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Examining Temporal Changes in Oceanographic Conditions and Their Impact on Seasonal Yellowfin Tuna Catch Trends in Palabuhanratu Bay Waters Toward Sustainable Fisheries Management

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ABSTRACT

Palabuhanratu Bay is one of Indonesia's strategic fisheries with significant potential, particularly for pelagic fish such as the yellowfin tuna (*Thunnus albacares*). This study aimed to analyze the influence of oceanographic variations, specifically chlorophyll-a and sea surface temperature, on the seasonal catch patterns of yellowfin tuna in these waters. The data include the yellowfin tuna production and satellite imagery of chlorophyll-a and sea surface temperature (2015–2020). The data were analyzed using SeaDAS, ArcGIS, and Microsoft Excel for data extraction, area cropping, interpolation with the IDW method, and the calculation of the fishing season index (FSI) to determine the correlation between oceanographic variations and the yellowfin tuna production at PPN Palabuhanratu. The analysis results indicated a significant correlation between chlorophyll-a (r=0.753; P<0.05) and sea surface temperature (r=-0.865; P<0.05) with yellowfin tuna production. The FSI revealed peak fishing seasons in February, March, October, November, and December, with FSI values exceeding 100%. Chlorophyll-a concentrations increased during upwelling (June–October), although the fishing season was delayed until the end due to a time lag. These findings suggest that oceanographic factors are crucial in determining fishing seasons, providing a scientific basis for sustainable fisheries management.

INTRODUCTION

Palabuhanratu Bay is one of Indonesia's strategic marine areas with significant potential in the fisheries sector, particularly pelagic fisheries. This area is a primary fishing ground for various economically valuable fish species, including the yellowfin tuna (*Thunnus albacares*). Yellowfin tuna, a large pelagic fish, is a fast swimmer and migratory schooling species commonly landed at the Palabuhanratu Fishing Port (PPN) **(Ihsan *et al.*, 2017)**. With abundant fishery resources, fishing activities in Palabuhanratu

Bay significantly contribute to the welfare of coastal communities while supporting national food security.

Fish abundance in a particular marine area is closely related to oceanographic conditions, including the abundance of the yellowfin tuna. Fish migrate to waters with optimal environmental conditions **(Ekaputra *et al*., 2019)**. Several studies have demonstrated this relationship. One aspect of this relationship can be observed in changes in catch rates influenced by variations in oceanographic parameters **(Nurani *et al*., 2021; Nurani *et al.*, 2022a; Nurani *et al.*, 2022b)**. Oceanographic parameters such as chlorophyll-a, which reflects primary productivity and sea surface temperature, which affects fish habitats and distribution, play a critical role in determining fish distribution patterns. Temporal and spatial variations in these parameters can lead to fluctuations in fish abundance in certain waters. Thus, understanding the relationship between oceanographic dynamics and fish abundance is a crucial aspect in supporting sustainable fisheries management.

The strong correlation between oceanographic conditions and fish abundance indirectly reflects the relationship between oceanographic conditions and fishing seasons. Peak fishing seasons occur when fish abundance is high, coinciding with optimal oceanographic conditions that promote fish aggregation in certain areas. Information about fishing seasons is essential to supporting effective and efficient fishing operations. Determining the optimal timing for fishing operations can increase catch yields and reduce operational costs for fishers **(Ridwan *et al*., 2022)**. Additionally, such information helps maintain fish resource sustainability by avoiding overfishing during less productive seasons. Understanding fishing conditions, particularly tuna catches in relation to total yield, is essential for sustainable fisheries management. Evaluating fishing trends can provide valuable insights for this purpose.

Pratama *et al.* (2022) highlighted that the fishing seasons for pelagic fish in Palabuhanratu are strongly influenced by the oceanographic conditions of the area. Therefore, elaborating on the relationship between oceanographic variations and fishing season patterns can provide more accurate methods for predicting the yellowfin tuna fishing seasons. This approach not only supports the optimization of fishing efforts but also aids sustainable management through scientifically based predictions.

This study aimed to analyze the influence of oceanographic variations, specifically chlorophyll-a and sea surface temperature, on the seasonal catch patterns of the yellowfin tuna in Palabuhanratu Bay. The findings are expected to contribute to developing more precise methods for predicting fishing seasons and supporting sustainable fishery resource management.

