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SPATIAL-TEMPORAL DISTRIBUTION OF NARROW-BARRED SPANISH MACKEREL (*Scomberomorus commerson*) FISHING GROUNDS IN KEPULAUAN RIAU WATERS, INDONESIA

Sebaran Spasial-Temporal Daerah Penangkapan Ikan Tenggiri Batang (Scomberomorus commerson) di Perairan Kepulauan Riau, Indonesia

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ABSTRACT

Narrow-barred Spanish mackerel (Scomberomorus commerson) is an exportable fish captured by gillnetters from Bintan Regency, Kepulauan Riau. The availability of information about the activities of fishing fleets operating in the waters of Kepulauan Riau is still limited. Such information is essential to the institution of the Agency for Marine and Fisheries Affairs of Kepulauan Riau Province for ensuring the sustainability of the fisheries, both economically and biologically. This study aims to determine the spatial-temporal distributions of the acceptable - exportable mackerel fishing grounds along the year concerning to the catch data, sea surface temperatures, chlorophyll-a concentrations, and salinity in the last four months of 2022. The data were obtained from fish export companies, the fisheries surveillance office based in Tanjungpinang, interviews with fishermen from 44 samples of fishing vessels, and remote sensing-based marine data. Analysis of the monthly fishing productivity and optimum marine conditions for the mackerels were applied to determine the prospects of five recognized fishing grounds. All fishing grounds are highly prospective from August to November, with an exception is Lingga islands. The longest season of mackerel fishing is found around Bangka Island (11 months). The spatial and temporal patterns show that the north-south-north shifts in fishing grounds are associated with regional climates, i.e., monsoon winds.

Keywords: *Fishing grounds, Gillnets, Kepulauan Riau-Indonesia, Spanish Mackerels*

ABSTRAK

Tenggiri batang (*Scomberomorus commerson*) adalah salah satu jenis ikan ekspor yang ditangkap armada jaring insang dari Kabupaten Bintan. Armada perikanan ini beroperasi di perairan Kepulauan Riau, namun informasi tentang kegiatan armada ini masih sangat sedikit. Informasi semacam ini penting bagi pengelola perikanan tangkap, khususnya Dinas Kelautan dan Perikanan Provinsi Kepulauan Riau yang bertugas memastikan keberlanjutan perikanan, baik secara ekonomi maupun biologis. Penelitian ini bertujuan menentukan sebaran spasial-temporal daerah penangkapan tenggiri sepanjang tahun berdasarkan data hasil tangkapan, suhu permukaan laut, konsentrasi klorofil, dan salinitas dari daerah penangkapan ikan selama 4 bulan terakhir tahun 2022. Data tersebut diperoleh dari perusahaan ekspor ikan, kantor Satwas SDKP Tanjungpinang, wawancara dengan nelayan dari 44 kapal ikan sampel, dan data kelautan berbasis penginderaan jauh. Analisis produktivitas bulanan dan tumpang-tindih kondisi optimum lingkungan laut bagi tenggiri diterapkan untuk menentukan tingkat prospek dari 5 daerah penangkapan ikan yang dikenal baik nelayan. Kecuali perairan di sekitar Pulau Lingga, semua daerah penangkapan ikan memiliki prospek tinggi untuk tenggiri mulai dari bulan August hingga November. Musim terpanjang penangkapan tenggiri di Perairan sekitar pulau Bangka (11 bulan). Pergerakan utara-selatan-utara dari lokasi penangkapan ikan ini berkaitan erat dengan angin monsun.

Kata kunci: Kepulauan Riau-Indonesia, *Gillnet*, Daerah Penangkapan Ikan

INTRODUCTION

The narrow-barred Spanish mackerel (*Scomberomorus commerson*) is one of the exportable fishes captured by the gillnet fishing fleets from Bintan Island in the Kepulauan Riau waters inside the Indonesia Fisheries Management Area 711 (Noegroho 2019; Budianto *et al.* 2022; Fauzi *et al.* 2023). In 2015, the volume of the export was 8,300 tons and the value was US$ 311,090, while in 2020 it was 14,250 tons (BPS Kepulauan Riau 2021). The major export destinations were Malaysia, Singapore, Australia, China, and USA. In the implementation of the Precision Fisheries Program (Indonesia: *Program Penangkapan Ikan Terukur*) initiated by the Minister of Marine Affairs and Fisheries Republic of Indonesia in 2023. The Provincial Government of Kepulauan Riau requires detailed information on the locations and periods of productive fishing grounds for the commercial fish, including the mackerels. The Provincial Government is responsible for managing the fisheries that take place in the fishing grounds from the coastlines to 12 nautical miles. Such information is essential to the Provincial Government to estimate potential economic outcomes regarding national and regional non-tax income based on fluctuated monthly landings and fishing efforts. Since promoting the sustainability of fish resources is one of the main goals of Indonesian fisheries management (Muawanah *et al.* 2018), the required information should include the periods of prospective fishing grounds where fish at acceptable - exportable sizes are available in abundance. This information is also essential to anglers, fishing boat owners and agents for determining prospective fishing trips.

