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Applicability of remote sensing oceanographic data in the detection of potential fishing grounds of *Rastrelliger kanagurta* in the archipelagic waters of Spermonde, Indonesia

Suhartono Nurdin[a,b], Muzzneena A. Mustapha[a,*], Tukimat Lihan[a], Mukti Zainuddin[c]

[a] *School of Environmental and Natural Resource Sciences, Faculty of Science and Technology, The National University of Malaysia, 43600, Bangi, Selangor, Malaysia*
[b] *Fisheries and Marine Services, Government of South Sulawesi Province, No. 269, Jenderal Urip Sumoharjo Street, 90245, Makassar, South Sulawesi, Indonesia*
[c] *Faculty of Marine and Fisheries, Hasanuddin University, 90245, Makassar, South Sulawesi, Indonesia*

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ABSTRACT

Rastrelliger kanagurta is among the pelagic fish of commercial value caught in the archipelagic waters of Spermonde, Indonesia. The dynamic oceanographic pattern in this area influences the distribution of this pelagic fish. Understanding the relationship between the distribution of fish and environmental factors is important in exploring fisheries resources. This study used *Rastrelliger kanagurta* fishing-catch data during the high-catch season in the second quarter, which was from April to June (2008 and 2009), and satellite data of chlorophyll-*a* (chl-*a*), and sea surface temperature (SST) from MODIS-Aqua. The study aimed to identify the relationship between fish distribution with chl-*a* and SST constructed using the Generalized Additive Model (GAM), detect the potential fishing grounds, and determine the impact of climate change on fish distribution based on temperature projection of IPCC-AR5-RCPs. The distribution of *Rastrelliger kanagurta* was significantly associated ($p < 0.0001$) with the preferred range of chl-*a* at 0.30–0.40 mg/m^3 and SST at 30.00–31.00 °C. The potential fishing ground maps showed that areas with high potential catch were located near the coast to offshore (3–20 M), with acceptable level of map accuracy at 83.34%; with kappa value at 0.70. Increased temperature of 1.80 °C resulted in movement of potential fishing grounds to the southern part of Makassar Straits leading to the archipelagic waters of Spermonde. In contrast, increased temperature of 2.60 °C and 3.30 °C resulted in lesser potential fishing grounds area which shifted further to the south. The results of this study indicated applicability of remote sensing in contributing to optimal fishing effort and decision making for long-term management of *Rastrelliger kanagurta* resources.

1. Introduction

The marine fisheries sector in Indonesia is one of the major activities that contribute towards the national economy. Increase in population increases the demand on fish as source of protein, which motivates the fishermen to improve fishing activities in order to achieve optimal catch. The archipelagic waters of Spermonde is one of the largest contributors of fishery production in Indonesia. This area is located at the southern part of the Makassar Straits, in Indonesia (Fig. 1). The fish with high economic value most caught in this area is the *Rastrelliger kanagurta* (Nurdin et al., 2015). It is a small pelagic fish which schools in large quantities and forages in the surface layer (Solanki et al., 2005b). Total production of pelagic fish including *Rastrelliger kanagurta* from this area is the highest during the second quarter period (April-June) of the East Monsoon (Fisheries and Marine Services of South Sulawesi FMS-SS, 2008).

The archipelagic waters of Spermonde is strongly influenced by the Asian-Australian monsoon. This area is also the main pathway of mean flow between the Pacific Ocean and the Indian Ocean, known as The Indonesian Throughflow (ITF) (Wajsowicz et al., 2003). Interaction between the monsoon and the ITF affects the current circulation system, heat transport, tidal mixing, wind induced upwelling and downwelling, the environmental variability of chlorophyll-*a* (chl-*a*) concentration, sea surface temperature (SST), and salinity of the area (Gordon, 2005). Recent global climate change also has the possibility of affecting the marine environment in the region. Climate change affects among others the physical and chemical properties of sea water, ocean acidification, salinity, current, vertical stratification, and oxygen concentration (Dueri et al., 2014).

These dynamic oceanographic processes will affect distribution of

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[*] Corresponding author.
E-mail address: muzz@ukm.edu.my (M.A. Mustapha).

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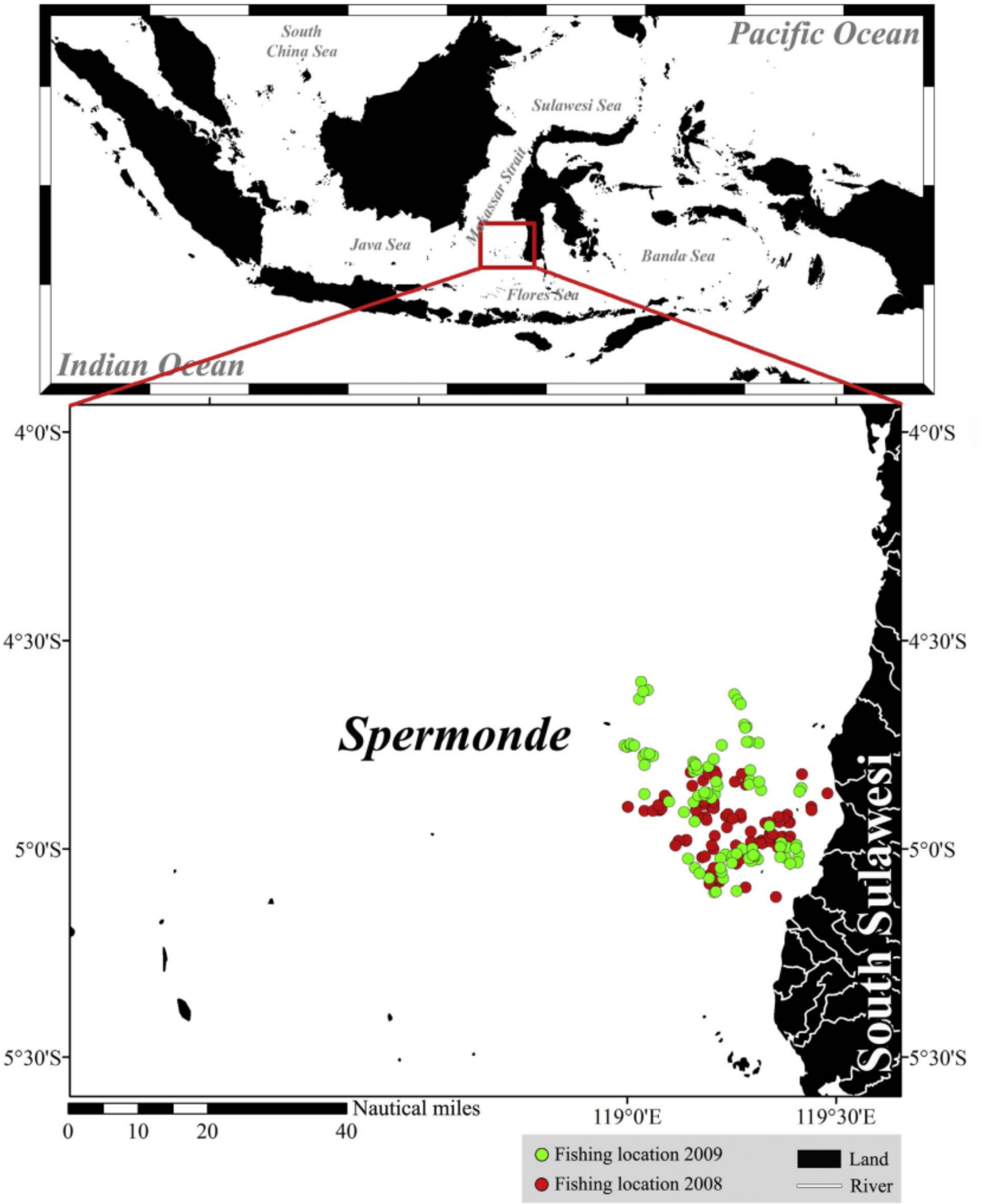

