

Utilization of remote sensing data to analyze the influence of oceanographic dynamics on scad fish (*Decapterus ruselli*) abundance in Kendari Waters, Indonesia

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Abstract. Scad fish (*Decapterus ruselli*) is an important pelagic fishery commodity in the Kendari Waters, but fluctuations in catch are often influenced by oceanographic dynamics. This study analyzed the relationship between oceanographic conditions and the abundance of scad fish based on fishermen's catch per unit effort (CPUE) data from 2022 and satellite-derived parameters, including sea surface temperature (SST), salinity (SSS), chlorophyll-a (CHL-a), and sea surface height (SSH). Spatial-temporal analyses were performed using Pearson correlation. Results revealed distinct seasonal variations with the highest CPUE observed in September (~665 kg trip⁻¹). Significant negative correlations were found between SST ($r=-0.36$; $p=0.041$) and SSH ($r=-0.30$; $p=0.048$), indicating that lower temperatures and sea surface heights correspond to higher fish abundance reflecting the influence of upwelling processes that enhance nutrient availability and productivity. These findings confirm that physical oceanographic factors are more dominant than chemistry or biology in determining the availability of scad fish. The eastern period (August–October) was identified as the most productive and potential phase for fishing activities. This research provides a scientific basis for season-based fisheries management and oceanographic dynamics, while encouraging the sustainable use of fish resources.

Keywords: Scad fish, oceanographic dynamic, Kendari waters, remote sensing, Pearson

1 Introduction

Kendari waters, located on the southeast coast of Sulawesi Island, is one of the important fishing ground in eastern Indonesia, particularly for small pelagic fisheries such as scad fish (*Decapterus ruselli*), which play a vital role in supporting local fishermen's livelihoods and

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the coastal economy [1-3]. The abundance and spatial-temporal distribution of pelagic fish are strongly influenced by oceanographic dynamics including sea surface temperature (SST), sea surface salinity (SSS), chlorophyll-a (CHL-a), and sea surface height (SSH) [4-6].

These parameters can have an impact on fish abundance [7] because small pelagic fish tend to follow zones with optimal environmental conditions for growth [8], spawning and even food availability [9]. In tropical waters such as Indonesia, variations in SST and SSH are closely related to upwelling and downwelling processes that regulate nutrient availability and primary productivity [10-12]. Meanwhile, SSS provides insight into water mass movement and mixing, which affect the physiological tolerance and distribution range of fish populations [13].

SSH, as an indicator of vertical water column dynamics, is often associated with the intensity of upwelling and the presence of nutrient-rich waters that can enhance biological productivity [14]. The integration of these parameters provides a more comprehensive understanding of how physical oceanographic processes drive ecosystem productivity and fish abundance.

Remote sensing data technology has become an essential approach in modern marine studies for monitoring oceanographic conditions over large spatial and temporal scales [14-15]. Satellite-derived data such as SST, CHL-a, SSS, and SSH have been widely used to predict potential fishing zones and assess pelagic fish distributions in several Indonesian regions, including the Java Sea [16] and the Makassar Strait [17]. However, specific studies in Kendari Waters remain scarce, especially those that quantitatively integrate catch per unit effort (CPUE) data with multi-parameter satellite observations.

Filed reports indicate that scad fish catches in several fishing ports in Southeast Sulawesi have shown fluctuating and even declining trends over the past five years, which are suspected to be linked to environmental variability, increased fishing pressure, and shifting migration routes due to climate change [18-19]. Yet, the mechanisms connecting these catch fluctuations with oceanographic parameters in Kendari Waters have not been thoroughly elucidated.

Therefore, this study aims to analyze the influence of oceanographic dynamics—represented by SST, CHL-a, SSS, and SSH—on the abundance of scad fish (*Decapterus ruselli*) using integrated satellite data and fishermen's CPUE records. This research is the first to apply remote sensing-based oceanographic data to quantify the spatial-temporal relationship between fish abundance and environmental variability in Kendari Waters. The findings are expected to provide a scientific basis for adaptive, season-based fisheries management and contribute to the sustainable utilization of pelagic fish resources in Southeast Sulawesi.

