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Validation of potential fishing zone forecast using experimental fishing method in Tolo Bay, Central Sulawesi Province

W E Rintaka and E Susilo

Institute for Marine Research and Observation, Ministry of Marine Affair and Fisheries
Jl. Baru Perancak, Jembrana - Bali, Indonesia

E-mail: era09.bpol@gmail.com

Abstract. The national scale of Indonesian Potential Fishing Zone (PFZ) forecast system has been established since 2000. Recent times this system use Single Image Edge Detection algorithm to automatically identify thermal front from remote sensing images. Its generate two fishing ground/FG criteria: FG (high probability) and potential fishing ground/PFG (medium/low probability). To quantify the accuracy of this algorithm, an experimental fishing/EF was carried out in Tolo Bay, Central Sulawesi Province at September 2016 the late southeast monsoon period by using a pole and line fishing vessel. Four fishing activities (P1, P2, P3, and P4) were conducted during this study at a different location nearby the PFZ forecast position, two of them had good results. Based on distance measurement, these locations P1 and P4 were associated with PFZ forecast position. They were associated with PFG and FG criteria. The distance between EF to P1 and P4 were 9.7 and 6.69 nautical miles. The amount of catch for each location was 850 and 900 kg, respectively.The other locations P2 and P3 were also associated with PFG criteria, but there was no catch. We conclude that the number of the catch is influenced by the distance from PFZ forecast position and criteria.

1. Introduction

The information of fishing ground forecast in Indonesian waters is very important. The fishermen face limitation in determining fish migration areas and fishing grounds. Oceanographic variability is considered to be the dominant factor affecting the pelagic fish distribution and abundance in the ocean [1,2,3]. It also tends to be influenced by regional and global climatic conditions [4, 5]. In the last few decades, the availability of satellite images allows us to monitor marine environmental conditions in near real time for large areas, making them particularly suitable for determining the pelagic fishing ground [6,7,8,9].

The Institute for Marine Research and Observation (IMRO) has developed a prediction system of pelagic fishing ground in Indonesian waters. A national scale of Potential Fishing Zone (PFZ) forecast system called *Peta Prakiraan Daerah Penangkapan Ikan* (PPDPI) has been established in 2000. The IMRO PFZ forecast system has provided the prediction of pelagic fishing ground locations throughout Indonesian waters routinely. The information of potential fishing locations is generated based on oceanographic variables such as chlorophyll-a concentration, sea surface temperature and sea surface anomaly derived from satellite oceanographic images. Recently, the PFZ forecast system uses Single Image Edge Detection (SIED) algorithm to identify thermal front from sea surface temperature images automatically. This system will generate two fishing ground criteria, namely fishing ground/FG (high probability) and potential fishing ground/PFG (medium or low probability) [10, 11]. PFZ forecast system is expected to be helpful to determine the potential locations for fishing activities and to make fishing operations more effective and efficient.

In general, research and development activities are still underway to improve the availability and quality of IMRO PFZ forecast system based on three aspects, namely: 1) near real-time data retrieval processing; 2) algorithm development; and 3) accuracy assessment. The accuracy of PFZ information becomes an important aspect. Several studies have been carried out to determine the accuracy of this product based on fishing logbook and remote sensing data. After being compared with the fishing dataset, a significant accuracy value for Bali Strait area of 41.80 % was obtained. The highest value (69.57 %) occurred in October [12]. Furthermore, some radar images showed that the fishing vessel activities at Natuna Sea corresponded to PFZ information (40.97 %) with the highest value reaching 86.74 % in May [13]. Nevertheless, an accuracy assessment through direct fishing survey activities (experimental fishing) has not been done. The purpose of this study was to determine the variability of oceanographic conditions and trends and to validate PFZ forecast product requiring actual catch data at fishing grounds by collecting experimental fishing data at Tolo Bay, Central Sulawesi Province.

2. Methodology

2.1. Study area

Tolo Bay is the water lying between the eastern and south-eastern peninsulas of Sulawesi (Celebes) Island in Indonesia. Being included in the Fisheries Management Area (FMA) 714, the oceanographic conditions of Tolo Bay are highly influenced by the Banda Sea since Tolo Bay lies open to and face directly to this area (figure 1). Tolo Bay has a huge amount of small and large pelagic fish production, approximately 68.456 tons per year, which is dominated by skipjack tuna and eastern little tuna [14].

