Egyptian Journal of Aquatic Biology & Fisheries
Zoology Department, Faculty of Science,
Ain Shams University, Cairo, Egypt.
ISSN 1110 – 6131
Vol. 27(3): 967 – 978 (2023)
www.ejabf.journals.ekb.eg

Determining the Potential Fishing Zone of Small Pelagic Fishes Based on Spatial and Temporal Variability of Remote Sensing Satellite Data

Muhammad Syahdan[1,*], Aguss S. Athmadipoera[2], Setyo B. Susilo[2], Jonson L. Gaol[2]
[1]Faculty of Fisheries and Marine, Lambung Mangkurat University, Banjarbaru, Indonesia
[2]Faculty of Fisheries and Marine Science, IPB University, Bogor, Indonesia

[*]Corresponding Author: msyahdan@ulm.ac.id

ARTICLE INFO
Article History:
Received: Nov. 23, 2022
Accepted: April 19, 2023
Online: June 30, 2023

Keywords:
Cross correlation,
Fishing zones,
Remote sensing,
Small pelagic fishes,
Variability

ABSTRACT

The potential fishing zones detected by remote sensing satellite data in this study focused on the key region of small pelagic fish in the Makassar Strait in the Java Sea, Indonesia. The remote sensing satellite data used sea surface temperature (SST) and chlorophyll-a (Chl-a) imagery obtained from the Aqua-MODIS Level 3, with a time coverage of more than ten years. The fishing production data were sourced from fish landing records in the Nusantara Fishing Port of Pekalongan (PPN Pekalongan), Central Java, Indonesia. The mapping overlay method and cross-correlation analysis were used to determine the variability of relationships between sea surface temperature and chlorophyll-a and small pelagic fish catches. The pattern of fishing migration areas showed that spotted sardinella was dominant in the northwestern monsoon period, with the direction of movement towards the north of Makassar Strait controlled by warm SST. However, the shortfin scad was dominant in the southeast monsoon period with movement towards the south of Makassar Strait up to the east of Java Sea which is controlled by high Chl-a. The increase of shortfin scad catches occurred after 4 months of maximum Chl-a achievement, while spotted sardinella increased in 3 months before the maximum Chl-a achievement. For the SST, these two types of fish respond directly to changes in the waters. To the El Nino event, fish catches experienced an increase that was dominated by shortfin scad; while during La Nina, fish catches that experienced a decrease were dominated by spotted sardinella.

INTRODUCTION

The determination of potential fishing zones plays an important role in the success of fishing operations. **Santos (2000)** revealed that fishing ground that can be mapped correctly and precisely will increase effectiveness and efficiency in the fishing activity. An understanding of this matter can increase catches by 5 – 15%, save operational time by 10 – 15% and save fuel usage by 20 – 25%. With the development of technology, mapping fishing areas is not only based on fishing production data, but also on the oceanographic parameters determined by satellite remote sensing.

The existence of fish species is greatly influenced by the condition of its environmental factors. The nature of fish that have a preference for certain environmental conditions, migration patterns are controlled by the circulation of water masses and various biological activities such as food resources (**Sadhotomo & Durrand, 1996; Harrison & Parsons, 2000**).

Various physical processes and influences of climate factors both monsoon and ENSO (El Nino Southern Oscillation) especially in the Makassar Strait through the Java Sea lead to the formation of spatial patterns and temporal variability that describe these waters (**Lumban-Gaol & Sadhotomo, 2007; Susanto *et al.*, 2012**). The implications that may occur changes are always dynamic both spatially and temporally.

Sea surface temperature (SST) and chlorophyll-a concentration (Chl-a) are important oceanographic parameters in detecting fish distribution patterns. Temperature is an important component in controlling the survival of organisms, such as growth, activity, mobility of movement, spawning among others. In addition, it is also physically an indicator of processes in the ocean such as coastal upwelling, advection, medium-scale dynamic features such as fronts and eddies, etc.. (**Jenning *et al.*, 2001; Robinson, 2010**). The Chl-a is an important pigment found in phytoplankton for photosynthesis, thus it becomes a parameter to determine the primary productivity of water (**Afdal & Riyono 2004**).

Research on the determination of potential fishing zones until now is quite intensive, but its variability has not been comprehensively disclosed. As it is known, Makassar Strait through the Java Sea is the main fishing ground for small pelagic fish from the 1990s to the present time (**Atmaja *et al.*, 2003; Chodriyah & Hariati, 2010**).

