Original Research Article

Evaluating VIIRS Sensor Capabilities for Light Fishing Detection and Oceanographic Analysis in Tegal Northern Waters, Indonesia

ABSTRACT

Aims: To evaluate VIIRS sensors' capability in detecting light fisheries distribution in Tegal Northern Waters and assess related oceanographic parameters.
Study design: Observational study analyzing VIIRS Day-Night Band data and oceanographic parameters.
Place and Duration of Study: Tegal Northern Waters, Indonesia; 2019-2021, and data in-situ 2022.
Methodology: VIIRS Day-Night Band data was analyzed alongside sea surface temperature (SST) and chlorophyll-a data. Field verification was conducted to assess accuracy.
Results: Highest vessel detection occurred during transitional seasons (March-May and September-November), lowest during western monsoon (December-February). Fishing grounds concentrated 5-9 miles offshore (6°42'0" - 6°48'0" S and 109°15'0" - 109°21'0" E). Optimal conditions: SST 29.5-30°C, chlorophyll-a 0.5 mg/m^3. VIIRS imagery accuracy: 97% for SST, 94.68% for chlorophyll-a detection.
Conclusion: VIIRS sensors effectively map light fishing spatial distribution and relate to key oceanographic parameters, providing valuable data for optimizing pelagic fish resource utilization. This approach offers an improved method for identifying potential fishing zones and understanding spatiotemporal patterns of nocturnal fishing.

Keywords: Chlorophyll-a, Nocturnal fishing, Oceanographic parameters, Sea surface temperature.

1. INTRODUCTION

Light fishing refers to the practice of utilizing light-based equipment for fishing activities. The distribution of light fishing vessels is predominantly observed in the Northern Waters of Tegal, Central Java. The fishermen of North Java, particularly those from PPP (Coastal Fishing Port) Larangan, Tegal Regency, employ mini purse seine as their light-assisted fishing gear, with fleet sizes of less than 30 GT. Each type of fishing gear is characterized by a distinct level of illumination. The intensity of lighting employed by each fishing apparatus can significantly influence the fish catch in these waters.

The fisheries activities in Tegal Waters are predominantly characterized by small pelagic fisheries, which are integral to the development of the fisheries sector. As noted by Khatami and Setyobudiandi (2019) and Imron et al. (2020), the small pelagic species harvested by fishermen in Tegal Waters include anchovy (*Stolephorus* sp), sardine fish (*Sardinella fimbriata*), and mackerel (*Rastrelliger* sp.). The substantial potential of pelagic resources positively influences the production of pelagic fish fisheries in Tegal City, Tegal Regency, and the surrounding areas. Nevertheless, the limited adoption of technology by Tegal fishermen has resulted in suboptimal utilization of pelagic fisheries resources.

Current knowledge regarding potential fishing areas for nocturnal light fishing fleets remains limited. Consequently, there is a need for research employing remote sensing techniques. Remote sensing can be utilized to examine the spatiotemporal distribution of light fishing activities in relation to sea surface temperature (SST) and chlorophyll-a concentrations, thereby identifying potential fishing zones. This approach is anticipated to enhance the optimization of pelagic fish resource utilization in the Northern Waters of Tegal by analyzing data that overlays vessel positions with chlorophyll-a and SST

parameters, ultimately facilitating fishermen's operations. As noted by Li et al. (2023), remote sensing is capable of observing nocturnal fishing activities that depend on artificial lighting.

The detection of ship lights can be effectively conducted using the VIIRS sensor, specifically through the Monthly Day-night Band (DNB) channel. This sensor is applicable for various purposes, including the observation of light intensity associated with human activities, particularly those related to fisheries. The VIIRS sensor is equipped with the Day and Night Band (DNB), which is specifically designed to measure nocturnal light, such as the artificial illumination emitted by fishing vessels during nighttime operations. This sensor is capable of detecting light from activities occurring in visible waters, regardless of whether the intensity is low or high, within the wavelength range of 500 to 900 nm (Gaol et al., 2019).

Fishing activities in the Tegal waters predominantly employ a one-day fishing system. The typical yield from each fishing expedition is not consistently optimal, primarily because fishermen determine fishing locations based solely on their personal experience. The operation of the mini purse seine light boat is conducted nocturnally, with varying locations for each fishing trip. Consequently, it is imperative to undertake research on the application of remote sensing technology to detect fishing vessels equipped with light-based fishing aids and to analyze the spatio-temporal distribution of such fishing activities. The objectives of this study were to evaluate the capability of the VIIRS sensor in detecting the distribution of light fisheries within the fishing areas of Tegal Northern Waters and to assess the oceanographic parameters, specifically sea surface temperature (SST) and chlorophyll-a, in relation to the distribution of light fisheries identified by VIIRS sensors during nocturnal fishing operations.