Fig. 1. Map indicating the study area in the archipelagic waters of Spermonde at Makassar Strait, Indonesia and locations showing fish catch positions in 2008 and 2009.

pelagic fish in the region. Fishes are known to find suitable habitat for feeding, spawning, migration and protection (Palacios et al., 2006). Distribution of pelagic fish which is a complex phenomenon is controlled by the interaction of several factors in the marine environment (Maravelias, 1999). This complexity makes it difficult for fishermen to determine potential fishing grounds. The majority of the fishermen apply traditional methods to locate potential area for fishing activities. Fishing locations are randomly determined based on the repetitive habits or information from fellow fishermen (Nurdin et al., 2015). Natural features such as flying seabirds, schools of dolphins, bubbles on the surface, wood or other floating objects on the surface are also used as guide in locating fishing area (Zainuddin, 2011). The search for fish ends up in a lot of resources and time being spent, thus resulting in increase of cost and low profits.

However, the distribution of fish is predictable through the biophysical conditions. Chl-a and SST are among the biophysical parameters which greatly influence the distribution of pelagic fish, and are often used to predict potential fishing grounds (Lanz et al., 2009;

Mustapha et al., 2010; Solanki et al., 2005b; Zainuddin, 2011). Chl-*a* determines water productivity and fish production (Bertrand et al., 2002). In contrast, SST greatly affects the phytoplankton growth and directly influences the physiological condition of the fish (Solanki et al., 2005a). It is known that SST plays a key role as the only environmental predictor highly related to diversity of many pelagic fishes (Tittensor et al., 2010). SSTs perform as an indicator of potential habitats. These parameters are often used to describe the conditions of the marine environment and the availability of food sources in an ecosystem to explore the fishery resources. These parameters can be obtained in near real time at high resolutions using satellite sensors (Solanki et al., 2005b).

Determination of potential fishing grounds using satellite data has been applied by detecting the important oceanographic parameters influencing the presence of fish schooling such as chl-*a* and SST. Mustapha et al. (2010) and Nurdin et al. (2015) have demonstrated the capability of using satellite derived chl-*a* and SST to predict the potential fishing grounds of *Rastrelliger kanagurta* in the tropical area of Southeast Asia. Several analysis have been applied to determine potential fishing grounds which includes Generalized Additive Model (GAM) (Bellido et al., 2008; Damalas et al., 2007; Wang et al., 2007; Zainuddin et al., 2008), Multiple Linear Regression (Nurdin et al., 2015), frequency analysis (Andrade and Garcia, 1999; Lanz et al., 2009; Tseng et al., 2011; Zainuddin et al., 2008; Zainuddin, 2011), and Suitability Index (SI) (Mustapha et al., 2010; Nurdin, 2016) among others.

Pelagic fishes have been shown to be related to a certain range of oceanographic parameter appropriate to their life stages (Mustapha et al., 2010; Zainuddin et al., 2008; Zainuddin, 2011). Understanding the relationship between target fish species with the oceanographic parameters enables prediction of potential fishing grounds. In this perspective, this study aims to determine the relationship between *Rastrelliger kanagurta* distribution with oceanographic parameters (chl-*a* and SST), to identify the potential fishing grounds, and to determine the effect of climate change on the spatial distribution of *Rastrelliger kanagurta* in the archipelagic waters of Spermonde.

2. Materials and methods

Fishery data and satellite-based chl-*a* and SST oceanographic data of 2008 and 2009 were used in this study. To achieve the objectives of the study, we focused our analysis over the high catch period, April to June (East monsoon), of *Rastrelliger kanagurta* in the archipelagic waters of Spermonde, (Zainuddin et al., 2008).

2.1. Fishery data

Daily *Rastrelliger kanagurta* catch data collected from field survey around the archipelagic waters of Spermonde throughout 2008 and 2009 were analysed. Data obtained included catch weight (kg) and fishing location (longitude and latitude). The catch data were divided into three categories (Andrade and Garcia, 1999; Zainuddin et al., 2008): (1) catch weight equal to zero (null catches), (2) catch weight greater than zero but lower than 12 kg (positive catches), and (3) catch weight greater than 12 kg (high catches). The value of 12 kg represents the lower limit of the upper quartile of *Rastrelliger kanagurta* catch weight greater than zero.

According to Zainuddin et al. (2008), we used high catches data to obtain the optimal relationship between *Rastrelliger kanagurta* distribution with oceanographic parameters (chl-*a* and SST). Our preliminary study indicated a significant difference between the high catches data distribution and the other distribution (positive and null catches) using *t-test* ($p < 0.001$). The high catches data distribution also had a greater tendency for chl-*a* and SST than the other distributions.

2.2. Remotely sensed environmental data

Remotely sensed chl-*a* and SST data were derived from MODIS satellite measurements. The data were downloaded from the Ocean Colour website (http://oceancolor.gsfc.nasa.gov/). We downloaded level 1 (1 km) daily data from 2008 and 2009 which coincided with the timing of the daily fish catch data to acquire the value of chl-*a* concentration and SST. The data sets were used to obtain the preferred oceanographic conditions and also to develop the statistical predictive models for determination of potential fishing grounds. We also analysed level 3 (4 km) data from April to June in 2014 to produce weekly predicted potential maps for *Rastrelliger kanagurta* to analyse the impact of climate change.

2.3. Potential fishing grounds of *Rastrelliger kanagurta*

Fish distribution and oceanographic parameters are shown to have non-linear relationship (Bertrand et al., 2004; França et al., 2012). Optimum range of chl-*a* and SST will be suitable for the fish, while if chl-*a* concentration and SST are less or higher than the optimal range, it will be demonstrated as less suitable. Analysis of fish data in this study using normality test (*Kolmogorov-Smirnov* test) indicated that the catch data demonstrated non-normal distribution ($p < 0.010$).

Based on this characteristic of the catch data, GAM analysis was selected as the most appropriate analysis to determine the relationship between fish distribution with chl-*a* concentration and SST. GAM analysis is a statistical non-parametric corresponding to non-linear data (Bellido et al., 2008; Bertrand et al., 2004; França et al., 2012; Hastie and Tibshirani, 1990; Zainuddin et al., 2008).

