014). Simplicity is one of the advantages that make the live coral cover index very popular. However, this index has a weakness. The ecological condition of each coral reef ecosystem may be different, although they are contained within the same live hard coral cover. Misleading judgment may happen between locations that are composed of a low hard coral cover, with low mortality, and high levels of abiotic factors, especially sand, compared to another location that is composed of the equivalent level of hard coral, but with high mortality and coral bioerosion by algae or soft coral cover (Zamani & Madduppa 2011).

This study presents a simple combination of coral mortality and bioerosion ratio (ratio between hard coral and their major benthic competitors, which are soft coral, sponge, and algae) as an index to access the health condition of coral reef in MPAs. The index was developed on statistical multivariate quantification of chronic stress factors that affect the reef in Indonesian Banda-Neira Conservation Park. This location is one of the famous tropical coral reef regions in Indonesia, located in the Banda Sea (the deepest sea in Indonesia) in the central area of the CTI region. The location is unique, as the eruption of Gunung Api volcano in 1998 provided a rapid *Acropora* spp. colonization on an andesitic lava flow (Tomascik et al 1996). Previous findings show that underwater CO_2 vents surrounding Gunung Api volcano influence the environmental conditions around Gunung Api Island (Januar et al 2016). However, environmental stress is pressuring the coral reef in several sites (Welly et al 2013). This paper aims to quantify the effects of those pressures and to develop a simple index that is reliable for measuring the relationship between coral cover and environmental parameters based on the coral reef condition in Banda Neira Conservation Park to facilitate conservations authorities in evaluating coral reef condition.

Material and Method

Description of the study sites. The study was conducted inside the area of Banda-Neira Marine Conservation Park, Maluku Province, Indonesia, in 2017. Coral mining, destructive fishing activities, and other acute stress factors are prohibited in this region. However, other environmental stress factors, particularly terrestrial pollution run-off from domestic areas may effect the reef. Twelve coral reef sites (4-6 m) were selected in the marine protected area (Figure 1). 7 sites are located near Banda Island, 3 sites near Neira Island, and 2 sites near Gunung Api Island. The sites were chosen based on visual observations to have gradient effects of environmental stress that enables the coral reef index to develop. The GPS coordinates of each site were recorded using Garmin eTrex 10.

Coral cover and environmental parameters. The coral cover at each site was analyzed at depths between 4-6 m by employing three 30 m line intercept transects (LIT) that are fringing reef parallel to the seashore. Underwater photographs were taken using a digital camera every meter on both sides of the transect line with a 0.5x0.5 m quadrant frame. Seawater samples were collected from the same depth. Seasonal water samples (east, intermediate, and west monsoon season) with three replications were collected at each transect (three transects at each site).

Water sampling was also conducted twice a day, at the high and low tide, two days in a row. Water clarity (% of water penetration depth), pH, DO (ppm), salinity (ppt), phosphate (ppm), nitrate (ppm), and ammonia (ppm) were analyzed *in situ* using a Secchi disk and digital portable devices (HACH DR-890, HACH HQ40d with rugged DO and pH probes, and a Eutech Salt +6 Digital Salt-meter). Water clarity was calculated as a percentage of the depth determined with the Secchi disk and the total depth at the site. Water clarity analyses were conducted during daylight (11.00-13.00), in clear weather. The pH electrode was calibrated based on Nemzer & Dickson (2005) using tris-buffer in synthetic seawater before each sampling activity. Heavy metals (As, Cd, and Pb) were measured (ppb) using an ICP-MS spectrometer by the method of Gray et al (2015).

