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Estimation of Skipjack Tuna (Katsuwonus pelamis) Fishing Areas in Fisheries Management Area 573 Waters Based on Oceanographic Parameters and Fish Movement Patterns, Indonesia

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Abstract: Sendang Biru waters were one of the waters in IFMA 573 that contribute a lot to the catch of Skipjack tuna. The Ina-WIS program was an interactive maritime weather information system developed by BMKG that can be used for Fishing Area Estimation. This study aims to analyze oceanographic parameters, the relationship between oceanographic parameters and DPI, and analyze fish movement patterns and their relationship to DPI of Skipjack tuna (Katsuwonus pelamis) in Sendang Biru waters. The method used in this study is quantitative descriptive. The oceanographic parameters used in this study are currents, thermal fronts and upwelling, and Sea Surface Temperature (SST) data and chlorophyll-concentrations are used to strengthen the oceanographic parameter data (Thermal front and upwelling). The research data comes from Aqua-MODIS satellite imagery, while the current map comes from Ina-WIS BMKG. The research obtained based on the oceanographic parameter conditions in the Sendang Biru Waters (IFMA 573 Waters) April - May 2024 can be used as a DPI for Katsuwonus pelamis. The SPL conditions and chlorophyll-a concentration in May at the thermal front location have an SPL ranging from 26.58 - 28.93 ° C and chlorophyll-a concentration of 0.18 mg / m³. It is recommended that in April and May, skipjack tuna fishing be carried out around the East in the Southern part of Java Island (9 ° 0'0 - 9 ° 30'0 LS and 113 ° 0'0 - 113 ° 30'0 BT) and the West of the Southern part of Java Island (9 ° 0'0 - 9 ° 30'0 LS and 112 ° 0'0 - 112 ° 30'0 BT). Thus, it can be said that the movement pattern of skipjack tuna can be influenced by the conditions of oceanographic parameters, direction and speed of currents and Sea Surface Temperature (SST).
Keywords: Katsuwonus pelamis, DPI, Ina-WIS, Oceanography, Sendang Biru

I. INTRODUCTION

The fisheries sector contributes significantly to economic growth in Indonesia, particularly through leading commodities such as tuna, skipjack tuna, and skipjack tuna (TCT). TCT catches contribute significantly to the United States' export market share and must be maintained. However, this also results in an annual increase in demand for TCT fish [29]. Therefore, TCT is considered a leading Indonesian product, contributing significantly to fisheries exports.

Indonesia is listed as one of the largest producers among the 32 member countries of the Indian Ocean Tuna Commission (IOTC), with TCT export volumes continuing to increase from 174,764 tons in 2021 to 203,202 tons in 2023 (KKP, 2023). One of the main production centers is the waters of Sendang Biru, East Java, which directly faces the Indian Ocean. This area has high fisheries potential and is a base for fisheries operations, especially with purse seine fishing gear, trolling rods, and handlines [126].

In the process of mapping potential fishing areas, several things are needed such as oceanographic and biological aspects to support the Fishing Potential Zone (ZPPI) map, so that the resulting map is in accordance with the fishermen's catch targets. Sendang Biru waters are one of the waters that have an active role in producing skipjack tuna catches in the southern waters of eastern Java, this is because these waters are one of the skipjack tuna migration routes. The existence of this fish is closely related to the dynamics of environmental factors, especially in the location of forage habitat or feeding grounds, this is because this fish carries out 2 migration phases, namely trophic migration to find food and other reproductive migrations to lay eggs, based on this, the existence of this fish can be followed spatially and temporally. According to [35] and [86], skipjack tuna in the Eastern Indian Ocean in the Southern waters of Java is known that the opportunity for spawning in this fish occurs throughout the year and spawns more than once a year, with the spawning season for skipjack tuna in Indian waters estimated to occur in April and November. ZPPI mapping generally uses oceanographic parameters that include the distribution of SST, chlorophyll-a concentration, current, salinity and others. Information on chlorophyll-a and SST variability can be used as a reference to estimate potential areas for fishing [69]. The distribution and abundance of large pelagic fish such as skipjack tuna (Katsuwonus pelamis) are greatly influenced by oceanographic variability. A number of previous studies have utilized satellite imagery to map potential fishing areas (TPI) with the main parameters of sea surface temperature (SST) and chlorophyll-a concentration [108,20,23,102]. These two parameters are important because they are related to the primary productivity of the waters. However, this limited approach still leaves gaps, considering other oceanographic dynamics such as ocean currents [52,21], thermal fronts [4,135,77] and upwelling [17] also play a major role in supporting food availability, phytoplankton distribution, and pelagic fish migration routes. Furthermore, the estimation of skipjack tuna movement patterns [122,92] can be used as an indicator to estimate the ZPPI of skipjack tuna in IFMA 573, especially around the waters of Sendang Biru, which is still limited.

Based on these conditions, this study aims to analyze the influence of oceanographic parameters (currents, thermal fronts, SST, and chlorophyll-a) on the distribution and movement patterns of skipjack tuna in the waters of Sendang Biru, IFMA 573. The results of this study are expected to provide scientific and practical information in supporting sustainable fisheries management strategies and planning of fishing activities in the area. Furthermore, the use of BMKG's Ina-WIS product combined with Aqua-MODIS satellite imagery to detect skipjack tuna fish catches in research is currently limited. Therefore, this research is expected to provide valuable information for future studies.

II. LITERATURE RIVIEW

A. Mapping of Fishing Areas

Fishing Areas are very beneficial, especially for fishermen. Once the DPI is known, the next step is mapping. DPI mapping aims to support fishermen in various ways, such as increasing fishing efficiency and effectiveness, optimizing catches, ensuring fishing sustainability, protecting prohibited species, and various other benefits. One method for DPI mapping is utilizing a Geographic Information System (GIS), which uses secondary data in the form of satellite imagery. The satellite frequently used is Aqua-MODIS (EOS PM), which is capable of detecting the distribution of chlorophyll-a and Sea Surface Temperature (SST). Chlorophyll-a and SST are important elements in DPI mapping because they influence fish distribution patterns and habitats. In addition, currents and thermal fronts play a role in the DPI of skipjack tuna [77,21]. Chlorophyll is a phytoplankton pigment that reflects the fertility of a body of water. The higher the chlorophyll-a levels in an area, the more ideal the waters are as a DPI, as they serve as a natural food source or feeding ground. SST also plays a role in determining the usual fishing grounds (TPI) because it influences fish migration, distribution, and presence. In addition to oceanographic parameters, catch data is also used to improve the accuracy of DPI mapping.

Ocean currents in the IFMA 573 region move at varying speeds, influenced by monsoon winds and regional circulation. These currents play a role in the transfer of water mass and mixing of surface water layers. The currents passing through the Lombok Strait originate from a branch of the Indonesian Throughflow that passes through the Makassar Strait, while the baroclinic currents entering through the Ombai Strait and the Timor Sea are branches of the Arlindo Current originating from the north of the Banda Sea [24]. The surface layer also shows an eastward surface current south of Java. This current is known as the South Java Current (SJC). Variability in the direction of the SJC flows along the Indian Ocean coast of Sumatra and Java only during the west monsoon season. During the east monsoon season, the SJC is largely in the same direction as the westward direction of the Indonesian Throughflow [104]. Current movements cause a redistribution of sea surface temperatures (SST), where warm or cold water masses can spread horizontally, thus creating spatial and temporal variations in SST. Currents also affect the distribution of chlorophyll-a by transporting phytoplankton and nutrients horizontally, so that the concentration of chlorophyll-a at the sea surface can increase or decrease depending on the direction and speed of the current. The flow of water masses in the Indian Ocean will carry chlorophyll-a spatially distributed. According [101], the distribution of zooplankton is generally much more uneven than phytoplankton, this is because zooplankton respond to their environment at a much slower rate than phytoplankton. The time from increasing food supply to spawning, successful hatching, and maturation can take several days to several weeks, compared to the relatively rapid response of phytoplankton (a few days) to increased light or nutrients.