2. MATERIAL AND METHODS

2.1 Data Collection

The Day and Night Band (DNB) channel of the VIIRS sensor presents substantial advantages for the detection of nocturnal fishing activities. The data utilized, spanning from 2019 to 2021, is accessible for download on the official NOAA website (https://www.ngdc.noaa.gov/eog/viirs/download_indo_boat.html). The sensor's capability to measure light intensity across a broad spectrum of wavelengths renders it particularly effective in identifying artificial illumination from fishing vessels. This functionality allows researchers to map the spatial distribution of light-emitting fishing fleets with enhanced accuracy and precision. Moreover, the integration of VIIRS data with oceanographic parameters, such as sea surface temperature and chlorophyll-a concentrations, can yield valuable insights into the relationship between fishing activities and marine environmental conditions.

The samples utilized in this study comprise sea surface temperature (SST), chlorophyll-a, temporal data, and the coordinates of the capture location, which will be corroborated with image data to assess the accuracy of capture in relation to potential capture areas. A purposive sampling technique was employed, adhering to a predetermined capture point. The primary data collected consist of in situ water parameter data that are instrumental in determining fishing areas. This primary data, obtained directly from the field, include chlorophyll-a and sea surface temperature data, acquired during hauling operations using mini purse seine fishing methods. Sampling was conducted over a three-day period, from November 24 to 27, 2022, with distinct points for each collection. The sampling process adhered to the geographical positioning of fishing activities, as measured using GPS.

2.2 Data Processing

Data processing for the detection analysis of the distribution area of light fisheries begins with the collection of data from satellite detection results, which are downloaded via the website. The light and sea surface temperature data utilized are daily data collected in October 2022. VBD light data in the waters are downloaded in CSV format, which can be directly processed using Arcmap 10.8 software. The VBD data employed in detection utilizes QF 1 (strong detection). The point with QF 1 is selected from the VBD data because it can be confirmed that the quality of QF 1 corresponds to a fishing vessel. The VBD data is then SST as QF 1 detection (boat detection) in Arcmap 10.8 software, while SST and chlorophyll-a data are initially extracted and cropped using SeaDAS software in TXT format. Subsequently, the -a distribution.TXT data is processed using Microsoft Excel to select the data extracted from the geobiophysical index required, namely latitude, longitude, and the value of each parameter. The processed SST results are then overlaid with data on the distribution of fisheries lights to ascertain the value of sea surface temperature and chlorophyll-a at the processed point. The final stage is the layout process, which produces a ship detection distribution map with each oceanographic parameter. Data processing is conducted to determine the map of fishing areas based on the distribution of light fisheries with SST and chlorophyll

2.3 Data Analysis

2.3.1 SST primary data analysis

In this study, primary data collection involved the identification of five sampling points or stations, the coordinates of which were determined using GPS technology. Sea surface temperature data were obtained directly at each sampling location by immersing a thermometer into the water surface.

2.3.2 Chlorophyll-a primary data analysis

Primary data analysis commences with the collection of chlorophyll-a data by obtaining a 1-liter water sample at each designated capture point. This sample is subsequently filtered using filter paper, followed by the application of a $MgCO_3$ solution and aquabidet to prevent degradation of chlorophyll-a. The filter paper, now containing chlorophyll-a, is folded and wrapped in aluminum foil. It is then stored at freezer temperatures for subsequent laboratory-scale testing. Laboratory analysis is conducted at the Faculty of Fisheries and Marine Science, Universitas Diponegoro Laboratory utilizing a spectrophotometer. Prior to spectrophotometric analysis, acetone is added to the filter paper, which is placed in a test tube and left to stand for two nights to ensure complete dissolution of chlorophyll-a into the acetone. Chlorophyll analysis is performed using a UV-Vis spectrophotometer, with samples analyzed at a wavelength of 750 nm for turbidity correction, and at 664 nm, 647 nm, and 630 nm. The concentration of chlorophyll-a is then calculated using the following equation.

