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Stressor-Response of Reef-Building Corals to Climate Change in the Menjangan Island, West Bali National Park, Indonesia

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Abstract. Climate change has been identified as a stressor to coral reef ecosystem. Last El-Ninõ episode occurred in 2015-2016, leads to worldwide coral bleaching and mortality, including Indonesia. This study attempted to determine the stressor-response of reef-building corals to climate change in the Menjangan Island, Bali. Temperature data logger measurements and remote sensing dataset observing sea surface temperature (SST) and sea surface height (SSH) were used. The logger was deployed at five-meter depth recording hourly temperature during 2017. Monthly anomalies of SST and SSH covering ten years of observation (2007-2017) were calculated for the region. Monitoring of coral in the region was conducted on February, April and August 2017. Our findings indicate that there was evidence of mortality in the site, particularly on the northern reef flat, coinciding with both high positive SST and high negatives SSH anomalies occurred during the El-Ninõ period.

1. Introduction

Coral reef ecosystems have declined all over the world in the last 30 years, and declines are projected to continue in the future threatened by climate change, increasing human uses, sedimentation, nutrients, pollutants, and other stressors [1]. Determining stressor-response relationships in reef-building corals remains a critical component of understanding global change and water quality impacts on coral reef ecosystems [2].

Many species of reef-building (Scleractinian) corals are particularly sensitive to small increases in temperature because they live near their upper threshold for temperature. The vulnerability of reefs to climate change became fully evident in 1997-1998 when elevated sea surface temperatures (SSTs) linked to global warming and a strong El Niño caused widespread coral bleaching and mortality throughout the tropical oceans [3-5]. The last bleaching episode has occurred in 2015-2016 during what occurs to be the strongest El Niño event on record [6].

El Niño has impacted Indonesian coral reefs since 2015 through a different process than temperature-induced bleaching. In March 2016, Bunaken Island (North Sulawesi) displayed up to 85% mortality on reef flats. For reef flat communities which were living at a depth close to the pre-El Niño mean low sea level, the fall induced substantial mortality likely by higher daily aerial exposure a least during low tide periods. The altimetry historical records suggest that such event was not unique in the past two decades, therefore rapid sea level fall could be more important in the dynamics and resilience of Indonesian reef flat communities than previously thought [7]. The altimetry data gives the information on sea surface height (SSH), furthermore the ocean being a dynamic and processes result in anomalies in the SSH. Therefore, SSHa can be used as a proxy for detection sea level phenomena [8].

The objective of this work is to determine the stressor-response of reef-building corals to climate change, by means of temperature and altimetry data, in the Menjangan Island, Bali. First, the measurements methods are explained in section 2. Section 3 summarizes data result from our study, consist of temperature data from in situ measurements (February-October 2017), SST and SSH data from remote sensing dataset (2007-2017) and reef status from field survey on February, April and August 2017. Furthermore, the third section also discuss how the variability of SST and SSH affects the reef-building corals.

2. Research methods

2.1. Study site

The study site is located on the NW coast of Bali, Indonesia. Menjangan Island is a small island (about 1.75 km^2), it's part of West Bali National Park (114°26'-114°35' E and 8°5'-8°13' S), which conserves animal and vegetation of low land rain forest (Figure 1). It has no permanent inhabitant but there were four temples to which people come to pray. Average rainfall is around 1,365 mm/year and average humidity is about 85.29%. Highest rainfall is on February, which is affected by the hilly area in western part of Bali Island (between 310 to 803 meters high). Temperature of surface water is around 26 to 27°C and current speed is between 0.1 to 0.4 m/second. Water salinity is around 31 to 33‰, pH is about 7 to 8 and visibility can reach 100% in 25 m depth. Menjangan Island is surrounded by patch reef, it's dominated by *Porites* [9].
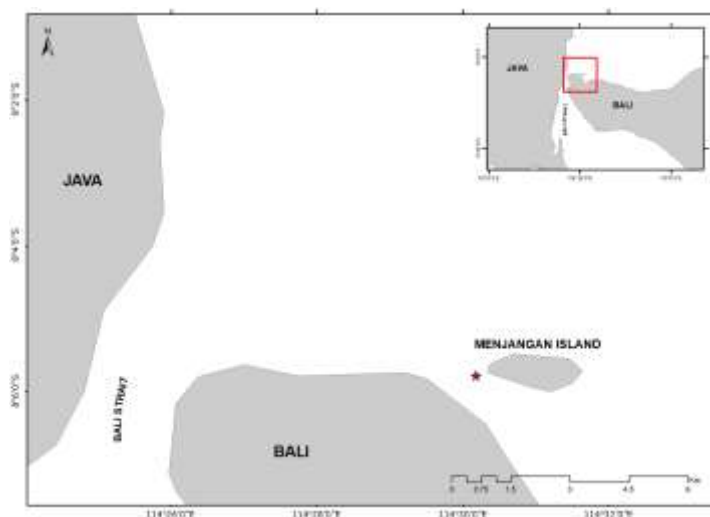