MATERIALS AND METHODS

The research was conducted through secondary data processing, including data on the yellowfin tuna fishery production and satellite imagery of chlorophyll-a and sea surface temperature from 2015 to 2020. Yellowfin tuna production data were obtained from the Palabuhanratu Fishing Port (PPN) managers in January 2022, while the satellite imagery data were downloaded from the website www.oceancolor.gsfc in May 2022. The imagery data were downloaded in Non-Conformance (.nc) format. It should be noted that the presence of fish aggregation devices (FADs) in the waters around Palabuhanratu may interfere with the correlation analysis. This is because FADs attract fish, causing fish abundance in the surrounding area to no longer fully reflect natural conditions influenced by oceanographic dynamics.

Subsequently, the data underwent several processing steps. First, data extraction was performed using the SeaDAS 7.5.3 application, followed by area cropping with coordinates from 103.713 to 107.9578 East longitude and -6.6462 to -9.0529 South latitude. After cropping, the next step was to export the data into a tab-delimited text file (.txt). This .txt data were then processed using Microsoft Excel to remove unnecessary or irrelevant data and to correct cloud cover data. The .txt data were subsequently processed using ArcGIS to enable further analysis, including interpolation using the Inverse Distance Weighted (IDW) method. This method offers the advantage of customizable interpolation characteristics, allowing the input points used in the process to be limited as needed. Additionally, this method facilitates the removal of points that are far from the sample or have low to no spatial correlation **(Pasaribu & Haryani, 2012)**.

Data analysis in this study was conducted to obtain the fishing season index (FSI) values and to determine the correlation between oceanographic variations and the yellowfin tuna fishery production recorded at PPN Palabuhanratu. The FSI values were used to determine the fishing season. According to **Dajan (1983)** and **Nurdin and Panggabean (2017)**, the FSI values were derived from the following mathematical procedure:

a. Calculating the CPUE series:

$$CPUE = n_i$$

Where:
i = 1,2,3, ... , n
ni = the i-th order

b. Calculating the 12-month moving average of CPUE:

$$RGi = \frac{1}{12}\left[\sum_{i=i-6}^{i+5} CPUEi\right]$$

Where:
RGi = the 12-month moving average at the i-th position
$CPUEi$ = the CPUE at the i-th position

i = 7,8, ... , n-5

c. Calculating the centered moving average of CPUE (*RGP*):

$RGPi = \frac{1}{2}[\sum_{i=1}^{i+1} RGi]$

Where:
RGPi = the centered moving average of CPUE at the *i*-th position
RGi = the 12-month moving average at the *i*-th position
i = 7,8, ... , n-5

d. Calculating the ratio of average for each month (*Rb*):

$Rbi = \frac{CPUEi}{RGPi}$

Where:
Rbi = the ratio of average for the *i*-th month
CPUEi = the CPUE at the i-th position
RGPi = the centered moving average of CPUE at the *i*-th position

e. Arranging the values of Rbi into an i x j matrix as Rbij, then calculating the average for each month, starting from Januari 2016 to December 2019

f. Calculating the Total Monthly Average Ratio (JRRB):

$JRRBi = \sum_{i=1}^{12} RRBi$

Where:
JRRBi = the total monthly average ratio
RBBi = is the monthly average ratio for the *i*-th month
i = 1,2, … , 12

g. Preferably, the total monthly average JRBB ratio should be equal to 1200. However, due to various influencing factors, it may deviate from this value. To address this, the monthly average ratio needs to be adjusted using a correction factor known as the correction factor (FK). The formula to calculate the correction factor is as follows:

$FK = \frac{1200}{JRRB}$

Where:
FK = the correction factor value
JRRB = the total monthly average ratio

i The formula to calculate the fishing season index (FSI) is as follows:

$$FSIi = RRBi \times FK$$

Where:
FSIi = the fishing season index for the *i*-th month
RRBi = the monthly average ratio
FK = the correction factor value
i = 1,2, ... , 12

The classification of FSI values into seasonal categories is based on the FSI index table formulated by **Syahrir (2010)** and **Nurani *et al.* (2021)**.

Table 1. FSI value categories

FSI value	Season category
< 100%	Not a fishing season
≥ 100%	Fishing season

The relationship between oceanographic variations and the yellowfin tuna fishery production was analyzed using Pearson correlation. This method produces a coefficient that indicates the strength of the association between two variables, assuming the relationship is linear **(Sekaran, 2010)**. If the obtained *P*-value is less than 0.05, it signifies a strong and significant positive relationship between the two variables. In this study, the guideline for interpreting the correlation coefficient values refers to the formulation proposed by **Sugiyono (2010)**.

