The Egyptian Journal of Remote Sensing and Space Sciences 25 (2022) 257–265

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The Egyptian Journal of Remote Sensing and Space Sciences

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Distribution pattern of potential fishing zones in the Bangka Strait waters: An application of the remote sensing technique

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ARTICLE INFO

Article history:
Received 20 July 2021
Revised 8 December 2021
Accepted 8 December 2021
Available online 23 December 2021

Keywords:
Chlorophyll-a
GIS
MODIS
Sea surface temperature
Seasonal variability

ABSTRACT

Information regarding fishing grounds was needed to assist fishermen in their fishing activities. Information about the sea surface chlorophyll-a concentration (SSCC) and sea surface temperature (SST) could be used as a reference to identify potential fishing zones (PFZ). The purpose of this study was to identify SST and SSCC data using MODIS (Moderate Resolution Imaging Spectroradiometer) satellite imagery for determining the PFZ and analyzing their distribution pattern seasonally. The determination of the PFZ point was carried out by overlaying the SSCC and SST data based on the results of image data processing. The results showed that the distribution pattern of PFZ points in the Bangka Strait waters was predominantly found in the Banyuasin waters. The distribution pattern of PFZ points in the dry season (June-August) and transition season II (September-November) had the same pattern and tended to dominate the coastal areas of the waters. The distribution patterns in the wet season (December-February) and transition season I (March-May) spread throughout the Bangka Strait waters. The most PFZ points were found in transition season I (636 PFZ points), while the minor PFZ points were found in transition season II (219 PFZ points). Integrating the remote sensing and GIS technique with statistical validation tests were useful and became a simple method for identifying the PFZ distribution. However, validating the PFZ distributions using the catch data was required.

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1. Introduction

The Bangka Strait waters are waters that separate the Sumatra and Bangka islands. These waters have an area of 11,543,142 km^2 and have become the center of fishing activities for fishermen from Banyuasin and Ogan Komering Ilir Regency of the South Sumatra province as well as the South Bangka Regency of the Bangka-Belitung province. Based on the capture fisheries statistics data, the catch production from the Banyuasin regency has drastically increased from 5,479 tons in 2017 to 64,587 tons in 2019. The catch production from the South Bangka Regency has also increased from 37,382 tons in 2017 to 38.867 tons in 2019. On the contrary, decreasing in catch production occurred in Ogan Komering Ilir Regency, where the decline in production was probably due to climatic factors.

The changes in the sea surface chlorophyll-a concentration (SSCC) and sea surface temperature (SST) are the most critical parameters that used for identifying fish availability and abundance of the pelagic species (Fitrianah et al., 2016b; Karuppasamy et al., 2020) as well as considered for estimating potential fishing zones (PFZ) (Fitrianah et al., 2016a; Guidetti et al., 2010; Nammalwar et al., 2013). Both parameters synergistically influence marine biota availability, ranging from plankton to marine mammals (Karuppasamy et al., 2020; Rajagopal et al., 2010). The SST and other environmental factors (pH, oxygen, salinity) would covary depending on the region characteristics. For different environments variables, there are different characteristics for determining the PFZ (Fitrianah et al., 2016b). Additionally, SSCC is a proxy for phytoplankton biomass and is used to identify habitats of fish resources (Karuppasamy et al., 2020; Nurdin et al., 2015; O'Reilly et al., 1998). The PFZ is a short-term prediction and credible on the zone of fishes aggregation in the open sea (Subramanian et al., 2014). It also explained that the PFZ is the zone where the fishes aggregate due to a food abundance. Their availability is limited by this zone in the open sea, where a sharp SST gradient with optimal SSCC co-occurrence at a given period. (Giri et al., 2016). Appropriately estimating the PFZ can optimize the fishing operation schedule (Nammalwar et al., 2013).

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☆Peer review under responsibility of National Authority for Remote Sensing and Space Sciences..

https://doi.org/10.1016/j.ejrs.2021.12.003
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In recent decades, the utilization of remote sensing technology and geographic information systems (GIS) have been conducted to analyze SSCC and SST for estimating the PFZ (Devi et al., 2015; Harahap et al., 2020; Suhadha and Asriningrum, 2020) as well as for identifying the distribution patterns of fish and their interactions with other factors (Mustasim et al., 2015). MODIS algorithms have been of greater value for oceanographic data extraction (e.g., SST and SSCC data). Using in-situ data helps test the PFZ validity (Ardianto et al., 2017; Daqamseh et al., 2019). This present research identified PFZ's and analyzed their distribution pattern using MODIS data for three years (2017–2019).

2. Materials and methods

2.1. Study area

The study area and sampling location are illustrated in Fig. 1. Besides the main maritime gateway for South Sumatra, the Bangka Strait waters are also a significant fishing ground, especially for fishermen from the Banyuasin, Ogan Komering Ilir (OKI), and South Bangka Regency. These waters are categorized into the Indonesian Fisheries Management Area 711 (WPPNRI-711). The oceanographic conditions in these waters are influenced by the monsoon and tide cycle. Most fishing activities from South Sumatra that operated in the Bangka Strait include small-scale fisheries. The Banyuasin waters are strongly affected by the Musi River run-off (Fauziyah et al., 2019).

2.2. Data collection

The satellite data used in this study were SST and SSCC monthly data derived from level-3 MODIS satellite imagery for three years (2017–2019) with a resolution of 4 km. Besides providing monthly data, this level-3 data also provides daily, weekly and yearly data (Suhadha and Asriningrum, 2020). Images data were downloaded from the oceancolor.gsfc.nasa.gov website using the Aqua MODIS Chlorophyll Concentration OCI Algorithm sensor and the Aqua MODIS Sea Surface Temperature (11 day time). Image data collection and processing were carried out in the Remote Sensing Laboratory and Marine Geographic Information System, Faculty of Mathematics and Natural Sciences, Sriwijaya University.

The PFZ parameter (SSCC and SST data) derived from the MODIS data would be validated using field data. The field data collection was carried out on October 24–28, 2020. Determination of the sampling locations was carried out using the purposive sampling methods by considering the conditions and characteristics of the coastal waters around the Berbak Sembilang National Park (BSNP). In this study, ten sampling locations were taken. Each location point was recorded in its geographic position on the device (GPS). Chlorophyll-a water samples were taken directly by using a water sampler on the sea surface with one repetition, were then put into the sample bottle. Measurement of sea surface temperature parameters was carried out using the Water Quality Checker.