Figure 1. Menjangan Island

2.2. In situ SST measurements

SST measured used data logger at a user defined time interval were used, with the date, time and sampling interval set by software through a specific interface. An Onset HOBO U20 Water Level Logger U20-001-02 deployed near Menjangan Island's pier, attached to a pillar at approximately five meters below the surface. The logger have autonomy a sampling interval of one record by 60 minutes, which has been selected for the whole period of study. This instrument can record temperatures in range -200 to 500°C with the accuracy about ± 0.37° @ 20°C and ± 0.5° over -5° to 50°C. Each loggers includes calibration certificate of accuracy in accordance with NIST-traceable standards at three pressure points distributed throughout the range. This device can record 21,700 combined pressure and temperature measurements up to 30 meters water depth at sea level [10]. The SST data was downloaded using the HOBOware Pro with an Onset Optic USB Base Station (BASE-U-4) and a coupler (COUPLER2-B). Daily SST data were available from February to October 2017 from the 24 hourly recordings.

2.3. Monthly anomalies of SST

In order to assist in the interpretation of the SST variability and trend from our logger, other datasets concerning temperature from satellite were used. The monthly anomalies of SST obtained from MODIS (Moderate Resolution Imaging Spectroradiometer) on board the Aqua satellite was used in this study. The 3 level images with a 4-km spatial resolution from January 2007 to December 2017 were downloaded from Giovanni website (http://gdata1.sci.gsfc.nasa.gov/).

2.4. Monthly anomalies of SSH

SSHa relative to the geoid (mean ocean surface of the Earth if the ocean is at rest) is derived from satellite altimeter measurements. The altimetry data available from Copernicus Marine Environment Monitoring Service (CMEMS) measured by satellite. This data was used to map sea level fall throughout Menjangan Island over 2007-2017.

2.5. Reef status

The medium scale approach (MSA) was used for field survey [11] on February, April and August 2017 at Menjangan island's reef flat (Figure 2). In general, this approach were perform by in situ survey, however it also can undertake by transect photographs [12]. In this work, the approach conducted using techniques 5x5 m quadrat estimates and view benthic cover along the transect habitat on the reef [13]. The GPS was used to marked every single location were found dead corals.

Figure 2. Transect survey at Menjangan Island

3. Results and Discussion

3.1. In situ SST measurements

The daily in situ SST variations data series shows that the lowest temperature was observed in the early morning (4 to 8 am) and the highest was in the afternoon (1 to 3 pm) (Figure 3a). The annual mean of temperature in this region during 2017 was 28.6°C. The high temperature average (± 29.2°C) recorded in the first transitions period (March-May), while the low temperature average (± 28.3°C) was observed in the second transitions period (September-November), (Figure 3a and 3b). In the boreal winter (December-January) the moderate temperature average (± 28.9°C) was recorded. Meanwhile, in the boreal summer (June-August), the temperatures average (± 28.4°C) nearly close to the figure of second transitions period SST data series.