Table 2. Guidelines for interpreting the correlation coefficient

No	r Value	Interpretation
1	0.00-1.199	Very weak
2	0.20-0.399	Weak
3	0.40-0.599	Moderate
4	0.60-0.799	Strong
5	0.80-1.000	Very strong

RESULTS AND DISCUSSION

Fishing location of yellowfin tuna in the waters around Palabuhanratu

Catch production data were obtained from fishermen's fishing activities in the Bay of Palabuhanratu. The common fishing gear used to catch the yellowfin tuna included tonda hooks, purse seines, longlines, and handlines, each with varying effectiveness depending on oceanographic conditions and the fishing season. In addition, these fishing gears were adjusted to fish migration patterns and habitat preferences. The fishing locations throughout the year are shown in Fig. (1), which illustrates the distribution of fishermen's activities based on the season.

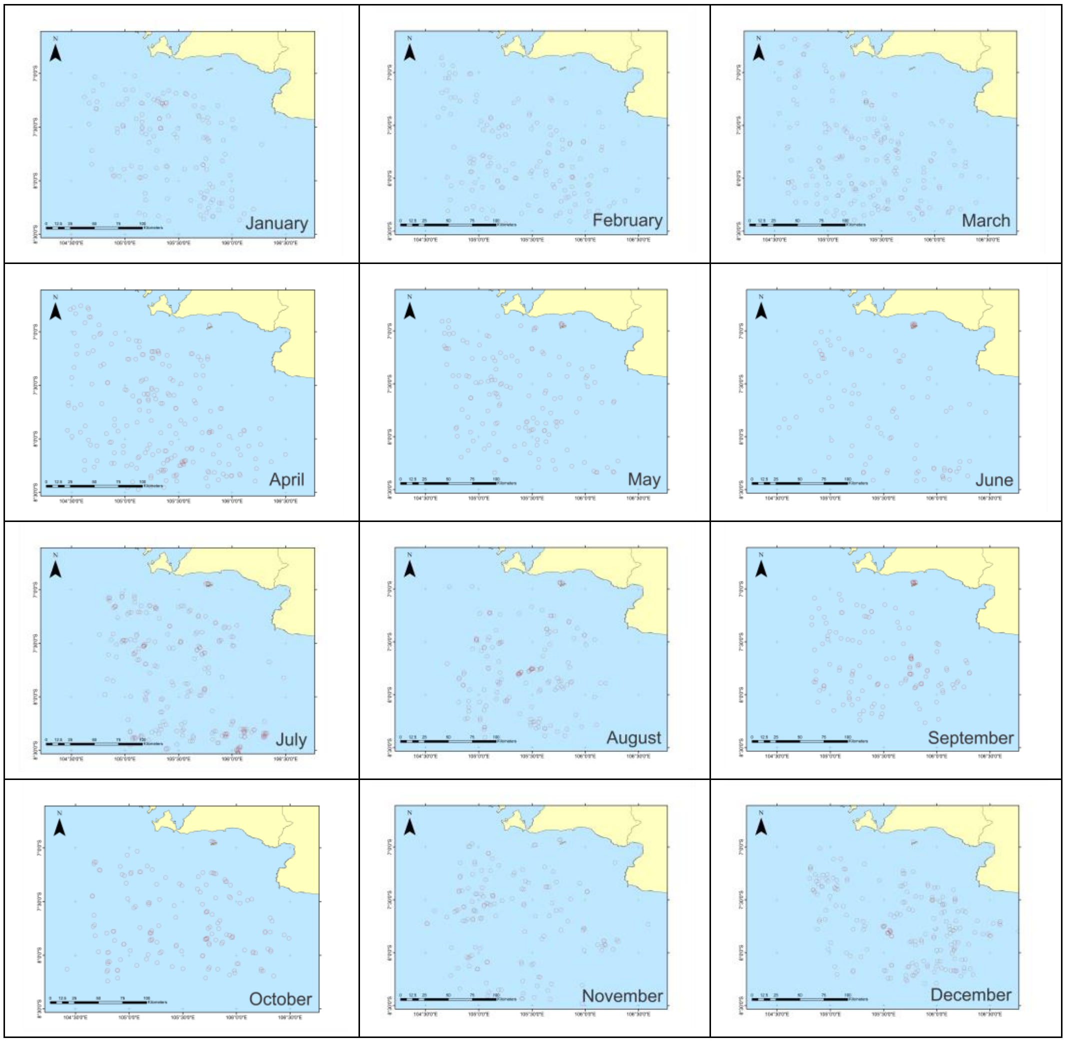

Fig. 1. Map of the yellowfin tuna fishing locations

Based on the map of yellowfin tuna fishing locations in Fig. (1), it is evident that the fishing locations selected by fishermen vary each month. This condition means that fishermen do not always fish in the exact location; instead, they follow the dynamics of fish abundance, which changes over time. The changes in fishing locations indicate fluctuations in fish abundance in the area, which are believed to be caused by changes in oceanographic conditions. The oceanographic condition such as currents, surface temperature, salinity, and chlorophyll-a **(Rumpa *et al*., 2022)**. This dynamic suggests that fish move according to optimal environmental or habitat conditions. Additionally, fish behavior, such as foraging, metabolism, and reproduction, may also influence these movements **(Mondal *et