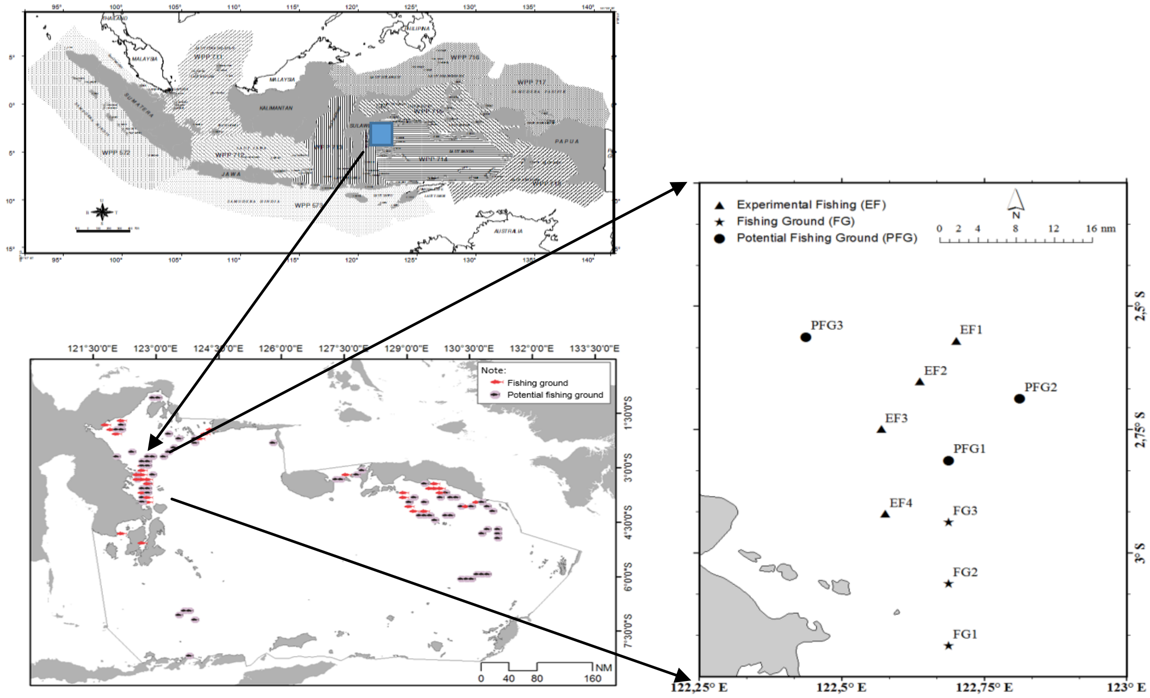

Figure 1. The study area (blue square). The location of experimental fishing (▲), PFZ forecast criteria (●: *PFG or* ★*: FG*).

2.2. Potential fishing zone data set
The spatial distribution and trends of potential fishing zone were prepared based on the time series analysis of the IMRO PFZ forecast system in 2016, particularly in the Banda Sea. This forecast system provided information three times per week routinely (Monday, Wednesday and Friday). It generated two PFZ criteria (fishing ground/FG and potential fishing ground/PFG) based on the appearance of thermal front and favorable range of chlorophyll-a concentration. Both variables were derived from MODUS (Moderate Resolution Imaging Spectroradiometer)/Aqua or MODUS/Terra Level 3 images. The sea surface temperature images were used to identify thermal front by using Single Image Edge Detection (SIED) algorithm. Meanwhile, the favorable range of chlorophyll-a concentration was determined to be 0.2-0.5 mg/m^3 [10]. These satellite images were downloaded from the NASA's OceanColor web (http://oceancolor.gsfc.nasa.gov). The daily fishing ground locations were used for validation purpose. There were three pieces of FG information and three pieces of PFG information generated by the PFZ forecast system coinciding with the experimental fishing survey time (figure 1).