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A front is an oceanographic phenomenon that indicates the meeting of two water masses with different characteristics. At the location of the front in the water, there is a change in sea surface temperature, chlorophyll-a, and salinity distribution with a horizontal gradient. This property is homogeneous in the surrounding water mass and has an effect on aquatic biology. Generally, this phenomenon can be linked to other oceanographic processes such as upwelling and downwelling. When wind blows over the sea surface, it creates pressure that causes the water to move in the same direction as the wind. Once the water moves, its movement is affected by the Coriolis force, which is a result of the Earth's rotation, causing the water movement to be deflected by 90° to the left or right of the wind direction (Ekman Transfer). If the wind direction occurs far from the coast, surface water will be displaced offshore, where it will then be replaced by colder, deeper water that flows up near the coast. This process is called upwelling and is caused by wind, with bottom and coastal topography playing a significant role in this process. The rising water usually originates from deep water masses that are rich in nutrients. Phytoplankton floating on the surface use nutrients from the rising water as a food source and for reproduction [116]. According to [101], weak converging currents at the surface can easily concentrate phytoplankton at the front location. Phytoplankton increases can arise directly due to several dynamic properties of the front that facilitate access to nutrients and light in surface waters. Increased nutrient availability in the upwelling region is one indicator that the waters have a high production rate of phytoplankton, zooplankton, and fish. Predators often have a preferred prey size range. Larger prey may contain more energy, but more energy may be required to capture them and they may take longer to find and process them. Conversely, small prey may be easy to capture and quickly processed, but large quantities of small prey may be needed to maintain energy intake, making consuming them inefficient [37].

III. METHODS

This research was conducted at the Pondokdadap PPP in the Sendang Biru waters from March to May 2024. The data collection location was the Sendang Biru Waters, specifically at the Pondokdadap Coastal Fisheries Port (PPP), Sendang Biru Hamlet, Tambakrejo Village, Sumbermanjing Wetan District, Malang Regency, East Java Province. The Pondokdadap PPP is an ideal location for this research, because geographically, this location directly faces the Indian Ocean-South Java and has ecological suitability for Skipjack tuna. The Pondokdadap PPP is one of the main bases for purse seine and handline fishing vessels in South Java, with the vessel's operational range capable of exceeding 100 nautical miles from the Pondokdadap PPP. Location details can be seen in Figure 1.

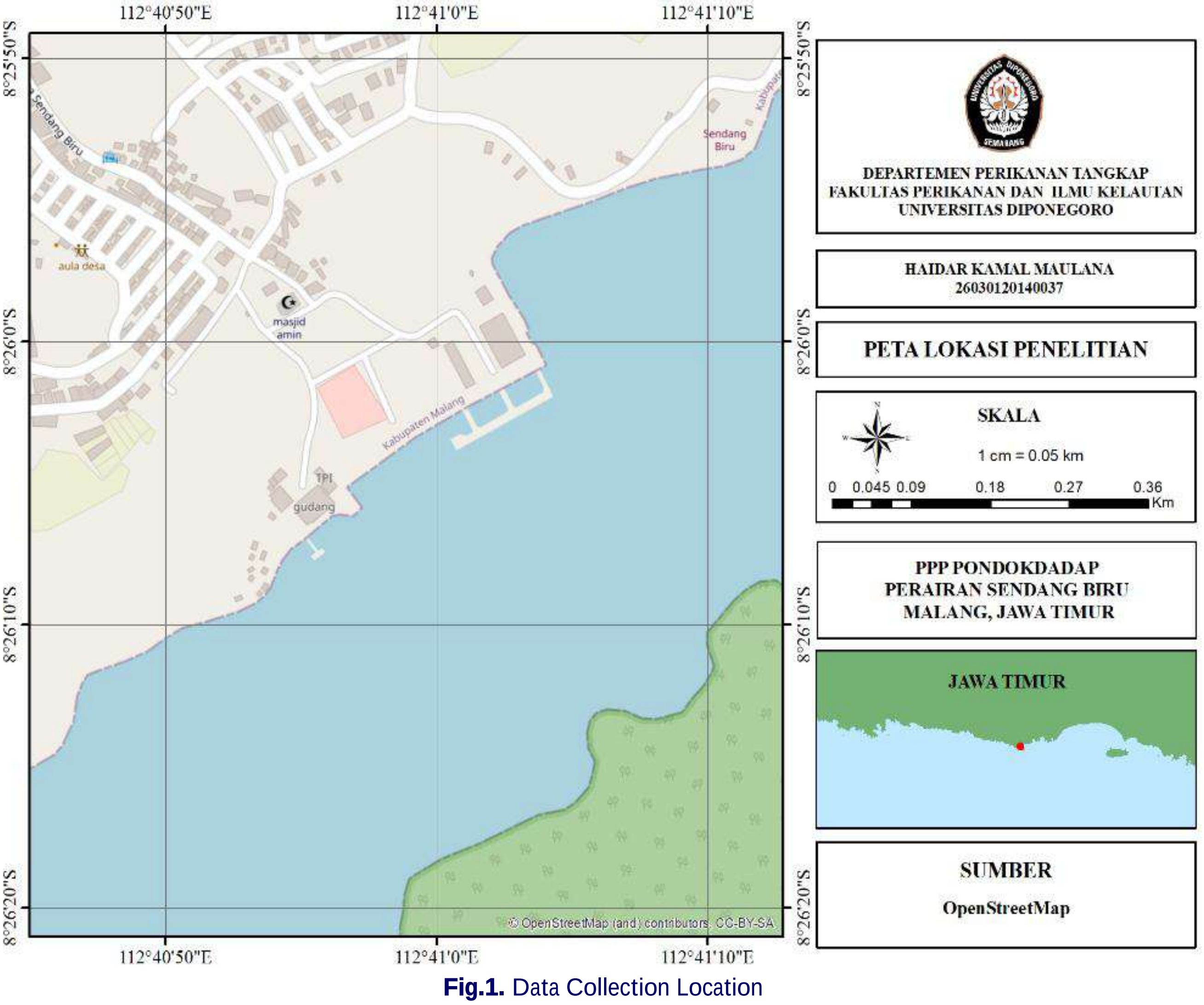

Fig.1. Data Collection Location

The research method used was descriptive quantitative. Quantitative methods with a descriptive approach aim to describe and analyze numerical data obtained from research samples in a systematic and objective manner. Therefore, this method is very useful, as quantitative data is often a crucial component in the analysis and decision-making process. Observations must be objective to minimize researcher subjectivity in making interpretations. The SPL and chlorophyll-a data analysis method uses the data interpolation method with Inverse Distance Weighting (IDW). In principle, sample points that are closer will have a greater influence than points that are further away. The value at the estimated location is obtained through a weighted average of the surrounding sample points, where the weight is determined based on the distance function with a certain power.

The thermal front location analysis method uses the Single Image Edge Detection (SIED) algorithm by inputting SPL data obtained from the MODIS satellite. The image data used has a spatial resolution of 4 km, a histogram window size of 32 x 32 pixels is used to detect stable temperature gradient patterns at a resolution of 4 km. The SIED algorithm works by detecting significant changes in temperature gradients in the image, and the use of SIED in determining the front from an image will be more accurate than the visual method. The use of the SIED method is considered more objective and can help in determining the DPI of Skipjack Tuna. The data analysis technique in this study is to analyze the results of image overlay (merging) that shows the area where the upwelling phenomenon occurs in IFMA 573. The image overlay technique is carried out by combining two (2) image data, namely sea surface temperature and chlorophyll-a, which are then processed in Ms. Excell and ArcGIS. In this study, the upwelling map analysis technique refers to the research of [8], which refers to the research of [44]. According to [8], the determination of upwelling criteria in IFMA 573 is carried out in two ways, namely upwelling criteria based on chlorophyll-a distribution values and upwelling criteria based on SST distribution values, namely:

1) Upwelling criteria based on chlorophyll-a distribution values

a). Determining the Line Boundary

Lower Boundary (C) = Average Value - Standard Deviation
Central Boundary (B) = Average Value + Standard Deviation
Upper Boundary (A) = Average Boundary + (2 x Standard Deviation)

b). Determining Upwelling Criteria

Weak Upwelling (WU) = WU < Lower Boundary (C)
Medium Upwelling (MU) = Lower Boundary (C) ≤ MU < Central Boundary (B)
Strong Upwelling (SU) = Central Boundary (B) ≤ SU < Upper Boundary (A)