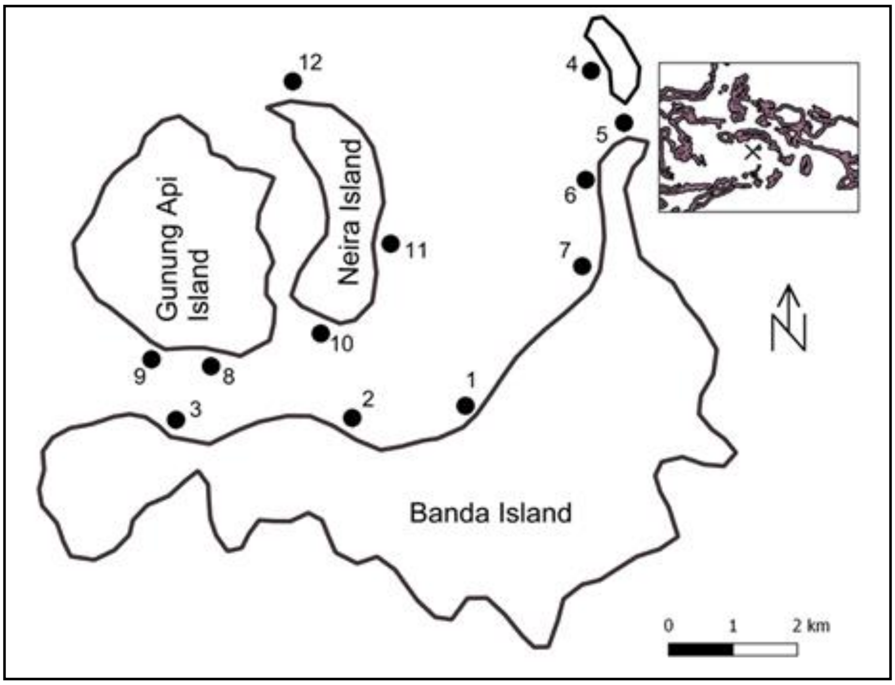

Figure 1. Sampling sites in Banda Neira Conservation Park at the center of the Indonesian Coral Triangle Initiative (CTI) region.

Coral identification and statistical analysis. The analysis of benthic community composition was conducted using CPCe 3.6 software (Kohler & Gill 2006). Fifty random points were automatically placed on each photo, and each point was grouped into 8 classes: hard coral Acropora, hard coral non-Acropora, soft coral, sponge, algae, rubble/DCA (dead coral with algae), rock/sand, and silt. Scleractinian and Octocorallia were identified by morphological inspections according to Coral Finder 2.0 and Fabricius & Alderslade (2001). The graphical tabulation of coral cover was made from 4 major groups: hard coral (sum of hard coral Acropora and non-Acropora), hard coral competitor (sum of soft coral and sponge), autotropic organism and dead coral (sum of algae and DCA/rubble), and abiotic (sum of rock/sand and silt).

Further study of correlations between environmental parameters and coral cover was conducted by multivariate Canonical Correspondence Analysis (CCA) and multiple linear regression according to Dinsdale & Harriott (2004). Before statistical analyses, environmental variables were log transformed, and coral cover classes were square root transformed for normality (Loayza-Muro et al 2010; Huang et al 2011). Data normality was checked using the Shapiro-Wilk W-test. Partial and total adjusted R^2 in multiple linear regression were interpreted according to Hair et al (2011): values between 0.25-0.5 are categorized as "weak determination", 0.51-0.75 as "moderate determination", and above 0.75 as "substantial determination".

The proposed coral index is based on two variables: mortality and competition ratio. Competition ratio may explain the shift from hard coral into non-coral builder organisms (sponge, soft coral, and algae). Mortality ratio was calculated as follows (English et al 1997):

Mortality ratio = % of cover dead coral / % of cover dead and live coral

The bioerosion ratio was calculated with the following formula:

Bioerosion ratio = % cover of hard coral / (% cover of hard coral + soft coral + sponge + algae + other)

Both ratios range from 0 to 1. Quantification was applied on each ratio to develop an index. The mortality ratio between 0-0.249 is quantified as 4, between 0.25-0.49 as 3, between 0.5-0.749 as 2, and between 0.75-1 as 1. The bioerosion ratio between 0.75-1 is quantified as 4, between 0.5-0.749 as 3, between 0.25-0.49 as 2, and between 0-0.249 as 1. The sum of both explains the ecological coral status: 0-2 is categorized as "very poor", 3-4 as "poor", 5-6 as "good", and 7-8 as "excellent". Statistical Canonical Discriminant Analysis (CDA) was applied alongside environmental parameters to evaluate the mortality-competition index. All statistical analyses were conducted with Past Statistical Software v3.08 (Hammer et al 2001).

