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Preliminary Findings on Distribution and Abundance of Flying fish in Relation to Oceanographic Conditions of Flores Sea Observed from Multi-spectrum Satellite Images

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Abstract

To describe the short term relationship between oceanographic conditions and flying fish catches and to visualize a spatial pattern of potential fishing grounds in the Flores sea, remotely sensed satellite images of sea surface temperature (SST), chlorophyll-a concentration, fishing depth and absolute geostrophic current together with catch data were used. Results indicated that the highest flying fish catch per unit efforts (CPUEs) occurred in areas of SST 27.5-29.5 °C, chlorophyll-a 0.25 - 0.70 mg. m^{-3} and current velocities 25.0 - 42.5 m. s^{-1}. The fishing depth locations have no significant correlation with the CPUEs. The three preferred oceanographic ranges provided a good indicator for spatially detecting the potential flying fish fishing grounds particularly in the peak season. The predicted potential fishing areas were located in the southwestern Takalar waters approximately 118°45'E-119°40'E and 5°30'S-6°10'S and were confirmed by the fishing data. It is likely that the potential fishing grounds correspond to the occurrence of the oceanographic structures such as upwelling and frontal zones which may be responsible for concentrating the fish schools. This short descriptive study suggests that these findings provide some preliminary results on the flying fish fishing grounds in the Flores Sea.

Introduction

Flying fish (*Hyrundichthys oxycephelus*) is an important pelagic fish targeted by commercial gillnet fishery in the Flores Sea, located in the eastern part of Indonesia. The fish are believed to migrate from the north of Sulawesi Island around February into the Makassar Strait (Dwiponggo et al. 1981). They swim and move to the southern part of Makassar Strait and Flores Sea from about April through August, in concurrence with their spawning season. Then, the flying fish may continue eastward, some to the north to Maluku Sea and others to the south to Banda Sea (Dwiponggo et al. 1981; Ali et al. 2004).

Several previous studies suggested that environmental factors such as SST and ocean current play a role on the flying fish geographical distribution and abundance, gonad maturation and spawning area (Davenport, 1994; Khokiattiwong et al. 2000; Stevens et al. 2003; Ali et al. 2005). However, the oceanographic factors that control the distribution and abundance of the flying fish and the dynamic nature of their potential fishing grounds are still unclear.

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Remotely sensed satellite observations of sea surface may provide significant oceanographic information to explore and improve the potential yield of fishing grounds. Laurs et al. (1984) used satellite images of Nimbus ⁄ CZCS chlorophyll-a and NOAA⁄AVHRR SST to relate albacore catches and oceanographic features and found that being near the ocean color and thermal fronts appeared to be necessary for fishing success. Polovina et al. (2001) concluded that ocean color feature is a good indicator of oceanic front as indicated by 0.2 mg. m^{-3} surface chlorophyll-a density estimated from SeaWiFS where albacore were using the front as a migration route and as a forage habitat. Zainuddin et al. (2006) discussed the importance of geostrophic current parameter to identify possible highly productive fishing ground for tuna such as eddy fields. Therefore, a combination of all these variables may play important mechanisms in detecting potential fishing locations for pelagic species (Zainuddin et al. 2008) including flying fish in the Flores Sea.

Most previous studies concerned only on the biological aspects of flying fish in the Flores Sea without considering in detail the spatial dynamics of the environmental preferences and potential fishing areas. The aims of this paper are to analyze the relationship between the oceanographic conditions and flying fish catches, and to visualize the spatial pattern of their predicted potential fishing grounds in the Flores Sea.

Materials and Methods

This study used two types of datasets, satellite and fishery data from April to July 2009. This period was selected since the high flying fish abundance and high fishing operation occurred during the period of study.

Satellite Data

Satellite remote sensing data, SST, chlorophyll-a concentration (hereafter Chl-a) and absolute geostrophic current velocity were used to analyze oceanographic conditions in relation to high productive fishing areas. The SST and Chl-a data were derived from Aqua/MODIS distributed by the NASA. The monthly mean composites of both SST and Chl-a with spatial resolution of 4 km were used. The temporal composite of the current velocity ranged from daily to monthly (during fishing period) with spatial resolution of 1/3° of both longitude and latitude. The current velocity data were obtained from AVISO dataset. The fishing depth (bathymetry) data were derived from etopo-1 dataset with spatial resolution of 1.85 km (0.016°). Since the spatial resolutions of the SST, Chl-a and ocean current are 4 km, 4 km and 1/3°, respectively, all these images were then resampled onto 1.85 km grid to match with the ocean depth etopo-1 data.

