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SKIPJACK TUNA FISHING SEASON AND ITS RELATIONSHIP WITH OCEANOGRAPHIC CONDITIONS IN PALABUHANRATU WATERS, WEST JAVA

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ABSTRACT

Skipjack tuna (*Katsuwonus pelamis*) is the main catch species in Indonesian Palabuhanratu waters. The dynamics of skipjack fishing areas are influenced by oceanographic parameters such as sea surface temperature and chlorophyll-a concentration. This study aims to predict the skipjack fishing season, to analyze the dynamics of oceanographic conditions, especially the distribution of both sea surface temperature and chlorophyll-a, and to determine the relationship between skipjack fishing season and the dynamic distribution of sea surface temperature and chlorophyll-a concentration in the Palabuhanratu waters, West Java. Catch per unit effort analysis was used to determine the fishing season index. At the same time, the dynamics of sea surface temperature and distribution of chlorophyll-a were analyzed from monthly MODIS image data from 2015 to 2019. This study showed that skipjack fishing season in Palabuhanratu waters was from July to November. Monthly sea surface temperatures range from 26-30 *℃* with an average value of 29 *℃*. The concentration of the chlorophyll-a was 0.09 to 0.51 mg/m^3 (average of 0.23 mg/m^3). There was a negative relationship between sea surface temperature and skipjack tuna production, while a positive relationship with the chlorophyll-a concentrations.

Key words: Catch, chlorophyll-a concentration, season, sea surface temperature, skipjack

INTRODUCTION

Fish's life patterns in water areas are strongly related to oceanographic parameters such as temperature, salinity, currents, and chlorophyll-a concentration. Each fish species has a habitat with a different oceanographic parameter to support optimal life. Oceanographic conditions, especially sea surface temperature and chlorophyll-a concentration affect fish distribution in waters and can be used to indicate potential fishing ground and fishing season (Fraile *et al*., 2010).

The success of fishers in utilizing fish resources depends on the quality of fish resources. Knowledge of the abundance of fish in the sea is essential to predicting the right place and time to catch the fish. Estimating fishing grounds is essential for efficiency in fishing operations (Nurani *et al*., 2015; Nurani *et al*., 2016; IOTC, 2016).

Skipjack tuna (*Katsuwonus pelamis*) is the main catch species in Indonesian Palabuhanratu bay. Palabuhanratu fishers catch skipjack tuna using longline fishing units and trolling rods. The dynamics of skipjack fishing areas are influenced by oceanographic parameters such as sea surface temperature, salinity, and marine chlorophyll-a concentration. Oceanographic parameters and their changes will affect fish life and growth, such as fish feeding speed, metabolism, spawning, and other activities (Hsu *et al*., 2021). According to Damora *et al*. (2021), a fish's growth pattern might be affected by many factors such as season, gonad maturity, habitat, health, food, gut contents and annual growth variation, the average size of fish, number of fish samples, fish conditions, and environmental factors.

Sea surface temperature (SST) image data can provide skipjack tuna's exact isotherm distribution pattern. In tropical waters, Lehodey *et al*. (1997) found a match between the density of skipjack tuna and the SST isotherm of 29 ºC. In Brazilian waters, associations were also found between skipjack tuna with SST conditions of 24-26 ºC (Andrade & Garcia 1999). At the same time, the chlorophyll-a factor is a factor that can provide a direct indication of the existence of both fish prey and the migration route of tuna (Polovina *et al*., 2001).

This study was intended to (1) predict skipjack fishing season, (2) analyze the dynamics of oceanographic conditions, especially the distribution of sea surface temperature and the distribution of

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chlorophyll-a, and (3) determine the relationship between skipjack fishing season and the dynamic distribution of both sea surface temperature and chlorophyll-a concentration in the waters of Palabuhanratu, West Java. The study results are expected to provide an overview of the pattern of fishing seasons and their relationship to the dynamics of oceanographic conditions of the waters.

MATERIALS AND METHODS

Materials

This research was carried out from 2015 to 2019 in Palabuhanratu Bay, Sukabumi Regency, West Java Province. The map of the research location is shown in Figure 1.

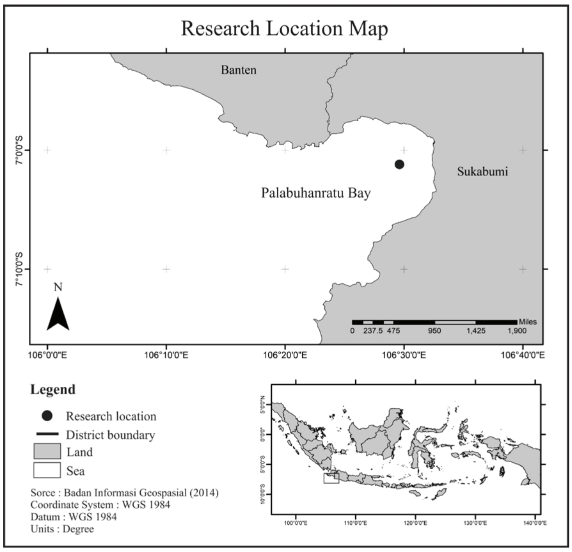

Fig. 1. The study location is in Palabuhanratu bay.

