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MORALITY BEFORE KNOWLEDGE

Patterns of oceanographic factor distribution and tuna fishing potential: Spatial and temporal analysis

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ABSTRACT

Background: The North Natuna Sea, located south of the South China Sea, is renowned for its rich marine biodiversity and significant role in regional fisheries. Oceanographic factors such as sea surface temperature (SST), chlorophyll-a concentration, and salinity are key influences on fish distribution and abundance in this area. While previous studies have highlighted the relationship between these factors and fishing patterns, the connection between oceanographic conditions and mackerel fishing potential remains insufficiently explored. This study aims to analyze the spatial and temporal variation of these oceanographic factors and their impact on mackerel fishing potential in the North Natuna Sea. **Methods**: The study utilized Aqua-MODIS satellite imagery data from 2017 to 2021 for spatial and temporal analysis of oceanographic factors. **Results**: Significant variations were observed in sea surface temperature, chlorophyll-a concentration, and salinity across different seasons. Higher mackerel fishing potential was identified during the Western Season and Transitional Season II, which were characterized by lower sea surface temperatures and higher chlorophyll-a concentrations. **Conclusion**: Understanding the seasonal variations in oceanographic factors is crucial for optimizing sustainable fishing practices in the North Natuna Sea. **Novelty/Originality of this Research**: This study offers new insights into the interplay between oceanographic conditions and mackerel fishing potential, providing valuable information for the sustainable management with a focus on the seasonal dynamics of marine environments.

KEYWORDS: chlorophyll-a concentration; mackerel fishing potential; oceanographic factors; sea surface temperature (SST).

1. Introduction

The North Natuna Sea region, located on the border between Indonesia and neighbouring countries such as Malaysia, Vietnam and China, has a strategic position as the main entry point to Indonesia via the northern route. As an integral part of the Indonesian Archipelagic Sea Route (ALKI), the region plays a significant role as a major passage for ships travelling from the Indian Ocean to Asia (Shabrina, 2017). Within the framework of marine and fisheries resource management, the Indonesian Ministry of Maritime Affairs and Fisheries issued a Ministerial Regulation, PERMEN-KP No.18/2014, which established the State Fisheries Management Areas of the Republic of Indonesia/*Wilayah Pengelolaan*

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Perikanan Negara Republik Indonesia (WPPNRI). The North Natuna Sea is officially included in WPPNRI zone 711 in accordance with this regulation. This designation is based on the great potential of fisheries resources and the vast area of waters in the Natuna Sea. Based on the Decree of the Minister of Marine Affairs and Fisheries No. 50/2017, the WPPNRI 711 area is known to have a potential fishery resource of 767,126 tonnes, with a current utilisation rate of around 10.66% (Putri, 2021).

Fishermen operating in the Natuna region are known for their traditional fishing practices, using simple equipment such as ropes and hooks. However, they face serious challenges from fishers outside the region who utilise advanced technology and foreign fishers who engage in illegal fishing in the North Natuna Sea, using modern fishing gear such as pair trawls. The presence of these actors poses a significant threat to the fish catch of local fishermen, while also causing damage to the Natuna marine ecosystem. As a result, fish catches continue to experience an alarming decline. The Approximate Potential Fishing Areas/*Peta Prakiraan Daerah Penangkapan Ikan* (PPDPI) map is used to mark water zones where fish resources are abundant and fishing operations can be conducted sustainably. The utilisation of this map aims to increase the effectiveness and efficiency of fishing activities, providing economic benefits by reducing fish location search time, saving fuel, and reducing operational costs (Laevastu, 1970).

The waters of the North Natuna Sea show marked variations in temperature, with average temperatures ranging from 27.5ºC to 29.5ºC. In the Natuna region, dominant fish species include mackerel, kite, grouper, red snapper and king crab. Tuna, for example, is a large pelagic fish species whose growth is influenced by optimal chlorophyll-a concentrations, within the range of 0.07 to 1.44 mg/L, and is usually found in waters with sea surface temperatures between 25.23°C and 32.23°C (Hartanto, 2018). The natural habitat of tuna is generally located in waters with normal salinity of the open sea, ranging from about 33 to 35 ppt (Sandi, 2014).

Monitoring of oceanographic phenomena such as chlorophyll-a concentration and Sea Surface Temperature (SST) can be done through the Aqua satellite, which is equipped with a MODIS (Moderate Resolution Imaging Spectroradiometer) sensor (Kuswanto et al., 2017). With advanced thermal band features and temporal resolution, the Aqua Modis satellite is able to support monitoring and mapping of SPL and chlorophyll-a, facilitating continuous observation of SPL changes (Hamuna et al., 2015). This research aims to carefully map fish distribution zones in North Natuna waters, using observations of changes in marine biota and detection of physical changes in the sea surface (Munthe et al., 2018). In addition, other oceanographic factors such as salinity also play an important role in maintaining fish survival because salinity is a key physical factor in the ecology of marine organisms. Variations in salinity and other environmental factors can significantly affect the living conditions of organisms within an aquatic ecosystem (Laevastu & Hayes, 1981). Measurements of oceanographic phenomena related to salinity can also be made through the HYCOM (Hybrid Coordinate Ocean Model) satellite.

Remote Sensing and Geographic Information System (GIS) technologies have proven to be effective tools in providing the spatial data needed to identify potential fishing areas. This research will focus on analysing the distribution of sea surface temperature, salinity, and chlorophyll-a concentration, with the aim of identifying areas that have high potential in terms of fisheries resources.

The core issue addressed in this study arises from the increasing presence of foreign fishers engaging in illegal fishing activities within Indonesian waters, particularly in the North Natuna Sea, using pair trawl technology that poses a threat to marine habitats. In contrast, local fishers still rely on traditional methods, such as handlines and hooks. This situation presents potential losses and threats to Indonesia, both in terms of defense and economic interests. Therefore, this study explores an alternative approach by conducting an evaluation using remote sensing techniques. This approach involves the analysis of satellite imagery from Aqua MODIS, focusing on parameters such as chlorophyll-a, salinity, and sea surface temperature, and their relationship with seasonal cycles in the North Natuna Sea—namely the eastern monsoon, western monsoon, and the first and second transitional seasons. These data are utilized to identify zones with high potential for fishing activity. The analysis is conducted using the Google Earth Engine and ArcGIS platforms.

2. Methods

This research adopts remote sensing methods as well as an associative quantitative approach with the aim of enriching the analytical results obtained from the use of remote sensing technology. In the initial stage of the research, digital and visual interpretation techniques were applied to collect data related to fish catches and analyse relevant oceanographic factors. Subsequently, an associative quantitative approach was used to explore and elaborate on the possible relationships between the oceanographic factors studied and the observed fishing yields.

In an effort to ensure a more in-depth focus, this research limited the determination of the study area. The area chosen as the object of study is the North Natuna Sea, which was chosen due to its position as part of Indonesia's border with neighbouring countries such as Vietnam and Malaysia. The geographical condition of this region makes it vulnerable to Illegal Fishing activities that threaten the sustainability of fisheries resources.

