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Determination of Potential Fishing Grounds of *Rastrelliger kanagurta* Using Satellite Remote Sensing and GIS Technique

(Penentuan Kawasan Penangkapan Potensi *Rastrelliger kanagurta* Menggunakan Satelit Penderiaan Jauh dan Teknik GIS)

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ABSTRACT

*Analysis of relationship between sea surface temperature (SST) and Chlorophyll-*a *(chl-*a*) improves our understanding on the variability and productivity of the marine environment, which is important for exploring fishery resources. Monthly level 3 and daily level 1 images of Moderate Resolution Imaging Spectroradiometer Satellite (MODIS) derived SST and chl-*a *from July 2002 to June 2011 around the archipelagic waters of Spermonde Indonesia were used to investigate the relationship between SST and chl-*a *and to forecast the potential fishing ground of* Rastrelliger kanagurta*. The results indicated that there was positive correlation between SST and chl-*a *(*R*=0.3,* p*<0.05). Positive correlation was also found between SST and chl-*a *with the catch of* R. kanagurta *(*R*=0.7,* p*<0.05). The potential fishing grounds of* R. kanagurta *were found located along the coast (at accuracy of 76.9%). This study indicated that, with the integration of remote sensing technology, statistical modeling and geographic information systems (GIS) technique were able to determine the relationship between SST and chl-*a *and also able to forecast aggregation of* R. kanagurta*. This may contribute in decision making and reducing search hunting time and cost in fishing activities.*

*Keywords: chl-*a*; fish forecasting; satellite imageries; Spermonde Indonesia; SST*

ABSTRAK

*Analisis hubungan antara suhu permukaan laut (SST) dan klorofil-*a *meningkatkan pemahaman kita berkaitan kepelbagaian serta produktiviti persekitaran marin kerana ia penting untuk meneroka sumber perikanan. Imej SST dan klorofil-*a *bulanan (peringkat 3) dan harian (peringkat 1) daripada Satelit Pengimejan Spektroradiometer Resolusi Sederhana (MODIS) dari Julai 2002 hingga Jun 2011 di sekitar perairan kepulauan Spermonde Indonesia telah digunakan untuk mengkaji hubungan antara SST dan klorofil-*a *serta meramal kawasan potensi penangkapan bagi spesies* Rastrelliger kanagurta*. Keputusan menunjukkan bahawa terdapat korelasi positif antara SST dengan klorofil-*a *(*R*=0.3,* p*<0.05). Hubungan positif juga diperoleh antara SST dan klorofil-*a *dengan tangkapan* R. kanagurta *(*R*=0.7,* p*<0.05). Kawasan potensi penangkapan bagi spesies* R. Kanagurta *adalah di sepanjang perairan pantai (pada ketepatan 76.9%). Kajian ini menunjukkan bahawa, dengan integrasi teknologi penderiaan jauh, pemodelan statistik dan teknik sistem maklumat geografi (GIS) dapat menentukan hubungan antara SST dan chl-*a *dan juga dapat meramalkan kawasan pengumpulan* R. kanagurta*. Keputusan kajian ini mampu menyumbang dalam membuat keputusan dan menjimatkan masa dan kos dalam aktiviti penangkapan ikan.*

*Kata kunci: Klorofil-*a*; imej satelit; ramalan kawasan perikanan; Spermonde Indonesia; SST*

INTRODUCTION

The Indian mackerel *Rastrelliger kanagurta* is one of the most abundant and commercially important small pelagic fishery resources in Indonesia. *R. kanagurta* is a highly migratory epipelagic fish. This species is a surface feeder which preys primarily on phytoplanktons and zooplanktons (Solanki et al. 2005a) and schools by size (Collette & Nauen 1983). The schooling indicates the presence of large numbers of fish which will be good fishing grounds for fishing activities.

The fishing grounds are still determined by traditional hunting method based on repeated experiences as well as gathering information from fellow fishermen. On the other hand, spatial structure and distribution of the pelagic species is not random (Planque et al. 2011). They are particularly vulnerable and change rapidly in accordance with the dynamic environmental factors and global changes, resulting in distinct distributions and assemblages. This complexity makes it more difficult for fisherman to determine the fishing grounds. However, the existence of small pelagic fish is still predictable through physical and biological indicators of sea surface environment. Physical processes in the upper ocean influence biological processes and ultimately determine the distributions of pelagic fish (Solanki et al. 2005b).