2 Methods

2.1 Study area

This study was conducted in Kendari Waters, Southeast Sulawesi, Indonesia, located approximately between 122°- 123°E and 3°- 4°S covering Kendari Bay and adjacent coastal waters directly connected to eastern Banda Sea [20] (**Fig. 1**). The bathymetry, the waters of Kendari are relatively shallow with an average depth of less than 30 - 60 meters, with steep slopes extending toward offshore areas. Ocean circulation in this region is influenced by the Indonesian Throughflow (ITF), which transports warm Pacific waters through the Maluku and Banda Seas. During the southeast monsoon (June-August), strengthened current from the

Banda Sea promote upwelling along pasts of eastern Sulawesi, bringing nutrient-rich subsurface waters to the surface and enhancing primary productivity [21].

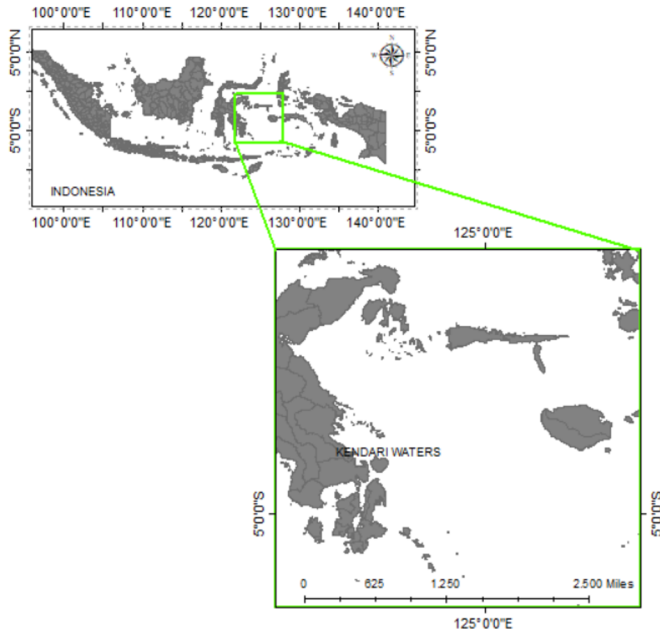


Fig. 1. Study area covering the Kendari Waters.

2.2 Fisheries and oceanographic data

Monthly fisheries catch of scad fish (*Decapterus ruselli*) were obtained from fishermen landing at Kendari Fishing Port (PPI Kendari) throughout 2022. The data included total catch (kg) and fishing effort (number of trips), which were used to calculate Catch Per Unit Effort (CPUE). Then, oceanographic parameters obtained from satellite sources: Sea Surface Temperature (SST) and Chlorophyll-a (CHL-a) were derived from the MODIS-Aqua sensor with spatial resolution of 4 km and a monthly temporal resolution, Sea Surface Salinity (SSS) and Sea Surface Height (SSH) were obtained from the Copernicus Marine Environment Monitoring Service (CMEMS) with a 0.25° spatial resolution and monthly temporal resolution (**Table 1**).

Table 1. Satellite imagery data source.

No	Oceanography parameter	Units / Resolutions	Data source	Relevance to scad fish (<i>D. ruselli</i>)
1	Sea Surface Temperature (SST)	°C	https://www.modis.gsfc.nasa.gov	Determining optimal thermal habitat; affect the distribution and migration of scad fish. Changes in SST can indicate the phenomenon of upwelling/downwelling.
2	Sea Level Salinity	psu	https://data.marine.copernicus.eu/	Describe the character of water masses; affects habitat preferences and physiological tolerance of fish.

No	Oceanography parameter	Units / Resolutions	Data source	Relevance to scad fish (<i>D. ruselli</i>)
3	Chlorophyll-a (CHL-a)	mg m ⁻³	https://www.modis.gsfc.nasa.gov	Primary productivity indicators; The high concentration of chlorophyll-A indicates the potential availability of natural feed (zooplankton) for scad fish.
4	Sea Surface Height (SSH)	m	https://data.marine.copernicus.eu/	Indicates the vertical dynamics of the sea; Low SSH related upwelling (high nutrients) which can increase fish abundance.

All satellite datasets were downloaded in NetCDF format and converted to GeoTIFF using SeaDAS 8.3 (NASA OBP) and QGIS 3.30 for further spatial analysis.

Satellite-derived oceanographic parameters used in this study were not directly validated using in-situ CTD measurements due to the absence of concurrent field observations during the study period. In addition, the consistency of satellite-derived parameter variability with known seasonal oceanographic processes in the Southeastern Sulawesi waters especially Kendari water provides further confidence in the reliability of the datasets. Similar approaches have been applied in previous studies where in-situ validation data were limited.