2.3. Data analysis

2.3.1. Identifying SSCC and SST from the MODIS data

After collecting the level-3 data, image data processing used SeaDAS 7.4 software, Microsoft Excel, and ArcGIS 10.5. Image processing steps include image cropping, NaN correction, interpolation, contouring SST and SSCC, overlay, and determinating PFZ points. Image cropping was done to make the observed area easier to analyze and reduce the image storage size. NaN data is the result of reflection from objects that are not numerically detected by satellite imagery. Meanwhile, interpolation is performed to predict unknown values by using known values around them. Contouring SST and SSCC were carried out using the contour tools on ArcMap. SST is used to identify the thermal front zone indicated by a tem-

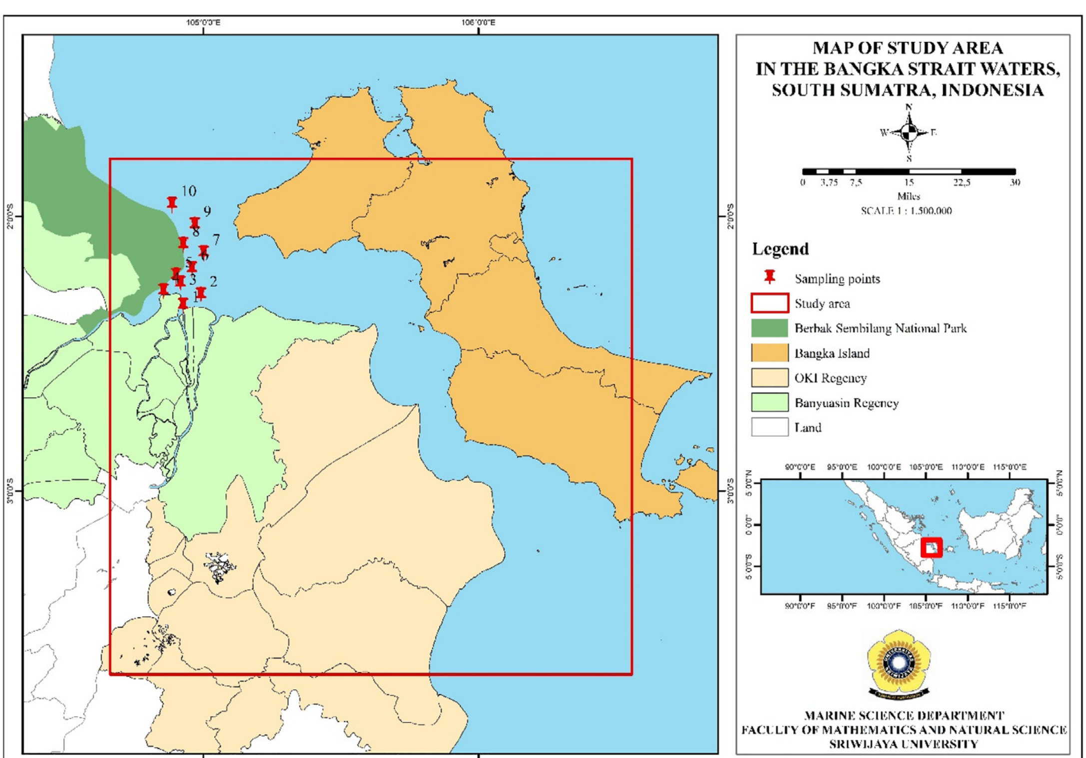


Fig. 1. Map of the study area and sampling points in the Bangka Strait waters.

perature gradient of 0.5 °C (Ardianto et al., 2017; Hasyim et al., 2009). Meanwhile, SSCC selected data to identify PFZ is 0.2–0.5 mg/m^3 (Ardianto et al., 2017; Suhadha and Asriningrum, 2020).

The SST MODIS data for daytime are generated based on the following algorithm (Brown and Minnett, 1999):

$$SST = c_1 + c_2 * T_{11} + c_3 * (T_{3132}) * T_{src} + c_4 * (\sec(\theta) - 1) * (T_{3132})$$

where T_{31} and T_{32} are the brightness temperatures measured in bands 31 and 32, θ is the satellite zenith angle measured at the sea surface, as well as c_1, c_2, c_3, and c_4 are the coefficients whose values are determined depending on the difference T_{31}-T_{32}. Meanwhile, the SSCC MODIS data are processed based on the OC3M algorithm (O'Reilly et al., 2000):

$$Chl_a = 10^{0.283 - 2.753R + 1.457R^2 + 0.659R^3 - 1.403R^4}$$

$$R = log_{10}\left(\frac{Rrs(442)}{Rrs(550)} > \frac{Rrs(490)}{Rrs(550}\right)$$

where Chl_a is the chlorophyll-a concentration in mg.m^{-3}, *Rrs* is the remote sensing reflectance, and *R* is the reflectance ratio. The SeaDAS software version 7.4 was used to process and analyze the MODIS SST and Chl-a datasets.

2.3.2. Analyzing in-situ data

The SST data obtained from measurements using the Water Quality Checker were tabulated according to the sampling sites. For calculating the SSCC based on spectrophotometric analysis, the following formulas were used (Aminot and Rey, 2001; Johan et al., 2014):

$$Chl_a(\mu g/L) = (11.86xE_{664}) - (1.54xE_{647}) - (0.08xE_{630}) \quad (1)$$

$$Concentration\ of\ Chl_a(mg/L) = \frac{[Chl_a x v]}{VxL} \quad (2)$$

where v is acetone extraction volume (10 mL), V is filtered volume (500 mL), L is cuvette light-path (cm), E_{664} is absorbance value at wavelength 664 nm, E_{647} is absorbance value at wavelength 647 nm, and E_{630} is Absorbance value at wavelength 630 nm.

2.3.3. Validating MODIS data

The multiple linear regression model could be developed to validate the SST and SSCC data from the Image Data Processing against in-situ data measurements (Daqamseh et al., 2019). The linear relation was applied for determining the best-fitted model. In addition, the RMSE-observations Standard Deviation Ratio (RSR) and determination coefficient (R^2) were used as statistical parameters for the model validation (Fauziyah et al., 2020). For validating the MODIS data, the MODIS SSCC and SST data on October 2020 closest to the sampling stations were selected.

2.3.4. Identifying PFZ

An overlay was done by combining the contour of SST and SSCC using the Intersect tool on the Geoprocessing bar, in which the output was converted into a point to produce a PFZ point. The results of the PFZ map will be made monthly data and grouped seasonally referring to a fishing season (Fauziyah et al., 2018), namely the wet season (December-February), the transitional season I (March-May), the dry season (June-August), and the transitional season II (September-November).

3. Result and discussion

3.1. Distribution of sea surface temperature (SST)

The SST distribution map for three years (2017–2019) was analyzed and displayed (Figs. 2 and 3). The SST explains a suitable marine environment for PFZ. In the wet season (Fig. 2a), the SST values ranged from 25.2 to 35.5 ℃, with the SST mean gone from 28.9 to 30.4 ℃ (Fig. 3). Visually showed that warm temperatures tend to be in the northern part in the waters of Bangka Strait, and cold temperatures are seen in the southern region in the waters of Bangka Strait. Still, this condition did not show a regular pattern. Entering transition season I (Fig. 2b), the SST value in the waters of the Bangka Strait ranged from 28.2 to 36.2 ℃ and was visually distributed throughout these waters. These waters tend to be stable, and their SST distribution pattern was evenly distributed and had almost the same pattern from 2017 to 2019, with the SST mean ranging from 30.4 to 31.6 ℃ (Fig. 3). Compared to the wet season, the transitional season I have a higher SST average, and a difference in the movement of SST with the wet season was seen. In the dry season (Fig. 2c), the SST values ranged from 25.7 to 35.1 ℃, with the SST mean values ranging from 29.1 to 31.3 ℃ (Fig. 3). Visually warm temperatures were seen in the northern part of the waters of the Bangka Strait and tended to approach the coastal waters of Banyuasin. Cold temperatures tend to be in the southern part of the waters of the Bangka Strait. Entering the transitional season II (Fig. 2d), the SST values ranged from 26.9 to 35.7 ℃, with the SST mean values ranging from 29.2 to 31.3 ℃ (Fig. 3).

