VARIABILITY OF SEA SURFACE TEMPERATURE IN FISHERIES MANAGEMENT AREA 715, INDONESIA AND ITS RELATION TO THE MONSOON, ENSO AND FISHERY PRODUCTION

Komang Iwan Suniada[1*]
[1]Institute for Marine Research and Observation
Ministry of Marine Affairs and Fisheries
*e-Mail: komang.suniada@kkp.go.id
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Abstract. Sea surface temperature (SST) is one of the important oceanographic and climate parameters. Its variability and anomalies often influence the environment and organisms, both in the oceans and on land. This study aims to identify the variability of SST and help the fisheries community to understand how climate phenomena such as ENSO and monsoonal phases (represented by wind speed) are related to SST and fishery production in Fisheries Management Area (FMA) 715. SST was measured at Parimo, which represents conditions in the western part of the area inside Tomini Bay, and at Bitung, which represents SST in the open ocean, with a more exposured geographical position. SST was derived from MODIS satellite imagery, downloaded from the oceancolor database (https://oceancolor.gsfc.nasa.gov/) with a 4 km spatial resolution, from January 2009 to December 2018. Wind speed data, historical El Niño or La Niña events, and fish production data were also used in the study. Pearson's correlation (Walpole, 1993) was used to test the relationship between SST variability or anomaly and ENSO and monsoons. The results show that the SST characteristics and variability of the Parimo and Bitung waters are very different, although they both lie in the same FMA 715. SST in Parimo waters is warmer, but with lower variability than in Bitung waters. SST in Parimo has a low correlation with ENSO (r=0.06, n=66), low correlation with wind speed (r=-0.29, n=120), with also a low correlation between SST anomaly and ENSO (r=0.05, n=66). SST in Bitung has a higher, but inverse, correlation with ENSO (r=-0.53, n=66), high correlation with wind speed (r=-0.60, n=119), with also a high correlation between SST anomaly and ENSO (r=-0.74, n=66). Unlike in other parts of Indonesia, fishery production in Parimo, or the western part inside Tomini Bay, is not affected by ENSO events.

Keywords: *SST, FMA 715, ENSO, monsoon, Tomini Bay*

1 INTRODUCTION

Sea surface temperature (SST) is one of the most important oceanographic and climate parameters (Kaplan et al., 1998; Corvianawatie et al., 2014; Davies and Cressie, 2016) since it plays the key role in regulating climate and its variability, together with several other atmospheric parameters including wind speed, air temperature, humidity and cloudiness (Deser et al., 2010). Variability in SST is influenced by both atmospheric and oceanic processes and phenomena. Wind speed, air temperature, cloudiness and humidity are the dominant factors in the atmosphere which regulate SST dynamics, while heat transport by currents, vertical mixing and boundary layer depth are the dominant factors influencing SST variability which originate from the ocean. The widely recognised climatological phenomenon known as the El Niño Southern Oscillation (ENSO) clearly demostrates how variability at the ocean surface,

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especially SST in the tropical Pacific Ocean, corresponds to atmospheric variations, that will have an impact on weather conditions worldwide (Davies and Crissie, 2016). ENSO consists of two established events, El Niño (a warmer eastern tropical Pacific) and La Niña (a cooler eastern tropical Pacific). During the El Niño event, dry conditions increase and precipitation is lower in the Australia, Indonesia, New Guinea, Micronesia, Fiji, New Caledonia and Hawaii regions (Pui et al., 2012). During the La Niña event, SST in the western tropical Pacific Ocean is warmer than normal, and rainfall increases around Australia and Indonesia (Vitri and Marzuki, 2014). These conditions also correlate with the increasing number of tropical cyclones compared to normal climatology condition (Chand et al., 2013). The Oceanic Niño Index (ONI) is the standard measure of the ENSO phenomenon, using the combination of a part of the Niño 3 and Niño 4 regions, also known as the Niño 3.4 region. Five consecutive of three-month moving average of SST anomalies within the Niño 3.4 region which are above (below) the threshold of +0.5 (-0.5), indicate the occurrence of the El Niño (La Niña) phenomenon (https://www.ncdc.noaa.gov/teleconnections/enso/indicators/sst/).

Beside ENSO, the Indonesian archipelago is influenced by the Asia Australia monsoonal system. Monsoon systems are fundamentally driven by solar position and radiation, which trigger pressure differences between the two continents. These differences generate different wind speeds and directions in Indonesia during such phases (Webster et al., 1999). In July, Australia is colder (higher pressure) than Asia (warmer, lower pressure), so the wind blows from Australia to Asia; this phase is known as the southeast monsoon. On the other hand, in January Asia is colder (higher pressure) than Australia (warmer, lower pressure), which means the wind direction is from Asia to Australia, in a phase known as the northwest monsoon.