The closely coupled physical and biological processes in marine ecosystems varies depending on various space and time scales, and it is represented by sea surface temperature (SST) and Chlorophyll-*a* (chl-*a*), respectively (Solanki et al. 2005b). Chl-*a* is known as a very important oceanographic parameter in determining the productivity of the ocean. Chl-*a* pigment is a convenient index of phytoplankton biomass (Solanki et al. 2001) and it could be related to fish production (Bertrand et al. 2002). SST is assumed to be an index of the physical environment, which controls the physiology of the living organisms (Solanki et al. 2005b) and influences phytoplankton growth (Tang et al. 2003).

Physical and biological features, in real time, can be detected by sensors of satellite remote sensing. This technology is able to provide reliable global ocean coverage of SST and chl-*a* at relatively high spatial and temporal resolution, which can be measured from space. This is an effective and efficient way compared with field sampling that requires time, cost and limited coverage areas. Meanwhile, geographic information systems (GIS) techniques are widely used in processing satellite images (Castillo et al. 1996). It provides integrating theoretical aspects of the oceanography and ecology approaches, with spatial database and statistical functions.

Determination of fishing ground using satellite data has been applied by detecting the important oceanographic parameter influencing presence of fish schooling such as SST and chl-*a*. Mustapha et al. (2010), Nurdin et al. (2014) and Zainuddin (2007) indicates the capability of using satellite derived SST and chl-*a* integrated with GIS to predict the potential fishing grounds of *R. kanagurta* in the tropical area of Southeast Asia. Satellite data assimilated into GIS and integrated with other databases can provide rich information system, which is more sophisticated and useful (Radiarta et al. 2008) to determine the potential fishing grounds more quickly and accurately. These will help the fisherman to exploit marine resources more effectively and efficiently.

The aim of the present study was to investigate the relationship between SST and chl-*a* concentration and also define a simple methods for determining the potential fishing grounds of *R. kanagurta* in the archipelagic waters of Spermonde Indonesia by using integration of satellite data, statistical model and GIS technique.

MATERIALS AND METHODS

STUDY AREA

The study was conducted in the archipelagic waters of Spermonde at Makassar Strait, the center part of Indonesia (Figure 1). This area belongs to the fisheries management area of the Republic of Indonesia (WPP-RI) 713 (KKP 2011) and it is a major fishing ground for fishermen on the west coast of South Sulawesi. WPP-RI 713 is an area of considerable fishing potential in Indonesia, with total production of the second largest catching area after the fisheries management of WPP-RI 712 (Java Sea). The production is dominated by small pelagic fish, with annual catch during 2005 to 2010 that reached an average of 250 thousand tons per year, with production of *R. kanagurta* at 44.1 thousand tons in 2010 (KKP 2011). Most of the fishing activities in this area are concentrated in the inshore waters where marine resources are optimally exploited.

FISHERIES DATA

Data analyzed in this study were daily fisheries data of *R. kanagurta* that was collected from field survey around the archipelagic waters of Spermonde throughout 2008 and 2009. Data obtained included catch weight (kg) and fishing location (longitude and latitude).