GAM analysis was performed on the catch weight, chl-*a* concentration, and the SST data at the fishing location using the following formula (Hastie and Tibshirani, 1990):

$$y = a + s(\mathrm{chl}) + s(\mathrm{SST}) + e \tag{1}$$

where “*y*” is catch weight, “*a*” is a constant, “*s*(.)” is a spline smoothing function of the variables (chl-*a* and SST), and “*e*” is a random error.

Based on the relationship between catch with chl-*a* concentration and SST, GAM resulted in a potential predicted catch weight (kg) at each pixel corresponding to the data input. The output generated the potential fishing ground maps for *Rastrelliger kanagurta*. The accuracy assessment of the potential fishing ground maps was carried out using Kappa statistics. It was performed by comparing the actual catch with the potential predicted area based on the GAM analysis. A total of 34 actual catch data were used for this assessment. The assessment determines the level of accuracy of the forecasting model used to generate the potential fishing ground maps (Vasconcelos et al., 2013). This method resulted in KHAT statistics as an approximate for Kappa assessment that indicates the size of approval or accuracy (Congalton, 1991). The Kappa statistics equation is as below:

$$\hat{K} = \frac{N\sum_{i=1}^{r} x_{ii} - \sum_{i=1}^{r} (x_{i+}{*}x_{+i})}{N^2 - \sum_{i=1}^{r} (x_{i+}{*}x_{+i})} \tag{2}$$

where “*K*” is the Kappa statistics; “*N*” is a total number of observations; “*r*” is a number of rows in the matrix; “x_{ii}” is a number of observations in row *i* and column *i*; “x_{i+}” and “x_{+i}” are the marginal number of row *i* and column *i*, respectively. The columns represent the reference data and the line shows the classification resulting from remote sensing data (Arcidiacono and Porto, 2012).

2.4. Impact of climate change on spatial distribution of *Rastrelliger kanagurta*

The most obvious impact of climate change is global increase of SST (Coyle et al., 2011). The increase of SST has significant impact on the structure of marine ecosystems and communities (Ménard et al., 2007).

In climate change models, projecting the SST is the technique widely used by experts in studying the impact of climate change on marine species (Dueri et al., 2014; Hare et al., 2010; Lehodey et al., 2012; Tseng et al., 2011).

Intergovernmental Panel on Climate Change (IPCC) is an organization that compiles comprehensive reports based on scientific study, technical and socio-economics of climate change, the causes, and the resolved strategies. The Fifth Assessment Report (AR5) of IPCC introduced a new scenario called The Representative Concentration Pathways (RCPs) as a substitute of scenarios of Special Report on Emission Scenario (SRES). RCPs play an important role in providing input in the study of climate models and long-term projections of climate change, which includes the pre-industrial period to the year 2100 (Van Vuuren et al., 2011).

At the end of this century, RCP scenario projected SST rising at 1.80 °C–3.30 °C (IPCC 2014). In this study, we projected the SST data of the high fishing season in April, May and June in 2014. Projection was based on the IPCC-AR5-RCPs scenarios with three temperature rise selected at 1.80 °C, 2.60 °C and 3.30 °C until the year of 2040.

Determination of weekly potential fishing grounds of *Rastrelliger kanagurta* in April, May and June of 2014 was derived using GAM and was based on the projected values of SST. The use of weekly satellite data is acceptable and is able to represent the status of the marine environment because it still retains the characteristics of the parameters with only minor changes (Meskhidze et al., 2007). The use of weekly data also reduces clouds disturbances on satellite image used (Wang et al., 2010b).

3. Results

3.1. Preferred oceanographic conditions for *Rastrelliger kanagurta*

Rastrelliger kanagurta was found in the area with chl-*a* concentration ranging between 0.01 mg/m^3–1.00 mg/m^3 and SST ranging between 26.05 °C–31.97 °C. The average catch and fishing frequency were highest at chl-*a* concentration range of 0.35 ± 0.05 mg/m^3 which were 50.72 kg (Fig. 2a) and 26.03% (Fig. 2b), respectively. In contrast the average catch and fishing frequency were highest at SST range of 30.51 ± 0.46 °C which were 48.87 kg (Fig. 2c) and 33.56% (Fig. 2d), respectively.

Table 1
GAM analysis (for non-parametric ANOVA) on the influence of chl-*a* and SST towards the catch of *Rastrelliger kanagurta*.

	Npar F	Pr (F)	Significant codes
(Intercept)			
s (Chl-*a*)	7.3904	0.0001260	a
s (SST)	7.1355	0.0001729	a

a = 0

3.2. Relationship between *Rastrelliger kanagurta* and the environmental factors

GAM analysis indicated that chl-*a* and SST have significant influences ($p < 0.0001$) on the distribution of *Rastrelliger kanagurta* (Table 1). The GAM plots (rug plots) on the horizontal axis represent observed catch data points. The fitted function is shown by the thick line, and the dashed line indicates the 95% confidence bands (Fig. 3). A strong relationship was observed in chl-*a* concentration range of 0.30 mg/m^3–0.40 mg/m^3 (Fig. 3a) and SST range of 30.00 °C–31.00 °C (Fig. 3b). This is evident by the highest relative density distribution of catch data (fishing frequency) within these ranges. The results are also consistent with the graph of average catch and fishing frequency shown in Fig. 2.

3.3. Spatial prediction of potential fishing grounds of *Rastrelliger kanagurta*

The GAM model was used to determine the potential fishing grounds of *Rastrelliger kanagurta* in the archipelagic waters of Spermonde. Zones with less potential catch (≤12.00 kg) and high potential catch (> 12.00 kg) are shown. The actual catch data were plotted on the maps to show the actual fish catch on the fishing location (Fig. 4).

Generally, the areas with high potential catch were located near the coast (3–20 M). Contrastingly, the areas with less potential catch were