2.3. Validation method
The experimental fishing activities were carried out for five days in the late southeast monsoon period (20-24 September 2016) in four different locations near the PFZ (figure 1). The fishing activities were conducted by using a pole and line vessel from Kendari Fisheries Port. The results of this survey include the information on the actual fishing activities, i.e. fishing location (longitude/latitude) and characteristics of fish catch (species, amount, and size). The accuracy assessment was done by comparing the PFZ information with the experimental fishing dataset based on the distance from PFZ and amount of catch. We also measure the oceanographic variables (temperature, salinity, chlorophyll-a) in the fishing location to know the relationship between oceanographic conditions, particularly the vertical profile of temperature and chlorophyll-a concentration, and the number of catches.

2.4. Oceanography variables
Measurement oceanography variables (temperature, salinity, chlorophyll-a) to know environmental parameters in the fishing location. The oceanography variables in the fishing location to know relationship vertical profile of temperature and chlorophyll-a concentration, with the abundance variability and number of catch.

3. Results and Discussion
3.1. Relationship between potetial fishing zone and oceanographic conditions
Time series analysis of the potential fishing zone generated by IMRO PFZ forecast system is important to know the occurrence of the potential fishing zone in experimental fishing areas and its relationship with the variability of the oceanographic conditions. The highest number of fishing grounds in 2016 occurred during the southeast monsoon period (June-July), which coincided with the peak of upwelling in the Banda Sea. The feature occurring peak upwelling shows low sea surface temperature (SST) and high chlorophyll-a concentration according to the satellite images. The time series of MODIS/Aqua or MODIS/Terra satellite images revealed that the SST and chlorophyll-a ranges during this period were 26.82-30.9^{o}C and 0.13-1.63 mg/m^3, respectively. However, the number of fishing grounds decreased significantly during the rainy season (December-May). This is because of the fact that the satellite images in that period had high cloud cover so that the PFZ forecast system could not generate any PFZ information. Warmer SST and chlorophyll-a concentration fall during the northwest monsoon period trigger the decrease of number of fishing ground occurrences. The full temporal variability of SST, chlorophyll-a and number of fishing grounds in 2016 can be seen in figure 2.

The distribution and seasonal variation of fish involve the study of diverse factors such as the availability of food supply [14], as well as temperature, light, salinity and other chemical properties of water quality [15, 16]. SST will lead to changes in current pattern, upwelling and accumulation of plankton [17]. Water temperature and phytoplankton concentration usually influence the behavioral response of fish [18, 19]. During the northwest monsoon period, the average temperature of the Banda Sea was 4°C warmer than that in the southeast monsoon period [20]. Other research concludes that in February the wind blows from the northwest, which causes the waters in the Banda Sea, Java Sea and Flores Sea to be relatively warm [21].

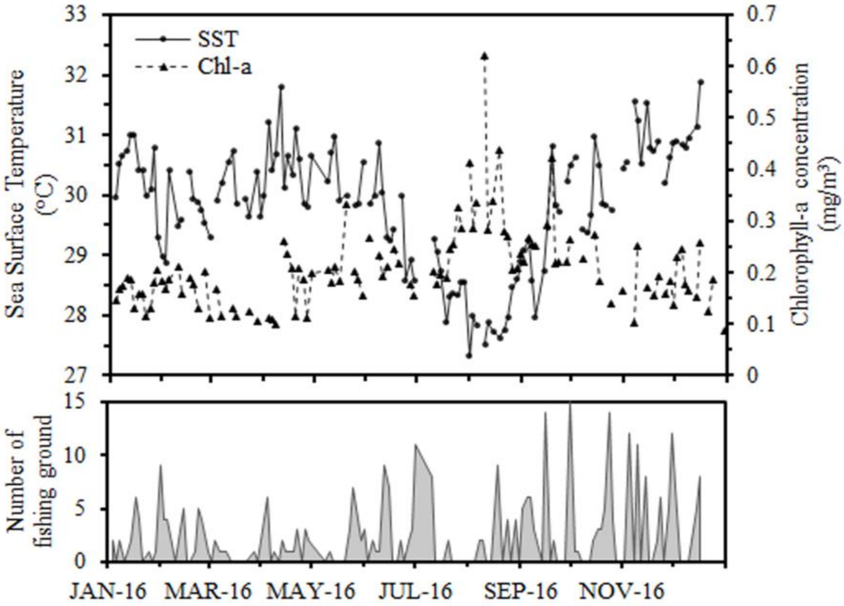

Figure 2. Temporal variability of sea surface temperature, chlorophyll-a concentration, and number of fishing ground in 2016.