The SST distribution pattern in the waters of the Bangka Strait showed that temperatures were increasing from September to November. Still, in September, cold temperatures were seen in the southern part, and warm temperatures were in the northern part of the waters of the Bangka Strait. In the wet season (Fig. 2a), there was a quite significant fluctuation entering transitional season I. This is because the rainfall is getting lower in this season so that the sea surface temperature begins to stabilize and has an optimum SST value, which can affect a good fishing area. Entering the dry season and transition season II, the SST fluctuations tend to be unstable but have almost the same pattern.

Overall, the fluctuation of SST values during three years showed the same pattern (Fig. 3). This results in line with the SST distribution pattern that occurred in the northern waters of West Java (Harahap et al., 2020). During the transitional seasons, the high-SST values are affected by rainfall, wind speed, sea surface current, and the sun's daily motion (Harahap et al., 2020). In this study, the SST mean was highest in transition season I, and this result was similar to the SST characteristics of Indonesian waters (Marini and Setiawan, 2018).

3.2. Distribution of sea surface chlorophyll-a concentration (SSCC)

The SSCC distribution map for three years (2017–2019) was analyzed and displayed (Figs. 4 and 5). Similar to the TSS distribution, the SSCC distribution also plays an essential role in determining PFZ. In the wet season (Fig. 4a), the SSCC value ranged from 0.24 to 35.4 mg/m^3, while the SSCC mean values ranged from 2.3 to 8.3 mg/m^3 (Fig. 5). Visually, the highest SSCC value was seen in the middle of the Bangka Strait waters, and the lowest SSCC value tends to be in the southern part of the Bangka Strait waters. The distribution pattern of SSCC for three years appears to have the same distribution pattern. Entering transition season I (Fig. 4b), the SSCC values in the Bangka Strait waters ranged from 0.16 to 27 mg/m^3, with the SSCC mean ranging from 4.0 to 9.0 mg/m^3 (Fig. 5). Their mean values in this season slightly increased than in the wet season. Visually, it shows that the SSCC values tend to be evenly distributed throughout

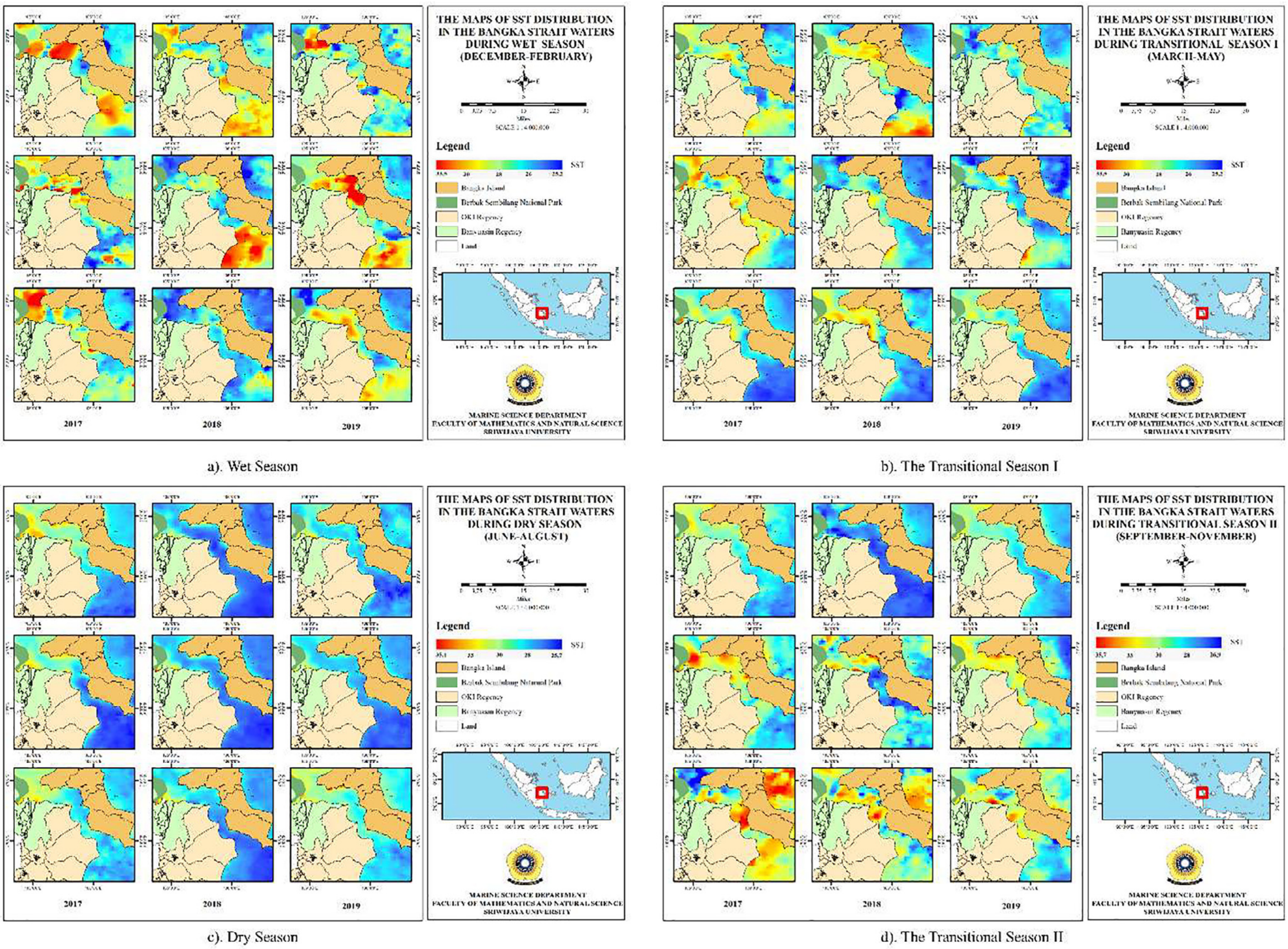
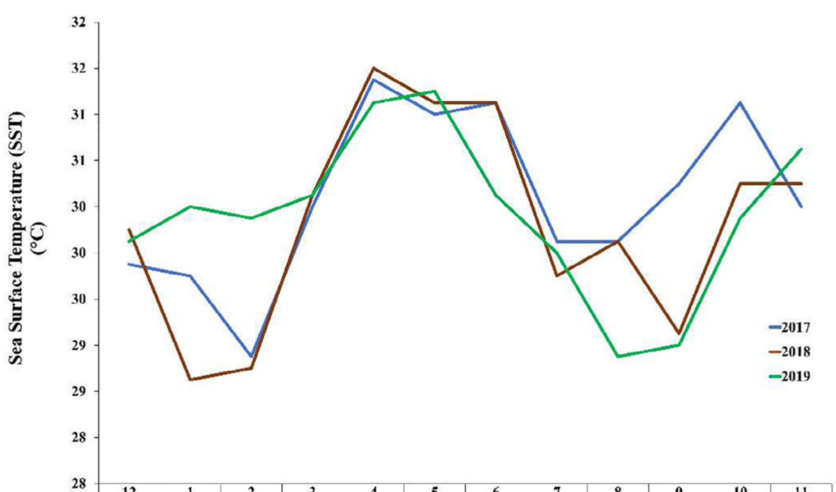


Fig. 2. The maps of SST distribution: a) Wet Season (December-February); b) Transitional Season I (March-May); c) Dry Season (June-August); d) Transitional Season II (September-November).