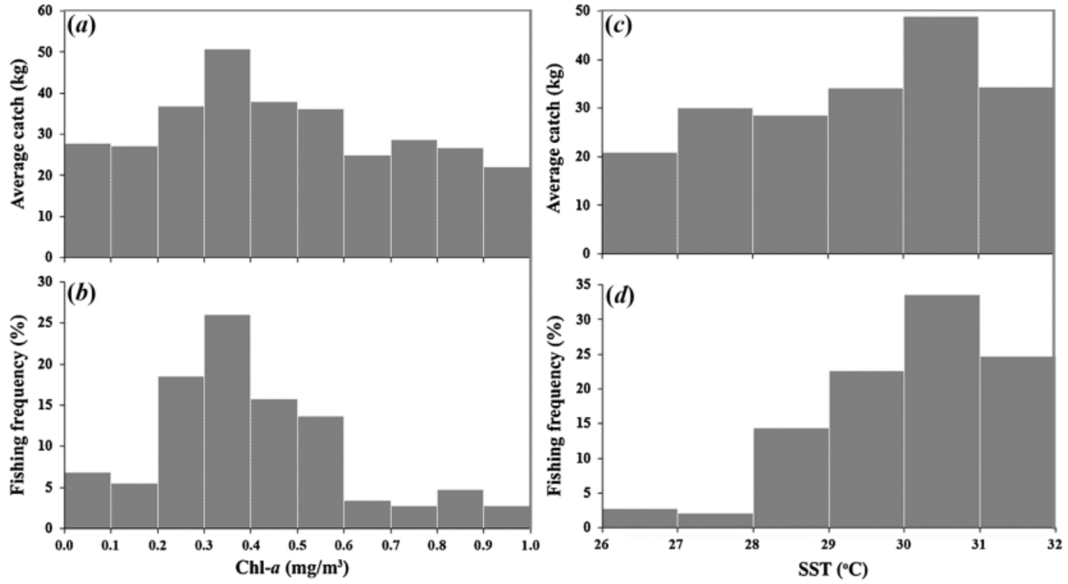

Fig. 2. Left panel: (a) the average catch weight and (b) the fishing frequency of *Rastrelliger kanagurta* in different range of chl-*a* concentration. Right panel: (c) the average catch weight and (d) the fishing frequency of *Rastrelliger kanagurta* in different range of SST.

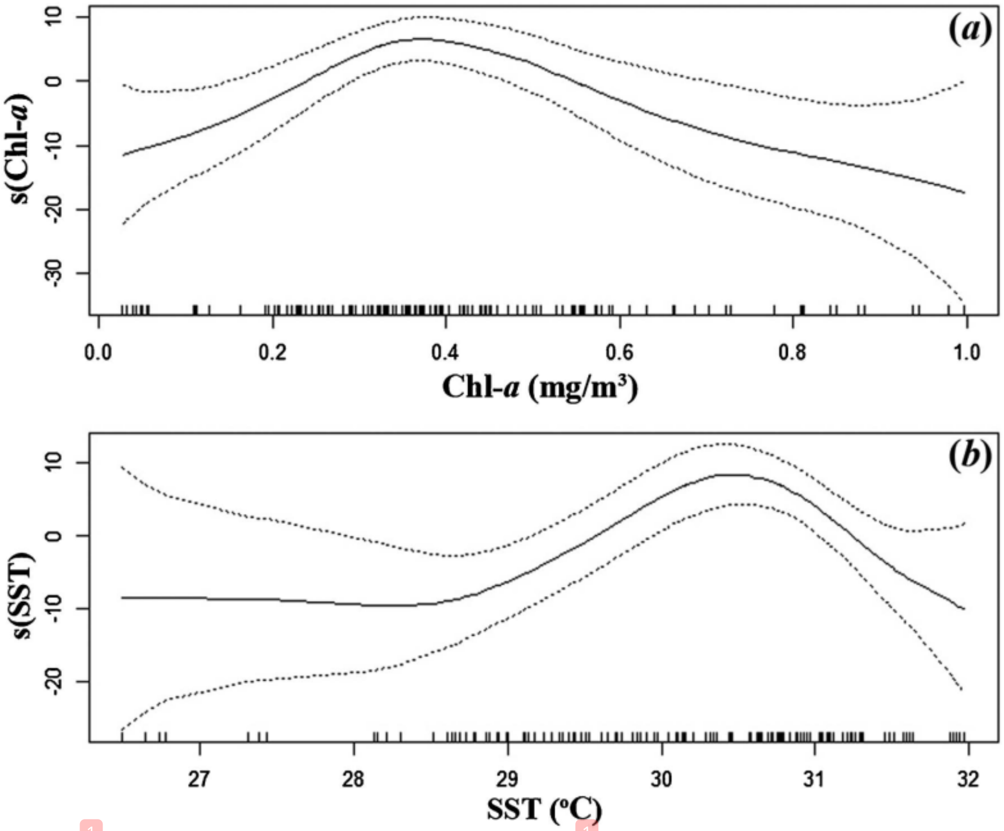

Fig. 3. GAM analysis of *Rastrelliger kanagurta* catch against: (a) chl-*a* and (b) SST. Distribution of relative density data is shown on the x-axis.

located along the coast (< 3 M) and offshore areas (> 20 M) in the archipelagic waters of Spermonde.

The accuracy assessment of the potential fishing ground maps represented the extent of accuracy developed by the GAM model and the reliability of forecasting. The accuracy assessment was performed using 34 actual catch data that were not included in the GAM analysis (independent data). The accuracy assessment showed that the overall accuracy of the potential fishing ground maps were 83.34% with Kappa statistics of 0.70.

3.4. Climate change effects on potential fishing grounds of Rastrelliger kanagurta

Weekly SST data from 23 to 30 April, 1–8 May and 18–25 June 2014 were projected in three scenarios of SST increase based on IPCC-AR5-RPCs at 1.80 °C, 2.60 °C, and 3.30 °C (Fig. 5).

The west coast of Sulawesi Island indicated the variations of SST were 27.19 °C–31.33 °C on 23–30 April, 26.54 °C–30.58 °C on 1–8 May, and 26.00 °C–30.05 °C on 18–25 June (Fig. 5a). Projection of SST at 1.80 °C increased the variation of temperature to 28.99 °C–33.13 °C on 23–30 April, 28.34 °C–32.38 °C on 1–8 May, and 27.80 °C–31.85 °C on 18–25 June (Fig. 5b). Projection of SST at 2.60 °C increased the variation of temperature to 29.79 °C–33.93 °C on 23–30 April, 29.14 °C–33.18 °C on 1–8 May, and 28.60 °C–32.65 °C on 18–25 June (Fig. 5c). In contrast, projection of SST at 3.30 °C increased the variation of temperature to 30.49 °C–34.63 °C on 23–30 April, 29.84 °C–33.88 °C on 1–8 May, and 29.30 °C–33.35 °C on 18–25 June (Fig. 5d).

On 23–30 April, large areas of high potential catch occurred in the northern parts at latitudes of 1°30′S–5°00′S (Fig. 6a). Meanwhile, small areas of high potential catch occurred in the southern part (archipelagic waters of Spermonde) and in the northern part, with increased of SST at 1.80 °C (Fig. 6b). These potential areas become smaller with further increased of SST at 2.60 °C (Fig. 6c). Finally, the increased of SST at 3.30 °C resulted in the entire region to have low potential catch (Fig. 6d).

On 1–8 May, high potential catch existed in most of the region (Fig. 6a). However, the increased of SST at 1.80 °C resulted in the high potential catch to decline drastically. The high potential catch occurred only in the southeastern and northern part of the archipelagic waters of Spermonde (Fig. 6b). The increase of SST at 2.60 °C (Fig. 6c) and 3.30 °C (Fig. 6d) resulted in the entire region to have low potential catch.

On 18–25 June, high potential catches with relatively small areas occurred in the northern part at latitudes of 1°30′S–4°00′S (Fig. 6a). Nevertheless, the increase of SST at 1.80 °C resulted in the high potential catch to increase drastically, covering almost the entire region (Fig. 6b). Contrastingly, the increase of SST at 2.60 °C reduced the high potential catch area, the high potential area occurred only in the southern part of the archipelagic waters of Spermonde (Fig. 6c). Increased of SST at 3.30 °C reduced the potential area and it shifted further to the south (Fig. 6d).