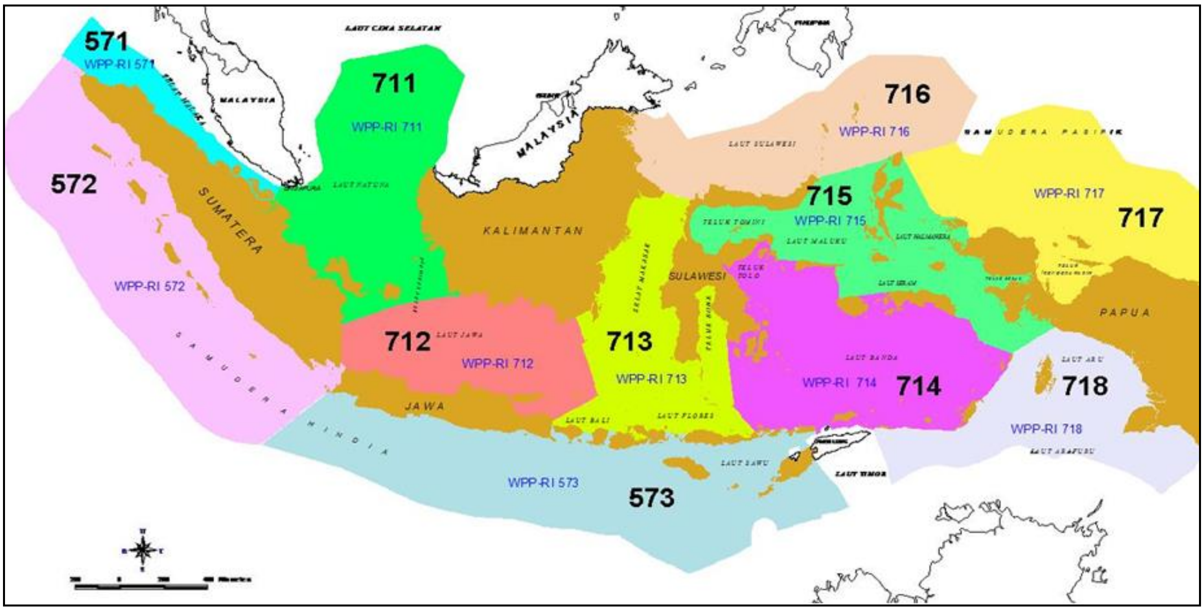


Figure 1-1: Fisheries Management Areas in Indonesia

The Indonesian archipelago, according to the Ministry of Marine Affairs and Fisheries regulation No. 18/PERMEN-KP/2014, is divided into 11 Fisheries Management Areas (FMAs), as shown in Figure 1-1. This classification was based on the resource characteristics and biophysical environment. An Ecosystem Approach to Fisheries Management (EAFM) was also used as a basis for developing the FMAs, with the management scope including the capture fisheries, marine culture, conservation, research, and fisheries development (Muawanah et al., 2018).

FMA 715 covers a large area from Tomini Bay, the Maluku Sea, Seram Sea, Halmahera Sea, to Berau Bay. The seabed topography of FMA 715 is very varied. It generally consists of oceanic deep waters, some area has a little coral bottom, especially around Tomini Bay, and rather shallow waters consisting of sand mud around Berau Bay. This varied topography leads to numerous fisheries resources within FMA 715. Tomini Bay is inhabited by many coral fish that can be caught throughout the year; shrimp resources are abundant in the muddy waters of Berau Bay; small pelagic fish resources are available in the shallow waters; while larger pelagic fish resources are available in the deeper waters. Other resources, such as lobster and squid, are also available in FMA 715 (Suman et al., 2014). Some water masses in FMA 715 are influenced by the Indonesian Through Flow (ITF), which carries water mass from the Pacific Ocean, entering Indonesia waters from the Sulawesi Sea through the Maluku Sea, Halmahera Sea and Seram Sea (Radjawane and Hadipoetranto, 2014). Other types of water mass characteristic in FMA 715 are semi-enclosed water such as Tomini Bay and Berau Bay.

Generally, climate phenomena including ENSO influence most SST around Indonesia, but only a minor information state about the ENSO effect on semi-enclosed water. In this study, the characteristics of semi-enclosed water SST in FMA 715 are represented by Parimo waters, which are located in the western part of Tomini Bay, while open ocean characteristics are represented by the area around Bitung waters. The objective of this study is to identify one of the ocenaographic parameters (SST) and how climate phenomena such as ENSO and monsoonal processes are related to the variability of SST in Parimo and Bitung. The study also identifies the relationship between climate phenomena and fishery production within semi-enclosed water.

2 DATA AND METHOD

The main data used in the study were the monthly average SSTs derived from Moderate Resolution Imaging Spectroradiometer (MODIS) satellite images from January 2009 to December 2018. SST satellite data with a spatial resolution of 4 km were successfully downloaded from the oceancolor database (https://oceancolor.gsfc.nasa.gov/). A map of the monthly mean climatological SST was then created using QGIS software to show the spatial distribution of SST within FMA 715. To understand the variability, the SST data were extracted at two locations, one representing the variability at the western part inside Tomini bay (Parimo; 120.17°E and -0.76°S) and the other the SST variability in the open ocean (Bitung; 125.25°E and 1.38°N) within FMA 715 (figure 2-1). Another important oceanic indicator is SST anomaly. In this study, the anomaly in Parimo and Bitung was calculated by subtracting the monthly variation to its monthly mean data:

$$SSTA = SST_i - \overline{SST} \qquad (2\text{-}1)$$

where SSTA is SST anomaly and $\overline{\text{SST}}$ is SST monthly mean data

$$\overline{SST} = \frac{\sum_{i=1}^{n} SST_i}{n} \qquad (2\text{-}2)$$

Wind speed data were downloaded from the Indonesian Agency of Meteorology, Climatology and Geophysics database center (http://dataonline.bmkg.go.id/data_iklim). This agency has many climate observation stations scattered throughout Indonesia, one of which is located in Bitung City (125.18°E and 1.44°N). In situ data from local observing stations were choosen for the study, since they can describe more realistic conditions compared to modelling data available online. Daily wind speed data from January 2009 to December 2018 were downloaded from that database centre, then processed into a monthly average using a simple mathematic equation. The monthly average wind speed data are useful in describing their variability related to the monsoon.

The Oceanic Niño Index (ONI) is the standard measure of the ENSO phenomenon using a combination of part of the Niño 3 and Niño 4 regions, also known as the Niño 3.4 region. The occurance of El Niño is indicating by SST anomaly with a value more than +0.5 for five consecutive months. While the occurance of La Nina is indicating by the value of SST anomaly lower than -0.5. Historical El Niño or La Niña event data represented on the Oceanic Niño Index (ONI) are available at the Climate Prediction Center – National Weather Service website (https://origin.cpc.ncep.noaa.gov/products/analysis_monitoring/ensostuff/ONI_v5.php). ONI data from January 2009 to December 2018 are used in this study.

Fish production data recorded by the Parimo Marine and Fisheries Office provide information about dominant small or large pelagic fish caught inside the western side of Tomini Bay. This data series is also a useful indicator for describing fish production during El Niño or La Niña events.