2.3 Data analysis

CPUE was calculated to standardize fishing effort and allow spatial and temporal comparison of scad fish abundance using the following equation:

$$CPUE = \frac{C}{E} \tag{1}$$

Where C is Total catch (kg) and E is Capture attempt (number of trips or length of time of capture operation). CPUE calculations aim to normalize the capture data so that it can be compared between different locations and times. In addition, oceanographic parameter data including SST, SSS, CHL-a, and SSH obtained through remote sensing data were downloaded for the same period as CPUE data and then extracted at the coordinates of the fishing location. The goal is to be analyzed spatially and temporally. The stages of the data analysis process are described in general through the following figure.

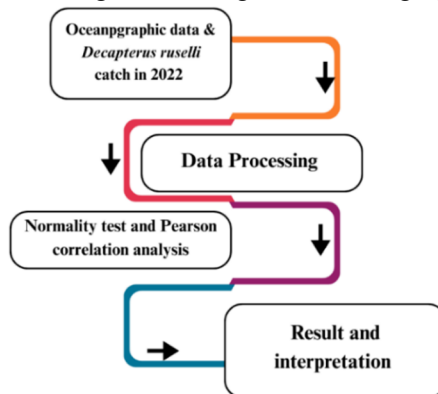


Fig. 1. Flowchart of research analysis.

The processed datasets were statistically tested using the Shapiro-Wilk normality test to test the null hypothesis that the sample is derived from normal distribution [23]. Normality testing is important because correlation testing using parametric statistical assumptions (Pearson Correlations) requires data normality or residual for the validity of inference (p-value and confidence interval) as follows:

H_0 = Normal distribution sample

H_1 = Sample not normally distributed

For statistical testing (W test) the following equations are used:

$$W = \frac{(\sum_{i=1}^n a_i x_{(i)})^2}{\sum_{i=1}^n (x_i - X)^2} \tag{2}$$

Information:

$x_{(i)}$ = observed values that have been ordered upwards (statistical order), $I = 1, \dots, n$.

x_i = the value of observation I (not yet sorted)

\bar{x} = average sample

a = weight dependent on sample size n

Pearson correlation analysis is used to measure the strength and direction of the linear relationship between independent variables (oceanographic parameters such as SSS, SSS, chlorophyll-a and SSH) and bound variables (scad fish abundance represented by CPUE values) [24]. This correlation is expressed by the coefficient r which has a value range between -1 to +1 (**Table 2**). The general equation of Pearson's correlation coefficient is:

$$r = \frac{\sum_{i=1}^n (X_i - X)(Y_i - Y)}{\sqrt{\sum_{i=1}^n (X_i - X)^2 \sum_{i=1}^n (Y_i - Y)^2}} \tag{3}$$

Information:

X_i = Value of the oceanographic parameter i - i

Y_i = the value of the CPUE i - i

X = average oceanographic parameters

Y = average CPUE amount

n = number of observations

The strength of correlation was classified as follows:

Table 2. Classification of correlation strength based on r -value (Pearson correlation).

r_value	Power of Relationships	Direction of Contact */**
0.00 – 0.19	Very weak	Positive / Negative
0.20 – 0.39	Weak	Positive / Negative
0.40 – 0.59	Common	Positive / Negative
0.60 – 0.79	Strong	Positive / Negative
0.80 – 1.00	Very powerful	Positive / Negative

*The direction of the positive relationship indicates an increase in the X variable (oceanographic parameters) followed by an increase in the Y variable (Fish abundance), and vice versa.

** The direction of the negative relationship shows that the increase in variable X is followed by a decrease in variable Y .

The last steps is result and interpretation, The result from the correlation analysis were interpreted to identify which oceanographic parameters had the strongest influence on scad

fish abundance. Seasonal and spatial trends were analyzed to support conclusions on how oceanographic variability affects fish availability in Kendari waters.

3 Results and discussions

3.1 Spatial conditions of scadfish (*Decapterus ruselli*) in Kendari waters

The spatial distribution of scad fish in Kendari Waters shows that there is a fairly clear variation in abundance between fishing locations throughout the year. The CPUE value obtained from the catch record at PPI Kendari in 2022 ranges from 288.77 kg trip⁻¹ to 664.97 kg trip⁻¹ (**Fig. 3**).

