The method for estimating and verification of upwelling phenomenon as a potential fishing ground

[1]Domu Simbolon, [1]Roza Yusfiandayani, [2]Carlos L. Susanto, [3]Eka Aprianti

[1] Department of Fisheries Resources Utilization, Faculty of Fisheries and Marine Sciences, IPB University, Bogor, West Java, Indonesia; [2] Capture Fisheries Technology and Management Study Program, Faculty of Fisheries and Marine Sciences, IPB University, Bogor, 16680, Indonesia; [3] Faculty of Fisheries and Marine Science, Khairun University, North Mollucas, 97719, Indonesia. Corresponding author: E. Aprianti, ekaaprianti100@gmail.com

Abstract. The availability of information on fishing areas is limited for fisher in the southern Yogyakarta waters, leading to inefficient operation. To overcome this problem, there is a need to determine the existence of upwelling locations, contributing to the formation of potential fishing grounds. These locations can be predicted by analyzing big data of the aquatic environment, particularly sea surface temperature, chlorophyll-*a*, and mean sea level anomaly downloaded from Marine Copernicus on the website https://marine.copernicus.eu/. The current use of marine big data is suboptimal due to limited analytical methods to detect upwelling locations, showing the need for further investigations. Therefore, this research aimed to develop a method for detecting upwelling locations and predicting their occurrence as an indicator of potential fishing grounds. The results showed that the upwelling index generated for prediction was 0.56 mg m^{-3}, 27°C, and 0.39 m, for the chlorophyll-*a*, sea surface temperature, and mean sea level, respectively. The analysis conducted from June to September 2020 showed upwelling occurrences in southern Yogyakarta waters were found from July to September, with the highest intensity observed in July and August. This phenomenon occurred more frequently in the coastal zone compared to offshore. Furthermore, upwelling locations were verified as potential fishing grounds, showing higher catch productivity compared to other areas without upwelling.

Key Words: big data, fishing ground, method, upwelling indeks, Yogyakarta.

Introduction. Upwelling is an oceanographic phenomenon occurring due to the rising of water masses from the lower layers to the surface. The phenomenon can cause the surface layer to become more fertile, attributed to the nutrient content in the water (Liu et al 2021; Vinayachandran et al 2021). These nutrients are essential in increasing phytoplankton growth and primary productivity in upwelling locations (Largier 2020; Hieu et al 2022; Broullón et al 2023). The fertility of water will stimulate other biological processes, and increase fish abundance, serving as an indicator of potential fishing ground (Simbolon 2019).

The water masses transported from the bottom layer to the surface during upwelling can cause characteristics to change, particularly the horizontal distribution pattern of sea surface temperature (SST), salinity, and fertility. In this case, the SST profile becomes cooler, and the salinity level increases in the surface layer around the upwelling location (Abrahams et al 2021; Awo et al 2022).

The main factors causing upwelling phenomenon in coastal areas are the dynamics of water masses (currents), wind, and topography. Onshore wind that blows continuously in coastal areas causes water masses on the surface to be pushed away from the coast toward offshore direction, resulting in a lower mean sea level (MSL) anomaly. Subsequently, water masses at this level fill the empty space on the surface due to negative anomaly of MSL, which is called a coastal upwelling (Simbolon 2019). Fadlan & Rosanti (2019) stated that MSL variability in Indonesian waters cannot be separated from the impact of water currents influenced by monsoon wind. Based on Ekman's theory the formation of upwelling occurs due to a decrease of MSL, while downwelling is attributed to the accumulation of water masses or rising of MSL (positive anomaly).

Spatio-temporal variability of oceanographic parameters such as temperature, salinity, currents, water fertility, etc., and oceanographic phenomenon (upwelling or downwelling) can affect fish behavior, particularly, regarding migration, feeding patterns, schooling, spawning, and other activities (Sambah et al 2021; Wilson & Laman 2021). Subsequently, changes in fish behavior affect the distribution, fish abundance, and dynamics of the fishing ground (Simbolon 2019). This indicates that the distribution of fish is dynamic, leading to difficulty in the detection of potential fishing grounds.

Fisher's limited understanding of the dynamics and movement patterns of fishing grounds poses a significant challenge to increasing catch productivity. In Indonesian waters, including in southern Yogyakarta, fishers still apply traditional methods in determining fishing grounds. The common methods include observing the presence of seabirds swooping above sea level, the appearance of foam on the surface layer, and changes in the color of water masses. However, these natural signs are not always found during fishing operations, leading to inefficient operations due to longer operating trips, excessive use of fuel, and high operational costs (Simbolon et al 2013).

The problem of limited information regarding the potential fishing ground can be resolved by detecting the upwelling locations. However, these locations are difficult to detect due to the limitations of analytical methods in using available big data such as chlorophyll-*a* (chl-*a*), SST, and MSL. The use of big data due to remote sensing detection is the optimal solution, as direct observations (in-situ) of water characteristics require high costs and a long period. These upwelling locations analysis method has a high urgency to provide accurate potential fishing ground information. The analytical method is also capable of producing an index of upwelling criteria that can easily be compared with the observed chl-*a*, SST, and MSL values.