4. Discussion

4.1. Distribution of Rastrelliger kanagurta

Potential fishing grounds of *Rastrelliger kanagurta* in the archipelagic

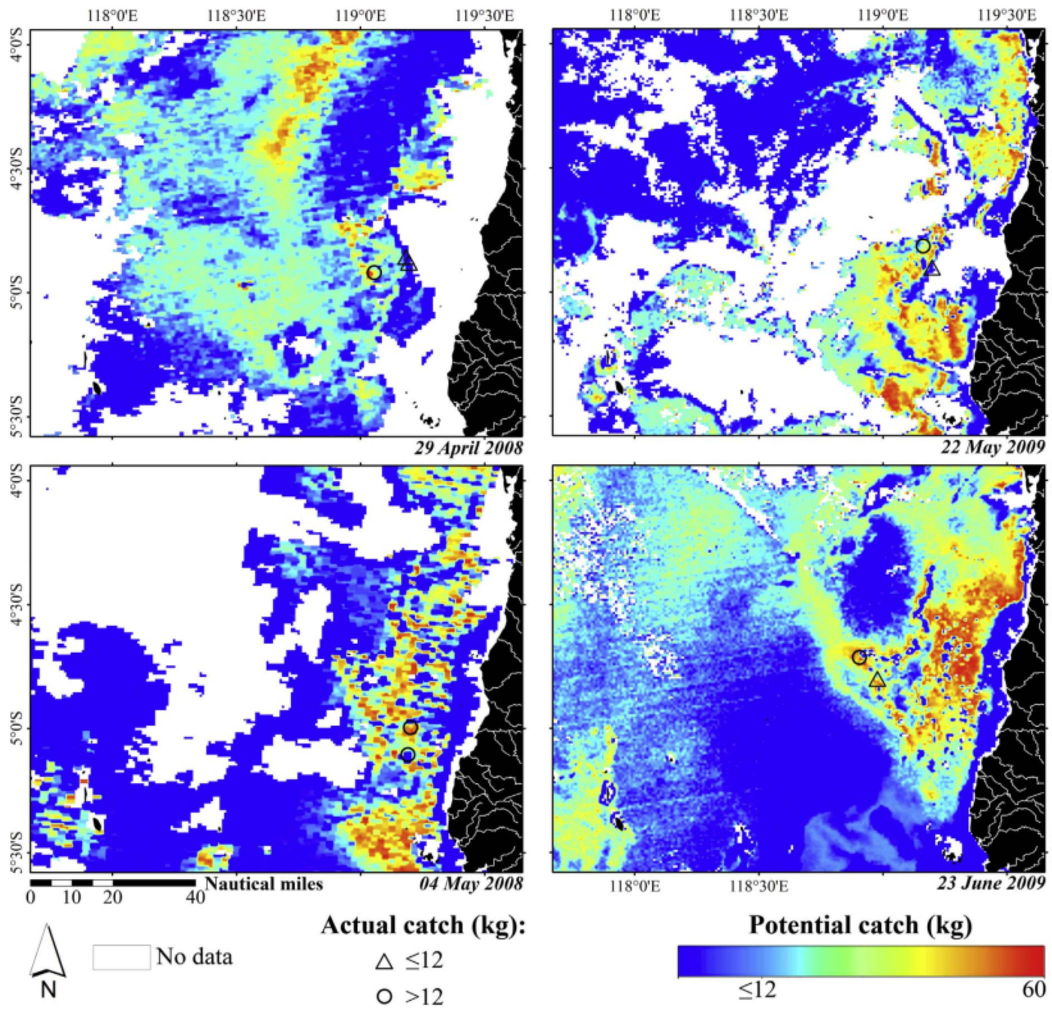

Fig. 4. Potential fishing ground maps of *Rastrelliger kanagurta* in the archipelagic waters of Spermonde on 29 April and 4 May 2008 (left panel) and on 22 May and 23 June 2009 (right panel).

waters of Spermonde were determined using catch data in the high fishing season, of the second quarter period (April, May and June) during the East monsoon. High fishing season was based on catch data from Fisheries and Marine Services of South Sulawesi FMS-SS (2008). The use of high fishing season catch data has been proven to determine the potential fishing grounds with high probability of the presence of species (Zainuddin et al., 2008).

During the sampling periods of high fishing season (April-June), the range of chl-*a* concentration and SST in the archipelagic waters of Spermonde was at 0.02 mg/m^3–1.00 mg/m^3 and 26.50 °C–31.97 °C, respectively. Chl-*a* in this area is always high during the East monsoon (Fig. 7a) and West monsoon seasons (Fig. 7b), contributing to high productivity throughout the year. However, SST during the East monsoon is cooler (Fig. 7a) than during the West monsoon (Fig. 7b), Nurdin (2016) found that the average range of chl-*a* concentration in the archipelagic waters of Spermonde was at 0.21 mg/m^3–0.60 mg/m^3 during the East monsoon and 0.29 mg/m^3–0.63 mg/m^3 during the West monsoon. In addition, the average range of SST was at 28.36 °C–30.20 °C during the East monsoon and 29.30 °C–30.34 °C during the West monsoon. The variations of chl-*a* and SST in this area was greatly influenced by the monsoons.

Based on GAM analysis, chl-*a* and SST were found to significantly affect the distribution of *Rastrelliger kanagurta* in the archipelagic waters of Spermonde. As shown in Fig. 3, the GAM plots could be interpreted as the individual effect of each predictor (chl-*a* and SST) variable on catch. Most *Rastrelliger kanagurta* were found in strong association with chl-*a* concentration range of 0.30 mg/m^3 to 0.40 mg/m^3 and SST range of 30.00 °C–31.00 °C. The preferred environmental ranges are parallel to the distribution of relative catch density (Fig. 3) and also coincide with the average catch weight and the fishing frequency histogram (Fig. 2). The chl-*a* and SST values outside the preferred ranges were not significant because the reduce density of catch data points leads to larger standard errors. The GAM plots are substantially reinforced by the histogram graphs (Fig. 2). The average catch weight and the fishing frequency were highest within these preferred ranges, which confirms that the frequency of fishing sets mostly distributes within the preferred environmental conditions. This was similar to the results of the study by Mustapha et al. (2010) in the tropical waters of South China Sea, where it was found that the highest fishing frequency of *Rastrelliger kanagurta* was at chl-*a* range of 0.24 mg/m^3–0.30 mg/m^3 and SST range of 29.60 °C–30.20 °C.