al*., 2023)**. Oceanographic conditions, habitat environment, and fish behavior significantly influence fish abundance and movement **(Suhermat *et al*., 2022)**. Therefore, understanding the relationship between oceanographic variations and fish distribution is crucial for identifying potential fishing locations and enhancing fishing operations' efficiency.

Relationship between chlorophyll-a (CHL) variation and yellowfin tuna production

The relationship between chlorophyll-a variation and yellowfin tuna production, based on production data and satellite imagery from 2015-2020, is shown in Fig. (2). Chlorophyll-a concentrations in the waters of Teluk Palabuhanratu and surrounding areas fluctuate, with monthly average values ranging from 0.02 to 1.25mg/ m^3. The presented graph shows a positive correlation between the increase in chlorophyll-a concentration and yellowfin tuna production, mainly observed throughout 2015, 2017, 2018, 2019, and 2020. This pattern was not evident in 2016 due to the negative phase of the Indian Ocean Dipole (IOD) in that year **(Bramawanto & Abida, 2017)**. Yellowfin tuna production increased as the region entered the east monsoon and the second transition season, from September to November, where a chlorophyll-a concentration in Teluk Palabuhanratu and its surroundings was observed. The rise in chlorophyll-a concentration is attributed to the high intensity of upwelling in the area **(Iskandar *et al*., 2010)**. This condition leads to an abundance of phytoplankton containing chlorophyll-a, making the aquatic environment more fertile **(Purba *et al*., 2024)**.

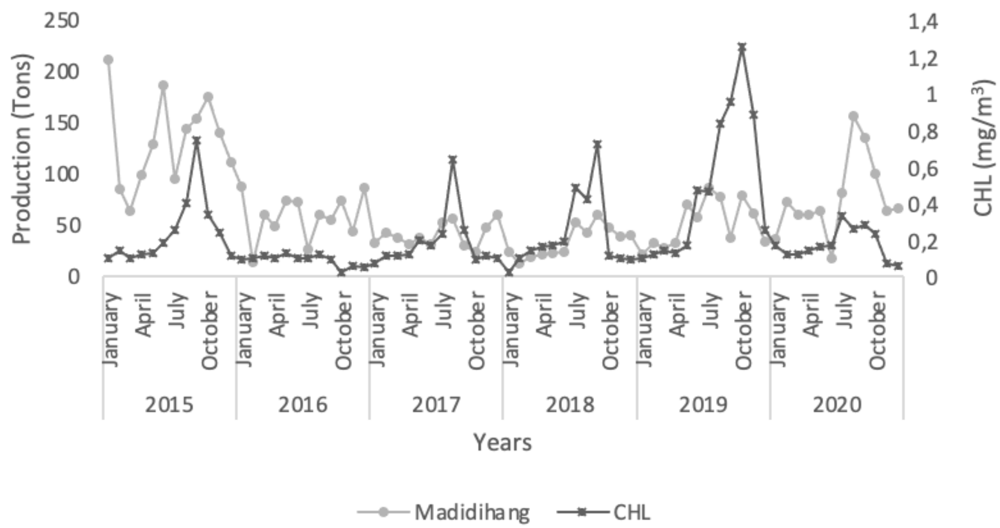

Fig. 2. Relationship between chlorophyll-a (CHL) concentration and yellowfin tuna catch production