Fishery data

The fishery data consisted of drift gillnet fishing positions in latitude and longitude, and daily catch per unit effort (CPUE) obtained from fishing survey during April-July 2009. A brief description of the fishery activity in one trip is important to clarify some of the terminology used in this paper. Usually, fishermen tend to go to predetermined fishing locations based on previous experience and natural clues such as floating objects, ocean color and flying seabird schools. The first step in gillnet fishery is the sighting of the marine bird schools near the sea surface and then setting the fishing gear for about 3-4 hours. Then, the ship approaches the gillnet and tries to catch the flying fish. This study defines a trip in which at least one fishing set was made as a fishing trip. Usually, only one fishing set was conducted for each day or for a trip. Thus, CPUE was defined as a number of flying fish catches (tons) per trip.

Relationship between flying fish CPUEs and oceanographic conditions

Following Andrade and Garcia (1999), the catch data were also divided into three categories: (1) cases with CPUE equal to zero – 'null catches'; (2) cases with CPUE greater than zero but lower than 0.387 tons – 'positive catches'; and (3) cases with CPUE greater than 0.387 tons – 'high catches'. The value 0.387 tons represents the lower limit of the upper quartile of CPUEs greater than zero. Then, the high catch data were used to calculate all proxy indicators of the oceanographic conditions.

To describe the relationship between oceanographic conditions of SST, Chl-a, current velocity and fishing depth, and flying fish CPUE, first, this study used histogram graphs of high catch data. Second, this study analyzed the stronger association between all the oceanographic variables and flying fish CPUEs using empirical cumulative distribution function analysis. In this analysis, three functions were used (Andrade and Garcia, 1999; Zainuddin et al. 2008) as follows:

$$f(t) = \frac{1}{n}\sum_{i=1}^{n} l(xi) \tag{1}$$

with the indicator function

$$l(xi) = \begin{cases} 1, & \text{if } xi \le t \\ 0, & \text{otherwise} \end{cases}$$

$$g(t) = \frac{1}{n}\sum_{i=1}^{n} \frac{yi}{\bar{y}}\, l(xi) \tag{2}$$

$$D(t) = \max|\, f(t) - g(t)\,| \tag{3}$$

where, $f(t)$: empirical cumulative frequency distribution function, $g(t)$: catch-weighted cumulative distribution function, $l(xi)$: indication function and $D(t)$: absolute value of the difference between two curves $f(t)$ and $g(t)$ at any point t, and assessed by standard Kolmogorov-Smirnov test, n : the number of fishing trips, xi : the measurement for satellite-derived oceanographic variables in a fishing trip i, t : an index, ranging the ordered observations from lowest to highest value of the oceanographic variables, yi : the CPUE obtained in a fishing trip i, and $\bar{y}$: the estimated mean of CPUE for all fishing trips. The coordinate labeled "max" represents the specific value of the variables at which the difference between the two curves ($|g(t)-f(t)|$) was maximum.

Potential fishing grounds were constructed from the significant and favorable ranges of all significant environmental variables (SST, Chl-a and geotrophic current). The map consisted of binary output in which the white color represents non predicted area, and the green color denotes high probability area of finding flying fish. The potential fishing ground map was computed by combining all significant favorable oceanographic conditions into a single map with the same spatial and temporal scale for each grid satellite data using ArcGIS 9.2 Spatial Analyst. The fisheries data were then superimposed on the map in the peak season and the high CPUEs (fishing data) were compared and were verified with the potential fishing grounds.

Results

Flying fish distribution and abundance in relation to environmental variables

During study period (April-July 2009), highest flying fish CPUEs were found in July. In this month, distribution of flying fish on environmental map of fishing depth showed that the fish occupied a wide range of fishing depth from 122 to 994 m (Fig. 1:A). Fishing grounds mainly occurred outside 12 nautical miles from fishing base (in Takalar Regency). In July 2009, SST observed from satellite images ranged from 26.66 to 33.07°C (Fig. 1:B). The fish distribution on environmental SST map indicated that flying fish tended to occur in areas of 27.5-28.32°C SST. However, highest CPUEs were obtained in waters of 27.9 – 28.1°C SST. Using environmental Chl-a map, flying fish distributed mainly in waters of 0.31-0.85 $mg.m^{-3}$ (Fig. 1:C). However, most catches were obtained in specific areas where chlorophyll density varied primarily between 0.35 and 0.65 $mg.m^{-3}$. It means that the forage concentration of flying fish was indicated with this range. In this month, satellite data performed that Chl-a in Flores Sea (study area) ranged from 0.17 to 11.13 $mg.m^{-3}$.

Geostrophic current map indicated that flying fish fishing grounds in July tended to concentrate in waters of 30.3-60.7 $cm.s^{-1}$ current velocity (Fig. 2). The species were mostly taken in substantial number in areas where the current speed ranged from 30 to 42 $cm.s^{-1}$. Figure 2 shows that current velocity in study area varied approximately from 10 to 125 $cm.s^{-1}$. This figure indicates that current direction was initially from northeast (Bone Bay) to the Flores Sea and continue to the northwest and then move to the northeast along Makassar Strait, South Sulawesi province.

