Coral reefs ecosystem degradation at Nusa Penida, Bali

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Abstract. Coral reefs interference by multiple threats from local and global source. The aggregate effects of local stressors such as tourism activity, pollution, overfishing, and coral harvesting can decrease resilience of the reefs. Furthermore, increased ocean temperatures, changing ocean chemistry, and sea level rise are the greatest global threats to coral reef ecosystems. The objective of this work is to assess coral reefs ecosystem degradation at Nusa Penida (NP), Bali. In this works, monitoring of coral reef ecosystem was conduct by transect photographs on May and October 2018. We observed the evidence of coral reefs degradation in the site, particularly on the northern and southern reefs area. We also found that algal cover much higher than our previous monitoring activities, linked to higher coral mortality at these locations.

1. Introduction
Coral reefs play an important role in ocean life. In addition, these habitats also threatened throughout the world. Coral reefs are being threatened by an increase of stresses from human activities such as coastal development, pollution, overfishing, destructive fishing practices, and tourism activity. Despite of this stress, long-term changes in the oceans and atmosphere interactions, as well as elevated sea temperatures and concentration of CO2, and stresses from heavy storms, earthquakes, volcanic eruptions and highly variable seasons also affect coral reefs [1].

Coral reefs and their associated marine life are one of the greatest natural treasures of Indonesia. Both their quality and their quantity are impressive: Indonesia is located at the centre of the world’s coral reef diversity and, with some 75,000 km² of coral, it holds approximately one-eighth of the world’s coral reefs [2]. The aesthetic beauty of coral reefs attracts millions of tourists worldwide who come to dive and snorkel amongst these natural treasures. Damage to the reefs has often been caused by the increase in tourism itself [3].

Nusa Penida Islands are the few among other popular tourist destination in Bali. In 2016 there were 439,061 international tourists who visited Nusa Penida in 2016, an increase of 35.89 % compared to the year 2015 of 281,468 [4]. Based on ecological surveys since 2002 – 2009, in Nusa Penida found 1419 hectares of coral reef, 230 hectares of mangrove with 13 species and 108 hectares of seagrass bed with 8 species [5]. Furthermore, a marine Rapid Ecological Assessment (REA) in Nusa Penida’s water found 296 species of coral reef [6].

Thus, the objective of this work is to assess coral reefs ecosystem degradation at NP, Bali. In this study, some previous research works were used as references with respect to seek for the information of ecosystem condition.
2. Research methods

2.1. Study state
The study area is adjacent to the Lombok Strait in the northern part and the Indian Ocean in the southern part. NP district as a part of Klungkung regency consists of three islands namely NP, Nusa Lembongan (NL) and Nusa Ceningan (Figure 1). The research location in NP (8.44°44′S 115°32′E) is precisely at the dive point of Crystal Bay and NL in Pontoon Bali Hai, this area was part of Coral Triangle.

![Figure 1. Nusa Penida, Bali.](image)

2.2. Reef condition
On May and October 2018, our team conduct a field survey to monitoring Bioreeftek (Patent ID: S0001231) in Nusa Penida waters. Bioreeftek was a technology for coral recruitment developed by Institute for Marine Research and Observation, Ministry of Marine Affairs and Fisheries, Indonesia. Coral recruitment defined as the attachment and establishment process of planulae (tiny coral larvae) to the reef community. The field survey was undertaken by photo transect using Medium Scale Approach (MSA) [7][8]. In addition, to observing sea surface temperature (SST) at NP and NL, temperature data logger was deployed attached to Acropora sp. at eight- and five-meters depth, respectively.

3. Result and discussion
NP was the western boundary of the Coral Triangle area. Approximately 260 species of coral were observed during the Marine Rapid Assessment Program (MRAP) in 2008 and 2011. The high diversity of NP’s corals was combination of coral species in the Indian Ocean and Pacific Ocean. In general, the condition of corals in NP was classified as healthy, with a percentage of live coral cover 61.17% [9]. NP’s reef, at 5-15 meters depth, was dominated by Scleractinian corals. The range percentages of corals were 52.00% (good) to 97.00% (very good). Meanwhile, the corals mortality index ranged were 0.00 - 0.01 at 3 meters depth and 0.00 - 0.025 at 10 meters depth [10]. In 2018, the status of Indonesia's coral reefs was change in several areas due to multiple threats, including in the research location [11].

In our 1st field survey on May 2018, the abundance (approximately 80%) of soft coral (Octocorallia) from genus Xenia sp. that attached to Acropora sp., were discovered at northern and southern reefs area of Nusa Penida (Figure 2a, 3a). Soft coral are tentacle-bearing invertebrates that belong to the phylum Coelenterata. The name soft coral refers to Octocorallia, which have nonmassive skeleton as internal axis. The rest of Acropora sp. at this area, were invaded by soft coral from genus Montipora sp. This genus commonly exists near or beyond environmental limits of reefs distribution, which based on physiochemical tolerance boundaries for temperature, salinity, nutrients and light, suspended solids and rates of sedimentation [12][13].
Furthermore, several dead coral colonies that covered by Cyanobacteria also observed during the first field survey. Cyanobacteria have an important role in coral reef ecosystems by produce a major component of epiphytic, epilithic, and endolithic communities and also microbial mats. Cyanobacteria are grazed by reef organisms and also supply nitrogen to the coral reef ecosystems through nitrogen fixation. Cyanobacteria use techniques beyond space occupation to prevent coral recruitment. Cyanobacteria can produce pathogenic microbial consortia as well, in association with other microbes on living coral tissues, causing coral tissue lysis and mortality, and immediately declines in coral reefs [14]. A cyanobacteria-dominated microbial mat that affects coral tissues as it instantaneously spreads
over coral colonies may cause black band disease (BBD) [15].