Serving as potential fishing grounds, upwelling locations still require validation to eliminate the doubts of business actors about using the resulting method. This validation can be achieved through catch analysis at various fishing sites, enabling a comparison of catch productivity between suspected locations with and without upwelling. Therefore, this research aimed to develop an analytical method for detecting upwelling locations and predicting their occurrences as an indicator of potential fishing grounds. The results are expected to be a significant advancement, providing accurate potential fishing ground information for fishers, and leading to enhanced operational efficiency. This research also provided valuable insights to enrich existing knowledge in the field of evaluating upwelling.

Material and Method. The data utilized in this study comprises information collected from June to September 2020, encompassing marine environmental conditions such as SST, CHL-*a*, MSL, and catch data. Field observations were conducted between April and May 2021 to verify fishing activity data in the southern waters of Yogyakarta (Figure 1) and collect catch data recorded during the same period from local institutions. The selection of the location was based on upwelling phenomenon around these waters (Rachman et al 2018), although the potential to assist fishers in identifying fishing grounds remains suboptimally used.

The purposive sampling method was used to determine vessel size by selecting samples based on specific purposes and not strata, random, or region (Heridiansyah 2012). This method was used because fishing logbook data were only owned by > 30 GT purse seiner located in coastal fishing ports Songbanyu Village, Girisubo District, Gunung Kidul Regency, Daerah Istimewa Yogyakarta Province. Other vessels under 30 GT were not selected as samples due to their inability to use logbook. Specifically, the fishing logbook is the captain's daily report containing data regarding fishing activities, species, number of catches, fishing gear, and location. The data in the logbook were obtained from fishing activities in June-September 2020, coinciding with predicted upwelling events at the research location (Hsu et al 2021). Additional detailed data and information regarding fishing locations' condition, species, and number of catches in April-May 2021 was obtained through direct observation and in-depth interviews with captains or crews of purse seine vessels. The observation data from April-May were used as verification and validation that upwelling phenomenon could be used as indicator of potential fishing zone.

The SST, chl-*a*, and MSL data used were retrieved from the website https://marine.copernicus.eu/ from June to September 2020, as the outcome of satellite remote sensing detection. These data were processed with Ocean Data View 5.4 and Microsoft Excel software, followed by descriptive analysis to determine the spatio-temporal distribution, monthly average trend, and cumulative average. The results of the processed data were used to create a method for detecting upwelling locations in the form of an index of upwelling criteria. Subsequently, upwelling index was generated considering three main factors, namely (1) the SST value was lower than the average (Siemer et al 2021), (2) chl-*a* was higher than the average (Ferreira et al 2021), and (3) the MSL was anomaly-negative (Safinatunnajah et al 2021).

The method developed was used to detect upwelling locations as potential fishing grounds. The detection process was carried out through several stages, namely estimation of upwelling locations as well as verification and validation of locations as potential fishing grounds. Furthermore, upwelling index was compared with the observation values of SST, chl-*a*, and MSL. The upwelling locations could be presented in a thematic map using ArcGIS 10.7 software. This map was used to facilitate the interpretation of upwelling spatial distribution, as shown in Figure 1, which was overlaid on catch productivity data simultaneously at the same locations.