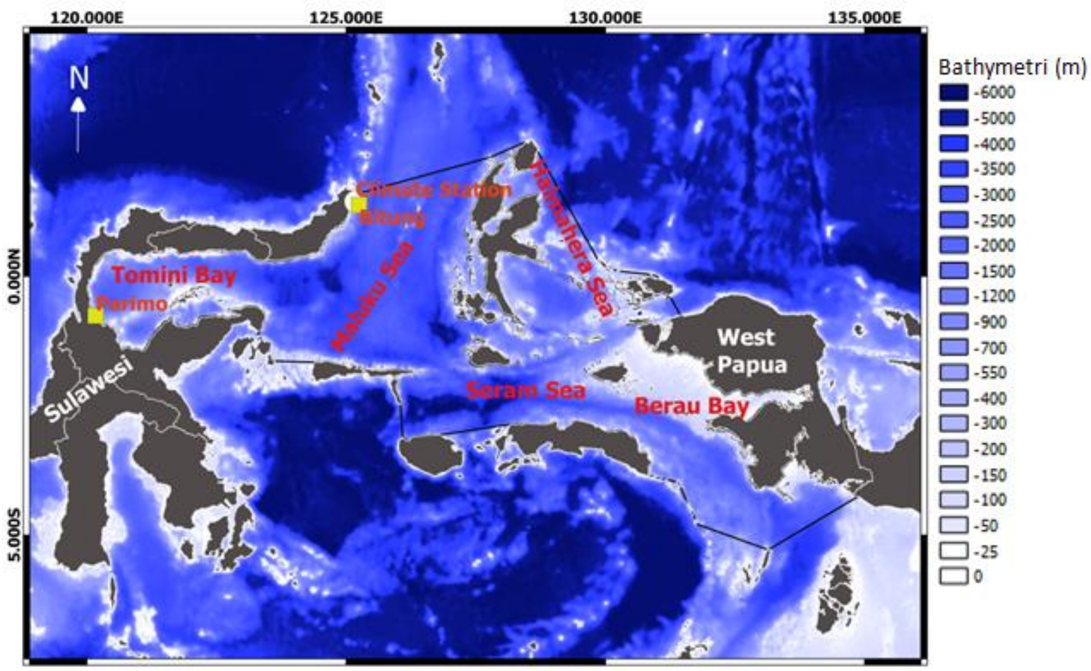


Figure 2-1: Study Area at FMA 715

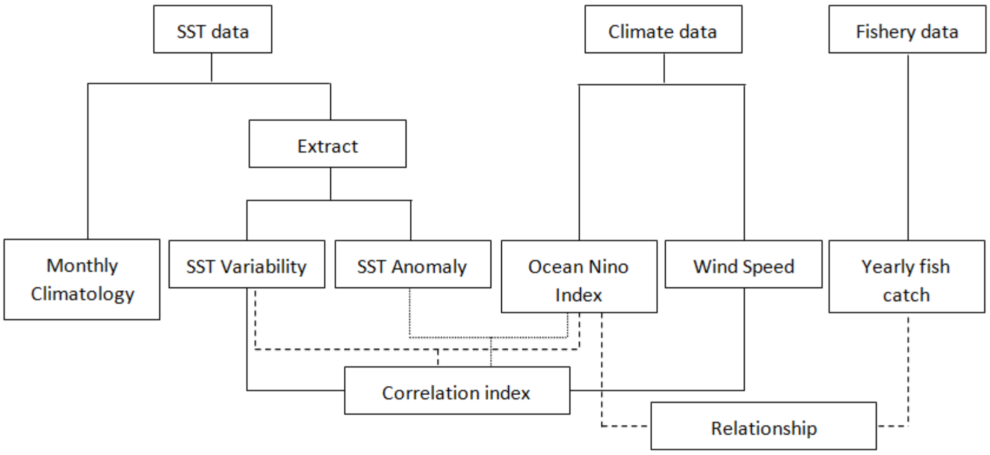


Figure 2-2: Block diagram of this study

Pearson's correlation (Walpole, 1993) is used to test the relationship between SST variability or SST anomaly and the ENSO and monsoons, represented by wind speed.

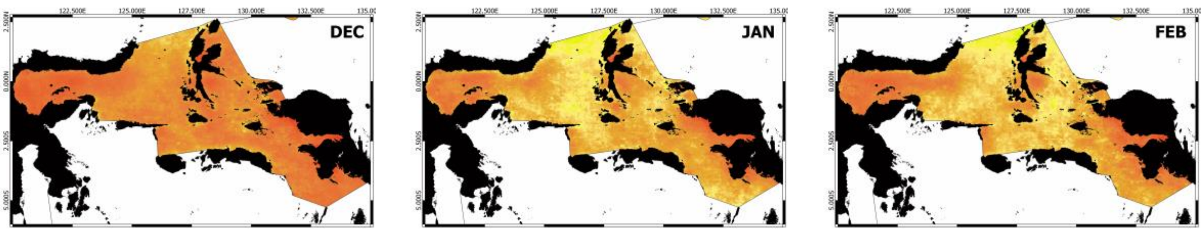
A block diagram of the study is shown in Figure 2-2.

3 RESULTS

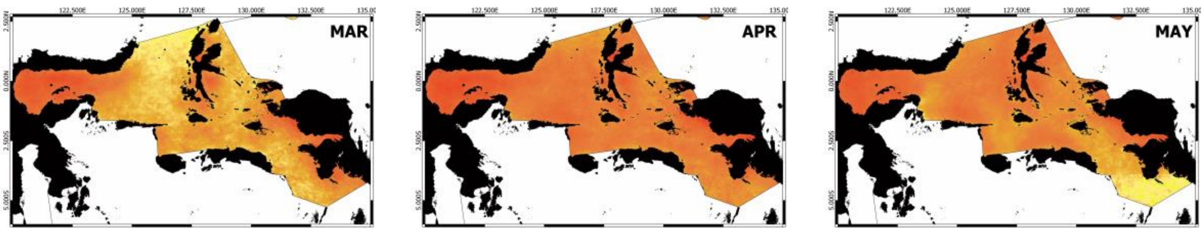
Map of Monthly Climatology SST Mean

Evidence of the close relationship between SST and monsoonal systems within FMA 715 is shown in Figure 3-1. Slightly cooler temperatures are found in some areas in FMA 715 during the boreal winter months (December to March). On the contrary, due to the southeast monsoon, cooler temperatures are found to the south of the equator from June to August. It is also shown that the variability of SST at Parimo, or the western part within Tomini Bay, is relatively stable, with only small SST variations compared to those near Bitung waters.