The strongest variability of daily temperatures (± 0.5°C) occurs in early June to August, while the lowest variability (± 0.1°C) observed in early September to November, as depicted in Figure 3c by the standard deviation of daily SST. Overall, the daily temperatures variations recorded at the sampling

site does not exceed 0.5°C, which is represent as the coastal waters. In low-latitude coastal waters, where circulation with the open ocean is restricted, isothermal conditions prevail [14]. As well as area in equator regions, Menjangan Island also get a longer exposure more than other areas [15]. In addition to monsoon and solar radiation, the diurnal cycle and variability of SST in coastal area can affect by, tidal mixing, earth's rotation, evaporation process, wind and wave mixing [15-19].
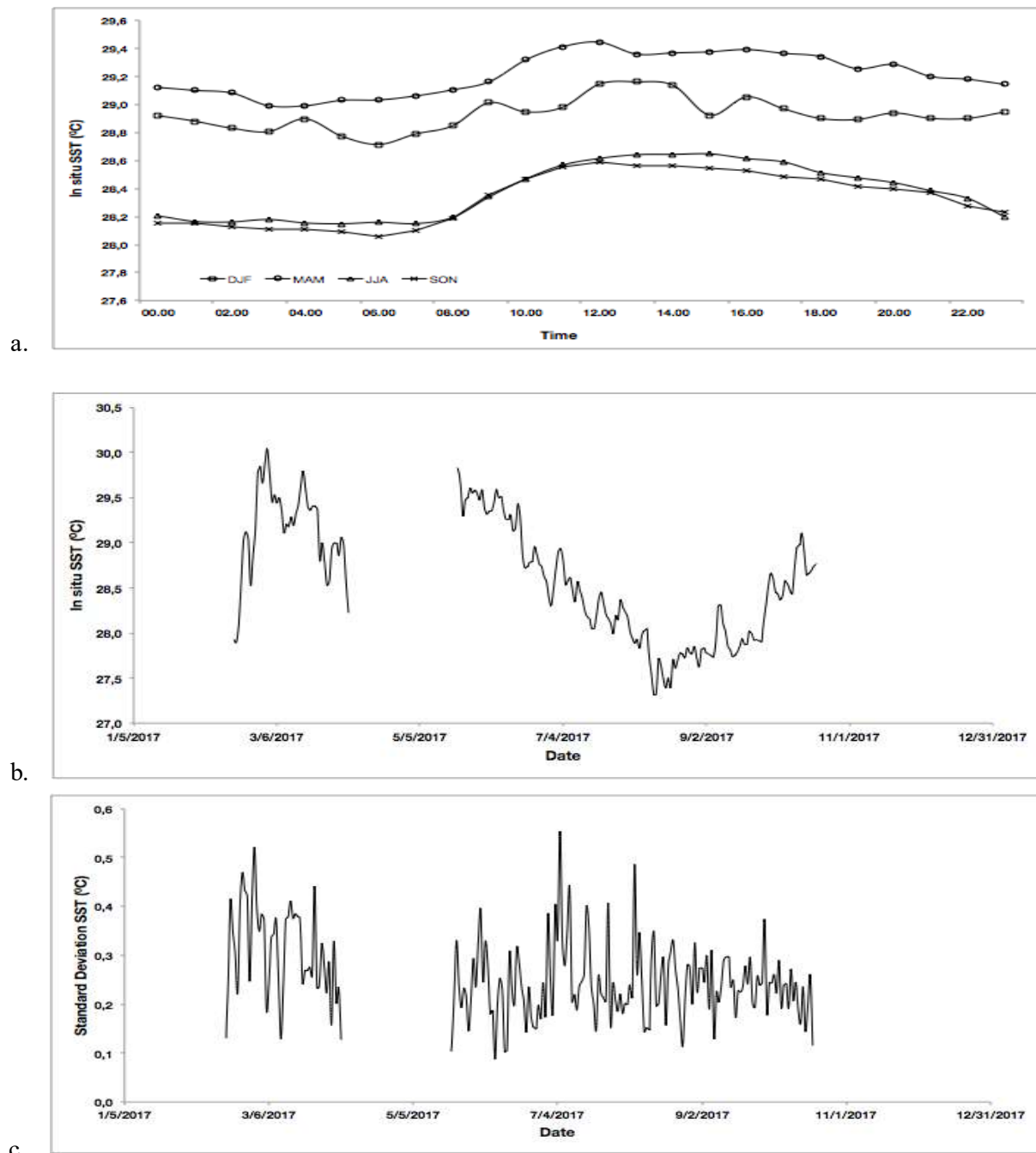

a.

b.

c.