The spatial and temporal analyses of SST according to satellite images show that low-temperature conditions occurred from mid-July to mid-September 2016, which ranged between 22-23 °C (Figure 3). This condition coincided with the period of the monsoon, which is characterized by the gusts of southeast monsoon winds that carry cold temperatures from the eastern part of the Banda Sea. Conversely, during the northwest monsoon period, the ocean temperature conditions become warmer in the range of 26-29°C. Being one of the waterways from the Pacific Ocean to the Indian Ocean through Arlindo system, the Banda Sea has characteristics and dynamics strongly influenced by the topography and configuration of the existing islands and the monsoon winds that occur in the region. The basic variation of the waters and the configuration of the archipelago can lead to mixing of water masses, changes in current direction and upwelling, which cause current deflection due to the threshold and the sea. Monsoon winds blowing in the Banda Sea, as in Indonesian waters in general, are the northwest monsoon in December-February and southeast monsoon in June-August [22]. Low SST and high chlorophyll-a concentration tend to be seen in near-shore areas. The high concentration of chlorophyll-a in these coastal waters as a result of upwelling occurs in coastal areas. High concentration of chlorophyll-a is also suspected to be caused by the high supply of nutrients derived from the mainland through river runoff. Conversely, they tend to be low in offshore area. The chlorophyll-a concentrations ranged between 0.65 mg/m^3 and 0.90 mg/m^3. In general, chlorophyll-a concentration has a negative correlation with SST, in that when the SST reaches a minimum value, chlorophyll-a concentration is relatively close to a maximum value. This can be seen clearly in December-January when the minimum surface-chlorophyll-a occurs and in July-August when the maximum occurs (figure 4). This result is close to the result of research [23], showing that the chlorophyll-a concentration of the Banda Sea reaches a maximum value (0.45 mg/m^3) in the the

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eastern monsoon period and, on the contrary, reaches the minimum value (0.15 mg/m^3) in the western monsoon period.