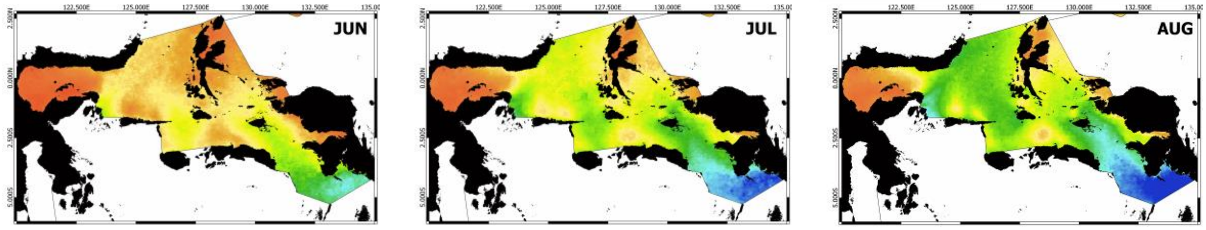
a. Monthly Climatology SST Mean from 2009 to 2018; Northwest Monsoon



b. Monthly Climatology SST Mean from 2009 to 2018; Transition I



c. Monthly Climatology SST Mean from 2009 to 2018; Southeast Monsoon



d. Monthly Climatology SST Mean from 2009 to 2018; Transition II

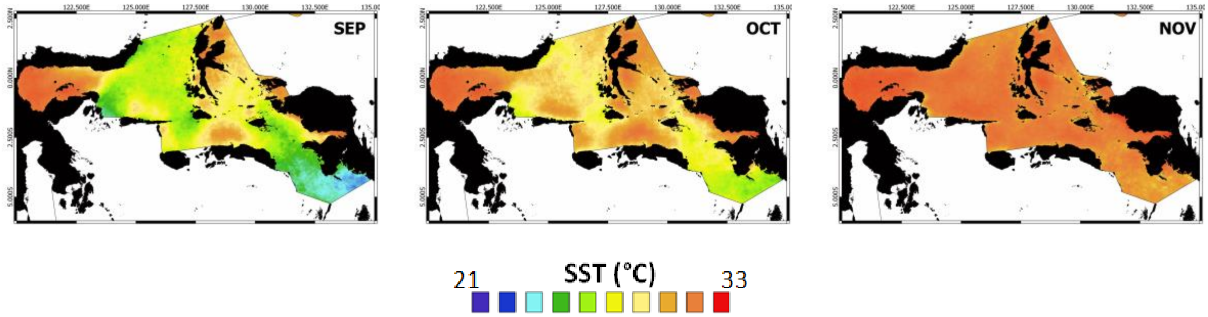


Figure 3-1: Monthly Climatology SST Mean from 2009 to 2018

SST variability

The mean SST value in Parimo waters during the period 2009 – 2018 is 30.68°C (σ = 0.51, n = 120), with a maximum value of 32.22°C in April 2010 and a minimum of 28.73°C in February 2015. The variability in monthly average SST shows that the maximum peak can be present in any month. For example, in 2009 the maximum peak was in October; in 2010, 2015 and 2017 it was in April; in 2011 in May; in 2012 in December; in 2013 in July; in 2014 and 2018 in March; and in 2016 the maximum SST peak occurred in June. Unlike the maximum peak, the minimum SST peak mostly occurs in January or February, except in 2012 when it was August. During the period 2009 – 2018, the mean SST value in Bitung waters was 29.34°C (σ = 0.87, n = 119), with a maximum value of 31.01°C in December 2016, and a minimum value of 26.47°C in August 2015. The pattern of monthly variability in Bitung waters shows that the minimum SST peak is mostly found in July and August, although in 2010 it occurred in February. Similar to Parimo, the maximum peak in Bitung waters can also be found in several different months: in 2009 and 2018 it occurred in April; in 2010, 2014 and 2017 in November; in 2011 in February; in 2012 in March; in 2013 and 2015 in June; and in 2016 the maximum SST peak occurred in December. Figure 3-2 also shows that the SST in Parimo and Bitung waters have completely different characteristics. Most of the year, SST in Parimo tends to be higher than in Bitung. During the period 2009 – 2018, July, August, September and October 2015 were recorded as having the coolest SST in Bitung, with a minimum peak occurring in August.

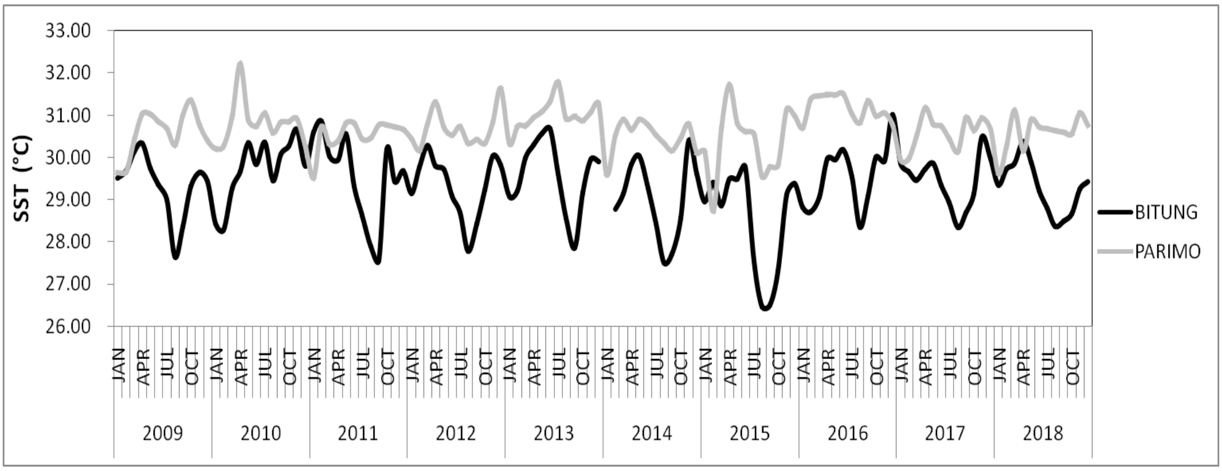


Figure 3-2: SST variability in Parimo and Bitung 2009 - 2018

The monthly climatological mean of SST at Parimo and Bitung waters is presented in Figure 3-3. This clearly shows that the two regions have different variability and surface temperatures. In Parimo, the lowest SST occurs in January (northwest monsoon), increasing in March and reaching its maximum in April (Transitional I). It then slightly cools in August (southeast monsoon), before slightly increasing again until November (Transitional II). In Bitung, SST tends to decrease during the northwest monsoon, especially in January and February. It then starts to increase during Transition I, reaching a maximum in May. Entering the Southeast monsoon, SST starts to decrease and drops to a minimum in August. During Transition II, SST increases again, until a maximum value is reached in November. In general, Bitung waters are cooler than those of Parimo, and also the climatological variation of SST in Parimo is relatively small, with the value of 30.02°C - 31.11°C, compared to that of Bitung, with a variation of 28.04°C – 30.01°C.