The objective of this research was to determine the annual and inter-annual variability of oceanographic parameters (SST and Chl-a) and its relation with fishing production. Based on the data obtained, this work described the potential fishing areas, with respect to the small pelagic fishes in the Makassar Strait along the Java Sea.

MATERIALS AND METHODS

1. Data description

The study area was selected in the Java Sea and Makassar Strait between the coordinates 108^o E-121^{o}E and 0^o–8^o S (Fig. 1). The data used for the measurement of SST and Chl-a were daily taken from a satellite image of Aqua-MODIS Level-3, with a spatial resolution of 0,05^o x 0,05^o and temporal resolution of 8, covering the period from July 2002 to December 2012. Additional data were obtained from the Pacific Islands Fisheries Science Center (PIFSC), which is part of the National Oceanic and Atmospheric Administration (NOAA) - USA via its web page (**http://oceanwatch.pfeg.noaa.gov; Wyrtki, 1961**).

Whereas, fish catch data were collected from the daily fish landing record of Nusantara Fishery Port of Pekalongan, Central Java in the period extending from 2002 -

2012. The fishing gear unit chosen as the database was the purse seine with ship volume > 30 GT, where the target species were the small pelagic fishes, and the fishing area was relatively included in the observations of this study.

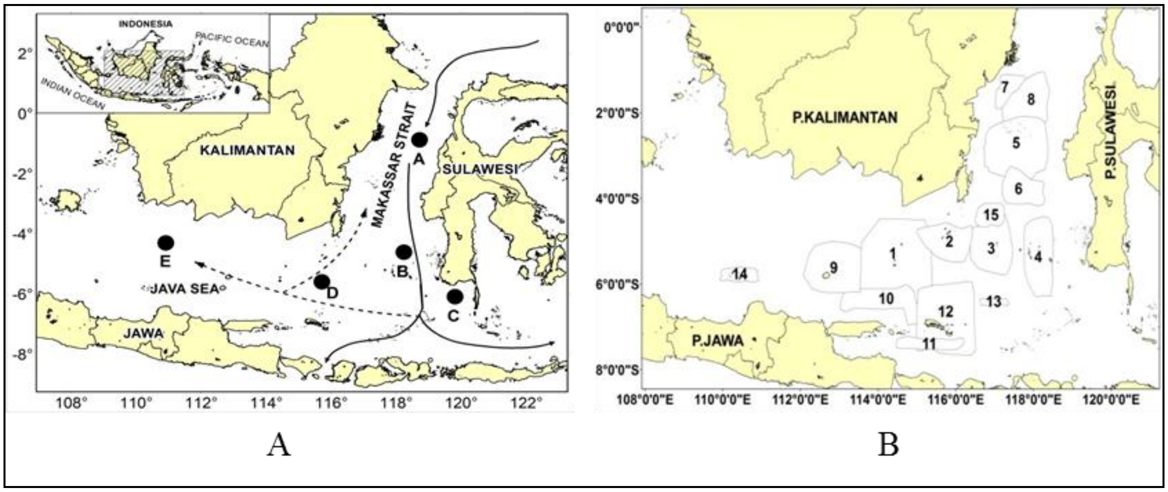

Fig. 1. Study area in the Makassar Strait - Java Sea region. Sampling area as A indicates the time series of the SST and Chl-a, whereas B indicates the fishing area

2. Data processing and analysis

The spatial pattern of each parameter observations i.e. SST, Chl-a and fish catches were generated in a thematic map based on the annual cycle (monthly average of the entire scope of the time). SST and Chl-a values were made in an annual cycle, where pixel value was already included in the data package. SST values were resulted from the Miami Pathfinder SST algorithm (MPFSST) (**Brown & Minnet 1999**), while the Chl-a value was an output of the OC3M algorithm (**Pan *et al.*, 2010**).

The value of fish catches resulted from the formula of the catch per unit effort or CPUE (**Gulland, 1982**) for each location based on the total and species. The fish species was used based on two species that have the highest CPUE i.e. shortfin scad (*Decapterus* sp.) and the spotted sardinella (*Amblygaster sirm*). CPUE is formulated as follows:

$$\text{CPUE}_\text{i} = \frac{catch_i}{effort_i} \qquad \text{i} = 1, 2, ..., \text{n} \tag{1}$$

Where,

CPUEi = Catch per unit effort (kg/unit) in month I;
catch$_\mathbf{i}$ = Catch (kg) in month I, and
efffort$_\mathbf{i}$ = Effort in month i.