Methods

The data of skipjack tuna production (ton), fishing effort (trip), sea surface temperature (℃), and chlorophyll-a concentration (gr/m^3) in the waters of Palabuhanratu Bay for five year period (from 2015 to 2019) was used in this study. The skipjack tuna production and fishing effort were obtained from catch statistical data of the Palabuhanratu Archipelago Fishing Port (PPN). Meanwhile, the sea surface temperature and chlorophyll-a concentration were obtained from remote sensing data of the Terra/MODIS satellite, http://oceancolor.gsfc.nasa.gov/. Data analysis was carried out by calculating the catch per unit effort and the fishing season index (Fadhilah & Dewinta, 2021). Further data analyzed to estimate the average sea surface temperature (SST) and chlorophyll-a concentration were conducted using MODIS satellite imagery data (Sachoemar *et al*., 2012).

Data analyses

CPUE analysis

The CPUE analysis estimates the productivity of fishing gear by comparing the total catch and the total number of fishing efforts. Skipjack fishing gear in Palabuhanratu Bay were troll lines and longlines. According to Gulland (1982), CPUE is estimated using the following formula:

1. Data catch and effort are made in tabular form, then CPUE is calculated
   $CPUE = \frac{Catch}{Effort}$
   where,
   CPUE: catch per unit effort (ton/trip),
   The catch: volume of skipjack catch (ton)
   Effort: Effort, number of the trip of the skipjack fishing vessels

2. Standardization effort catch
   In case there are several fishing gears used to fish the skipjack in the study area, there are multi-gear (longline and troll line). Then one of the dominant numbers is used as the standard fishing gear of these fisheries for CPUE analysis, and the other gears are standardized against the standard one. Standardization is necessary because each fishing gear has a different size of capability. The fishing gear used as the standard fishing gear for skipjack tuna was the longline. The following formula was used to standardize the gears:
   a) Calculation of Fishing Power Index (FPI)
   $FPI = \frac{CPUE\ dst}{CPUEst}$
   where,
   FPI: *Fishing power index*
   CPUE*dst*: CPUE of fishing to be standardized (tons/trip)
   CPUE*st*: CPUE standard fishing gear (tons/trip)

b. Calculation of standard effort
Fs = FPI × Fdst
where,
Fs: Effort to catch standardization result (trip)
Fdst: Effort to catch results to be standardized (trip)

c. CPUE Analysis
The CPUE value is recalculated with the standardized catch effort value, while the catch value remains.
CPUEs = Catch/Effort
where,
CPUEs : Catch unit effort standard (tons/trip)
Catch: The catch month i (tons)
Effort: Standardization of fishing effort in month i (trip)

Suppose the value of the CPUE trend increases from year to year. In that case, it can be assumed that the fish stock in the fishing area is in good condition (not overfishing yet), which indirectly implies that the fishing business is still profitable. Vice versa, if the CPUE trend decreases, it is an indicator of overfishing (Nurhayati *et al*., 2018).

Fishing season pattern

Based on Maiyza and El-karyoney (2020); Dajan (1983), as modified by Wiyono (2001), the fishing season were estimated as following steps and formulas:

a) The CPUE sequence
CPUE = ni
where,
i : 1,2,3, ….n
Ni: order-i

b. Compiling a 12-month CPUE moving average (RG)

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

where,
RGi: 12-month moving average order-i
CPUEi: CPUE of order-i
i : 7,8, …, n-5

c. Constructing a centered CPUE moving average (RGP):

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

where,
RGPi: i-th centered CPUE moving average
RGi: 12-month moving average order-i
i: 7,8, …, n-5

d. Compiling the average ratio per month (Rb):
$Rbi = \frac{CPUEi}{RGPi}$
where,
Rbi: Average ratio of the i-th order months
CPUEi: CPUE of order-i
RGPi: i-th centered CPUE moving average

e. Set the average ratio value in a matrix size i × j which is compiled for each month, starting from January 2015 to December 2019.

f. Calculate the total monthly average ratio

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

where,
JRRBi: Total monthly average ratio
RBBi: Average Rbij for month order-i
i : 1,2, ….,12

g. Fishing season index
Ideally, the average monthly ratio of JRBB is equal to 1200, but due to many factors, it causes JRBB not always equal to 1200. Therefore, the value of the monthly average ratio must be corrected with a correction value called the Correction Factor (FK).
The formula for obtaining the Correction Factor value is:
$FK = \frac{1200}{JRBB}$
where,
FK: Correction factor value
JRRB: Total monthly average ratio

The fishing season index (FSI) can be calculated using the formula:
FSIi = RRBi × FK
where,
FSIi: Index of the i-month fishing season
RRBi: Monthly average ratio
FK: Correction factor value
i : 1,2, ….,12

The fishing seasons can be classified into two categories based on the fishing season index (FSI): fishing season and nonfishing season.

