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Projected Impacts of Ocean Warming on the Potential Fishing Zone of Eastern Little Tuna *(Euthynnus affinis)* in the Java Sea

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ABSTRACT

In this research, the impact of ocean warming was examined on sea surface temperature (SST) in the habitats of eastern little tuna in the Java Sea, following the IPCC's projected temperature rise scenarios of 1, 2, and 4°C. Satellite-derived SST, chlorophyll-a, salinity, and the eastern little tuna catch data from 2016 to 2020 were analyzed. SST preference for *E. affinis* was determined from the histogram of CPUE against SST. The highest average catch per unit effort (CPUE) occurred during the northwest monsoon season (December to February) and the first transitional season (March to May), with 85 and 72kg/ trip, respectively. The locations with SST of 29- 30°C appeared to be the most productive fishing areas, i.e. CPUE of 80kg/ trip. Shifting in the locations of potential fishing areas was identified from the SST at the current condition and each of the three scenarios of projected temperature rises. Optimal habitat projections for eastern little tuna fluctuate between the northwest and first transitional seasons due to the projected SST rises. During the northwest season, a 1°C temperature increase maintains a potential habitat in the Java Sea, particularly in February, but it disappears with temperatures' increase of 2 and 4°C. Conversely, during the first transitional season, potential habitats appear only in January with a 1°C rise and are not present under the 2 and 4°C increase scenarios. The fish concentration is expected to move closer to Java's coastal waters while seasonal factors may drive the fish westward.

INTRODUCTION

The Indonesian region, commonly known as the "Maritime Continent," has been highlighted as having significant climatic importance locally and globally. The Asian monsoon significantly influences SST variability **(Qu *et al.*, 2005)**. According to the Climate Change Monitoring Report, 2023 was the warmest year since global records began in 1850 by a wide margin. It was 2.12°F (1.18°C) above the 20th-century average

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of 57.0°F (13.9°C). Conspicuous effects of climate change are evident in Indonesia, particularly in the Java Sea.

The Java Sea's distinctive features result from seasonal changes in monsoon system currents. During the northwest monsoon (Asian monsoon), ocean currents move eastward, and during the southeast monsoon (Australian monsoon), currents move westward **(Ulha *et al.*, 2014; Rahmawitri *et al.*, 2016)**. The government's commitment to preparing for climate change adaptation must include impact-based research to guarantee the availability of high-resolution climate change scenarios. Global warming occurs when the average temperature of the atmosphere, seas, and land increases. Due to changing ocean conditions, this climate impacts the distribution and abundance of fish species **(Syamsuddin *et al.*, 2016; Prakash, 2021)**.

The primary oceanographic factor influencing marine biological resources is SST **(Robles-Tamayo *et al.*, 2018; Nugraha *et al.*, 2020)**. Temperature has an indirect impact on various oceanic processes, including upwelling, fronts **(Yuniarti *et al.*, 2013; Ahmed *et al.*, 2019)**, and determines the location of certain species' warm and cold water boundaries **(Sukresno, 2021)**. Empirical studies supporting the impact of SST on the distribution of marine species include the dispersion of yellowfin tuna **(Tussadiah *et al.*, 2019)** and the appearance of whale sharks **(Ranintyari *et al.*, 2018)**. However, because of the dynamics of the ocean, oceanographic conditions vary throughout time **(Shabrina *et al.*, 2017)**. With the use of remote sensing technology, these oceanographic changes can be identified **(Zainuddin *et al.*, 2023)**.

Eastern little tuna (*Euthynnus affinis*) was the major targeted species in the Java Sea **(Syamsuddin *et al***., **2016)**. They prefer waters with high-temperature fluctuations and rich in nutrients **(Girsang, 2008 as cited in Nuraisyah *et al.*, 2019)**. As a pelagic fish, eastern little tuna has migration patterns and distributions that can be predicted by estimating indicators, primarily environmental factors such as SST. The eastern little tuna (ELT) in FMA 712 has been assessed as overexploited **(Rizal *et al.*, 2023)**. The suspected cause is the decreased biomass of large pelagic fish due to increased fishing pressure. According to **Froese *et al.* (2017)**, excessive overexploitation of fish commodities, characterized by continuous overfishing operations and excessively low biomass levels, leads to depletion to attain maximum sustainable yield.

According to **Perry *et al.* (2011),** fish populations shift to deeper waters or higher latitudes when ocean temperatures rise. Although it is anticipated that tuna habitats will shift toward the poles, the effect of SST will probably differ depending on the species' tolerance for temperature **(Muhling *et al*., 2011)**. In this study, we used the catch and effort data for eastern little tuna from the logbook of the Ministry of Marine and Fisheries Affairs of the Republic of Indonesia and SST data from the satellite AquaMODIS to analyze the impact of SST increases on the eastern little tuna in the Java Sea.

Identifying the locations of prospective fishing grounds poses a significant challenge in the utilization of marine fish resources **(Hakim *et al.*, 2006)**. Scientific research is necessary to simulate the eastern small tuna hotspots in the Java Sea, including the impacts of global warming, utilizing long-term oceanography and remote sensing satellite data. Satellite data offers more extensive information while encompassing a broader research area. The fishing area prediction model optimizes fishing operations by minimizing fishing time and enhancing fuel efficiency. This study will generate a predictive map of possible fishing zones (hotspots) by employing remote sensing and geographic information systems (GIS), based on increases in sea surface temperature (SST) of 1, 2, and 4°C. To mitigate the impacts of global warming, the research will generate recommendations for fishermen and the government to enhance fishing operations and the management of the eastern small tuna production in the Java Sea.