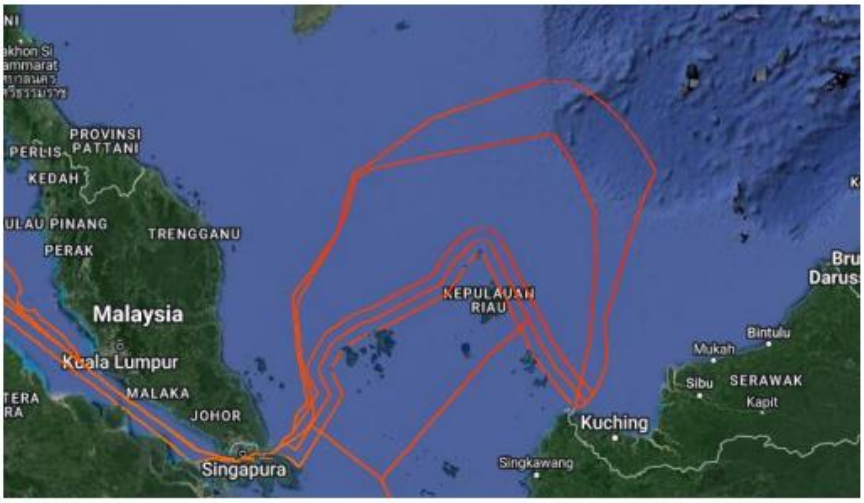


Fig. 1. Illegal fishing area

The population of this study consists of fisheries catch data in North Natuna waters, obtained from the Ministry of Marine Affairs and Fisheries, as well as sea surface temperature data, chlorophyll-a concentrations contained in Aqua-MODIS satellite images, and salinity values available in the HYCOM model. After identifying the population, the next step is sample selection, which is a subset of the overall population. In the context of this study, samples were selected based on optimal values for tuna related to sea surface temperature, salinity, and chlorophyll-a concentration obtained from Aqua MODIS satellite image data. The sample selection technique used is the purposive sampling method, where the determination of the sample is based on characteristics relevant to the research objectives. The parameter values used for the purposive sampling method have been determined and can be found in the research Table 1.

Table 1. Parameter values

Parameters	Criteria	Score	Weight	Reference
Chlorophyll-a concentration (mg/m3)	<0.07mg/L and >1.44mg/L	1	33.3%	Hartanto, 2018
	0.07 mg/L–1.44mg/L	2		
Sea Surface Temperature (C)	<25.23°C and >32.23°C	1	33.3%	
	25.23°C–32.23°C	2		
Salinity (ppt)	<33.0 and >35.0	1	33.3%	Sandi, 2014
	33.0–35.0	2		

2.1 Data processing technique

The processing of sea surface temperature (SST), chlorophyll-a, and salinity data in this study used satellite data from the Moderate Resolution Imaging Spectroradiometer (MODIS) Satellite developed by NASA's Earth Science Data Systems (ESDS). The data were processed using Google Earth Engine and ArcGIS platforms. The SPL and chlorophyll-a data were taken at a monthly frequency during the time span from 2017 to 2021, as well as a seasonal frequency that includes the west season, east season, and transition periods I and II. The salinity data came from the HYCOM model, which was also processed using Google Earth Engine and ArcGIS platforms. The salinity data was taken at a monthly frequency over the same time span, with an emphasis on the seasonal frequency as mentioned earlier. The use of Google Earth Engine in processing salinity data from HYCOM is considered an efficient method in determining potential fishing zones.

2.2 Data analysis

In this study, fish catch data were analysed with the aim of understanding the relationships and interactions between oceanographic variables, namely chlorophyll-a, salinity, and sea surface temperature, and the influence of these oceanographic factors on the four seasons in North Natuna waters. The fishing zone evaluation was conducted by considering various indicators that have a significant impact on the presence of fish. The three main indicators considered were sea surface temperature, salinity and chlorophyll-a. To obtain sea surface temperature and chlorophyll-a concentration data from Aqua MODIS images, a series of steps were implemented. These included cloud and land removal (masking), extraction of relevant parameter values, clipping of the focal area, and generation of monthly composites. The sea surface temperature, salinity and chlorophyll-a data most relevant to fish presence were then combined using overlay and raster calculator methods.

3. Results and Discussion

The capture fisheries sector is a crucial component of the fisheries industry, contributing significantly to both the economy and the national food supply. This activity involves the harvesting of fish using various methods and gear types, conducted in resource-rich fishing grounds. It attracts not only local fishers but also large-scale fishing fleets. A comprehensive understanding of potential fishing zones is essential to enhance the effectiveness and efficiency of fish catches, which can, in turn, increase fishers’ income and support the sustainability of food supply. Amidst global economic competition, the application of blue economy principles plays a vital role in promoting sustainability and innovation—particularly relevant for Indonesia, a country endowed with vast fisheries potential. These principles emphasize the responsible management of fishery resources and the use of advanced technologies, such as satellite-based monitoring of fishing areas.

The use of satellites to identify efficient potential fishing zones can help fishers optimize their routes and methods, enhancing productivity while promoting more sustainable fisheries management. This is also crucial in combating illegal fishing and strengthening maritime border surveillance. Cross-sector collaboration—among government, military, relevant agencies, and fishing communities—is key to sustaining the fisheries industry. Such joint efforts promote responsible fishing practices and ensure maritime border security, which is essential for national territorial integrity. Successful implementation of blue economy principles in capture fisheries offers long-term benefits both economically and ecologically.

3.1 Sea surface temperature

The sea surface temperature data used in this study comes from Aqua-MODIS Level 3 satellite images with a spatial resolution of 4km. This data is a monthly composite covering the period from January 2017 to December 2021. Figure 2 presented in this study shows the spatial distribution of the results of data analysis of the average monthly sea surface temperature in the North Natuna Sea during the period 2017 to 2021.