Thereby, the spatial pattern analysis of relationships between SST and Chl-a with CPUE is based on the total and fish species that were spatially analyzed, and then the distribution pattern occurring was addressed in detail.

Continuous wavelet transform (CWT) analyzed temporal variation of SST, Chl-a and CPUE to generate the dominant period of time (**Torrence & Compo, 1998**). Furthermore, the band pass filter was used to generate an annual and inter-annual variability for each observation parameter depending on the emerging dominant period. CWT equation is formulated as follows:

$$W_n(s) = \sum_{n'=0}^{N-1} x_{n'} \psi * \left[\frac{(n'-n)\delta t}{s}\right] \quad (2)$$

Where, one is assumed to have a time series, *xn*, with equal time spacing d*t* and *n* = 0 … *N* - 1. Moreover, one is suggested to have a *wavelet function*,y, that depends on a nondimensional "time".To be "admissible" as a wavelet, this function must have zero mean and be localized in both time and frequency space. The (*) indicates the complex conjugate. By varying the wavelet scale *s* and translating along the localized time index *n*, one can construct a picture, showing both the amplitude of any features versus the scale and how this amplitude varies with time.

The relationship between SST and Chl-a with CPUE in the annual and inter-annual variability focused on sampling area coverage that has the same position with the fishing ground to get an accurate relationship. Therefore, based on Fig. (1A, B), to analyze this relationship, the location chosen was the eastern Java Sea (area D) for oceanographic parameters; while the fishing ground of Masalembu (area number 1) was selected for fish catches. Detailed observations of temporal variation resulted may describe SST and Chl-a variations to monsoon and ENSO and its implication on small pelagic fish catches.

Cross correlation analysis were used to determine the sequence of relationships between SST and Chl-a with small pelagic fish based on total and species. This analysis could notify whether or not there is a relationship between SPL or Chl-a fluctuations and fish catches consisting of cospectrum energy, coherence and different phases. The cospectrum of energy density describes the period of simultaneous fluctuation between the two parameters. If SST or Chl-a affect fish catches, both will show the same period of fluctuation. A high coherence value indicates a strong relationship between the two parameters (**Bendat & Pirsol, 1971**):

$$S_{xy}(f_k) = \frac{2h}{N} |X(f_k) * Y(f_k)| \quad (3)$$

Where, f_k = *k/Nh, k=0,1,2,3,….,N-1;*
$X(f_k)$ = Fourier component of x_t, and
$Y(f_k)$ = Fourier component of y_t

RESULTS

1. Spatial pattern of the relationship between SST and the small pelagic fishes

The spatial pattern of fishing areas with sea surface temperature is shown in Fig. (2). The four maps in Fig (2) represent the Munson wind period of January (northwest monsoon/NWM), April (first transitional monsoon), July (southeast monsoon/SEM) and October (second transitional moonson). Based on the proportion of CPUE indicated by the circular size, it was noticed that the catch reached the maximum at the peak of the monsoon period of both the northwest monsoon and the southeast monsoon. Whereas, in both transitional monsoos, SST was cool.

For fish species, the period of NMW till the first transitional monsoon (December to May) was dominated by spotted sardinella concentrated in the Makassar Strait, with a pattern of movement from the south to the north. However, shortfin scad was more concentrated in the Java Sea, with a movement from the east to the west. The trend movement of spotted sardinella was more concentrated in warmer SST.

