Spatial distributions of the thermal front and of catches of mackerel (*Scomberomorus commerson*) in the Java Sea, Indonesia

[1]Mega L. Syamsuddin, [2]Hammami U. Faiz, [1]Mochamad R. Ismail, [1]Sheila Zallesa

[1] Department of Marine Sciences, Faculty of Fisheries and Marine Sciences, Padjadjaran University, Sumedang, Indonesia; [2] Marine Science Study Program, Faculty of Fisheries and Marine Sciences, Padjadjaran University, Sumedang, Indonesia. Corresponding author: M. L. Syamsuddin, mega.syamsuddin@unpad.ac.id

Abstract. The thermal front can be used as an indicator to estimate the potential fishing ground in the ocean, especially for pelagic fishes. To determine the potential fishing areas, it is necessary to analyze the relationship between the distributions of the thermal front and mackerel catches. This research was conducted in the Java Sea, at the central part of the Indonesian seas by using oceanographic satellite datasets. The research method used was descriptive analysis with spatial and temporal approaches. Data on average sea surface temperatures and mackerel catches were analyzed from 2018-2020 (on a monthly basis). Based on the results, the thermal front distribution from 2018 to 2020 is mostly located near the coast, where the frequency of occurrence fluctuates every month and season. Data on mackerel catches are spread throughout the Java Sea, with an average sea surface temperature of 29°C. In general, it can be concluded that the mackerel catches distribution does not always coincide with the occurrence of a thermal front, except for January and August 2020. We highlighted that there is no direct relationship between the fishing location and the thermal front.
Key Words: catch, Java Sea, mackerel, sea surface temperature, thermal front.

Introduction. The Java Sea is bordered by Kalimantan (known as Borneo) on the north, the southern end of the Makassar Strait on the northeast, Celebes, Flores and Bali on the east. It is influenced by the confluence of water masses from the South China Sea and the Makassar Strait (Simanjorang et al 2018). These mixing water masses have the potential to cause a phenomenon called a front which can be defined as an oceanographic process that affects the biological and physical conditions of seawater. The oceanic fronts that can be detected by sea surface temperatures are called thermal fronts. This thermal front can be used as an indicator for estimating potential fishing areas especially pelagic fish in the Java Sea (Simbolon & Wahyuningrum 2013).

The Java Sea is part of the State Fisheries Management Area of the Republic of Indonesia 712 (namely WPPNRI 712). The largest estimated potential for fish resource groups in WPPNRI 712 is large pelagic fish with a total potential of 104,017 tons year^{-1} (Kepmen KP 79 2016). Mackerel (*Scomberomorus commerson*) is a large pelagic fish group that have high economic. This pelagic fish species, known in international trade as narrow-barred Spanish Mackerel, is a commodity with increasing demand both domestically and internationally (Harahap et al 2020). This fish is relatively abundant in the waters of the Java Sea, with total catches, in the period 2005–2014, ranging from 69,441–211,643 tons year^{-1} with an average of 90,972 tons year^{-1} (Kepmen KP 79 2016). Tint et al (2020) reported that the Indo-Pacific mackerel is one of the major commercially important species but its production has been reported to be declining.

Oceanographic parameters influence the abundance of pelagic fish in the Java Sea waters, and cause seasonal fishing activities, shifts in catchment areas and fluctuations in the fertility levels. Changes in these parameters cause pelagic fish moves, according to their growth needs, to the areas that are rich in food sources (Hermawan et al 2021; Sepri et al 2021). The thermal front area has an abundance of food because there is a convergence process and a mixing process that can produce an abundance of plankton and primary productivity which are the main source of food for fish (Ningsih et al 2018). To optimize the potential of mackerel fisheries, it is necessary to understand the correlation between the thermal front and mackerel catches in the Java Sea. Observing the identification of the thermal front directly tends to be difficult because it requires long time series data and wide area coverage. Instead, remote sensing satellite technology was used to solve this problem (Belkin 2021). Automatic identification of thermal fronts can be applied using the Single Image Edge Detection (SIED) method developed by Cayula & Cornillon (1992). This algorithm was created to detect thermal fronts in the Sea Surface Temperature (SST) satellite imagery. This SIED algorithm has been implemented in ArcGIS software with an additional toolbox, namely Marine Geospatial Ecology Tools (Hamzah et al 2014).