2) Upwelling criteria based on SST distribution values

a). Determining the Upwelling Boundaries

Lower Boundary (C) = Mean Value + (0.5 x Standard Deviation)
Central Boundary (B) = Mean Value - (0.5 x Standard Deviation)
Upper Boundary (A) = Mean Limit - (Standard Deviation)

b. Determining Upwelling Criteria

Weak Upwelling (WU) = UL > Lower Boundary (C)
Medium Upwelling (MU) = Mean Limit (B) ≤ UM < Lower Boundary (C)
Strong Upwelling (SU) = Upper Boundary (A) ≤ UK < Mean Limit (B)

IV. RESULTS AND DISCUSSION

Results

A. Current Conditions of Sendang Biru Waters Based on Satellite Imagery

Currents are oceanographic parameters that play a significant role in the dynamics of other oceanographic distributions, such as temperature, salinity, water fertility, thermal fronts, upwelling/downwelling, and so on. According to [64], ocean surface currents are caused by winds blowing over them. However, the reality is not so simple. In addition to wind, currents are also influenced by at least three other factors: the shape of the water bed, geography, and air pressure. Consequently, the currents flowing on the ocean surface are the result of a combination of these factors. Ocean currents in the IFMA 573 region move at varying speeds, influenced by monsoon winds and regional circulation. These currents play a role in the movement of water masses and the mixing of surface water layers. The currents passing through the Lombok Strait originate from a branch of the Indonesian Throughflow that passes through the Makassar Strait, while the baroclinic currents entering through the Ombai Strait and the Timor Sea are branches of the Arlindo Current originating from the northern Banda Sea [24].

Every month, the direction and speed of the currents change due to the dynamic circulation originating from the South Java Coastal Current (SJC), the South Equatorial Current (SEC), and the Indonesian Ocean Current (Arlindo). In January-March, the SJC is stronger, but the ARLINDO is weaker. Meanwhile, in April-May, the ARLINDO is stronger and the APJ is weaker. The meeting of the SJC and ARLINDO can form divergent and convergent currents on the surface of the water. Surface currents are one of the factors that form divergent and convergent currents. The location of the convergent/front zone phenomenon is characterized by the presence of eddies in the current that can cause mixing of two different water masses such as SST, chlorophyll-a, salinity, and nutrient concentration. According to [27], the zone where convergent and front currents occur is a combination of mechanisms that play a very important role in the life of plankton, micronekton, and tuna and skipjack tuna as one of their predators that has an opportunistic feeder nature.

In addition, currents are one of the causes of the upwelling phenomenon in the waters, the upwelling location is considered a fertile location and a gathering place for fish, so that the food chain process occurs in that location.

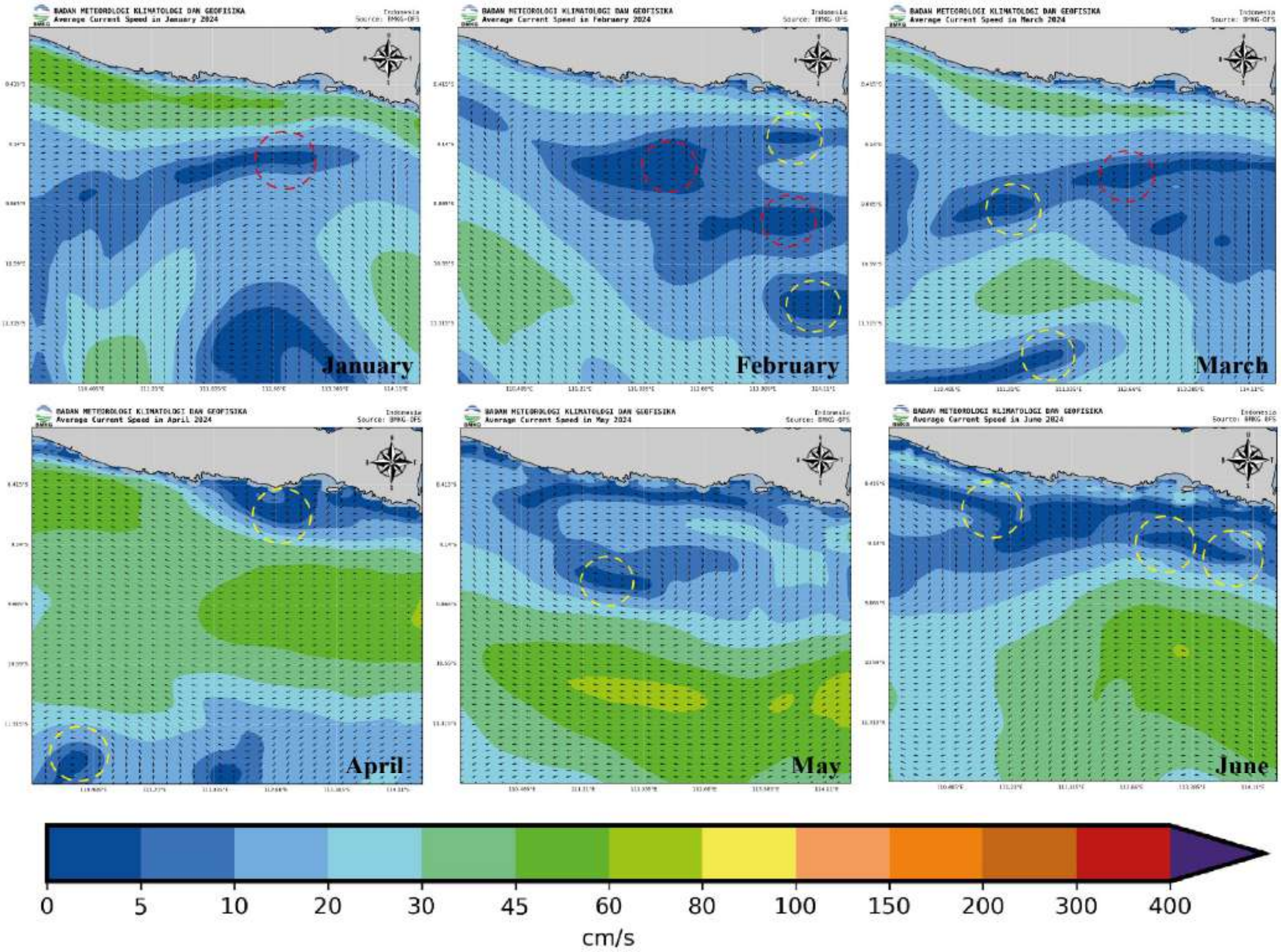

Fig.2. Average Current Velocity in Sendang Biru Waters from January to June 2024

Note: (red circle) = Divergence current
(yellow circle) = Convergence current/front

The factor that causes upwelling in the waters of South East Java is due to the influence of Arlindo which has an influence of 55-65% in the process of forming upwelling in the waters of South East Java [46]. Currents can affect fish migration patterns, because some fish such as Skipjack tuna often use currents as migration routes or paths [52]. The existence of Skipjack tuna is closely related to the dynamics of environmental factors, especially in the location of forage habitat or feeding grounds. Skipjack tuna undergoes 2 migration phases, namely trophic migration to find food and reproductive migration, based on this, the existence of this fish can be followed spatially and temporally.

B. Distribution map of SST, Chlorophyll-a and Thermal Front in Sendang Biru Waters

The process of determining the Potential Fishing Zone requires information related to factors that can affect the presence of fish. Common indicators used to determine the level of water fertility include Sea Surface Temperature (SST), chlorophyll-a, thermal fronts and upwelling. Skipjack tuna has the ability to adapt to a relatively wider temperature tolerance compared to some other pelagic fish, but is still relatively limited overall, with the aim of adapting to temperatures in tropical waters. Therefore, the use of SST parameters is important to determine the location of this fish in the waters. Generally, thermal fronts occur due to the presence of a clear transition zone boundary between two water masses with different temperature gradients in the sea. This phenomenon often occurs in waters with active oceanographic dynamics, such as around major ocean currents, upwelling or the meeting of currents that carry water with different temperatures. Therefore, in the process of estimating the location of the thermal front, it must be adjusted to the temperature of the target fish catch, namely Skipjack tuna. According to [88], the distribution of skipjack tuna often moves following the convergence currents between cold and warm currents, which are also known as areas rich in organisms and are believed to be good locations for catching skipjack tuna and tuna. Based on the image above, it can be seen that the Single Image Edge Detection (SIED) method is capable of detecting the location of thermal fronts each month. According to [42] and [129] in [100], fish migration, distribution, and presence are known to be strongly linked to the presence of front phenomena. Therefore, understanding the location of waters affected by thermal fronts and upwelling can be used by fishermen to identify the potential for the formation of high-risk skipjack tuna fishing grounds (IPI).