	12	1	2	3	4	5	6	7	8	9	10	11
	Wet Season			Transitional Season I			Dry Season			Transitional Season II		
2017	30.0±0.7	29.8±0.6	29.1±0.7	30.5±0.6	31.5±0.6	31.2±0.5	31.3±0.5	30.2±0.7	30.2±0.5	30.7±0.6	31.3±0.6	30.4±1.0
2018	30.3±0.7	29.0±0.7	29.1±0.5	30.5±0.7	31.7±0.5	31.3±0.6	31.3±0.5	29.8±0.6	30.1±0.8	29.4±0.4	30.6±0.6	30.6±0.6
2019	30.2±0.8	30.4±0.8	30.4±0.7	30.6±0.6	31.4±0.5	31.5±0.5	30.6±0.5	30.0±0.7	29.2±0.4	29.2±0.5	30.4±0.6	30.9±0.6

Monthly Season

Fig. 3. Graph of fluctuation in the average distribution of sea surface temperature in the waters of the Bangka Strait.

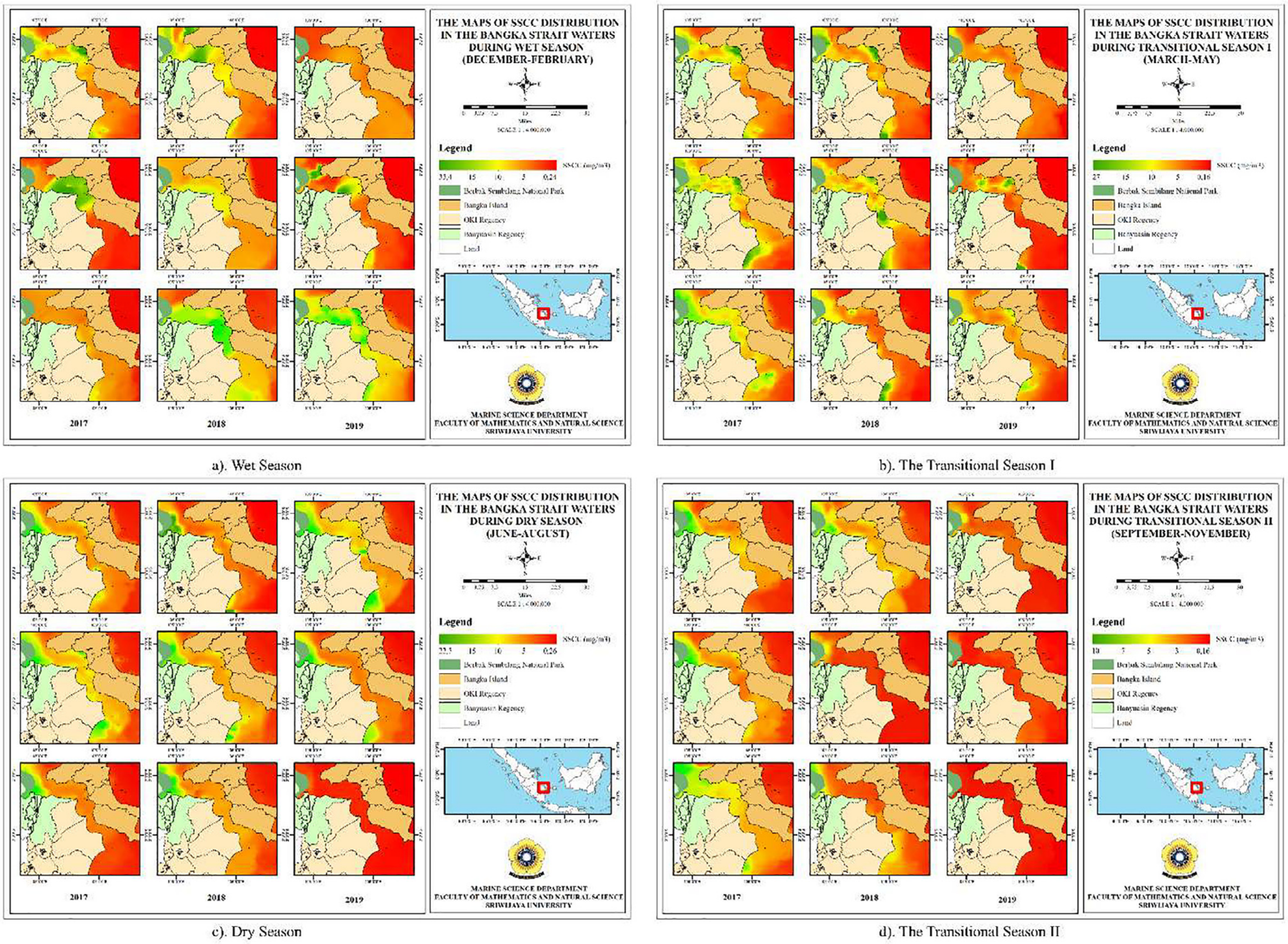
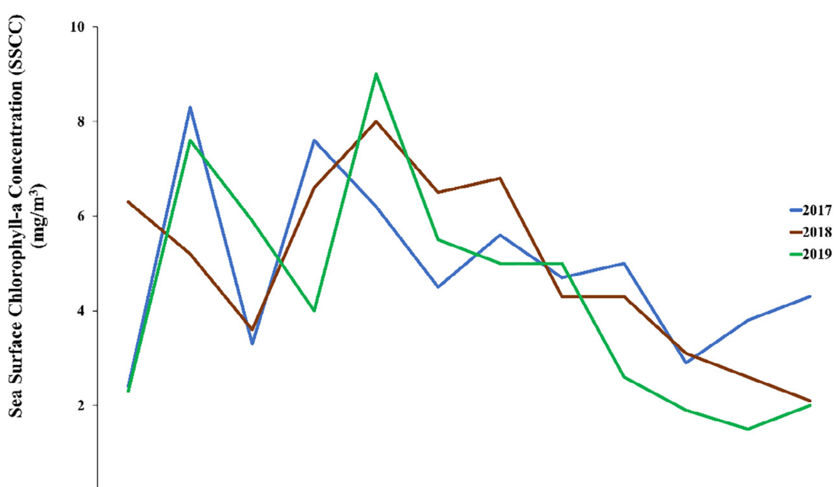


Fig. 4. The maps of SSCC distribution: a) Wet Season (December-February); b) Transitional Season I (March-May); c) Dry Season (June-August); d) Transitional Season II (September-November).