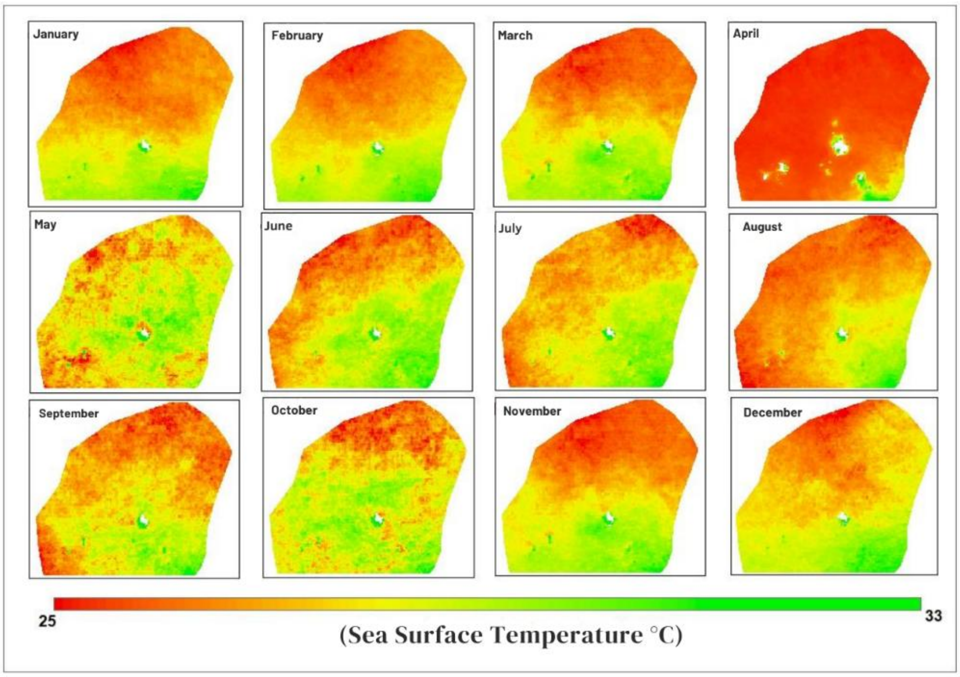


Fig. 2. Map of average monthly sea surface temperature distribution for 2017-2021

The results of the sea surface temperature distribution are strongly influenced by the prevailing wind patterns in a region. Based on the analysis that has been done, it can be concluded that in the West Season, which occurs between December and February, sea surface temperatures tend to be lower than in other months. The range of sea surface temperatures during the West Season ranges from 25.66ºC to 33.04ºC. On the other hand, during the East Season, which runs from July to August, sea surface temperatures increase and range from 29.16ºC to 33.92ºC.

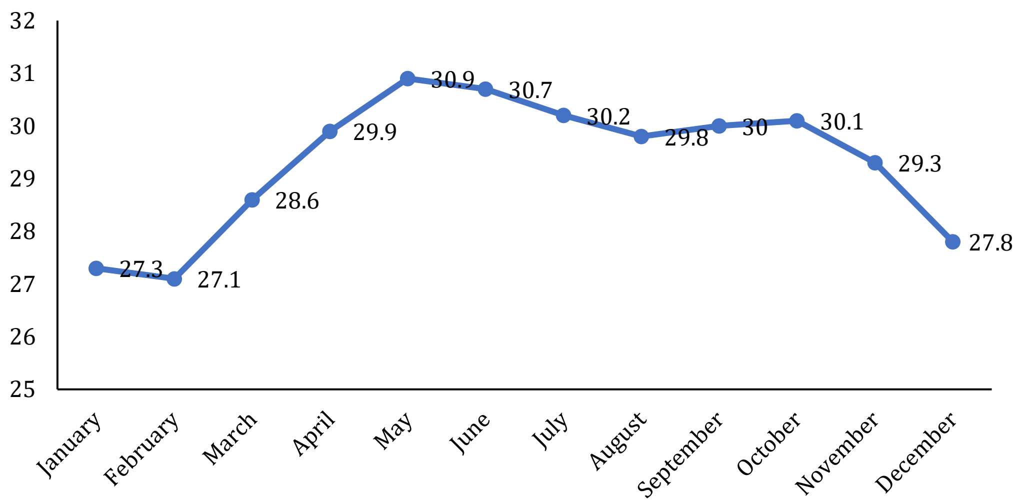


Fig. 3. Average SPL 2017-2021

In general, the North Natuna Sea shows a relatively high sea surface temperature trend throughout the year, except during the West Monsoon period, particularly from December to February, where temperatures tend to be cooler. This decrease in temperature, especially in the northern waters, is influenced by the flow of water masses originating from the South China Sea, which has a lower temperature in general. This phenomenon is also influenced by increased rainfall and wind strength during the West Monsoon in the South China Sea region (Ilahude, 1997).

During the period from 2017 to 2021, there were significant variations in sea surface temperature. The lowest value was recorded in February, with sea surface temperature reaching 27.1°C, while the highest value occurred in May, reaching 30.9°C. During the Western Season (December to February), there is a trend towards lower SSTs. An increase in temperature then occurred in the First Transitional Season (March to May), where the graph shows a significant increase. The increase in SPL that lasted until October signalled a trend towards warmer temperatures during the East Season to Transitional Season II (June to November) in the North Natuna Sea, with temperatures ranging from 30.7 to 29.3°C. Distribution of low temperatures tends to occur in offshore areas and increases in coastal areas during the West Monsoon in the North Natuna Sea, with SPL tending to be lower compared to the East Monsoon. SST levels in these waters play an important role in determining potential fishing zones. As cold-blooded animals, fish need to adjust their body temperature to the temperature of the surrounding environment, so this can affect the distribution and number of fish in these waters.

Sea surface temperature (SST) has a significant influence on fish presence, though the relationship between the two is quite complex. In tropical regions, temperature variations tend to be more consistent due to more frequent solar radiation over the equatorial zone compared to the polar regions. SST is affected by several weather-related elements, including rainfall, evaporation, air temperature, humidity levels, wind speed, and sunlight intensity. While SST tends to vary with the seasons, the fluctuations may not always be substantial. Other factors influencing SST include the time of day, atmospheric circulation patterns, cloud cover, as well as ocean currents and water depth (Sukojo, 2009).

Significant fluctuations in SST can be observed particularly when comparing coastal areas to open sea regions. In coastal zones, SST is generally higher due to the greater influence of landmasses, whereas in the open sea, temperatures remain relatively stable because of reduced exposure to external environmental factors (LAPAN, 2014). Indonesia, located in the tropical zone, has an SST range of approximately 28–38°C, though it typically ranges between 26–29°C and fluctuates with seasonal changes. This temperature range can affect the photosynthetic process of phytoplankton, which serves as a primary food source for fish (Dahuri et al., 1996).

3.2 Chlorophyll-a

The North Natuna Sea, located in the southern part of the South China Sea, is known for its fertile waters. Human activities and water mass changes that occur throughout the year have a significant contribution to the high composition and abundance of phytoplankton in this region. Spatial observations of the distribution of chlorophyll-a concentrations in the North Natuna Sea were made using Aqua-MODIS Level 3 Satellite Imagery data with a resolution of 4km. This data was taken on a monthly average basis from January to December from 2017 to 2021. This analysis aims to provide a detailed picture of the distribution of chlorophyll-a concentrations in the North Natuna Sea region.

Chlorophyll-a distribution in the North Natuna Sea shows high chlorophyll-a concentrations, exceeding 4mg/m^3, especially in nearshore areas. This is due to significant nutrient contributions from river estuaries and land-based activities. In the chlorophyll-a concentration map, areas with high concentrations are coloured light blue to dark blue, while areas with relatively lower concentrations are coloured green.