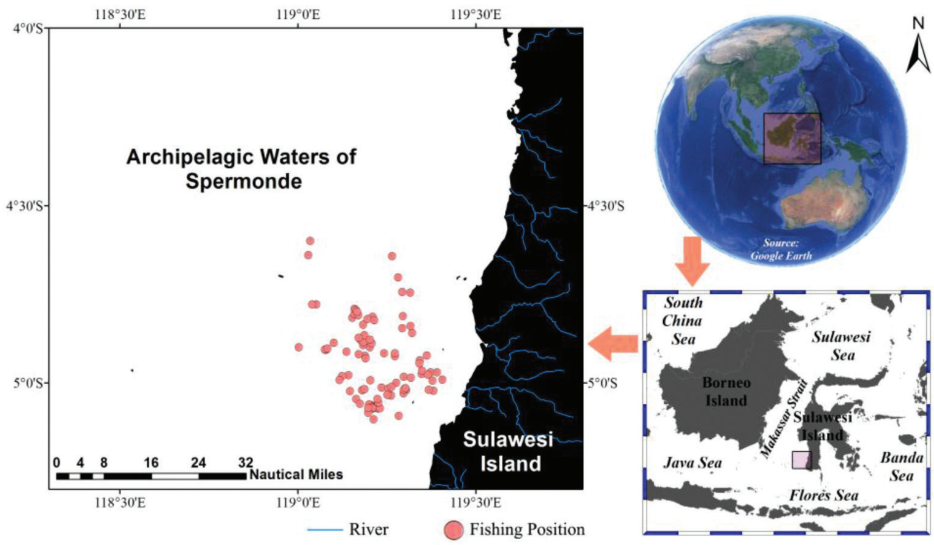

FIGURE 1. The study area in the archipelagic waters of Spermondeat Makassar Strait Indonesia

REMOTELY SENSED ENVIRONMENTAL DATA

The primary satellite data set used in this study was SST and chl-*a* data derived from MODIS measurement. The SST and chl-*a* level 3 (4 km) monthly standard mapped image (SMI) data from July 2002 to June 2011 and level 1 (1 km) daily data from 2008 and 2009, coinciding with the timing of the daily catch data were downloaded from the ocean color website (http://oceancolor.gsfc.nasa.gov/). SeaWiFS Data Analysis System (SeaDAS) version 6.1 software was used to extract and process the data (O'Reilly et al. 1998). The data were subset to the study area with geographical extend of 118.30-119.80 E and 4.00-5.30 S using ERDAS Imagine version 10.0 software.

Monthly mean surface wind speed data were downloaded from the NOAA Earth System Research Laboratory website (http://www.esrl.noaa.gov/) and monthly mean sea surface current data were downloaded from the NOAA Ocean Surface Current Analysis (OSCAR) website (http://www.oscar.noaa.gov/). The data were processed using the Grid Analysis and Display System (GrADS) version 2.0 software (Nurdin et al. 2013) to explain the effect of wind and surface current against sea surface environment.

STATISTICAL MULTIPLE REGRESSION MODEL

Statistical predictive modelling techniques have been widely used and have shown to be proficient in explaining the relationship between fish distribution and surrounding environmental features (Guisan et al. 2002; Ko et al. 2008; Vasconcelos et al. 2013). Traditionally, models used in ecology to predict potential species distributions were multivariate in nature and based on linear functions (Ko et al. 2008).

Multiple regressions are one of the oldest statistical techniques and has long been used in biological research (Guisan et al. 2002). It is very useful for predicting fish distributions in unsurveyed areas. Multiple regressions provide the most accurate predictions for high species richness class (Pittman et al. 2007). Zainuddin (2007) showed the ability of multiple regression analysis to predict the abundance of *R. kanagurta* in Bantaeng waters of South Sulawesi Indonesia. Multiple regression was used to find out the coefficient of regression (*b*) for each parameter (SST and chl-*a*) which will be used to construct the prediction model. The multiple regression equation used in this study is as follow (StatSoft 2014):

$$Y = a + b_1X_1 + b_2X_2 \tag{1}$$

where Y is the catch weight (kg), a is the constant, b_1 is the coefficient regression of SST, b_2 is the coefficient regression of chl-*a*, X_1 is variable of SST and X_2 is variable of chl-*a*. This analysis was implemented using the predictive analytics software IBM SPSS version 20.0.

POTENTIAL FISHING GROUNDS MAP

Based on the (1), the constant (*a*) value and the coefficient of regression (*b*) were used to construct the prediction model as follow:

$$\hat{Y} = -40.426 + 2.024X_1 + 42.722X_2 \tag{2}$$

where $\hat{Y}$ is the predicted catch weight (kg), X_1 is the variable of SST and X_2 is the variable of chl-*a*.

Prediction by multiple regression models can be used in combination with GIS technique in providing maps and information. Daily maps of potential fishing grounds of *R. kanagurta* were generated. The value of each SST and chl-*a* concentration in each pixel throughout specific days were used in themodel (2) and the values of predicted catch ($\hat{Y}$) for each pixel were obtained. The matching SST and chl-*a* features throughout the model were considered as the location of potential fishing grounds. Raster map were produced using ArcGIS version 10.0. Maps to visualize the distribution forecast of R. *kanagurta*. The predicted maps were then verified and validated using independent catch data to ensure the accuracy (Vasconcelos et al. 2013). A total of 111 independent catch data coincided with predicted catch.