MATERIALS AND METHODS

1. Study area

The study area is in the Java Sea between 2 – 8°S and 105 – 117°E (Fig. 1). The area is also known as the Fisheries Management Area of the Republic of Indonesia 712 (FMA 712).

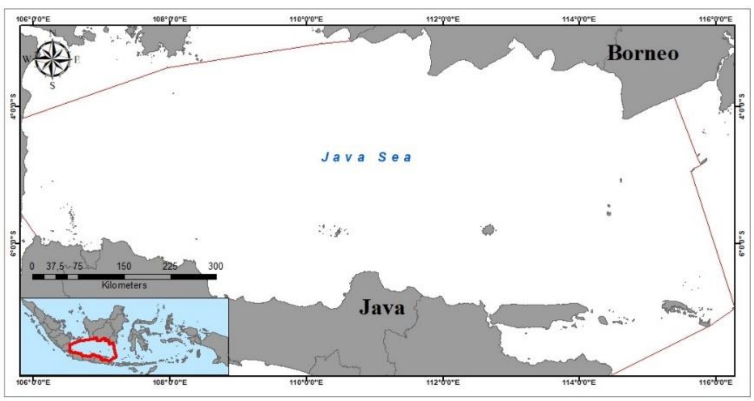

Fig. 1. A map showing the study area in the Java Sea

2. Data

This study analyzed SST, chlorophyll-a, salinity, and the eastern little tuna catch for 5-year datasets from January 2016 to December 2020. Fish catches were obtained from the logbook of the Marine and Fisheries Department of Indramayu West Java, and the Ministry of Marine Affairs and Fisheries, Republic of Indonesia. The data encompassed fishing coordinates (latitude and longitude), operational days, fish weight (in kilos), fishing gear (purse seine, hand line, gillnet), and the quantity of fish captured (Table 1).

Table 1. Summary of specification of oceanographic parameter data and eastern little tuna

Parameter	Sensor	Unit	Resolution		Sources
			Temporal	Spatial	
Sea surface temperature	Aqua MODIS	°C	Monthly	4 km	podaac.jpl.nasa.gov
Chlorophyll-a	Aqua MODIS	mg/m^3	Monthly	4 km	podaac.jpl.nasa.gov
Salinity	Aqua MODIS	psu	Monthly	4 km	podaac.jpl.nasa.gov
Eastern little tuna		kg/trip	Monthly		Marine and Fisheries Department of Indramayu, and the Ministry of Maritime Affairs and Fisheries, Republic of Indonesia

3. Methods

3.1 Data preparation and data processing

The Ocean Color website provided SST, chlorophyll-a, and salinity Level 3 data with a 0.04º spatial resolution and a monthly temporal resolution. The data were further processed using ArcGIS software and the Inverse Distance Weighted (IDW) interpolation method to create spatial visualization. The "extract value by point" tool was used to extract the fish catch location, which was overlaid on the SST. The obtained values were then used as the basis for building a CPUE frequency histogram of the SST value to determine the optimal SST value. The monthly contour maps of SST satellite images were created using the mean values of the preferred oceanographic parameters for relatively high CPUE values. We simulated SST increases of 1, 2, and 4ºC to examine the effects of climate change on possible displacements of potential little tuna habitats. Catch data were expressed in catch per unit effort (CPUE) to track the fishery productivity. The CPUE was calculated using the equation **(Gulland, 1983)**:

$$CPUE = \frac{Catch}{Effort}$$

Where:

CPUE = catch per fishing effort (kg/trip)

Catch = catch in year-t (kg)

Effort = fishing effort in year t (trip)

Monthly CPUE layers from 2016 to 2020 were analyzed to examine spatial and temporal variations associated with the relevant environmental parameters, including satellite-derived SST data. First, the CPUE utilizing standard fishing gear was calculated prior to establishing the CPUE value. The standardized fishing gear was determined by computing the fishing power index (FPI) for each gear type.

$$FPI = \frac{CPUE_i}{CPUE_s}$$

Where:

FPI = the fishing effort factor depends on the type of fishing gear

$CPUE_i$ = annual catch per fishing effort of other fishing gear (kg/trip)

$CPUE_s$ = catch per annual effort of standard gear (kg/trip)

RESULTS AND DISCUSSION

1. Spatial distribution of monthly mean oceanographic parameters

The patterns of the climatological annual cycle of SST during 2016-2020 in the Java Sea are shown in Fig. (2). There is a clear seasonal dependence of SST during 2016-2020; the average SST ranges from 27.74–31.25℃. The SST distribution fluctuated according to the monsoons. During this period, the highest SST values were distributed from March to May (MAM), or transitional season 1, with temperatures ranging from 30 to 31℃.