Results and Discussion

Variation of water variables showed gradient environmental pressures in Banda-Neira coral reef environment (Figure 2). The DO and salinity levels varied within the normal range of tropical coral reef environments. However, high turbidity and insufficient sunlight (low percentage of sunlight penetration to water depth) were detected at site number 1, 2, and 7. Furthermore, low pH level was detected at sites 1, 2, 5, and 6. A high level of phosphate (in a range between 0.04-0.12 ppm) was detected at all sites, in particular on the southern part of Gunung Api Island (sites number 8 and 9). Inorganic nitrogen ions (nitrate and ammonia) were higher in all sites located in front of villages (sites 2, 3, 7, 8, 9, and 10). The port at Banda Island (site 6) and at the outer areas of Banda-Neira archipelago were contaminated with higher Pb concentrations.

The average hard coral cover in all sites varied between 5.33 and 67.67% (Figure 3). Sites 4, 8, and 11 were the areas with the highest hard coral cover. A phase shift from hard coral domination into non-builder coral organism was detected in several sites. High covers of soft coral and sponge (up to 41%) and algae (up to 11.67%) were found in sites 1, 2, 4, 5, 6, and 7. Serious reef degradation was also detected at the southern part of Gunung Api and Neira Island (sites 9 and 10) with a high percentage of algae, DCA, and rubble cover (up to 71.67%). The condition of coral cover is an effect of environmental conditions (Figure 3). CCA revealed that hard coral cover, either Acropora or non-Acropora corals, was related to higher levels of pH and light intensity. In increasing environmental stress, higher non-builder reef organisms or rubble were detected. Nitrogen was the major factor that related with the cover of algae, dead coral with algae (DCA), rubble, or silt.

Multiple linear regression analyses were able to quantify the dominant environmental variables that drive the structure of coral cover (Table 1). Partial R^2 value showed ammonia as a significant ($P<0.05$) and strong ($R2>0.5$) determination factor to algae (+) and soft coral (-) cover. Combined with other factors, this study found four coral covers that were significantly driven by the environmental parameter. The non-Acropora cover presented higher levels in better water clarity, pH, and lower nutrient content. It was also noted that non-Acropora cover has higher resilience than Acropora in lower salinities. Decreased water clarity shifts the community into soft coral cover. However, the soft coral cover was higher in low nutrient levels. A low level of water clarity and high nutrient level seem to be related to the silt level. Furthermore, increasing nitrogen nutrients (nitrate and/or ammonia) were found to significantly increase the cover of algae and dead coral.

The calculation of mortality and phase-shift ratio showed that environmental stress factors had damaged the structure of coral reef at Banda Neira Conservation Park (Figure 4). The mortality ratio was up to 93%. Furthermore, the phase shift ratio showed that there is a site with only 18% hard coral in all benthic life forms. Based on both of these ratios, our proposed index identifies that there are 3 poor, 6 fair, 2 good, and 1 excellent coral sites in Banda Neira Conservation Park. The CDA of this index showed that the mortality-phase shift index successfully separated environmental conditions between categories (Figure 4). Excellent and good condition coral sites are related to higher level of water clarity, pH, and DO. Meanwhile, poor and very poor sites were found to be an effect of eutrophication, particularly of ammonia and nitrate high contents.