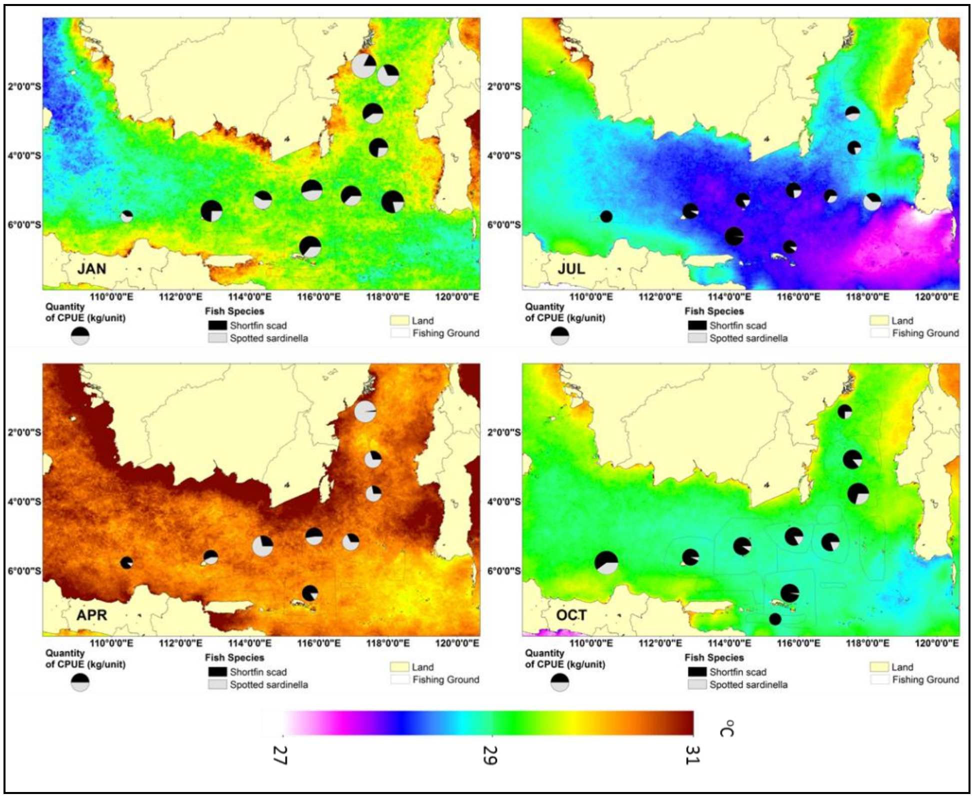

Fig. 2. Spatial pattern of the relationship between SST with fish catches

Different conditions occurred in the SEM period to the second transitional monsoon (June to November); this period was dominated with shortfin scad that is concentrated also in the Makassar Strait and controlled by the cooler SST. The pattern of distribution was contrary to the previous period that led to the south of the Makassar Strait, even to the eastern part of the Java Sea. However, spotted sardinella experienced a significant decrease with concentrations tending to move from the east of the Java Sea/south of the Makassar Strait to the north of the Makassar Strait while still looking for a warmer SPL.

2. Spatial pattern of relationship between Chl-a with the small pelagic fishes

The spatial pattern of Chl-a concentration-catch fish relationship is displayed Fig. (3). It shows that the high concentration of Chl-a at a specific time did not directly influence the increase in total CPUE at this particular time, but it required time for fish resources to use until reaching the maximum condition in the next time.

It can be seen that when the Chl-a reached its maximum on the eastern coast of Kalimantan in NWM in January, CPUE increased in April. While, when the maximum Chl-a concentration on south coast of Kalimantan was in the SEM in August, the CPUE reached its maximum in November-December. Besides, the maximum CPUE achievement during this period was also supported by the upwelling occurrence in the southern part of South Sulawesi, where it enriched Chl-a concentration so that high CPUE condition can stay in longer time. Thus, the time needed by fish resources to use primary productivity until reaching the maximum abundance was 2 to 3 months.