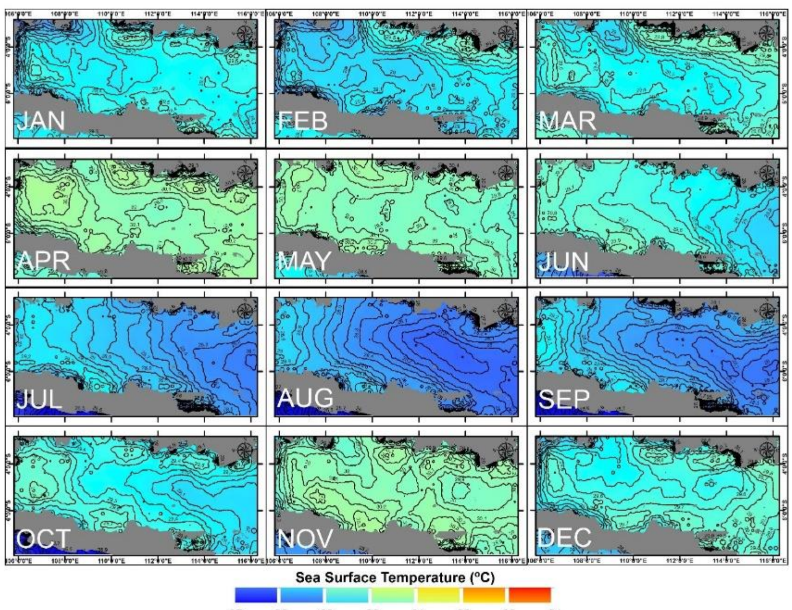

Fig. 2. Spatial map of monthly mean climatology of SST from 2016 – 2020 in the Java Sea

In contrast, these conditions occur during the southeast monsoon (June-August/JJA), while SST tends to decrease, ranging from 27 to 29℃. The SST continued to warm in November, notably along its northern shores and on the eastern side of the Java Sea. The SST was higher in November compared to the previous month. During the northwest monsoon (December-February/DJF) period, the SST distribution in the Java Sea varied from 28 to 30℃, with the highest temperature occurring in December.

A water mass with a low sea surface temperature from the South China Sea traverses the Java Sea during the DJF season. During the northwest monsoon, the Java Sea acquires a mass of seawater from the South China Sea, while both wind and surface currents shift eastward **(Sagala *et al.*, 2014)**. Simultaneously, in JJA, low-value sea surface temperatures from the Makassar Strait and the Flores Sea flow into the Java Sea, subsequently leading to the South China Sea. The reduction in sea surface temperature between the December-January-February and June-July-August periods is attributable to monsoons influencing the displacement of water masses in the Java Sea. Furthermore, during the MAM and SON periods, the impact of monsoons was comparatively diminished, leading to a rise in sea surface temperature (SST) in the Java Sea attributable to solar heating of the water column **(Putra, 2012)**.

The Java Sea's seasonal variation in SST has been the subject of numerous studies **(Sulistya *et al*., 2007; Sachoemar & Yangi, 2013; Martono, 2016)**. They stated that the speed and direction of the monsoon wind mostly control the semi-annual SST cooling and warming peak in the Java Sea. Known as one of the paths of the Indonesian Throughflow, the deep Banda Sea borders the Java Sea to the east **(Gordon, 2001)**. This position causes variations in many oceanographic parameters, such as SST in the Java Sea, that are affected by monsoons **(Wirasatriya *et al*., 2018)**. **Clark *et al*. (2000)** also stated that the amount of evaporation, vertical mass mixing, and Ekman transport produced by monsoons affects the SST's ability to cool or heat. As additional evidence for the existence of ELT, the spatial distribution maps of salinity and chlorophyll-a were examined.

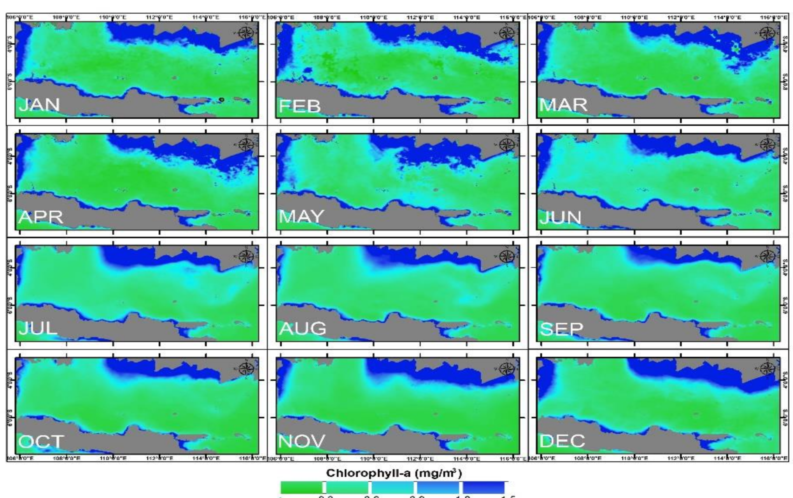

Fig. 3. Spatial map of monthly mean climatology of chlorophyll-a from 2016 – 2020 in the Java Sea

The spatial distribution map of chlorophyll-a indicates that the concentration of chlorophyll-a in open sea areas is generally low (0 - 0.3mg/ m³), as depicted by the green color on the map. Concentrations of elevated values, specifically between 1.2 - 1.5mg/ m³, are observed in the coastal regions of North Java and South Kalimantan. High water productivity and abundant food sources for large pelagic fish are indicated by the large amount of chlorophyll-a in a body of water **(Putri *et al.*, 2021)**. Chlorophyll-a, is a key parameter in determining primary productivity and phytoplankton abundance **(Marpaung *et al.*, 2014)**. Fishing zone identification can be based on higher values, which suggest possible upwelling episodes **(Purwanto *et al.*, 2021)**.

The spatial distribution map of salinity shows that from January to May, salinity is at a lower average value ranging from 32.4 to 33.2 psu. Then, the value increases from June to August, especially in the eastern part of the Java Sea (33.2 to 34 psu). The increase continues to occur until it reaches a peak in October, namely 33.2-34 psu, which can be seen in all waters. Then from November to December, salinity gradually decreases. This aligns with the findings of **Bahiyah *et al.* (2019)**, which indicate that from December to May, the Java Sea and its vicinity exhibit lower salinity levels compared to other bodies of water. Moreover, the salinity of the Java Sea increased between June and November, which corresponds with the current season.