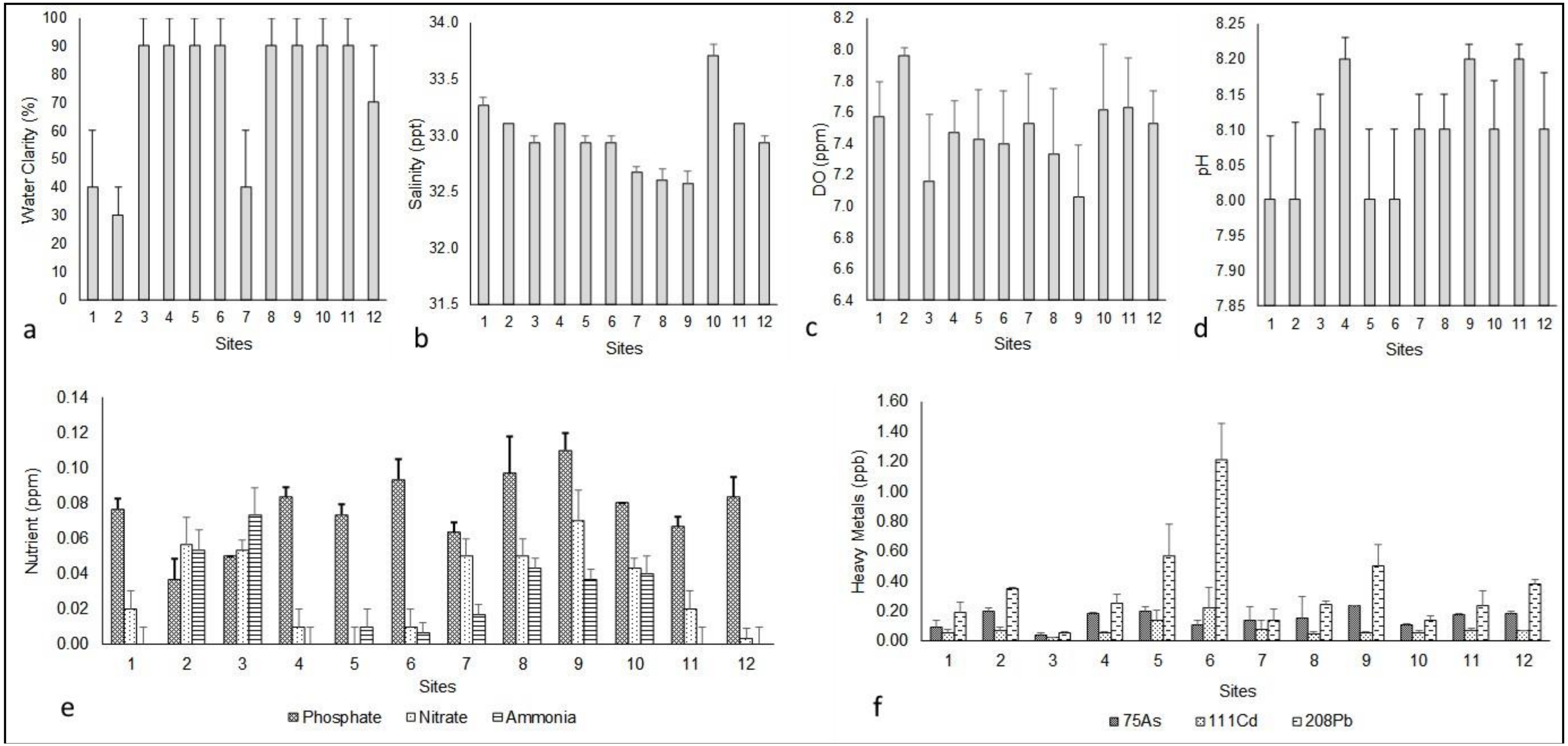

Figure 2. Seawater characteristics of: a - water clarity; b - salinity; c - dissolved oxygen (DO); d - pH; e - nutrients; f - heavy metals, at coral reef sites in Banda-Neira Conervation Park. Sites: 1 - Kumber; 2 - Spancibi; 3 - Lonthoir; 4 - Pisang Island; 5 - Northern Selamon; 6 - Wali; 7 - Selamon; 8 - Southern Gunung Api; 9 - Southern Gunung Api; 10 - Kampung Baru; 11 - Malole; 12 - Tanah Rata.