The areas with high potential catch were found within 3–20 M

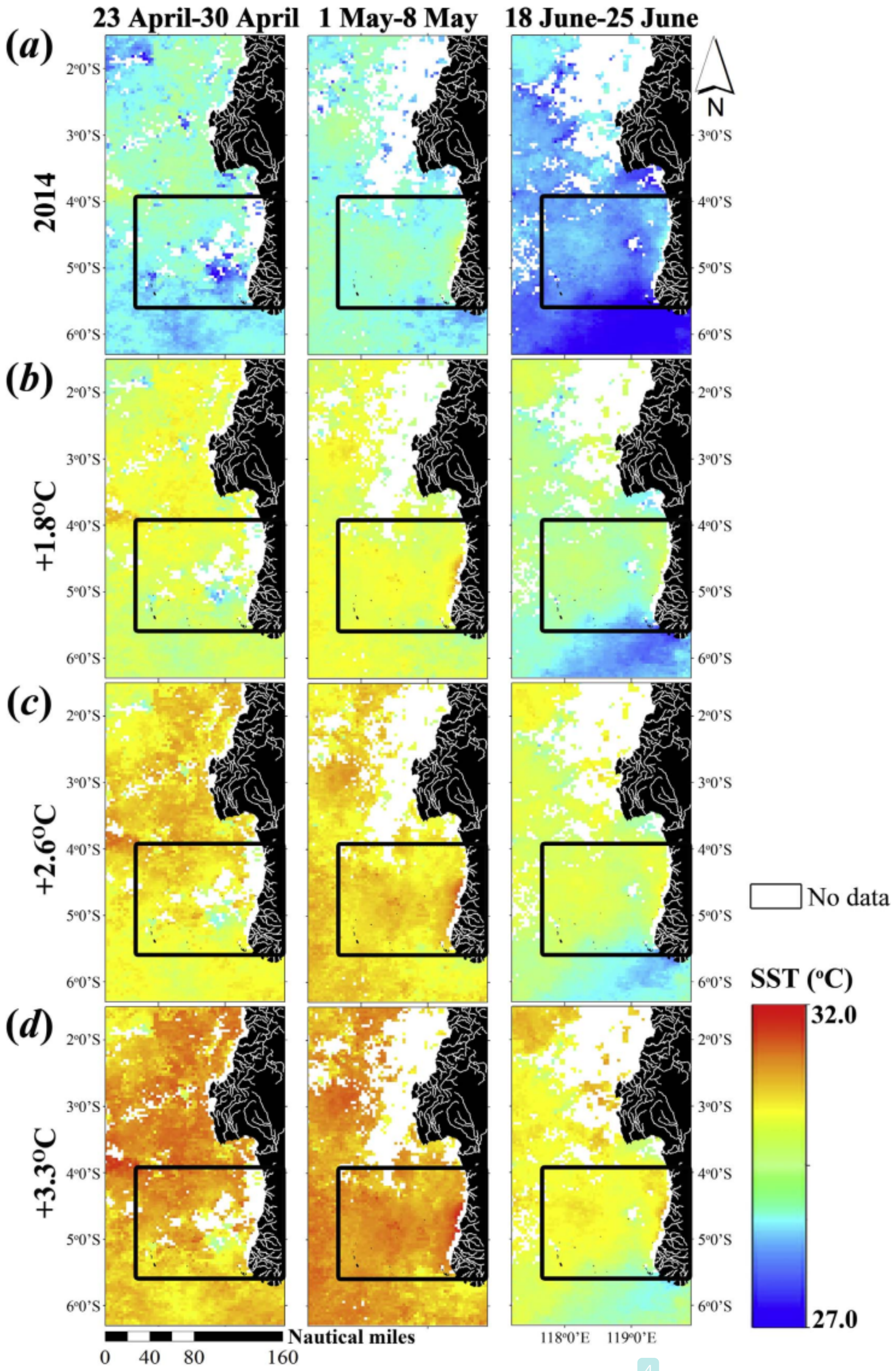

Fig. 5. (a) The distribution of SST from 23 to 30 April, 1–8 May and 18–25 June 2014; and the projected increases of SST at (b) 1.80 °C; (c) 2.60 °C; and (d) 3.30 °C, up to the next 30 years in the west coast of Sulawesi Island. Areas in the box show the archipelagic waters of Spermonde.

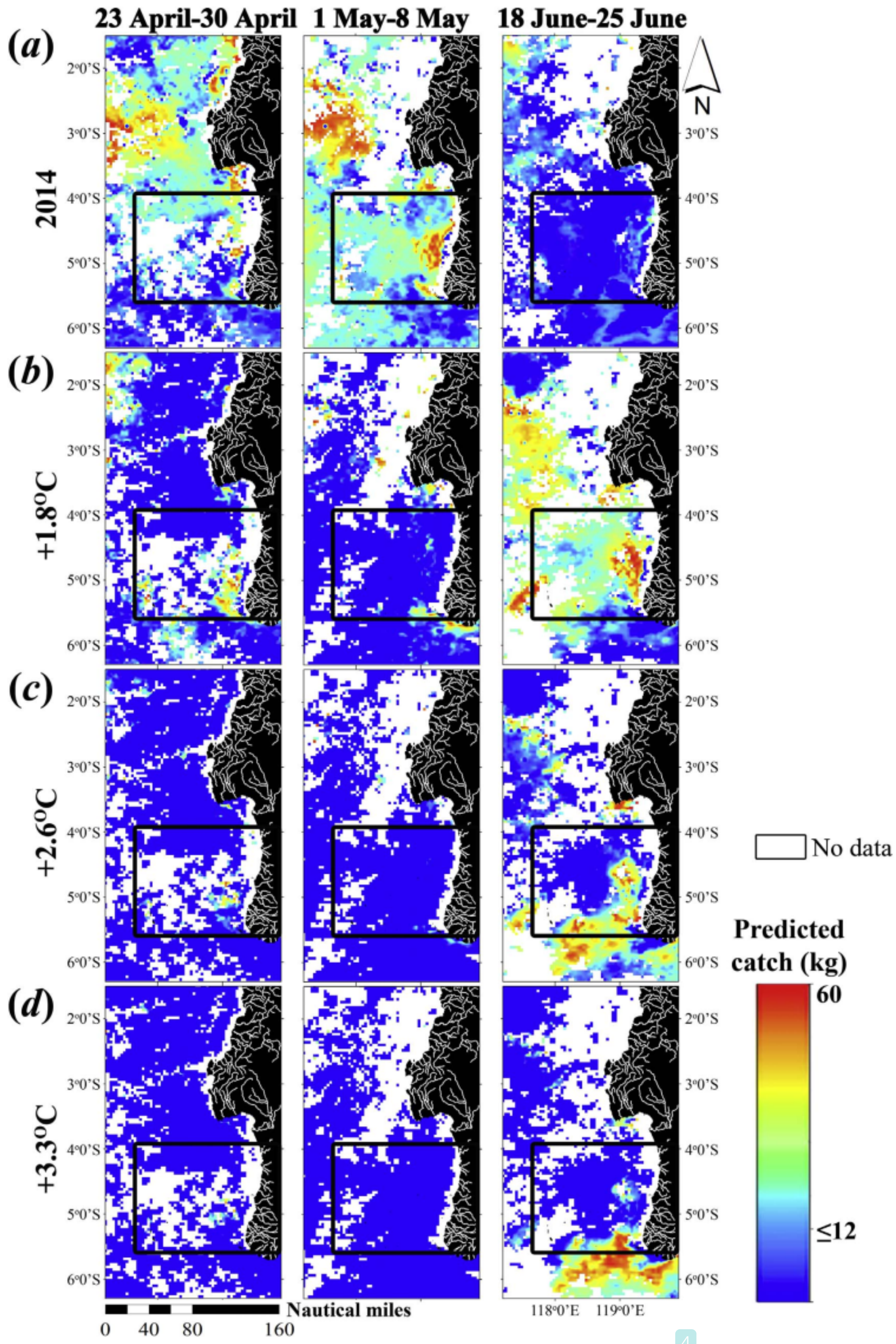

Fig. 6. (a) The predicted potential catch from 23 to 30 April, 1–8 May and 18–25 June 2014; and the predicted potential catch based on projected increases of SST at (b) 1.80 °C; (c) 2.60 °C; and (d) 3.30 °C, up to the next 30 years in the west coast of Sulawesi Island. Areas in the box show the archipelagic waters of Spermonde.