Fig. (2) shows the relationship between chlorophyll-a concentration (CHL) in mg/m³ and yellowfin tuna catch production in tons from 2015 to 2020. In general, there is a fluctuating pattern between these two variables, where chlorophyll-a concentration is often followed by catch production, although with a specific time lag. Chlorophyll-a concentration, which reflects primary productivity in the sea, affects the availability of phytoplankton as the base food source in the marine food chain. This condition supports the population of small fish, which eventually become prey for predators such as yellowfin tuna. For example, in 2015, 2017, 2018, 2019, and 2020, an increase in chlorophyll-a concentration was observed in July, followed by an increase in catch production.

A seasonal pattern can also be seen, where chlorophyll-a concentration tends to increase from mid-year (June to October), followed by an increase in catch production. However, in 2016, there was a significant decrease in chlorophyll-a concentration compared to previous years, potentially leading to a decline in catch production. Chlorophyll-a is contained in phytoplankton biomass as an index of productivity in a water body and, therefore, influences fish catch production **(Tangke *et al.*, 2024)**. Thus, the higher the chlorophyll-a concentration, the more distinct the seasonal fish pattern becomes, and conversely, when chlorophyll-a concentration is low, the fish seasonal pattern becomes less visible **(Ningsih *et al*., 2021)**.

Relationship between sea surface temperature variations and yellowfin tuna production

The correlation between sea surface temperature variations and yellowfin tuna production, derived from production data and satellite imagery spanning 2015 to 2020, is presented in Fig. (3). Generally, a negative relationship is observed between the two, where yellowfin tuna catch production tends to decrease as sea surface temperature increases.

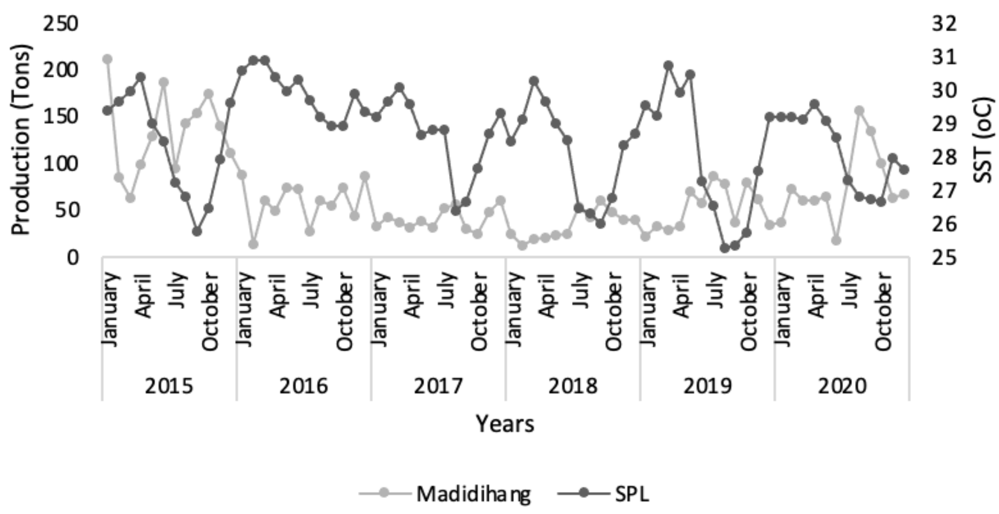

Fig. 3. Relationship between sea surface temperature and yellowfin tuna catch production.

Fig. (3) shows the relationship between sea surface temperature (SST) in °C and yellowfin tuna catch production in tons from 2015 to 2020. SST generally exhibits a stable seasonal fluctuation pattern ranging from 27–30°C. Yellowfin tuna production tends to correlate with SST, though in a more fluctuating pattern. In the optimal SST range of around 27–29°C, the catch production tends to be high, as seen in early 2017 and

2018. On the other hand, excessively high SST, such as >30°C in mid-2019, is often followed by a decrease in catch production, likely due to reduced dissolved oxygen availability in the waters or fish migrating to areas with more ideal temperatures.