The mackerels are estimated to migrate between the South China Sea, the shallow waters of the Sunda continental shelf, and its neighboring waters in the Indo-Pacific regions (Fischer dan Whitehead 1974; Hood *et al.* 2017; Noegroho 2019; Griffiths *et al.* 2020). Their migrations may be driven by various factors, such as currents that carry some physical and biological characteristic that will affect the distributions of their prey, predators, and other marine biota and determine the habitat qualities for their life cycle (Simbolon 2011; Calado dan Leal 2015; Woods *et al.* 2016). The sea surface temperature (SST), salinity (SSS), and chlorophyll-a (CHL-a) are commonly considered as significant factors in forecasting prospective fishing grounds (Cahya *et al.* 2016; Dutta *et al.* 2016; Kaplan *et al.* 2016; Siregar 2018; Sari *et al.* 2019; Fauziah *et al.* 2020). The distributions of SST, SSS, and CHL-a in the Kepulauan Riau waters likely correlate with the regional monsoon in which wind directions and speeds affect the spatial and temporal surface currents in the fishing grounds of mackerels (Kok *et al.* 2015; Gaol dan Sadhotomo 2017; Mahabror *et al.* 2017; Kok *et al.* 2021). In addition to the three parameters, fishing productivity or catch per unit effort (CPUE) are also considered in determining prospective fishing grounds (Maina *et al.* 2016; Cahya *et al.* 2016). The analysis applies the Simple Moving Average (SMA) calculation to monthly productivity data over three months, it is assumed that conditions in the two months prior to a given month have an impact on productivity as well as the resources and the fishing grounds environment during that month. According to Noegroho (2019), in contrast to some previous studies that used the 12-month average percentage method, the fishing season pattern using the SMA method has its own advantages of being able to isolate fluctuations in seasonal and annual factors. The fishing season pattern using the SMA method has the advantage of being able to isolate fluctuations in seasonal and annual factors. Furthermore, of the four factors considered, the economic factor of monthly productivity is of the main interest to fisheries managers and businesses. This is because fish sales revenue and operational costs are taken into account when assessing the performance of the local fishing business.

Information on the patterns of water circulation in the South China Sea and in the surrounding areas is now available. The integration of satellite imagery data for SST, SSS, and CHL-a with water circulation patterns provides a complete picture of the dynamics occurring in the mackerel fishing grounds of Bintan fishermen. The Agency for Marine and Fisheries Affairs of Kepulauan Riau Province could potentially utilize this information to prepare for future fisheries outlooks and implement Precision Fisheries. This approach may be supported by predictions that could help reduce the risk of failure in managing mackerel fisheries. Therefore, a study on the spatial and temporal distributions of prospective fishing grounds in the Kepulauan Riau waters for the acceptable – exportable mackerels is needed. This study aims to determine the spatial-temporal distributions of the mackerel acceptable – exportable fishing grounds along the year which is based the catch data, SST, CHL-a, and SSS in the last four months of 2022.

METHODS

The data on gillnetter fishing grounds that targeted the Spanish mackerel were collected through interviews with fishers associated with 44 gillnetters in Barek Motor, Bintan, from September 2022 to January 2023 and also from the fishing logbooks collected by the Marine and Fisheries Resources Surveillance (Pengawas Sumberdaya Kelautan Perikanan/PSDKP) units in Tanjungpinang and Bintan. After explaining the purpose of the interview and reviewing the prepared maps for spatial orientation, respondents were questioned about the location and timing of fishing activities. In addition, they were also asked to report the name and size of the vessel, along with the fishing location from January to December 2022.

Research Procedure

The information on fishing grounds was processed with ArcGIS, which is licensed to IPB University. Then the reported areas of the fishing trips were processed using software to estimate the spatial extent of the fishing areas. The spatial extent was determined by considering the total length of the main line over the gillnet, the potential distance or drift area of the vessel and gillnet, and the accessible area for maneuvering all fishing vessels operating in the fishing area. Based on the interview results, it was found that all respondents knew the location of the Natuna Islands, Tambelan Islands, Bangka Islands, Lingga Islands, and Bangka Islands.