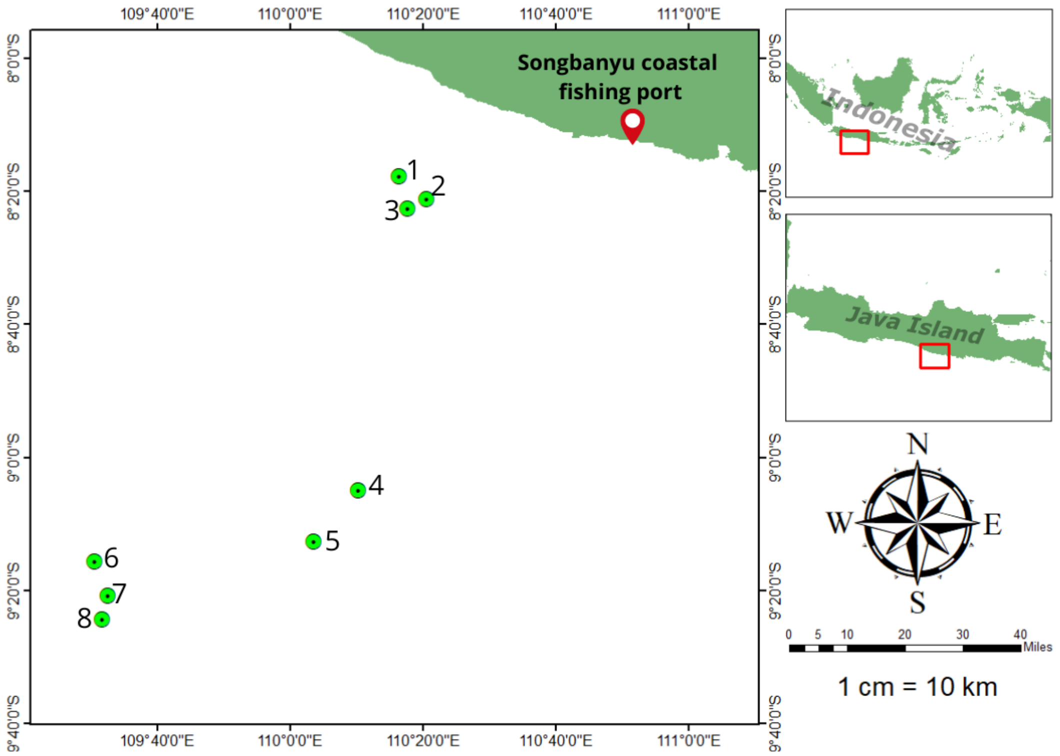


Figure 1. Fishing spots in the southern Yogyakarta waters in June-September 2020 to be verified as potential fishing grounds.

The verification and validation were carried out in three stages by proving that catch productivity at upwelling locations was higher than in the surrounding waters. The first stage included the calculation of catch productivity in various fishing spots using the catch per unit effort (CPUE) method. Subsequently, CPUE value was calculated by comparing the number of catches to that of trips (Rahman et al 2024). The level of catch productivity was grouped into high, medium, or low categories according to cumulative CPUE average value, as shown in Table 1.

The second stage included the making of a thematic map regarding CPUE distribution patterns spatially for various observed fishing grounds. Meanwhile, in the third stage, overlaying between CPUE distribution and upwelling was made, which further verified whether the upwelling locations were potential fishing grounds. The criterion used was the CPUE value mapping, where the inclusion in high category indicated a potential fishing ground. However, when the CPUE level was in the low category, the upwelling locations could be doubted. The fishing ground that did not have upwelling was also evaluated to provide a comprehensive description regarding the spatial distribution of potential fishing grounds in the research locations, as shown in Table 2.

Table 1
Determination of productivity category based on CPUE level assessment (Simbolon et al 2011)

No.	*Criteria*	*Category*
1.	$CPUE_{(obsevation)} > CPUE_{(cumulative\ average)}$	High catch productivity
2.	$CPUE_{(obsevation)} = CPUE_{(cumulative\ average)}$	Medium catch productivity
3.	$CPUE_{(obsevation)} < CPUE_{(cumulative\ average)}$	Low catch productivity

Table 2
Validation of upwelling and without upwelling locations as potential fishing ground

Fishing spot	*Upwelling location*	*Level of CPUE*			*Fishing ground category*	*Validation results*
		High	*Medium*	*Low*		
1	Yes	√	-	-	Potential	Proven
		-	√	-	Moderate	Doubtful
		-	-	√	Low	Not proven
2	No	√	-	-	Potential	Proven
		-	√	-	Moderate	Doubtful
		-	-	√	Low	Not proven

Results

The development of analytical methods in estimating upwelling locations. A total of 32 processed chl-*a*, SST, and MSL data were collected from 8 fishing grounds from June to September 2020. The distribution of chl-*a*, SST, and MSL values varied spatially based on different fishing grounds and temporally depended on various months. Specifically, the values of chl-*a* ranged from 0.26 to 0.78 mg m^{-3} with a cumulative average of 0.56 mg m^{-3}. The SST values ranged from 25.90 to 29.41°C with a cumulative average of 27°C, while MSL values varied between 0.29 and 0.56 m with an average of 0.39 m, as shown in Figure 2.

The cumulative average value was used as an index of upwelling criteria for comparison with the chl-*a*, SST, and MSL, at each fishing ground. Compared to the monthly average obtained from 8 data, the use of cumulative average was more appropriate due to its derivation from 32 data, reducing bias and better representing the actual conditions.