SST also affects the presence of phytoplankton and zooplankton, which are part of the food chain, significantly influencing the availability of target fish species like yellowfin tuna. Although SST is relatively stable year by year, catch production declined at the end of the period, especially in 2020, which could be attributed to a combination of environmental factors, rising SST, and fishing pressure. Therefore, the relationship between SST and yellowfin tuna production demonstrates that sea surface temperature is an important factor to monitor in fisheries management, as optimal temperatures support fishery productivity, while extreme temperatures can negatively influence the catch production. In the study by **Sambah *et al.* (2021)**, yellowfin tuna production was inversely related to sea surface temperature, meaning that the higher the yellowfin tuna production, the lower the sea surface temperature or the optimal condition.

Chlorophyll-a and sea surface temperature correlation with yellowfin tuna production

A Pearson correlation test was conducted to validate the relationship between chlorophyll-a, sea surface temperature, and yellowfin tuna production. The correlation values describe the type and strength of the relationship between chlorophyll-a, sea surface temperature, and yellowfin tuna production. The correlation values obtained from this calculation are presented in Table (3).

Table 3. Pearson correlation analysis of chlorophyll-a concentration with sea surface temperature and yellowfin tuna production

		Yellowfin tuna
CHL	*Pearson correlation (r)*	0,753
	P-value	0,005
SPL	*Pearson correlation (r)*	-0,865
	P-value	0,000

Based on the Pearson correlation analysis in Table (3), the correlation value between chlorophyll-a and yellowfin tuna production is 0.753 (*P*-value < 0.05). This value indicates a strong and significant positive relationship between chlorophyll-a and yellowfin tuna fish production. Meanwhile, the correlation between sea surface temperature (SST) and yellowfin tuna production is -0.865 (*P*-value < 0.05), which indicates a powerful and significant negative relationship between sea surface temperature and yellowfin tuna production. This condition aligns with the study by

Elasari *et al.* (2022), which stated that the correlation between temperature and catch is positive, meaning temperature and catch have a direct relationship: as the temperature increases toward its optimum, the catch increases. The positive relationship suggests that increasing oceanographic parameters can increase in the yellowfin tuna production. In contrast, the negative relationship suggests that increasing oceanographic parameters may decrease the yellowfin tuna production.

Yellowfin tuna fishing season

Yellowfin tuna production and fishing effort data were processed to determine the fishing season index value (FSI). The FSI value is used to identify the yellowfin tuna the fishing season in the waters around Palabuhanratu. The criteria for identifying the fishing season are that an FSI value exceeding 100% indicates a fishing season, while values below 100% signify that it is not a fishing season **(Syahrir *et al*., 2010)**. The monthly FSI values from 2016 to 2020 are shown in Fig. (4). These values were then processed to produce an overall FSI value that describes the fishing season. The yellowfin tuna fishing season obtained from the FSI value can be seen in Fig. (5).