The results of CPUE data showed the highest catch in September (~665 kg trip⁻¹) followed by the secondary peak in March (~615 kg trip⁻¹). Meanwhile, the lowest CPUE value was recorded in December (~289 kg trip⁻¹).

This seasonal variation of the CPUE indicates that catch rates are influenced by oceanographic dynamics and possibly also by the pattern of capture efforts. CPUE upgrades in March and September are likely to coincide with an optimal environment. On the other hand, the decline in CPUE in December was related to less favorable conditions or changes in fish migration patterns.

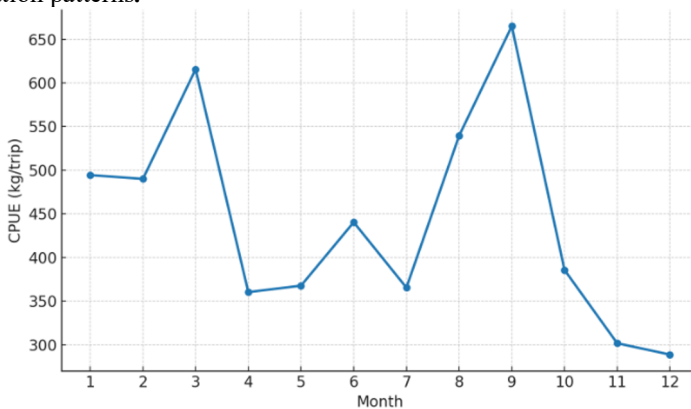


Fig. 3. Monthly variation of Catch Per Unit Effort (CPUE) of *Decapterus ruselli* in Kendari Waters during 2022.

3.2 Spatial conditions of oceanographic parameters

To analyze the condition of oceanographic parameters in Scad fish, data selection is carried out according to data trends from low, medium to high, so that spatial analysis can be carried out to obtain the relationship of each parameter to the catch.

Based on monthly average data, oceanographic parameters in Kendari waters show seasonal variations that are quite clearly reflective of the dynamics of tropic waters which are influenced by oceanographic phenomena such as upwelling (**Table 3**).

Table 3. Monthly variation of oceanographic parameters (SST, SSS, CHL-a, and SSH) and corresponding CPUE of *Decapterus ruselli* in Kendari Waters during 2022.

Month	SST	SSS	CHL	SSH	Trend catches	CPUE
1	30.50	33.87	0.20	0.74	Common	494.39
2	30.52	33.80	0.14	0.75	Common	490.02

Month	SST	SSS	CHL	SSH	Trend catches	CPUE
3	30.25	33.65	0.16	0.74	High	615.62
4	30.26	33.72	0.11	0.71	Low	360.32
5	30.70	33.64	0.24	0.71	Low	367.70
6	30.31	34.01	0.14	0.69	Common	440.38
7	28.30	34.43	0.28	0.67	Low	365.46
8	28.44	34.18	0.51	0.65	Common	539.43
9	29.48	34.01	0.20	0.65	High	664.97
10	30.78	33.73	0.17	0.71	Low	385.74
11	30.60	33.74	0.22	0.73	Low	301.74
12	31.22	34.23	0.17	0.75	Low	288.77

Overall, the combination of low SST, low SSH, high SSS and high CHL-a in the July-September period showed highly favorable oceanographic conditions for increased scad fish abundance. This is in line with the pattern of Indonesia's eastern season which is known as the peak period of aquatic productivity.

3.2.1 Sea surface temperature (SST)

Sea surface temperature is one of the key factors that affect the spatial and temporal distribution of scad fish. This species chooses an optimal temperature ranging from 28 – 30°C to support metabolism and swimming activities so that it actively forages. If the temperature is low due to oceanographic phenomena such as upwelling, increasing nutrients triggers an explosion of chlorophyll-a and the food supply chain in the waters.