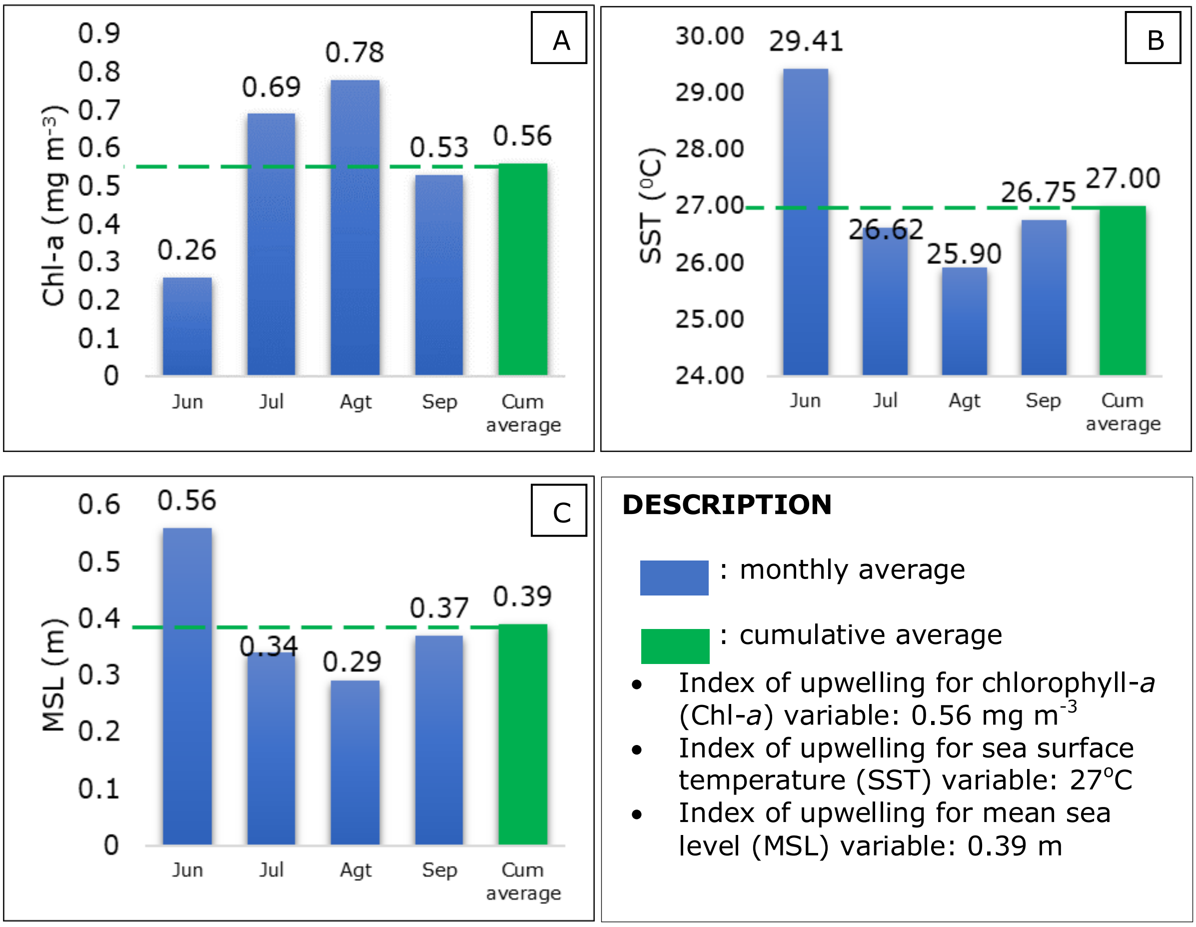
The analytical method used in this research for detecting upwelling phenomenon consists of four stages. Specifically, the first stage included determining indicators/ variables to be evaluated, with their profiles subjected to change due to chl-*a* and SST, which could trigger events of MSL. The second stage was determining upwelling index based on calculating the cumulative average of each indicator/variable, serving as a reference point to create upwelling criteria. The third stage was the formulation of assessment criteria by comparing observation results to the upwelling index as follows:

1. waters with chl-*a* exceeding upwelling index for chl-*a* are prone to be upwelling locations;
2. waters with SST lower than upwelling index for SST will have a greater possibility of being upwelling locations;

3. waters with MSL lower than upwelling index for MSL (negative anomaly) have a higher tendency to be upwelling locations;

4. Waters that have the opposite characteristics to points (1), (2), and (3) are prone to experiencing no upwelling.

The fourth or last stage in detecting upwelling locations is making a decision based on three upwelling criteria. In this case, there is a possibility that only one or two to three indicators fulfill the criteria, or none of the indicators are fulfilled. Based on these conditions, the following decisions are (1) when all indicators/variables' criteria are fulfilled, high-intensity upwelling is suspected, (2) when only two criteria are fulfilled, upwelling is suspected, and (3) when there is no or only one criterion fulfilled for the three indicators, the condition is assumed to be the absence of upwelling.



DESCRIPTION

🟦 : monthly average

🟩 : cumulative average

- Index of upwelling for chlorophyll-*a* (Chl-*a*) variable: 0.56 mg m^{-3}
- Index of upwelling for sea surface temperature (SST) variable: 27°C
- Index of upwelling for mean sea level (MSL) variable: 0.39 m

Figure 2. Monthly average distribution and cumulative average for chl-*a* (A), SST (B) and MSL (C) variables.

Spatial and temporal distribution of upwelling. Upwelling phenomenon did not occur during June 2020 because the index criteria for SST, chl-*a*, and MSL variables were not fulfilled. In July, upwelling phenomenon was found in all fishing grounds with high intensity, except for fishing grounds number 1 and 4 where only two criteria were fulfilled, as shown in Table 3. The high frequency of occurrence in August was similar to July, where the three criteria were fulfilled for all fishing spots. This showed that the largest area of upwelling occurred in July and August.

Upwelling occurred in September at fishing grounds 1-5, while there was no occurrence at grounds 6-8. The phenomenon that occurred in September was similar to August, where there was a significant concentration in the zone close to coastal areas, namely fishing grounds 1, 2, and 3. Upwelling intensity was higher or often occurred in the coastal zone compared to offshore such as fishing grounds 4 and 5.