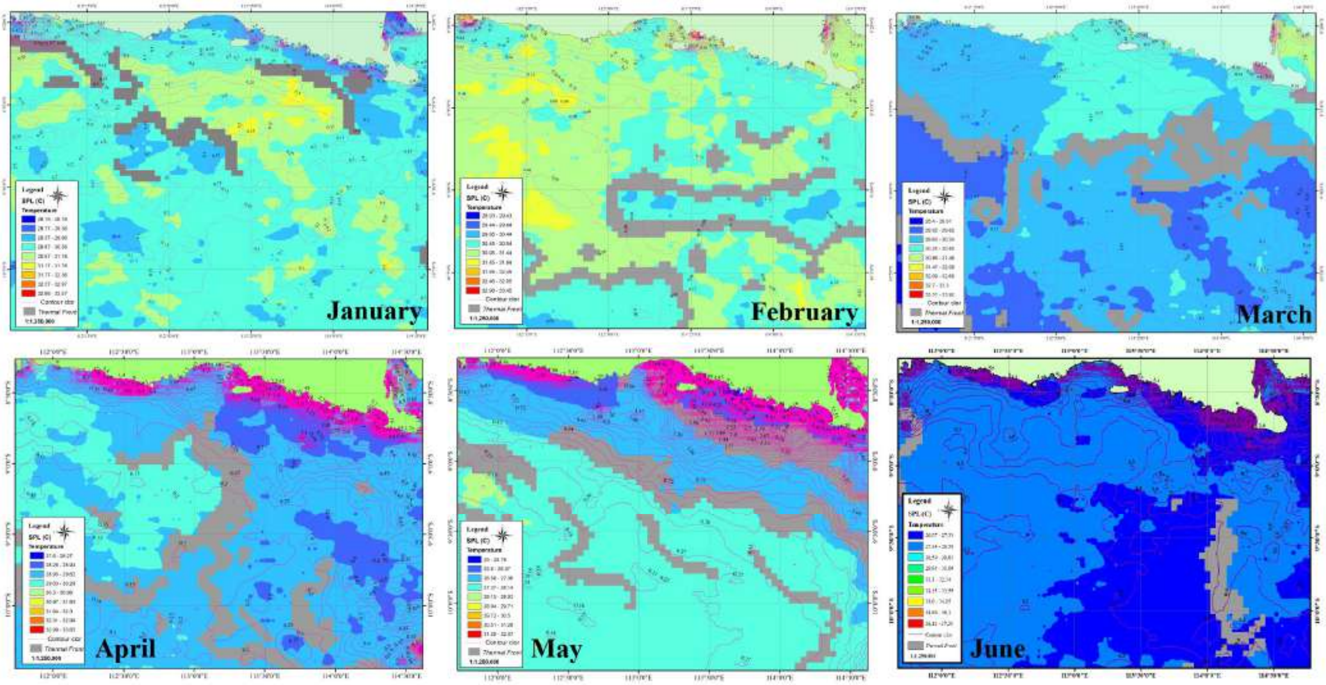

Fig.3. Distribution of SST, Chlorophyll-a and Thermal Front in Sendang Biru Waters

The distribution of primary productivity in waters can be influenced by physical (SST) and biological (chlorophyll-a) factors. Therefore, identifying the location of increased chlorophyll-a (phytoplankton pigment) concentrations in waters is crucial because chlorophyll-a content is a fundamental part of the food chain in marine ecosystems. Furthermore, increases and decreases in chlorophyll-a can be influenced by factors such as currents and SST in the waters, as well as phenomena such as the IOD, ENSO, and monsoon winds, which have direct and indirect effects on chlorophyll-a in the waters. SST, chlorophyll-a and thermal front have different values every month (Table 1).

Table I - Distribution of SST, Chlorophyll-a and Thermal Front Location January-June 2024

Bulan	Oceanographic Parameters		
	Chlorophyll-a (mg/ m³)	SST (°C)	Thermal Front (°C)
Januari	0,15 - 0,4	28,77 - 31,17°C	29,15 - 30,56°C
Februari	0,08 - 0,2	29,95 - 31,45°C	30,45 - 30,94°C
Maret	0,15 - 0,5	29,02 - 30,86°C	29,63 - 30,24°C
April	0,15 - 1,75	28,28 - 29,63°C	28,95 - 29,62°C
Mei	0,18 - 4,7	25 - 28,15°C	27,37 - 28,14°C
Juni	0,3 - 4,5	26,07 - 27,34°C	27,34 - 28,58°C

According to [134], the distribution of chlorophyll-a concentration in skipjack tuna fishing areas is around 0.1-0.6 mg/m³ and sea surface temperatures in skipjack tuna fishing areas vary greatly from 27.5-32.5°C. This is supported by [69], who stated that the optimal average SST and chlorophyll-a values for skipjack tuna fishing in WPP 573 are 28.5°C and 0.23 mg/m³.

C. Results of Calculation and Classification of Upwelling Criteria in the Waters of IFMA 573 for January-June 2024 Sea Surface Temperature (SST) January-June 2024

Table II - SST Distribution at Upwelling Locations January-June 2024

	January	February	March	April	May	June
A	28,723	29,226	28,502	28,727	27,595	27,110
B	29,430	29,897	29,101	29,249	28,197	27,728
C	30,137	30,569	29,699	29,771	28,799	28,345

January Upwelling Classification

Weak Upwelling (WU) = WU > 30.137°C
Upwelling Medium (MU) = 29,430°C ≤ MU < 30,137°C
Strong Upwelling (SU) = 28,723°C ≤ SU < 29,430°C

February Upwelling Classification

Weak Upwelling (WU) = WU > 30,569°C
Upwelling Medium (MU) = 29,897°C ≤ MU < 30,569°C
Strong Upwelling (SU) = 29,226°C ≤ SU < 29,897°C

March Upwelling Classification

Weak Upwelling (WU) = WU > 29,699°C

Upwelling Medium (MU) = 29,101°C ≤ MU < 29,699°C
Strong Upwelling (SU) = 28,502°C ≤ SU < 29,101°C

April Upwelling Classification
Weak Upwelling (WU) = WU > 29,771°C
Upwelling Medium (MU) = 29,249°C ≤ MU < 29,771°C
Strong Upwelling (SU) = 28,727°C ≤ SU < 29,249°C

May Upwelling Classification
Weak Upwelling (WU) = WU > 28,799°C
Upwelling Medium (MU) = 28,197°C ≤ MU < 28,799°C
Strong Upwelling (SU) = 27,595°C ≤ SU < 28,197°C

June Upwelling Classification
Weak Upwelling (WU) = WU > 28.345°C
Upwelling Medium (MU) = 27,728°C ≤ MU < 28,345°C
Strong Upwelling (SU) = 27,110°C ≤ SU < 27,728°C

Sea Surface Temperature (SST) increases and decreases from January to June. Based on the upwelling criteria based on the distribution of Sea Surface Temperature values, February showed the highest SST value of 30.569°C which then continued to decrease until June with the lowest SST value of 28.345°C. Sea Surface Temperature (SST) at the location of upwelling which tends to be lower than the surrounding waters can increase chlorophyll in the area. Lower sea surface temperatures have a major impact on the biological metabolism of fish, and allow microorganisms such as phytoplankton to grow and the area becomes more fertile. According to [40] in [136], the temperature in a body of water can affect the growth of phytoplankton, the optimal temperature for phytoplankton growth ranges from 25-30°C. Phytoplankton carry out optimal photosynthesis activities in the morning, because as the afternoon approaches the water temperature begins to rise and will disrupt the phytoplankton metabolic process.