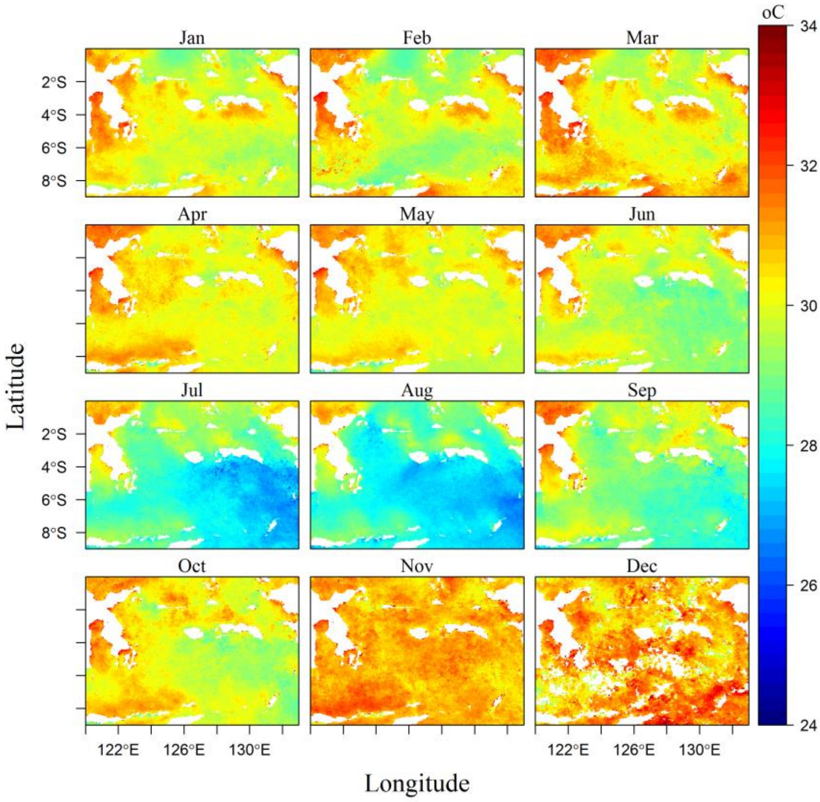

Figure 3. Spatial and temporal distribution of monthly sea surface temperature in 2016.

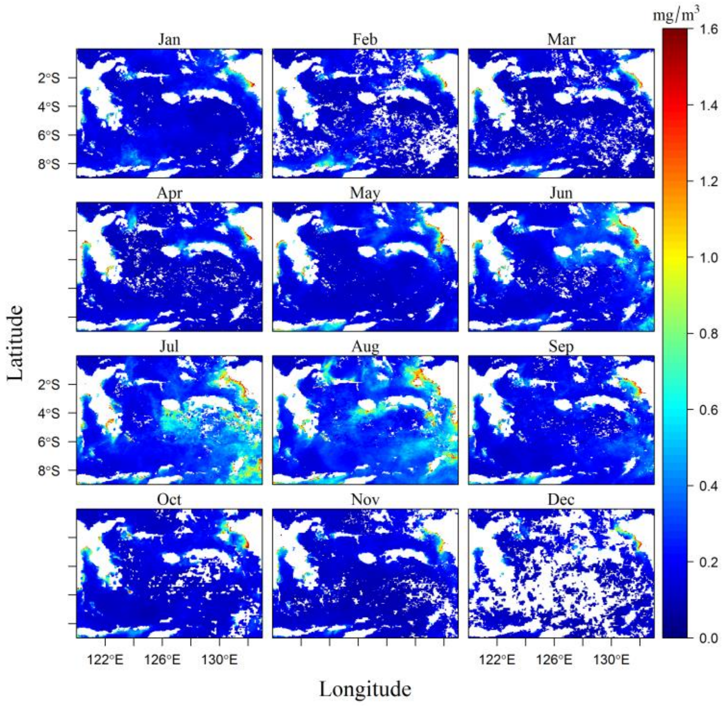

Figure 4. Spatial and temporal distribution of monthly chlorophyll-a concentration in 2016.

Upwelling causes nutrients enrichment on the ocean surface layer. High nutrients increase phytoplankton growth and primary productivity [5, 24]. In addition, the emergence of cold air mass increases the chances of the front temperature [25]. The front temperatures at the moment rise more clearly and strongly by the longer front line [11]. However, the use of image data from passive sensor recording, such as MODIS, is associated with cloud cover problem. This prevents the identification of front temperature and favorable chlorophyll-a concentration, which are the main parameters of PFZ forecast system, from being carried out. The horizontal variation in SST and chlorophyll-a concentration results in a change of current patterns indicative of upwelling process and accumulation of phytoplankton along the thermal front/boundaries. Upwelling is quite pronounced in the equatorial region when trade wind blows and surface water flows from east to west in the southeast monsoon period [17]. During the southeast monsoon period (July-September) strong winds from the Banda Sea blow to Tolo Bay until the southest coast of Sulawesi and cause upwelling in this area. Meanwhile, weak upwelling is observed during the northwest monsoon period (Februari-Maret).