RESULTS AND DISCUSSION

VARIABILITY AND RELATIONSHIP BETWEEN SST AND CHL-*a*

The Spermonde archipelagic waters are located at the southern hemisphere close to the equator. The position of the sun crossing the equator twice each year causes the variation of seasonal solar heating which drives the monsoons in this area (Webster et al. 1998). This monsoon consists of the Northwest monsoon (November-March), the Southeast monsoon (May-September) and the Transition monsoon in April and October (Susanto et al. 2006). The Spermonde archipelagic waters within Makassar Strait also has unique geographical location and complex coastal geometry and is thought to be the main canal system between the western equatorial Pacific Ocean and the eastern Indian Ocean (Wajsowicz et al. 2003). Due to these complexities, physical and biological condition varies.

The patterns of the climatological annual cycle of SST and chl-*a* in the archipelagic waters of Spermonde were illustrated by the monthly composites of MODIS images. Spatial (Figure 2) and temporal (Figure 3(a)) analyses showed that SST in this area is generally relatively high from November to May (except January), while relatively low from June to October throughout the year. SST pattern in this area coincided with the timing of the occurrence of the monsoon. In contrast with SST, chl-*a* concentration was relatively high and available throughout the year. However, the chl-*a* concentration from December to July was higher compared with from August to November throughout the year. The higher chl-*a* concentration was almost scattered along the coast with lower concentrations offshore.

The relationship between SST and chl-*a* in the archipelagic waters of Spermonde was calculated based on monthly data during 2002 to 2011. There was a positive correlation between SST and chl-*a* (Figure 3b), with coefficient of correlation at R=0.3, which means increase in SST resulting in the increase of chl-*a* concentration. This is in contrast with the finding from Barnard et al. (1997), Choudhury et al. (2007), Georgakarakos and Kitsiou (2008), Radiarta and Saitoh (2008), Solanki et al. (2001), Thomas et al. (2003) and Yoder et al. (2002) which found inverse correlation between SST and chl-*a*. This inverse correlation was reported in areas with occurrence of upwelling. When upwelling occurs, the bottom layer with colder water and rich nutrient will rise to the surface and will encourage phytoplankton blooms. Meanwhile, positive correlation between SST and chl-*a* in this area, were probably because the variability of SST in this area were effected by seasonal change in the southern hemisphere, while the chl-*a* concentration is greatly influenced by river run-off.

The coefficient of determination at $r^2 = 0.1$ (p<0.05) which means that SST had 10.2% of contribution for the variation in changes of chl-*a* concentration, while the remaining of 89.8% was influenced by other factors together. The factors that may affect the variability of chl-*a* in coastal waters were rainfall (Katara et al. 2008; Navarro & Ruiz 2006) and river run-off (Navarro & Ruiz 2006; Tang et al. 2003), current, wind and salinity.

The effect of the seasonal change in the southern hemisphere seems to play an important role in influencing SST pattern in the archipelagic waters of Spermonde. From June to August, the southern hemisphere experiences