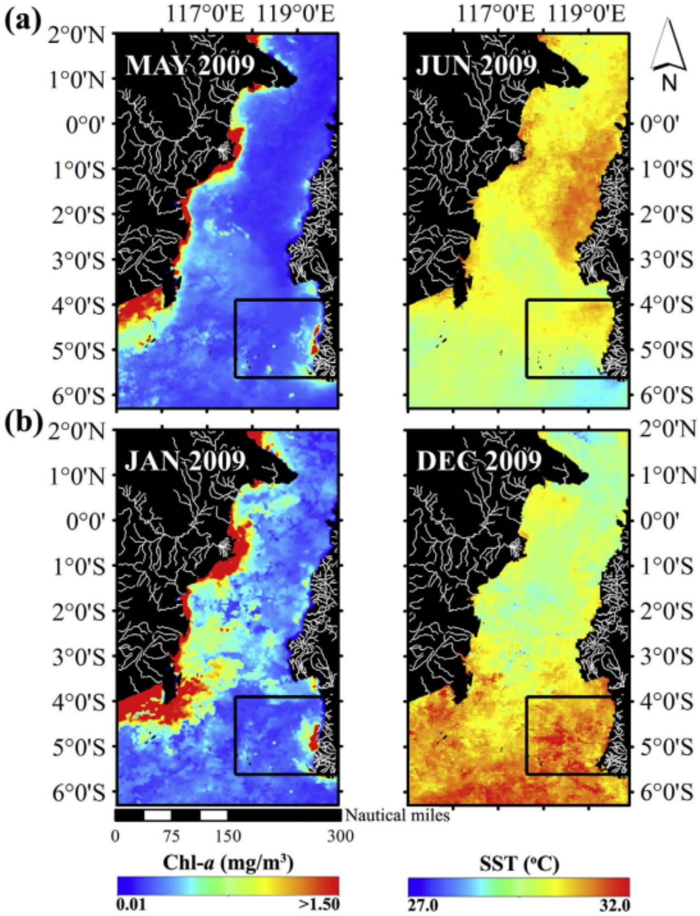

Fig. 7. The distribution of chl-*a* concentration (left panel) and SST (right panel): (a) during the East monsoon; and (b) during the West monsoon. Areas in the box show the archipelagic waters of Spermonde.

distance from the coast, with the range of chl-*a* concentrations of 0.35 ± 0.05 mg/m^3 and SST of 30.51 ± 0.46 °C (Fig. 4). The chl-*a* concentration range indicated distribution of food which is suitable for the feeding activity of *Rastrelliger kanagurta*. Chl-*a* is an indicator relating to formation of area where small pelagic fish concentrates for foraging (Lanz et al., 2009). In contrast, the SST range indicated temperature conditions appropriate for the adaptation of *Rastrelliger kanagurta*'s physiology (Solanki et al., 2005a). SST is an indicator for aggregation and migration of fish (Santos, 2000; Zainuddin, 2011). The study by Bertrand et al. (2002) in the tropical Pacific Ocean found that SST plays an important role in the physiology of tuna. Temperature variations also affect the biological productivity of the ocean in this area. The availability of food and comfortable SST stimulates the presence of fish.

The study also found that areas which have less potential for *Rastrelliger kanagurta* are mainly located in the coastal area (< 3 M) (Fig. 4). As shown in Fig. 8a, the coastal area has a high concentration of chl-*a* (> 0.60 mg/m^3) due to river discharge which carries nutrients from the mainland and several dynamic processes which occurs in the coastal area (Xian et al., 2012). However, as shown in Fig. 8b, high chl-*a* concentration was less suitable for fish. According to Tang et al. (2004) and Wang et al. (2010a), high chl-*a* concentration generates high water density that reduces oxygen supply in the water. High chl-*a* concentration is also an indicator of the availability of food in large quantities that will attract various species of fish, birds and other predators (Palacios et al., 2006; Wang et al., 2007). Predators may also influence distribution of prey (Bergmann et al., 2004).

The catch area with less potential was also found in the offshore waters (> 20 M from the coast). The offshore waters have low concentration of chl-*a* (< 0.20 mg/m^3). There is no direct nutrient input from the land (Hendiarti et al., 2004). This is also demonstrated by Fig. 8a. Low chl-*a* concentration reduced the availability of food which results in the fish to leave the area (Fig. 8b). According to Gower (1972), chl-*a* concentration of at least 0.20 mg/m^3 is required to provide adequate levels of food to support a viable commercial fishery.

Fig. 8a also shows the area with combination of high chl-*a* concentration and low SST (area inside the black box) in the southern part of South Sulawesi. In this area, chl-*a* concentration was more than 1.00 mg/m^3 and SST was 28.50 °C. The predicted catch of *Rastrelliger kanagurta* in this area was low (Fig. 8b). The biophysical characteristics of the area highly relates to features of an upwelling area (Solanki et al., 2005b, Wang et al., 2010b Solanki et al., 2005b, Wang et al., 2010b; Xian et al., 2012 Xian et al., 2012). Studies by Choudhury et al. (2007) found that during upwelling, some fish populations move into the shallow surface waters while some move offshore, away from the centre of strong upwelling to avoid cool and low oxygen zone. Krishnakumar and Bhat (2008) also found that the pelagic species such as mackerel, sardines and whitebaits would avoid the upwelling areas because of less oxygen.

