AACL BIOFLUX
Aquaculture, Aquarium, Conservation & Legislation
International Journal of the Bioflux Society

Notes: coral reef bleaching in Weh Island, Indonesia, a natural climate variability or global climate change impact?

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Abstract. Many studies linked the climate change impact on coral bleaching without a good basic understanding of climate science, particularly with regard to the utilization of climate change term. If the climate is changing yearly and temperature is continuously rising, then coral reef may suffer from bleaching annually. The statement should be corrected because climate change may lead climate variabilities will be likely to occur very often in frequency which further become a serious threat on coral biodiversity as well as its ecosystem that might lead to mass mortalities. The purpose of the study is to prove that two natural climate variabilities, i.e., El Niño and Southern Oscillation (ENSO) and Indian Ocean Dipole are responsible for coral bleaching in certain period and occassionally in Weh Island as well as to straighten the meaning of climate change term as often used in many coral bleaching studies. The result show that the increase of Sea Surface Temperatures (SST) leading to bleaching watch status are preceded by emergences of ENSO and dipole mode from Indian Ocean. It is also shown that SST has slowly increased that may lead these climate variabilities to occur very often in future climate. In conclusion, the increase of ENSO and dipole mode frequencies become a serious threat to coral biodiversity which may bring a new status of home of lost corals in Weh Island.
Key Words: climate variabilities, ENSO, Indian Ocean Dipole, coral biodiversity.

Introduction. The coral reef bleaching has become a serious marine aquatic problem recently. The bleaching occurs when zooxanthellae leaves the corals, which cause them to lose their life color and turn into pale appearances (Hoegh-Guldberg 1999). It happens as a result of coral responses to environmental changes, which one of them is often associated with the increase of Sea Surface Temperatures (SST) (Hoegh-Guldberg et al 2007; Rudi 2012).

Weh Island (95.22 to 95.37 E and 5.77 to 5.9 N), situated further in the north of Aceh Waters Indonesia and border Indian Ocean in the west, is a home of rich coral biodiversity, as reported by Rudi et al (2012a) who discovered an equal number of coral reef species as in Coral Triangle Initiative area. The coral bleaching surely will be the biggest threat to the survival of coral species, and in longer periods it may lead to mortalities and even extinctions of some coral species in Weh Island (Bridge et al 2013). Besides, corals are habitats for reef fish, thus, the event will not only degrade the environment but also disturb the food chain leading to decrease marine resources and production. The bleaching event in Weh Island have been reported by Rudi et al (2012b) and have a significant impact in the reduction of reef fish as well as fishermen catches around Weh Island.

Recently, the rise of SST is often related to climate change. Intergovernmental Panel of Climate Change (IPCC) in the newly released report found that due to anthropogenic effect, the average surface temperature in the last century had globally increased about 0.8°C and projected to increase about 3 to 4°C in the next century over Southeast Asia region (IPCC 2013). Certainly, the global temperature changes cannot be denied. Despite having all necessary informations, the fluctuations of temperatures, in particular SST is closely related to natural climate variability, mainly concerning the so-called El Niño and Southern Oscillation (ENSO) and Indian Ocean Dipole (IOD). The two

climatic oscillations play major roles in resulting ocean and atmospheric anomalies in the Pacific and Indian Ocean, and are responsible for coral bleaching event. Brown & Suharsono (1990) described the El Niño impact on coral damages. Stone et al (1999) reported mass coral bleaching as a result of El Niño occassion. Spillman et al (2011) also linked the 1997/1998 ENSO with bleaching event and attempted to make their seasonal ocean temperature anomaly prediction as the indicator of bleaching event. In Indian Ocean, Sutthacheep et al (2013) revealed the connection between 1998 and 2010 El Niño episodes with mass coral bleaching, Marimutu et al (2013) also linked Indian Ocean bleaching event with 2010 El Niño period. IOD is an ENSO look-alike event as firstly reported by Saji et al (1999). The relationship between IOD and coral bleaching are still poorly studied. Thus, it motivates the present study to prove that IOD may also have connection to the bleaching event in Indian Ocean. In fact, scientists and agencies tried to relate severe bleaching in 2010 to coupled appearances of El Niño and IOD (Baird, unpublished data; CORDIO, unpublished data).