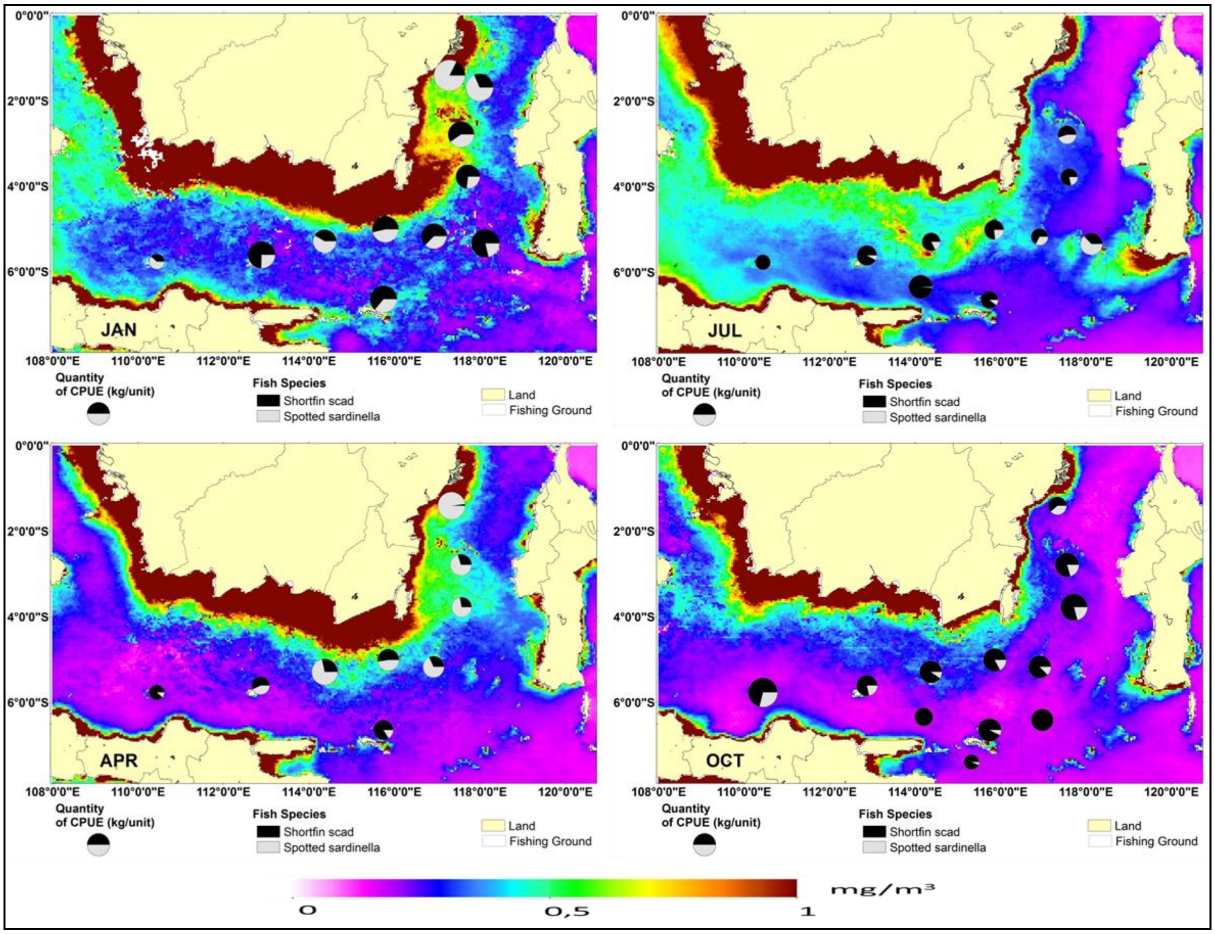

Fig. 3. Spatial pattern of the relationship between Chl-a and fish catches

The relationship between Chl-a concentration and CPUE, with respect to fish type showed that the spotted sardinella had higher CPUE in areas with high concentrations of Chl-a than shortfin scad. This condition was clearly visible in the first transitional season (March to May), with high Chl-a concentration in the eastern side of Kalimantan. Whereas, shortfin scad reached a maximum CPUE in areas with relatively low Chl-a concentration, as occurring in the transitional season (east to west) up to the beginning of NWM in October-December. This indicates that both types of these fish utilized the high concentration of Chl-a that occurred in the SEM (June to August) to grow and develop so that these were found abundantly in the next few months.

Annual variability of the relationship between sea surface temperature and Chlorophyll-a with fish catches

SST relationship (Fig. 4) in an annual variability showed that the fluctuation pattern between spotted sardinella had similarities with SST conditions, whereas the shortfin scad's SST relaionship tended to be inversely proportional. The SST maximum condition occurred in April, while the minimum was recorded in August. This condition indicates that in the inter-annual variability, the spotted sardinella followed the warmer water mass, compared to the Indian mackerel and the shortfin scad. The total CPUE had the lowest level of fluctuation and relatively less unchanged from the beginning to the end of the observation period.