Data on SST, CHL-a and SSS were obtained from one of the European Union Programs at *https://data.marine.copernicus.eu/.* The SST, CHL-a and SSS data originated from the images generated by the marine Sentinel satellite. The SST and SSS data were downloaded from the menu of Global Ocean Physics Analysis and Forecast, whereas the CHL-a data from the menu of Global Ocean Biogeochemistry Reanalysis. SST and SSS data have spatial resolutions of 0.083°×0.083°×50 levels for water depths of 0.5–5 m, whereas the CHL-a had a spatial resolution of 0.25°×0.25°×50 levels for water depths of 0.5–5 m. All three data types used in this study have a temporal resolution of one day and are downloaded from the format of Network Common Data Form (NetCDF). The SST, CHL-a and SSS data cover a 12-month observation from January to December 2022 for spatial coverages over the estimated fishing grounds that were processed the information of the reported locations for 176 fishing trips made by the gillnetter targeting the mackerels in September to December 2022.

This study hypothesized that the water conditions and three environmental indicators found in the fishing trip locations from September to December 2022 are adequate for exportable mackerels. This assumption adheres to the technique used by (Harris *et al.* 2020; Hsu *et al.* 2021). The current acceptable-exportable size is based on PT AK Fishery Bintan, which is a minimum of 1.4 kilogram each piece or at least 53 cm fork length. The appropriate SST, CHL-a, and SSS values were determined as a range. For each fishing field, a monthly frequency distribution of the daily average SST, CHL-a, and SSS was produced from January to December 2022. For each fishing ground, the monthly frequencies or days of eligible SST, CHL-a, and SSS ranges were computed. If the total number of appropriate days exceeded or equaled 70% of the total days in the month, the month was classified as prospective time.

Data on landings of the mackerels for each boat were obtained from two sources. The first source was PT AK Fishery Bintan which records the quantity of the exportable fish received from 176 fishing trips conducted by the 44 boats in September – December 2022. The second source was the PSDKP Unit at Tanjungpinang and Bintan, which keeps the

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compilation of data from the fishing logbooks from January to December 2022. The logbook data includes information about the vessel, gear specifications, dates of departure and arrival for each boat, codes for fishing trip locations, and catch by fish group from each trip.

The monthly fishing productivity of the 44 fishing boats for each fishing ground from January to December 2022 was calculated using data from the PSDKP. The monthly productivity for one fishing ground ($P_{g,m}$) was defined as total catch from participated boats divided by total fishing trips (t) in the fishing ground (g) in a month (m). The calculation was carried out using the following formula:

$$P_{g,m} = \frac{\sum_{i=1}^{n} c_i}{\sum_{i=1}^{n} t_i} \quad \text{...} (1)$$

where n is the trip number.

The productive months were determined by applying simple moving average analysis (SMA) over 3 months. The formula for determining the monthly average productivity ($P_{t=SMA,\, g,m}$) is:

$$P_{SMA,g,m} = \frac{P_{g,m-2}+P_{g,m-1}+P_{g,m}}{3} \quad \text{....................} (2)$$

This value was then processed to obtain the monthly fishing productivity index ($M_{g,m}$). Given the potential influence of factors on a one-year scale on general conditions and fishing ground dynamics, $M_{g,m}$ was calculated by standardizing the monthly productivity ($P_{SMA,g,m}$) to the average ($\bar{P}_{SMA,g,m}$), taking into account the standard deviation ($S_{P_{SMA,g,m}}$) in the year 2022. The formula to calculate the monthly fishing productivity index is:

$$M_{g,m} = \frac{P_{SMA,g,m} - \bar{P}_{SMA,g,m}}{S_{P_{SMA,g,m}}} \quad \text{..........................} (3)$$

The criteria for the productive month for the narrow-barred Spanish mackerels is $M_{g,m} > 0$. Other than that, it could be a more productive month for the mackerels.

Data Analysis

Prospectives of each fishing ground each month were assessed on the basis of the existence of suitable SST, CHL-a and SSS. If appropriate SST, CHL-a and SSS are identified in a month, then fishing grounds in that month will be recommended highly prospective. If only 2 out of 3 indicators, the fishing ground in that month will be recommended prospective, and if only one out three indicators, the fishing ground will be recommended less prospective for fishing the narrow-barred Spanish mackerels.

RESULTS

Fishing Vessels and Their Fishing Grounds

During data collection in December 2022, the PSDKP recorded 171 units of Barekmotor-based gillnetters operating in Kepulauan Riau waters (Figure 1). The 44 boats in the study have dimensions of around 18×5×2 m (length, width, and depth) and primary engines with a power of 40-120 PK. Each boat was operated by 6-8 anglers, and fishing trips lasted 16-20 days, including a 2-4-day cruise. As a result, the actual fishing activity lasted approximately 12-16 days. The distribution of fishing locations from the interviews is presented in Figure 2.