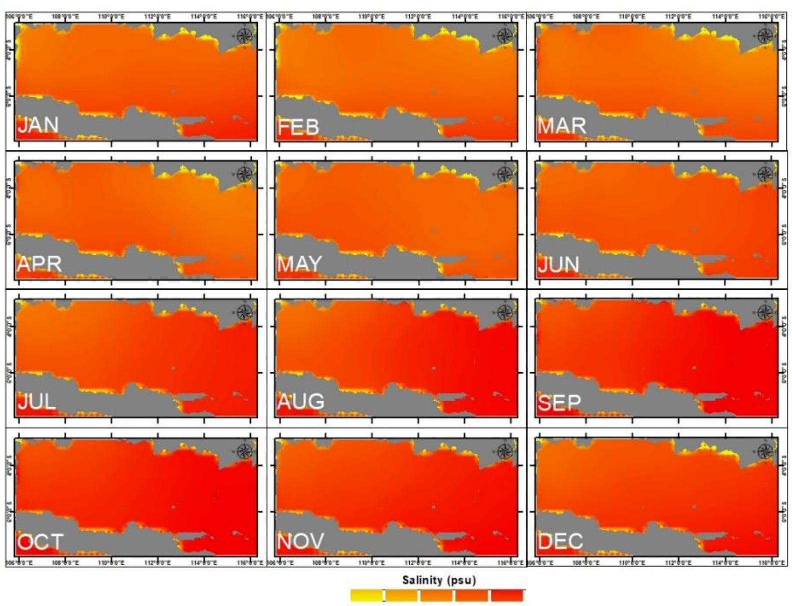

Fig. 4. Spatial map of monthly mean climatology of salinity from 2016 – 2020 in the Java Sea.

2. Temporal pattern of monthly mean SST

The temporal distribution of monthly SST for 2016-2020 is shown in Fig. (3). The monthly mean variation of SST values in the Java Sea ranges from 27.74–31.25℃. The variation in SST values is caused by the influence of lower water masses from the South China Sea in the northwest monsoon and colder water masses from the Makassar Strait in the eastern monsoon **(Siregar *et al.*, 2017)**.

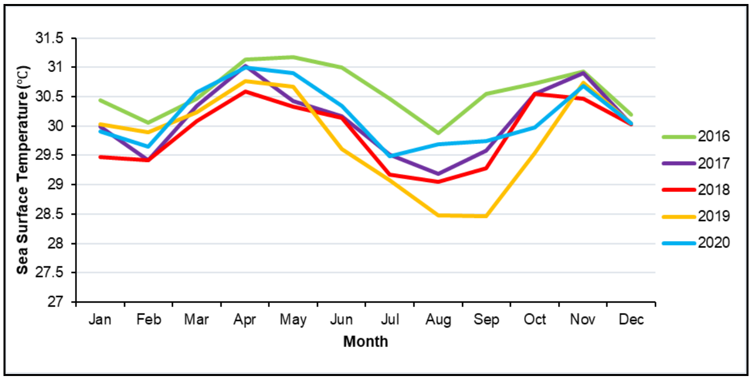

Fig. 5. Inter-annual variability of monthly SST during 2016 – 2020

The temporal pattern of SST exhibits a distinct seasonal trend, with consistency in the temporal pattern that can be identified for March, April, and November. The highest SST values were recorded in April during the first transition season, with SST values ranging from 30.72–31.25℃. This is consistent with study results by **Heryati *et al.* (2018)**, who discovered that the Java Sea reached its peak in April. The changing season from the rainy to the dry season is mostly the cause of increased SST in the Java Sea **(Siregar *et al.*, 2017)**. On the other hand, the lowest SST values were observed in August, corresponding to the southeast season (27.78–29.74℃). In general, the pattern of SST in the northwest monsoon experienced the highest increase in January and decreased in February. The most significant increase during the transitional season I occurred in April. Meanwhile, the lowest SST value occurred in the JJA. In transitional season II, SST increased by 30.81℃. This is due to the influence of monsoon winds that bring large amounts of water from the east, increasing the monthly temperatures **(Nugraha *et al.*, 2019)**.

The southeast monsoon tends to have a lower SST value of 28.74℃, while the transitional season increases the SST to 31.03℃ due to surface currents. The lower SST values in the eastern season are due to the sun's position in the northern hemisphere, so the southern hemisphere tends to receive less solar radiation **(Kusmiati *et al.*, 2020)**. This is also consistent with a study by **Siregar *et al.* (2017)**, which showed that the SST value in the Java Sea increased in the first transitional season and decreased in the eastern season.

3. CPUE variation of eastern little tuna

Eastern little tuna catch is processed as catch per unit effort (CPUE). Fig. (6) shows the average CPUE of eastern little tuna in the Java Sea for 2016 – 2020.