Some research was carried out on the pelagic fish migration patterns and their relationship to oceanographic parameters (Tussadiah et al 2018; Hermawan et al 2021) and on the fishing areas identification based on oceanographic parameters (Syamsuddin et al 2016; Ranintyari et al 2018; Sambah et al 2021). Research on the identification of the thermal front and fish catches has been carried out by Mustasim et al (2015) and Ahmad et al (2019), using short-term datasets. However, studies on the correlation between the spatial distribution of thermal front and mackerel catch using long-time series datasets have rarely been reported. In this study, oceanographic parameters including sea surface temperature and ocean current was analyzed in order to examine the spatial distribution of the thermal front and how they relate to the mackerel catches in Java Sea Indonesia using monthly basis remote sensing data approaches.

Material and Method

Description of the study sites. The research location is in the Java Sea spanning between coordinates 2°–8° South and 105°–117° East (Figure 1). The data used in this research were monthly sea surface temperature (SST), ocean currents, and fish catches. The SST data were obtained from the AquaMODIS Level 3 images downloaded through the home page: https://oceancolor.gsfc.nasa.gov/l3/. Ocean current data were downloaded through the Copernicus Marine Environmental Monitoring Service (CMEMS) homepage. The mackerel fisheries data were obtained from the Fishing Port called as Pelabuhan Perikanan Samudera/PPS Nizam Zachman Jakarta logbook. The fishing locations and fisheries datasets in the Java Sea, from January 2018 to December 2020, were obtained from the Marine Affairs and Fisheries, Indramayu West Java.

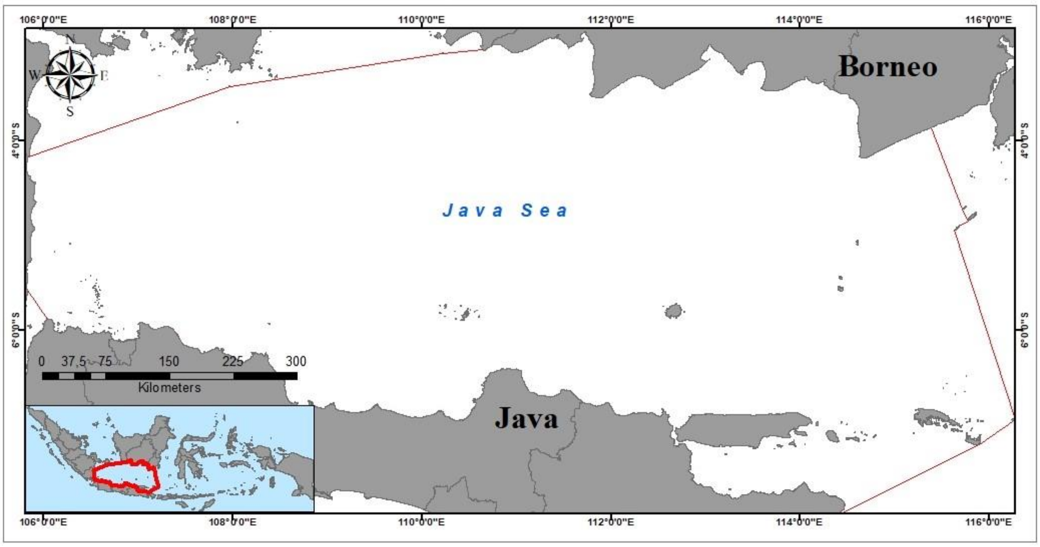

Figure 1. The research area in the Java Sea, Indonesia.

Thermal front data processing. Data were cropped according to the coordinates of the research location. The thermal front identification process was done by converting raster data into points. Land-ocean arrangements are created with data clips from the land. The value type of SST was changed from floating point to integer. The final process was using the Cayula and Cornillon algorithm provided in the MGET toolbox, with a threshold value of 5 for the identification of strong front thermal (temperature difference of 0.5°C) and a threshold value of 3 for the identification of weak thermal front (a temperature difference of 0.3°C) (Mustasim et al 2015).

Ocean current data processing. Ocean current data were downloaded in netcdf (.nc) format and converted to text (.txt) format using Ocean Data View (ODV) software, and then processed in Excel to convert U and V components of current into direction and velocity. Then the data was visualized in a horizontal profile to support the analysis.

Mackerel data processing. Fish catch and fishing location data were formatted in text format and then combined with the coordinate data against the results from the detection of the thermal front. Data on catches with different fishing gears requires standardization of fishing gear. Then the formula used to calculate the standardization of fishing gear is as follows (Gulland 1983):

$$\text{FPIi} = \frac{CPUEi}{CPUEs}$$

Standard Effort = FPI x amount of effort (monthly)

Where:
CPUEs - catch per fishing gear effort;
CPUEi - catch per fishing gear effort i;
FPIi - fishing gear catch i.