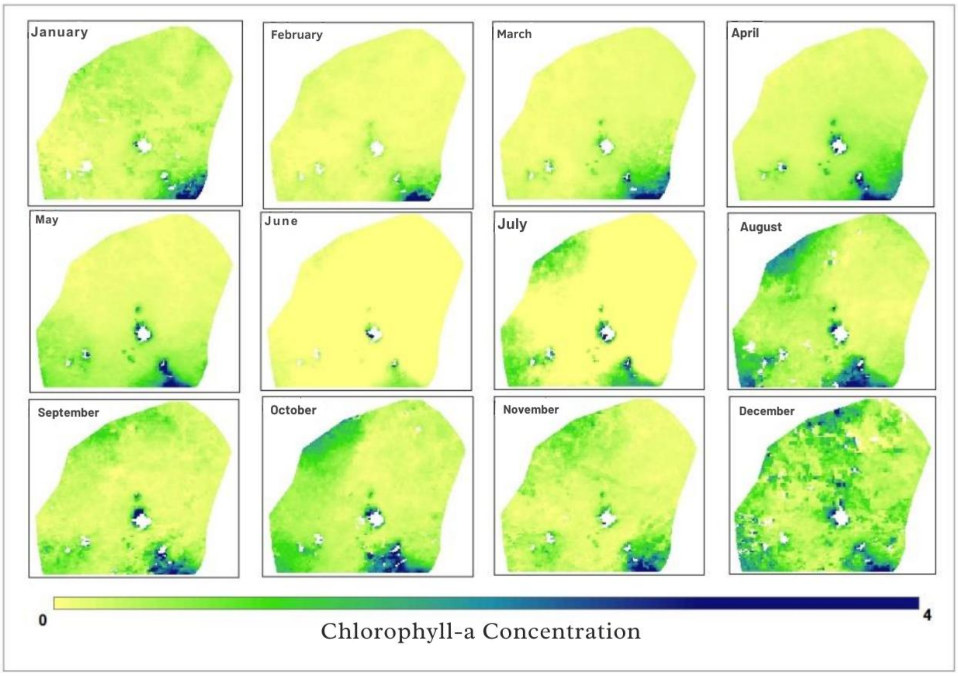


Fig. 3. Map of distribution of average monthly chlorophyll-a concentration 2017-2021

In the West Monsoon period (December to February), there is a high distribution of chlorophyll-a in the coastal areas with concentrations ranging from 1.97 to 4.47 mg/m^3, while concentrations in the high seas range from 0.07 to 2.14mg/m^3. During the East Monsoon and transitional periods I and II, chlorophyll-a concentrations tend to have a similar distribution, especially in waters close to the coast.

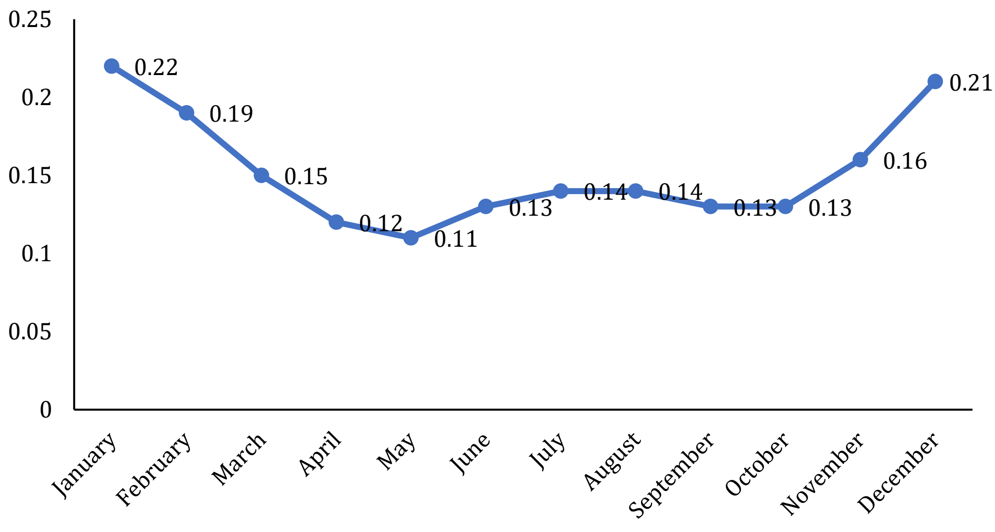


Fig. 5. Average chlorophyll-a 2017-2021

During 2017 to 2021, there were variations in chlorophyll-a concentrations in the North Natuna Sea. The lowest value was recorded in May, with a value of 0.11 mg/m^3, while the highest value occurred in January, reaching 0.22mg/m^3. Spatial analysis shows that during these months, there is a tendency for high chlorophyll-a concentrations during the West Monsoon, which then begins to decrease during the Transitional Seasons I and II. High chlorophyll-a concentrations tend to occur in offshore areas.

High chlorophyll-a concentrations in offshore waters are often an indicator of upwelling. Upwelling is identified by a decrease in sea surface temperature and an increase in nutrient content in the region compared to the surrounding area. This increase in nutrients can stimulate the growth and development of phytoplankton in the surface water. An increase in the number of phytoplankton indicates a higher level of water fertility. The upwelling process is directly related to the increase in phytoplankton abundance and water fertility, which in turn leads to an increase in the number of fish in the area. This is an important factor in determining potential fishing grounds (Mahabror, 2016).

Chlorophyll-a is one of the key indicators of water fertility and can be used to map potential fishing grounds, as it serves as a primary producer for fishery resources. In Indonesia, the average distribution of chlorophyll-a is approximately 0.19mg/m^3. Chlorophyll-a concentrations are generally higher during the eastern monsoon than during the western monsoon, a pattern closely associated with the upwelling phenomenon. The distribution of chlorophyll-a in marine waters can be influenced by various oceanographic factors such as currents and wind, which are seasonal in nature, and this distribution may vary from year to year. High levels of chlorophyll-a in an area typically indicate high primary productivity, signifying the abundance of phytoplankton. This creates a cascading effect within the food chain, where zooplankton feed on phytoplankton and, in turn, become prey for smaller fish, which are subsequently consumed by larger predatory fish (Kasim, 2015). Therefore, areas with high chlorophyll-a concentrations are often hotspots for fish aggregation. Phenomena such as upwelling, in which cold, nutrient-rich water rises to the surface, can also be detected by elevated chlorophyll-a levels and are frequently correlated with increased fish abundance (Setyono & Harsono, 2014).

3.3 Salinity

Salinity data obtained from the HyCOM model using "Salinity_4" data at a depth of 4 metres has been processed from raster data using ArcGIS software. The purpose of this analysis is to understand the characteristics and distribution patterns of salinity in the North Natuna Sea. By analysing this salinity data, we can understand the distribution of salinity as an indicator of the environment that supports fish life and growth, and understand the phenomenon of upwelling as an indicator of potential zones of abundant fishing. Using data from the HyCOM model and processing using ArcGIS software, detailed mapping of the salinity distribution in the North Natuna Sea region can be done. This analysis aims to provide a deeper understanding of the salinity distribution in the study area.