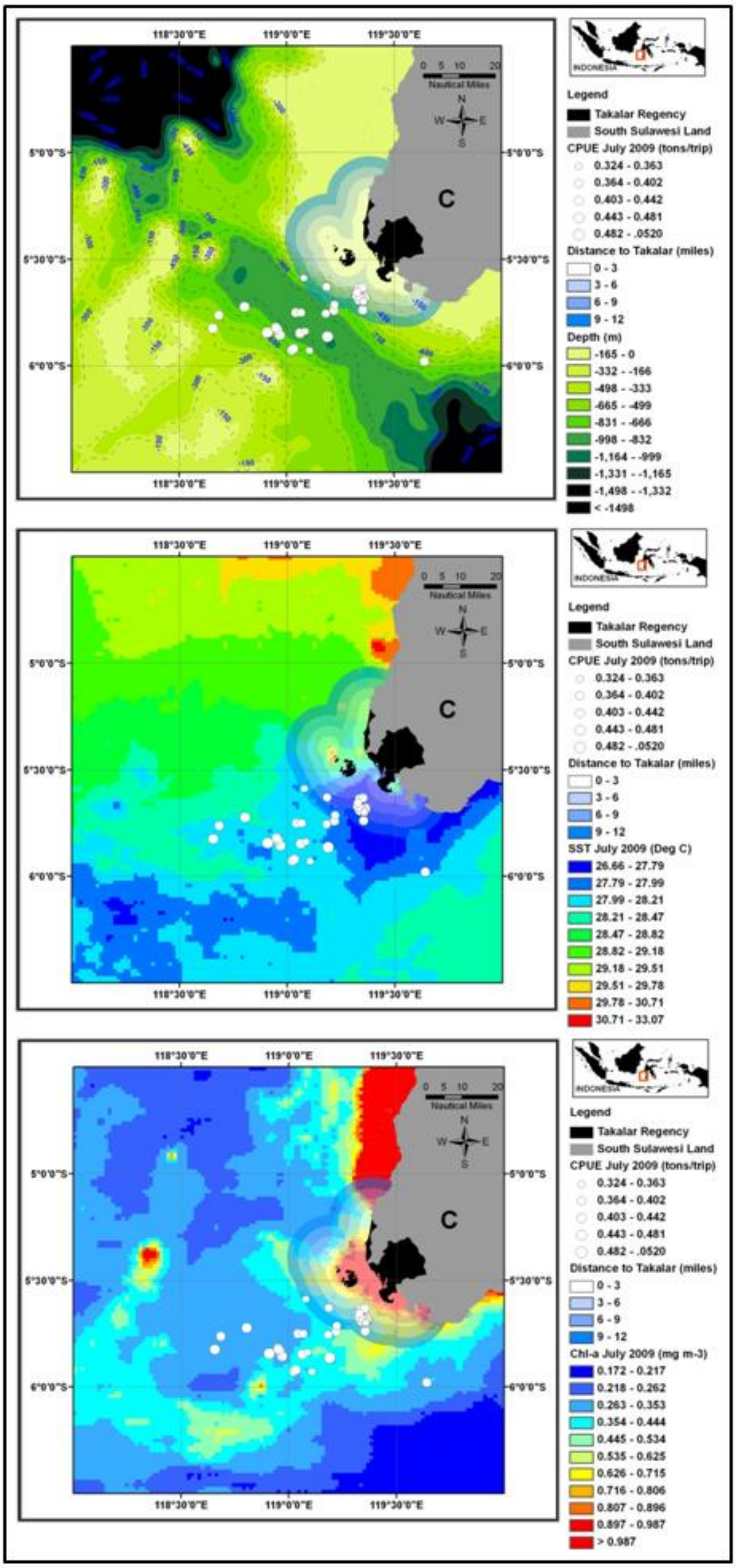

Fig. 1. The spatial distribution of flying fish CPUE (tons/fishing trip) from gillnet fishery in July 2009 superimposed on Etopo-1 fishing depth (A), Aqua/MODIS SST (B) and Aqua/MODIS Chl-a (C).