The gillnets were made of nets with mesh sizes ranging from 4.5 to 4.8 inches. The overall lengths of the gillnets ranged from 2,500 to 3,900 meters, with each piece of net measuring 9-13.5 meters in height and 50-65 meters in length per piece. Each section of the gillnets has no sinker; the nets hang freely on the main line. The gillnets operation was worked twice at night, once from roughly 5:00 PM to midnight and again from midnight to 5:00 AM. In the daytime, the boats might move to different locations while the nets were being repaired onboard or the boat crews took their break. The catch comprised more than just Spanish mackerels; it also included demersal species, including giant catfish (*Netuma thalassina*) and striped snakehead. Such composition suggests that the gillnets can be used to catch both pelagic and bottom species by adjusting the net depth. In September-October 2022, the catches for all fishing grounds ranged from 650-950 kg/trip, whereas November-December the catch increased in all fishing grounds to 950-1250 kg/trip (Figure 3).

The monthly fishing productivity indices for the 12-month data in 2022 show regional differences in peak fishing season across the five fishing grounds (Figure 4). Peak seasons in the northern Kepulauan Riau waters occurred near Natuna islands in January, February, July, September, and November, and around Anambas islands in April, May, June, September, October, November, and December. The high seasons around Lingga occurred in January, February, September, and November, whereas the peak seasons around Bangka waters happened in March, September, October, November, and December. Peak seasons in the Kepulauan

Riau waters around Tambelan islands occur in January, February, September, October, November, and December. The indices were typically quite low from March to May (the first transitional monsoon season) and again from June to August (the south-eastern monsoon wind season).

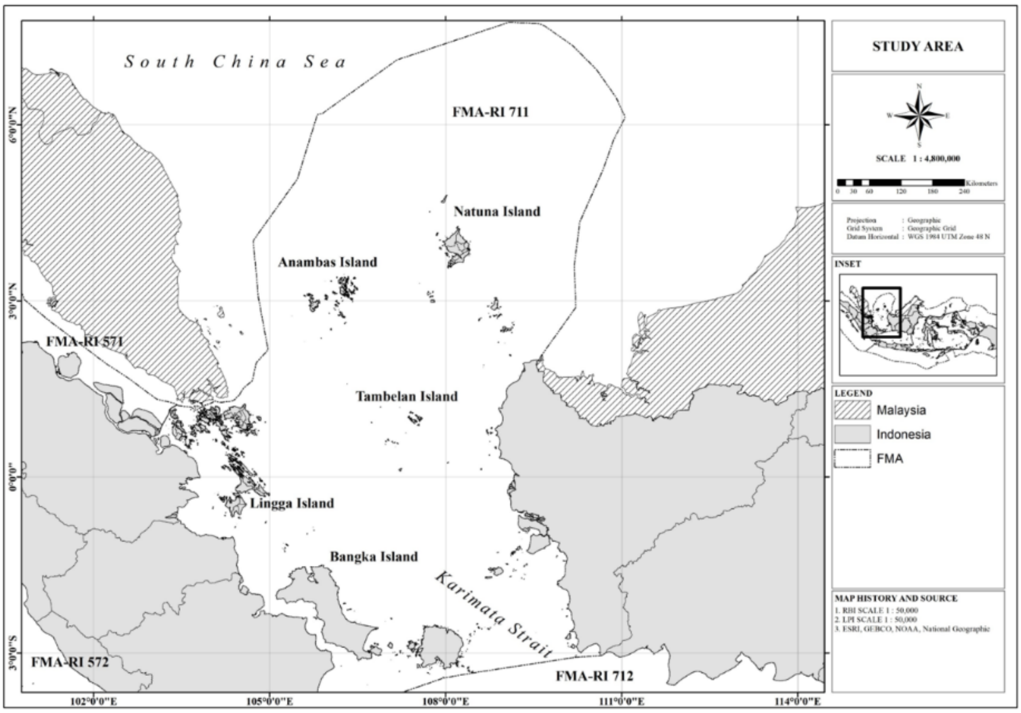

Figure 1 The locations of studied areas in the waters of the Kepulauan Riau Waters in the Fisheries Management Area-711 (WPPNRI 711), Indonesia.