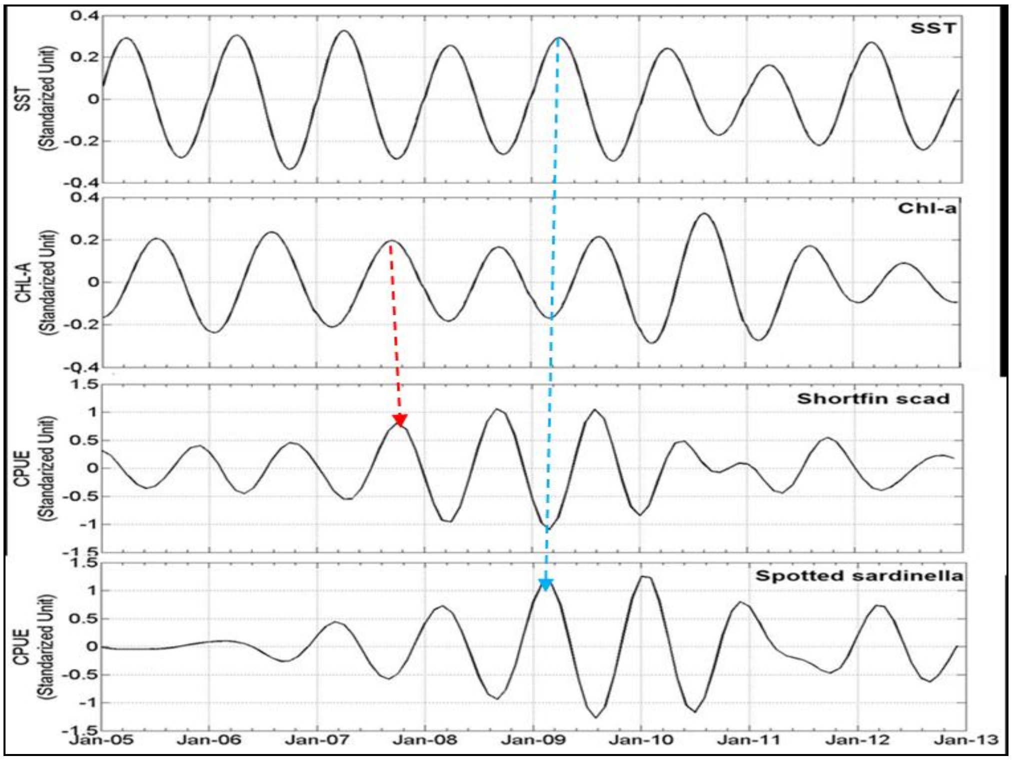

Fig. 4. Annual variability of relationship between SST and Chl-a with CPUE

Relationship of Chl-a with a total CPUE in annual variability **(Fig. 4)** showed that the increase and decrease of Chl-a was not directly followed by CPUE in the same month. The condition occurred in annual cycles spatially (Fig. 3) that was significantly shown by the shortfin scad, confirming that the increase in CPUE occurred after 2-3 months of increasing the concentration of Chl-a.

3. Inter-annual variability of the relationship between sea surface temperature and chlorophyll-a with CPUE

Relationship between SST and CPUE (Fig. 5) in the inter-annual variability showed that when a strong El Nino happened from 2009 to 2010, in which SST increased significantly, total CPUE experienced maximum achievement. Based on the type of fish, shortfin scad was in the minimum condition while spotted sardinella was in the maximum condition. The reverse condition was shown during a strong La Nina from 2007 to 2008 and from 2010 to 2011 with the SST decreased, total CPUE tended to be in an average condition until reaching a minimum. While, it was in a different condition with La Nina events. During La Nina, the fish species that reached a maximum was the shortfin scad while the spotted sardinella was at the very minimum.