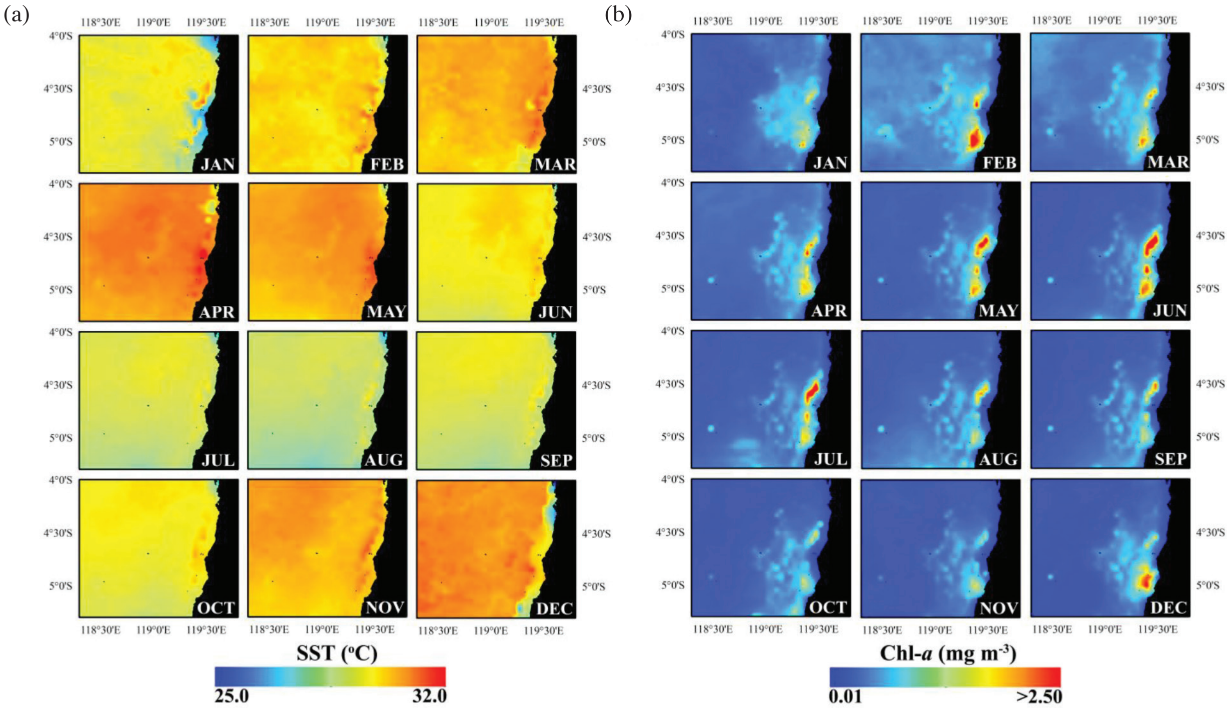

FIGURE 2. Climatological monthly composite of MODIS (a) SST (°C) and (b) chl-*a* (mg m^{-3}) throughout July 2002 to June 2011 at the archipelagic waters of Spermonde Indonesia

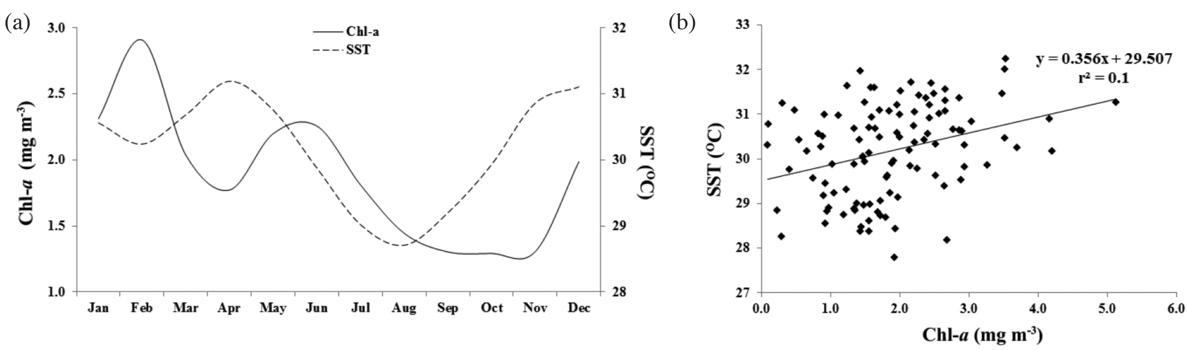

FIGURE 3. (a) Monthly climatologically average of SST (°C) and chl-*a* concentration (mg m^{-3}) and (b) cross-plot of monthly SST (°C) versus chl-*a* concentration (mg m^{-3})

winter causing cooler SST in the southern hemisphere. This caused SST in the archipelagic waters of Spermonde to become cooler (Qu et al. 2005). This event also coincides with the Southeast monsoon in Spermonde. The southeast monsoon is stronger in terms of its effect on ocean properties (Susanto et al. 2006). During that time, strong southeasterly winds drive the surface current which contributes cold water from the southern part and moves northward into Makassar Strait (Figure 4a). This may also develop upwelling and enhance vertical mixing thus reducing the SST in the southern part of Sulawesi Island (Nurdin et al. 2014), which may influence the neighboring area.