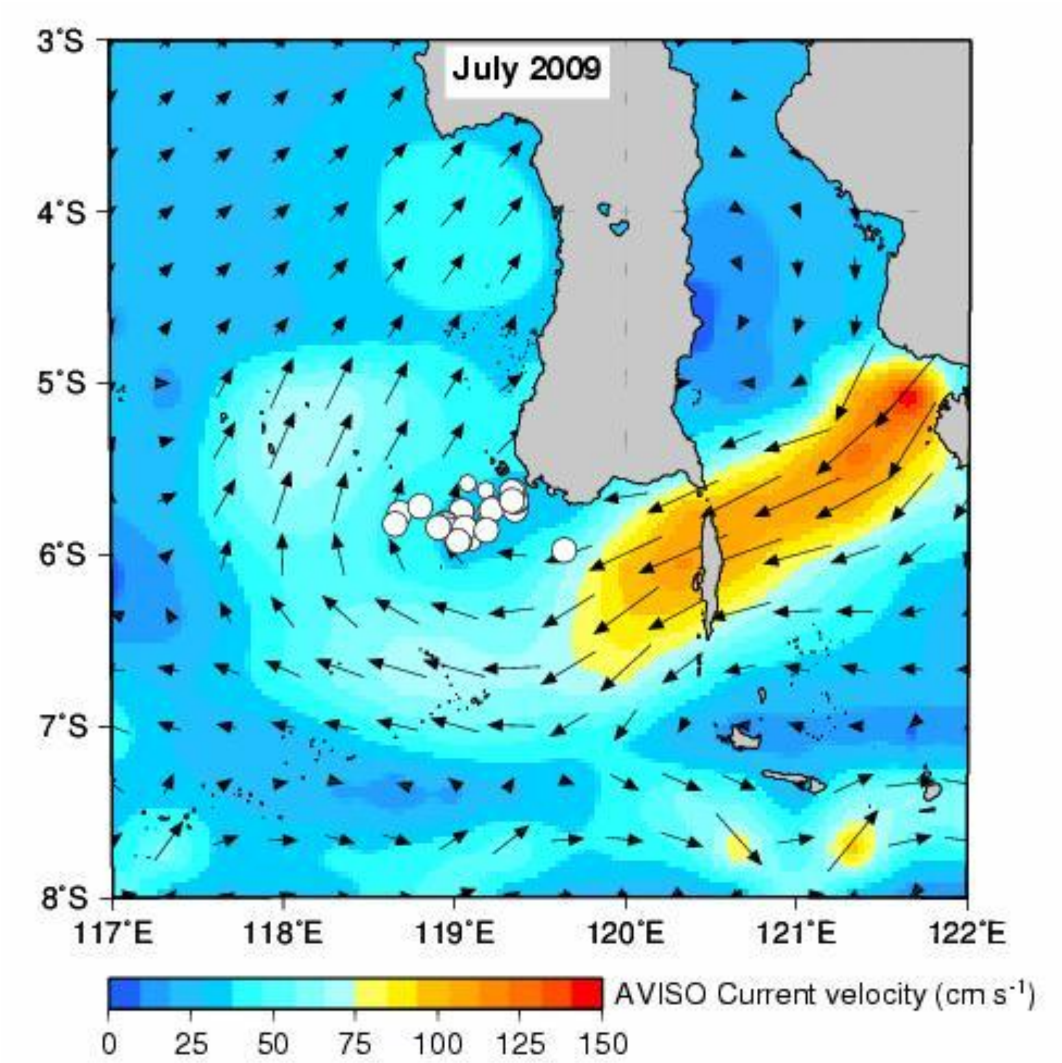

Fig. 2. The spatial distribution of flying fish CPUE (tons/fishing trip) from gillnet fishery in July 2009 overlaid on AVISO absolute geostrophic current velocity and direction images.

Flying fish fishing frequency in relation to environmental variables

Based on catch data, flying fish fishing frequency in relation to fishing depth showed that there was no specific range where fishing trips were high. Fishing sets tended to be constant along fishing ground depth from 100 to 1000 m (Fig. 3a). In contrast, the variables of SST, Chl-a and geostrophic current velocity have specific ranges where fishing frequencies were high. Fishing frequency in relation to absolute geostrophic current velocity showed that most of flying fish fishing sets occurred in areas where the geostrophic current ranged from 27.5 – 42.5 cm.s $^{-1}$ (Fig. 3b). In relation to SST, fishing sets were found in areas of 27.5-28.3 °C SST (Fig. 3c). However, highest frequency tended to center at 28ºC SST. Fishing days in relation to Chl-a showed that highest fishing frequency occurred in areas where Chl-a varied from 0.25-0.65 mg.m^{-3} (Fig. 3d). Highest fishing sets of high catch data tended to concentrate near 0.4 mg. m^{-3}.