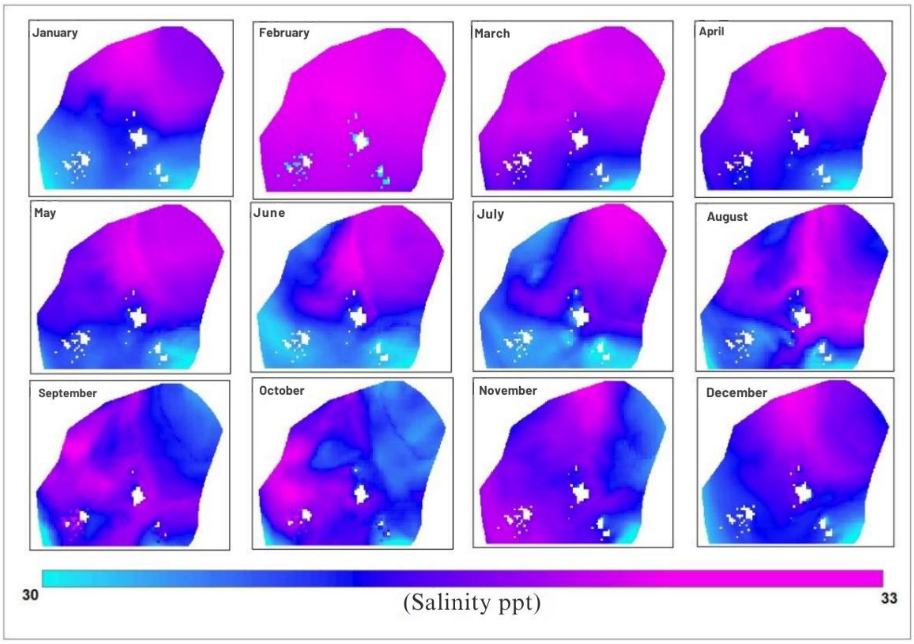


Fig.4. Average monthly salinity distribution map 2017-2021

Analysis of salinity distribution in the North Natuna Sea revealed the highest values exceeding 33 ppt. On the map, areas with low salinity values are coloured light blue to dark blue, while areas with relatively higher values are coloured purple. During the West Monsoon period (December to February), it was observed that the monthly distribution of salinity increased until it reached an even distribution in February, with values ranging from 30.4 to 33.6 ppt, and had an average of 33.3 ppt until the First Transitional Season (March to May). However, during the Eastern Season and Transitional Period II, salinity values tend to decrease in distribution.

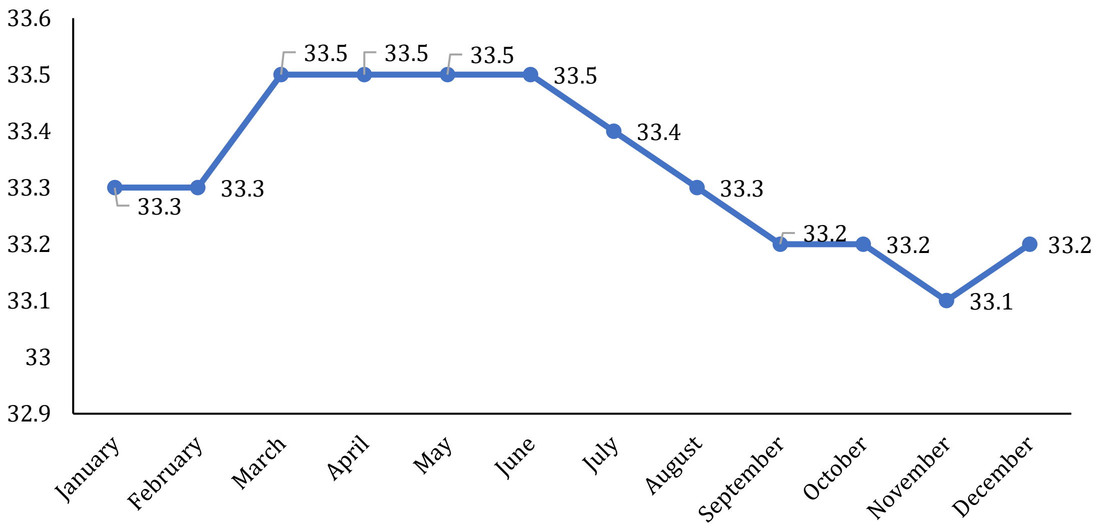


Fig. 7. Average salinity 2017-2021

Over the period 2017 to 2021, it was observed that there were variations in salinity values in the North Natuna Sea. The lowest salinity value was recorded in May, with an average of 33.1 ppt. Meanwhile, the highest salinity values occur during the Transitional Season I (March-May), with a relatively stable average. Spatial analysis shows that during the West Season, there is an increase in salinity values, while during the Transitional Season I, salinity values tend to stabilise around 33.5 ppt. Furthermore, during the Eastern Season and Transitional II, there is a decrease in salinity values.

Salinity is one of the key factors in aquatic life, including in fishing zones. It refers to the concentration of dissolved salts in water and is typically measured in Practical Salinity Units (PSU). Salinity affects the distribution of fish species as well as the overall dynamics of aquatic ecosystems. It influences various physiological processes in fish, including osmoregulation and metabolism (Royan et al., 2014). Several studies have shown that salinity levels can significantly impact fish density and distribution.

Extremely high or low salinity levels are generally unfavorable for the sustainability of fish populations. Most marine organisms can only survive within relatively narrow salinity ranges. Factors influencing salinity include freshwater inflow into the ocean, rainfall intensity, seasonal variation, topography, tidal phenomena, and evaporation (Sumarno & Rudi, 2013). Increased river discharge into marine areas typically leads to lower salinity levels, and vice versa (Taufiqullah, 2015).

3.4 Tuna fishing potential

The results of the map analysis that has been conducted using the raster calculator method show a change in the distribution of potential fishing zones during the observed period. During the Western Season (December to February), there is an increase in potential zones characterised by a wider distribution, especially in the northern region of the North Natuna Sea. This phenomenon can be attributed to low sea surface temperature conditions in these northern areas and variations in chlorophyll-a concentrations from the coast to the open sea, which affect fish migration and foraging behaviour.