Table 1. Fishing season category

FSI Value	Fishing Season Category
≥100%	Fishing season
<100%	Nonfishing season

Source: Hamka and Rais (2016)

Oceanographic conditions

Image data of chlorophyll-a concentration and sea surface temperature (SST) in this study were obtained from the National Aeronautics and Space Administration (NASA) through the https://oceancolor.gsfc.nasa.gov/ website. The downloaded data were the monthly AQUA MODIS Level-3 image from 2015 to 2019. The AQUA MODIS Level-3 satellite image data have been processed and have a resolution of 4 km. Level-3 data has the advantage of being less cloudy and has been corrected by NOAA, both geometrically and radiometrically. According to O'Reilly *et al*. (1998), the algorithm model on OC3M refers to the following equation.

$$Ca = 10^{0.283 - 2.753 * R1 + 1.457 * R2 + 0.659*R3 - 1.403*R4}$$

$$R = \log10(Rrs\,(\frac{443}{551}) > Rrs\,(\frac{448}{551}))$$

Where:

chlorophyll-a concentration (mg/m^3)

Ca =

R = reflectance ratio

R_1, R_2, R_3, R_4 = squared reflectance ratio by 1, 2, 3 and 4

Rrs = reflected wavelength spectrum (unit?)

while for sea surface temperature data, the extraction of its value was obtained from the *algorithm Theoretical Basic Document Modis 25* (Brown & Minnet, 1999), with the following equations:

$$\text{Modis SST} = c_1 + c_2{*}T_{31} + c_3{*}T_{31-32} + (c_4{*}\sec(\theta) - 1)$$

Where:

c_3, c_4 = SPL coefficient on band 31 and 32

c_1, c_2,

and

T31 = *Brightness Temperature* (BT) on channel 31 (ºC)

T31-32 = Difference BT on channel 31 and 32

Θ = satellite zenith angle

The coefficient value of c_1, c_2, c_3, and c_4 used in the above equation can be seen in Table 2.

Table 2. Coefficients for MODIS bands 31 and 32 SPL algorithms

Coefficient	ΔT ≤0.7	ΔT ≥0.7
c_1	1.11071	1.196099
c_2	0.9586865	0.9888366
c_3	0.1741229	0.1300626
c_4	1.876746	1.627125

The processing data starts from downloading chlorophyll-a and sea surface temperature data at https://oceancolor.gsfc.nasa.gov/ site. The selected data format is NonConformance (.nc). The data was extracted using the SeaDAS 7.5.3 software and cropping according to the coordinates of the research area. After that, export mask pixel and store in the form of Text Tab Delimited (.txt). The next process is the creation of chlorophyll-a and SPL distribution maps using the ArcGIS 10.8 software.

RESULTS

The monthly production of skipjack tuna in Palabuhanratu is shown in Table 2. Monthly production ranges from 1.03 to 128.57 tons. Meanwhile, skipjack tuna production per year ranges from 53.73 to 318.00 tons. In Table 3, it can be seen that skipjack tuna production in Palabuhanratu decreased sharply in 2016 and began to increase again in 2017, 2018, and 2019. The decline in production resulted from government policies related to the moratorium on capture fisheries business permits and the prohibition of transshipment. This is also recorded in Benoa Bali fishing port, where tuna production from longline catches went down in 2016-2017 due to government policies (Imron *et al*., 2021).

Table 3. Average skipjack catch per month

Month	Catch (Tons)				
	2015	2016	2017	2018	2019
January	1.86	2.29	5.94	1.03	7.92
February	2.44	1.76	6.01	5.72	19.91
March	5.20	5.30	10.72	16.89	18.02
April	8.39	8.80	15.21	10.47	24.73
May	25.06	5.96	15.56	13.59	19.73
June	128.57	4.62	14.51	9.81	19.79
July	9.76	3.30	36.18	16.09	62.95
August	24.36	4.16	29.23	28.88	54.41
September	55.63	2.30	21.27	43.83	22.31
October	14.60	3.08	14.80	32.67	25.98
November	5.47	6.01	4.71	30.57	29.14
December	3.86	6.16	2.25	16.03	13.11
Total	285.19	53.73	176.40	225.58	318.00

#Footnote: Palabuhanratu fishing port statistics data (processed data)

Skipjack tuna in Palabuhanratu Bay were caught using fishing gear, namely longline and trolling. The average number of longline and trolling in the 2015-2019 period was 21 and 52 units, which fishing efforts have monthly fluctuated. A standardized fishing effort with standard longline, as shown in Table 4.

Table 4. Average skipjack fishing trip per month (source: statistics data of Palabuhanratu Fishing Port)

Month	Fishing Efforts (trips)				
	2015	2016	2017	2018	2019
January	37	26	33	13	12
February	29	16	23	19	11
March	33	27	35	31	18
April	56	35	46	37	18
May	73	37	49	37	33
June	68	38	42	34	24
July	59	19	50	40	37
August	63	29	49	40	36
September	71	22	46	34	21
October	54	25	44	32	12
November	36	25	32	23	18
December	28	29	20	21	17
Total	603	326	466	358	256

The calculation results of catch per unit effort from 2015 to 2019 showed that the lowest skipjack tuna CPUE value was in 2016, which was around 0.0086 tons per trip, while the highest CPUE value in 2017 was around 3.0679 tons per trip (Figure 3). The CPUE value obtained is then used to determine the skipjack tuna fishing season index in Palabuhanratu bay.