	12	1	2	3	4	5	6	7	8	9	10	11
	Wet Season			Transitional Season I			Dry Season			Transitional Season II		
2017	2.5±1.0	8.3±3.7	3.3±0.9	7.6±3.4	6.22.4	4.5±1.1	5.7±2.3	4.7±2.0	5.1±3.1	2.9±2.2	3.9±1.8	4.4±1.3
2018	6.4±2.4	5.3±1.2	3.7±1.9	6.7±3.3	8.0±3.0	6.6±2.9	6.9±3.5	4.4±1.9	4.4±1.9	3.2±1.4	2.6±1.2	2.2±1.1
2019	2.3±0.5	7.7±3.5	5.9±2.1	4.1±1.2	9.0±3.0	5.6±2.2	5.0±1.8	5.1±2.6	2.6±1.3	2.0±0.8	1.5±0.5	2.0±0.7

Monthly Season

Fig. 5. Graph of fluctuation in the average distribution of sea surface chlorophyll-a concentration (SSCC) in the waters of the Bangka Strait.

the Bangka Strait waters. Their distribution pattern tends to be higher in the coastal part of the Bangka Strait waters and forms a water mass pocket on the coastal part of Bangka waters. The dry season (Fig. 4c) ranged from 0.26 to 22.5 mg/m^3, while the SSCC mean values ranged from 2.6 to 6.8 mg/m^3 (Fig. 5). Visually, their distribution pattern tends to be in the coastal part of Banyuasin waters. The high SSCC values in Banyuasin waters were thought of since several large estuaries as nutrient inputs from land affect their high values in Banyuasin waters. Entering transition season II (Fig. 4d), the SSCC values had decreased from the wet season to the dry season. In that season, the SSCC value in the Bangka Strait waters only ranged from 0.16 to 10 mg/m^3 with an average of 1.5–4.3 mg/m^3 (Fig. 5). Their distribution pattern appears to have the same, but the values were lower.

In the wet season and transition season I, the SSCC mean values were around 5.0 mg/m^3 and 6.4 mg/m^3, respectively (Fig. 5). By Entering the dry season and transition season II, their values were decreasing, and the lowest SSCC value occurred in transition season II. The dry season commonly represents less precipitation, available sunlight intensity, higher air temperature, high phosphate and nitrate concentration (Sidabutar et al., 2020). The highest SSCC values occurred during transition season I, which was likely due to rainfall, light intensity, and nutrient concentration at optimal conditions for phytoplankton growth.

The SSCC values depend on differences in rainfall, light intensity, river run-off, wind, current, and salinity at optimal conditions for plankton growth during this season (Katara et al., 2008; Navarro et al., 2006; Nurdin et al., 2015). In this study, the rainfall, light intensity, river run-off, current, and salinity were the main factors thought to influence the chlorophyll-a distribution. The highest SSCC values occurred during transition season I, which was likely due to the optimal condition for the phytoplankton photosynthesis. The lower SSCC values are found around the offshore and higher near the coastal areas due to the nutrient sources availability derived from the river estuaries (Harahap et al., 2020; Nurdin et al., 2015). Based on the fertility waters (Pelly et al., 2020; Vollenweider et al., 1998), there were four categories of SSCC values namely Oligotrophic (the SSCC value < 1 mg/m^3), Mesotrophic (1 mg/m^3 $\leq$ the SSCC value $\leq$3 mg/m^3), Eutrophic (3 < the SSCC value $\leq$ 5 mg/m^3), and Hypereutrophic (the SSCC value >5 mg/m^3). According to that category, the Bangka Strait waters were included in the Eutrophic category (rich in nutrients), except during transition season I included in the hypereutrophic category (nutrient enrichment in high level and frequently found algal bloom).

3.3. Data validation

MODIS data acquisition in October 2020 and in-situ data taken on 24–28 October 2020 can be seen in Table 1. The linear regression model for the validation test between the MODIS data and in-situ data was revealed in the scatter plots (Fig. 6). This R^2 value of the SST regression model is demonstrating a good model performance ($0.75 < R^2 = 0.8215 \leq 0.86$) as well as the RSR value is demonstrating an excellent model performance ($0 < RSR = 0.07 \leq 0.5$). For the SSCC regression model, an excellent model performance is demonstrated by the R^2 value ($0.86 < R^2 = 0.9031 \leq 1$), on the contrary, unsatisfactory based on the RSR value (RSR = 1.2 16 > 0.7). The validation results are in line with the previous study in the Red Sea Coastal of Saudi Arabia (Daqamseh et al., 2019) and a study in the Eastern Indian Ocean (Fitrianah et al., 2016b). It's worth highlighting that lower values were revealed in the in-situ data than in the MODIS data. This result indicates that the algorithm used to calculate chlorophyll from satellite reflectance is inadequate, probably due to the optical properties of the water masses (which were affected hypothetically by terrestrial discharges). This result is an initial identification of PFZ points and has not validated the PFZ points distribution by using the catch or hydroacoustics data.

3.4. The seasonal distribution pattern of the potential fishing zone (PFZ)

The main objective of this study was to identify the SST and SSCC derived from MODIS data in determining the PFZs distribution across the Bangka Strait waters. The thermal front (SST) dan SSCC data is commonly recognized as the most significant oceanographic factor for indicating the natural fish habitat. In this study, SST and SSCC were considered to be shared a similar influence level over the PFZ mapping. Based on the data validation test (Fig. 6), the MODIS data successfully demonstrated excellent model performance in predicting the SST and SSCC data.

The water zones considered a highly potential fishing ground are assumed to have a large amount of available fish stock in consequence of the SST and SSCC aggregation. This is because both parameter distributions will affect the fish distribution, fish activity, metabolism, and fish nutrients in the sea waters. Some researchers (Devi et al., 2015; Nammalwar et al., 2013) stated that the SST and SSCC parameters are also used to indicate fish availability. The SST and SSCC parameters were helpful as the key parameters which affect the abundance and distribution of *Rastrelliger Kanagurta* in the South China Sea and Makassar Strait of Indonesia (Nurdin et al., 2015).

The PFZ distribution pattern has been illustrated spatially and temporally (Fig. 7- and 8). Fig. 7a demonstrates the distribution pattern of PFZ points (452 PFZ points) in the Bangka Strait waters during the wet season for three years. Their distributions in 2017 tend to be concentrated near the fishing area of OKI Regency. During 2018, it concentrated on the fishing area of

Table 1
Sea Surface Temperature (SST) and Sea Surface Chlorophyll-a Concentration (SSCC).