Chlorophyll-a January-June 2024

Table III - Chlorophyll-a Distribution at Upwelling Locations January-June 2024

	January	February	March	April	May	June
A	0,214	0,122	0,193	0,343	0,715	0,476
B	0,138	0,088	0,130	0,194	0,367	0,312
C	0,062	0,054	0,067	0,045	0,020	0,148

January Upwelling Classification
Weak Upwelling (WU) = WU < 0.062 mg/m³
Upwelling Medium (MU) = 0.062 mg/m³ ≤ MU < 0.138 mg/m³
Strong Upwelling (SU) = 0.138 mg/m³ ≤ SU < 0.214 mg/m³

February Upwelling Classification
Weak Upwelling (WU) = WU < 0.054 mg/m³
Upwelling Medium (MU) = 0.054 mg/m³ ≤ MU < 0.088 mg/m³
Strong Upwelling (SU) = 0.088 mg/m³ ≤ SU < 0.122 mg/m³

March Upwelling Classification
Weak Upwelling (WU) = WU < 0.067 mg/m³
Upwelling Medium (MU) = 0.067 mg/m³ ≤ MU < 0.130 mg/m³
Strong Upwelling (SU) = 0.130 mg/m³ ≤ SU < 0.193 mg/m³

April Upwelling Classification
Weak Upwelling (WU) = WU < 0.045 mg/m³
Upwelling Medium (MU) = 0.045 mg/m³ ≤ MU < 0.194 mg/m³
Strong Upwelling (SU) = 0.194 mg/m³ ≤ SU < 0.343 mg/m³

May Upwelling Classification
Weak Upwelling (WU) = WU < 0.020 mg/m³
Upwelling Medium (MU) = 0.020 mg/m³ ≤ MU < 0.367 mg/m³
Strong Upwelling (SU) = 0.367 mg/m³ ≤ SU < 0.715 mg/m³

June Upwelling Classification
Weak Upwelling (WU) = WU < 0.148 mg/m³
Upwelling Medium (MU) = 0.148 mg/m³ ≤ MU < 0.312 mg/m³
Strong Upwelling (SU) = 0.312 mg/m³ ≤ SU < 0.476 mg/m³

The highest chlorophyll-a value was in May with a value of 0.715 mg/m³, and the lowest chlorophyll-a value was found in February with a value of 0.122 mg/m³. Sea surface temperature is the reason why the chlorophyll-a value in February was very low. The temperature in the upwelling area tends to be lower than the surrounding waters and this can increase chlorophyll-productivity in the area. This will result in increasingly abundant food availability from the first level of the food chain, namely phytoplankton, this will increase the population of both upper and lower levels of the food chain. In addition, upwelling can bring nutrients from the lower layers to the surface, so that the area is fertile and rich in phytoplankton, making the area a feeding ground for fish. Therefore, upwelling is often associated with fishing ground areas.

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This is in accordance with the statement of [134], the abundance and presence of living things in estuary waters are influenced by microorganisms that have a role as a food source and primary producers for all living things in the water. Phytoplankton is at the first level in the food pyramid chain, so its existence plays a very important role.

D. Results of upwelling layout in the Sendang Biru Sea Waters Area from January to June 2024

The upwelling phenomenon that occurs in a body of water can increase productivity in those waters, so the location of the upwelling is an important factor in determining the fish's DPI. When phytoplankton growth increases in a body of water, it will attract zooplanktons, which then become a food source for small fish, so that the location becomes a forage habitat for other predatory fish, such as tuna and skipjack tuna. Forage habitat can form when the location has an abundance of prey, as well as optimal water environmental conditions for skipjack tuna, so that skipjack tuna have a food supply in that location.

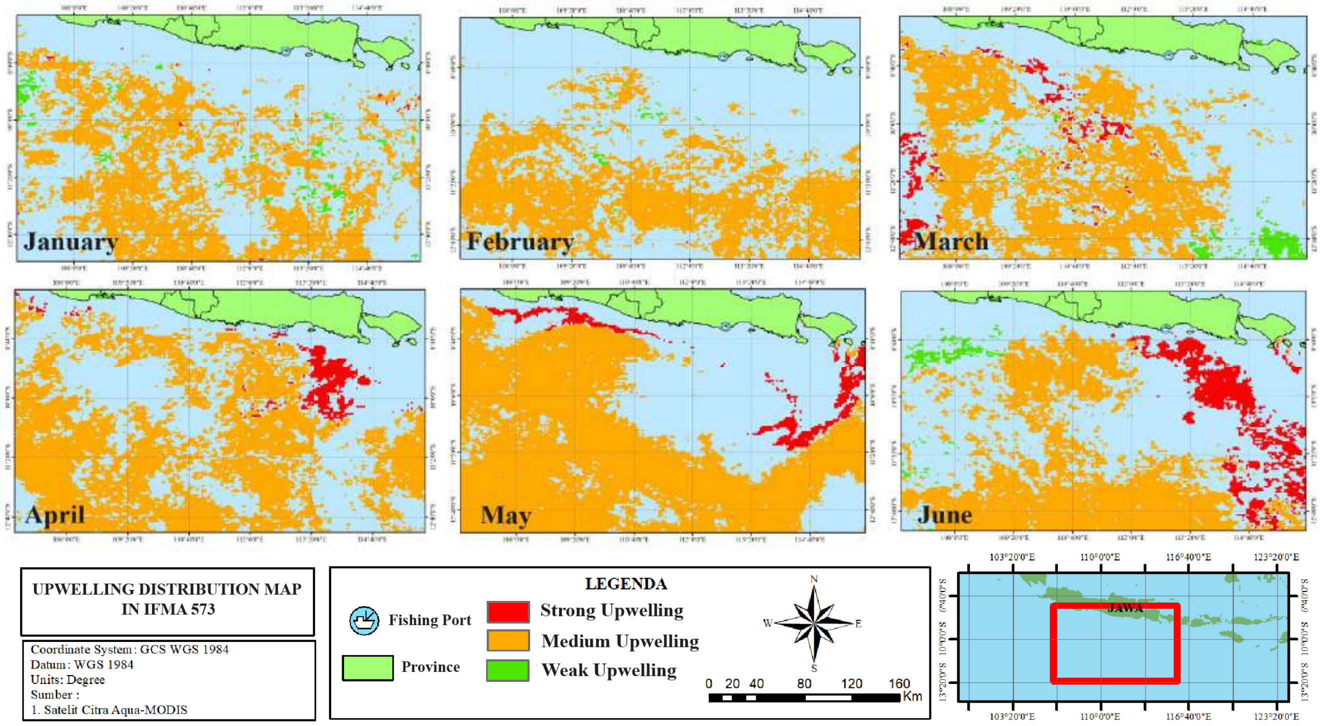

Fig.3. Results of upwelling layout in the Sendang Biru Sea Waters Area from January to June 2024

The map above is the result of an upwelling map layout by combining sea surface temperature (SST) and chlorophyll-a data from January-June 2024. The use of SST and chlorophyll-a data in the map-making process is useful for identifying the location of highly fertile and productive waters. Although determining upwelling locations does not only use SST and chlorophyll-a data because there are other oceanographic factors such as ocean current conditions, seasonal patterns, thermal fronts and fronts, this is because a body of water will always be dynamic and have relationships with one another. However, in determining the location of fish, sea surface temperature and chlorophyll-a are important factors, because fish will always be associated with the temperature of the surrounding waters, and the high productivity of chlorophyll-a allows phytoplankton and zooplankton to live in these waters, which generally become food for small fish, so that the food chain process occurs in these waters. According to [54] and [74] in [45], primary productivity plays a crucial role in the food web, producing organic compounds that are the primary source of carbon and energy for organisms in aquatic environments. The primary productivity food chain is the primary food source for marine life, and chlorophyll-a is an essential pigment for aquatic plants (phytoplankton) in the photosynthesis process. Chlorophyll-a concentration can therefore be used as an indicator parameter for estimating primary productivity in Sendang Biru waters. However, it should be noted that the upwelling phenomenon does not directly influence the emergence of skipjack tuna, but plays an important indirect role through increased nutrients, phytoplankton growth (chlorophyll-a), and water productivity, which is a gathering place for small fish, which then become a food source for skipjack tuna [17].

E. Map of Estimated Movement Patterns of Skipjack Tuna in April and May in Sendang Biru Waters

The estimated movement pattern of skipjack tuna in April 2024 is thought to be influenced by currents originating from the East to the West of the southern part of Java Island, with current speeds reaching 60 cm/s. As a large pelagic fish that is classified as a fast (active) swimmer, skipjack tuna will utilize currents to aid migration and movement in search of food. This fairly strong current drives skipjack tuna to move westward following the water flow, while searching for areas with optimal environmental conditions. Surface winds cause the dominant current movement to the west. Then the South Equatorial Current in the Indian Ocean begins to weaken due to the transition season, so that local currents begin to strengthen. Also, there is a meeting of currents from the east and the flow from Arlindo in the South which will then create shear or a difference in speed or direction between two layers of water that rub against each other (Around 11.3°S 110.5°E (large eddy, cyclonic and counter clockwise rotation direction) and Around 9.1°S 111°E (small eddy)) and give rise to eddies.