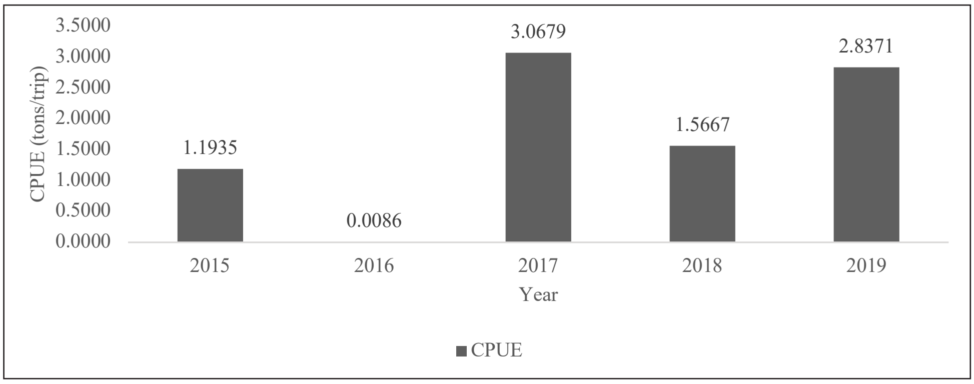

Fig. 3. CPUE Skipjack Palabuhanratu year 2015-2019.

Figure 4 shows the fishing season index (FSI) for skipjack tuna in Palabuhanratu bay. The FSI values of more than 100% were obtained in March and July to November. This indicates that the fishing season occurs in these months. While in other months, the FSI value was less than 100%, with the lowest FSI value in January, indicating that these months were not the fishing season in the bay.

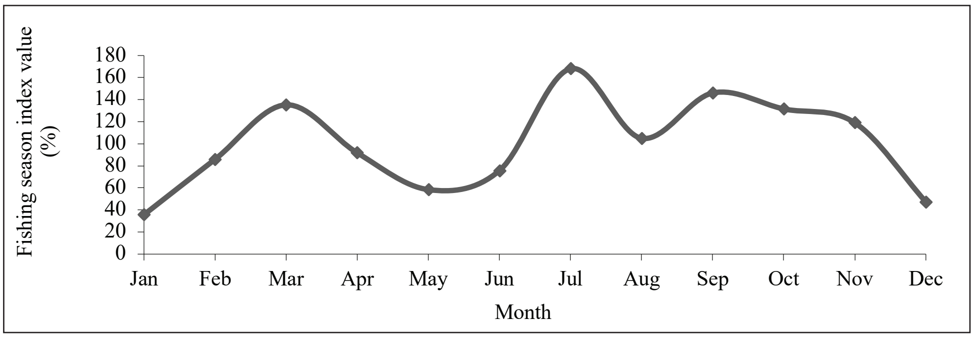

Fig. 4. Skipjack tuna fishing season index value 2015-2019 in Palabuhanratu bay.

The map of the distribution of monthly sea surface temperatures in Palabuhanratu bay from 2015 to 2019 is presented in Figure 5. Areas in blue to green indicate low sea surface temperatures. While the yellow, orange to red areas indicate that the sea surface temperature is getting higher.

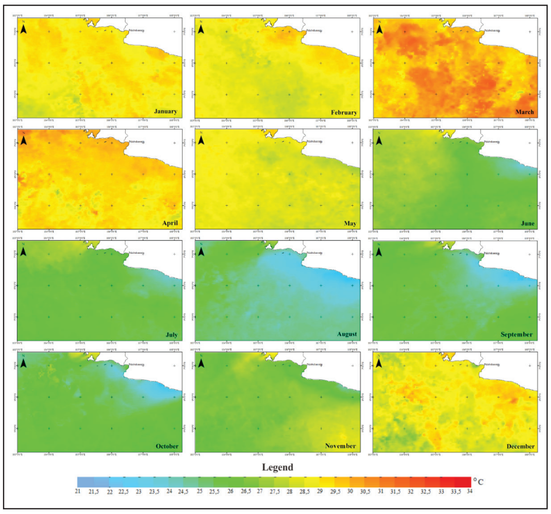

Fig.5. Map of monthly sea level distribution in Palabuhanratu bay January-December 2019.

The map of chlorophyll-a concentrations in Palabuhanratu bay from 2015 to 2019 every month is presented in Figure 6. The red area shows a high concentration of chlorophyll-a. Chlorophyll-a indicates phytoplankton biomass in sure water, indicating water productivity.