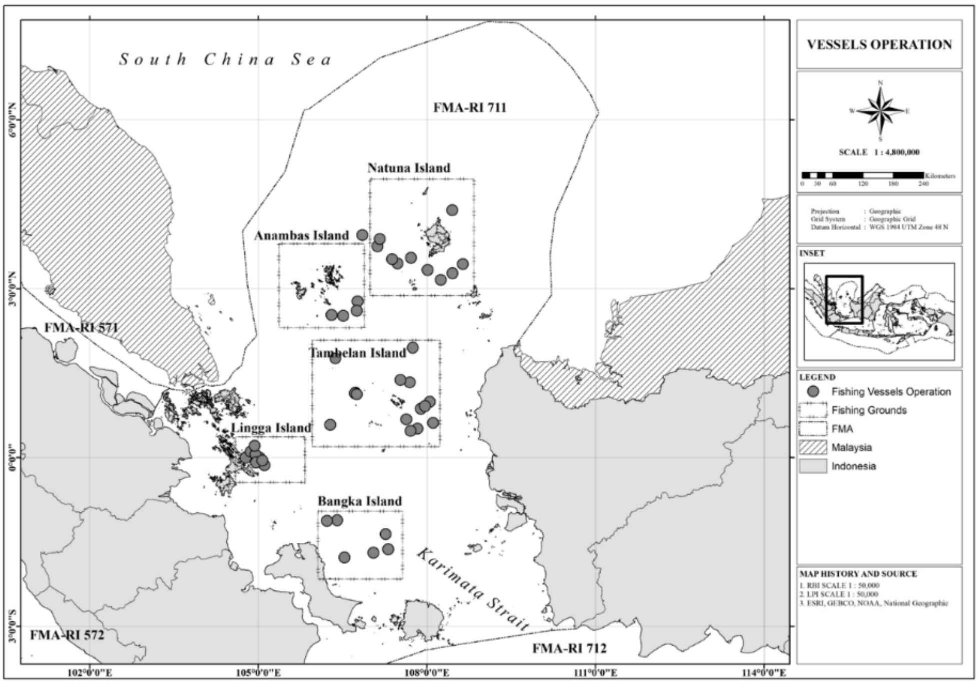

Figure 2 Distribution of fishing locations of the gillnetter targeting the narrow-barred Spanish mackerels from September to December 2022 in Kepulauan Riau waters of Fisheries Management Area-711 (WPPNRI711), Indonesia.

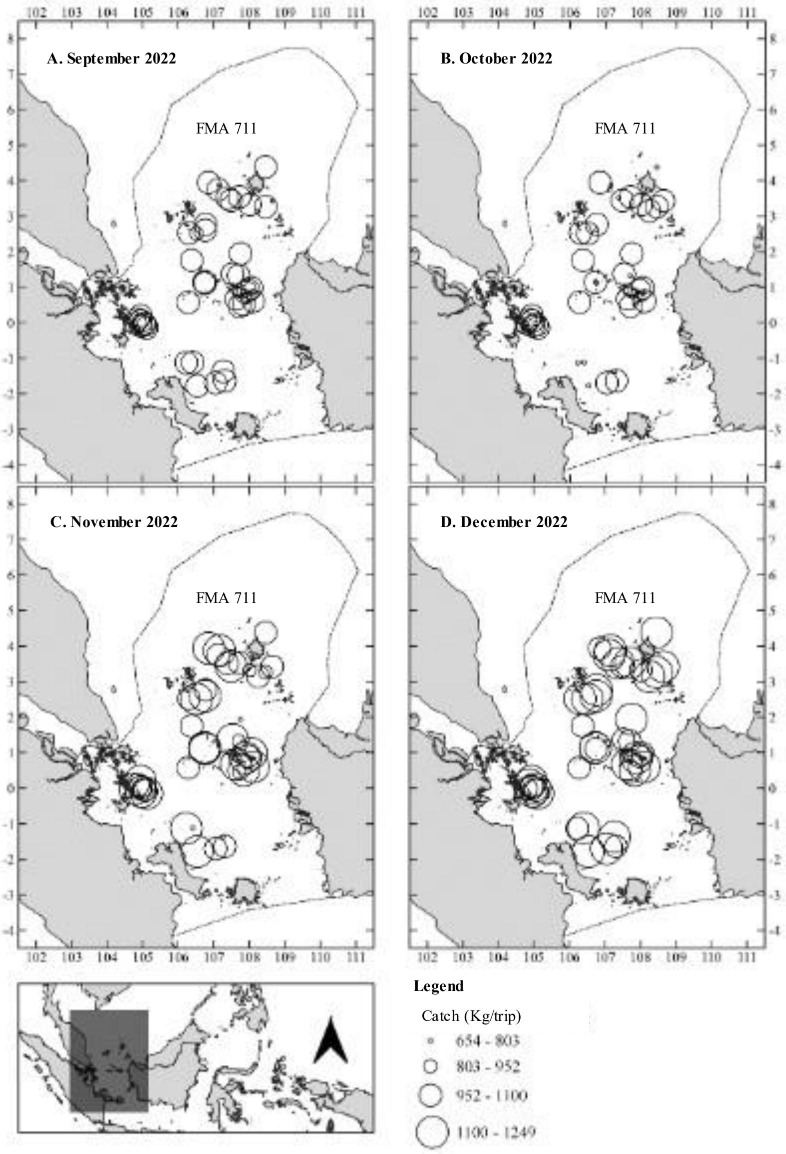

Figure 3 Distribution of catches per trip of the narrow-barred Spanish mackerel from 44 samples of gillnetter from September to December 2022 in Kepulauan Riau waters of Fisheries Management Area 711 (WPP-NRI711), Indonesia

Between September and December 2022, differences in SST, CHL-a, and SSS were found among the five fishing locations (Figure 5). SSS levels were significantly more significant in the Anambas and Natuna fishing sites than in the other three, while CHL-a levels were higher in Bangka and Lingga. SST trends decreased at Natuna, Anambas, and Lingga, whereas SST climbed in Bangka from October to December 2022. From September to December, the SST ranged between 29.0-30.0℃ across all fishing locations. Tambelan showed a decrease in SSS but an increase in CHL-a (Figure 5).