Nevertheless, many studies have linked climate change impact on coral bleaching (e.g., Reaser et al 2000; Goldberg & Wilkinson 2004; Lesser 2007; Hoegh-Guldberg 2012). The utilization of climate change term still remains question, what is the climate change actually? In climate science, climate change term is related to global climate change due to anthropogenic effect (e.g., Lutgens & Tarbuck 2007; Ramanathan & Carmichael 2008; Ahrens 2009; Bey, personal communication). Despite the changing of the climate is, however, becoming more certain recently, it still remain questions whether the corals are always bleaching due to a continous increase in temperature?. In fact, the bleaching event seems to occur in repetitive periods which coincide with ENSO and IOD emergences as previously mentioned. In fact, climate change impact may result in these two cyclic events to become more frequent and stronger in intensity (IPCC 2013). Hence, a good understanding of the term is necessary before we arrive in a conclusion that climate change higly correlates to coral bleaching event. The objective of the study is to prove that two natural climate variabilities, i.e., ENSO and IOD are responsible for coral bleaching in certain period and occassion in Weh Island as well as to straighten the meaning of climate change term as often cited in many coral bleaching studies. It is essential since there is still no study yet to describe the relationship between ENSO/IOD and coral bleaching in Weh Island, Indonesia.

Material and Method. The time-series of SST data (e.g., SST, SST anomaly, climatological montly mean maximum SST, and bleaching threshold) in Weh Island Indonesia are taken from National Oceanic and Atmospheric Administration (NOAA) coral reef watch program under Southeast Asia coral bleaching data products from 2001 until 2013 (NOAA Coral Reef Watch 2000). The explanation about methods and algorithms used in the products refer to Wellington et al (2001), Liu et al (2006), and Strong et al (2006). Meanwhile, The ENSO and IOD events are diagnosed using monthly climate indices (i.e., Nino 3.4 for Indonesian region and Dipole Mode Indices (DMI)). Time-series of Nino 3.4 indices are taken from NOAA available at http://www.cpc.noaa.gov/data/indices/sstoi.indices and DMI are taken from Japan Agency for Marine-Earth Science and Technology (JAMSTEC) at http://www.jamstec.go.jp/frcgc/research/d1/iod/HTML/Dipole%20Mode%20Index.html. For DMI, HadISST analysis data are used in the study.

The SST variables data and climate indices (i.e., Nino 3.4 and DMI) are plotted in a graph. If SST exceed the bleaching theshold, it present a bleaching warning status. If SST exceed the maximum monthly mean SST, the status is bleaching watch, if SST is below the maximum mean SST, the status is no stress (Liu et al 2006). Meanwhile, the ENSO (El Niño and La Niña) condition indicated by Nino 3.4 and DMI are given in Tables 1 and 2, respectively. A statistical test of Pearson's correlation coefficient (*r*) shown in below formula is used to find the strengthen of linear relationship between Nino 3.4, DMI and SST anomaly:

$$r = \left(\frac{\sum_{i=1}^{n}(X_i - \bar{X})(Y_i - \bar{Y})}{\sqrt{\sum_{i=1}^{n}(X_i - \bar{X})^2}\sqrt{\sum_{i=1}^{n}(Y_i - \bar{Y})^2}} \right),$$

where *X* is SST anomaly, *Y* is Nino 3.4 (or DMI). *r* values range from $-1 \leq r \leq +1$. If *r* is greater than 0.9, it means a perfect correlation, if *r* is between 0.7 and 0.89, it means a very strong correlation, if *r* is between 0.5 and 0.69, it means a strong correlation, if *r* is between 0.3 and 0.49, it means a moderate correlation, if *r* is between 0.1 and 0.29, it means a weak correlation, if *r* is between 0.01 and 0.09 and if *r* equal to 0, it means no correlation. The same thing applies in negative correlation (Walpole 1995).