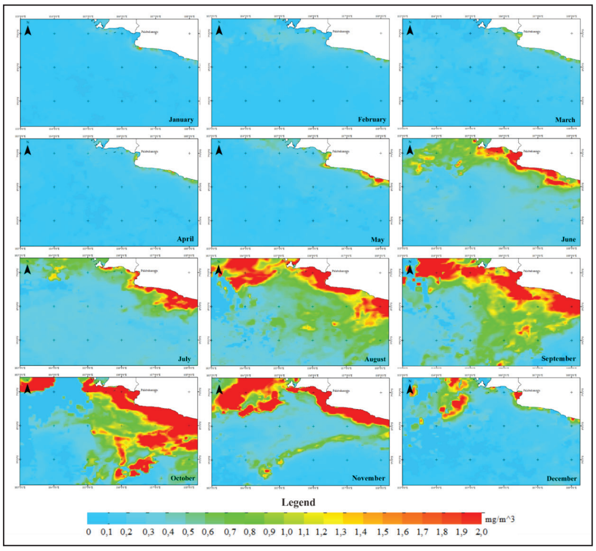

Fig. 6. Map of monthly chlorophyll-a distribution in Palabuhanratu bay January-December 2019

Figure 5 shows the average fluctuation in the distribution of sea surface temperature (SST) in five years (2015-2019). The SST values increase in the west monsoon (November-April) and decrease in the east monsoon (May-October). Monthly sea surface temperatures in the waters of Palabuhanratu Bay ranged from 26-30 ºC with an average value of 29 ºC. Sachoemar *et al*. (2012) showed that sea surface temperature had no significant effect on fish catches, while chlorophyll concentration significantly affected catches. When chlorophyll-a has a high concentration, the catch was high, but when the concentration of chlorophyll-a was low, the catch was also low (Kurniawan, 2015).

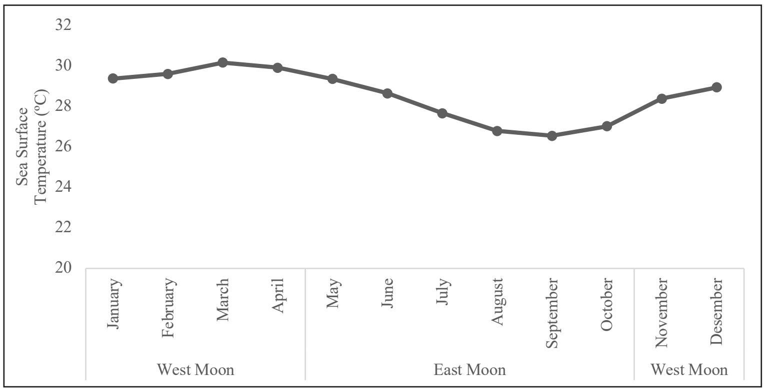

Fig. 5. The average of sea surface temperature on east and west monsoon in Palabuhanratu bay

Figure 6 shows the relationship between sea surface temperature and skipjack tuna production. Skipjack tuna production tends to increase when sea surface temperatures are low. This is because there is an increase in the concentration of chlorophyll-a. The chlorophyll-a concentration indicates an upwelling phenomenon because the sea surface temperature is low or feels cold around the waters (Nurani *et al*., 2015).

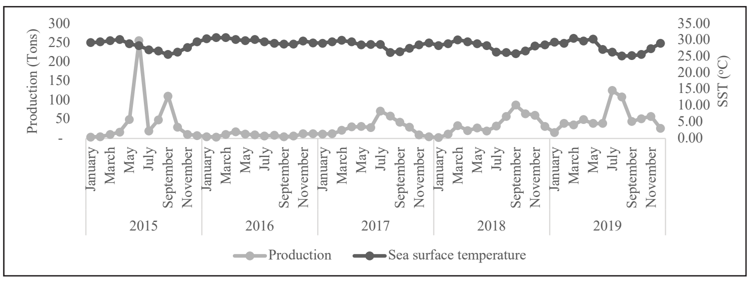

Fig. 6. The relationship between skipjack production and sea surface temperature in Palabuhanratu bay.

The value of chlorophyll-a concentration in the surface layer of Palabuhanratu bay in 2015-2019 ranged from 0.09 to 0.51 mg/m^3; the average value was 0.23 mg/m^3 (Figure 7). Chlorophyll-a is an indicator of phytoplankton biomass in particular water.

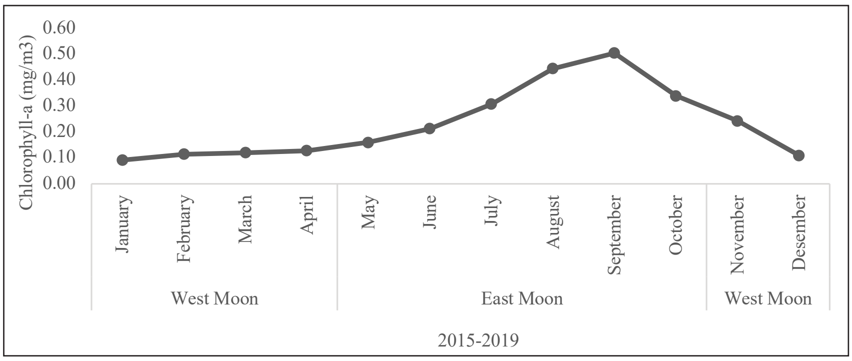

Fig. 7. The concentration of chlorophyll-a in Palabuhanratu bay 2015-2019.

The relationship between skipjack tuna production and chlorophyll-a is presented in Figure 8. The concentration of chlorophyll-a in Palabuhanratu Bay seems to fluctuate. Figure 8 shows that the increase in skipjack production is directly proportional to the chlorophyll-a concentration. The chlorophyll-a concentration causes the catch to increase, and vice versa, the decrease in the chlorophyll-a concentration causes the catch of fish to decrease.