Ca = 11.85 (OD664) – 1.54 (OD647) – 0.08(OD630)

Chlor-a (mg/m^3)=(Ca × extract volume)/(Volume of sample (L))

Information:
(OD664), (OD647), (OD630)   : Spectrophotometer measurement value
Ca   : Chlorophyll-a concentration (µg/ml)

2.3.3 Overlay result data analysis

The present study employs a descriptive analysis methodology utilizing overlay results from ArcGIS software to ascertain the values among research variables. This analysis involves examining the distribution of ship point positions corresponding to each chlorophyll-a and Sea Surface Temperature (SST) value. The distribution of points in the Northern Waters of Tegal was subsequently represented in a graph illustrating the distribution of points for each SST and chlorophyll-a value. Spatial analysis was conducted visually through imagery to determine the distribution of SST, chlorophyll-a, and Vessel-Based Data (VBD). Temporal analysis of chlorophyll-a concentration, SST, and VBD was performed based on the data collection timeline. Data processing was executed for each parameter, such as chlorophyll-a with ship points and SST with ship points.

3. RESULTS AND DISCUSSION

3.1 Vessel Detection Results at Night

Table 1.   Number of VBD ship detections 2019 - 2021

| Year | Number of Vessel |
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Des
2019	89	44	101	230	496	85	17	10	76	204	216	64
2020	89	17	55	214	118	114	34	20	125	45	136	65
2021	5	3	68	154	52	103	135	46	78	149	80	69
$\bar{X}$	61	21	75	199	222	101	62	25	93	133	144	66

Table 1 presents the average vessel detection results for the years 2019 to 2021. According to the data, the highest number of vessel was recorded during the transitional seasons 1 (March, April, and May) and 2 (September, October, and November), whereas the lowest number was observed during the western monsoon (December, January, and February). During the western season, wave conditions are generally more severe compared to the eastern monsoon, with a higher frequency of large waves occurring over a certain period. Conversely, fishing activities are more prevalent during the eastern and transitional seasons (Imron et al., 2021). Tani et al.(2020), fishing activities are significantly affected by meteorological conditions and oceanic wave patterns. In the Java Sea, the westerly season, which extends from late December to February,

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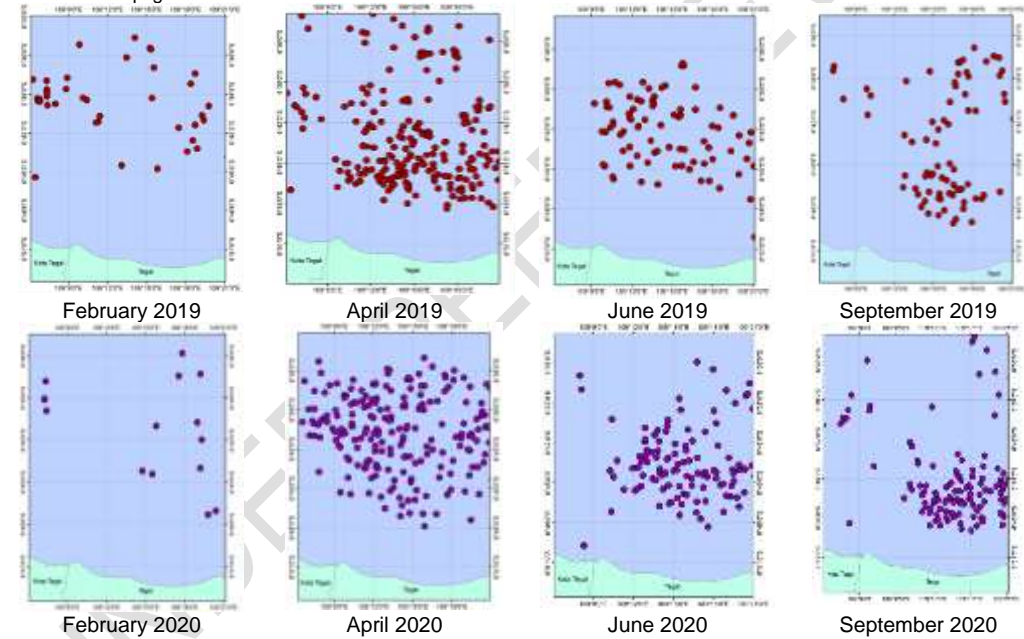Commented [SDi35]: past tense
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is characterized by large waves. These waves are primarily a consequence of high rainfall and strong winds during this period.

Interviews with Tegal Regency fishermen revealed that fishing activities in the Tegal Northern Waters are influenced by the fishing season, categorized as famine, normal, and peak, as well as by the wave conditions resulting from monsoon winds. Fishermen from the Tegal Regency indicate that fishing operations are more frequent during transition 1 and transition 2 seasons, as these periods are characterized by relatively low wave heights, with peak fishing seasons occurring in April and October. According to Zeny et al. (2022), the peak purse seine season in WPP 712 is observed in April, May, October, and November, whereas the lean season occurs in June and August, with other months experiencing a medium season.