Table 1

The ENSO condition based on Nino 3.4 indices (Indonesian Agency for Meteorology, Climatology, and Geophysics (BMKG), unpublished data)

Climate índices	*ENSO condition*
-0.5< Nino 3.4 <0.5	normal
El Niño	
0.5 < Nino 3.4 < 1	weak
1 < Nino 3.4 < 2	moderate
2 < Nino 3.4 < 3	strong
La Niña	
-1 < Nino 3.4 < -0.5	weak
-2 < Nino 3.4 < -1	moderate
-3 < Nino 3.4 < -2	strong

Table 2

The IOD condition based on Nino 3.4 indices (Indonesian Agency for Meteorology, Climatology, and Geophysics (BMKG), unpublished data)

Climate índices	*IOD condition*
-0.4 < DMI <0.4	normal
0.4 < DMI < 1.2	strong positive
-1.2 < DMI < -0.4	strong negative

Results and Discussion. It is shown in Figure 1 that 13-years time-series of SST in Weh Island do not yet exceed the bleaching threshold that may lead to status upgrading into warning condition. It is important since the warning status, also stated as the second stadium of potential bleaching event, may directly interfere with corals survival. Only SST above its maximum monthly mean climatology that lead to bleaching watch status is regularly found over certain periods. Although the watching status describe the first stadium of possible bleaching event which may not have severe impact on corals, but the status should always be monitored, particularly for long-term occurrences since it may also harm the corals. The significant status of bleaching watch occurs in four consecutive years from 2002 to 2005. The maximum bleaching watch status with SST of 31°C occurs in 2010 where nearly exceed the bleaching threshold. Meanwhile, in the next three years (2011-2013), the status of bleaching watch is still found. The same status appears in previous years of 2001, 2007, and 2009 as well.

The increase of SST leading to bleaching watch in 2003, 2005, 2007, 2010, and 2013 is associated with appearances of El Niño signals, in particular for the period of 2003 and 2010 where preceded by moderate El Niño signals. Meanwhile, coral bleaching from 2001 to 2004, 2007, 2009, and from 2010 until 2012 related to emergences of strong positive IOD signals. In fact for some events, it occurs simultaneously with

appearances of El Niño which might then strengthen and extend bleaching episodes in Weh Island, such as 2002 and 2010 bleaching events. Furthermore, long-term moderate signals of La Niña appear during 2007 until 2008 leading SST to decrease in these periods which also result in degrading the status into category no stress effect. In addition to La Niña, negative IOD also have an impact on declining SST at certain periods, such condition occur at the end of 2005 to 2006. However, bleaching watch status observed in early 2005 was accompanied by appearances of Pacific El Niño signals (Figure 1).