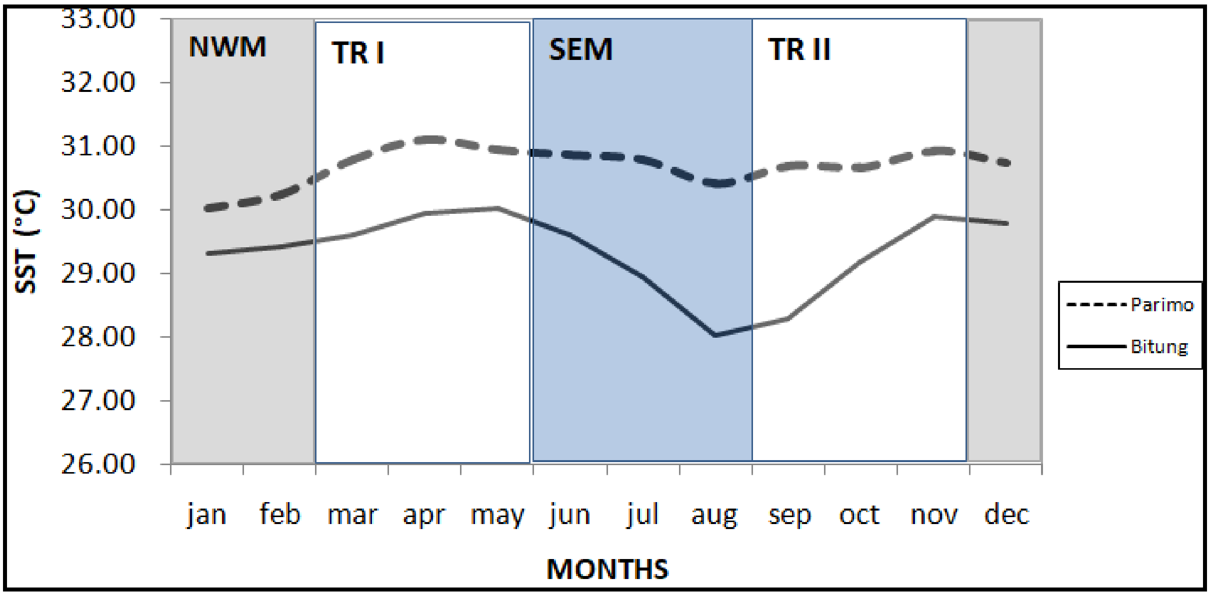


Figure 3-3. Climatology of SST in Parimo and Bitung 2009 – 2018
(NWM: Northwest Monsoon; TR I: Transition I; SEM: Southeast Monsoon; TR II: Transition II)

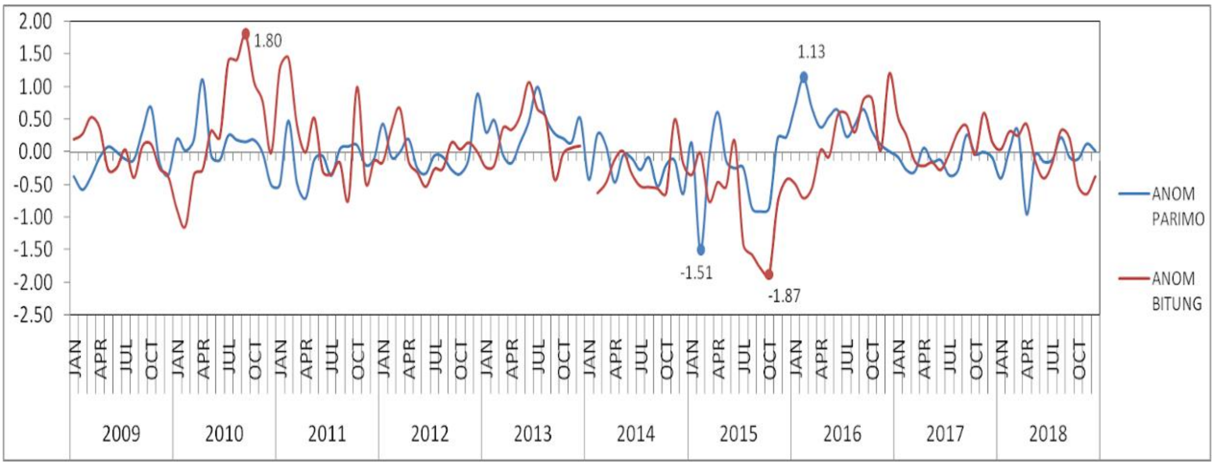


Figure3-4: SST anomaly in Parimo and Bitung 2009 – 2018

The SST anomaly in Parimo and Bitung is shown in Figure 3-4. This is calculated by subtracting the monthly variation to its monthly mean data. The highest positive anomaly in Parimo occurred in February 2016 at 1.13°C, with the lowest negative anomaly of -1.51°C in February 2015. In Bitung, the highest positive anomaly was in September 2010 at 1.80°C, and the lowest negative anomaly found in October 2015 with a value of -1.87°C.

SST anomaly is one of the important oceanic indicators, especially for coastal environments and organisms. Anomalous SST, either cool or warm, in the ecosystem can result in bacteria, algae or fish thriving or suffering. A warm SST anomaly in a certain period sends the signal that the coral reef may be in danger of bleaching.

Wind Speed

Differences in atmospheric pressure will generate wind, which is the movement of air from higher to lower pressure areas. The velocity of the air motion defines the strength of the wind. The mean value of wind speed at FMA 715 is 1.22 m/s (σ = 0.58, n = 120), with the strongest wind speed in January 2014 with a value of 2.48 m/s, while the weakest in July 2010. The monthly climatology mean of wind speed from 2009 to 2018 clearly shows the connexion between the speed and monsoonal systems (Figure 3-5). Low wind speeds tend to occur during Transition I and II periods, with higher speeds occurring during the northwest monsoon and the highest during the southeast monsoon.