The spatial distribution of fishing vessels utilizing lights, as detected by VIIRS, for the 2019-2021 season is illustrated in (Figure 1). The west season is represented by February, the first transition season by April, the east season by June, and the west season again by September. The data obtained from the VIIRS sensor detection indicate that the fishing grounds in Tegal North Waters exhibit varying quantities, although the patterns remain relatively consistent. As noted by Siregar et al. (2016), fluctuations in the number of VIIRS sensor detections can be attributed to several factors, including cloud cover, which obstructs satellite data recording. Furthermore, the number of vessels detected by the VIIRS sensor in these waters is influenced by fishermen's operational decisions, which are often guided by lunar phases. During the bright moon phase, fishermen typically reduce their fishing activities because of the diminished effectiveness of artificial light in attracting fish. According to Nurlindah et al. (2017), the bright moon phase exerts a more substantial influence on fish catch than the attraction of shiplights.

February 2019   April 2019   June 2019   September 2019

February 2020   April 2020   June 2020   September 2020

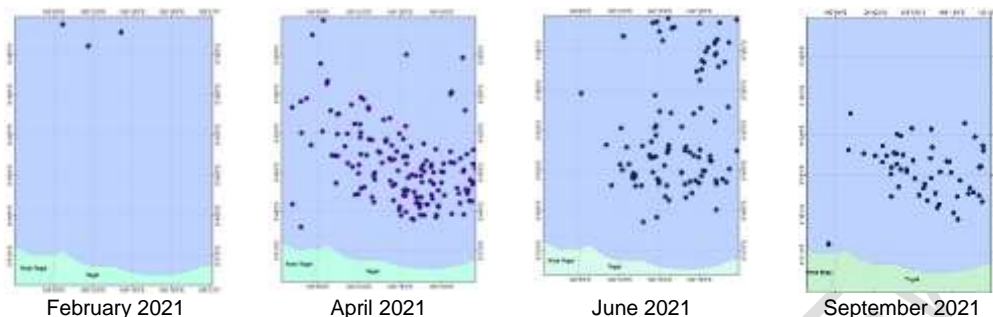|			
February 2021	April 2021	June 2021	September 2021

Fig. 1. VBD detection results in Tegal North Waters

In terms of spatial distribution, the fishing grounds in the northern waters of Tegal are classified as line II fishing areas, which are located more than four nautical miles from the coastline. The fishing zones utilized by mini-purse seine vessels, which are based on PPP (Coastal Fishing Port) Larangan, are concentrated in the northern waters of Tegal Regency, specifically at $6^0$42'0" - $6^0$48'0" S and $109^0$15'0" - $109^0$21'0" E, with a distance ranging from 5 to 9 miles from the coast. These regions serve as the primary base for the small pelagic fishery fleet employing mini-purse seine gear, resulting in a significant concentration of vessel distribution in these areas.

The distribution intensity of vessels during the western season (DJF) appeared to be lower than that during other seasons. This phenomenon is attributed to the fact that fishing operations were limited during this period because of the prevalence of high sea waves. As noted by Wicaksana et al. (2015) and Nabila et al. (2019), high waves occur frequently in the western season, particularly in February, with significant wave heights in the Java Sea ranging from 0.5 to 2.5 meters. In contrast, the distribution of vessel operations during the first transitional season (MAM) indicated a shift in the fishing patterns of light vessels, diverging from those observed in the western season. During this transitional period, many vessels migrated northward, a trend corroborated by Sarangi and Nagendra (2022), who reported that in May, fishing vessels moved northward due to the onset of the spawning season. The intensity of fishing point distribution increased, with the highest concentration of vessels observed in April.

During the East season (JJA), the highest concentration of ships is observed at coordinates $6^0$42'0" - $6^0$48'0" S and $109^0$12'0"- $109^0$18'0" E. The number of ships during the East season has decreased compared to the previous season, attributed to the East season being a lean period for pelagic fishing by Tegal fishermen. During Transitional Season II (SON), ship operations tend to be closer to land, with a concentration of ships at coordinates $6^0$45'0" - $6^0$51'0" S and $109^0$12'0"- $109^0$18'0" E. The increase in vessel operations detected from 2019 to 2021 is attributed to Transitional Season II being the peak season for pelagic fishing by Tegal fishermen. According to Imron et al. (2021), during the East season and Transitional Season II, fishing activities are generally not significantly hindered, as the dry season's water conditions are relatively favorable, allowing for continued fishing activities in Transitional Season II.