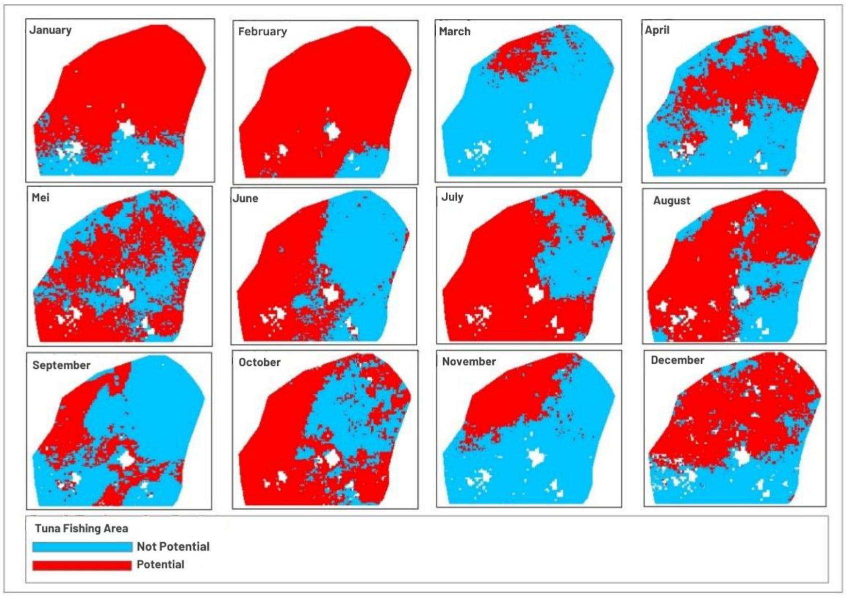
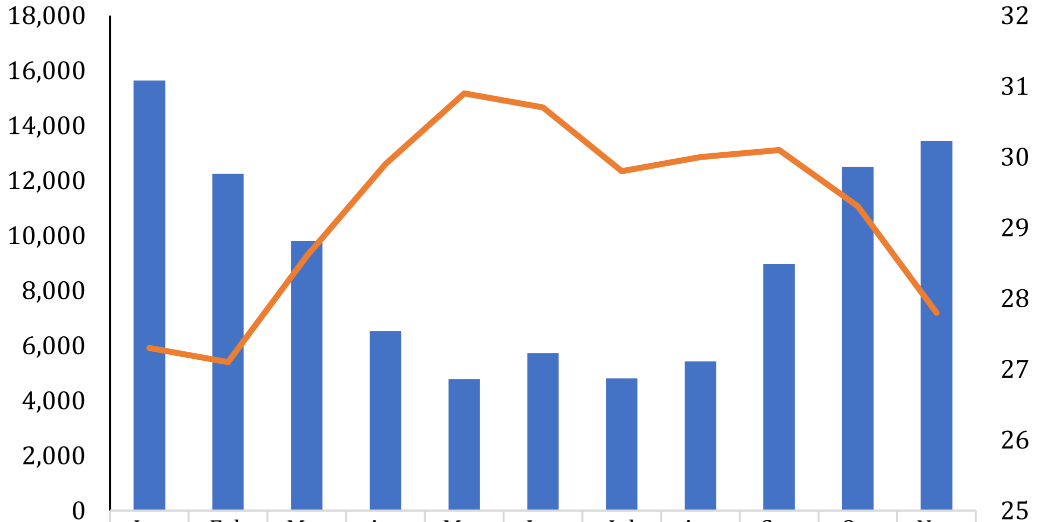


Fig. 8. Map of potential fishing zone distribution per month

During Transitional Season I (March-May), there was a decrease in potential fishing zones in early March after the end of Transitional Season I in February. However, in March to April, the potential zones again reach their optimal distribution. The Eastern Season (June-August) is characterised by high sea surface temperatures and a wide distribution of chlorophyll-a. Fishing locations during this season are spread from the north to the west of the North Natuna Sea, with an increase in the number of fishing spots seen in July and August compared to June. During Transitional Season II (September-November), the distribution of potential fishing zones tends to be more limited. However, in October, the potential fishing zones are spread throughout the North Natuna Sea, reflecting ideal sea surface temperature conditions and optimal chlorophyll-a concentrations throughout the region. The analysis shows that the North Natuna Sea offers potential fishing locations that fluctuate throughout the year, depending on changes in oceanographic conditions such as sea surface temperature, salinity and chlorophyll-a concentration. This confirms the opportunity for consistent fishing throughout the year in the region (Hastuti et al., 2016).

3.5 Influence of oceanographic factors and fish catch

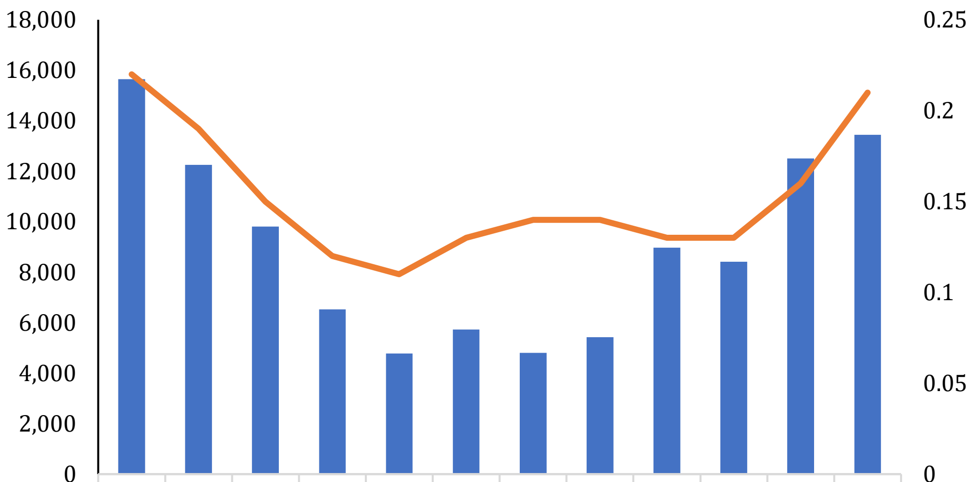
The distribution patterns of sea surface temperature and fish catch need to be carefully analysed, not only taking into account common fishing locations but also taking into account time patterns associated with fishing seasons. This is strategic to anticipate optimal times for fishing activities. The North Natuna Sea is significantly influenced by seasonal cycles, including the southeast monsoon, the northwest monsoon, and the transition period between them, the intermediate season. Based on a classification introduced by Wyrtki in 1961, seasonal wind patterns in Indonesia are divided into four main categories: the west monsoon that runs from December to February, the first transitional period from March to May, the east monsoon that occurs between June and August, and the second transitional period from September to November. This division is closely related to the fishing season and sea surface temperature fluctuations in areas where fishing activities are focussed. Figure 9 displays the distribution pattern of sea surface temperature along with fish catch over a monthly period from 2017 to 2021. This analysis provides a more comprehensive picture of the relationship between sea surface temperature and fishing activity over the observed time period.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov
Series1	15,644	12,249	9,810	6,527	4,782	5,732	4,809	5,423	8,968	12,500	13,437
Series2	27.3	27.1	28.6	29.9	30.9	30.7	29.8	30	30.1	29.3	27.8

Fig. 9. Number of fish catches and sea surface temperature conditions

Fishing in the North Natuna Sea mainly occurs during the Western Monsoon month, which is characterised by sea surface temperatures ranging from 27.3-28.6ºC oceanographically. The month with the highest mackerel catch is December, with the total fish catch during January from 2017 to 2021 reaching 15,644Kg. Meanwhile, the lowest total catch of mackerel occurred in April, with a total catch of 4,782Kg. During the transitional season I and the eastern season, sea surface temperature conditions in the North Natuna Sea were relatively warm, along with the catch of mackerel which ranged from 4,782–8,968Kg. Overall, there was a significant relationship between mackerel catch and sea surface temperature.