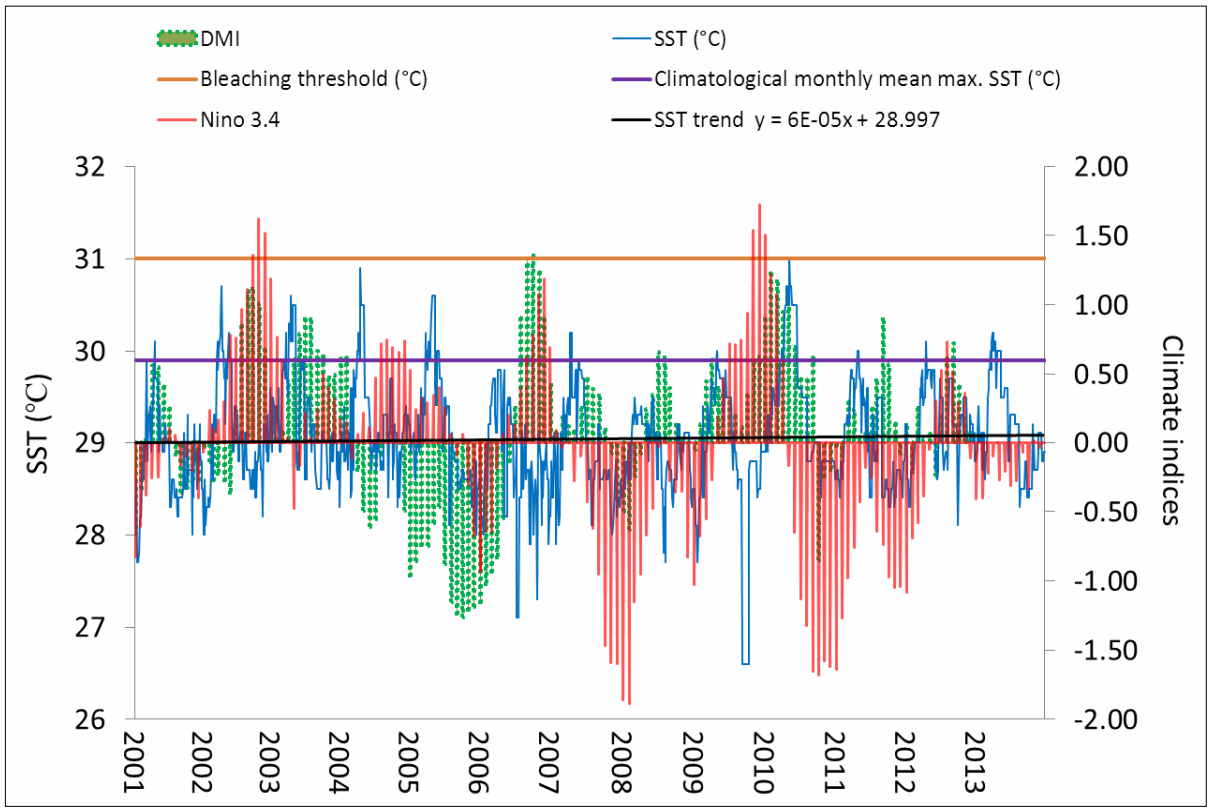

Figure 1. The 13-year SST observation along with ENSO and IOD events (as indicated by Nino 3.4 and DMI) in Weh Island, Indonesia. SST data are derived from NOAA CRW (2000).

It is shown that the increase of SST leading to bleaching phenomena is believed to have connections with positive IOD and El Niño. On the contrary, the reduction of SST is linked with negative IOD and La Niña event. Based on a statistical test, it is found that the relationship between SST anomaly and IOD and ENSO is statistically significant even though they just show a weak correlation (r = 0.2) (Walpole 1995). Weak correlation does not mean they do not have good relationships. It is, however, solely due to thermal delay since the appearance of these two climatic events do not directly affect the increase of SST at that time but as we know that ocean has a slow ability in absorbing heat, thus, the heat is firstly stored, accumulated and then released after reaching their peak periods. It is observed in Figure 1 that the rises of SST leading to bleaching event are often preceded by either ENSO or positive IOD or the combination of both.

Furthermore, the two climatic events seem to have regular oscillations. Intervals of ENSO events are frequently between 2 and 7 years (CPC 2005). It coincide with the present paper where La Niña instead of El Niño occurs for 2007-2009 and 2010-2012. This transition period take two years to oscilate. However, El Niño that last longer at the beginning of the millenium (2002-2005) still remain question, whether it is a climate change impact, we shall discuss later, but as we know that El Niño tend to last longer than La Niña (regularly between 9 and 15 months). Long-term effect cause SST to remain high leading to longer watching periods which might cause corals to die. Unfortunately, there was no report of coral condition in Weh Island during this bleaching

