The Impact of Coral Reefs Destruction and Climate Change in Nusa Dua and Nusa Penida, Bali, Indonesia

D Susiloningtyas*, T Handayani and A N Amalia
Department of Geography, Universitas Indonesia, Indonesia

*dewi.susiloningtyas@ui.ac.id

Abstract. Coral reefs are marine ecosystems with one of the highest levels of biodiversity that provide valuable goods and services. Coral reefs are fragile ecosystem and highly vulnerable to overfishing, destructive fishing practices, pollution, and natural factors. Climate change is one of the natural factors that impacted coral reefs. Southeast Asian coral reefs have the highest level of biodiversity for the world’s marine ecosystem. Indonesia hold 12.5% of the world’s total coral reefs area (±58,000 km²). Bali is one of the popular area in Indonesia that becomes part of The Coral Triangle (The Coral Triangle and Marine Biodiversity). This research examines the relationship between the level of coral reefs destruction with climate change index in Nusa Dua and Nusa Penida, Bali Province, Indonesia. This research was based on secondary data of the analyzed LANDSAT 7+ and LANDSAT 8 OLI. The method performed by descriptive and quantitative analysis. The result shows that there is the difference about level of coral reefs destruction in 2012 and 2016.

1. Introduction

Coral reefs are marine ecosystem with one of the highest levels of biodiversity. They are found in clear, shallow, warm, and topical waters around the world. They provide habitat for diverse communities of marine plants and animals, such as fish, turtles, sharks, eels, crabs, shrimps, urchins, sponges, algae, and others. Southeast Asian coral reefs have the highest level of biodiversity for the world’s marine ecosystem. Indonesia hold 18% of the world’s total coral reefs area (± 51,000 km²). Bali is one of the popular area in Indonesia that becomes part of The Coral Triangle (The Coral Triangle and Marine Biodiversity) include, Malaysia, Philippines, Papua New Guinea, Timor Leste and Solomon Islands. The Coral Triangle is a marine area in the western Pacific Ocean that contain at least 600 species of reef-building corals [1]. In 2011, the large of coral reefs in Bali are 7,765 hectares. They are spread in 6 area, such as Buleleng District, Karangasem District, Klungkung District, Badung District, Gianyar District, Denpasar City, and Jembrana District [2].

In Indonesia, 85% of coral reefs is at risk. The damage of coral reefs mostly due to destructive fishing practices, pollution, and natural factors. Fishing activity have unpredictable and uncertainty aspects, like as season variability [3]. Season variability is identical with climate change. Climate change is one of the natural factors that impacted coral reefs caused by the increasing concentrations of carbon dioxide in the atmosphere, while warmer sea temperatures are disturbing the symbiosis between coral organism and algae. For example, during a single extreme ENSO (El Niño Southern Oscillation) in 1997 – 1998, 16% of all tropical coral reefs were dead by thermal stress [4]. Thermal stress could be seen when corals bleach and become the main causes of coral mortality in the last 20 years. The warmer sea temperature
can also affect the growth and reproduction of corals. Based on experiments, it could reduce egg and sperm production and an incomplete fertilization cycle in corals due to warm water [5, 6]. Based on the publication about Climate change, coral bleaching, and the future of the world’s coral reefs, the increase of sea temperatures, that happened because climate change, could make coral bleaching occurs and make significant losses of live coral reefs in the world [7]. This research conducting about how climate change could affect the condition of coral reefs and make it classified to live and dead coral reefs.

2. Literature Review

2.1. Nusa Dua and Nusa Penida

2.1.1. Nusa Dua. Nusa Dua is an area in the southern part of Bali that located 22 kilometres from Denpasar. Nusa Dua located in Badung District. Nusa Dua has the high level of marine biodiversity, because it is a part of The Coral Triangle (The Coral Triangle and Marine Biodiversity). Nusa Dua is the part of coastal and marine area of Badung District that becomes one of priority location for conservation areas in Bali. The shoreline of Nusa Dua is ±16 km and filled by coastal and marine ecosystems, such as coral reefs, seagrass, mangroves, and other species such as turtles, dolphins, sharks and dugongs. Coastal and marine area of Nusa Dua has an economic value for the local resident, especially marine tourism based on coral reefs ecosystem.