The in situ SST from CTD measurenment during the southeast monsoon period ranges between 29.01°C and 29.51°C, which is relatively constant from the surface to a depth of 16-50 m. The temperature decreases with the increase of depth. Relative temperatures decrease drastically at a depth of 50 (28.32°C) to 100 m (19.76°C). The minimum temperature at a depth of 120-150 meters having been observed ranges between 19.46°C and 21.21°C. The surface salinity ranges between 33.61 psu and 33.75 psu. At a depth of 20 meters, it decreases between 34.17 psu and 34.21 psu. The salinity ranges between 34.08 psu and 34.28 psu at a depth of 50 to 100 m. Salinity increases with the increase in the depth and reaches the maximum at a depth of 120-150 meters. The surface chlorophyll-a concentration ranges between 0.04 mg/m^3 and 0.09 mg/m^3. It increases with the increase in depth until reaching a maximum value, and the concentration decreases until the maximum depth is reached. The maximum chlorophyll-a consentration is obtained at a depth of 45-50 meters, ranging between 0.66 mg/m^3 and 0.88 mg/m^3. The vertical distribution of temperature, salinity and chlorophyll-a is very important because it is closely related to the distribution of fish, especially pelagic fish such as skipjack tuna and yellowfin tuna. Skipjack tuna can be caught at a depth of 0-40 meters. Its spread in tropical waters is strongly influenced by the thermocline layer (figure 5).

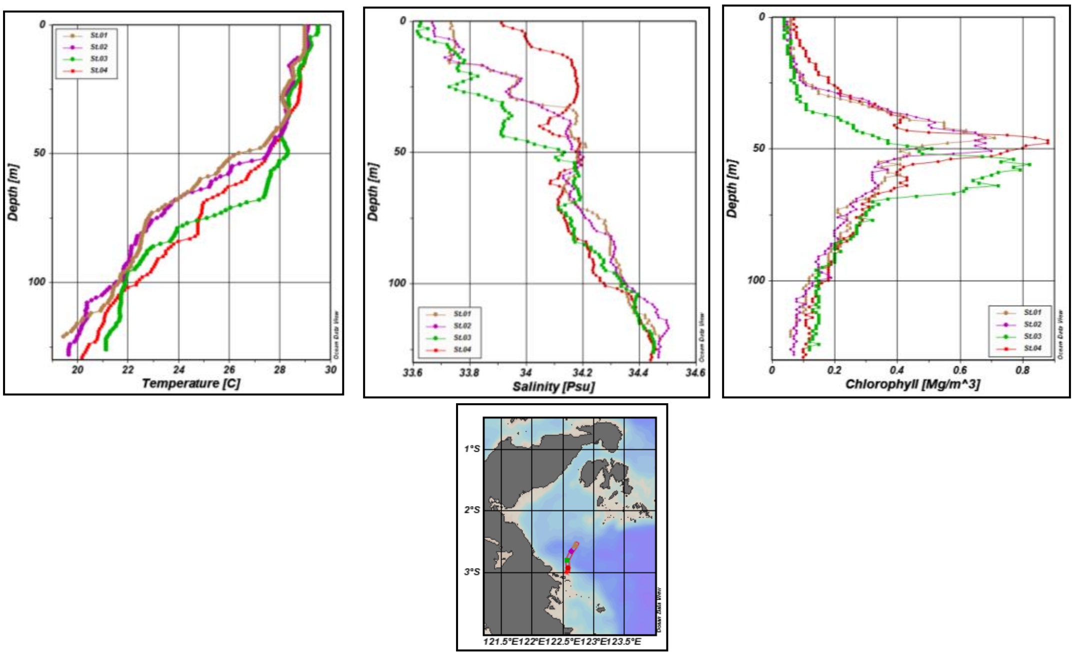

Figure 5. Vertical distribution of temperature, salinity, and chlorophyll-a concentration from in-situ measurement.

3.2. Validation of potential fishing zone forecast

Validation of PFZ Forecast was conducted by using inter-cropping method between the location of experimental fishing (▲) and the PFZ location (★for fishing ground; ●for potential fishing ground). The location identification of the PFZ forecast system refers to the information of the existence of fronts temperature (*thermal fronts*) and water fertility. Thermal fronts are an oceanographic phenomenon characterized by the meeting of water masses that have different temperatures [26]. The identification of the thermal fronts in the PFZ forecast system is carried out by applying different temperature gradients in order to obtain the most accurate temperature gradient. The temperature gradient for detecting thermal fronts is 0.5 °C. This value was used as a proxy for the detection of two different water masses of temperature at the study site. Pelagic fish converge at the current boundaries that have horizontal temperature gradient (thermal front). Meanwhile, the value of water fertility indicated high abundance of phytoplankton at a limit of between 0.2 and 1 mg/m^3. The abundance of phytoplankton serves as a sign of potential fish presence in the prediction area. But at the time of the field survey the value of chlorophyll-a concentration in the northern part of Tolo Bay was detected by satellites to be < 0.2 mg/m^3. Cloud coverage was also seen at several points adjacent to the experimental fishing locations. This condition caused some prediction sites to be declared as potential fish areas because they did not meet the criteria of water fertility. By using this method on September 22-24, 2016, the PFZ forecast system provides information on three locations of fishing ground and three locations of potential fishing ground (figure 6).