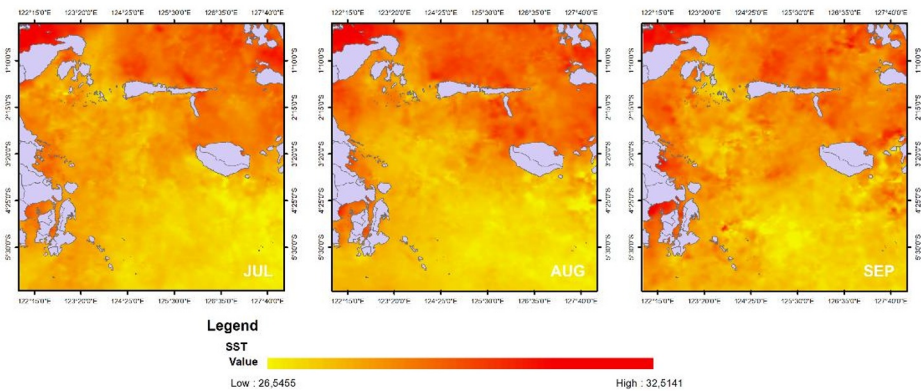


Fig. 4. Monthly spatial distribution of Sea Surface Temperature (SST) in Kendari Waters during July–September 2022.

Based on spatial analysis, it shows that the sea surface temperature in Kendari Waters is in the range of 26.54°C to 32.51°C (**Fig. 4**). In July, relatively lower temperatures are seen in the eastern and southeastern regions. Meanwhile, in August, the area with low temperatures expanded, especially in the southern and northeastern parts of Kendari which indicated a peak of upwelling activity due to easterly winds so that this phenomenon carried a mass of nutrient-rich cold water from the bottom layer to the surface. In September, the peak season of scad fishing, warm temperature patterns began to dominate again in some

areas, especially in waters near the coast and the west side. This condition indicates that the upwelling process is starting to weaken, but the productivity of the waters is still relatively high.

3.2.2 Sea surface salinity (SSS)

The results of spatial analysis of sea surface salinity show that there are quite clear seasonal variations in Kendari Waters with a value range of 32.50 – 35.09 psu (**Fig. 5**). The results of data visualization showed that in July, high salinity was close to 35 psu, observed in the eastern and southern regions of the waters directly connected to the Banda Sea. Entering August, high salinity persists in the eastern and southern regions, indicating that the supply of saltwater masses from the open sea is still coarse. However, some areas with low salinity also expanded compared to the previous month. Furthermore, in September, distribution patterns showed that high salinity was still dominant in the eastern and southern regions.

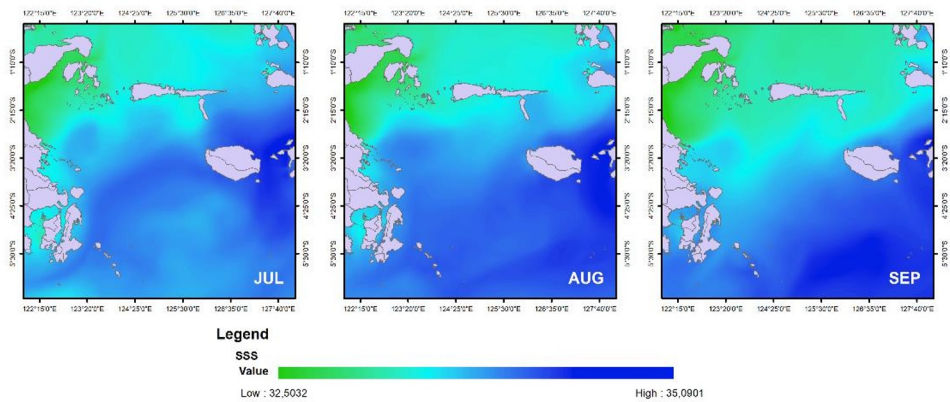


Fig 2. Monthly spatial distribution of Sea Surface Salinity (SSS) in Kendari Water during July–September 2022.

3.2.3 Chlorophyll-a (CHL-a)

Based on the results of spatial analysis, seasonal fluctuations in chlorophyll-a conditions range from 0.073 mg m⁻³ to 0.977 mg m⁻³ with a seasonally varying contribution (**Fig. 6**). In July, concentrations began to increase, especially in the west and south coastal regions, signaling the beginning of a period of high productivity. August is the peak of productivity with the contribution of wider chlorophyll-a concentrations, especially in the southern coastal waters of Southeast Sulawesi and some eastern regions triggered by upwelling. Then entering September, chlorophyll-a concentrations began to decline but productivity still persisted in coastal areas. This condition is an optimal phase of primary productivity that greatly supports the availability of feed for flying fish so as to increase the catch of fishermen in this region.