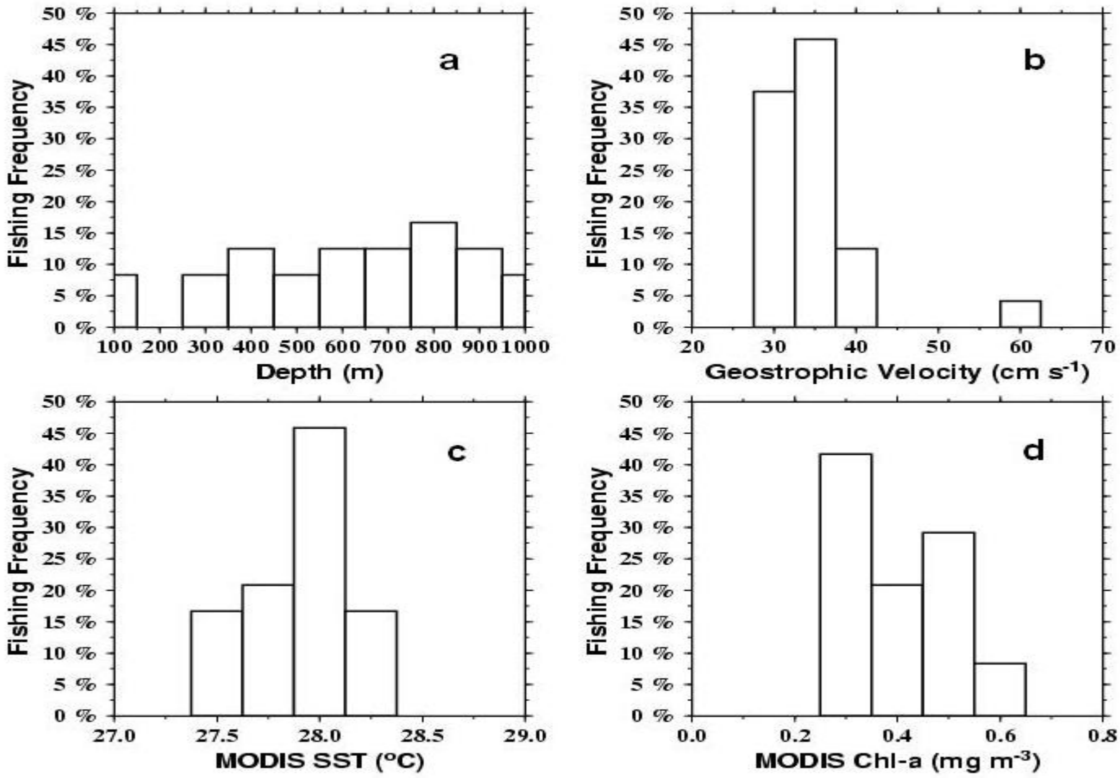

Fig 3. Flying fish fishing frequency in relation to fishing depth (a) and AVISO geotrophic current velocity (b), Aqua/MODIS SST (c) and Aqua/MODIS chlorophyll-a (d) based on high catch data during April-July 2009.

Using empirical cumulative distribution function (ECDF), the relationship between flying fish CPUE and the three environmental variables reinforce the result obtained above (Fig. 3). The cumulative distribution curves of the variables are different and the degrees of the difference between two curves (Dt) are statistically significant ($P<0.05$). The results showed the stronger association between CPUE and the variables, geostrophic current velocity ranging from 25 to 42.5 cm. s^{-1} (Fig. 4B), SST ranging from 27.5 to 29.5ºC (Fig. 4C) and Chl-a ranging from 0.25 to 0.70 mg.m^{-3} (Fig. 4D). The strongest associations between CPUE and the three variables occurred at 35 cm.s^{-1} current velocity, 28.27 ºC SST and 0.51 mg.m^{-3} Chl-a, respectively. Flying fish catch rates tended to decrease in areas outside those favorable ranges. Fishing depth did not show a significant relationship with flying fish catch rates (Fig. 4A). Based on these results, synoptically significant oceanographic ranges for flying fish were defined as the potential fishing ground.