Stations	Sea Surface Temperature (SST)(℃)		Sea Surface Chlorophyll-a Concentration (SSCC) (mg/m3)	
	MODIS Data	In Situ Data	MODIS Data	In Situ Data
1	31	29.6	4.6	0.8
2	31.7	29.2	4.5	0.3
3	31.6	29.6	4.5	2.7
4	31.7	28.5	4.5	3.6
5	31.9	29.1	4.4	3.4
6	32.1	29.7	4.2	1.2
7	31.9	30.0	2.8	1.8
8	31.8	29.6	3.8	0.7
9	31	29.5	2.2	1.0
10	31	28.8	2.5	0.9
Mean	31.6	29.3	3.8	1.6
Stdev.	0.42	0.46	0.94	1.18

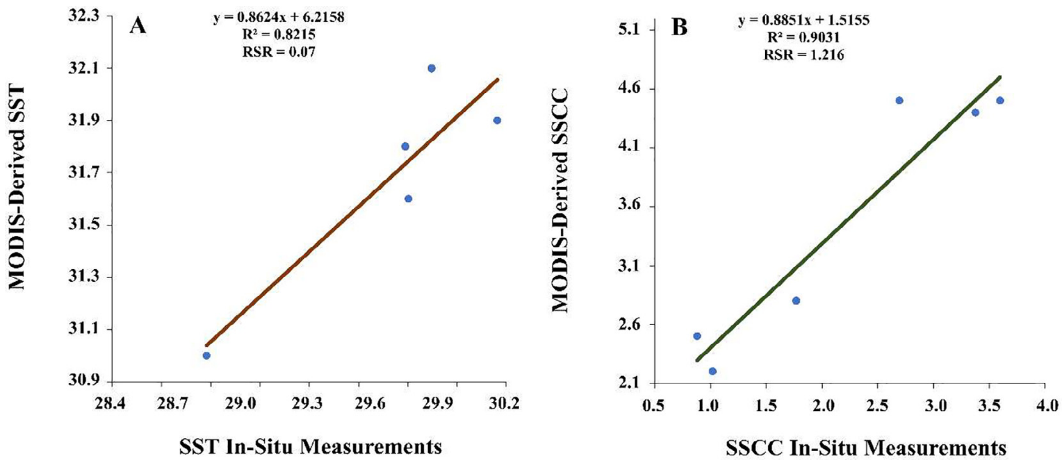


Fig. 6. Correlation test using the third-order polynomial: a) Sea Surface Temperature (SST); b) Sea Surface Chlorophyll-a Concentration (SSCC).

the Banyuasin district then moved towards the fishing area of OKI Regency. Meanwhile, during 2019 it spread in the Banyuasin and OKI waters and the coastal waters of Bangka. Entering transition season I (Fig. 7b), their distribution pattern (636 PFZ points) spreads throughout the fishing areas of Banyuasin, OKI, and South Bangka Regencies. During three years, it have the same pattern and tends to be dominant spread in the middle to the northern waters of the Bangka Strait. Entering the dry season (Fig. 7c), their distribution pattern (291 PFZ points) is dominant in many areas of the fishing area of Banyuasin Regency and the coastal part of the waters Ogan Komering Ilir Regency, and only a few in the Bangka Regency area. Until entering transition season II (Fig. 7d), their distribution patterns (219 PFZ points) have the same patterns but decrease in the number of PFZ points (Fig. 8). The PFZ points numbers were less than the wet season and transition I (Fig. 8) during this season.

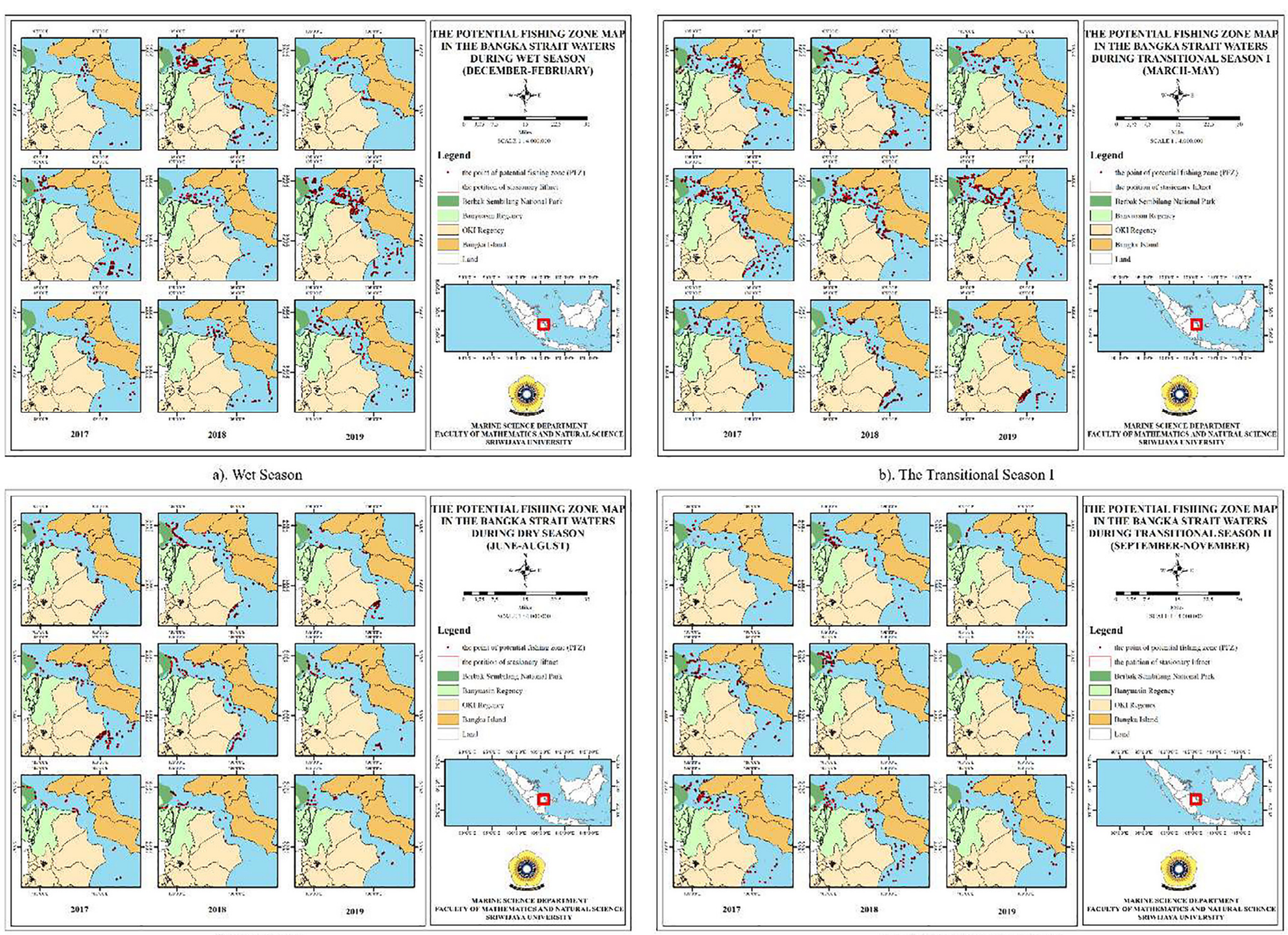


Fig. 7. The maps of PFZ distribution: a) Wet Season (December-February); b) Transitional Season I (March-May); c) Dry Season (June-August); d) Transitional Season II (September-November).