The maximum wind speeds occur during Southeast monsoon and because the wind is closely related to the current, it will increase the flow southward and induces emptiness at the surface layers that will be replaced by water masses from the bottom layers which is characterized by cooler temperature and rich in nutrient (Hendiarti et al. 2005). Whereas, from December to February the southern hemisphere experiences summer, thus the SST in the southern hemisphere becomes warmer. This event coincides with the Northwest monsoon in the archipelagic waters of Spermonde. However, this monsoon has less influence on the pattern of SST in this area because it is located at the south of the equator line, therefore heating at the southern hemisphere is dominant, which causes this area to become warmer (Figure 4b). This indicated that SST pattern in this area is influenced by the seasonal change in the southern hemisphere which is driven by the monsoon. The recent studies also confirmed that SST in Makassar Strait (Nurdin et al. 2013) and over the Indonesian region (Susanto et al. 2006) was influenced by the monsoon cycle. In contrary with SST, chl-*a* variability was the highest along the coast and decreases with distance towards offshore (Barnard et al. 1997; Radiarta & Saitoh 2008; Tang et al. 2003). This is due to the nutrient rich run-off from land which flows to the coastal area through several rivers in South Sulawesi. The rivers flow continuously over time, however the flow peaks during the Northwest monsoon (rainy season). Availability of nutrient due to river run-off and relatively high solar energy (sunlight) throughout the year creates favorable conditions for the photosynthesis of phytoplankton.

POTENTIAL FISHING GROUND

SST and chl-*a* can be used as natural tracers of dynamic patterns (Solanki et al. 2008). There are relationships between biophysical features and the catch of *R. kanagurta*. SST and chl-*a* has been determined as the most important parameters which influence the distribution and abundance of *R. Kanagurta* in tropical region of South China Sea (Mustapha et al. 2010) and Indonesia (Nurdin et al. 2014; Zainuddin 2007). Satellite derived SST and chl-*a* as an environmental data source were combined with statistical