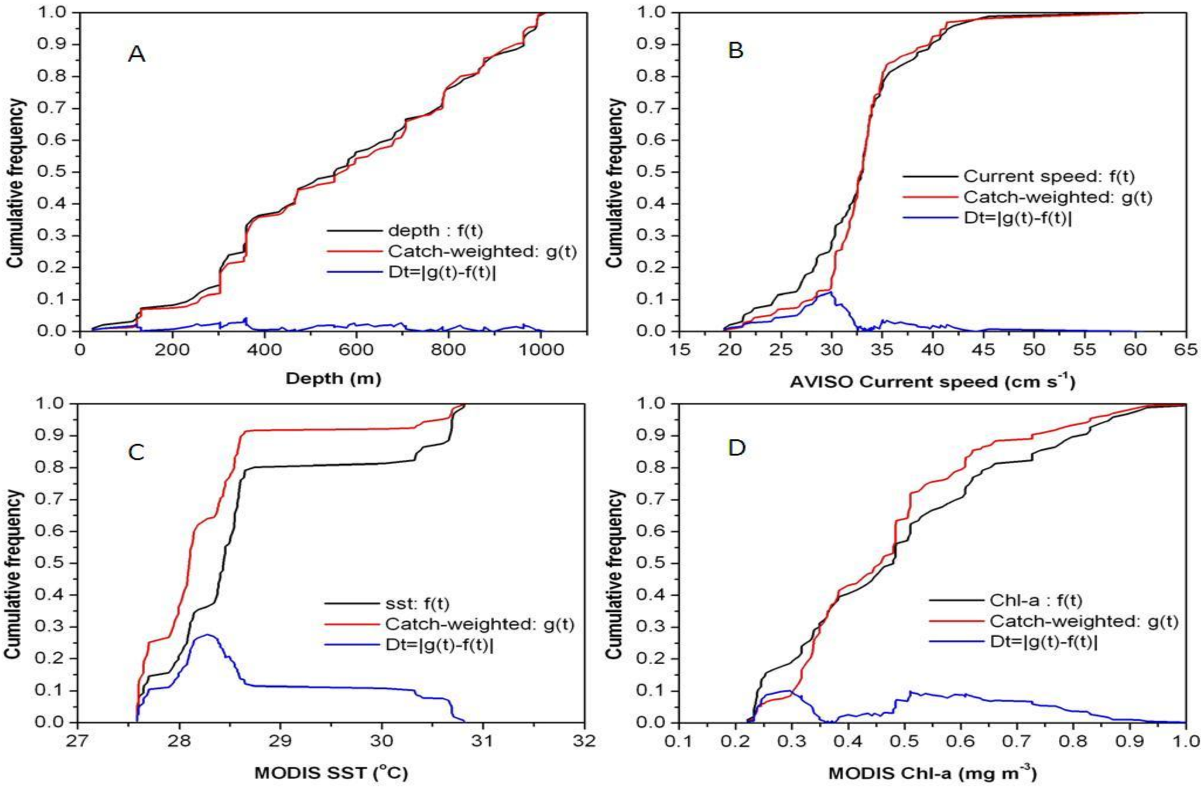

Fig. 4. Empirical cumulative distribution frequencies for (A) Etopo-1 fishing depth (B) AVISO geotrophic current velocity, (C) Aqua/MODIS SST, and (D) Aqua/MODIS chlorophyll-a, and fishing depth, SST and current velocity as weighted by flying fish catch as well as absolute difference of the two functions during April-July 2009.

Potential Flying Fish Fishing Ground Map

This study found that there were three oceanographic variables which have significant relationship with flying fish distribution and abundance: (1) SST, (2) geostrophic current velocity, and (3) Chl-a. The strongest association between flying fish and these variables occurred in areas where SST, current velocity and Chl-a ranged from 27.5 to 29.5 ºC, from 25 to 42.5 $cm.s^{-1}$ and from 0.30-0.70 $mg.m^{-3}$, respectively. The combination of the three environmental preferences was considered as an important environmental index where the spatial pattern of potential fishing ground of flying fish was readily predicted.

Figure 5 shows a distribution pattern of potential fishing areas where the greatest catches were predicted in areas of approximately 118°45’E-119°40’E and 5°30’S-6°10’S especially in July 2009. Fishing data in July confirmed that the highest flying fish CPUEs were obtained within that area. The average CPUEs in this month was approximately 0.416 tons/ trip. The greatest CPUEs were mainly concentrated along the southwest of Takalar coastal waters where the three preferred oceanographic factors were formed. Some parts of that area were within 12 nautical miles from fishing base, but the main fishing grounds were mostly outside the distance.