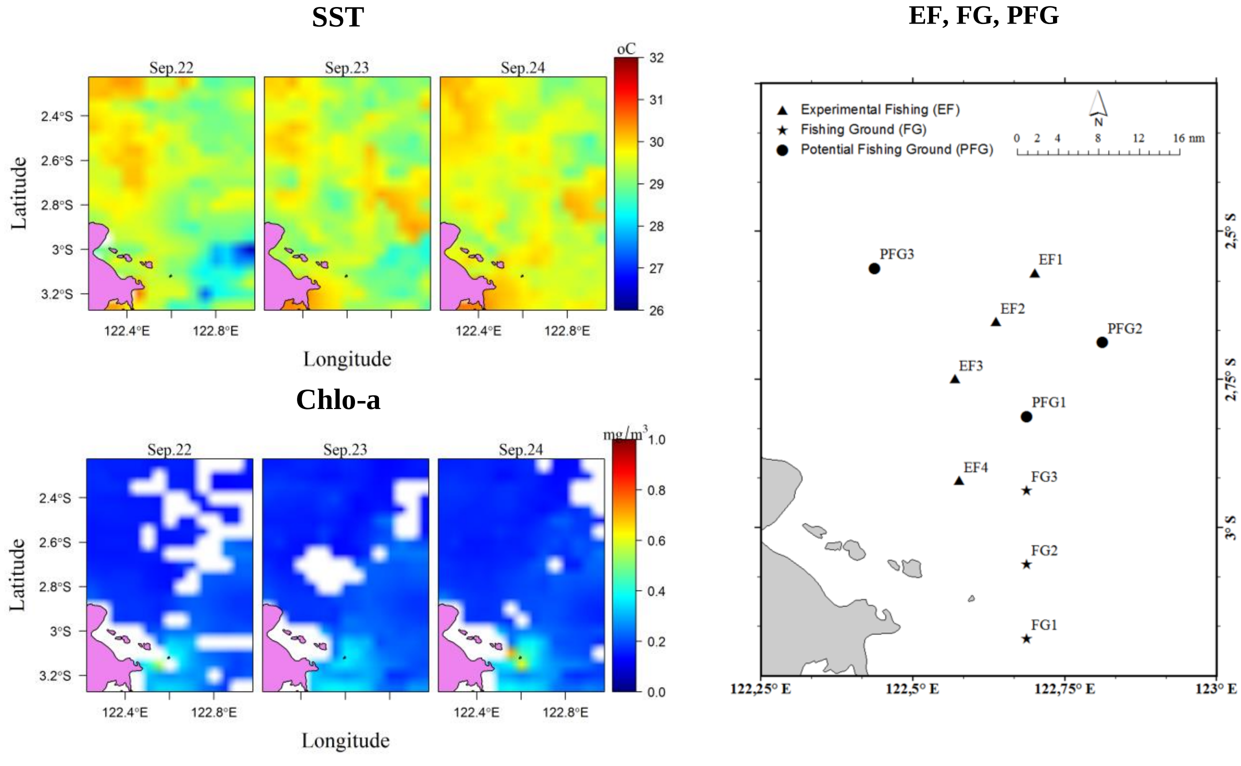

Figure 6. Sea surface temperature, chlorophyll-a concentration and the location of experimental fishing (▲), PFZ forecast criteria (●: *PFG or* ★*: FG*) on September 22-24 2016.