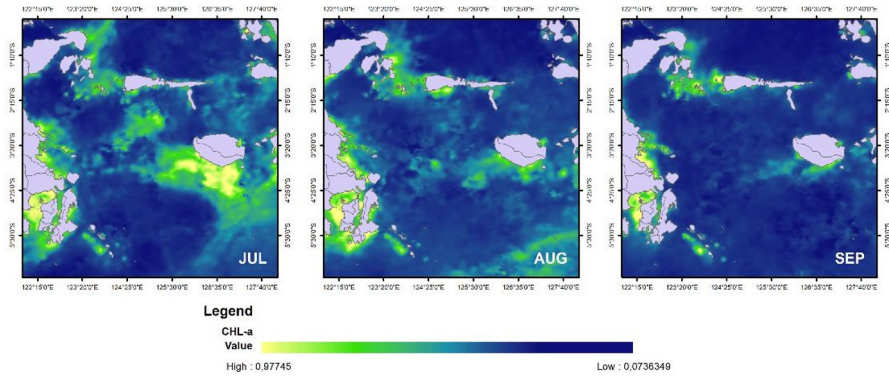


Fig. 6. Monthly spatial distribution of chlorophyll-a (CHL-a) in Kendari Waters during July – September 2022.

3.2.4 Sea surface height (SSH)

Sea level is an indicator of water mass dynamics and can be used to detect the phenomenon of upwelling. Low SSH often correlates with nutrient-rich waters. The variability of sea level high values affects the variability of the catch of scad fish (*Decapterus ruselli*). Based on the results of data visualization, from July to September, the spatial variation of the SSH value was relatively subtle with a value of 0.596 – 0.715 m (Fig. 7). In that period, several coastal areas with low SSH were seen. In September, the SSH pattern was relatively stable with slight changes in the eastern and southern coastal areas.

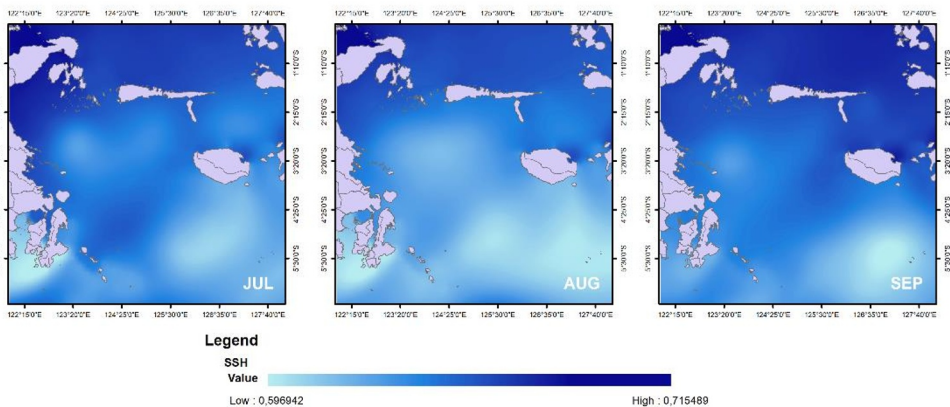


Fig. 3. Monthly spatial distribution of Sea Surface Height (SSH) in Kendari Waters during July–September 2022.

3.3 The relationship between oceanographic parameters and the catch variability of Scad Fish (*Decapterus ruselli*)

Based on the results of the analysis of oceanographic conditions, a Shapiro-Wilk data normality test was carried out to determine the distribution of oceanographic parameter data and normal or abnormal catch data (Fig. 8).