Data analysis. After finishing the data visualization, the next step was to analyze the data descriptively with temporal and spatial approaches. The SST parameter was identified using the SIED method to obtain a thermal front.

Results. In general, the condition of the SST in the Java Sea is affected by the monsoon, similarly to other Indonesian waters. The average monthly fluctuation of SST values in the Java Sea ranges from 27.74–31.25°C (Figure 1). This variation in SST values is due to the influence of water masses from the South China Sea during the Northwest Monsoon and the influence of colder water masses from the Makassar Strait during the Southeast Monsoon (Siregar et al 2017; Simanjorang et al 2018).

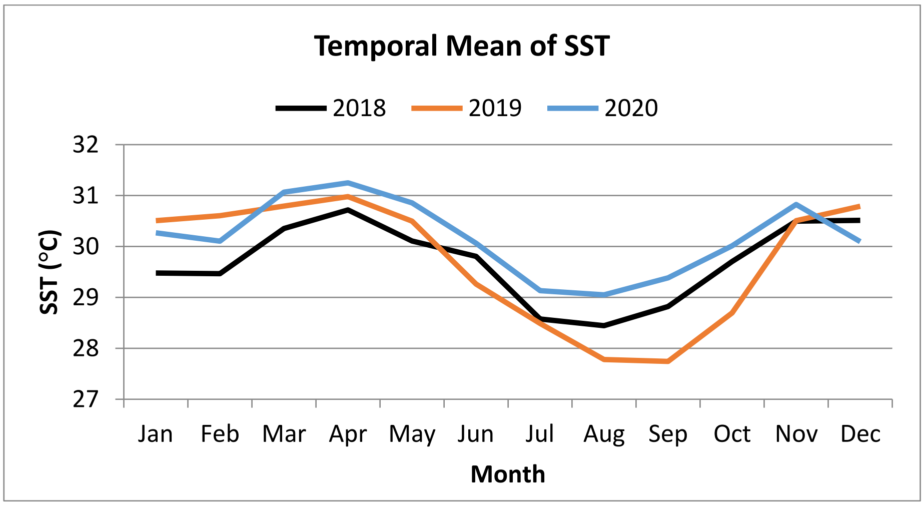

Figure 1. Monthly mean SST during 2018-2020 in the Java Sea.

Generally, the temporal SST pattern in the Java Sea shows the seasonal pattern. During the Northwest monsoon (December-February), the higher level of SST occurs in January (30.5°C) then slowly decreases in February. The highest increase in SST value was in April (31°C) during the Transition Season I (March-April) and the lowest value of SST occurred during the Southeast monsoon (June-August). The SST value starts to increase in the Transition Season II (September-November). This is caused by the influence of the monsoon winds that supply water masses from the east, resulting in an increase of temperature, every month (Nugraha et al 2019). The low SST value in the Southeast Monsoon is due to the position of the sun in the Northern Hemisphere which causes the sun rays obtained in the Southern Hemisphere to tend to be lower (Kusmiati et al 2020). This is also in line with the research conducted by Siregar et al (2017) and Syamsuddin et al (2016), which showed an increase in SST value in the Java Sea during the Transitional Season I and a decrease during the Southeast monsoon.

The number of thermal fronts was calculated based on the number of pixels in the image, for each month from 2018-2020. Thermal fronts can be identified as an area of 500 m^2 per pixel (Suhadha & Ibrahim 2020). Based on the results of statistical calculations, it can be seen that the frequency of the thermal front fluctuates every month (Figure 2).