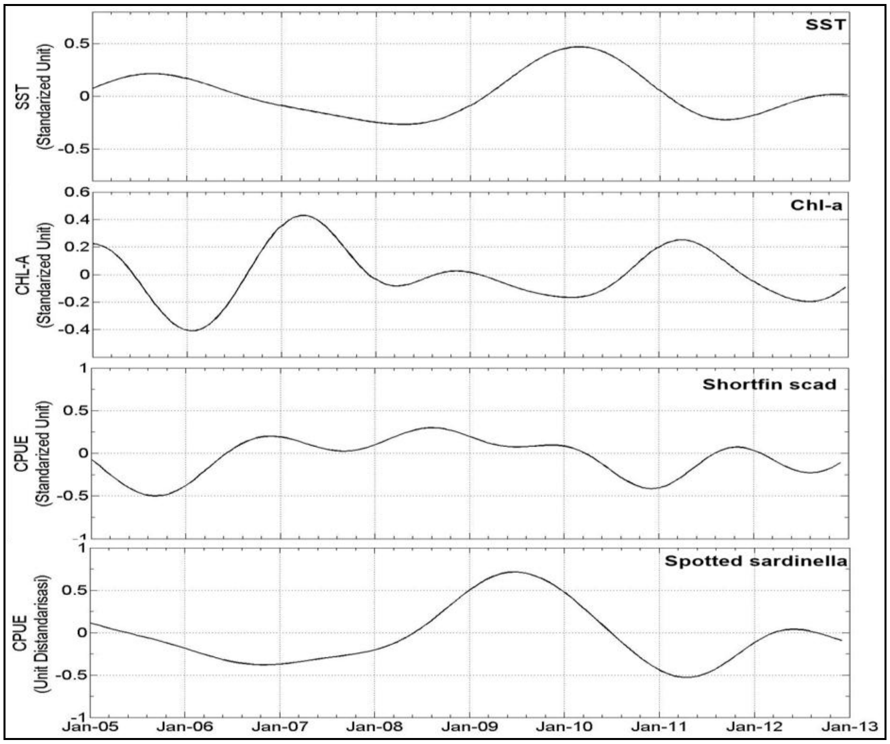

Fig. 5. Interannual variability of relationship between SST and Chl-a with CPUE

Results showed that when a strong El Nino happened, the Chl-a concentration decreased in 2009-2010, and total CPUE experienced the minimum condition (Fig. 5). Based on the type of fish it was noticed that, the spotted sardinella responded more positively to the presence of Chl-a concentration than shortfin scad.

At the strong La Nina events in 2010 to 2011, Chl-a concentrations were increased, total CPUE opposite experienced minimum conditions. Types of fish that experienced the maximum CPUE condition at this time were the spotted sardinella fish, while shortfin scad was at the very minimum condition.

Thus, it can be stated that (the ENSO phenomenon influence of the ENSO toward CPUE in this area), El Nino event was a moment achieving maximum CPUE in total, while La Nina event led to the achievement of the minimum conditions of total CPUE. For the type of fish, the spotted sardinella reached a maximum condition during El Nino, while shortfin scad reached its maximum during the La Nina. The detailed observations on the impact of Chl-a on CPUE reveal that the maximum CPUE achievement occurred after 2-3 months, especially during La Nina events.

4. Cross corelation between SST and Chlorophyll-a with fish catches

The relationship between fish species and SST, based on cross-correlation analysis (Fig. 6), it was clear that. the spotted sardinella and shortfin scad did not have a phase of difference to the SST, indicated by a coefficient of 0. This suggests that small pelagic fish of both shortfin scad and the spotted sardinella tended to respond directly to SST changes. The sequences of the relationship between SPL and shortfin scad (0.78), compared to the spotted sardinella (0.67) indicate that the shortfin scad was stronger in response to SPL than spotted sardinella.

The response of fish species to Chl-a changes showed differences between the two species of fish. The spotted sardinella can reach a maximum condition before 3 months in the maximum Chl-a achievement; while for the shortfin scad, the maximum was recorded after 4 months of maximum Chl-a achievement. This difference may be attributed to the food habit and feeding habit of each fish species.

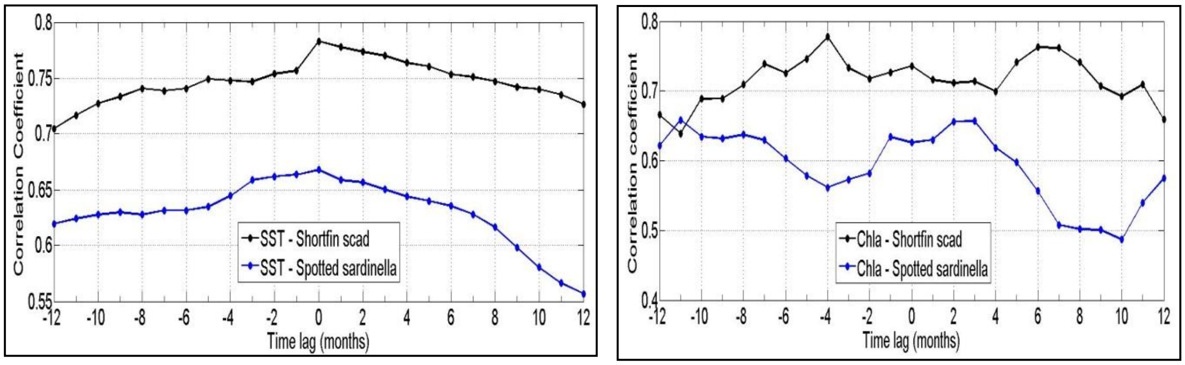

Fig. 6. Cross corelation between SST (left) and Chl-a (right) with fish specieses