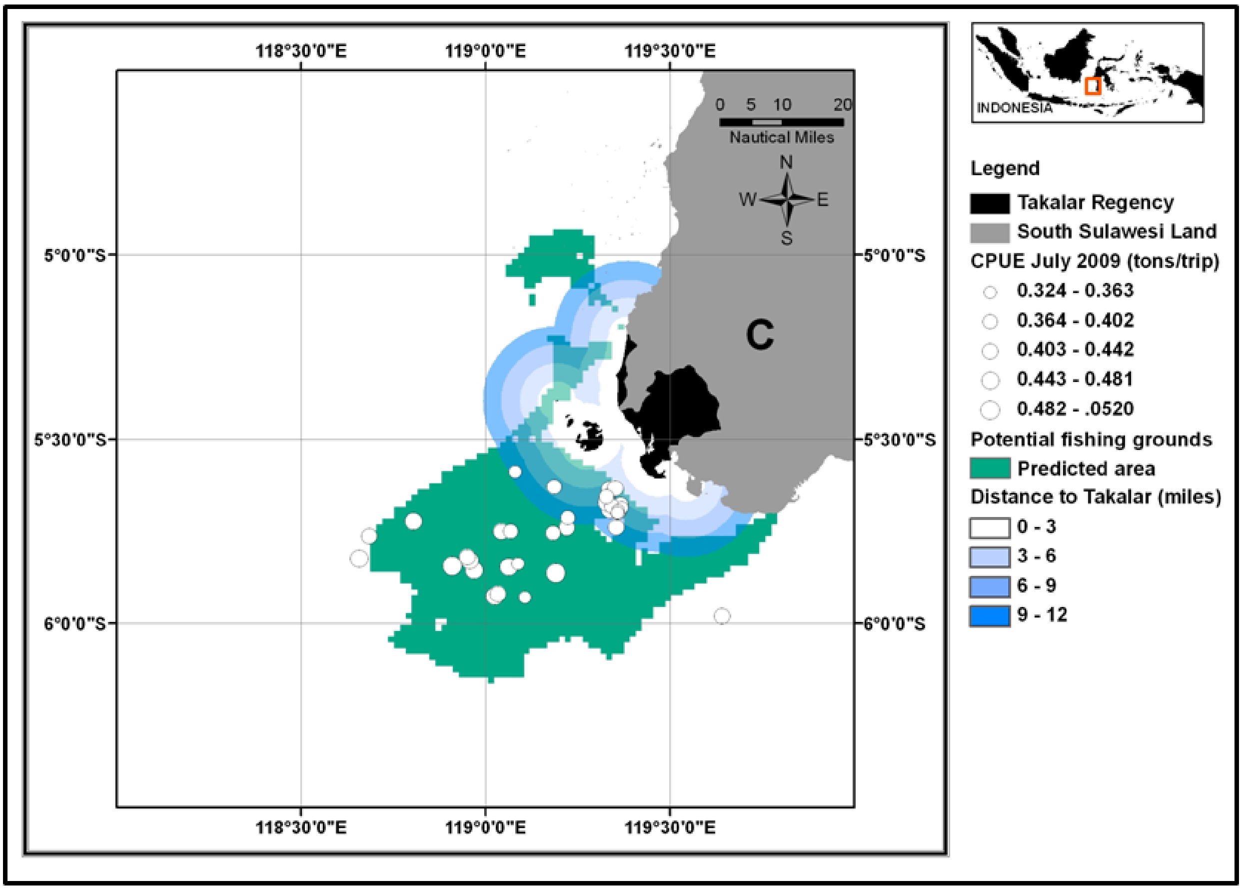

Fig. 5. The spatial distribution of flying fish CPUEs (tons/fishing trip) from gillnet fishery in the peak season (July 2009) plotted on potential fishing ground map.

Discussion

Using a short term dataset, this study attempted to describe briefly from a scientific perspective what the fishermen believe as a potential flying fish fishing ground in the season of high abundance. As a result, these findings could be of a preliminary nature in providing some insight into identifying potential fishing grounds for flying fish.

The use of multi-spectrum satellite images to explore the short term relationship between flying fish CPUEs and oceanographic conditions provides the significant information needed to initially detect potential fishing areas. This study indicates three environmental variables (i.e. geostrophic current, SST and Chl-a) which have important contributions in the understanding of the high productive flying fish fishing locations. These results strengthen the previous studies that the fish respond concurrently to several environmental factors (Khokiattiwong et al. 2000; Stevens et al. 2003; Ali et al. 2005).

Satellite images clearly show that the highly productive flying fish fishing grounds mainly concentrate in areas of increased Chl-a density and relatively low SST (Fig. 1), indicating that the potential fishing grounds may link with the occurrence of upwelling. The current velocity map reinforced the results (Fig. 2). The relatively high current velocities with the clockwise direction (cyclonic current) illustrate the upward movement of thermocline depth and the upwelling of nutrient rich water in which an excellent feeding environment for flying fish will form. As a result, the highest flying fish CPUEs are obtained in the potentially productive fishing areas. This suggests that the upwelling of nutrient (such as phosphate and nitrate) rich waters up into the euphotic zone would stimulate a highly biological productivity (Mann and Lazier, 1996) and attract the preferred forage prey of flying fish such as *Rhizosolenia*, *Nitzschia* and *Thalassiosira* (Oktaviani et al. 2005), which then lead to the high flying fish abundance. The upwelling areas driving enhanced primary production in the study area are previously suggested by several oceanographic studies (Ilahude, 1971; Birowo, 1979).

Another possible reason for the congregation of this species in the Flores Sea is the development of upwelling intensity in the Banda Sea which could transport nutrient rich waters into the study area following the regional current pattern during the east monsoon (June-August) (Wirtky, 1961). Using satellite data, this fact has clearly been confirmed (Qu et al. 2005). The enhancement of upwelling during June-August is also used by the flying fish not only as a forage habitat but also as a spawning ground (Grudtsev et al. 1987; Ali et al. 2005).

In addition, the largest catches during the season of high abundance (June-July) may associate with the frontal zones developing around the upwelling area (Figs. 1 and 2). The biological importance of fronts is that they can sustain the secondary producers such as zooplanktons abundance, in turn, stimulate a good feeding opportunity (Polovina et al. 2001), so that ultimately a large flying fish school is assembled (Oktaviani et al. 2005).