2.1.2. Nusa Penida. Nusa Penida is a sub-district in Klungkung District that has the high level of marine biodiversity, because it is a part of The Coral Triangle. Nusa Penida located in 155° 30’ 00”–155° 36’ 00” E and 8° 40’ 00”–8° 45’ 00” S. The total area of Nusa Penida is 202.840 hectares. The topography condition is classified as slope to hill. The small islands, include Nusa Penida, Nusa Lembongan, and Nusa Ceningan in Klungkung District has 1.419 hectares of coral reefs, 230 hectares of mangroves and 108 hectares of seagrass [8]. Nusa Penida’s marine biodiversity has brought economic benefits from environmental services, such as diving, snorkeling, swimming, sailing, fishing, surfing, parasailing and other activities. Marine tourism activities in Nusa Penida certainly become source of income and provide employment for the local resident. Based on data from Tourism Office of Klungkung District (2009), it is estimated that ±200.000 tourists visit Nusa Penida every year. Climate condition in Nusa Penida is dry season in April to October and rainy season in October to April, with temperature ranging from 27º C to 30,9º C and the average rainfall is 1562,67 mm per year [2].

2.2. Coral reefs

Based on The National Aquarium Fact Sheet, Coral reefs are important marine ecosystem that are found in clear, shallow, warm, and tropical waters around the world [9]. Coral reefs consist of individual animals called coral polyps and their hard exoskeletons. These small animals have soft, cylindrical bodies and a ring of tentacles surrounding a mouth. The tentacles are covered with stinging cells called nematocysts, which can stun or even kill small animals called zooplankton that drift too close to the coral. Coral reefs live in the inter-tropical zone and require warm salt water around 22–26° C with the level of salinity is 32–38 psu. Coral reefs also live in high ambient light levels and high water clarity and extremely low nutrient concentration [10].

Coral reefs are indeed a major marine ecosystem because those species diversity greatly exceeds that of any other marine environment. They are generally known as the rainforest of the oceans. It is assumed that coral reefs host almost 30% of all the marine biodiversity [10] and their total area is less than 0.2% of the sea surface [11].

Coral reefs are valuable and productive ecosystems that provide humans with many services. Coral reefs can be beneficial for support human life and livelihoods economically, 500 million people depend on coral reefs for their livelihoods, food and other resources [12]. Furthermore, it is estimated that around 30 million of the poorest human populations in the world depend entirely on coral reefs for their food. The reason why lots of people depend on coral reefs because coral they have intrinsic, aesthetic
and recreational values. They are also easy to be accessed and visiting coral reefs is an important recreation for snorkelers, scuba divers, recreational fishermen and beach lovers.

Around 20% coral reefs in the world have been destroyed; 24% are at high risk of collapse and 26% at risk from long term collapse because of human activities [12]. If the present rate of coral reefs destruction continues, 70% of the world’s coral reefs will be destroyed in 2050. It is caused by destructive fishing practices and overexploitation for food, aquarium and trinket trade, and medicinal purposes [13, 14].

2.2.1. Climate change effect. In Climate, Carbon and Coral Reefs Book, climate change is defined as any change in climate over time, whether due to natural variability or because of human activity. Climate change and high carbon emissions can affect coral reef systems in several ways. Emerging threats to coral reefs are bleaching and mortality associated with global warming. Elevated sea temperatures are recognized as the primary cause of mass coral bleaching events. Coral bleaching occurred because the loss of symbiotic algae (zooxanthellae) from coral tissues during times of stress. The biology structure of reef-building corals breaks down when elevated sea temperatures exceed the corals’ physiological thresholds for an extended period (weeks to months). The results can be widespread bleaching, which corals lose their ability to grow and reproduce, and in severe cases, it makes coral mortality. The consequence can affect the habitats that live of associated species of fish and invertebrates. The intensity and scale of observed coral bleaching events have increased since the 1960s, and mass bleaching events in 1998, 2002 and 2005 have negatively affected entire reef systems. The mass bleaching events in 1998, 2002, and 2005 caused by an El Niño Southern Oscillation (ENSO) warm event.