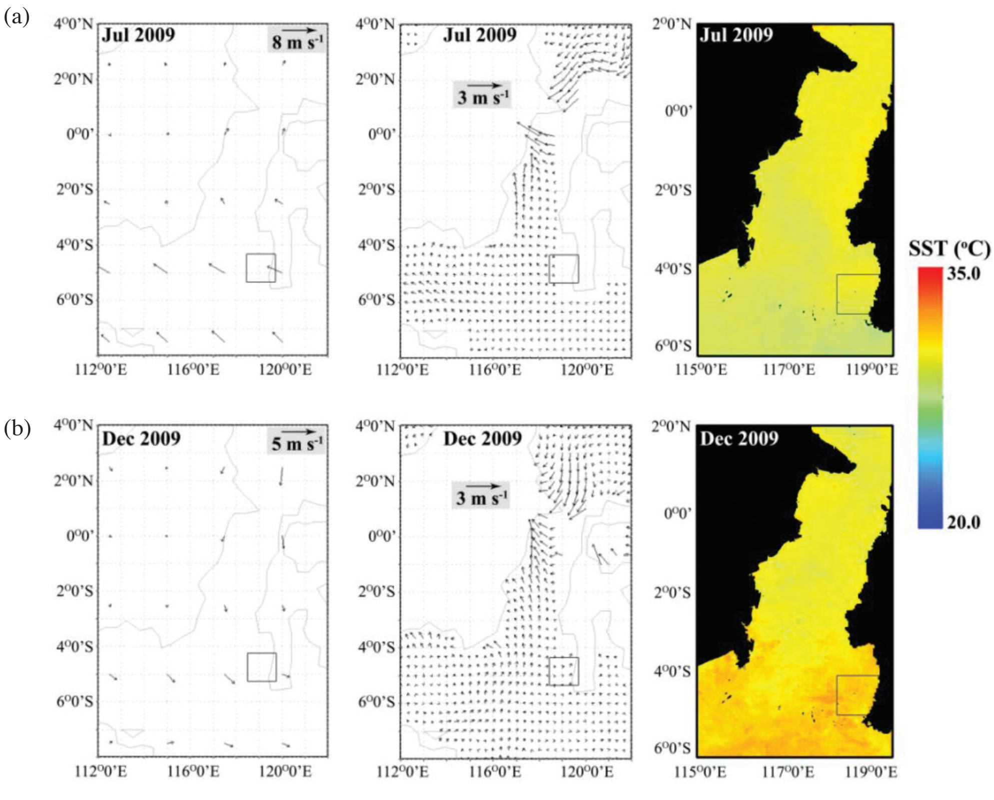

FIGURE 4. Influence of wind speed (left panel) and surface current (middle panel) on SST (right panel) in the archipelagic waters of Spermonde. The small box in each map indicated the study area

multiple regression to construct the predicted model and integrated with GIS technique to map the prediction of the presence of *R. kanagurta* in the whole area of the archipelagic waters of Spermonde.

Analysis of variance which explains the influence of SST and chl-*a* against the catch of *R. kanagurta* was obtained. Significant value (p=0.000 < 0.05) was found, which means that there is significant relationship between the catch of *R. kanagurta* and both SST and chl-*a*. In other words, using both parameters, at a certain level of accuracy, this enables prediction of the catch of *R. kanagurta* using the equation model above. *t*-test analysis was performed to determine the influence of each oceanographic parameter with the catch of *R. kanagurta*. In the *t*-test analysis, SST (p=0.05 ≤ 0.05) and chl-*a* (p=0.000 < 0.05) were found having significant influence against the catch of *R. kanagurta*. This indicated that the model (2) is acceptable. Positive correlation between SST and chl-*a* against the catch of *R. kanagurta* was obtained. The coefficient of correlation at R=0.7, indicates that if SST and chl-*a* increase, the catch increases. The coefficient of determination at r^2=0.5 (Figure 5), demonstrate that SST and chl-*a* had 49.6% of contribution for the variation in changes of the catch of *R. kanagurta*, while the remaining of 50.4% was influenced by other factors.

The potential fishing ground maps were based on statistical multiple regression models with SST and chl-*a* as independent variables. Generally, the amount of observed catch has coincided with predicted catch as shown in prediction maps in Figure 6. High catch amount are shown by large circles, moderate catch by medium circle and low catch by small circles, which consist with the predicted areas as shown with high catch (red color), moderate catch (green-yellow color) and low catch (blue color), respectively. The accuracy of the prediction map indicating that the distribution and abundance of *R. kanagurta* around the study area was 76.9%. The potential

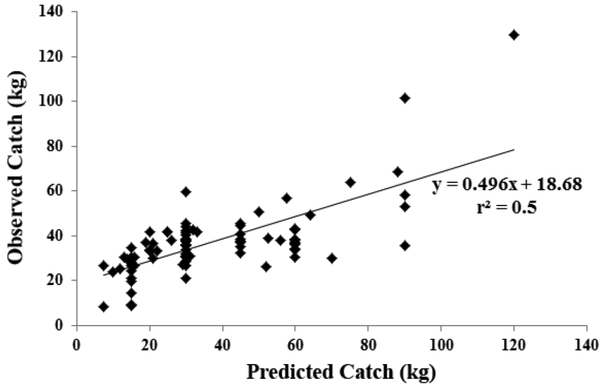

FIGURE 5. Cross-plot of daily observed catch against predicted catch of *R. kanagurta*