DISCUSSION

Small pelagic fish such as shortfin scad and spotted sardinella are among the species with a large scale of distribution. **Pedrosa-Gerasmio *et al.* (2015)** in the observations of small pelagic fishes along the Sulu Sea to the Sulawesi Sea found that frigate tuna, spotted sardinella, short mackerel, and blackfin scad are fish that live in the neritic and oceanic zones where their habitat is in shallow waters. The distribution is very wide-ranging from tropical waters to sub-tropical and from the west of the Pacific Ocean to the Indonesian waters. A key parameter that drives such widespread migration is the water temperature where these parameters affect the physiological interests of fish, such as reproduction, growth and survival ability. The specific review of **Chícharo *et al.* (2012),** reported the influence of several environmental parameters such as temperature, salinity, dissolved oxygen, and chlorophyll-a on the survival of fish starting from its recruitment period. The observations revealed that, in the lagoon area in the waters of Ria Formosa, Portugal, differences were detected in the pattern of distribution of larvae of several types of small pelagic fish, viz. anchovies and spotted sardinella based on seasonal conditions that resulted in changes or fluctuations in the parameters of the waters.

Several studies have also proven the effect of chlorophyll-a on fish distribution patterns. **Qiu *et. al.* (2008, 2010)** suggested that, land runoff and monsoon circulation with the movement of water masses in coastal areas were the physical factors that dominated the variability of catches, which is associated with nutrient supplies for primary production. The correlation between the two was that land runoff provides nutrient input to coastal areas, while monsoon played a role in controlling their distribution. With the movement of water masses to offshore areas, where observations in the East China Sea were very intensive in the monsoon period in the summer, it efficiently increased nutrient distribution. This had a very positive impact on fish production at that time. In line with this, **Pedrosa-Gerasmio *et al.* (2015)** stated that, in addition to temperature as a key parameter which controlled fish migration patterns, another very decisive factor was the search for food supported by the abundance of nutrients in a water area.

The response of small pelagic fish to changes in the distribution patterns of SST and Chl-a showed differences between each other. One of the causes was the factor of food habits. **Potier (1994)** suggested that, the lemuru (*Amblygaster sirm*) or the same family as: *Sardinella lemuru* or *Sardinella fimbriata* i.e. Clupeidae was a phytoplankton and zooplankton feeder or consume of both phytoplankton and zooplankton or herbivorous and carnivorous at once. Different conditions were found in species of shortfin scad that was only zooplankton feeder or zooplankton consumer or carnivorous.

The characteristic of spotted sardinella that can take the presence of zooplankton as food caused this species to remain even though the waters did not have abundant phytoplankton as contained in Chl-a. This species will reach its maximum condition when the concentration of Chl-a increases because the food source will increase both in number and composition.

The shortfin scad does not necessarily increase in areas with a high concentration of Chl-a. This was thought to result in shortfin scad taking a lag of about 4 months to give zooplankton a chance to develop in water first after replacing the period of the abundance of phytoplankton. Furthermore, the annual pattern that the upwelling events taking place in the south of the Makassar Strait during the SEM period result in an increase in the abundance of shortfin scad in the following months during the second transitional monsoon. The spotted sardinella can experience an increase in areas that have high Chl-a, both in the SEM period in the Java Sea area and in the NWM period in the Makassar Strait area.

CONCLUSION

Based on the results and discussion, it can be concluded that, the potted sardinella increased in the northwestern monsoon period, moving to the north of the Makassar Strait that is controlled by warm SST. While, the shortfin scad increased in the southeast monsoon period, with a movement towards the south of Makassar Strait up to the east of Java Sea that is controlled by high Chl-a. For the ENSO phenomena, shortfin scad increased in El Nino while the spotted sardinella proliferated during La Nina period. Shortfin scad increased in a 4- month period after maximum Chl-a, whereas the spotted sardinella increased after 3 months before the maximum of Chl-a. With respect to SST, both types of fish responded directly to their changes.

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