Meanwhile, the growth of planulae attached to the Bioreeftek at Nusa Lembongan also observed during the monitoring activity (Figure 4a). The result analysis shows that the coral recruitment of species *Stylophora pistillata* (33%) and *Alveopora gigas* (33%) were higher than *Echinopora sp.* (17%) and *Tubipora musica* (17%).

Regarding of SST observations, two temperature data loggers were recovered and redeployed in the same location to measured hourly SST for the next couple of months. This SST datasets completed the availability of SST time series data observations in Nusa Penida and Nusa Lembongan area. Since June 2011, SST time series data were collected to observe SST variability and trend for further analysis concerning its implications to ecosystem surrounding.

![Figure 5. SST variability in Crystal Bay, Nusa Penida (BROL, inprep.).](image)

The SST data series from 2011 to 2018 tend to rise (Figure 5). The high daily SST were recorded in 2015-2016 which shows El Nino signal in this area. This increases temperature will cause corals to turn brilliant white, as the zooxanthellae leave their tissue, hence bleaching episode. If the situation persists the coral colony eventually dies [16]. Research works at Nusa Penida reported severe coral bleaching occurs 27.51% at depths of 3 meters and 17.72% at a depth of 10 meters in June 2016. Coral bleaching consisted of branching coral and massive corals [17], [18] observed the decreased of live coral reefs in Nusa Penida, it was found that 83% live coral and 17% dead coral in 2012, meanwhile in 2016 are 69% live coral and 31% dead coral. It was assumed that the decreased of live coral reefs in Nusa Penida it is caused by elevated of sea temperature.

The second field survey was held on October 2018, two months after Lombok’s earthquakes event. Likely, the impacts of this disastrous event were evident during the field survey conducted at northern and southern reefs area of Nusa Penida. Some Scleractinian corals were dead, broken coral fragments, sediments were dumped on adjacent reefs and the skeletal debris of corals were noticed (Figure 2b, 3b). We observed that both of Nusa Penida (Figure 2b) and Nusa Lembongan (Figure 3b) branching corals, belonging to the genera *Acropora* sp. and *Montipora* sp., were broken into small pieces and some washed away. Fractures of branching corals are spread over the land. Heaped up of living corals were discovered in many places particularly in reef flats area. Sediments straightly stress corals by diminishing the availability of light energy, obstructing coral recruitment and smothering corals, which induces coral disease as well. Furthermore, [19] found that coral reefs in some locations have been damaged as a result of a storm that occurred in July, 2018 so this monitoring is important to record how much damage was caused by the storm. The location that was most affected by the big waves was Crystal Bay where there was a decrease in live coral cover up to around 28%. The impact of the massive waves on average caused a 10% reduction in live coral cover in the Nusa Penida Marine Protected Area.

Algal cover on coral surface and Bioreeftek were much higher than previous field survey (Figure 2b, 4b), linked to higher coral mortality at these locations. Algal covers exhibit that upward growing is restricted and die, whereas the lower part is arising to the outward. This coral case can easily be observed nearby to the coastline and at the reef crest area. Nutrients are generally recognized as beneficial for marine ecosystems; however, coral reefs are adapted to low nutrient levels; so, an excess of nutrients can lead to the growth of algae that blocks sunlight and consumes oxygen corals need for respiration.
This often results in an imbalance affecting the entire ecosystem. Excess nutrients can also support growth of microorganisms, like bacteria and fungi, which can be pathogenic to corals. Furthermore, we also observed the decreasing of coral recruitment on overturned Bioreeftek (Figure 4b). Another implication of this suffered catastrophic event was the failure to recovered two temperature data loggers at Nusa Penida and Nusa Lembongan. The temperature data logger that attached to Acropora sp. at eight- and five-meters depth disappeared because of the branching corals was broken into small pieces and some washed away. Previous studies reveals that scuba diving and snorkelling have empirically demonstrated can cause environmental damage to coral reefs and related coastal resources. The damage inflicted by divers and snorkelers consists mostly of breaking fragile, branched corals or causing lesions to massive corals. Boat anchors can cause considerable damage to coral reefs, including coral breakage and fragmentation. Larger ship anchors and heavy chains can break or dislodge corals, resulting in damaging vast areas of coral reef.

4. Conclusion
The coral reefs ecosystem degradation at Nusa Penida (NP), Bali may caused by elevated of sea temperature, evidenced by severe coral bleaching occurs consisted of branching coral and massive corals. A storm and Lombok’s earthquakes event that occurred in July and October 2018 resulted in a decrease in live coral cover up. Furthermore, scuba diving and snorkelling activity may impact damage to coral reefs, including coral breakage and fragmentation.

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