Figure 3. a) Daily in situ SST variations based on monsoon period; b) Daily in situ SST measurements; and c) Standard deviation of daily in situ SST measurements

3.2. Monthly anomalies of SST

The monthly anomalies of SST data series from January 2007 to December 2017, presented in Figure 4a. The highest anomalies were found in early year of 2010 (2.1) and midyear of 2011 (-1.4). The high daily SST positive anomalies (1.3-2.1) were also recorded in 2010-2011, 2015-2016, which shows El Niño signal in this area. El Niño cycle begins when warm water in the western tropical Pacific Ocean shifts eastward along the equator toward the coast of South America [14]. El Niño increases temperature in several coral reef regions in Indonesia and will cause corals to turn brilliant white, as the zooxanthellae leave their tissue, hence bleaching episode [20]. If the situation persists the coral colony eventually dies.

The three years period (2015-2017) of annual cycle of SST positive anomalies (Figure 4b), shows that the positive trend over 2016 period tend to be higher compare to 2015 and 2017 period. This higher positive trend observed as the strongest El Niño event on record [6]. During 2016, the highest SST positive anomalies was observed in the second transitions period (September-November).
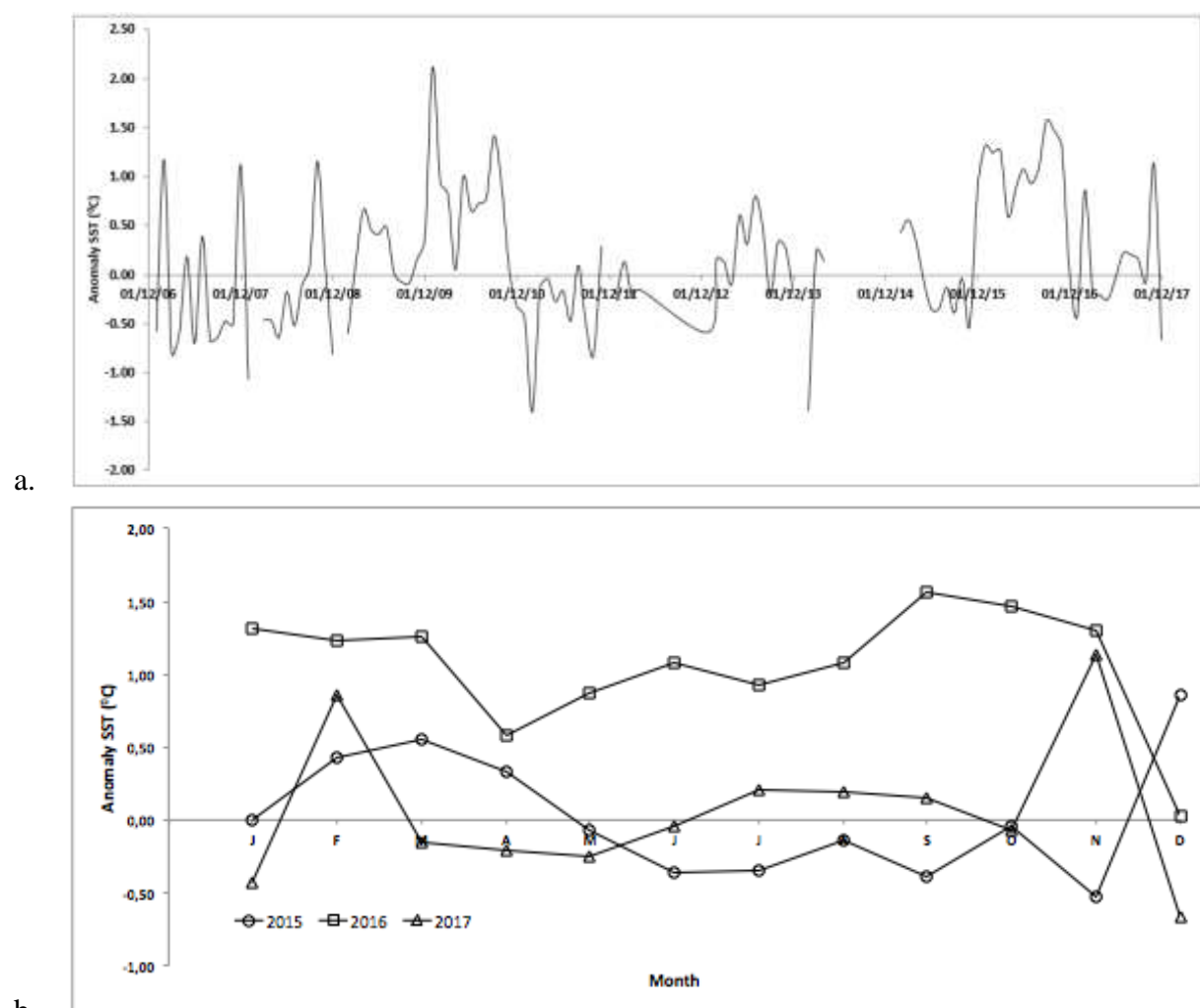