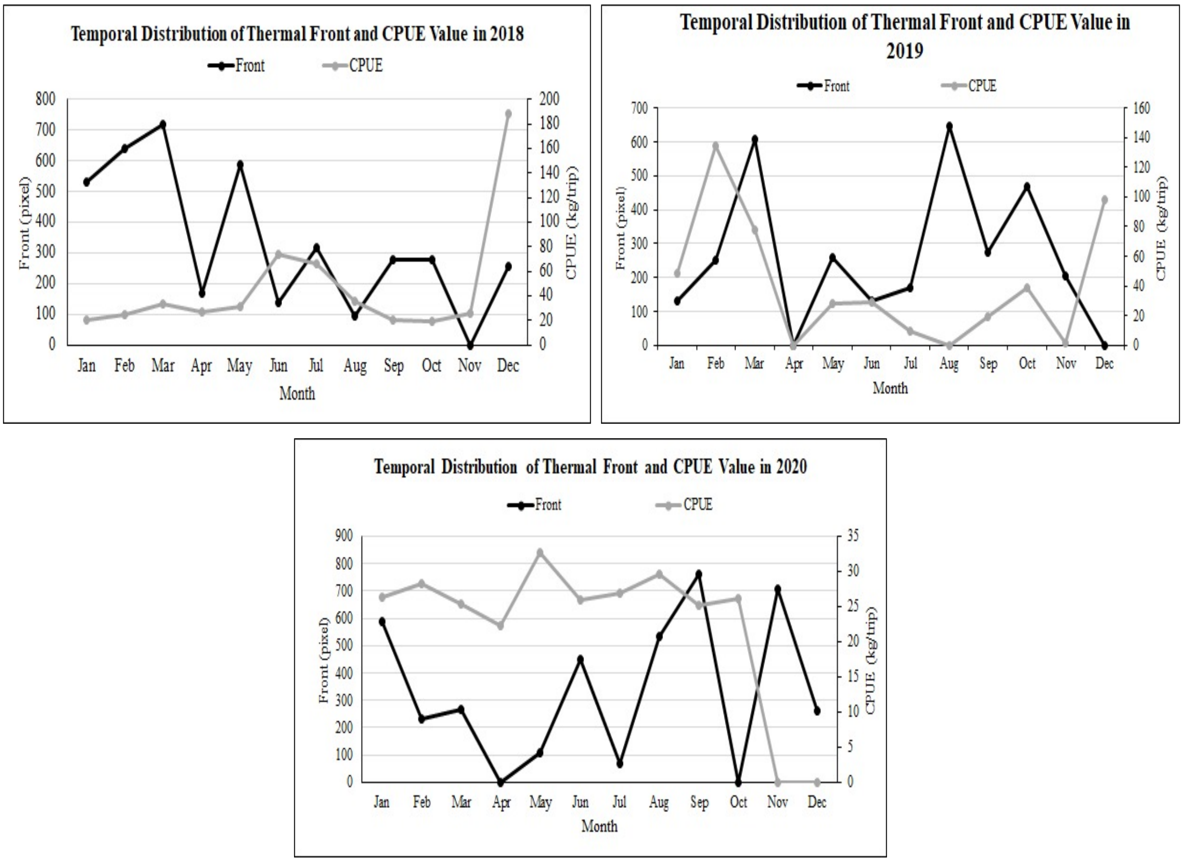

Figure 2. Temporal distribution of thermal front and CPUE of mackerel in the year of 2018, 2019, and 2020.

In 2018, the thermal front occurred every month except for November, with the highest frequency occurring in March (as many as 720 times). This was caused by the Transitional Season where there was a counterclockwise movement of currents carrying water masses from the South China Sea so it was suspected that there was a lot of water mass mixing (Trinugroho et al 2019). The highest CPUE value occurred in December (189 kg $trip^{-1}$), in line with the research conducted by Syamsuddin et al (2016), which stated the peak season for mackerel fishing was in December. In 2019, the highest thermal front event occurred in August (as many as 647 times). This was thought to be caused by the influence of the eastern monsoon wind which brought water masses from the Makassar Strait. Based on the temporal distribution of the thermal front, the frequency of thermal front events that occurred in March is similar to the previous year (608 times), presumably because the thermal front can occur regularly and seasonally, according to Daulay et al (2019). The highest CPUE value in 2019 occurred in February (134 kg trip^{-1}). Meanwhile, in 2020 the highest thermal front event occurred in September (762 times) and the highest CPUE value occurred in May (33 kg trip^{-1}). In general, the mackerel catches are higher during northwest monsoon (December and February) and during the transitional season I (May), due to seasonal oceanographic condition changes. This result is in accordance with Harahap et al (2020) and Chen et al (2021). The spatial distribution of the thermal front, overlaid with ocean current and CPUE of mackerel catches during the year 2018-2020, can be seen in Figures 3-5.