event that can support the present paper. Mass coral bleaching due to warm SST above normal in these periods was reported by McClanahan et al (2007a, 2007b) but in Western Indian Ocean. Since ENSO is a global climatic impact, it still has a posible effect even far from the Pacific (Reason et al 2000). The climatic event in this region is, however, dominantly influenced by IOD. The transition of IOD from negative to positive phase is irregular, it may sometimes take shorter (e.g., 2 or 3 years) or longer (6 years or more). It is shown in Figure 1 that the transition period from negative to positive IOD takes 3 years, and during negative IOD (2005 to early 2006), SST was decreasing leading to no heat stress effect on corals. Strong positive IOD in 2010 accompanied by El Niño cause mass coral damage in Weh Island due to the bleaching as discussed earlier by many scientists. Rudi et al (2012b) reported that 60-80% of hard corals in Weh Island suffer from bleaching in this period and this is the first record where mass bleaching has been observed on Weh Island (Figure 2). Bleaching also took effect recently in 2012 as reported by Australian scientist for Great Barrier but no report yet in Weh Island for that moment. The 2012 bleaching event was also resulted from coinciding appearances of positive IOD and El Niño. It can be concluded that most bleaching event in Weh Island coincide with positive IOD and El Niño as seen in Figure 1.

Figure 2. Mass bleaching of corals in Weh Island, Indonesia following high SST in 2010 (photos by Nur Fadli on May 31, 2010).

Recently, global climate change due to anthropogenic effects is becoming a familiar environmental issue that will threat the corals through the rising of SST. Based on recent IPCC report, the global surface temperature has reach 0.8°C and still projected to increase in future climate. This value is obtained from long-term observation began after industrial revolution, and it is certainly a small number since it only rise slowly from year to year even from decade to decade, but, it exactly continues to rise and as predicted by IPCC, it may turn into more unequivocal in the future. The SST trend for 13 years observation in Figure 1 shows that the increase of SST is much slower. The SST average is about 29°C which is still below the bleaching threshold. However, whether the increase of global temperature has influenced the current climate?, in Figure 1, it is shown that the transition period from La Niña to El Niño become shorter (e.g., La Niña 2008 and 2011). Actually, the regular cycle of La Niña to El Niño take more than 5 years, but now it happens more often. Similarly, El Niño also become more frequent. El Niño used to have regular cycle of 2 or 3 years in frequency but now the frequency only last for 1 or 2 years recurrences. It is noted that for 13 years, moderate El Niño signals occur five times

with longer periods occurred in the early 21th century leading to not only local (Weh Island) but also worldwide mass coral bleaching. This changing effect make the climate variabilities to become uncertainty and unpredictability. Sometimes, it will take shorter or longer, depend on how large the greenhouse gases concentration in the lower troposphere and how much heat is released back to the surface. Climate change is responsible for not only increasing the SST but also the irregularity of climate variabilities not only in Weh Island but also globally. The irregularity will cause El Niño and strong positive IOD turn out to be more frequent to happen that may lead to massive coral bleaching annually in Weh Island someday. If so, this situation may alter numerous biodiversities of coral reefs leading to lost marine biotic ecosystem in Weh Island. Such climate change understanding is what the author want to deliver in the present paper. Nevertheless, it should be good if SST data is available for 30 years of observation since it can actually represent a climatological condition. So that, the rise and fall of SST which is associated with ENSO and IOD events can be well-observed. And for longer period the fluctuations as well as frequencies of ENSO and IOD as assumed to be more frequent as a result of climate change effect can be clear-depicted as well.

Conclusions. Most bleaching events are preceded by either El Niño or positive IOD and sometimes these two climatic oscillation events appear simultaneously that might strengthen and extend bleaching events in Weh Island. Meanwhile, 13-years SST trend is increasing slowly which might be due to increase of greenhouse gases concentration recently. If it keep rising, it is feared that it may disturb the regularity of climate variability where ENSO and IOD may last very often in future climate. The understanding of the changing climate here relate to ENSO and IOD events that are likely to repeat in short periods of time. Thus, it certainly will cause bleaching in corals from year to year leading to mortality and even extinction which further degrade the status of Weh Island from home-rich coral biodiversity to home of lost biodiversity.

Acknowledgements. The author wish to express gratitude to NOAA CRW for providing necessary data to support this study.

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Received: 11 October 2014. Accepted: 15 December 2014. Published online: 21 December 2014.
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How to cite this article:
Ilhamsyah Y., Fadli N., Setiawan I., Haridhi H. A., 2014 Notes: coral reef bleaching in Weh Island, Indonesia, a natural climate variability or global climate change impact? AACL Bioflux 7(6):508-515.