The accuracy assessment results showed that the actual catch data plotted on the potential fishing ground maps coincided with the potential predicted catch. The overall accuracy of the potential maps was

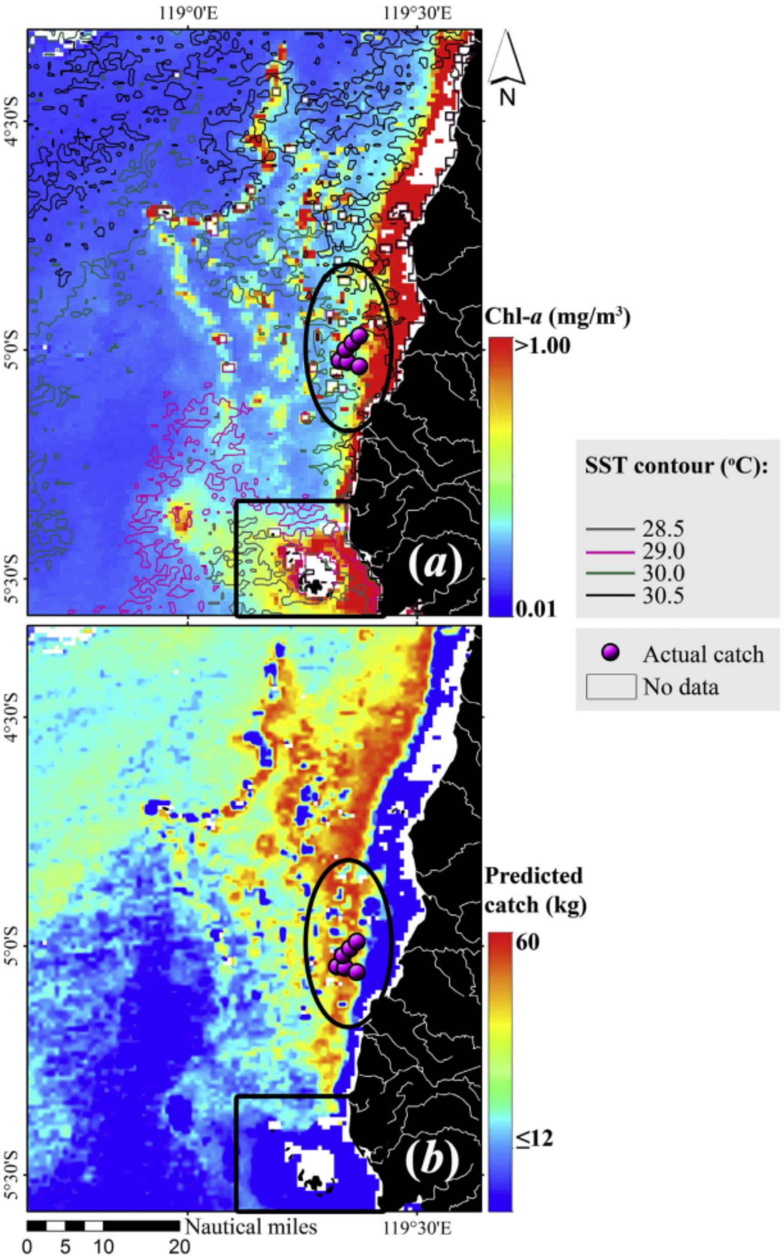

Fig. 8. The maps of 18 June 2009, indicating (a) the actual catch of *Rastrelliger kanagurta* against the SST contour and chl-*a* concentration; and (b) the potential fishing ground maps based on the GAM forecasting model. Oval-shaped area on the map (a) shows the actual catch in the area with the preferred range of chl-*a* and SST; (b) shows the actual catch area which coincided with areas of high predicted potential catch. The box on the maps (a) shows areas with combination of high chl-*a* and low SST; and (b) shows the low predicted potential catch.

83.34% with Kappa value at 0.70, which indicated that the accuracy of the predicted catch was acceptable (Mustapha et al., 2010; Vasconcelos et al., 2013). The accuracy assessment also showed the ability of the model in predicting the potential fishing grounds of *Rastrelliger kanagurta* in the archipelagic waters of Spermonde.

4.2. *Impact of climate change on the distribution of* Rastrelliger kanagurta

The climate change recently showed significant increases in SST (Coyle et al., 2011). The projection of SST is widely used in studying the impact of climate change on living marine species (Dueri et al., 2014; Hare et al., 2010; Lehodey et al., 2012; Tseng et al., 2011). SST has considerable influence on the distribution of fish (Dueri et al., 2014; Lehodey et al., 2012; Tseng et al., 2011). Several economically valuable pelagic fish species are very sensitive to water temperature conditions (Chen et al., 2005).

Increase of temperature at 1.80 °C from 18 to 25 June positively affected the distribution of *Rastrelliger kanagurta* with increased of high potential catch area especially in the archipelagic waters of Spermonde. The positive impact of the SST rise due to climate change was also reported in a study conducted by Lehodey et al. (2012) for Pacific skipjack tuna (*Katsuwonus pelamis*) in the west-central Pacific Ocean. In the study, they found that the catches and biomass of *Katsuwonus pelamis* were predicted to increase until year 2050 and then begin to decrease after 2060. Hare et al. (2010) also reported that climate change would increase the volume and the suitability of habitat, which would increase the abundance of population.

However, the increase of SST at 1.80 °C from 23 to 30 April and 1–8 May, and also the increase of SST at 2.60 °C and 3.30 °C from 23 to 30 April, 1–8 May and 18–25 June, decreased the areas of potential fishing grounds. High temperature increase is not suitable for *Rastrelliger kanagurta*.

Under the influence of global warming, apart from SST or chl-*a*, other environmental factors may also influence the spatial and temporal distributions of pelagic fish. Global warming may also change peak fishing season, variations in SST increase, and distribution of prey and prey-predator relationships. Variations of these factors must also be determined. Climate change can reduce the volume and the suitability of habitat which will decrease the rate of population growth and increases the extinction risk of species. Climate change also leads to habitat fission and affects the dynamics of spatial distribution and the resistance of population that may endanger the species. Habitat fission will change the spatial and temporal preferred range of environmental factors that contributes to the spread of the species (Hare et al., 2010). This was evidenced in the results of this study, which found that *Rastrelliger kanagurta* moved to the south (away from the archipelagic waters of Spermonde), heading to areas with suitable temperature. Migration is among the response of species against the changes in temperature (Cury and Roy, 1989). The negative impact and migration as a response to the increase in SST are also reported in a study conducted by Tseng et al. (2011) for Pacific saury (*Cololabis saira*) in the northwestern part of the Pacific Ocean. They found that the increased in SST due to climate change resulted in the potential fishing area to shift to the north of the encounter of Kuroshio and Oyashio current. In another study by Dueri et al. (2014), it was found that the habitat of skipjack tuna (*Katsuwonus pelamis*) decreased in most tropical regions and increased in high latitude regions. The existence and survival rate of the species depends on the ability of the species to adapt against the changing of abiotic and biotic factors through the changes in phenology (migration, nesting) or physiology (Pörtner, 2010) and adaptation (Donelson et al., 2011).

5. Conclusion

The GAM analysis showed that chl-*a* and SST affected the distribution of *Rastrelliger kanagurta* in the archipelagic waters of Spermonde. A strong relationship was found in chl-*a* range of 0.30 mg/m^3–0.40 mg/m^3 and SST of 30.00 °C–31.00 °C. The potential fishing ground maps showed that areas with high potential catch were located near the coast to offshore (between 3–20 M), with acceptable level of map accuracy. This was related to the suitability of the environmental conditions. The projection of increases in SST due to climate change according to IPCC-AR5-RCPs scenarios showed significant effects on the distribution of *Rastrelliger kanagurta*.

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