a.

b.

Figure 4. a) The monthly anomalies of SST data series from January 2007 to December 2017; b) Trends over three years period of annual cycle of SST anomalies during El Niño event

3.3. Monthly anomalies of SSH

The monthly anomalies of SSH data series observed from CMEMS, presented in Figure 5a. The high magnitude is found in end year of 2010 (0.1) and mid year of 2013 (0.1), as well as in midyear of 2016 (0.2). The high magnitudes of SSH are affected by El Niño event. During El Niño event, aerial exposure during low spring tide could have led to coral tissue heating, desiccation, photosystem or

other cell functions damage [21]. It is possible that colonies could have look bleached during that period [22].

The annual cycle of SSH anomalies from 2015 to 2017 presented in Figure 5b. The diagrams figure out the low monthly SSH anomalies in 2015 and 2017, while high positive SSH anomalies recorded since March to December 2017. High positive anomalies indices sea level rise occurrences, while sea level fall that indicates by negative SSH anomalies recorded since end year of 2015 to early year of 2016. It is suggested that sea level fall episode in this region occurs before the increase of SST.
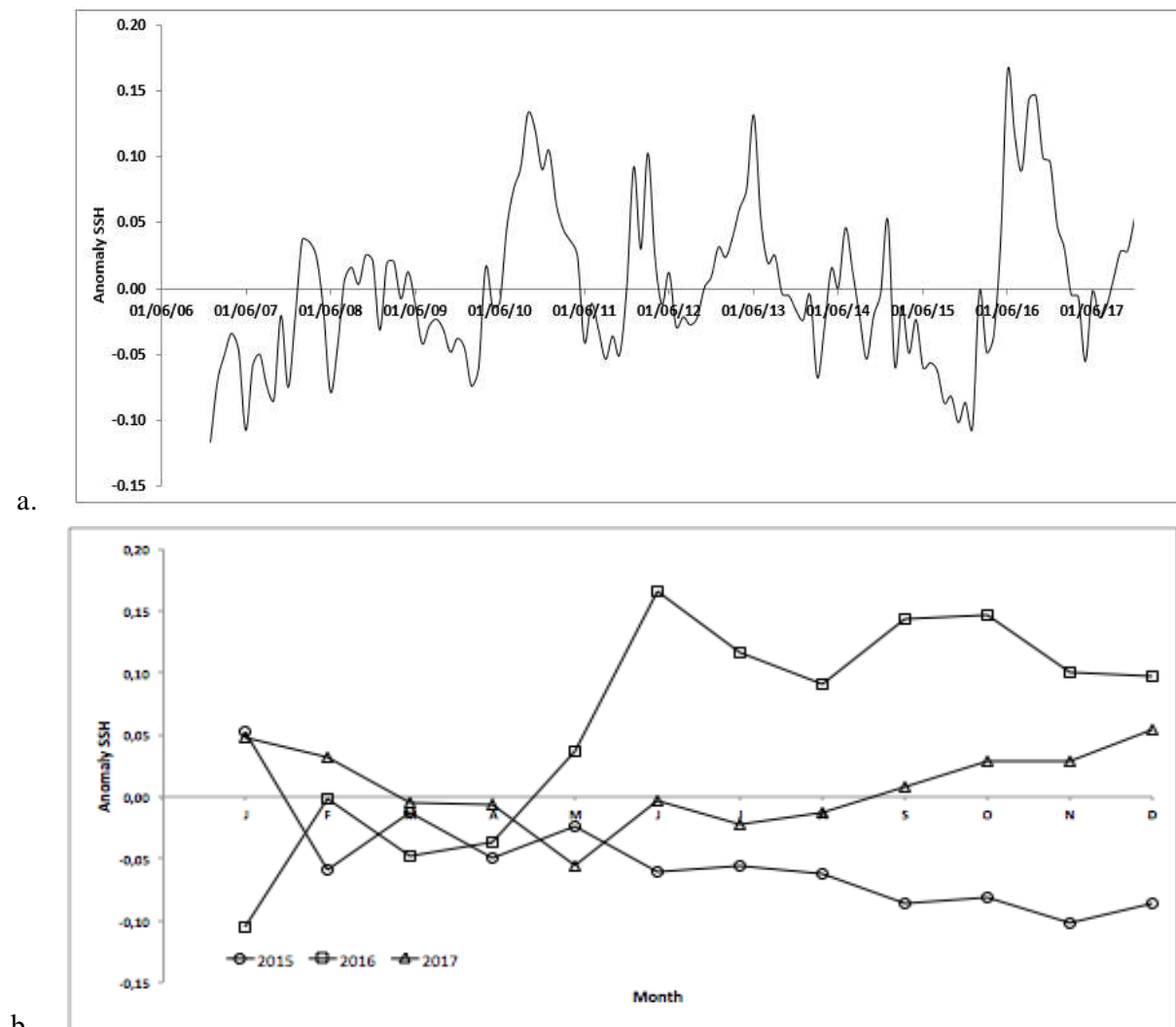