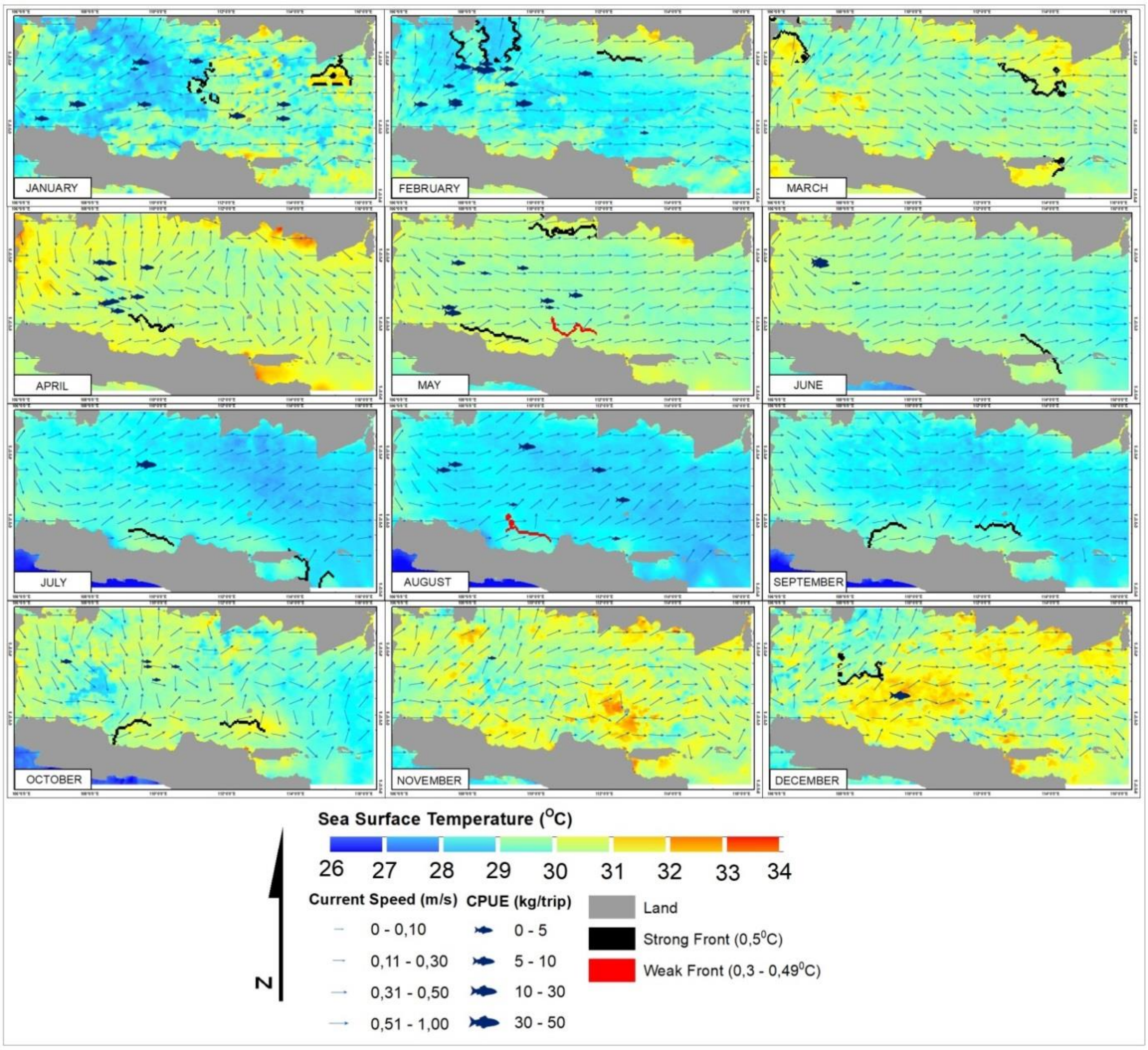

Figure 3. Spatial distribution of the thermal front overlaid, with the CPUE of mackerel fishing, during the year 2018.

In 2018, a thermal front in the northwest monsoon was formed in the center of the Java Sea, with a total frequency of 1172 events. The distribution of the mackerel caught during this season is mostly located in the center of the Java Sea and the northern coast of the Java Sea, with an SST value ranging from 29.27 to 31.04°C. During Transition Season I, the thermal fronts are formed in the South of the Kalimantan Island and South of Bangka Island with a total number of thermal fronts of 1476 occurrences. The distribution of mackerel catches tended to be located in the Northeast of Java, due to seasonal currents with SST ranging from 29.8 to 31.3°C. The thermal front during the Southeast monsoon tends to be different from the condition of the previous month or season in the north of the Java Sea. The thermal front seems to be located only near the coast north of Java. The mackerel distribution catch in this season is located in the central part of the Java Sea, with a SST ranging from 28.44 and 29.98°C. During the Transitional Season II especially in October, the thermal front is formed on the north coast of Java and then it disappears in November. The mackerel fishing location seems to be located far from the thermal front, in the center of the Java Sea, with an SST ranging from 29.75 to 30.45°C (Figure 3).