Table 3

Evaluation of SST, chl-*a* and MSL variables to predict upwelling

Spot	*Date*	*Upwelling variable*									*Result*
		SST (°C)			*Chl-a (mg m^{-3})*			*MSL (m)*			
		A	*B*	*C*	*A*	*B*	*C*	*A*	*B*	*C*	
1	12/06/20	≤27	29.67	×	≥0.30	0.34	√	<0.39	0.57	×	No-upwelling
2	13/06/20	≤27	29.60	×	≥0.30	0.35	√	<0.39	0.50	×	No-upwelling
3	14/06/20	≤27	29.34	×	≥0.30	0.41	√	<0.39	0.49	×	No-upwelling
4	15/06/20	≤27	29.23	×	≥0.30	0.21	×	<0.39	0.58	×	No-upwelling
5	16/06/20	≤27	29.52	×	≥0.30	0.20	×	<0.39	0.58	×	No-upwelling
6	17/06/20	≤27	29.31	×	≥0.30	0.18	×	<0.39	0.58	×	No-upwelling
7	18/06/20	≤27	29.40	×	≥0.30	0.17	×	<0.39	0.58	×	No-upwelling
8	19/06/20	≤27	29.22	×	≥0.30	0.18	×	<0.39	0.61	×	No-upwelling
1	22/07/20	≤27	27.15	×	≥0.30	0.87	√	<0.39	0.32	√	Upwelling
2	23/07/20	≤27	26.72	√	≥0.30	1.03	√	<0.39	0.33	√	Upwelling (*)
3	24/07/20	≤27	26.70	√	≥0.30	1.24	√	<0.39	0.30	√	Upwelling (*)
4	25/07/20	≤27	26.20	√	≥0.30	0.22	×	<0.39	0.35	√	Upwelling
5	26/07/20	≤27	26.57	√	≥0.30	0.46	√	<0.39	0.35	√	Upwelling (*)
6	27/07/20	≤27	26.60	√	≥0.30	0.42	√	<0.39	0.35	√	Upwelling (*)
7	28/07/20	≤27	26.45	√	≥0.30	0.68	√	<0.39	0.35	√	Upwelling (*)
8	29/07/20	≤27	26.59	√	≥0.30	0.60	√	<0.39	0.38	√	Upwelling (*)
1	01/08/20	≤27	25.47	√	≥0.30	1.29	√	<0.39	0.21	√	Upwelling (*)
2	02/08/20	≤27	24.84	√	≥0.30	1.31	√	<0.39	0.23	√	Upwelling (*)
3	03/08/20	≤27	25.32	√	≥0.30	1.12	√	<0.39	0.23	√	Upwelling (*)
4	04/08/20	≤27	26.38	√	≥0.30	0.45	√	<0.39	0.30	√	Upwelling (*)
5	05/08/20	≤27	26.35	√	≥0.30	0.50	√	<0.39	0.31	√	Upwelling (*)
6	06/08/20	≤27	26.36	√	≥0.30	0.57	√	<0.39	0.33	√	Upwelling (*)
7	07/08/20	≤27	26.27	√	≥0.30	0.53	√	<0.39	0.34	√	Upwelling (*)
8	08/08/20	≤27	26.23	√	≥0.30	0.46	√	<0.39	0.37	√	Upwelling (*)
1	11/09/20	≤27	25.45	√	≥0.30	1.12	√	<0.39	0.32	√	Upwelling (*)
2	12/09/20	≤27	25.85	√	≥0.30	1.06	√	<0.39	0.30	√	Upwelling (*)
3	13/09/20	≤27	25.95	√	≥0.30	1.01	√	<0.39	0.29	√	Upwelling (*)
4	14/09/20	≤27	27.10	×	≥0.30	0.20	√	<0.39	0.37	√	Upwelling
5	15/09/20	≤27	27.39	×	≥0.30	0.19	√	<0.39	0.39	√	Upwelling
6	16/09/20	≤27	27.47	×	≥0.30	0.18	√	<0.39	0.42	×	No-upwelling
7	17/09/20	≤27	27.44	×	≥0.30	0.19	√	<0.39	0.45	×	No-upwelling
8	18/09/20	≤27	27.32	×	≥0.30	0.25	√	<0.39	0.44	×	No-upwelling

Information: A = upwelling criteria index; B = actual value; C = evaluation result; × = criteria not fulfilled; √ = criteria fulfilled; (*) = high-intensity upwelling.

Catch productivity. The total daily catch from June to September 2020 tended to fluctuate, ranging from 6,984 kg in June to 20,537 kg in August, as shown in Figure 3.