There were a total of four locations of experimental fishing (EF) sites. Based on the analysis of the nearest distance between experimental fishing (EF) location and fishing ground (PFG or FG) location, there were one location adjacent to the fishing ground (EF4) and three locations adjacent to the potential fishing ground (EF1, EF2, EF3). EF1 was 9.7 nautical miles (17.96 km) away from the potential fishing ground (PFG2). The activity in EF1 yielded catch of 850 kg, which consisted of 680 kg of skipjack tuna (*Katsuwonus pelamis*) and 170 kg of yellowfin tuna (*Thunnus albacares*). The other experimental fishing locations (EF2 and EF3) were 10.05 nautical miles (18.52 km) and 8.01 nautical miles (14.83 km) away from the potential fishing ground (PFG1), respectively. The last experimental fishing location EF4 collected 900 kg of catch, which consisted of 540 kg of skipjack tuna (*Katsuwonus pelamis*) and 270 kg of yellowfin tuna (*Thunnus albacares*), 90 kg of mackerel tuna (*Euthynnus sp*) and dolphinfish (*Coryphaena hippurus*). EF4 location was the closest to FG. The distance between experimental fishing (EF) locations and fishing ground and catch is shown in Table 1. In the present study, the feedback analysis indicated that catch found to be high is a confluence of SST and chlorophyll features [12]. In this study, the validation of potential fishing zone (PFZ) forecast using experimental fishing in Tolo Bay, Central Sulawesi provides information about the shortest distance to the nearest PFZ location and the number of catches.

Table 1. The location conformance summary of experimental fishing and PFZ Forecast.

Name	Locations		PFZ Criteria	Distance (nautical mile)	No. of Catch (kg)	Chl-a $(mg/m^3)^a$
	Latitude	Longitude				
EF1	-2.57016	122.70107	PFG2	9.70	850	0.71
EF2	-2.65237	122.63751	PFG1	10.05	0	0.70
EF3	-2.74917	122.56985	PFG1	8.01	0	0.81
EF4	-2.92087	122.57716	FG3	6.69	900	0.88

[a]Maximum of chlorophyll-a concentration at 40-50 m depth

Temperature, salinity and chlorophyll-a concentration affect fish behavior, fish distribution and number of catches at an EF location. Temperature and depth of water are the most important influence and contribute the most to pelagic fish. Most of the catches in the EF location were pelagic fish, dominated by skipjack tuna, yellowfin tuna and mackerel tuna. The optimum temperatures for yellowfin tuna and skipjack tuna were 20-28^{o}C and 28-29^{o}C, respectively. Skipjack tuna around the equator are commonly found from the surface layer, above the thermocline layer, to a depth of 40 meters. The optimum temperatures for skipjack tuna in the experimental fishing (EF) locations are found from the surface to a depth of 30-40 meters. The optimum temperatures at EF1, EF2 and EF4 locations are found from the surface to a depth of 30 meters, while at EF3 location, they are found at deeper depths (figure 5). The optimum salinity for yellowfin tuna and skipjack tuna was 18-38 $^o/_{oo}$ and 33-35 $^o/_{oo}$, respectively. The optimum salinity for yellowfin tuna and skipjack tuna at all experimental fishing locations is measured from the surface to a depth of 120 meters. The maximum chlorophyll-a concentration of 0.7-0.88 mg/m^3 at the experimental fishing site was found at a depth of 30-50 meters. The highest maximum chlorophyll-a concentration at EF4 location was found at a depth of 40 meters. The EF4 location which has the highest chlorophyll-a concentration has the highest number of fish catches as compared to the others fishing locations.

4. Conclusion

Environmental parameters such as SST, salinity, depth and chlorophyll-a concentration affect fish habitat. The validation of experimental fishing (EF) conducted synchronously with PFZ forecast indicates that the synergetic use of SST and chlorophyll information derived from the satellite was found to be very useful in the exploitation of fisheries resources. The result of the validation of potential fishing zone (PFZ) forecast using experimental fishing (EF) at Tolo Bay, Central Sulawesi Province showed that the number of fish catches is influenced by the distance from PFZ forecast position and PFZ forecast criteria. The closer the experimental fishing (EF) location to fishing ground (FG), the greater the likelihood of fish catch, and the greater the number of fish catches.

5. References

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