This study suggests that the preferred ranges of all significant oceanographic factors can be regarded as an initial stage in identifying the potential fishing grounds for flying fish i.e. upwelling and fronts (Figs. 3 and 4). These reasonable indices provide a good indicator to simply generate a spatial pattern of predicted potential flying fish fishing grounds in the study area (Fig. 5). The predicted potential fishing zones during June-July have been confirmed by the fishing data.

Conclusions

The potential fishing grounds for flying fish may correspond well with the occurrence of upwelling and fronts which could be identified by synoptically preferred oceanographic conditions of SST, Chl-a and geostrophic current. This study suggests that the preferred ranges of the oceanographic conditions provide a good indicator of initially detecting the potential fishing grounds for flying fish in the Flores Sea. This short descriptive study illustrates that these findings could be of a preliminary nature in identifying potential flying fish fishing grounds in the Flores Sea using multi-spectrum satellite images.

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References

Ali, SA, M.N Nessa, I. D. Jawad and S.A. Omar. 2004. Season and flying fish (e*xocoetidae*) abundance in Takalar Regency, South Sulawesi (Text in Indonesian and abstract in English). Torani 3(14):165-172.

Ali, SA, M.N Nessa, I. A. Djamali, A. Syahailatua. 2005. The relationship between gonad maturation and environmental parameters of the flying fish (*Hirundicthys oxycephalus*) at the Flores sea, South Sulawesi (Text in Indonesian and abstract in English). Torani (Special Issue) 6 (15):403-410.

Andrade, H.A. and A.E Garcia .1999. Skipjack tuna in relation to sea surface temperature off the southern Brazilian coast. Fish. Oceanogr. 8: 245-254.

Birowo, S. 1979. The possibility of upwelling occurrence in Flores Sea and Bone Bay (Text in Indonesian and abstract in English). Oseanologi di Indonesia 79(12):1-12.

Davenport, J. 1994. How and why do flying fish fly? Reviews in Fish Biology and Fisheries 4: 184-214.

Dwiponggo, A., T. Sujastani and S. Nurhakim. 1981. Pengkajian Potensi dan TingkatPengusahaan Perikanan Torani di Perairan Sulawesi Selatan. Seminar Ikan Torani, Ujung Pandang, Indonesia.

Grudtsev, M.E., L.P. Salekhova and V.G. Lushchina. 1987. Distribution, ecology and intraspecific variability of flying fishes of the genus *exocoetus* of the Atlantic Ocean. J. Ichthyol. 27:39-50.

Khokiattiwong, S.R. Maho and W. Hunte. 2000. Seasonal abundance and reproduction of fourwing flying fish *Hyrundicthys affinis* of Barbados. Environmental Biology of Fishes 59:34-60.

Laurs, R.M., P.C. Fielder and D.R. Montgomery. 1984. Albacore tuna catch distributions relative to environmental features observed from satellites. Deep-Sea Res. 31: 1085-1099.

Ilahude, A.G. 1971. On the occurrence of upwelling in the southern Makassar Strait. Mar. Res. Indonesia 10:1-53.

Mann, K.H. and J.R.N. Lazier. 1996. Dynamics of marine ecosystems: Biological-physical interactions in the oceans. Blackwell Science. 394pp.

Oktaviani, I, M.M. Kamal and A. Syahailatua. 2005. Study on food habit of *Hirundicthys oxycephalus* (*exocoetidae*) in Binuangeun Waters (Banten). Torani (Special Issue) 6(15):361-368.

Polovina, J.J., E. Howel, D.R. Kobayashi and M.P. Seki. 2001. The transition zone chlorophyll front, a dynamic global feature defining migration and forage habitat for marine resources. Progress in Oceanogr. 49:469-483.

Qu, T., Y. Du, J. Strachan, G. Meyers and J. Slingo. Sea surface temperature and its variability in the Indonesian Region. Oceanography 18:50-61.

Stevens, J.W., C.K. Bennett and J.J. Berg. 2003. Flyingfish spawning (*Parexocoetus brachypterus*) in the northeastern Gulf of Mexico. Environmental Biology of Fishes 67:71-76.

Zainuddin, M., H. Kiyofuji, K. Saitoh and S. Saitoh. 2006. Using multi-sensor satellite remote sensing and catch data to detect ocean hotspots for albacore (*Thunnus alalunga*) in the northwestern North Pacific. Deep-Sea Res. II 53: 419-431.

Zainuddin, M., K. Saitoh and S. Saitoh. 2008. Albacore tuna fishing ground in relation to oceanographic conditions of northwestern North Pacific using remotely sensed satellite data. Fish. Oceanogr. 17(2): 61-73.

Wirtky, K. 1961. Physical oceanography of Southeast Asian waters. Naga Report 2. Script Institution of Oceanography, La Jolla, CA. 195pp.

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