	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Okt	Nov
Fish catch	15,644	12,248	9,810	6,527	4,782	5,732	4,809	5,423	8,968	8,414	12,500	13,437
Chlorophyll-a	0.22	0.19	0.15	0.12	0.11	0.13	0.14	0.14	0.13	0.13	0.16	0.21

Fig. 10. Number of fish catches and chlorophyll-a concentration conditions

In addition to sea surface temperature, chlorophyll-a is also an important indicator in determining fishing areas. Chlorophyll-a acts as an indicator of primary productivity in the water, reflecting the fertility of the water area. High concentrations of chlorophyll-a in a marine area can indicate an increase in fish populations because it indicates a more abundant amount of nutrients, which supports the growth and development of pelagic fish.

According to Siregar (2011), the optimal chlorophyll-a concentration for pelagic fish growth ranges from 0.1mg/m³ to 3.7mg/m³. In the North Natuna Sea, which is the general location of potential fishing zones, chlorophyll-a concentrations range from 0.08mg/m³ to 0.22mg/m³. There is a Figure 10 depicting the relationship between the catch of mackerel and chlorophyll-a concentration in the North Natuna Sea.

Catches of mackerel in the North Natuna Sea during the period 2017-2021 showed a significant correlation with chlorophyll-a concentrations. It is clear that mackerel catch rates are positively correlated with chlorophyll-a concentrations, where high catch rates often occur at high chlorophyll-a concentrations, while low catches occur at relatively low chlorophyll-a concentrations. For example, in December, the total catch of mackerel reached 15,644kg with a chlorophyll-a concentration of 0.22mg/m³, while in April, the total catch of mackerel decreased to 4,782kg with a lower chlorophyll-a concentration of 0.11mg/m³. Overall, during Transitional Season II, chlorophyll-a concentrations tended to be low, while during the Western Season, chlorophyll-a concentrations were higher. These findings suggest a positive correlation between mackerel catch and chlorophyll-a concentration, and a negative correlation between mackerel catch and sea surface temperature.

Besides sea surface temperature and chlorophyll-a, salinity also plays an important role in determining fishing grounds. Salinity serves as an environmental indicator for fish life in the waters, as optimal salinity conditions are essential for healthy growth and development. The distribution of salinity, sea temperature and chlorophyll-a can be used as indicators to detect upwelling events. The upwelling phenomenon has a significant impact as it causes an increase in nutrients in the water column, which in turn increases phytoplankton abundance. Phytoplankton is an important component in the marine food chain and is the main food source for fish and other marine organisms. Therefore, these parameters are often used as important data to determine potential fishing locations. Figure 11 illustrates the relationship between fish catch and salinity in the North Natuna Sea.

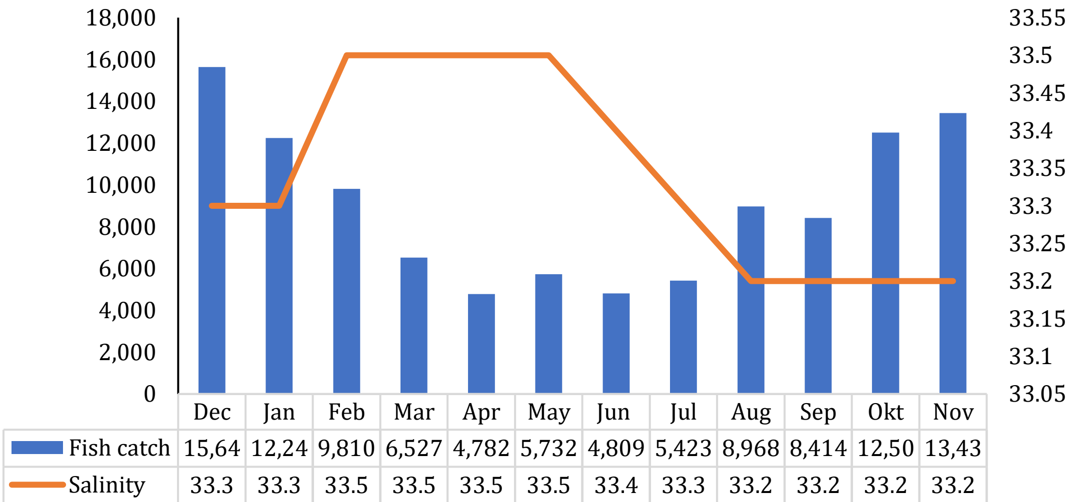


Fig. 11. Number of fish catches and salinity concentration conditions

The catch of mackerel in the North Natuna Sea during the period 2017–2021 shows a meaningful relationship with salinity. It can be seen that fishing predominantly occurs in the Transitional Season II to the West Season, where salinity tends to decrease during the Transitional Season II, ranging from 33.1–33.2 psu, with fish catches ranging from 8,414kg–13,437kg, while during the West Season, salinity ranges from 33.3 - 33.5 psu, with fish catches ranging from 9,810kg–15,644kg. The lowest amount of fish catch was recorded in April, with a fish catch of 4,782 kg and a salinity value of 33.5 psu. Thus, it can be concluded that salinity in the North Natuna Sea tends to decrease during Transitional Season II until

January in the Western Season, which correlates with an increase in the number of fish catches compared to other months.

The North Natuna Sea is a strategically important maritime area, rich in fishery resources and playing a vital role in both Indonesia's economy and national sovereignty. The identification of potential fishing zones in this region is not only beneficial for the livelihoods of fishers but also serves as a key aspect of national maritime security. From a defense perspective, these zones represent critical areas that require close monitoring to prevent illegal activities such as fish poaching by foreign vessels, which can deplete local fish stocks and threaten the fisheries industry. Strict surveillance in this region is essential to ensure that fishing activities are conducted within the legal framework, thereby protecting Indonesian fishers from unfair competition and upholding the sovereignty of the nation's waters.

The existence of potential fishing zones also enables better management of fishery resources, as the North Natuna Sea holds substantial economic potential for coastal communities. The region is endowed with a diverse array of high-value fish species. Sustainable and prudent management of these marine resources in the North Natuna Sea can enhance the productivity of fish catches, thereby directly improving the livelihoods of local fishers. Economically, increased fish catch resulting from the utilization of identified fishing zones can contribute significantly to the national GDP. Fishers who are able to fish more efficiently will gain greater economic benefits, positively impacting both local and regional economies.