a.

b.

Figure 5. a) The monthly anomalies of SSH data series from January 2007 to December 2017; b) Trends over three years period of annual cycle of SSH anomalies during El Niño event

3.4. Reef Status
Different species of corals coverage, on the upper part of reef flat of Menjangan Island, were observed in field survey conducted in 2017. In southern area of Menjangan island was dominated by massive and submassive colonies of *Porites*, while relatively high branching of *Acropora sp.* coverage was observed in northern part of island [23]. During three times field survey, we noticed the widespread occurrences of dead reef of branching *Acropora sp.* (Figure 6a) and severe reef of massive *Porites sp.* (Figure 6b) and submassive *Porites cylindrical* (Figure 6c) on reef flats of Menjangan Island.

Coral bleaching intensity has been related to different temperature thresholds, other environmental factors and stressors, and type of zooxanthellae and corals [24]. Generally, families of corals that are mostly characterised by branching growth forms (e.g., Acroporidae and Pocilloporidae) are considered to be most susceptible to bleaching and experience highest rates of mortality once bleached [25, 26]. While in contrast, families of corals that typically have massive morphologies (e.g., Faviidae, Mussidae, and Poritidae) appear fairly resistant to increasing temperature, being among the last to bleach and more frequently experience partial, rather than whole colony mortality [27-29].

a)   ; b)   ; c)

Figure 6. a) Branching *Acropora sp.*; b) Massive *Porites sp.*; and c) Submassive *Porites cylindrical*

During such El Niño event, the mortality was not just related to warm water induced-bleaching, but could be tracked to rapid sea level variations [7]. Suggested that mortality was related to sea level variations, with increased aerial exposure time during the last few months. The discrimination between thermal and sea level fall induced mortality could be difficult to pinpoint on reef flats, if surveys had occurred several months after the thermally induced bleaching. The fact that sea level fall, or extremely low tides, induces coral mortality is not new, but this study demonstrates that through rapid sea level fall, the 2015-2016 El Niño has impacted Indonesian shallow coral reefs well before that high sea surface temperature could trigger any coral bleaching.