3.2 Light Fishing Detection with SST Parameter

As illustrated in Figure 2, the majority of fishing vessels are observed in waters where the sea surface temperature ranges from 29.5℃ to 30 ℃. According to Syah and Abdillah (2021) and Kristiyani et al. (2020), small pelagic fish exhibit adaptability within a temperature range of 28–30 °C, with optimal fishing conditions typically occurring between 29 and 30°C. The distribution of fishing activities by light fishing in Tegal waters is associated with the optimal sea surface temperature for pelagic fisheries. Maulina et al. (2019) assert that the spatial distribution of sea surface temperature is closely linked to the location of fisheries activities, fish movement, and fish residence, serving as an oceanographic indicator for assessing water quality in relation to the distribution of fishing grounds.

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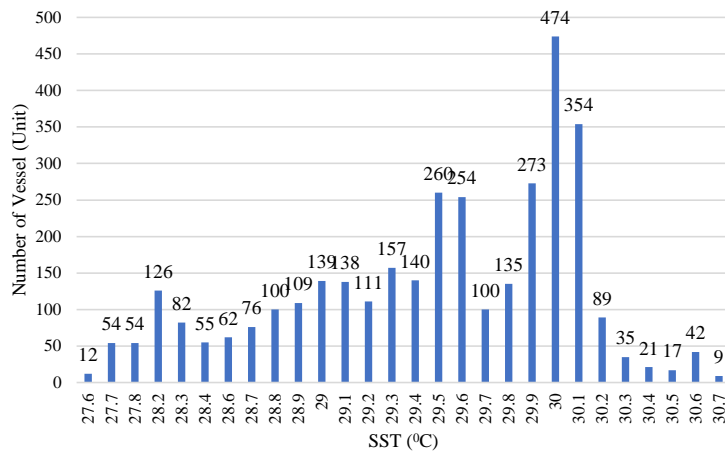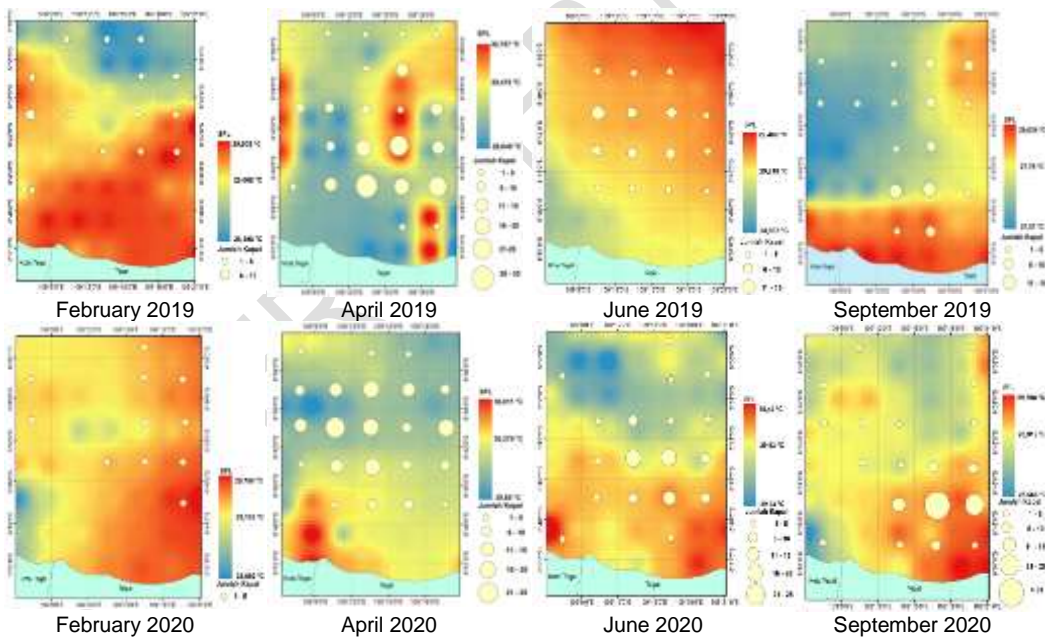
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Fig. 2. Distribution of the number of vessels at each SST value
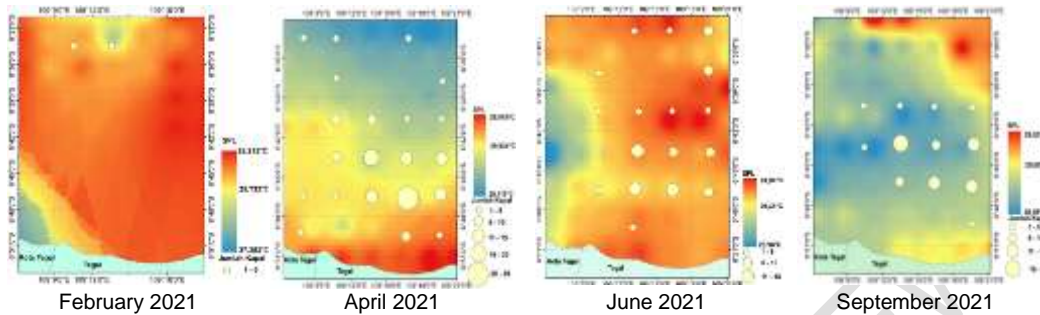