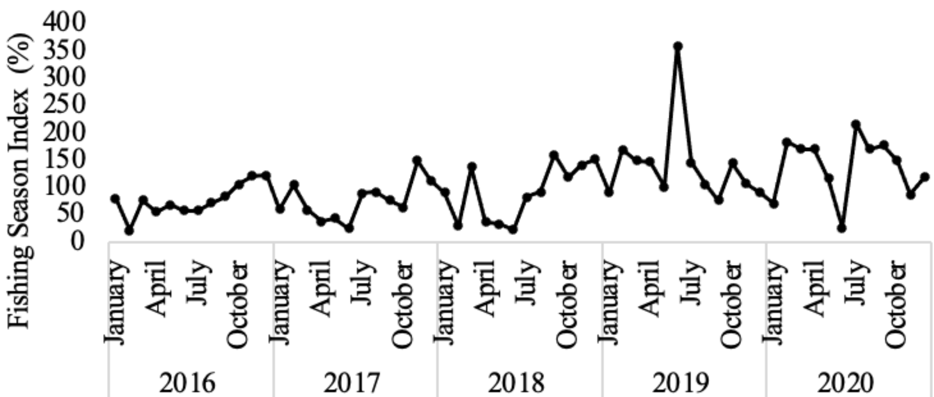

Fig. 4. Monthly FSI values from 2016 to 2020

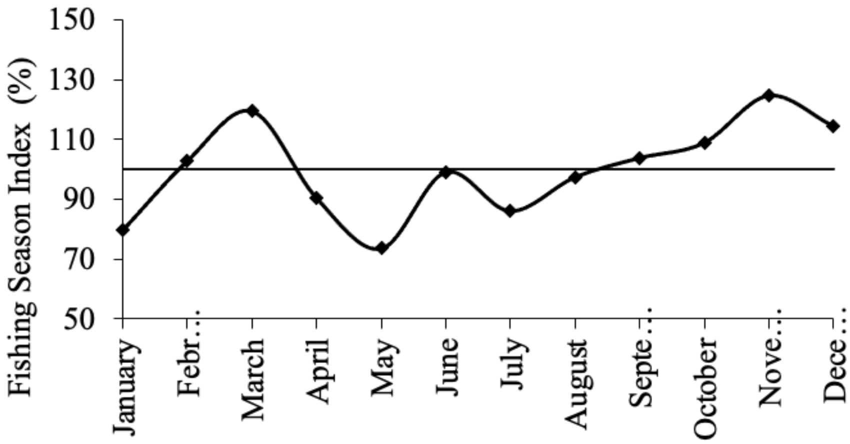

Fig. 5. Seasonal fishing index values for yellowfin tuna

The yellowfin tuna fishing season index (FSI) in the waters around Palabuhanratu Bay, with values greater than 100%, occurred in February (102.75%), March (119.38%), October (108.80%), November (124.56%), and December (114.48%). These FSI values indicate that these months represent the yellowfin tuna fishing season in the waters around Palabuhanratu Bay. In contrast, the months with FSI values below 100%, indicating the off-season, occurred in January (79.63%), April (90.49%), May (73.55%), June (99.05%), July (86.11%), and August (97.37%). Based on the annual FSI distribution for the yellowfin tuna, it can be concluded that the yellowfin tuna fishing season occurs from the end of the east monsoon to the second transitional season. This fishing season indicates high fish abundance in the waters during these months.

When looking at the temporal distribution of chlorophyll-a concentration from 2015 to 2020, there is a pattern where chlorophyll-a concentrations increase from June to October. This increase in chlorophyll-a concentration is influenced by the rising intensity of upwelling in the waters. During upwelling, fish abundance tends to increase because nutrients from the ocean floor are brought to the surface, boosting the concentration of phytoplankton, the primary food source in the waters **(Tambaru *et al.*, 2024)**. However, there is a time lag between the occurrence of upwelling and the increase in fish abundance. This time lag is because pelagic fish species, like yellowfin tuna, do not directly interact with phytoplankton or nutrients as food sources **(Simbolon & Girsang, 2009)**. Therefore, there is a delay between the increase in fish abundance and the rise in chlorophyll-a concentration in the waters. This time lag is believed to be the factor that causes the yellowfin tuna fishing season to begin in September, even though chlorophyll-a concentration had already started to rise in June.

Yellowfin tuna catch patterns are shaped by chlorophyll-a concentration and ocean-atmosphere dynamics, including sea surface temperature fluctuations and El Niño events. Higher catch rates of larger yellowfin tuna occur during seasonal transitions, specifically from May to July (shifting from the rainy to dry season) and October to November (transitioning from dry to rainy season). During May–July, SST declines while chlorophyll-a concentration rises, whereas the opposite trend is observed in October–November. Since SST influences chlorophyll-a levels and plankton productivity, tuna populations tend to increase in highly productive areas, such as upwelling zones and current boundaries, as they migrate toward regions with greater food availability, often with a slight time lag **(Wiryawan *et al.*, 2020)**.

Based on the findings of this study, we recommend that the government implement effective fisheries management. During the fishing season, fishermen should be allowed to catch fish while ensuring the sustainability of fish stocks. Proper management is crucial for maintaining fish populations and supporting their growth, ensuring resources remain available for the future.

CONCLUSION

Pearson correlation analysis reveals a strong and significant positive correlation between chlorophyll-a levels and the yellowfin tuna production. Conversely, sea surface temperature demonstrates a strong negative correlation with the yellowfin tuna production. The fishing season index (FSI) indicates that the yellowfin tuna fishing season in Palabuhanratu Bay occurs in February, March, October, November, and December. This period aligns with the transition from the east season to the second transitional season, when fish abundance peaks. The rise in chlorophyll-a concentrations from June to October, driven by upwelling intensity, enhances phytoplankton abundance, providing a key food source. However, the delay between upwelling events and fish abundance causes the fishing season to begin later, starting in September. We recommend that the government implement effective fisheries management to ensure sustainable fish stocks. Proper regulation during the fishing season is essential for maintaining fish populations and preserving resources for the future.

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