The analysis of monthly SST and SSH anomalies in Menjangan Island shows that the widespread occurrences of dead reef, may affect by the increase of monthly SST anomalies during El Niño episode. The sea level fall phenomenon also contributes as stressors to dead and severe reef in this region. Meanwhile, sea level fall appear as a major mortality factor for Bunaken Island in North Sulawesi, and altimetry suggests similar impact throughout Indonesia. Our findings confirm that El Niño impacts are multiple and the different processes need to be understood for an accurate diagnostic of the vulnerability of Indonesian coral reefs to climate disturbances [7].

In future years, monitoring SLA may be as important as monitoring SST. While there are several SST-indices specifically used as early-warning signals for potential coral bleaching [7, 30], there are no sea level indices specific for coral reef flats. However, several ENSO indices can help tracking the likelihood of similar events for Indonesia. For Indonesia coral reefs, in addition to sea level fall depending on the ENSO situation, further changes can be expected, due to coral bleaching, diseases, predator outbreaks, storms and sea level rise [7, 31, 32].

References
[1] Hughes, T.P., A.H. Baird, D.R. Bellwood, M. Card, S.R. Connolly, C. Folke, R. Grosberg, O. Hoegh-Guldberg, J.B.C. Jackson, J. Kleypas, J.M. Lough, P. Marshall, M. Nystrom, S.R. Palumbi, J.M. Pandolfi, B. Rosen, and J. Roughgarden. 2003. *Climate change, human impacts, and the resilience of coral reefs.* Science. 301: p. 929-933.

[2]   Fitt, W.K., B.E. Brown, M.E. Warner, and R.P. Dunne. 2001. *Coral bleaching: interpretation of thermal tolerance limits and thermal thresholds in tropical corals*. Coral Reefs. 20: 51-65.

[3]   Wilkinson, C. and G. Hodgson. 1999. *Coral reefs and the 1997–1998 mass bleaching and mortality*. Nature and Resources. 35: 16–25.

[4]   Hoegh-Guldberg, O. 1999. *Climate change, coral bleaching and the future of the world's coral reefs*. Marine and Freshwater Research. 50: 839–866.

[5]   Aronson, R.B., W.F. Precht, I.G. Macintyre, and T.J.T. Murdoch. 2000. *Coral bleach-out in Belize*. Nature. 405: 36.

[6]   Schiermeier, Q. 2015. *Hunting the Godzilla El Niño*. Nature. 526: 490-491.

[7]   Ampou, E.E., O. Johan, C.E. Menkes, F. Niño, F. Birol, S. Ouillon, and S. Andréfouët. 2017. *Coral mortality induced by the 2015-2016 El- Niño in Indonesia: the effect of rapid sea level fall*. Biogeosciences. 14: 817-826.

[8]   Kumar, N., N. Swetha, J. Nayak, R.P. Bright, and S. Kumar. 2015. *Utility of sea surface height anomaly (SSHa) in determination of potential fishing zones*. Technical report, Ministry of Earth Sciences (MoES). 33p.

[9]   Fahrudin, A. 2003. *Extended cost benefit analysis of present and future use of Indonesian coral reefs, an empirical approach to sustainable management of tropical marine resources*. Desertation. Christian Albrechts Universitat of Kiel. 209p.

[10]   Onset Computer Corporation. 2010. *Onset® energy & environmental monitoring*. Product catalog. 76p.

[11]   Clua, E., P. Legendre, L. Vigliola, F. Magron, M. Kulbicki, S. Sarramegna, P. Labrosse, and R. Galzin. 2006. *Medium scale approach (MSA) for improved assessment of coral reef fish habitat*. Journal of Experimental Marine Biology and Ecology. 333 (2): 219-30.

[12]   Andréfouët, S. 2008. *Coral reef habitat mapping using remote sensing: a user vs producer perspective. Implications for research, management and capacity building*. Journal of Spatial Science. 53 (1): 113-29.

[13]   English, S., C. Wilkinson, and V. Baker. 1997. *Survey manual for tropical marine resources 2nd ed*. ASEAN-Australia Marine Science Project: Living Coastal Resources, Australian Institute of Marine Science. 390p.