| February 2019 | April 2019 | June 2019 | September 2019 |

| February 2020 | April 2020 | June 2020 | September 2020 |

| February 2021 | April 2021 | June 2021 | September 2021 |

Fig. 3. SST distribution and light fishing detection in each season in Tegal North Waters

During the western season, the average sea surface temperature (SST) was 28°C, whereas in the first transitional season, it rises to 29.75°C. In contrast, the eastern season exhibits an average SST of 29.65°C, while the second transitional season records an average SST of 28.53°C. Variations in SST within a given body of water are influenced by solar movement patterns, wind, and air pressure. As noted by Kristiyani et al. (2020) and Maulina et al. (2019), the eastern season is characterized by an increase in SST, which is attributed to the position of the sun in the Northern Hemisphere. According to Figure 3, which illustrates the SST distribution and temporal position of the ship for each month from 2019 to 2021, SST conditions over these three years exhibit a consistent pattern, with seasonal variations in SST. The highest SST values were observed during the second transitional season, followed by a decrease in the eastern season. However, it is evident that the monthly SST distribution does not correlate with the number of fishing vessels because light fishing activities are aligned with the fishing season in these waters.

3.3 Light Fishing Detection with Chlorophyll-a Parameter

Figure 4 illustrates that, over the three-year period from 2019 to 2021, the highest number of vessels was observed at a chlorophyll-a concentration of less than 0.6 mg/m^3, with an optimal concentration of 0.5 mg/m^3. Conversely, the lowest number of vessels was recorded at a chlorophyll-a concentration exceeding 2.1 mg/m^3. Maulina et al. (2019) identified that the optimal chlorophyll-a concentration for the distribution of pelagic fish in these waters is 0.55 mg/m^3. This finding suggests that the optimal chlorophyll-a concentration significantly influences fishing activities in the Northern Waters of Tegal. Furthermore, Syah and Abdillah (2021) reported that the majority of light fishing activities occur at chlorophyll-a concentrations ranging from 0.2 to 0.5 mg/m^3.