3. Methods
The research location is in Nusa Dua and Nusa Penida, Bali Province. The research was conducted between 2012 and 2016. Variables used in the study include the distribution and the condition of coral reefs related to climate factor (index of climate change). Table 1 gives data from analyse LANDSAT 7 ETM+ and LANDSAT 8 OLI satellite imagery on the distribution and condition of coral reefs in Nusa Dua and Nusa Penida and sea surface temperature data by Center of Marine Research Indonesia (Pusat Riset Kelautan/Puriskel Indonesia).

Table 1. Analyse LANDSAT 7 ETM+ and LANDSAT 8 OLI satellite imagery on the distribution and condition of coral reefs in Nusa Dua and Nusa Penida and sea surface temperature data.

| Variable             | Indicator                          | Source                                      |
|----------------------|------------------------------------|---------------------------------------------|
| Distribution of Coral Reefs | Coral Reefs Location (2012) | LANDSAT 7 ETM+                             |
|                      | Coral Reefs Location (2016)      | LANDSAT 8 OLI                              |
| Climate Change       | Sea Surface Temperature (SST)     | Center of Marine Research Indonesia        |
|                      |                                   | Pusat Riset Kelautan (PURISKEL) Indonesia  |

Data needed in this research consisted of secondary data. Secondary data used in this study was obtained through the relevant agencies such as Badan Meteorologi dan Geofisika (BMKG) Bali; LANDSAT 7 ETM+ and LANDSAT 8 OLI (satellite imagery) and Pusat Riset Kelautan (PURISKEL) Indonesia; Sea Surface Temperature (SST). Data processing has done by classifying the data into two groups, namely quantitative and qualitative data. The steps being taken are as follows, (1) A simple classification to classify the condition of coral reefs using satellite imagery data; (2) Processing data with a spatial and tabular Geographic Information System (GIS). The process is occurred through a phase of spatial data entry, editing, labelling, annotation, joint map, overlay, classification, data entry attribute to the output; (3) Quantitative data processed by SPSS (Statistical Product and Service Solutions) version 13; (4) Spatial and qualitative data are analysed with qualitative descriptive method.
4. Results and Discussion

4.1. The distribution of coral reefs
LANDSAT satellite image data in 2012 and 2016 is used by processing and classifying with Lyzeng methods to determine the condition of coral reefs in Nusa Dua and Nusa Penida. Figure 1 show the condition of coral reefs of Nusa Dua and Nusa Penida in 2012 and 2016.

![Figure 1. The level of coral reefs destruction of Nusa Dua in 2012 and 2016.](image-url)
Figure 2. The level of coral reefs destruction of Nusa Penida in 2012 and 2016.
(Source: Data processing, 2017)

Figure 1 show that there are the differences of the condition of coral reefs in 2012 and 2016. Most of coral reefs in Nusa Dua were dead in 2012. Moreover, in 2016, the coral reefs have recovery and most of the coral reefs are live. The large of coral reefs that is still alive in Nusa Dua in 2012 amounted to 88,81 hectares and in 2016 amounted to 219,01 hectares. Moreover, the area of coral reefs that has been
dead continues to decrease with the rate of 95.71 hectares/year. The area of dead coral in 2016 is reduced almost four times from 2012, from 151.32 hectares to 40.10 hectares.

Figure 2 show that there are the differences of the condition of coral reefs in 2012 and 2016. The condition of coral reefs in Nusa Penida is in a good condition caused by it dominated by the live coral reefs. Moreover, there is some differences in 2016. In the north of Nusa Penida, the live coral reefs in 2012 has been dead in 2016. There are some reasons that make coral reefs are dead, such as destructive fishing practices, pollution, and natural factors. The large of coral cover that is still alive in Nusa Penida is in 2012 amounted to 176.89 hectares and in 2016 amounted to 151.65 hectares. While the area of coral cover that has been dead continues to grow with the rate of 52.23 hectares per year. Dead coral cover in 2012 increased almost double from 2016, from 36.47 hectares to 67.99 hectares.