[14]   Trujillo, A.P. and H.V. Thurman. 2011. *Essentials of oceanography 10th ed*. Pearson Education, Inc. Prentice Hall. 577p.

[15]   Yang, Y., T. Li, K. Li, and W. Yu. 2015. *What controls seasonal variations of the diurnal cycle of sea surface temperature in the eastern tropical Indian Ocean?* Journal of Climate. 28 (21): 8466-8485.

[16]   Martin, S. 2014. *An introduction to ocean remote sensing 2 ed*. Cambridge University Press. 489p.

[17]   Qu, T., Y. Du, J. Strachan, G. Meyers, and J. Slingo. 2005. *Sea surface temperature and its variability in the Indonesian region*. Oceanography. 18: 50-61.

[18]   Kida, S. and S. Wijffels. 2012. *The impact of the Indonesian Throughflow and tidal mixing on the summertime sea surface temperature in the western Indonesian Seas*. Journal of Geophysical Research. 117, c09007: 1-14.

[19]   Tito, C.K. and E. Susilo. 2017. *The correlation of upwelling phenomena and ocean sunfish occurrences in Nusa Penida, Bali*. 2nd International Conference on Tropical and Coastal Region Eco Development, IOP Conf. Ser.: Earth and Environ. Sci. 55, 012031: 1-9.

[20]   Hoegh-Guldberg, O. 2011. *Coral reef ecosystems and anthropogenic climate change*. Regional Environmental Change. 11: 215-227.

[21]   Brown, B.E. 1997. *Adaptations of reef corals to physical environmental stress*. Advances in Marine Biology. 31: 221-299.

[22]   Brown, B.E., R.P. Dunne, T.P. Scoffin, and M.D. LeTessier. 1994. *Solar damage in intertidal corals*. Marine Ecology Progress Series. 105: 219-230.

[23]   Ampou, E.E., I.N. Radiarta, R. Hanintyo, N.C. Mahdalena, and S. Andréfouët. *In rev*. Habitat bentik pada ekosistem terumbu karang di Pulau Menjangan. Jurnal Kelautan Nasional. 1-8.

[24]   Baker, A.C., P.W. Glynn, B. Riegl. 2008. *Climate change and coral reef bleaching: an ecological assessment of the long-term impacts, recovery trends and future outlooks*. Estuar. Coast. Shelf Sci. 80: 435-471.

[25]   Baird A. and P. Marshall. 2002. *Mortality, growth and reproduction in scleractinian corals following bleaching on the Great Barrier Reef*. Mar Ecol. Progr. Ser. 237: 133-141.

[26]   Jones R. 2008. *Coral bleaching, bleaching-induced mortality and the adaptive significance of the bleaching response*. Mar. Biol. 154: 65-80.

[27] Brown B. and Suharsono. 1990. *Damage and recovery of coral reefs affected by El Nino related seawater warming in the Thousand Islands, Indonesia*. Coral Reefs 8: 163-170.

[28] McClanahan, T. 2004. *The relationship between bleaching and mortality of common corals*. Mar. Biol. 144: 1239-1245.

[29] Riegl, B. 2002. *Effects of the 1996 and 1998 positive sea-surface temperature anomalies on corals, coral diseases and fish in the Arabian Gulf (Dubai, UAE)*. Mar. Biol. 140: 29-40.

[30] Teneva L, M. Karnauskas, C.A. Logan, L. Bianucci, J.C. Currie, J.A. Kleypas. 2012. *Predicting coral bleaching hotspots: the role of regional variability in thermal stress and potential adaptation rates*. Coral Reefs. 31:1-12.

[31] Baird, A.H., M.S. Pratchett, A.S. Hoey, Y. Herdiana, and S.J. Campbell. 2013. *Acanthaster planci is a major cause of coral mortality in Indonesia*. Coral Reefs. 32: 803-812.

[32] Johan, O., D.G. Bengen, N.P. Zamani, Suharsono, D. Smith, A.M. Lusiastuti, and M.J. Sweet. 2014. *Microbial community of black band disease on infection, healthy, and dead part of scleractinian Montipora sp. colony at Seribu Islands, Indonesia*. Indonesian Aquaculture Journal. 9: 1-11.