Chlorophyll-a data serves as an indicator of water fertility in aquatic environments. As noted by Luo et al. (2019) and Linus and Salwiyah (2016), the concentration of chlorophyll-a in a water body can be utilized as a measure of water fertility, aiding in the assessment of changes in fishery distribution and the prediction of fishery activity locations. In the Tegal North Waters, the chlorophyll-a concentrations exhibited monthly fluctuations throughout the year. An analysis of the average chlorophyll-a concentration over a three-year period reveals that the highest value was recorded in February, with an average of 1.142 mg/m^3. Muhammad et al. (2021) and Nababan et al. (2022), February falls within the western season and is characterized by elevated chlorophyll-a concentrations, likely due to high rainfall, which facilitates the influx of nutrients via river flow. Conversely, the lowest average chlorophyll-a concentration was observed in October during the second transitional season, at 0.4 mg/m^3. This decrease was attributed to low rainfall and the persistence of dry weather conditions during both seasons.
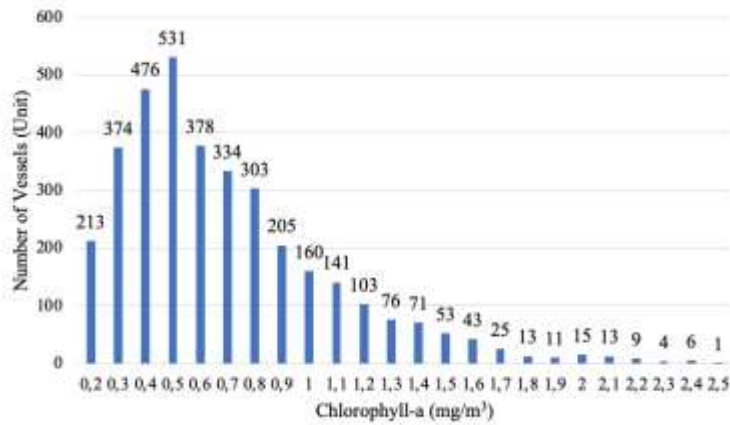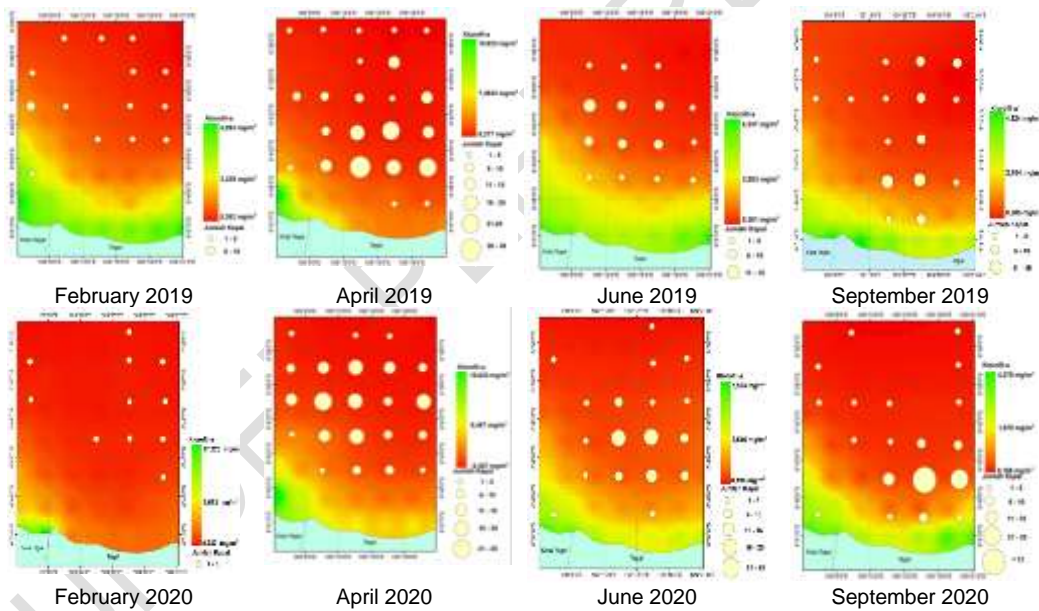
Fig. 4. Distribution of the number of vessels at each Chlorophyll-a value

February 2019

April 2019

June 2019

September 2019

February 2020

April 2020

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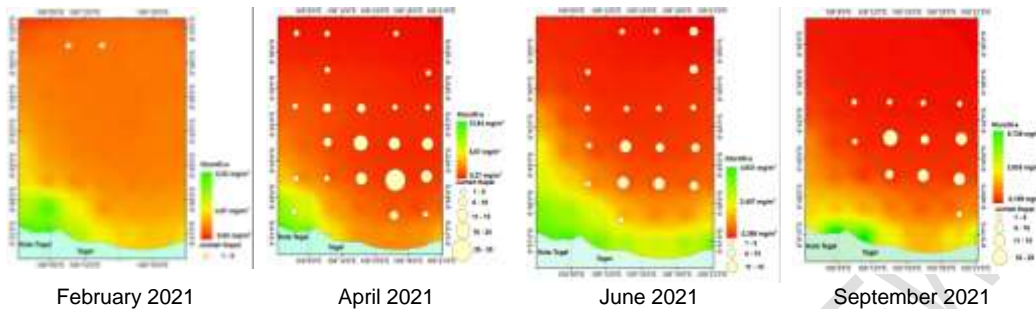| February 2021 | April 2021 | June 2021 | September 2021 |

Fig. 5. Chlorophyll-a distribution and light fishing detection in each season in Tegal North Waters

Fluctuations in the chlorophyll-a concentration values appear to exert no significant influence on the frequency of vessel detection. Elevated chlorophyll-a concentrations are indicative of increased phytoplankton presence. Phytoplankton distribution is predominantly observed on the water surface exposed to sunlight, whereas nocturnal light boat fishing operations occur in areas where zooplankton predominate over phytoplankton. As noted by Prihatin and Setyono (2018) and Oceanna et al. (2021), zooplankton exhibit nocturnal migration and negative phototaxis, resulting in their increased presence at the surface during the nighttime. This phenomenon is also associated with fish larvae, which frequently surface at night to consume zooplanktons. The nonlinear relationship between fishing activities and chlorophyll-a indicates that chlorophyll-a exerts a maximal impact on fishing activities at approximately 0.5 mg/m^3. At this concentration, fishing activity intensity is positively correlated with chlorophyll-a. However, the intensity of fishing activity diminished as the concentration deviates from 0.5 mg/m^3. This suggests that the chlorophyll-a concentration does not directly affect the number of boats, but is related to the productivity of zooplankton growth, thereby establishing a food chain system that attracts fish populations to these waters. The presence of these fish populations prompts fishing activities in boats.