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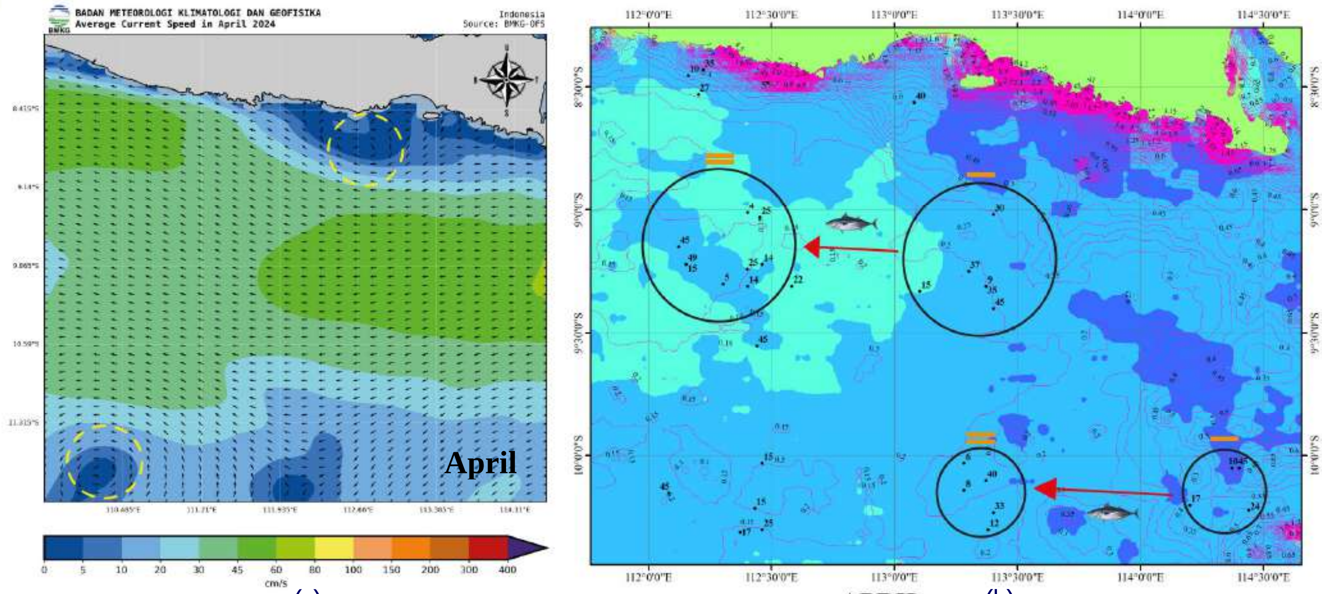
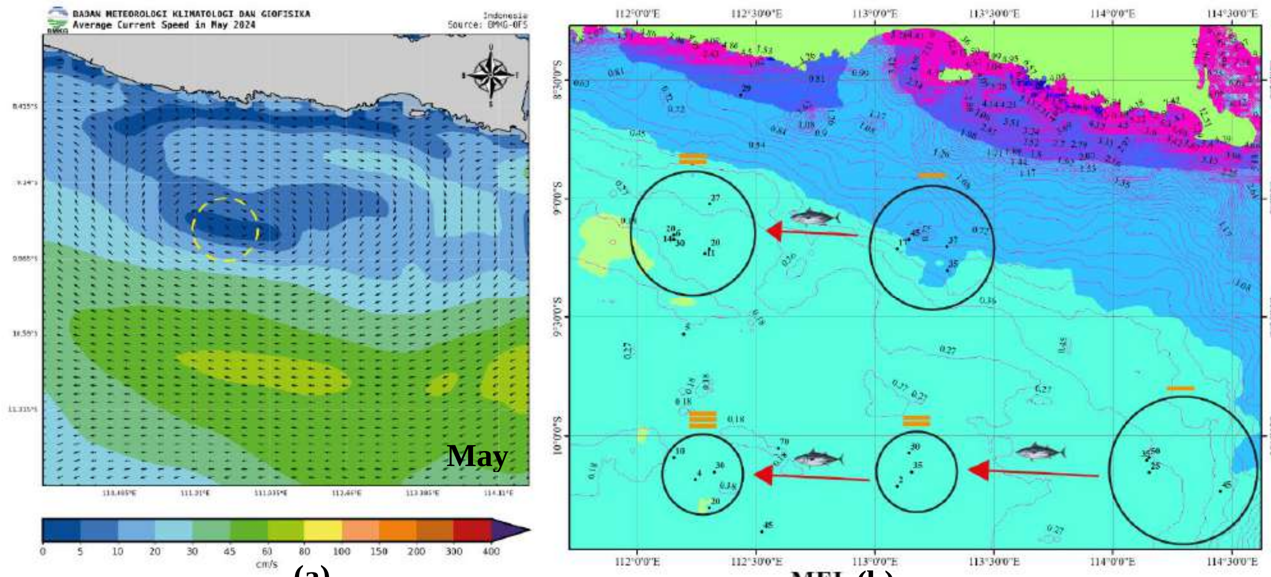


(a) (b)

Fig.5. Map of Current Conditions (a) and Movement Patterns of Skipjack Tuna (b) in April in Sendang Biru Waters

Note: = Starting location (1)
= Second location (2)
= Direction of Movement
= Fish Spot (1=100 Fish)

Circle Size =
= 5.000-10.000 Fish = 10.000-15.000 Fish = ≥ 15.000 Fish



(a) MEI (b)

Fig. 6. Map of Current Conditions (a) and Movement Patterns of Skipjack Tuna (b) in May in Sendang Biru Waters

Note : = Starting location (1)
= Second location (2)
= Direction of Movement
= Fish Spot (1=100 Fish)

Circle Size =
= 5.000-10.000 Fish = 10.000-15.000 Fish = ≥ 15.000 Fish

Therefore, the area around eddies and up welling is a productive zone. In April, skipjack tuna were recorded as being caught at SSTs ranging from 27.6 to 30.96°C. However, most skipjack tuna were caught at a narrower temperature range, namely 28.95°C to 29.62°C.

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This is in accordance with the statement of [69], who stated that in WPP 573 the optimal habitat for the emergence of skipjack tuna is at temperatures ranging from 28-31°C. This temperature supports physiological activity, movement, and the availability of planktonic food in their habitat. Then, skipjack tuna were caught this month in the waters of IFMA 573 with chlorophyll-a concentration value (as an indicator of phytoplankton abundance) of 0.15-0.65 mg/m³, this concentration is classified as quite low to moderate, but still adequate to support the food chain in tropical seas. The presence of skipjack tuna is associated with strong upwelling in these waters. The highest catch of skipjack tuna this month reached 6,000, caught at 9.22°S and 112.15°E, with sea level sea levels ranging from 28.95°C to 29.62°C. If the movement pattern of skipjack tuna is mapped based on physical oceanographic parameters (current and SST) and reinforced by the location and number of skipjack tuna catches, then the skipjack tuna that move by utilizing Arlindo from the east gather around 9°0'0 - 9°30'0 South Latitude and 113°0'0 - 113°30'0 East Longitude (Large yellow circle) with the number of catches reaching 17,100 fish and many are caught at a temperature of 28.95°C-29.62°C, then the skipjack tuna starts to move towards 9°0'0 - 9°30'0 South Latitude and 112°0'0 - 112°30'0 East Longitude (Large green circle), this is suspected based on the direction of the current movement and the number of skipjack tuna catches reaching 19,600 fish and also the movement of the current.