Furthermore, the identification of potential fishing zones facilitates international cooperation in fisheries management and maritime security. Such collaboration may include information sharing on vessel movements, the promotion of sustainable fishing practices, and the implementation of joint law enforcement measures, which collectively strengthen a country's capacity to manage its resources and defend its maritime rights. Accordingly, well-planned and sustainable fishing activities in the North Natuna Sea can serve as both a source of economic prosperity and a pillar of Indonesia's maritime defense and security. This involves the responsible use of marine resources to drive economic growth, reduce poverty, and ensure the health of marine ecosystems. The government can collaborate with various stakeholders—including fishing communities, non-governmental organizations, and the private sector—to develop inclusive and sustainable management strategies.

Indonesia's national defense system is based on the concept of total defense, which entails the involvement of all elements of the nation—its citizens, territory, resources, and national facilities—in the defense mechanism. This preparation is carried out proactively by the government and is organized in a comprehensive, integrated, and continuous manner. To build an effective defense, the total defense concept combines both military and non-military elements. Each component operates holistically, in a coordinated and unified command structure, integrating various defense strategies to form a resilient and cohesive national defense system.

National defense cannot stand alone; it must be an integral part of national development to ensure the welfare of the people. The approach to defense must be interconnected with a welfare-oriented approach. Addressing national security issues can no longer rely solely on military strategies or authoritarian measures involving armed force, as such approaches are no longer deemed appropriate and may hinder the achievement of public welfare. The fundamental concept underlying the development of Indonesia's national defense capabilities is known as the Total People's Defense and Security System (Sistem Pertahanan dan Keamanan Rakyat Semesta/Universal People's Defense and Security System or SISHANKAMRATA). SISHANKAMRATA is Indonesia's national defense and security system that involves all citizens, the national territory, and other national resources. This system is prepared in advance by the government and implemented in a comprehensive, integrated, focused, and continuous manner to uphold national sovereignty, territorial integrity, and protection from all forms of threats (Fauzi, 2021).

SISHANKAMRATA also includes an operational pattern composed of strategic defensive and strategic offensive phases. The concept of national resilience that underpins SISHANKAMRATA is characterized by independence, dynamism, unity, and authority, grounded in the principles of welfare and security, internal and external awareness, familial spirit, and a comprehensive, integrated approach. Thus, SISHANKAMRATA serves as a crucial strategy for confronting threats and strengthening Indonesia's national resilience (Suwito, 2017).

Maritime security refers to activities carried out by civilian or military entities to mitigate risks and counter illegal actions or threats within maritime areas (Bellamy, 2020; Pandey, 2023). It is a critical aspect in ensuring protection against security threats in territorial waters and surrounding regions. This concept encompasses the management and conservation of marine resources, prevention of illegal activities such as piracy, smuggling, and illegal fishing. Maritime security also emphasizes the safety of navigation and the prevention of maritime accidents. International cooperation and the application of advanced technologies, such as remote sensing, are key to enhancing maritime security. This form of security is closely linked to foreign policy, national defense, and the economic interests of coastal states.

Maritime security plays a crucial role in protecting the interests of fishers, especially in strategic areas such as the North Natuna Sea. When maritime security is effectively enforced, fishers can carry out their activities without the looming threat of piracy or illegal fishing. This condition not only enhances their safety while at sea but also contributes significantly to the sustainability of fish catches. In the long run, it helps preserve the balance and stability of marine ecosystems, which are vital for the survival of fish species and the viability of the fishing industry as a whole. Moreover, a secure maritime environment fosters a sense of confidence among fishers, encouraging them to invest in more advanced fishing equipment and technologies that can improve their efficiency and productivity.

In addition to safeguarding against security threats, maritime security in the North Natuna Sea also supports broader economic prosperity. It facilitates improved fishing efficiency by allowing fishers safer and more secure access to productive fishing zones, reducing the time and operational costs required to locate these areas. It also minimizes the risk of equipment loss, as secure zones decrease the chances of gear being damaged or stolen due to the actions of irresponsible or illegal vessels. Furthermore, with better knowledge of safe and optimal fishing areas, fishers can plan their routes more effectively, leading to significant fuel savings. This enhanced operational planning contributes to reduced fuel consumption and overall lower costs. Another economic benefit is the potential for reduced insurance premiums, as the risks associated with accidents or theft are considerably diminished in well-monitored and protected waters. Lastly, effective maritime security helps ensure the abundance of fish stocks by preventing illegal fishing practices, thereby allowing legitimate fishers to gain better yields and maximize returns on their investment of time and resources.

Maritime security is a vital aspect in ensuring protection against threats in maritime areas and their surroundings. Maritime security plays a crucial role in safeguarding food security and human well-being. The maritime domain is key to global food production and distribution, particularly as a primary source of fish and marine products. The serious threats to food security arise from illegal, unreported, and unregulated (IUU) fishing practices, which can lead to a drastic decline in fish stocks and adversely affect the livelihoods of coastal communities that rely on fishing as their main source of income. To ensure maritime security, efforts to combat IUU fishing and protect marine resources are essential for maintaining food security by preserving the availability of fish as a critical source of nutrition.

Illegal, Unreported, and Unregulated (IUU) Fishing refers to fishing practices that violate legal frameworks, are not reported to the appropriate authorities, or are conducted without adequate regulation under existing fisheries management systems. These activities have a significant negative impact on the global marine environment. In addition to posing a serious threat to the sustainability of marine resources, IUU fishing contributes to the decline of fish populations, destruction of marine habitats, and undermines the effectiveness of fisheries management policies that have been designed and implemented (Oyanedel et al., 2018). In Indonesia, illegal fishing in the Fisheries Management Areas of the Republic of Indonesia has detrimental effects not only on the environment but also on social and economic aspects (Ismail et al., 2018). Furthermore, this practice is classified as a non-traditional security threat, as it constitutes a form of transnational crime (Pratiwi, 2017).

According to Guggisberg (2016), in the FAO International Plan of Action, IUU fishing is classified into three main categories. First, Illegal Fishing refers to fishing activities conducted by foreign or domestic vessels in violation of national laws and regulations, including breaches of conservation, management, or international legal provisions. Second, Unreported Fishing involves fishing activities that are either not reported or misreported to relevant authorities, in violation of a country's or a regional fisheries organization's reporting requirements. Third, Unregulated Fishing refers to fishing conducted in areas not adequately governed by any national or regional authority—this includes operations by stateless vessels or those from countries that are not members of a relevant management organization, and which do not adhere to existing conservation measures. Such practices violate the principle of responsibility under international maritime law and are considered harmful to the framework of sustainable fisheries governance.

4. Conclusions

Based on the results of spatial and temporal analyses of oceanographic factors, including salinity, chlorophyll-a concentration, and sea surface temperature, distribution patterns that have different characteristics in each season in the North Natuna Sea region were observed. Significant sea surface temperature (SST) variations were identified based on seasonal changes, based on Aqua-MODIS satellite image data. From the analyses of the three oceanographic factors, on the catch of mackerel, it is concluded that the more potential season for fishing zones is the Western Season, with the potential to be spread throughout the North Natuna Sea area, as well as the Transitional Season II in the northern area of the North Natuna Sea.

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