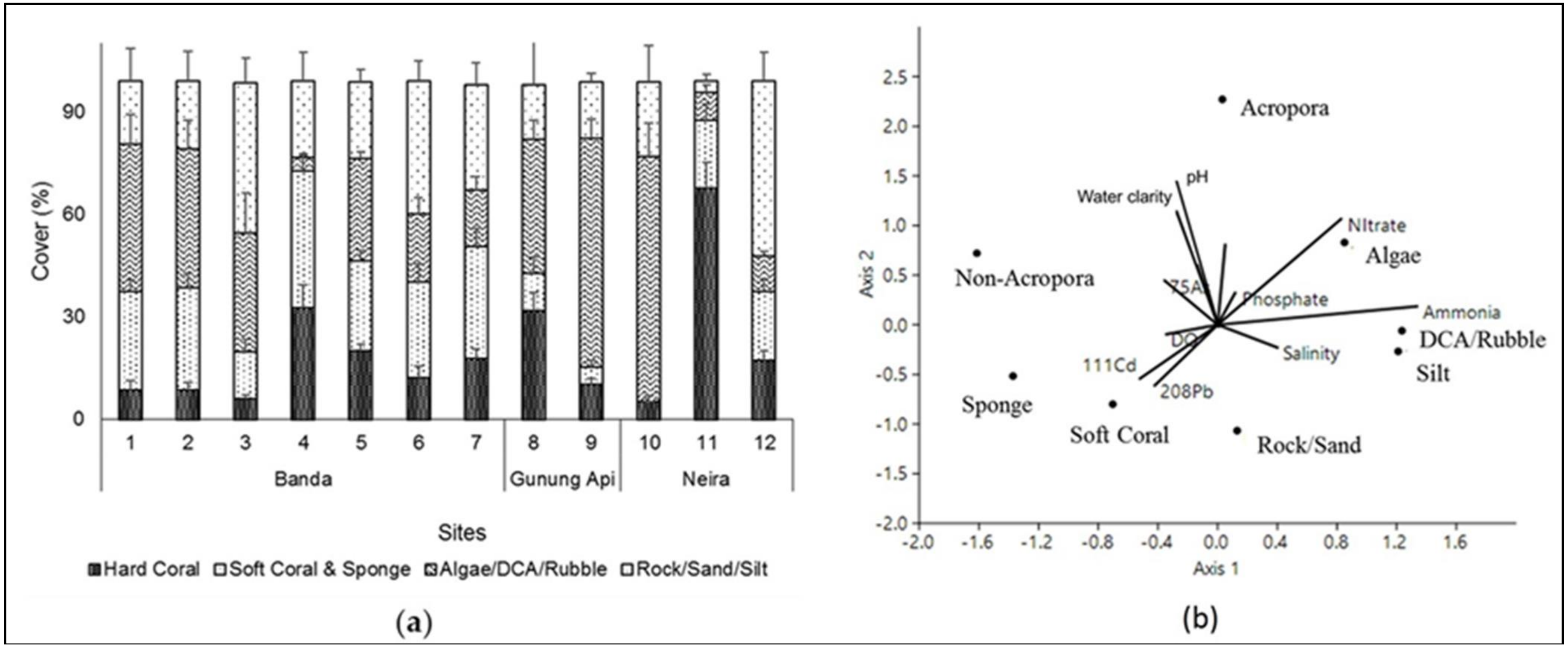

Figure 3. Coral reef; (a) composition in Banda-Neira Conservation Park at (1) Kumber, (2) Spancibi, (3) Lonthoir, (4) Pisang Island, (5) Northern Selamon, (6) Wali, (7) Selamon, (8) Southern Gunung Api, (9) Southern Gunung Api, (10) Kampung Baru, (11) Malole, (12) Tanah Rata; and (b) correspondence with environmental variables in Canoncial Corespondence Analysis (CCA); DO - dissolved oxygen; DCA - dead coral with algae.

Table 1

Multiple linear regression of environmental variables as predictor to coral cover

Coral cover variable	*Significant (P<0.05) environmental predictor at multiple linear regression*						*Total adjusted R^2*
Acropora			+(pH)				0.367
Non-Acropora	+(Light)	-(Salinity)	+(pH)	-(PO_4)		-(NH_3)*	0.744*
Soft coral	-(Light)	-(Salinity)		-(PO_4)	-(NO_3)	-(NH_3)	0.668*
Sponge		-(Salinity)				-(NH_3)	0.304
Algae					+(NO_3)	+(NH_3)*	0.782*
Dead Coral		-(Salinity)	-(pH)	+(PO_4)	+(NO_3)	+(NH_3)	0.618*
Rock/sand					+(NO_3)	+(NH_3)	0.240
Silt	-(Light)					+(NH_3)	0.620*

Notes: (+) sign in predictor means the variable has a positive correlation; (-) sign in predictor means the variable has a negative correlation; (*) sign in predictor shows moderate to substantial determination (R^2>0.5).