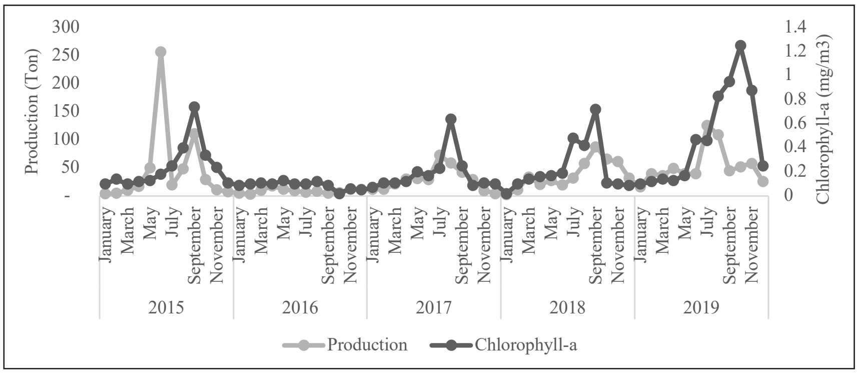

Fig. 8. The relationship between skipjack production and chlorophyll-a concentration in Palabuhanratu Water.

DISCUSSION

The results showed that the CPUE trend of skipjack tuna in Palabuhanratu still tended to increase, indicating that the skipjack tuna resources in Palabuhanratu fishing port were sustainable. The CPUE value describes the level of productivity of the fishing effort. The catch decreased even though the fishing effort was increased. It is because of a combination of several stock indicators, such as a decrease in average fish weight and ecosystem indicators, resulting in changes in the age and size structures and even changes in the size and composition of species in the population (Dollu & Muksin, 2019). Ramlah *et al*. (2020) added that CPUE differences could occur due to several factors such as the fishing gear used, variations in fishing gear, fishing grounds, fishing time, recording and reporting of catches, and natural factors such as seasons and oceanographic conditions. The CPUE value is also influenced by the fish to catch the fishing gear used. Skipjack tuna in the Banda Sea was caught using different gears, namely pole and line, purse seine, and troll line. Pole and line have the highest CPUE values because skipjack tuna was the main target (Waileruny *et al*., 2014).

Fish life patterns are influenced by oceanographic parameters such as temperature, salinity, currents, and chlorophyll-a concentration. Each type of fish has a habitat with different oceanographic conditions to support optimal life. Oceanographic conditions, especially sea surface temperature and chlorophyll-a content affect the distribution of fish in habitat and are an indicator for potential fishing ground and fishing season (Karman *et al*., 2016). Accuracy of the fishing season could be useful for fishery managers to formulate any management measures, such as open and close seasons. Even though skipjack tuna stock is not in the threatening condition, the reported decreasing catch in recent years should be an early warning for this fishery (IOTC, 2016). By knowing the seasonal catch rate of skipjack, the effectiveness of fishing operations can be improved, so that the operational cost can be reduced.

Laevastu & Hayes (1981) suggested that very small changes in water temperature (about 0.02ºC) can cause changes in fish population density in waters (sub-tropical areas). Water temperature also greatly affects the growth of fish, movement activity and mobility, breeding, distribution and abundance, breeding, maturation, fecundity, spawning, incubation period, hatching of eggs, and survival of fish larvae. Changes in water temperature from normal temperature or optimal temperature also cause changes in movement and feeding activities and affect the spawning process.

According to Kurniawan (2015), skipjack tuna in Palabuhanratu Bay can be caught all year round, with the fishing season occurring from August to December. Research on the fishing season index that has been carried out shows relatively the same results as skipjack tuna fishing season in Palabuhanratu waters in this study. The results showed that the skipjack season in Palabuhanratu bay occurred from March and July to December. Meanwhile, at a different location like in Pacitan, East Java, the peak fishing season of the skipjack was occurring in April and November (Setyadji *et al*., 2018).

The fishing season is related to oceanographic conditions such as sea surface temperature and chlorophyll-a. The range of monthly SST in the waters of Palabuhanratu Bay is between 28-30 ºC, averaging 29 ºC. A study by Sachoemar *et al*. (2012) showed that sea surface temperature had no significant effect on fish catches, while the concentration of chlorophyll-a had a significant effect on catches. Meanwhile, Kurniawan (2015) suggested that the chlorophyll-a concentration was a positive correlation with the volume of catches.

The concentration of chlorophyll-a is closely related to the primary productivity level shown by the large biomass of phytoplankton that forms the first chain of small pelagic food (Gabric & Parslow, 1989). The primary productivity of coastal waters is generally higher than the primary productivity of the open seas. The rate of primary productivity in the marine environment is determined by various physical factors. The main physical factors controlling phytoplankton production in eutrophic waters are vertical mixing, penetration of sunlight in the water column, and sinking rate of cells (phytoplankton) (Gabric & Parslow, 1989).