4.2. Climate change effect
Climate change can affect coral reef systems. It caused elevated sea temperatures that cause mass coral bleaching events. Figure 3 shows the data of sea surface temperature of Indonesia in 2012 and 2016.

**Figure 3.** Sea surface temperature of Indonesia in 2012 and 2016.  
(Source: Pusat Riset Kelautan (Puriskel) Indonesia)
Based on data from *Pusat Riset Kelautan (Puriskel) Indonesia* (Figure 3), there is a difference in sea temperature in 2012 and 2016. The sea temperature in 2016 is higher than 2012. The sea temperature range in Indonesia is nearly 27°C – 30°C in 2012 and 27°C – 32°C in 2016. Furthermore, in Bali, there is a difference in sea temperature between 2012 and 2016. In 2012, the sea temperature in Bali is warmer than 2016. The sea temperature in 2012 is nearly 20°C – 29.5°C, while in 2016 it is nearly 28°C – 30.5°C. El Niño in 2015 – 2016 was one of the strongest El Niño events in history [15].

### Table 2. The Large Amount of Live and Dead Coral Reefs of Nusa Dua and Nusa Penida in 2012 and 2016

| No | Area       | Year | Coral Reefs |      |      |
|----|------------|------|-------------|-----|-----|
|    |            |      | Live        | Dead|
| 1  | Nusa Dua   | 2012 | 88.81 ha    | 151.32 ha |
|    |            | 2016 | 219.01 ha   | 40.10 ha  |
| 2  | Nusa Penida| 2012 | 176.89 ha   | 36.47 ha  |
|    |            | 2016 | 151.65 ha   | 67.99 ha  |

The elevated sea temperatures caused by El Niño events have already impacted the condition of coral reefs. Figure 3 shows the differences in sea temperature in 2012 and 2016, which is 2012 warmer than 2016 and there is an elevation in sea temperature in 2016. Table 2 shows the large amount of coral reefs (live and dead) of Nusa Dua and Nusa Penida in 2012 and 2016. Based on the data, there is a difference in the large amount of coral reefs in Nusa Dua and Nusa Penida. In Nusa Dua, there is an increase in live coral reefs and a decrease in dead coral reefs, while in Nusa Penida, there is a decrease in live coral reefs and an increase in dead coral reefs.

### 4.3. Coral reefs and climate change

The climate change can impact the condition of coral reefs. It could cause coral bleaching to occur, which could lead to coral mortality in the long term. Furthermore, coral mortality is not only caused by climate change, but also by destructive fishing and pollution. In 2014 – 2016, there is an analysis showing that El Niño events could raise the sea temperature and affect the condition of coral reefs. In Nusa Penida, there is a decrease in the large amount of live coral reefs from 2012 to 2016 due to the elevated sea temperature. Furthermore, it is not occurring in Nusa Dua, while the large amount of live coral reefs is increased.

Nusa Dua is one of the centers for coral reefs and marine activities. There is the only one Reef Check Office in Indonesia that is located in Nusa Dua. Reef Check is the world foundation that exists to help preserve coral reefs and the ocean. There are many activities that are done by Reef Check to preserve the condition of coral reefs and maintain the live coral reefs, particularly in Nusa Dua. In addition to Reef Check’s activities, there is also some of activity to preserve coral reefs in Nusa Dua. One of them is the activity held by Coral Triangle Centre, the foundation that exists to engage people about preserving and protecting coral reefs. Because there are many activities about coral reefs preservation that are held in Nusa Dua, which makes coral reefs in Nusa Dua more protected than in Nusa Penida. It could make coral reefs in Nusa Dua not really affected by the elevated sea temperature. The preservation and protection makes coral reefs in Nusa Dua increased and make the dead coral reefs recovered.