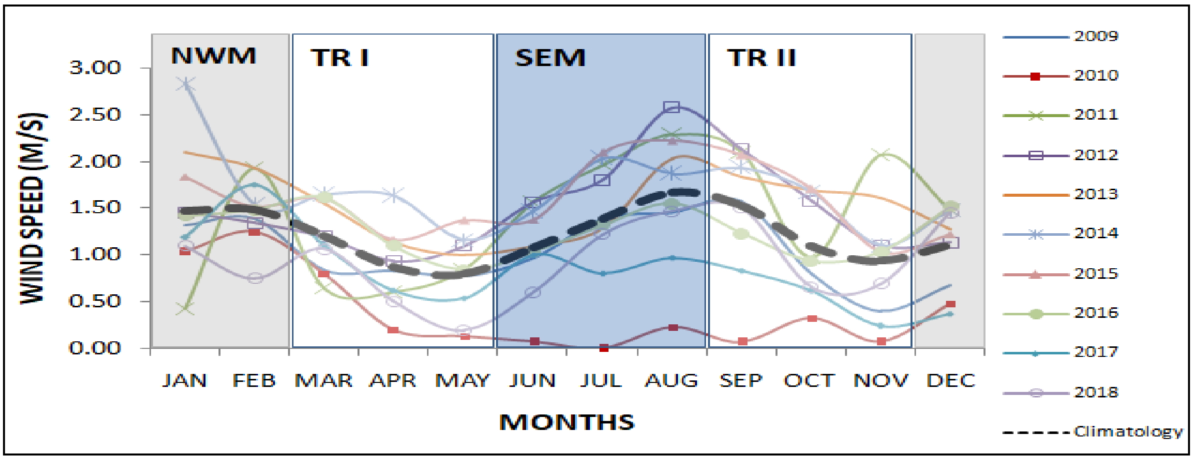


Figure 3-5. Variability and climatology of wind speed at FMA 715 2009 – 2018
(NWM: Northwest Monsoon; TR I: Transition I; SEM: Southeast Monsoon; TR II: Transition II)

Oceanic Nino Index

During the 2009 – 2018 period, several El Niño and La Niña events took place (Figure 3-6). The strongest El Niño started in November 2014 and lasted until May 2016, while the weakest and shortest period was observed between July 2009 and March 2010. From 2009 to 2018 several La Niña events also occurred. The strongest La Niña started in June 2010 and lasted until May 2011, with other weaker and shorter periods taking place between July 2011 and March 2012, August and December 2016, and October 2017 and March 2018. A long normal situation of SST anomaly also occurred between April 2012 and October 2014.

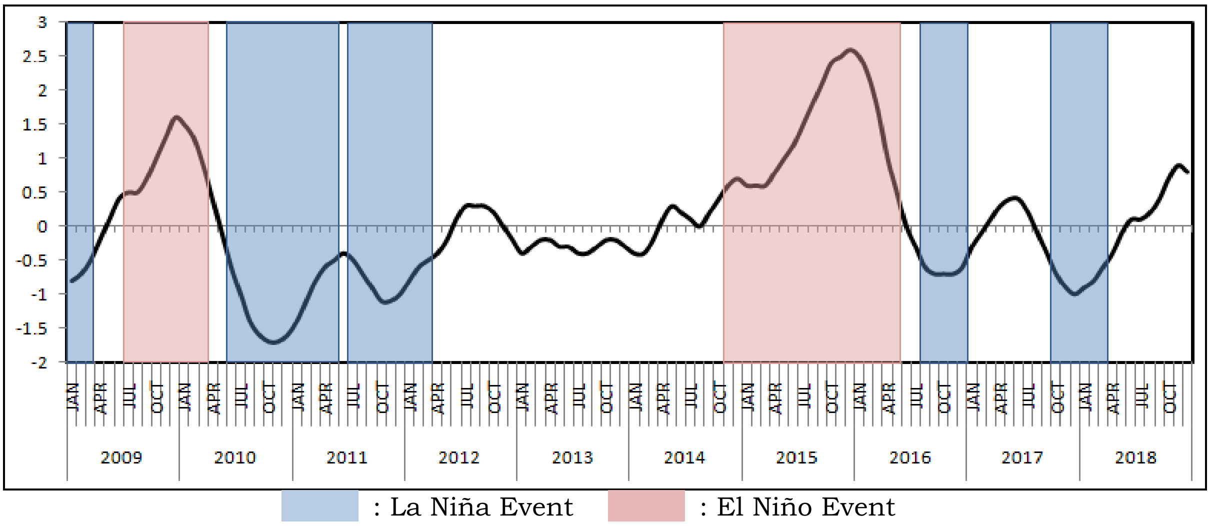


Figure 3-6. Oceanic Niño Index 2009 – 2018

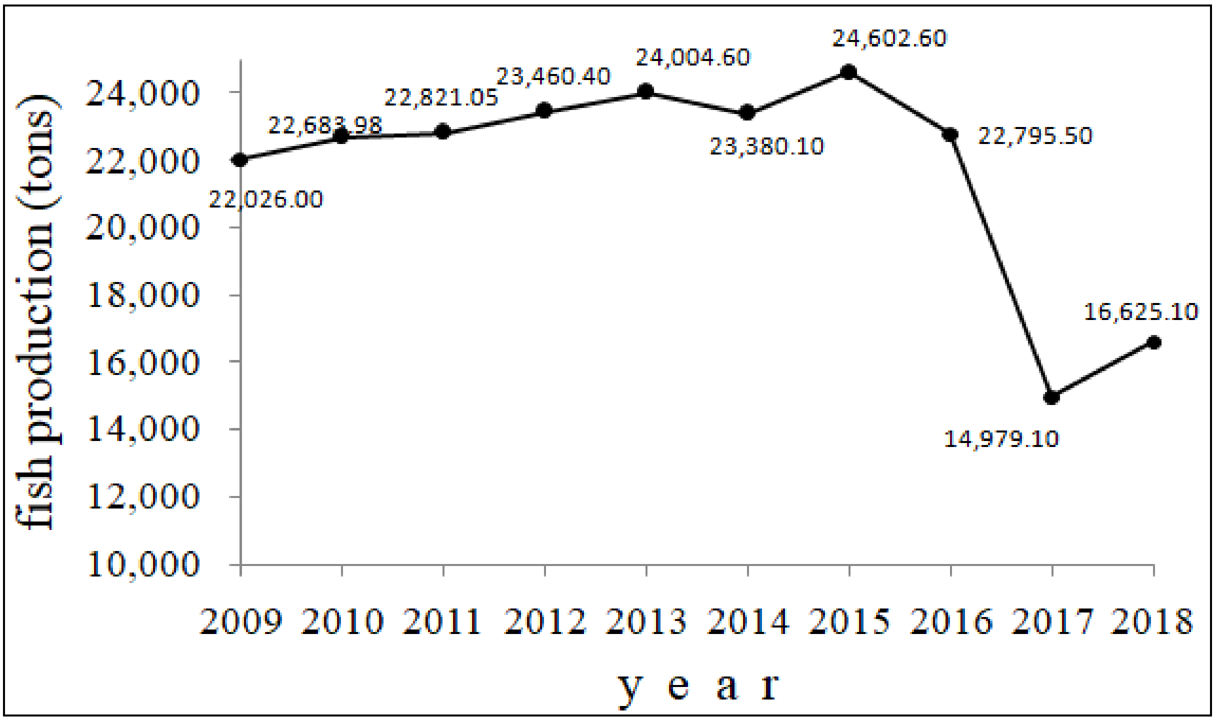


Figure 3-7: Overall fish production in the western part of Tomini Bay

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Yearly fish production in the western part of Tomini Bay