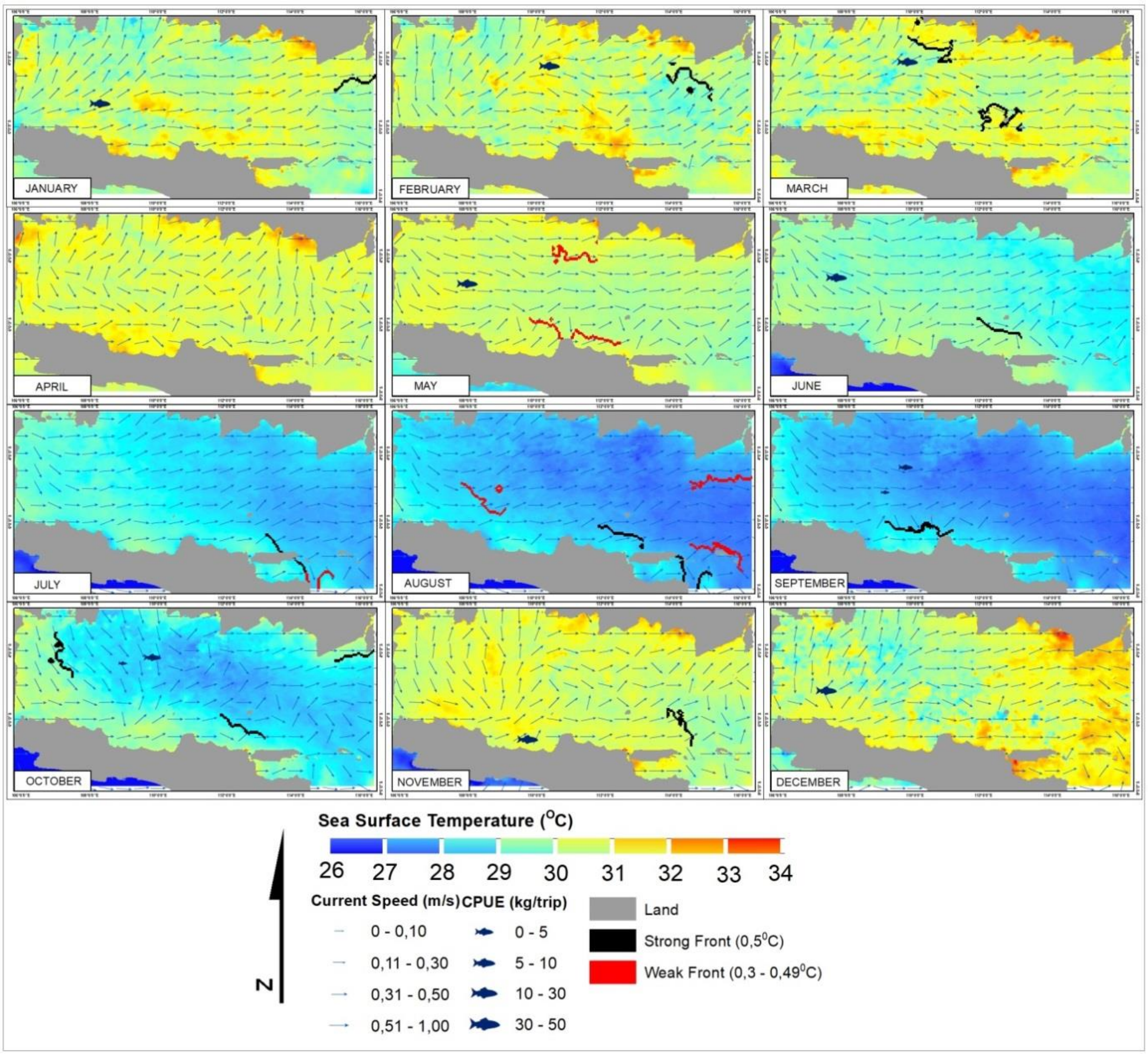

Figure 4. Spatial distribution of the thermal front overlaid with the CPUE of mackerel fishing, during the year 2019.

In 2019, there was a significantly decrease in fishing activities compared with the previous year, which is shown in Figure 4. In the northwest monsoon, a thermal front was formed in the center of the Java Sea and South Kalimantan Island, with a total of 640 incidents. The mackerel caught in this season tends to be the same as in the previous year in the center of the Java Sea, with an SST of around 31.2°C. During the Transition Season I, the thermal front formed tends to occur at the same location as in the previous year, namely in the South of Kalimantan Island and North of Java Island, and the catch of mackerel occurs in the middle of the Java Sea at an SST of around 30°C. During the Southeast monsoon, the thermal front formed is mostly located on the northern coast of Java Island and the catch of mackerel tends to occur in the center of the Java Sea, at SST values ranging from 28 to 29°C. In the Transitional Season II, generally, a thermal front is formed on the north coast of Java and the south coast of Kalimantan, and the catch of mackerel occurs in the center of the Java Sea, with SST values ranging from 27.6 to 28.3°C.