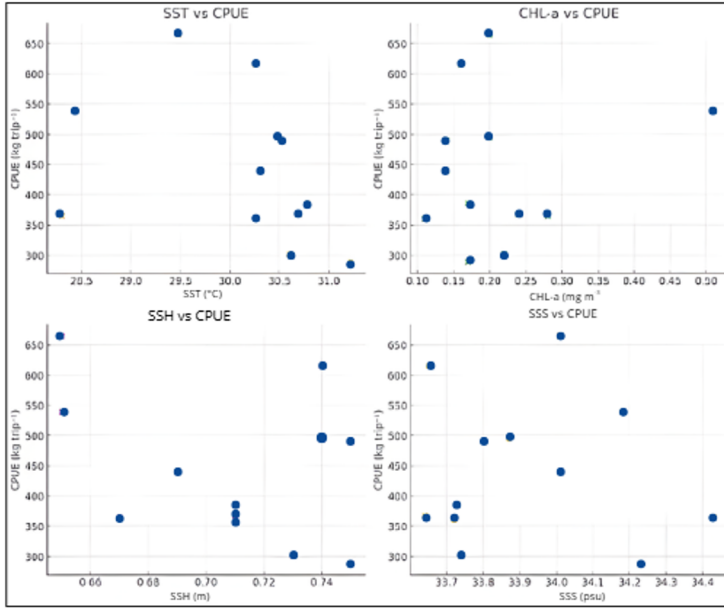


Fig. 4. Scatter plots showing the relationships between CPUE and oceanographic parameters in Kendari Waters during 2022.

Fig. 8 and **Table 4** illustrate the relationship between Catch Per Unit Effort (CPUE) and oceanographic parameters, including sea surface temperature (SST), sea surface salinity (SSS), chlorophyll-a (CHL-a), and sea surface height (SSH), in Kendari Waters during 2022. The scatter plots in (**Fig. 8**) show that SST and SSH display clear negative trends with CPUE, which is further supported by the Pearson correlation analysis in (**Table 4**), where both parameters exhibit significant negative correlations ($r = -0.36$, $p = 0.041$ for SST; $r = -0.30$, $p = 0.048$ for SSH).

These findings suggest that lower SST and SSH values are associated with higher fish catches, reflecting the influence of upwelling processes during the southeast monsoon season. The upwelling brings nutrient-rich subsurface water to the surface, enhancing phytoplankton productivity and attracting pelagic species such as *Decapterus ruselli* to the productive areas. The inverse relationship between SSH and CPUE also indicates that regions with lower sea surface height correspond to higher productivity zones, which are favorable for fish aggregation. Chlorophyll-a concentration shows a weak positive correlation with CPUE ($r = 0.15$, $p = 0.082$), as seen in the upper-right plot of (**Fig. 8**). Although this relationship is not statistically strong, it aligns with ecological theory that areas of higher primary productivity (high CHL-a) tend to support greater fish abundance. In contrast, salinity (SSS) shows a very weak and non-significant relationship ($r = -0.07$, $p = 0.512$), suggesting that salinity variations were relatively small and did not notably affect fish distribution in the study area.

Table 3. Pearson correlation results between oceanographic parameters and Catch Per Unit Effort (CPUE) of *Decapterus ruselli* in Kendari Waters during 2022.

Parameter	r-value	p-value	R ²	Correlation Type	Relationship
SST	-0.36	0.041	0.13	Negative	Significant
SSS	-0.07	0.512	0.01	Negative	Not significant
CHL-a	0.15	0.082	0.02	Positive	Weak
SSH	-0.30	0.048	0.09	Negative	Significant

The observed relationship between SST, SSH, and scad fish abundance can also be interpreted within the context of large-scale climate variability. Previous studies have shown that ENSO and Indian Ocean Dipole (IOD) events strongly influence upwelling intensity and primary productivity in the Banda Sea and surrounding waters. Positive IOD phases and El Niño conditions tend to enhance upwelling during the southeast monsoon, leading to lower SST and SSH and increased chlorophyll-a concentration. Although this study focuses on a single year, the oceanographic patterns observed in Kendari Waters during the eastern season are consistent with ENSO–IOD-driven circulation and Indonesian Throughflow (ITF) dynamics reported in earlier studies.

4 Conclusion

Seasonal variation in the abundance of scad fish (*Decapterus ruselli*) in Kendari Waters is strongly influenced by oceanographic dynamics, particularly sea surface temperature (SST) and sea surface height (SSH), which serve as key indicators of upwelling processes. Lower SST and SSH values are associated with higher catch rates, identifying the eastern season (August–October) as the most productive fishing period. Chlorophyll-a (CHL-a) showed a weak positive relationship with fish abundance, indicating its supportive role in enhancing primary productivity, whereas sea surface salinity (SSS) exhibited no significant effect. These findings confirm that physical oceanographic factors play a dominant role over chemical or biological factors in determining the spatial and temporal variability of *D. ruselli* abundance. The results provide a scientific basis for seasonally adaptive and sustainable fisheries management in Kendari Waters. Future research should incorporate in-situ measurements and long-term data to better assess the influence of large-scale climatic phenomena such as ENSO and the Indian Ocean Dipole (IOD) on marine productivity and fishery dynamics in this region.

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