### 5. Conclusions

Coral reefs are marine ecosystems with one of the highest levels of biodiversity. Indonesia holds 18% of the world’s total coral reefs area (~51,000 km²). Furthermore, 85% of coral reefs are at risk in Indonesia. The damage of coral reefs occurred caused by destructive fishing practices, pollution, and natural factors. Climate change is one of the natural factors that makes coral reefs mortality. It is occurred because climate change could elevate the sea temperature that potential to make coral bleaching. In few months to years, coral bleaching could make coral mortality. Bali is one of the popular areas in Indonesia that becomes part of *The Coral Triangle* (*The Coral Triangle and Marine Biodiversity*). In 2011, the large amount of coral reefs in Bali are 7.765 hectares. Nusa Dua and Nusa Penida is one of the popular coral
reefs in Bali. Furthermore, the condition of coral reefs in Nusa Dua and Nusa Penida has differences in 2012 and 2016. In 2012, coral reefs in Nusa Dua are 37% live and 64% dead and in 2016, 85% are live and 15% are dead. Besides of that, it differences with the condition in Nusa Penida. In 2012, coral reefs in Nusa Penida are 83% live coral and 17% dead coral, and in 2016 are 69% live coral and 31% dead coral. The decreased of live coral reefs in Nusa Penida it is caused by the effect of climate change, the elevated of sea temperature. In other side, it is not occurred in Nusa Dua, because Nusa Dua has lot of activity that related to preserve and protect the coral reefs there. It makes the effect of climate change does not make the live coral reefs decreased. Besides of that, it makes the live coral reefs increased.

Acknowledgement
Gratitude is addressed to Hibah PITTA 2017 from Universitas Indonesia with contract number 640/Un2.R3.1/HKP.05.00/2017.

References
[1] Coral Triangle Initiative (CTI) 2012 Indonesia State of the Coral Triangle Report (Jakarta: CTI- CFF Regional Secretariat).
[2] RPJMD Kabupaten Klungkung 2014 Rencana Pembangunan Jangka Menengah Daerah (RPJMD) Kabupaten klungkung Tahun 2013-2018 (Bali: Klungkung).
[3] Susiloningtyas D, Mennopatria B, Adiranto L and Julianda F 2014 The Influence of Fishing Assets and Migration Time to Catch Squid Fisheries on Seasons Variability Indonesia Jurnal of Geography 46 (1) pp. 22-29.
[4] World Meteorological Organization 2010 Climate, Carbon and Coral Reefs (Switzerland: World Meteorological Organization (WMO)).
[5] National Ocean Service What is coral bleaching? (U. S. Department of Commerce: National Oceanic and Atmospheric Administration).
[6] National Ocean Service How does climate change affect coral reefs? (U. S. Department of Commerce: National Oceanic and Atmospheric Administration).
[7] Guldberg-Hoegh O 1999 Climate change, coral bleaching, and the future of the world’s coral reefs (Australia: University of Sydney).
[8] The Nature Conservancy (TNC) 2010 Annual Report (Bali).
[9] National Aquarium. Coral Reefs (Baltimore: National Aquarium).
[10] Porter J W and Tougas J I 2001 Reef ecosystems: threats to their biodiversity (San Diego: Academic Press).
[11] Smith L 1978 Coral reef area and the contributions of reefs to processes and resources of the world's oceans (Nature 273).
[12] Wilkinson C 2004 Status of Coral Reefs of the World: 2004 Volume 2 (Australia: Australian Government and Australian Institute of Marine Research).
[13] Burke L, E Selig and M Spalding 2002 Reefs at Risk in Southeast Asia (World Resources Institute, Washington, District of Columbia).
[14] Burke L, Reytar K, Spalding M and Perry A 2011 Reefs at Risk Revisited (Washington, D.C. (USA).
[15] Lian T, Chen D K, Tang Y M 2017 Genesis of the 2014–2016 El Niño events Sci China Earth Sci 60 pp. 1589–1600.