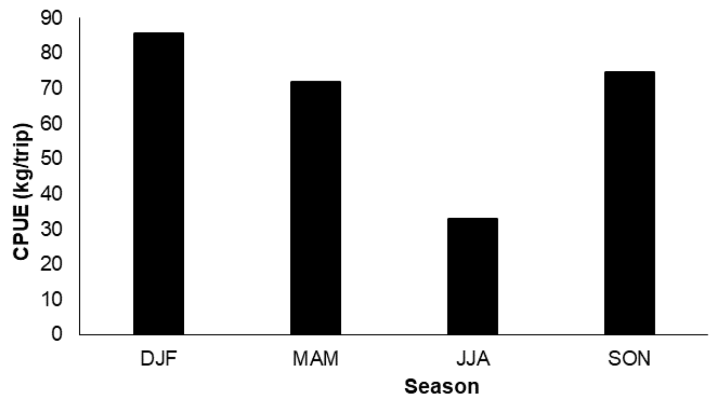

Fig. 6. Seasonal variation of CPUE value during 2016 – 2020

The number of vessels operating yearly influences CPUE values, the fishing season, and fish availability **(Nurdin, 2015)**. The average CPUE for the eastern little tuna in the Java Sea ranges from 4 to 144kg/ trip. The northwest monsoon (DJF) season has the highest average CPUE with 85kg/ trip. This is consistent with the previous study by **Syamsuddin *et al.* (2018)**, which found that the eastern little tuna catch was higher during the western monsoon. During the first transitional season (MAM), the average CPUE was 72kg/ trip. This value decreased during the eastern monsoon period by 33kg/ trip. The southeast monsoon (JJA) period has the lowest CPUE average of the year. In transitional season II, the average CPUE increased again by 7kg/ trip. Differences in the eastern little tuna catch results depend on fishing gear, gross tonnage (GT) of the vessel, and environmental and biological factors, such as food sources **(Realino *et al.*, 2007; Nurhalimah *et al*., 2018)**. Based on monthly and seasonal variations, this paper focuses on the 'DJF' and 'MAM' seasons.

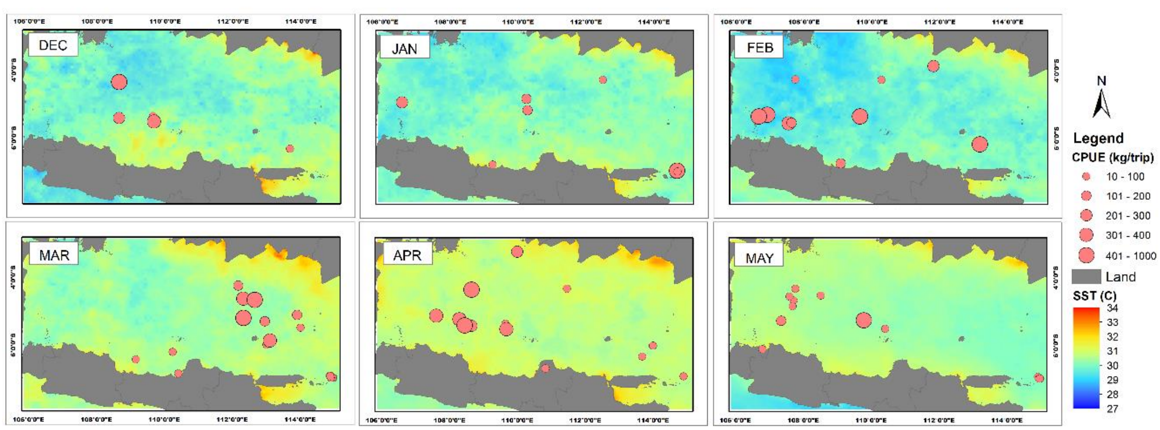

Fig. 7. Spatial distribution map of eastern little tuna during DJF and MAM (2016 – 2020)

The eastern little tuna can be found all across the Java Sea during the DJF period. February exhibited the highest average CPUE (100–1000kg/ trip), whereas January recorded the lowest (10–200kg/ trip). The ELT dispersion, with the highest average CPUE between 10 and 1000kg/ trip, shifted eastward of the Java Sea in March before spreading over the oceans in April. In May, the ELT distribution migrated westward, with a reduced average CPUE of 10 to 300kg each trip.

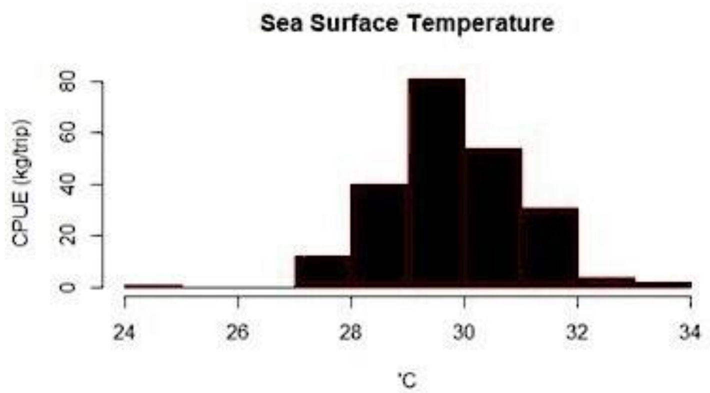

Fig. 8. Histogram showing the relationship between CPUE and SST

A histogram shows the relationship between CPUE values for the eastern little tuna and SST from 2016 to 2020 (Fig. 8). Based on the histogram, SST distribution values range from 24 to 34°C, and CPUE values range from 0–80kg/ trip. 29 to 30°C is the ideal SST range for capturing eastern small tuna; fishing at this temperature will yield a maximum CPUE. This aligns with the findings of **Puspita *et al.* (2023)**, postulating that eastern little tuna favor warmer water, specifically at temperatures of 29–30°C. **Syamsuddin *et al.* (2018)** also stated that this condition implied that various ocean climatic events might result in various oceanographic circumstances beneficial to the eastern little tuna catches in the Java Sea. A small temperature range where fish abundance or catch efficiency is greatest is highlighted by CPUE's noticeable decrease at the temperature extremes, both below 28 and above 32°C. According to this pattern, the targeted fish species are extremely sensitive to temperature changes and only survive in a particular thermal range, most likely between 28 and 32°C.