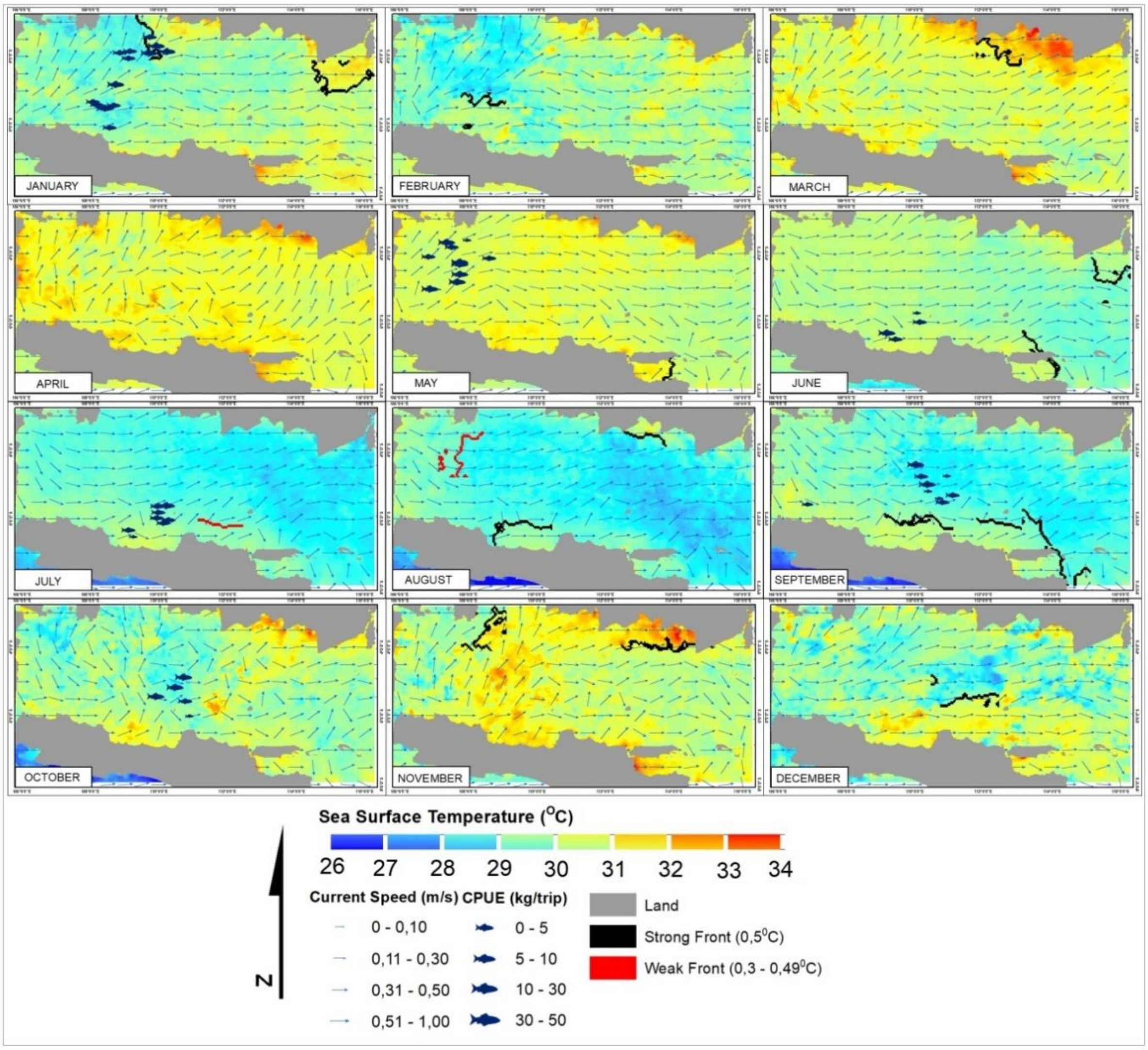

Figure 5. Spatial distribution of the thermal front overlaid, with the CPUE of mackerel fishing, during the year 2020.