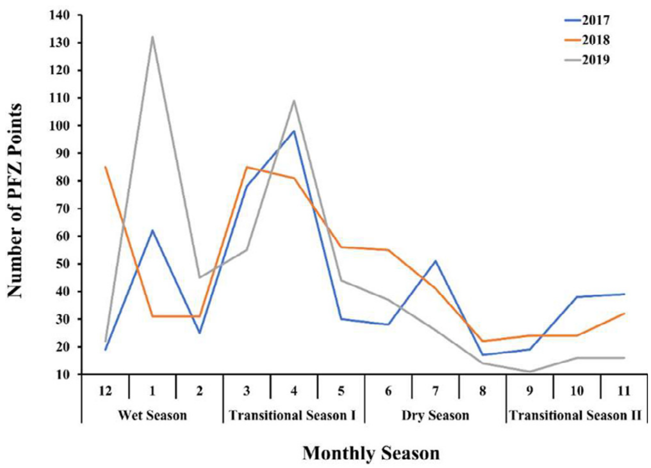


Fig. 8. Graph of the amount of PFZ points in the waters of the Bangka Strait.

Overall, the distribution pattern of PFZ points is prominently found more in the northern part of the Bangka strait and closer to the fishing ground of Stationary lift nets in the Banyuasin coastal waters. This is because the Banyuasin waters have a high value in SSCC with the optimum SST, where both parameters were essential for fish growth. The high values of SSCC are due to several large estuaries as an input of nutrient sources that affect the SSCC values in these waters. Meanwhile, the fewer points of PFZ in the southern part of the Bangka strait waters related to the least SSCC values in these waters due to at least in the number of estuaries as the nutrients sources input for phytoplankton food. Referring illustrated in Fig. 8, a decrease in PFZ points occurred during the dry season and transitional season II when low rainfall leads to an increase in SST values (Fig. 3) and a reduction of SSCC values (Fig. 5). The results align with the PFZ maps across the Red Sea Coastal of Saudi Arabia (Daqamseh et al., 2019). The seasonal shifts in both parameters can affect environmental changes that influence fish aggregation, hence affecting the fish availability in each season (Daqamseh et al., 2019; Daqamseh et al., 2013)

The study results demonstrated that integrating the remote sensing and GIS techniques with statistical validation tests was useful and became a simple method for identifying the PFZ distribution based on MODIS data. However, validating the PFZ distributions using the catch data were required. The PFZ can be determined using the SST and SSC derived from satellite data and can indicate the pelagic fish availability (Devi et al., 2015). Fast and reliable estimation of the PFZ points possibly supports the fishermen in the effectiveness of fishing time, which would increase their catch (Nurdin et al., 2015).

4. Conclusion

The PFZ points were identified based on SSCC and SST data derived from the MODIS data in this study. The seasonal distribution pattern of the PFZ points from 2017 to 2019 indicated the same pattern in each season and every year. During dry season and transition season II, the PFZ dominated the coastal waters. During the wet season and transition season I, the PFZ points spread throughout the Bangka Strait waters. Their distribution pattern from 2017 to 2019 mainly was found around fishing areas in the Banyuasin Regency waters. The PFZ points were primarily located in transition season I (636 points), while minor PFZ points were found in transition season II (219 points).

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgment

This work was funded by a grant from the Sriwijaya University (Grant Number: SP.DIPA-023/17.2.677515, 2020 and SP.DIPA-023/17.2.677515, 2021) and Ministry of Research, Technology, and Higher Education of the Republic of Indonesia (Grant Number: 211/SP2H/LT/DRPM/IV/2019 and 0164.02/UN9/SB3.LP2M.PT/2021). The authors would like to thank Ardani and Nabila Aprianti for their help. The authors wish to thank the anonymous reviewers who significantly improved this paper. And express special appreciation to the Banyuasin Team 2020, Marine Science Department, and Exploration of Marine Resources and Acoustic (ESAK) Laboratory Sriwijaya University for supporting our research.

References

Aminot, A., Rey, F., 2001. Chlorophyll a: Determination by spectroscopic methods. ICES Tech. Mar. Environ. Sci.

Ardianto, R., Setiawan, A., Hidayat, J.J., Zaky, A.R., 2017. Development of an automated processing system for potential fishing zone forecast. IOP Conf. Ser. Earth Environ. Sci. 54,. https://doi.org/10.1088/1755-1315/54/012081 012081.

Brown, O.B., Minnett, P.J., 1999. MODIS Infrared Sea Surface Temperature Algorithm, Algorithm Theoretical Basis Document Version 2.0. University of Miami.

Daqamseh, S.T., Al-Fugara, A., Pradhan, B., Al-Oraiqat, A., Habib, M., 2019. MODIS derived sea surface salinity, temperature, and chlorophyll-a data for potential fish zone mapping: west red sea coastal areas, Saudi Arabia. Sensors 19, 2069. https://doi.org/10.3390/s19092069.

Daqamseh, S.T., Mansor, S., Pradhan, B., Billa, L., Mahmud, A.R., 2013. Potential fish habitat mapping using MODIS-derived sea surface salinity, temperature and chlorophyll-a data: South China Sea Coastal areas, Malaysia. Geocarto Int. 28, 546–560. https://doi.org/10.1080/10106049.2012.730065.

Devi, G.K., Ganasri, B.P., Dwarakish, G.S., 2015. Applications of remote sensing in satellite oceanography: a review. Aquat. Procedia 4, 579–584. https://doi.org/10.1016/j.aqpro.2015.02.075.

Fauziyah, A.F., Melda Situmorang, D., Suteja, Y., 2018. Fishing seasons of fish landed at Sungailiat archipelago fishing port in Bangka Regency. E3S Web Conf. 47, 1–10. https://doi.org/10.1051/e3sconf/20184706008.

Fauziyah, Agustriani, F., Purwiyanto, A.I.S., Putri, W.A.E., Suteja, Y., 2019. Influence of environmental parameters on the shrimp catch in Banyuasin Influence of environmental parameters on the shrimp catch in Banyuasin Coastal Water, South Sumatra, Indonesia. IOP Conf. Ser. J. Phys. Conf. Ser. 1282 1282, 012103. https://doi.org/10.1088/1742-6596/1282/1/012103.

Fauziyah, Purwiyanto, A.I.S., Agustriani, F., Putri, W.A.E., Ermatita, Putra, A., 2020. Determining the stock status of snapper (Lutjanus sp.) using surplus production model: a case study in Banyuasin coastal waters, South Sumatra, Indonesia. IOP Conf. Ser. Earth Environ. Sci. 404,. https://doi.org/10.1088/1755-1315/404/1/012009 012009.