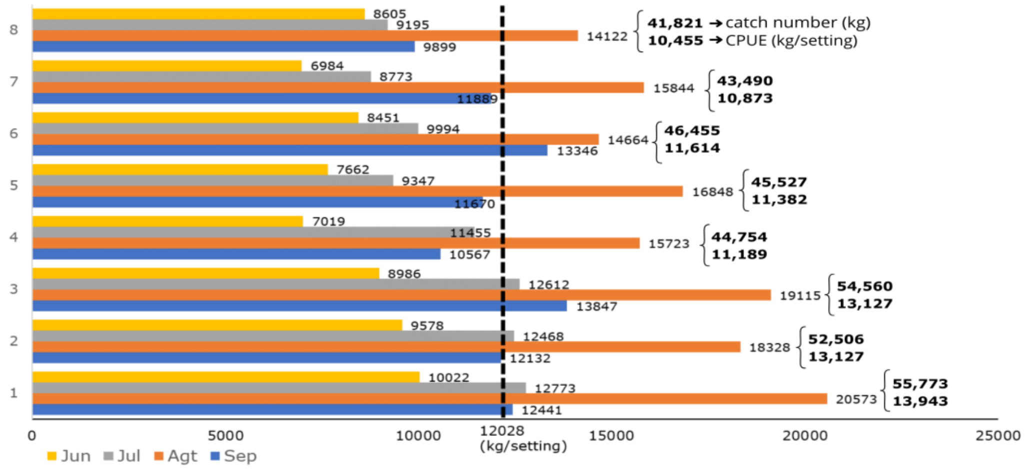


Figure 3. Spatio-temporal distribution of catches in the southern of Yogyakarta waters from June to September 2020.

The total catch from all fishing grounds in June-September period was 384,886 kg with CPUE 12,028 kg/setting (Figure 3). The daily and monthly catch has the same distribution pattern, with the lowest and highest number of monthly catches in June and August, respectively (Figure 4-A). Based on the CPUE value, there were 17 and 15 fishing grounds in the low and high productivity categories, respectively, as shown in Figures 3 and Figure 4-B.

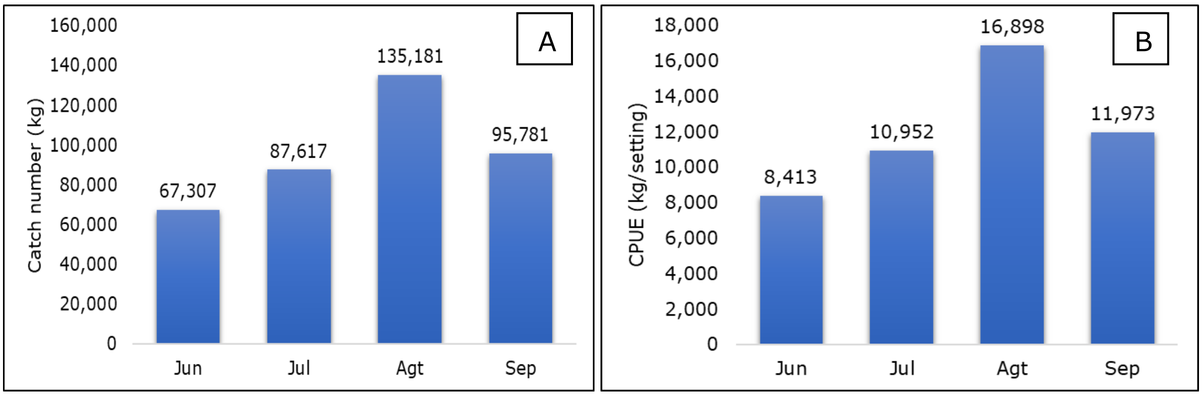


Figure 4. The number of catches (A) and catch productivity (B) temporally in the southern of Yogyakarta waters from June to September 2020.

Verification and validation of upwelling locations as potential fishing grounds. Verification and validation of upwelling locations as potential fishing grounds were carried out to determine variation in catch productivity. Based on the results, upwelling did not occur in June (Table 3), along with lower catch and CPUE were lower compared to July-September (Figure 4B). Furthermore, catch productivity increased from 8,413 kg/setting in June to 10,952 kg/setting in July, indicating the impact of upwelling on increasing the number of catches.

Upwelling with high intensity was found in all fishing grounds in August, as shown in Table 3. The phenomenon had a very significant effect on increasing catch productivity from 10,952 kg/setting in July to 16,898 kg/setting in August (Figure 4B). Total catch and CPUE in August were also the highest compared to June, July, and September. The area of upwelling decreased from August to September because the phenomenon did not reoccur in fishing grounds 6, 7, and 8, as shown in Table 3. This caused catch productivity to decrease in September, compared to August which was still higher due to high-intensity upwelling than in June-July.

Locations and times of upwelling occurrence related to number of catches during the research were presented in Figure 5. Production and catch productivity levels at fishing grounds 1, 2, and 3 were significantly higher compared to others. The frequency of upwelling at the three fishing grounds occurred 3 times in July, August, and September. Catch productivity was also in the high category, namely 13,943.3 kg/setting, 13,126.5 kg/setting, and 13,640.0 kg/setting for grounds 1, 2, and 3 respectively. The fishing grounds where upwelling rarely occurred were 6, 7, and 8 with two-times frequency, alongside low productivity and CPUE values of 11,613.8 kg/setting, 10,872.5 kg/setting, and 10,455.3 kg/setting, respectively.

Upwelling events showed a significant effect on increasing catch productivity, with a higher number of catches, serving as indicators of potential fishing grounds. The prediction of upwelling locations through an aquatic environment's big data analysis was still rarely studied in Indonesian waters. However, big data on the aquatic environment were available on various sites such as https://marine.copernicus.eu/, with easy accessibility. Despite being underutilized for capture fisheries purposes, this research showed the significant influence of upwelling on the potential fishing grounds in the southern Yogyakarta waters. The verification process was carried out by comparing the time and locations of upwelling in relation to catch productivity.