Nurani *et al*. (2016) have conducted a study to evaluate the relationship between the fishing season for yellowfin and bigeye tuna in Indian Ocean waters with oceanographic conditions, especially sea surface temperature and chlorophyll-a concentration. The results of the Nurani *et al*. study state that there was a pattern of relationship between the tuna fishing season and the water conditions, namely the tuna fishing season shifts from east to west and there was a different seasonal pattern for the southern waters of East Nusa Tenggara. The pattern of harvesting season for yellowfin and bigeye tuna occurs during the east monsoon, associated with decreased sea surface temperatures and increased chlorophyll-a concentrations.

The results of this study showed that the skipjack fishing season in the waters of Palabuhanratu Bay was occurring from July to November or coincided with the east monsoon season. The results of the analysis of the Modis satellite image show that the monthly sea surface temperature in the waters of Palabuhanratu Bay ranges from 26-30 ºC with an average value of 29 ºC, and the concentration of chlorophyll-a ranges from 0.09 mg/m^3 to 0.51 mg. / m^3 with an average distribution of chlorophyll-a content of 0.23 mg/m3. Skipjack tuna production tends to increase when sea surface temperatures are low, while skipjack tuna production increases when chlorophyll-a concentrations increase. The study of Zainuddin (2011) provides almost the same picture, namely SST and chlorophyll-a in Bone Bay were associated with skipjack tuna fishing that occurs in the east monsoon. Wiryawan *et al*. (2020) stated that there is a relationship between seasonal and annual tuna abundance patterns that are influenced by SST and chlorophyll-a and are associated with upwelling and El Nino events.

CONCLUSION

The skipjack fishing season in the waters of Palabuhanratu Bay occurred from July to November or coincided with the east monsoon season. The monthly sea surface temperature in the waters of Palabuhanratu Bay ranges from 26-30 ºC with an average value of 29 ºC, and the concentration of chlorophyll-a ranges from 0.09 to 0.51 mg/m^3 (average of 0.23 mg/m^3). The skipjack tuna production tends to increase as the concentration of chlorophyll-a, and sea surface temperatures were decreasing.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

REFERENCES

Andrade, H.A. & Garcia, A.E. 1999. Skipjack tuna fishery in relation to sea surface temperature off the Southern Brazilian Coast. *Fisheries Oceanography*, **8(4)**: 245-254. https://doi.org/10.1046/j.1365-2419.1999.00107.x

Brown, O.B. & Minnet, P.J. 1999. Modis infared sea surface temperature algorithm, Algorithm Teoritical Basis Document (ATBD) 25 version 2.0, Under Contract Number NAS5-31361 University of Miami, Miami.

Damora, A., Fazilla, F., Perdana, A.W., Rahmah, A., Aprilla, R.M. & Salmarika, S. 2021. Population dynamics of skipjack tuna (*Katsuwonus pelamis*) in the northern and western waters of Aceh. *IOP Conference Series: Earth and Environmental Science*, **674**: 012089. https://doi.org/10.1088/1755-1315/674/1/012089

Dollu, E.A. & Muksin, R. 2019. Sustainable catching analysis of cakalang (*Katsuwonus pelamis*) in Pantar Strait Waters, Alor Regency Nusa Tenggara Province. *International Journal of Fisheries and Aquatic Studies*, **7(2)**: 282-286.

Fadhilah, A.F. & Dewinta. 2021. Determination of fishing season mackerel (*Rastreligger kanagurta*) in The Waters of Belawan, Sumatera Utara. *IOP Conference Series: Earth and Environmental Science*, **782**: 042009. https://doi.org/10.1088/1755-1315/782/4/042009

Fraile, I., Murua, H., Goni, N. & Caballero, A. 2010. Effects of environmental factors on catch rates of FAD-associated yellowfin (*Thunnus albacares*) and skipjack (*Katsuwonus pelamis*) tunas in the western Indian Ocean, Paper presented in IOTC 12th session of working party of tropical tuna. IOTC-2010-WPTT-46, Seychelles.

Gulland, J.A. 1982. Manual of Methods for Stock Assessment. FAO, Rome.

Gabric A. & Parslow J. 1989. Effect of physical factors on the vertical distribution of phytoplankton in eutrophic coastal waters. *Australian Journal Marine Freshwater Resources*, **40**: 559-569. https://doi.org/10.1071/MF9890559

Hamka, E. & Rais, M. 2016. Determination of fishing catching season (*Decapterus sp*.) in East Waters of Southeast Sulawesi. *Jurnal IPTEKS PSP*, **3(6)**: 510-517.

Hsu,T.Y. Chang Y., Lee M., Wu R.F. & Hsiao S.C. 2021. Predicting skipjack tuna fishing grounds in the Western and Central Pacific Ocean based on high-spatial-temporal-resolution satellite data. *Remote Sensing*, **13(5)**: 861. https://doi.org/10.3390/rs13050861

Imron, M., Tawaqal, M.I. & Yusfiandayani, R. 2021. Fishing ground and tuna productivity by tuna longline based on Benoa Bay, Bali, Indonesia. *Biodiversitas*, **22(2)**: 961-968. https://doi.org/10.13057/biodiv/d220252

Indian Ocean Tuna Commission (IOTC). 2016. Report of the 18th Session of the IOTC Working Party on Tropical Tunas.. IOTC–2016–WPTT18–R[E]. IOTC, Seychelles.