CHL-a concentrations were higher around Lingga and Bangka Island in September-December compared to the other three fishing grounds. Natuna and Anambas Islands waters had a lower concentration of CHL-a (≤ 0.15 mg/m³) compared to other fishing areas. Narrow-barred Spanish mackerel catches of 900-1,300 kg/trip primarily occur in waters with CHL-a of 0.10-0.40 mg/m³ (Figure 5). From September to December 2022, CHL-a concentration (mg/m³) and narrow-barred Spanish mackerel catches (*Scomberomorus commerson*) were measured in five working regions of the Bintan gillnetter.

Increased SSS was identified in September-December from fishing grounds in the south to the north of the Kepulauan Riau waters. SSS in the two fishing grounds located in the southern part of the Kepulauan Riau waters or FMA711, namely the waters around the islands of Bangka and the Lingga Islands, is relatively consistent every month ≤ 32.5‰, lower than the SSS in the other three fishing grounds. The SSS in the Natuna Islands and Anambas Islands consistently exceeds 32.5‰ per month, with an average of roughly 33.0‰. The Tambelan Islands, located in the center of the two fishing grounds groupings, have an average SSS of 32.5 to 33.0‰. In the range of 32.0-33.2‰, perceived SSS does not significantly affect catch. Narrow-barred Spanish mackerel catches of 900-1300 kg/trip are obtained at varied SSS levels. From September to December 2022, SSS (‰) and narrow-barred Spanish mackerel (*Scomberomorus commerson*) catches were developed in 5 working locations of the Bintan gillnetter.