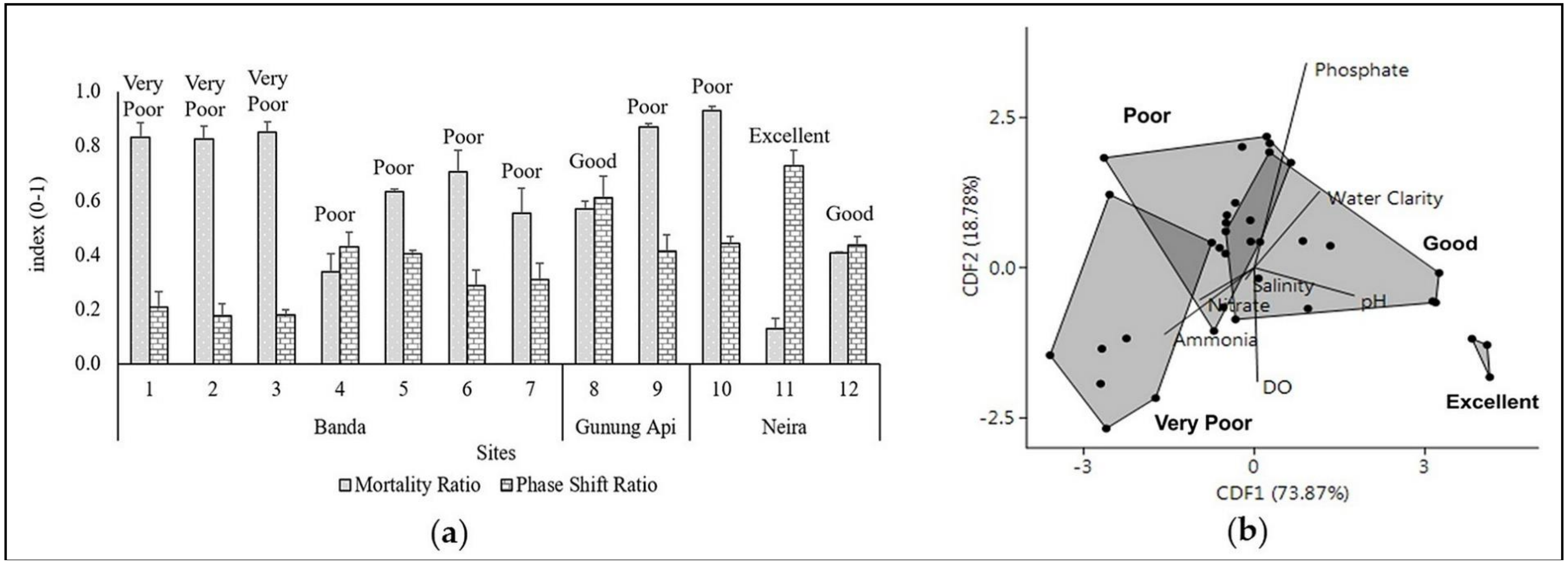

Figure 4. Mortality–bioerosion index; a - coral reef sites in Banda Neria Conservation Park; b - correspondences to environmental variables in Canoncial Discriminant Analysis; DO - dissolved oxygen; DCA - dead coral with algae.

Coral reefs in Banda Neira Conservation Park are divided in two groups. The first group was the area around Gunung Api, which was dominated by Acropora species. The second group was the area around Banda and Neira Island, which was dominated by non-Acropora coral. The dominance of Acropora in the reef around Gunung Api Island may be seen as an effect of low spatial competition after a volcanic explosion in 1998 and nutrient enrichment (particularly phosphates) from hydrothermal fluids or volcanic explosion materials (Tomascik et al 1996; Shoji & Takahashi 2002). Acroporidae is known to present resistance in eutrophic or low pH conditions. This condition may happen because of hydrothermal fluids from underwater volcanic activity (Anthony et al 2008; Dunn et al 2012; Towle et al 2015). The effects of volcanic explosion materials in Banda Neira environment can be seen in the phosphate levels in all sampling sites. However, apart from volcanic materials, other stress factors (heavy metals, turbulent water column or decreasing water clarity, and eutrophication) were also detected to affect the coral cover in this region.