The fishing activities during the year 2020 showed an increase in the total trips in the Java Sea compared with the year 2019. The thermal front that was formed in the northwest monsoon occurred at the southern coast of Kalimantan and northern Java Island. During this season, fish catches are in the front area, with the SST ranging from 29.3 to 31.3°C. In Transitional Season I, the thermal front only occurs in March, located in the southern part of the island of Kalimantan. Mackerel catches distribution in this season tend to be located in the Northwest of Java. The thermal front in the Southeast monsoon is generally the same as in the previous year, mostly located on the southern coast of Kalimantan Island and on the northern coast of Java Island. The mackerel fishing location tends to be located in the north of Java Island. In August, fish catches are found in the thermal front area. During the Transition Season II, the thermal front occurs on the southern coast of Kalimantan Island and in the North Java Island. Mackerel fishing locations during this season tends to be located in the center of the Java Sea, with SST values ranging from 28.9 to 30.1°C (Figure 5).

Based on three years of datasets, from 2018 to 2020, regarding the distribution of the thermal front events and mackerel catches in the Java Sea, we highlight that thermal front phenomena are generally located near the coast and that the pattern changes every month (monthly variations). Thermal front fluctuations in the ocean are strongly influenced by the monsoon system in Indonesia (Suhadha & Ibrahim 2020). During the Northwest monsoon, the thermal front formed is strongly influenced by the high intensity of rainfall in these months, resulting in seawater and river water mixing. As a result, thermal front events often occur in coastal areas (Daulay et al 2019). Ocean currents in each season also influence the distribution of fronts, so fronts can form following the pattern of the currents (Trinugroho et al 2019).

The distribution of fish catches is spread almost throughout the Java Sea, with an average SST of around 29°C. This agrees with Syamsuddin et al (2018a), stating that mackerel prefers SST conditions ranging from 29 to 30°C, and with Syamsuddin et al (2018b), stating that mackerel prefers SST conditions ranging from 28 to 29°C. A research conducted by Masturah et al (2014), regarding the relationship between mackerel and oceanography in the Karimata Strait, stated that the optimum SST of the mackerel habitats ranges from 25 to 30°C in the Southeast monsoon and from 26 to 32.9°C in the Northwest monsoon. A research conducted by Nugraha et al (2019), corroborates these findings, stating that the SST ranges from 28.5 to 30.71°C and it has a relationship with the CPUE of mackerel.

The distribution of mackerel catch does not always coincide with the occurrence of the thermal front in each month, except in January and August 2020. A similar research carried out by Nugroho et al (2019) concludes that the occurrence of the thermal front did not coincide directly with fishing activities. According to Suhadha & Ibrahim (2020), the occurrence of the thermal front precedes the peak of the catches. Although the thermal front can be used as an indicator of determining the fishing grounds, several factors affect the distribution and abundance of the fish in waters. Several other factors affect the distribution of fish, such as salinity, primary productivity, migration to spawning areas, chlorophyll-a content, and dissolved oxygen content. Similar research explained that higher catches of mackerel are likely to be influenced by higher Chlorophyll-a concentrations (Kizenga et al 2021; Chen et al 2021). However, the hotspot of mackerel in the Java Sea should be identified through further research considering Chlorophyll-a front to provide more scientific evidence.

Conclusions. This study concludes that the distribution of the thermal front from the 2018-2020 period is mostly located near the coast and the frequency of occurrence fluctuates every month and season. The distribution of mackerel catches is spread throughout the Java Sea, with an average SST value of 29°C. The distribution of fish catches does not always coincide with the occurrence of the thermal front in each month, except for January and August 2020. Further research is needed, regarding the analysis of the time interval between the occurrence of the thermal front and the catch of fish, and also of additional parameters that affect the high mackerel catch, such as Chlorophyll-a as primary productivity source.

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Conflict of interest. The authors declare no conflict of interest.

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Authors:
Mega Laksmini Syamsuddin, Padjadjaran University, Faculty of Fisheries and Marine Sciences, Marine Science Department, Bandung-Sumedang Km. 21, Jatinangor, West Java 45363, Indonesia, e-mail: mega.syamsuddin@unpad.ac.id
Hammami Ulwan Faiz, Padjadjaran University, Faculty of Fisheries and Marine Sciences, Marine Science Study Program, Bandung-Sumedang Km. 21, Jatinangor, West Java 45363, Indonesia, e-mail: hammamiuff@gmail.com
Mochamad Rudyansyah Ismail, Padjadjaran University, Faculty of Fisheries and Marine Sciences, Marine Science Department, Bandung-Sumedang Km. 21, Jatinangor, West Java 45363, Indonesia, e-mail: m.rudyansyah@unpad.ac.id
Sheila Zallesa, Padjadjaran University, Faculty of Fisheries and Marine Sciences, Marine Science Department, Bandung-Sumedang Km. 21, Jatinangor, West Java 45363, Indonesia, e-mail: sheila.zallesa@unpad.ac.id

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