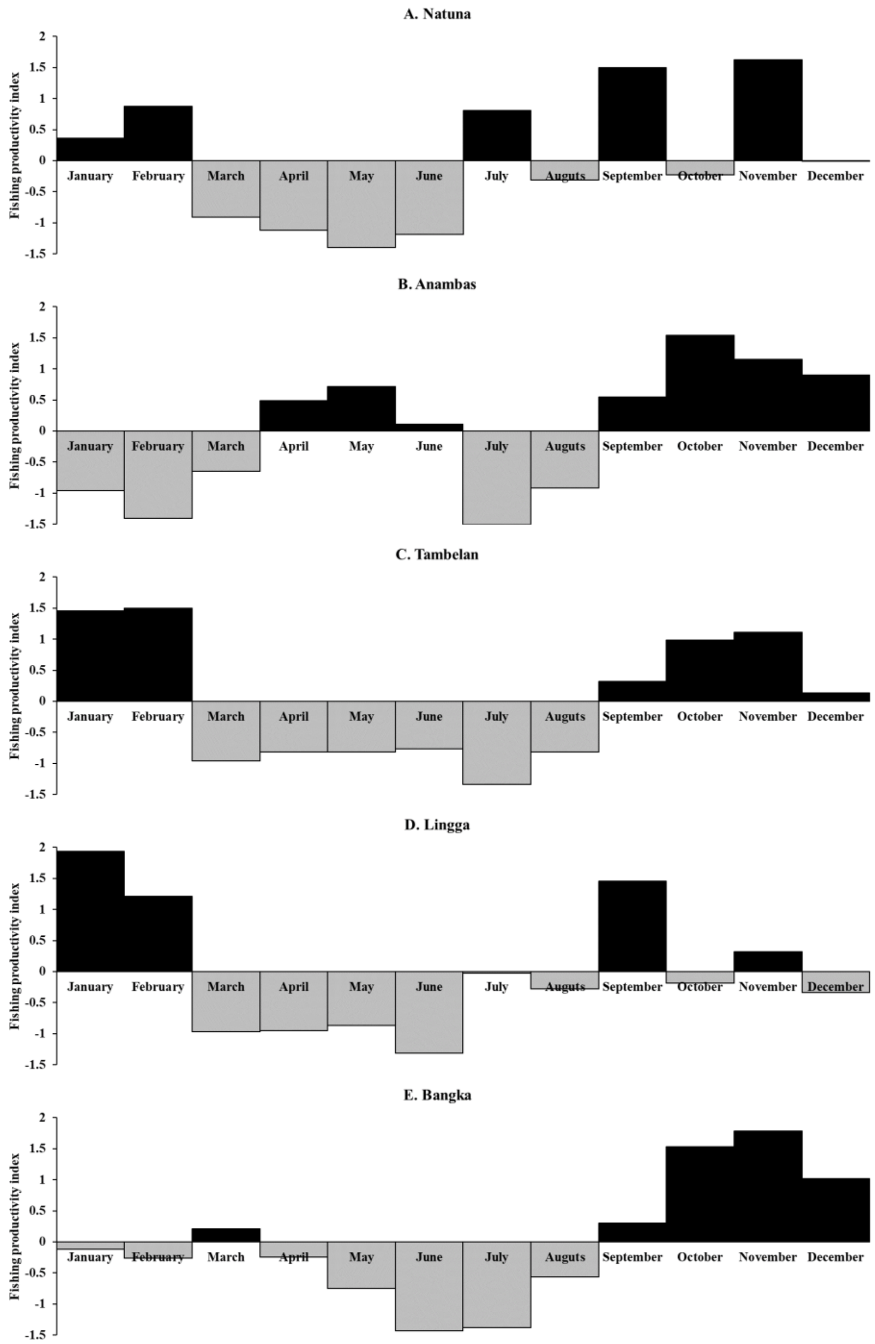

Figure 4 Monthly fishing productivity indices in the five fishing grounds of the narrow-barred Spanish mackerels for five fishing grounds in Kepulauan Riau waters of FMA 711 (Indonesia) from January to December 2022

From January to December 2022, 44 boats spotted by Barekmotor caught mackerels in waters with SST of 27,50-31,00℃, CHL-a of 0.10-0.60 mg/m³, and SSS of 32,00-33,50‰ (Figure 6). No significant association was found between these oceanic parameters and Spanish mackerel catches. However, these indication value ranges will be considered as a reference when estimating the upcoming month in each fishing ground.

Based on the SST, CHL-a, and SSS, where the mackerels of acceptable sizes were caught (Figure 6), the fishing grounds around Natuna, Tambelan, and Bangka islands are highly prospective in September, October, and November (Table 1). The prospective months for the mackerels around Natuna islands are August and December. June, July, and August are around the Anambas islands. Around Tambelan islands are May, June, and July. Around Lingga, islands are from February to June; around Bangka, they are from February and April to June.

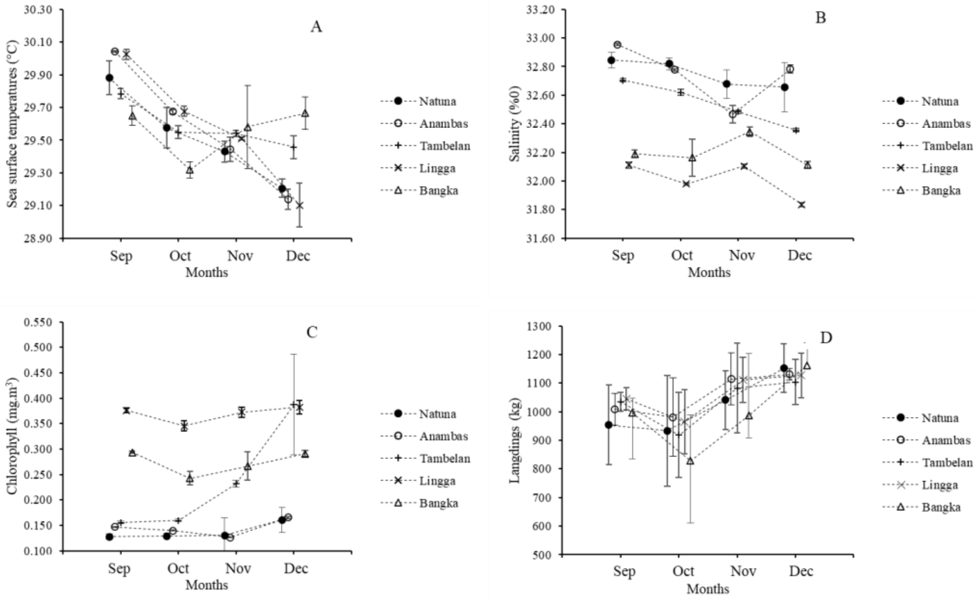

Figure 5 The SST, CHL-a and SSS and the catches of the narrow-barred Spanish mackerel (kg/trip) in 5 fishing grounds from September to December 2022