4. SST distribution based on the increasing scenarios of 1, 2, and 4

The SST spatial distribution maps of the northwest monsoon (Fig. 9) and first transitional season (Fig. 10), are shown as the optimal fishing season for ELT based on average CPUE.

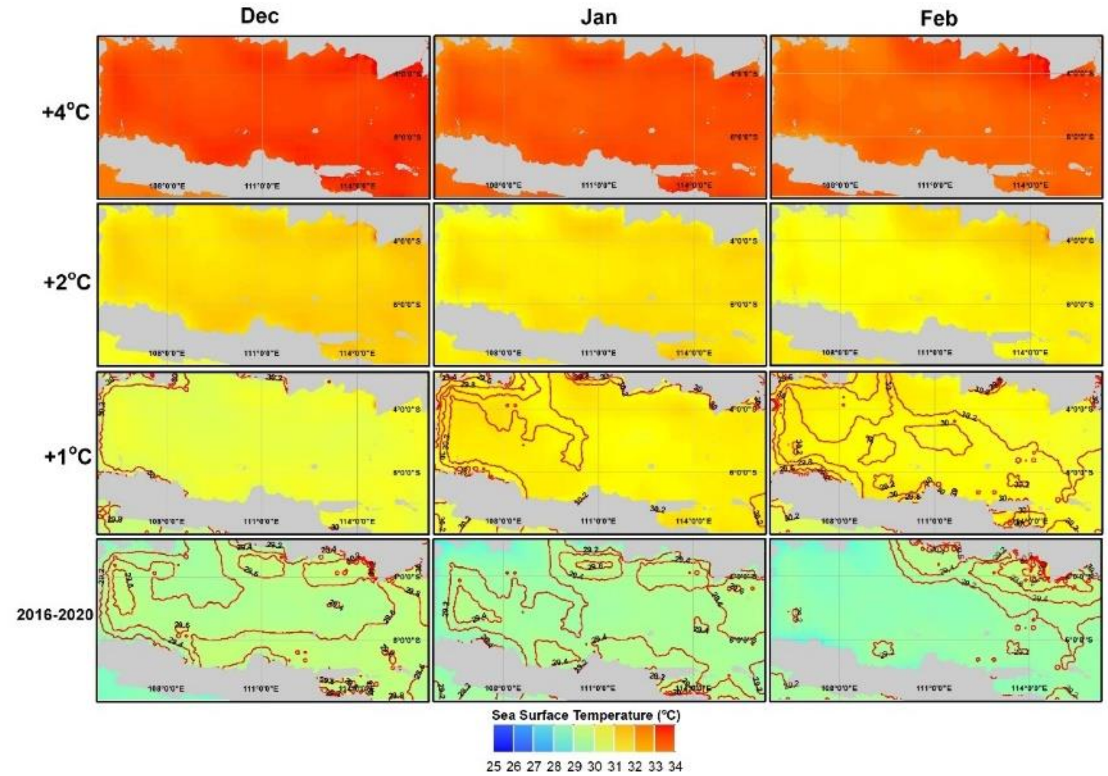

Fig. 9. Spatial distribution of mean SST during northwest monsoon from 2016 – 2020 and under the scenario of increasing SST + 1, 2, and 4ºC

In the northwest monsoon (2015–2020), under normal conditions, the optimal temperature distribution for tuna (29–30ºC) was spread throughout the waters of the Java Sea from December to January. In February, however, the water area with optimal temperatures was found only in the eastern part of the Java Sea. The area seems to be shifting toward the western part of the Java Sea when the SST scenario was increased by 1ºC. The optimum SST area is located at coordinates 107º30'9" E. Based on average spatial temperature data from December to January, 80–100% of the Java Sea represents the optimal area for ELT. In February, this area shrinks, with 40% of the optimal zone forming in the northern part of the Java Sea, between coordinates 110º30'0" E and 115º0'0" E.

The optimum SST area was progressively concentrated into a more significant area of the Java Sea with a +1ºC scenario. The ELT-suitable water region was completely absent in December. Then, in January, the area with the ideal temperature was discovered to be between 106 and 108ºE, or about 30% of the western water area. In February, the ideal temperature distribution expanded and was present in all Java Sea waters. Upon simulating scenarios with increased sea surface temperatures (SST) of 2 and 4°C, the optimal SST distribution area decreases.