Fishery data is very limited in this area, with no monthly production data available. Only yearly fish catch data based on fish species are available (Figure 10). Overall, based on these data, the highest fish production was recorded in 2015, with a total of 24,602 tons, while the lowest was recorded in 2017, with a total of 14,979 tons. Fish production for small pelagic fish in the western part of Tomini bay was dominated by Selar Kuning (*Selaroides leptolepis*), with a total catch in 2018 of 2,846 tons. This is consistent with Amri et al.'s (2006) findings. Production for large pelagic fish was dominated by Cakalang (*Katsuwonus pelamis*), with a total catch of around 3,273 tons in 2018.

During the strongest La Niña event in 2010, fish production tended to increase compared to previous years, with production showing a positive increasing trend until 2013. It then showed a slight decrease in 2014, which was considered to be a normal year. During the strong El Niño event in 2015, fish production increased and reached a maximum peak, before significantly falling in 2016 and reaching a minimum level in 2017. The lowest fish production during the 2009-2018 period was also recorded in 2017. In 2018, when a La Niña event occurred at the beginning of the year, fish production showed a sign of improvement.

Relationship between SST variability, ENSO and monsoons

A correlation test between the monthly variation in SST or SST anomaly in Parimo and Bitung, with ONI conducted after only the months with El Niño or La Niña events were selected, as shown in the scattergraphs below (Figures 3-8 and 3-9). The results show that the correlation coefficient between SST and ENSO in Parimo is r = 0.06 (n = 66), indicating that SST variation in Parimo has a very weak correlation with ENSO. On the contrary, SST variation in Bitung has a strong but reverse relationship with ENSO, at r = -0.53 (n = 66)

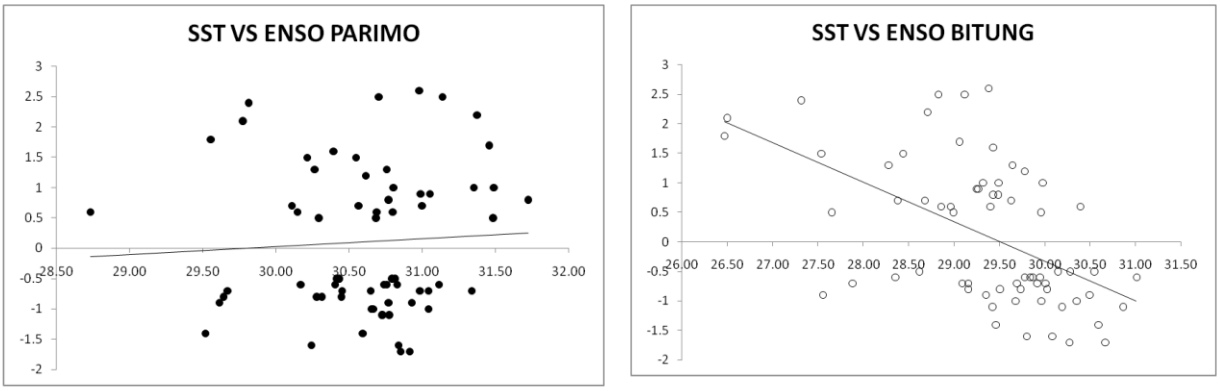

Figure 3-8: Scattergraph of relationship between SST and ENSO

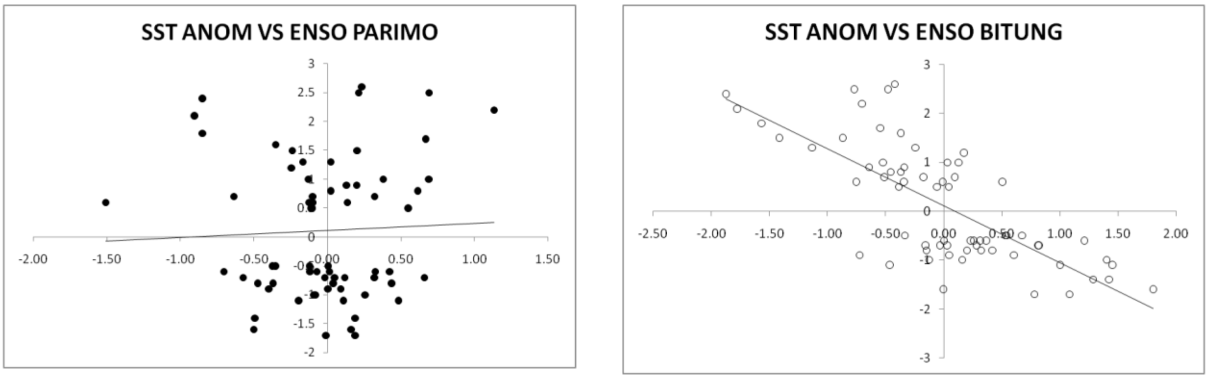

Figure 3-9: Scattergraph of relationship between SST anomaly and ENSO

The SST anomaly in Parimo also has a weak relationship with ENSO, at r = 0.05 (n = 66), but in Bitung the SST anomaly has a very strong, but reverse, relationship with ENSO, at r = -0.74 (n = 66).

Windspeed was also tested using a correlation test on the variation in SST in Parimo and Bitung in order to understand the relationship between monsoon systems, represented by wind speeds, and the variation in SST during the 2009 - 2018 period. The test shows that wind speed has a weak correlation, at r = -0.29 (n = 120), in Parimo, and a strong correlation, ay r = -0.60 (n = 119) in Bitung.