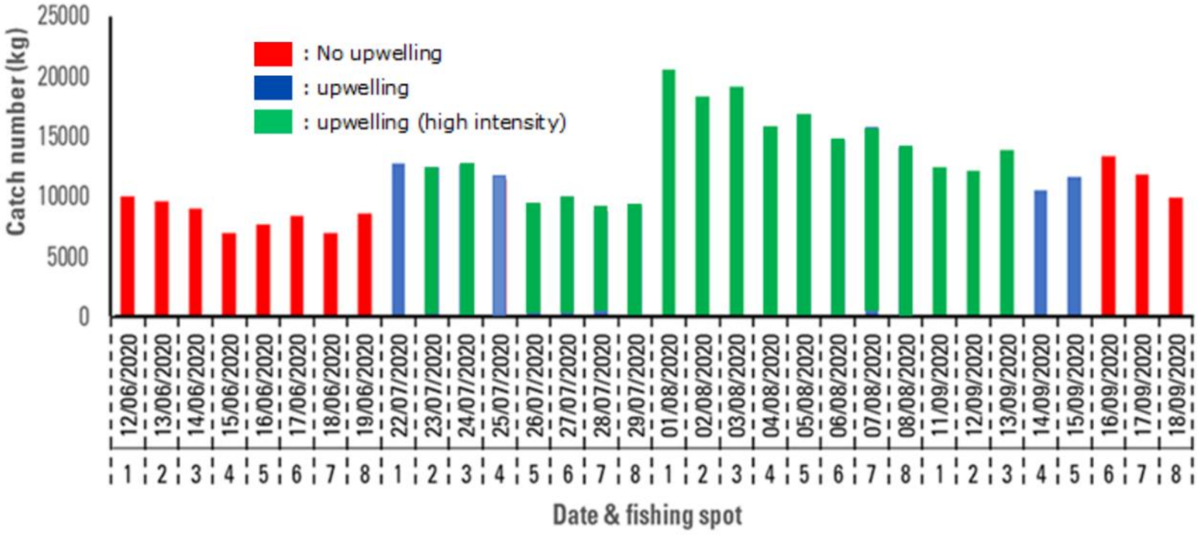


Figure 5. The relationship between catch number and the upwelling's time and location, from June-September 2020 in the southern Yogyakarta waters.

Discussion. The analytical method for detecting upwelling locations in southern Yogyakarta waters has been developed based on the criteria index. This method was created and developed with reference to the results of previous research related to SST variables (Amri et al 2013), chl-*a* (Kunarso et al 2011), and MSL (Simbolon et al 2013). The intensity of upwelling locations around the coastal fishing grounds 1, 2, and 3, was found to be higher compared to others, as all the criteria were fulfilled according to the upwelling criteria index. Locations of high intensity were found from July to September, with the peak occurring in August. This upwelling process is closely related to the Australian monsoon winds. The Australian monsoon intensity reaches a maximum in the JJA (June, July, August) – SON (September, October, November) season, so the upwelling intensity also reaches a maximum (Nurlatifah et al 2021). The highest frequency of upwelling at the research locations occurred in July and August, indicating seasonal occurrence. Similarly, Wen et al (2023) showing that climatic events indirectly affect fishery resources through upwelling effects in the southern Java Sea.

The close relationship between upwelling phenomenon and chl-*a* content as a representation of water fertility is evident in the spatial and temporal fluctuations observed in chl-*a* distribution pattern. When there was a high intensity of upwelling in August, the chl-*a* content was also relatively elevated, as shown in Figure 2-A. In contrast, according to Mandal et al (2022), a strong seasonality is significantly observed along the southern Java coast with chl-*a* blooms during the SEM (June-October) compared to the lower chl-*a* concentration values during December-April in the northwest. Furthermore, upwelling and distribution of chl-*a* content were influenced by the Indonesian throughflow or Arlindo (Napitupulu et al 2022; Apriansyah et al 2023).

Spatial distribution of high-intensity upwelling was found around the coastal areas, as shown in Figure 6. This phenomenon occurred due to the wind blowing from the land pushing water masses from the coast towards the open sea, leading to MSL anomalies (Fadlan & Rosanti 2019; Simbolon 2019). The MSL that has a value lower than the average is called a negative anomaly, while a value higher indicates a positive anomaly (Simbolon et al 2013). Therefore, when there is a push of water masses from the coast toward the open sea, a negative anomaly will occur in the coastal area (onshore) while a positive anomaly will occur in the offshore area. When a negative anomaly occurs in the coastal area, the surface layer is filled with water masses from the bottom (deep water) layer, often called a coastal upwelling.