In May 2024, the surface current from the east was strong, meeting with the local current from the South around 10–11°S latitude that entered (Impact of Arlindo from the East). The dominant current moved from East to West (especially at the bottom of the map around 10°–11°S) with a speed of 45–80 cm/s (Green-yellow zone). This is in accordance with the statement of [22], in the transition season I in May, the distribution of surface currents influenced by seasonal winds has begun to deflect moving from East to West. Then in the upper part, the current is weaker and somewhat curved, supporting the formation of shear and local eddies. In May, the movement of Skipjack tuna has more or less the same movement as in April, Skipjack tuna around 9°0'0 - 9°30'0 South Latitude and 113°0'0 - 113°30'0 East Longitude (medium yellow circle) with a total catch of 13,400 fish moving towards 9°0'0 - 9°30'0 South Latitude and 112°0'0 - 112°30'0 East Longitude (medium green circle) with a total catch of 12,800 fish. This is suspected based on the current movement (with a speed of 45–80 cm/s in the green-yellow zone) and Skipjack tuna were caught at SST values between 26.58°C-28.14°C and many were caught at SST 27.37°C-28.14°C. In May, the seasonal current from the east (the influence of the East Monsoon) is stronger than in April, making upwelling intensity stronger in May compared to April. Many skipjack tuna catches are concentrated in areas of chlorophyll-a around 0.18–0.72 mg/m³, locations near eddies or current confluences that are usually cooler due to upwelling. Strengthening seasonal currents moving from the east can trigger friction between water layers (shear) and eddies. This process then drives upwelling, namely the rise of nutrient-rich water masses from deep layers to the surface. The presence of these nutrients will increase chlorophyll-a concentrations, ultimately creating a fertile aquatic environment and supporting the development of the marine food chain.

F. Map of Potential Skipjack Tuna Fishing Areas in IFMA 573

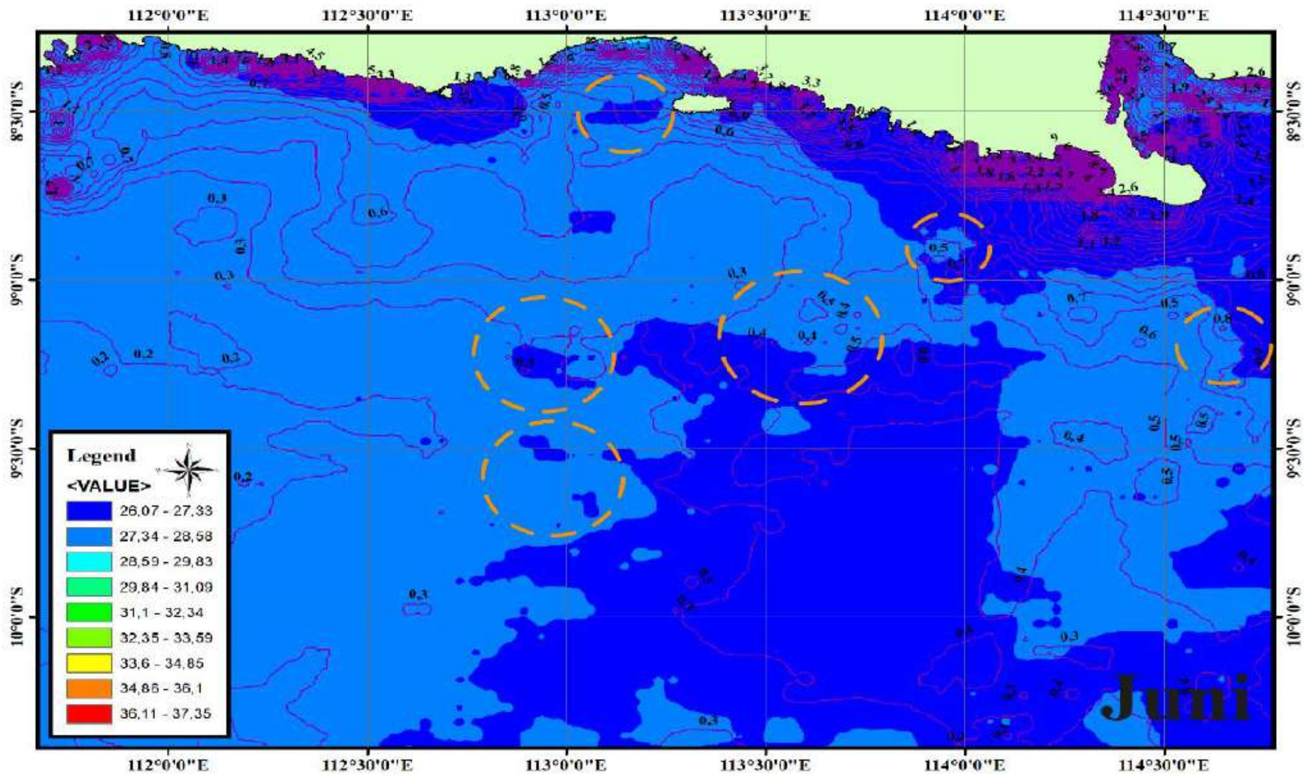

Fig.7. Map of Potential Skipjack Tuna Fishing Areas in IFMA 573

Note: ( ) = Fishing Ground Skipjack Tuna Indication

Estimation of Skipjack tuna fishing areas in Sendang Biru waters by accumulating data from current conditions, thermal fronts, and very strong upwelling, which were verified with SST and chlorophyll-a data in Sendang Biru waters. Current conditions around Sendang Biru waters in June 2024 were two convergent currents/fronts, these currents moved from the east and began to turn northward and began to form convergent currents when moving east again. Horizontally, currents are one of the factors in determining the pattern and direction of skipjack tuna movement. According to [88], the distribution of skipjack tuna often moves following the convergence current between cold and warm currents, which are also known as areas rich in organisms and are believed to be good locations for catching skipjack tuna and tuna. Understanding current circulation is very important, because the number of fish populations in the waters is greatly influenced by current characteristics. Based on the map above, there are 6 locations suspected as ZPPI Skipjack Tuna. The distribution of SPL and chlorophyll-a at each location, respectively, ranges from 26.07-28.58°C and 0.3 - 0.9 mg/m³. The locations suspected as DPI locations for skipjack tuna are adjusted to the location of the converging current/front and the location of strong upwelling around the waters of Sendang Biru, in addition, the location is also suspected as the location of the thermal front. According to [134], the distribution of chlorophyll-a concentration in skipjack tuna fishing areas is around 0.1-0.6 mg/m³ and the sea surface temperature in the skipjack tuna fishing areas varies greatly from 27.5-32.5°C. This is supported by [69], who stated that the optimal average SST and chlorophyll-a value for skipjack tuna fishing in WPP 573 are 28.5°C and 0.23 mg/m³, respectively. Thermal fronts and upwelling play a crucial role in determining locations with high primary productivity in waters. High primary productivity attracts skipjack tuna due to the abundance of food sources. Thermal fronts create a mixing zone between two water masses with different temperatures. This temperature difference encourages nutrient circulation, which then supports the growth of phytoplankton as primary producers. This enriches the marine food chain and attracts small fish that are prey to skipjack tuna, which then makes the location a location for upwelling.

DISCUSSION

Oceanographic parameters (physically and biologically) play a crucial role in the survival of all marine life. Living organisms constantly adapt to the marine ecosystems they use for shelter, spawning grounds, forage habitats, and shelter from predators. The presence and distribution of fish in the ocean are strongly influenced by the temporal and spatial variability of oceanographic parameters. When the water profile does not match fish preferences, it will lead to fish emigration, which will reduce fish abundance, making fishing areas less potential. Oceanographic parameters such as temperature, chlorophyll-a concentration, currents, salinity, and others are dynamic and have a causal relationship. For example, when sea surface temperatures are very high in a body of water, it can cause a decrease in chlorophyll-a content in that location. This is because chlorophyll-a is an important pigment for aquatic plants (phytoplankton) in the process of photosynthesis. Chlorophyll-a does indeed still require sunlight so that they can carry out photosynthesis, but high intensity sunlight can also interfere with the photosynthetic process, this phenomenon is called photo inhibition, namely a decrease in photosynthesis efficiency due to excessive light exposure, based on this research, this phenomenon is thought to have occurred in February 2024.