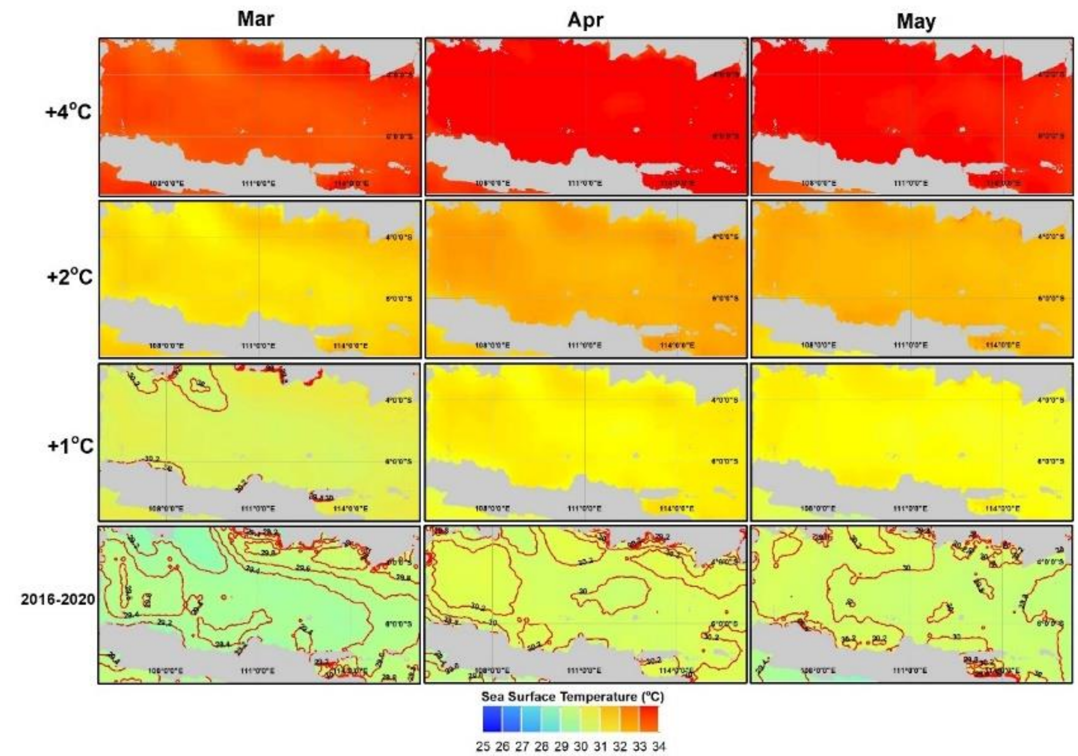

Fig. 10. The mean sea surface temperature (SST) distribution during the transitional season I from 2016 – 2020 is based on the increasing scenarios of 1, 2, and 4°C.

Contrary to the DJF period, a simulation of a 1ºC increase in SST resulted in the potential fishing area shrinking, shifting westward in March, and disappearing in other months. Furthermore, simulations of 2 and 4ºC temperature increases in the Java Sea revealed no optimal SST fishing areas. This is due to the higher SST in the Java Sea during transitional season I. Seasonal patterns, according to **Sadhotomo (2017)**, generally affect the SST distribution in the Java Sea. During transitional season I, water masses from the South China Sea and the Makassar Strait mix, leading to an increase in SST **(Siregar *et al.*, 2017)**.

5. Potential fishing zone of eastern little tuna based on the increasing SST

Figs. (11, 12) show the ELT's monthly potential habitats based on the corresponding SST preferences under recent years' conditions.

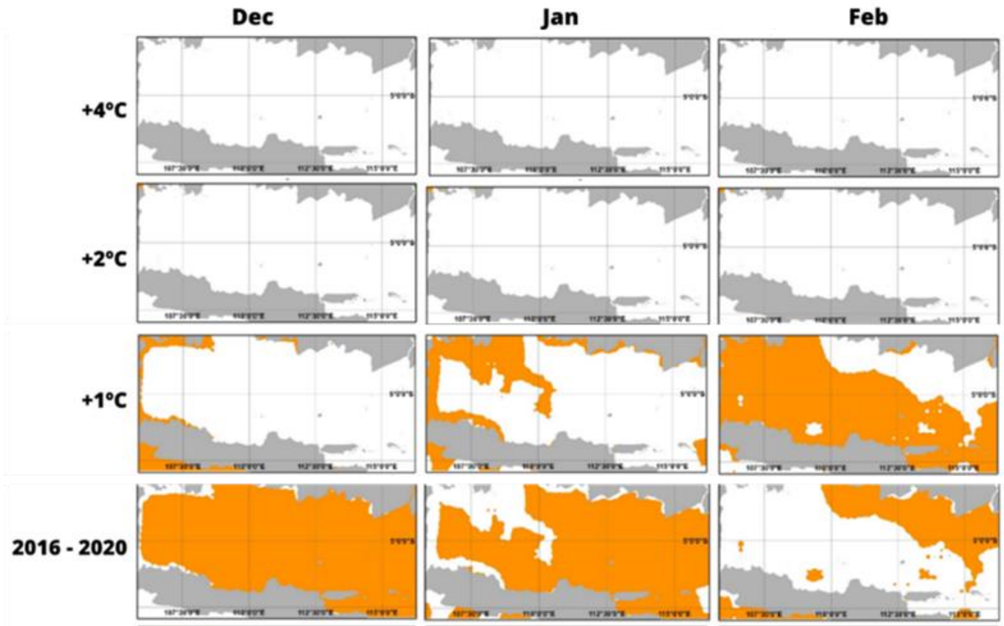

Fig. 11. The potential fishing zone for the eastern little tuna under scenarios of increasing sea surface temperatures of 1, 2, and 4°C during the northwest season

The map showed the potential fishing zone (PFZ) formation throughout the Java Sea waters from December to January. Potential fishing zones are spread throughout the Java Sea in December, under normal conditions. Additionally, the potential fishing zones shift eastward in January. In February, the PFZ for the eastern little tuna can only be found in the northeastern region of the Java Sea.

Under the SST +1ºC scenario, the PFZ shifts westward at 107º30'9" E and 110º0'0" E in December. In February, the PFZ was found in 80% of the northern Java Sea, spanning from 110º0'0" E to 115º0'0" E. Under the +1ºC scenario, the optimal SST became increasingly concentrated in a larger horizontal zone of the Java Sea. However, the PFZ becomes completely undetectable in SST +2 and +4ºC scenarios. Regional climate patterns have changed as a result of global climate change, which impacts fishing operations. Fishing activities are impacted because of the presence, distribution, and abundance of fish that are targeted by fishermen changing with the variations of the oceanographic parameters because of the regional and global climate change **(IPCC, 2007; Simbolon, 2019)**.