3.4 Verification of Image Data with Field Data

The potential zones for light fishing operations in the Northern Waters of Tegal exhibit average SST and chlorophyll-a concentrations that align with the optimal oceanographic parameters for the distribution of pelagic fish. The verification results of light fishing distribution in the field, when compared with image prediction outcomes based on oceanographic parameters, are as follows:

Table 2.   Verification of Image Data with Field Data

Coordinate		In-situ Data		Image Data		Error Value	
Longitude	Latitude	Chlor-a	SST	Chlor-a	SST	Chlor-a	SST
-6.74143	109.2171	0.1578	29.7	0,5095	29.6	7.0340	2.232
-6.73826	109.2100	0.2056	29.6	0,5324	29.6	6.5360	0.954
-6.72253	109.2484	0.4022	29.8	0,59227	30.0	3.8014	3.802
-6.71824	109.2361	0.1344	29.6	0,54931	29.9	8.2982	6.410
-6.72545	109.2538	0.5446	29.9	0,59304	30.0	0.9688	1.894
					Mean Relative Error (MRE)	5,32	3

Upon verification of in situ data values against satellite image data for Sea Surface Temperature (SST) parameters, it was observed that the SST values derived from the Suomi NPP VIIRS satellite images are higher compared to the in situ data. The lowest Relative Error (RE) was recorded at station 2, with a value of 0.9%, while the highest RE was observed at station 4, with a value of 6.4%. The Mean Relative Error (MRE) for SST was calculated to be 3%, indicating that the Suomi NPP VIIRS satellite images have an accuracy level of 97% in detecting the distribution of light fishing based on SST parameters. Conversely, the MRE for the chlorophyll-a parameter was found to be 5.32%, resulting in an accuracy level of 94.68% for field data verification concerning the distribution of light fishing based on chlorophyll-a concentration. Notably, the satellite image data for the chlorophyll-a parameter also exhibited higher values compared to the in situ data. The lower chlorophyll-

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a values in the in situ data can be attributed to nighttime data collection, during which zooplankton presence predominates over phytoplankton in the waters (Atthallah et al., 2022).

The identification of fishing grounds for light vessels can be achieved through the analysis of the spatiotemporal distribution of light fishing activities in conjunction with oceanographic characteristics. Key indicators for determining potential fishing areas include sea surface temperature (SST) and optimal chlorophyll-a concentration, which align with fish habitats. The distribution of vessels, when analyzed, reveals a consistent pattern of point concentration across different seasons. The number of vessels can be correlated with SST and the optimal chlorophyll-a distribution for pelagic fish. Detection results indicate that vessel distribution is concentrated in the fishing area with coordinates $6^042'0"$ - $6^048'0"$ S and $109^012'0"$ - $109^021'0"$ E. The VIIRS sensor detection results reveal a high density of vessel points at SSTs ranging from 29.5°C to 30°C, with chlorophyll-a concentrations between 0.2 and 0.5 mg/m³. Satellite image verification indicates that the accuracy of estimating potential light fishing areas based on each oceanographic parameter exceeds 90%, confirming the reliability of the Suomi NPP VIIRS satellite imagery in estimating potential fishing zones. According to Kristiyani et al. (2020), image results are deemed acceptable if the accuracy test, which compares image data with field data, yields a value of ≥80%. The parameter values align with the optimal temperature range for pelagic fish distribution in the Northern Waters of Tegal. Kristiyani et al. (2020) report that the optimal temperature for pelagic fish is between 29.5°C and 30°C. Maulina et al. (2019) indicate that the chlorophyll-a concentration is approximately 0.55 mg/m³.

4. CONCLUSION

The analysis of VIIRS sensor data demonstrates its effectiveness in mapping light fishing activities in the Northern Waters of Tegal, Indonesia. The study revealed seasonal patterns in vessel detection, identified concentrated fishing grounds, and determined optimal oceanographic conditions for fishing activities. VIIRS imagery showed high accuracy in detecting sea surface temperature and chlorophyll-a concentrations. The integration of VIIRS data with oceanographic parameters provides valuable insights for optimizing pelagic fish resource utilization, offering an improved method for identifying potential fishing zones and understanding spatiotemporal patterns of nocturnal fishing activities. This approach demonstrates significant potential as a valuable tool for fisheries management and sustainable resource exploitation in the region.

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