Fitrianah, D., Fahmi, H., Hidayanto, A.N., Arymurthy, A.M., 2016a. A data mining based approach for determining the potential fishing zones. Int. J. Inf. Educ. Technol. 6, 187–191. https://doi.org/10.7763/ijiet.2016.v6.682.

Fitrianah, D., Hidayanto, A.N., Gaol, J.L., Fahmi, H., Arymurthy, A.M., 2016b. A spatio-temporal data-mining approach for identification of potential fishing zones based on oceanographic characteristics in the eastern Indian ocean. IEEE J. Sel. Top. Appl. Earth Obs. Remote Sens. 9, 3720–3728. https://doi.org/10.1109/JSTARS.2015.2492982.

Giri, S., Manna, S., Chanda, A., Chowdhury, A., Mukhopadhyay, A., Chakraborty, S., Hazra, S., 2016. Implementing a spatial model to derive potential fishing zones in the Northern Bay of Bengal lying adjacent to West Bengal coast, India. J. Indian Soc. Remote Sens. 44, 59–66. https://doi.org/10.1007/s12524-015-0472-2.

Guidetti, P., Bussotti, S., Pizzolante, F., Ciccolella, A., 2010. Assessing the potential of an artisanal fishing co-management in the Marine Protected Area of Torre Guaceto (southern Adriatic Sea, SE Italy). Fish. Res. 101, 180–187. https://doi.org/10.1016/j.fishres.2009.10.006.

Harahap, S.A., Syamsuddin, M.L., Purba, N.P., 2020. Range of Sea Surface Temperature and Chlorophyll-α Values Based on Mackerel Catches in the Northern Waters of West Java. AACL Bioflux, Indonesia.

Hasyim, B., Hartuti, M., Sulma, S., 2009. Identification of fishery resources in Madura Strait based on the implementation of potential fishing zone information from remote sensing. Int. J. Remote Sens. Earth Sci. 6, 1–13. https://doi.org/10.30536/j.ijreses.2009.v6.a1234.

Johan, F., Jafri, M.Z., Lim, H.S., Wan Maznah, W.O., 2014. Laboratory measurement: Chlorophyll-a concentration measurement with acetone method using spectrophotometer, in: IEEE International Conference on Industrial Engineering and Engineering Management. pp. 744–748. https://doi.org/10.1109/IEEM.2014.7058737.

Karuppasamy, S., Ashitha, T.P., Padmanaban, R., Shamsudeen, M., Silva, J.M.N., 2020. A remote sensing approach to monitor potential fishing zone associated with sea surface temperature and chlorophyll concentration. Indian J. Geo-Marine Sci. 49, 1025–1030.

Katara, I., Illian, J., Pierce, G.J., Scott, B., Wang, J., 2008. Atmospheric forcing on chlorophyll concentration in the Mediterranean. Hydrobiologia 612, 33–48. https://doi.org/10.1007/s10750-008-9492-z.

Marini, Y., Setiawan, K.T., 2018. Indonesia sea surface temperature from TRMM Microwave Imaging (TMI) sensor. IOP Conf. Ser. Earth Environ. Sci. 149,. https://doi.org/10.1088/1755-1315/149/1/012055 012055.

Mustasim, Zainuddin, M., Safruddin, 2015. Thermal and Chlorophyll-a Front in relation to Skipjack Tuna Catch during the West-East Transition Season. Seram Waters. J. IPTEK PSP 2, 294–304.

Nammalwar, P., Satheesh, S., Ramesh, R., 2013. Applications of remote sensing in the validations of Potential Fishing Zones (PFZ) along the coast of North Tamil Nadu, India. Indian J. Mar. Sci. 42, 283–292.

Navarro, G., Ruiz, J., Huertas, I.E., Garcia, C.M., Criado-Aldeanueva, F., Echevarria, F., 2006. Spatial and temporal variability of phytoplankton in the Gulf of Cádiz through remote sensing images. Deep Res. Part II Top. Stud. Oceanogr. 53, 1241–1260. https://doi.org/10.1016/j.dsr2.2006.04.014.

Nurdin, S., Mustapha, M.A., Lihan, T., Ghaffar, M.A., 2015. Determination of potential fishing grounds of Rastrelliger kanagurta using satellite remote sensing and GIS technique. Sains Malaysiana 44, 225–232. https://doi.org/10.17576/jsm-2015-4402-09.

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. J. Geophys. Res. Ocean. 103, 24937–24953. https://doi.org/10.1029/98JC02160.

O'Reilly, J.E., Mueller, J.L., Chavez, F.P., Strutton, P., Cota, G.F., Carder, K.L., M̆uller-Karger, F., Harding, L., Magnuson, A., Phinney, D., Moore, G.F., Aiken, J., Arrigo, K. R., Letelier, R., Culver, M., 2000. SeaWiFS postlaunch calibration and validation analyses, part 3, NASA Technical Memorandum - SeaWIFS Postlaunch Technical Report Series.

Pelly, D.A., Marfai, M.A., Pangaribowo, E.H., Fadholi, A., 2020. Chlorophyll-a variability during positive IOD – the east season period in 2019 in Padang Sea, Indonesia. E3S Web Conf. 200, 06002. https://doi.org/10.1051/e3sconf/202020006002.

Rajagopal, T., Thangamani, A., Sevarkodiyone, S.P., Sekar, M., Archunan, G., 2010. Zooplankton diversity and physico-chemical conditions in three perennial ponds of Virudhunagar district, Tamilnadu. J. Environ. Biol. 31, 265–272.

Sidabutar, T., Srimariana, E.S., Wouthuyzen, S., 2020. The potential role of eutrophication, tidal and climatic on the rise of algal bloom phenomenon in Jakarta Bay. IOP Conf. Ser. Earth Environ. Sci. 429,. https://doi.org/10.1088/1755-1315/429/1/012021 012021.

Subramanian, S., Manjulekshmi, N., Narendra Pratap, S., Janhavi, K., Tejaswini, P., Pastta, M.F., 2014. Manual on The use of Potential Fishing Zone (PFZ) forecast. Technical bulletin No. 40, ICAR Research Complex for Goa (Indian Council of Agricultural Research), Old Goa – 403 402, Goa, India., Technical bulletin No. 40, ICAR Research Complex for Goa (Indian Council of Agricultural Research), Old Goa – 403 402, Goa, India.

Suhadha, A.G., Asriningrum, W., 2020. Potential fishing zones estimation based on approach of area matching between thermal front and mesotrophic area. J. Ilmu dan Teknol. Kelaut. Trop. 12, 565–581. https://doi.org/10.29244/jitkt.v12i2.28305.

Vollenweider, R.A., Giovanardi, F., Montanari, G., Rinaldi, A., 1998. Characterization of the trophic conditions of marine coastal waters with special reference to the NW Adriatic Sea: Proposal for a trophic scale, turbidity and generalized water quality index. Environmetrics 9, 329–357. https://doi.org/10.1002/(SICI)1099-095X(199805/06)9:3<329::AID-ENV308>3.0.CO;2-9.