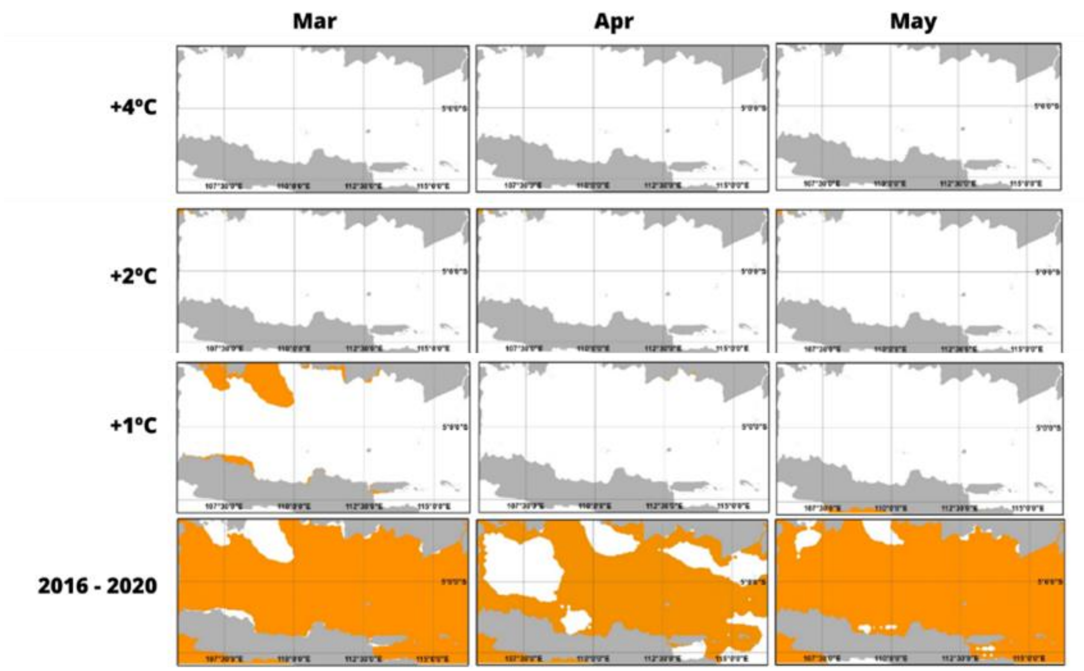

Fig. 12. The potential fishing zone for the eastern little tuna under the scenarios of increasing sea surface temperatures of 1, 2, and 4°C during the first transitional season

In the transitional season, the PFZ is observed across the Java Sea. Although a few minor, non-potential areas are indicated in white in April, PFZ typically dominates the Java Sea region from March to May under normal conditions, with an area coverage of 80-100%. The northwest area of the Java Sea exhibits a constricted PFZ for eastern small tuna under a scenario of a +1ºC increase in SST. Potential habitats for 1ºC scenarios exhibited a westward and southward latitudinal shift during the primary fishing season for the eastern small tuna and are absent under the 2 and 4°C rise scenarios.

Jung *et al.* (2014) forecast that by 2030, sea surface temperatures (SST) will rise, particularly in tropical regions, resulting in warmer SST compared to prior years. **Muhling *et al.* (2015)** asserted that SST would rise in many aquatic regions, leading to significant alterations in fish populations. The robust connection between the environment and the physiology and behavior of tuna elicits a complex response to environmental changes **(Lehodey *et al.*, 2012)**. **Lehodey *et al.* (2012)** also noted that the western equatorial warm pool will be less conducive to the skipjack spawning. **Dueri *et al.* (2014)** identified a considerable alteration in the spatial distribution and quantity of suitable skipjack habitats.

Global fisheries have been impacted by ocean warming, with catches of tropical and subtropical species becoming increasingly dominant. Since SST significantly impacts tuna dispersal, the population of tuna global fisheries is impacted by climate change **(Monllor-Hurtado *et al.*, 2017)**. Fish in warmer waters are smaller at first maturity and have smaller maximum body sizes. Natural death rates are often higher for smaller fish living in warmer environments. This has a significant impact on production and population dynamics **(Pauly, 2010)**. Due to its effects on the quantity and quality of marine fish catches as well as their distribution inside and between countries' exclusive economic zones, climate change will affect fishing economics **(Mollmann *et al.*, 2009)**. Catches, fishing expenses, revenues, earnings, discount rates, and economic rent—the amount left over after all expenses, including regular profits—as well as the world economy at large may all be impacted by climate change **(Sumaila *et al.*, 2011)**.

CONCLUSION

The highest CPUE value occurred during the northwest monsoon and the first transitional seasons, with 85 and 72kg/ trip, respectively. The optimal SST range for the eastern little tuna was 29 to 30°C. During the northwest season, a 1°C temperature increase maintains a potential habitat in the Java Sea, particularly in February, but it disappears with temperatures of 2 and 4°C increases. During the first transitional season, potential habitats appear only in March and May, with a 1°C rise, and are not present under the 2 and 4°C increase scenarios. The displacement of habitat shifts due to temperature rises in the Java Sea indicates a potential southward migration, while seasonal factors may drive a westward shift. These results enhance our understanding of the variations in the spatial distribution of tuna habitats and could provide a basis for future predictions and management strategies in fisheries.

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