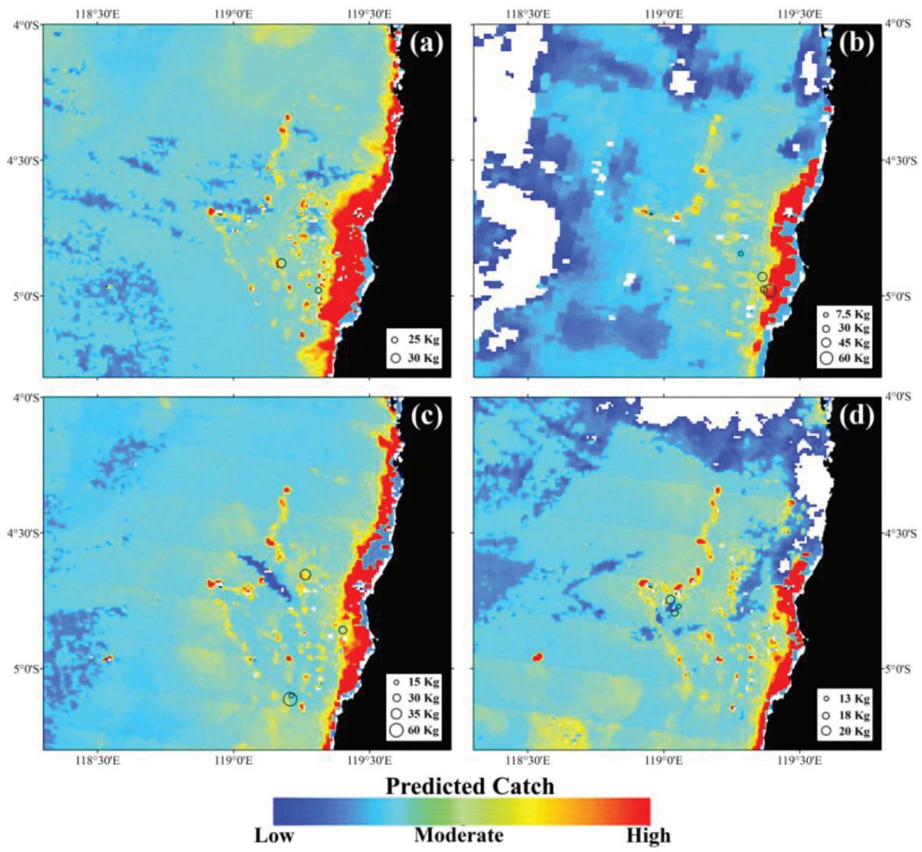

FIGURE 6. Fishing potential maps of (a) 14 April 2008, (b) 4 May 2008, (c) 16 June 2009 and (d) 25 June 2009. All prediction maps showed the potential fishing grounds which occurred along the coast

fishing grounds of R. *kanagurta* occurred along the coast of the study area. This is in accordance with the results of the study by Mustapha et al. (2010), Nurdin et al. (2014) and Zainuddin (2007). The fish tends to aggregate in the coastal area because this area is very productive and high in nutrient due to frequent upwelling (Bellido et al. 2008) and river discharge. Nutrients are fundamental for phytoplankton to grow, which in turn can be related to fish production (Chandran et al. 2009) and will attract the fish to come. Coastal area where nutrient supply and primary production are high favors food chains.

The model indicated that SST and chl-*a* have a significant influence against the catch of *R. kanagurta*. However, the coefficient of regression of both parameters showed that chl-*a* (p=0.000 < 0.05) was more dominant in influencing the catch of *R. kanagurta* in comparison to SST (p=0.05 ≤ 0.05). Chandran et al. (2009) also reported a less significant relationship between small fishes with SST in the Bay of Bengal, India. They also found that pelagic fishes tend to aggregate in regions of high phytoplankton. As a tropical region, the variability of SST in the archipelagic waters of Spermonde is low and relatively stable which causes slight influence of SST, while sufficient food tends to be the main reason influencing the presence of *R. kanagurta* in this area. Areas of relatively stable temperature and high chl-*a* concentration may attract feeding pelagic species (Chandran et al. 2009). Optimal foraging theory predicts that organisms seek out food items at locations where there is a higher probability of finding prey, hence reducing the energy utilized in searching for prey (Reese et al. 2011). The presence of *R. kanagurta* in this area could also be due to hunting and prey of phytoplankton, zooplankton and also small fish.

The present study found that SST and chl-*a* are important oceanographic parameters for studies on potential fishing grounds of *R. kanagurta*. However, several other factors may influence the presence of *R. kanagurta* in this area as well, such as availability of prey, wind and currents, salinity, sea surface height and lunar index.

The integration of satellite remote sensing derived chl-*a* concentration and SST features, with statistical modeling and GIS technique were found to be a simple methods but useful for determining and mapping the potential fishing grounds forecast of *R. kanagurta*. A reliable and fast forecast on the potential fishing grounds may help the user (fisherman) in decision making and reduction in searching time, which will increase catch with lesser effort.

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