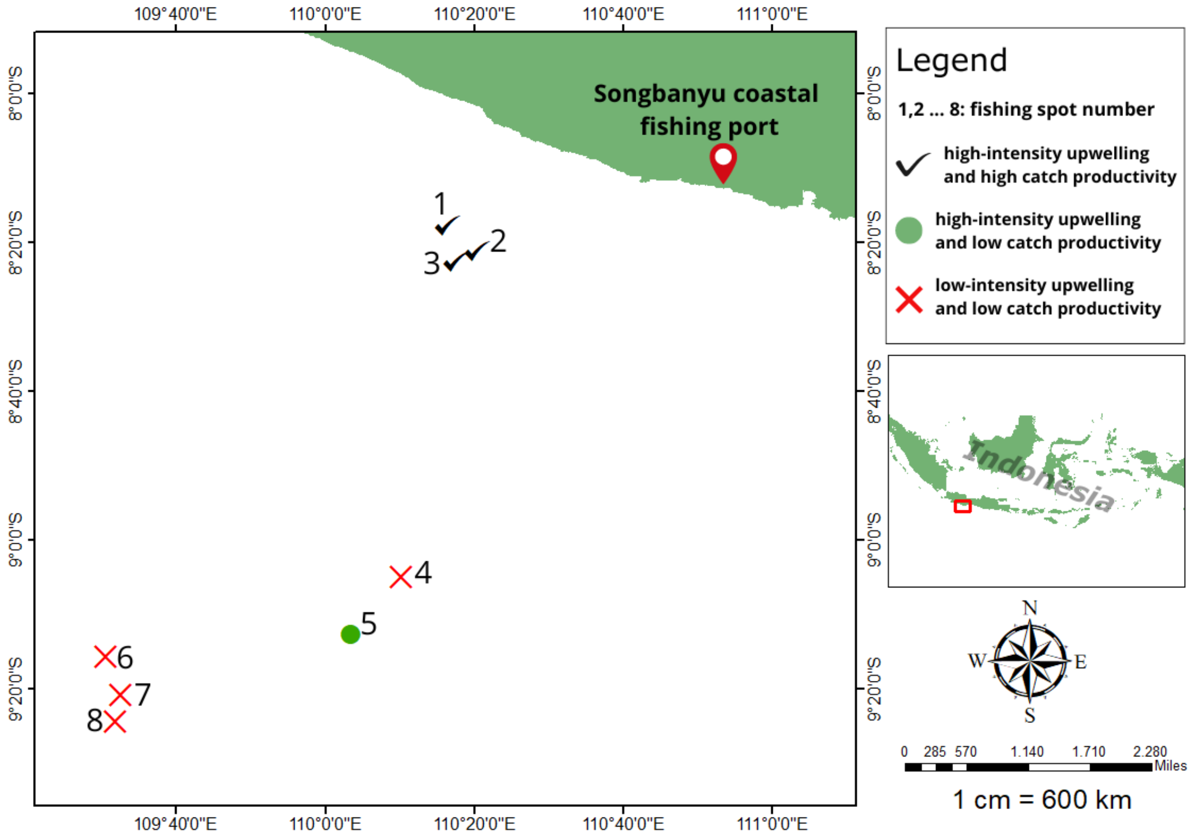


Figure 6. Spatial distribution of upwelling and catch productivity in the southern Yogyakarta waters in June-September 2020.

Seasonal changes in the southern Yogyakarta water can affect the volume of water masses entering, thereby affecting MSL variability. Mujadida et al (2021) and Handoko et al (2021) stated that MSL variability could occur due to differences in water masses transport according to changes in monsoon wind. Wyrtki (1962) also reported that runoff from rivers during high rainfall caused an increase in MSL in the southern Java Sea. However, a significant decrease in MSL was observed when there was a movement of currents causing water masses to flow from the southern Java Sea, leading to the formation of upwelling phenomenon.

Conclusions. This research developed the analytical method for estimating upwelling locations using chl-*a*, SST, and MSL indicators. This method successfully detected upwelling locations in southern Yogyakarta waters during the period of June-September 2020. These locations were found in July, August, and September, with the highest frequency and area, occurring accordingly around the coast. The results showed the use of upwelling phenomenon as an indicator of potential fishing grounds, due to the higher catch productivity.

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Conflict of interest. The authors declare that there is no conflict of interest.

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Authors:
Domu Simbolon, Department of Fisheries Resources Utilization, Faculty of Fisheries and Marine Science, IPB University, IPB Dramaga Campus, Agathis Street, 16128 Bogor, Indonesia, e-mail: domu@apps.ipb.ac.id
Roza Yusfiandayani, Department of Fisheries Resources Utilization, Faculty of Fisheries and Marine Science, IPB University, IPB Dramaga Campus, Agathis Street, 16128 Bogor, Indonesia, e-mail: ocha_roza@apps.ipb.ac.id
Carlos Lambok Susanto, Capture Fisheries Technology and Management Study Program, Faculty of Fisheries and Marine Science, IPB University, IPB Dramaga Campus, Agathis Street, 16128 Bogor, Indonesia, e-mail: carlos.hutauruk1233@gmail.com
Eka Aprianti, Faculty of Fisheries and Marine Science, Khairun University, Pertamina Kampus II Unkhair Gambesi street, 97719 North Mollucas, Indonesia, e-mail: ekaaprianti100@gmail.com

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