4 DISCUSSION

SST variablitiy in Parimo

In general, the seasonal variability of SST in Indonesian waters is very varied and mostly affected by the monsoonal systems (Martono, 2016). Some areas, such as the Makassar Strait, Sulawesi Sea and the Halmahera Sea, experience only small variations, with warm SST over the years, which is similar to SST characteristics in Parimo. The variability of SST in FMA 715, especially around Tomini Bay, was examined over the period 2002 to 2003 (Amri et al., 2006), showing a similar pattern to the SST variability found in this study, which used SST satellite data from 2009 to 2018. The pattern of SST variability tends to be high during the northwest monsoon and low during the southeast monsoon. In-situ measurements from 2002 to 2003 also showed that SST within Tomini Bay is higher than that at the mouth of the bay. Inside Tomini Bay, wind speed has a small and inverse correlation with the variability of SST (r = -0.29), indicating the wind is not a dominant factor in SST variations. Another factor that might influence the SST variability inside Tomini Bay is tidal currents. Qu et al. (2005) state that in the Indonesian region these are very strong. The currents generate an intense ocean mix, which influences SST in numerous channels and basins in the archipelago. As well as wind speed, the ENSO event does not influence the variability in SST (r = 0.06) inside Tomini Bay a situation which is also found in other parts of Indonesian waters. In Ambon Bay, Corvianawatie et al. (2014) argued that the monthly SST anomaly was not correlated with ENSO, but was strongly influenced by the local morphological conditions of the bay, which has the semi-enclosed basin characteristic.

SST variability in Bitung

The higher SST variation in Bitung waters is closely related to the upwelling indicator found in the northern (near Bitung) and southern part of the mouth of Tomini Bay (Amri et al., 2005). Some other areas in Indonesia have similar conditions, with a higher variation in

SST caused by the upwelling process, for example in the southern waters of Java, the Timor Sea, Arafura Sea and Banda Sea. Upwelling is a process caused by the stress of surface wind, which brings cooler and nutrient-rich water near to the surface. The geographical position of Bitung waters is more exposed than those of Parimo, which mean they are more influenced by the watermass from the Pacific throughflow. The Sulawesi Sea is the entrance for the cooler watermass from the Pacific ocean (Gordon, 2005) to Indonesia waters, including to the Maluku Sea and Halmahera Sea (Radjawane and Hadipoetranto, 2014). The cooler SST from the Pacific Ocean is suspected to be a key factor that causes the climatological SST in Bitung to be always lower than that in Parimo. Unlike within Tomini Bay, the variability in SST in Bitung waters is influenced by, and has a strong but reverse relationship with both wind speed (r = -0.60) and ENSO events (r = -0.53). The SST anomaly in Bitung also shows a strong inverse relationship with ENSO events (r = -0.74).

SST variability and monsoons in general

By this study, the lowest SST anomaly (-1.87°C) was found during the strongest El Niño event, while the highest (1.80 °C) was found during a La Niña event. SST variability in Indonesia is generally low compared to the tropical eastern Pacific, due to the lack of strong equatorial upwelling. The interannual variability in the eastern part of Indonesia, such as in Timor, Arafura and the Banda Sea, is less than 2.0 °C (Qu et al., 2005). SST anomalies in Indonesia waters are also affected by the monsoonal systems and global climate change, such as the Indonesian Dipole and El Niño (Martono, 2016). Other research has also found that wind speed is an important factor that influences SST variability and anomalies in other Indonesian waters, especially in the Makassar Strait (Nababan et al., 2016), the Java Sea and Jakarta Bay (Corvianawatie, 2019). The Asia-Australia monsoon which influences Indonesian waters is characterised by seasonal changes in wind speed/stress direction. The lowest wind speed/stress takes place in April, which is clearly the month of transition between the northwest and southeast monsoons. A characteristic of the southeast monsoon is the intensified easterly winds, which start in June and reach their peak in July and August, after which they begin to subside. October is a monsoon transition month, when winds are low within the internal Indonesian Sea. In December, the wind changes direction and reaches a maximum in January-February (Susanto et al., 2006).

ENSO and fishery production

An impact of El Niño across Indonesian waters is the increase in ocean productivity due to anomalous easterly wind stress, that generates strong upwelling in some parts of Indonesian waters (Susanto et al., 2006). Upwelling is characterised by nutrient-rich water, but cooler SST. This anomalous wind is believed to be a key factor in causing the lowest SST and SST anomaly in the 2009 to 2018 period. Elsewhere, for example in the South China Sea, Piton and Delcroix (2018) state that the variability in SST is also connected to upwelling due to wind stress curl or Ekman pumping during the El Niño phase. Indonesian waters respond differently to the ENSO event. In some areas, such as Sumatra, Java and the Banda Sea, productivity increases due to the stronger upwelling during the El Niño event. Higher productivity during the El Niño phase is connected to fisheries production; for example, in the eastern Indian Ocean, the highest CPUE (Catch Per Unit Effort) of swordfish was found during an El Niño event (Setyadji and Amri, 2017); the highest tuna landings from the Indian Ocean have been recorded during El Niño years (Kumar et al., 2014); and skipjack catches in southeastern Java are also influenced by ENSO, with production increasing during El Niño events and declining during La Niña events (Handayani et al., 2019). In addition, the climate change that has intensified alongshore wind stress and accelerated coastal upwelling in the Bali Strait has likely increased sardine production (Gaol et al., 2012). In the western part of Tomini Bay, near Parimo waters, yearly catch data indicate that fish production has not been affected by ENSO events; yearly production may increase or decrease in any phase, during La Nina, El Niño or in normal conditions. Related to data on the decrease in fish production in 2017, Kadim et al. (2017) state that environmental degradation due to pollution might affect the abundance of the fish population around the western part of Tomini Bay. Another theory is that fish caught but unreported to the authorities may have been the reason for the decrease in fish production in 2017.

5 CONCLUSION

SST characteristics and variability in Parimo and Bitung waters are very different, although they are both located in the same FMA. SST in Parimo waters is warmer, but with lower variability compared to Bitung waters. Based on the mean climatology of SST, the minimum SST in Parimo occurs during the northwest monsoon, while in Bitung it is during the southeast monsoon. In Parimo, wind speed and ENSO events have a weak relationship with SST variability. The opposite was found in Bitung, where wind speed and ENSO have a stronger relationship with SST variability. In other parts of Indonesian waters, El Niño and La Niña are connected with fishery production; production increases during the El Niño and decreases during La Niña. Unlike in other parts of Indonesia, fishery production in Parimo or the western part within Tomini Bay is not affected by ENSO events.

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