Karman, A., Iksan, K., Surahman & Sunarti. 2016. Relationship between sea surface temperature and chlorophyll-a with the production and productivity of skipjack on Bacan Island Waters. *International Journal of Emerging Research in Management &Technology*, **5(8)**: 116-122. https://doi.org/10.24843/EJES.2021.v15.i01.p02

Kurniawan, W. 2015. Fishing season of skipjack tuna in the southern waters of West Java and its relation to oceanographic parameters. *Oseana*, **40(4)**: 53-60.

Laevastu, T. & Hayes, M.L. 1981. Fisheries Oceanography and Ecology. Fishing News Book, Ltd, England. 199 pp.

Lehodey, P., Bertignac, M., Hampton, J., Lewis, A. & Picaut, J. 1997. El Nino southern oscillation and tuna in the Western Pacific. *Nature*, **389**: 715-718. https://doi.org/10.1038/39575

Maiyza, S.I. & El-karyoney, I.A. 2020. Seasonality of fish catch and gish prices in natural Egyptian fisheries. *Egyptian Journal of Aquatic Biology & Fisheries*, **24(1)**: 541-552. https://doi.org/10.21608/EJABF.2020.74473

Nurani, T.W., Wahyuningrum, P.I., Wisudo, S.H., Endriani, R. & Komarudin, D. 2015. Catch of tuna fish on trolling fishing in Indian Ocean Waters, Southern Coast of East Java related to sea surface temperature variability. *Malaysian Applied Biology*, **44(3)**: 25–28.

Nurani, T.W., Wahyuningrum, P.I., Wisudo, S.H., Arhatin, R.E. & Gigentika, S. 2016. The dynamics of fishing season and tuna fishing in The Indian Ocean Waters (FMA) 573. *International Journal of Development Research*, **6(7)**: 8288-8294.

Nurhayati, M., Wisudo, S.H. & Purwangka, F. 2018. Productivity and seasonal pattern of yellowfin tuna (*Thunnus albacres*) fishing in fisheries management area 573. *Jurnal Akuatika Indonesia*, **3(2)**:127-135.

O'Reilly, J.E., Maritorena, S., Mitchell, B.G., Siegel, D.A., Carder, K.L., Garver, S.A., Kahru, M. & McClain, C. 1998. Ocean color chlorophyll algorithms for SeaWiFS. *Journal Geophysics Resource*, **103(11)**: 24937-24953.

Polovina, J.J., Howel, E., Kobayashi, D.R. & Seki, M.P. 2001. The transition zone chlorophyll front, a dynamic global feature defining migration and forage habitat for marine resources. *Progress in Oceanography*, **49**: 469-483. https://doi.org/10.1016/S0079-6611(01)00036-2

Ramlah, S., Sara, L., Padangaran, A. & Tadjuddah, M. 2020. The status of catch per unit effort (CPUE) and utilization rate of skipjack tuna (*Katsuwonus* *pelamis*) in The Kolaka Waters, South Sulawesi, Indonesia. *International Journal of Scientific & Technology Research*, **9(1)**: 977-982.

Sachoemar, S.I., Yanagi, T. & Aliah, R.S. 2012. Variability of sea surface chlorophyll-a, temperature and fish catch within Indonesian region revealed by satellite data. *Marine Research in Indonesia*, **2**: 75-87. https://doi.org/10.14203/mri.v37i2.25

Setyadji, B., Pranowo, W.S. & Amri, K. 2018. Sea-air impacts on fishing season of hand line skipjack tuna *Katsuwonus pelamis* (Linnaeus, 1758) in Southern Pacitan Waters, East Java-Indonesia. *Omni-Akuatika*, **14(1)**: 1-10. https://doi-org/10.20884/1.oa.2018.14.1.207

Waileruny, W., Wiyono, E.S., Wisudo, S.H., Purbayanto, A. & Nurani, T.W. Bio-economics analysis of skipjack (*Katsuwonus pelamis*) fishery on Banda Sea-Maluku Province. *International Journal of Science: Basic and Applied Research (IJSBAR)*, **14(1)**: 239-251.

Wiryawan, B., Loneragan, N., Mardhiah, U., Kleinertz, S., Wahyuningrum, P.I., Pingkan, J., Wildan, Timur, P.S., Duggan, D. & Yulianto, J. 2020. Catch per unit effort dynamic of yellowfin tuna related to sea surface temperature and chlorophyll in Southern Indonesia. *Fishes*, **5(28)**: 1-16. https://doi.org/10.3390/fishes5030028

Wiyono, E.S. 2001. Optimasi Manajemen Perikanan Skala Kecil di Teluk Palabuhanratu, Jawa Barat. IPB University, Bogor. (Indonesian).

Zainuddin, M. 2011. Skipjack tuna in relation to oceanographic conditions of Bone Bay using remotely sensed satellite data. *Jurnal Ilmu dan Teknologi Kelautan Tropis*, **3**: 82-90. https://doi.org/10.29244/jitkt.v3i1.7837