The current movement along the South coast of Java from west to east in January-March 2024 (figure 2) was caused by the Java Coastal Current (SJC). This current movement occurs every year, the direction from west to east is thought to be because January-March is still influenced by the west monsoon winds and only enters the transitional monsoon I in March. Then, in April-June 2024 (figure 2) shows a different SJC direction, namely moving from east to west caused by the transition process from the transitional monsoon I (April and May) to the east monsoon (June). In addition to the SJC, the waters of Sendang Biru (IFMA 573) are also influenced by the South Equatorial Current (SEC). The SEC is part of the gyre that forms between the APJ and the Australian Northwest Coast Current (East Gyral Current/EGC) which in general the EGC current moves westward. Based on Figure 2 in January the direction of the SEC comes from the Southeast, but in February and April-June the direction of the AKS comes from the East, and the SEC moves from the south in March. Generally, the SEC water mass transport will strengthen when entering the east monsoon, so this is why the SEC in January-March only reaches an average current speed of around 30 cm/s and begins to increase to 45 cm/s in March because this month begins to enter the transitional monsoon I. Then, the speed of the SEC in April-June strengthens to reach 80 cm/s, the strengthening of the SEC speed is estimated to be due to Arlindo flowing out of the Banda Sea through the Timor Sea to the Southern Waters of Java. The SEC flows every year and spreads from Northwest Australia between 10°-20° South Latitude and moves westward to the Indian Ocean to Madagascar. The SEC will strengthen in the east monsoon, and the SEC also has variations in each season both spatially and temporally. During the first transition season, the AKS can spread up to 8°-18° South Latitude and in the east season the SEC can spread up to 5°-15° South Latitude due to the strong influence of the Southeast Monsoon Wind, so that the SEC extends northward beyond 10° South Latitude and moves from Sumbawa to along the South Coast of Java [109, 115; 127]. Based on Figure 3, the distribution of Sea Surface Temperature (SST) values in January-March 2024 ranged from 28-31°C, then the SST in April-June 2024 decreased by around 26-30°C. There are several factors that can influence the distribution of SST values in Sendang Biru waters, one of which is the current. Based on Figure 2, the speed of the SST in January-March tends to be weak and not as strong as in April-June, so the SST is thought to have a role in reducing SST in April-June because during the transition period of the first transition season (April and May) the SST begins to strengthen and the SST will be stronger when entering the east season (June). According to [83], the SST has a role in pushing surface water masses originating from the east to the west, the movement of the SST on the surface will be strengthened by Arlindo which mostly originates from the Timor Sea towards South Java and strengthens the direction of current movement from east to west.

In addition, the Lombok Strait is part of the second exit route for the Arlindo to go to South Java, which will affect surface waters above 200 m [95]. In addition, the Indian Ocean Dipole (IOD) and El Nino Southern Oscillation (ENSO) certainly have an important role in changes in SST in the waters of South Java. For example, ENSO plays a role in the movement of the Arlindo originating from the Pacific Ocean to the Indian Ocean, when El Nino the Pacific surface pressure decreases while the Indian increases, which can cause the Arlindo geostrophic current transport process to weaken. Likewise, when La Nina, the Arlindo geostrophic current transport process originating from the Pacific to the Indian will be greater due to the pressure difference, so that the Arlindo is able to flow water masses well to the waters of South Java and indirectly plays a role in temperature changes in the waters of South Java [55, 24]. According to [73], the IOD plays a role in changes in oceanographic variability of waters such as current conditions, SST and chlorophyll-a distribution in Indonesian waters, as well as the distribution of upwelling related to the IOD phenomenon in South West Java.

The determination of skipjack tuna fishing areas in June 2024 in IFMA 573 used oceanographic parameters such as currents, thermal fronts, and upwelling. Currents play a significant role in skipjack tuna movement patterns, therefore determining the direction and speed of currents is crucial. Furthermore, currents are a factor in the occurrence of convergent/front and divergent currents. Thermal fronts are an important factor in determining fish presence, as they tend to carry relatively cool, nutrient-rich water, thus increasing productivity in these waters. Thermal front locations are identified by a temperature gradient of 0.5–1°C. In June, four thermal front locations are suspected, with temperatures at each location ranging from 26.07–28.58°C and chlorophyll-a values ranging from 0.3–0.7 mg/m³. According to [77], in the capture of skipjack tuna in the Banda Sea using thermal front parameters, the results showed that the sea surface temperature (SST) and thermal front parameters significantly influenced the catch of skipjack tuna, with SST ranging from 28-30°C. Then, this statement was reinforced by [39], in the number of skipjack tuna catches in the Sawu Sea, it was found that an increase in chlorophyll-a concentration accompanied by a decrease in SST tended to be followed by an increase in the CPUE (Catch per Unit Effort) value of skipjack tuna, and vice versa. In this study, the highest chlorophyll-a value was recorded at 0.63 mg/m³ and the lowest SST was 26.6°C, both of which occurred in August 2015.

In the process of establishing fishing grounds, especially for predatory fish such as skipjack tuna, it requires a time lag for the skipjack tuna to gather when upwelling occurs in a body of water. This is indeed common because waters with high productivity levels require time for the food chain process in that location, until finally predatory fish such as skipjack tuna come to those waters. For example, in March and April (Tables II and III), in March the SST and chlorophyll-a at the location of strong upwelling were 28.502°C and 0.193mg/m³, then in April the SST and chlorophyll-a at the location of very strong upwelling were 28.727°C and 0.343mg/m³, however the difference in production amounts in March and April was quite significant, namely in March the production amount reached 237,507 kg and in April it reached 405,459 kg. Based on this, it can be concluded that waters with good oceanographic parameters can be followed by increased catches. According to [97], the presence of small fish in the upwelling area is what attracts predatory fish, including skipjack tuna, to gather at the upwelling location. This process shows that the occurrence of upwelling cannot directly invite skipjack tuna to gather at the location and time of the upwelling, but there is a time lag between the time of the upwelling and the time the skipjack tuna gathers at the upwelling location.

Based on Figure 4. and Table II and Table III, it can be seen that May has optimal conditions for the formation of water zones with high water productivity, which is characterized by the location of strong upwelling, with the SST and chlorophyll-a values at that location of 27.595°C and 0.715mg/m³. The location of Skipjack tuna is associated with sea surface temperatures (SST) ranging up to 18°-32°C with a preferred temperature range between 23°-29°C. According to [130], the dynamics of potential areas for catching Skipjack tuna are thought to be related to the development of upwelling and front phenomena that can concentrate the fish. Then this was reinforced by research conducted in the waters of Tamperan in Pacitan with the target of catching skipjack tuna, upwelling that occurred in the east season (June-September 2015) had an influence on increasing the distribution of skipjack tuna in the waters of Tamperan in Pacitan [4]. According to [50] in [92], upwelling that occurs in the South Java Sea occurs in June-October, while downwelling occurs in November-March.

V. CONCLUSIONS

1. Based on research conducted in the waters of Sendang Biru (IFMA 573) from January to May 2024, it was found that the current reached its highest speed in May, reaching a value of 60 cm/s, moving from the southern east of Java Island to the southern west of Java Island. The optimal thermal front location occurred in April, with a chlorophyll-a content of 0.2-0.3 mg/m³ and a temperature of around 28.95-29.62°C. Optimal strong upwelling occurred in May, with a chlorophyll-a content of 0.715 mg/m³ and an SST of 27.595°C.

2. The oceanographic parameters used in this study have both direct and indirect influences. Currents directly influence skipjack tuna movement. Furthermore, sea level (SST) also plays a direct role in skipjack tuna's presence. Therefore, assessing the location of thermal fronts and upwelling in Sendang Biru waters is crucial for identifying potential skipjack tuna fishing locations. When water productivity increases, phytoplankton, the primary producers, attract zooplankton, and small, planktivorous fish. These waters then become forage habitats for predatory fish like skipjack tuna. Forage habitats can form when prey is abundant and the environment is optimal (SST, chlorophyll-a, and currents), allowing skipjack tuna to survive and prey on small fish.

3. Based on the results of the estimated movement pattern of skipjack tuna in the waters of WPP 573 in April and May 2024, it can be seen that the movement of skipjack tuna is estimated to be around the East in the Southern part of Java Island (9°0'0 - 9°30'0 S and 113°0'0 - 113°30'0 E) which then moves towards the West of the Southern part of Java Island (9°0'0 - 9°30'0 S and 112°0'0 - 112°30'0 E). This is influenced by oceanographic parameters in the form of direction and speed of currents and sea surface temperature. In addition, it is suspected that the installation of FADs at latitudes 9°-12° with longitudes 110°-114° in the waters of WPP 573 is the cause of the similarity of skipjack tuna movements in April and May.

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