The contamination with heavy metals in Banda-Neira waters was detected in ppb concentrations. Higher contamination in the outer regions of the conservation area and around the Port of Banda Island could appear because of harbor and shipping activities. Pb generally comes from boat motor oil and ballast water (Yilmaz 2009). However, statistical analysis showed that heavy metals do not significantly affect coral cover. This may happen because negative effects of heavy metals on coral reef organisms occur at higher concentration, between 15-2400 ppb, depending on the type of heavy metal (Reichelt-Brushett et al 2005). Declining water clarity was detected in sites near villages (Kumber, Spancibi, Solamon, and Tanah Rata Village). The runoff of organic and numerous inorganic wastes were observed. As a result, hard coral cover in those sites was less than 20%. Light adequacy is a limiting factor for Zooxanthellae productivity, an important symbiont for corals. Symbiont density is known to decrease in lower water clarity (Li et al 2008).

In addition, domestic sewage is also a source of eutrophication. Higher inorganic nitrogen contamination increases the spatial competitiveness of algae, which has a direct effect on coral mortality. Soft coral and sponge cover decreased in higher nutrient levels, even though both are known for their resistance in eutrophication conditions (Koop et al 2001; Fleury et al 2004). This condition could appear as an effect of coral disease agents that usually increase at higher concentrations of inorganic nitrogen in seawater (Fabricius 2005). The overall relationship between coral cover and environmental parameters was determined through CCA and multiple linear regression. Inorganic nitrogen (nitrate and/or ammonia) was a major factor that determined the coral reef structure in Banda Neira Conservation Park.

The existence of environmental stress factors should be the major concern of conservation authorities in Indonesia, as well as developing countries in other tropical areas. Eutrophication stress is the most common threatening factor for the survival of coral reefs. Most large-scale studies used the percentage cover of living hard corals as an index of reef condition because hard corals are the principal framework builders of coral reefs (Sweatman et al 2011). However, site characteristics, bioerosion of hard coral due to environmental stress, and other ecological relationships between environmental parameters and coral reef are not considered in this method. These are important factors to the health of coral reef ecosystems. Previous research has suggested other criteria for the categories of coral reef health, like coral mortality index, coral morphology, deterioration index, and population distance index (Gomez et al 1994; Hodgson 1999; Edinger & Risk 2000; Ben-Tzvi et al 2004). Some other indexes combine live cover with the coral reef diversity index as a basis for determining coral reef health. Although some of those indexes are accurate in explaining the health condition of the coral reef ecosystem, they are quite difficult to implement. Simplification is needed to enable the index to be implemented by local conservation authorities in periodic monitoring activities, particularly in the conservation areas of developing countries.

A previous study suggested a combination of live coral cover, mortality index, algae cover, and sand cover as a standard for coral reef health (Zamani & Madduppa 2011). However, there are difficulties in determining the index if there is a difference between the limits of each category. This study proposes two important categories for the determination of coral reef condition. The first is mortality index as proposed by Gomez et al (1994), and the second is the bioerosion index. Coral mortality and bioerosion of hard coral by the non-coral builder are known as effects of environmental stress factors. Thus, both are important in quantifying coral reef condition and in evaluating conservation effectiveness, as shown in the proposed index. The application of this index may help conservation authorities in the field to periodically assess the ecological condition of coral reef in their region.

Conclusions. This study shows that eutrophication is the major factor that causes hard coral mortality and community shift into non-builder reef organisms. The proposed mortality-bioerosion index is a simple application to assess the ecological condition of particular coral reef regions. The reliability of this index is in the successful separation of ecological conditions in coral reef environments into: very poor and poor (environment with low light intensity and inorganic nitrogen eutrophication), good (environment with a slight pressure from eutrophication), and excellent (environment with adequate water clarity, DO, and pH).

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