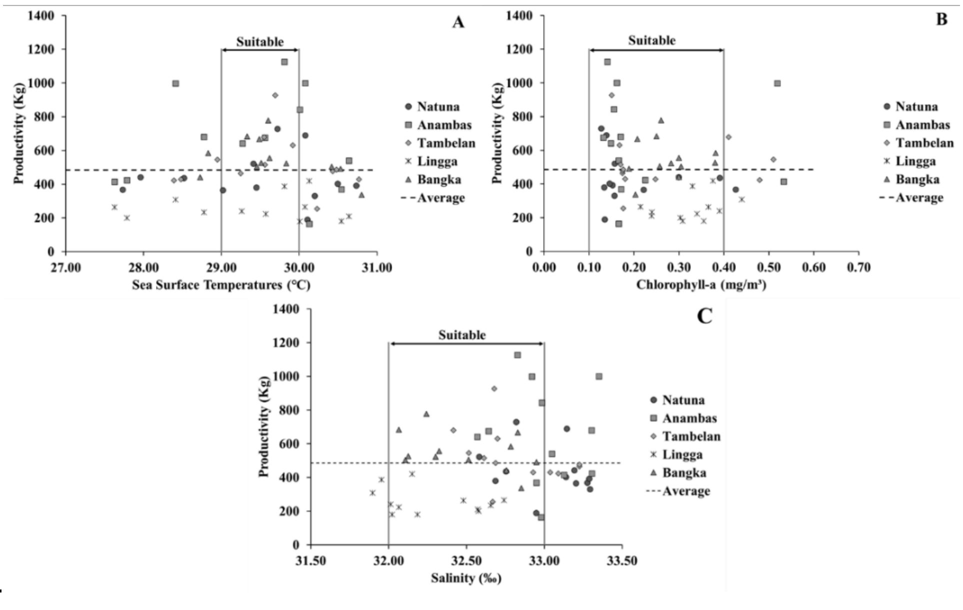

Figure 6 Monthly fishing productivity of the narrow-barred Spanish mackerels (kg/trip) and daily averages of SST (℃), CHL-a (mg/m³), SSS (‰) from January to December 2022 and 5 fishing grounds in Kepulauan Riau waters of FMA711.

Table 1 Prospective fishing grounds for the narrow-barred Spanish mackerels in Kepulauan Riau, Indonesia

		Fishing grounds				
Months	**Season**	**Natuna**	**Anambas**	**Tambelan**	**Lingga**	**Bangka**
Dec	Southwest monsoon	P	-	-	-	P
Jan		-	-	-	-	-
Feb		-	-	-	P	P
Mar		-	-	-	P	P
Apr		-	-	-	P	P
May		-	-	P	P	P
Jun	Northeast monsoon	-	P	P	P	P
Jul		-	P	P	-	HP
Aug		P	P	HP	-	HP
Sep		HP	HP	HP	-	HP
Oct		HP	HP	HP	-	HP
Nov		HP	HP	P	-	HP
Dec	Southwest monsoon	P	-	-	-	P
Jan		-	-	-	-	

Notes: HP: highly prospective; P: prospective

DISCUSSION

Locations of prospective fishing grounds of the narrow-barred Spanish mackerels can be identified from several aspect. We are able to identify fish populations and suitable sea conditions for fishing fleets by examining the environmental factors that lead fish to gather in specific locations. Mapping of the environmental conditions, tolerable marine conditions and the correlation between the catch and the environmental condition have been widely used to determine fishing ground. Satellite-derived data enhance the accuracy of predicting potential fishing grounds for mobile target migration fish, whose home ranges are larger than the area where fishing boats are positioned, taking into account the dynamics of the maritime environment and fish migration.

Water temperature is an essential factor that affects the metabolism rate of marine organisms (Simbolon 2011; Yasuhara dan Danovaro 2016; Siregar 2018). Correlations between the catch and SST have been commonly reported for migratory pelagic fishes (Lynch *et al.* 2018; Ebango *et al.* 2020; Yu *et al.* 2020). This study, however, failed to show such a correlation for the narrow barred Spanish mackerels. The absence of such a correlation should not be perceived as a nonsignificant effect of the temperature. Instead, the SST and other factors may simultaneously affect the fish distribution. There is also a potency of lag time correlation between SST and catch of pelagic fish (Wiryawan *et al*. 2020).

SST, CHL-a and SSS are expected to be significant factors in determining the spatial and temporal distribution of the Spanish mackerels (Masturah *et al.* 2014; Bukhari *et al.* 2017; Rajesh *et al.* 2017; Noegroho 2019). The ranges of SST, CHL-a and SSS where the mackerels were found can be used to indicate its tolerable limits (Table 2). The present study provides SST, CHL-a and SSS for specific sizes of mackerels that were accepted by the seafood processing industry (i.e. PT AK Fisheries, Bintan). It was found that for fishing grounds of the mackerels in the Kepulauan Riau waters, the SST was like what was reported by Bukhari *et al.* (2017), the SSS were similar to what was written by Noegroho (2019), but the CHL-a were lower than what written by (Bukhari *et al.* 2017). For the ranges outside the present study, the information did not provide sufficient details if the fish are caught at acceptable size or not.

The spatial pattern depicts the existence of highly potential locations in Bangka in 2022. Bangka waters are likely to be potential all year due to their interaction with Java Sea. Throughout the year, Indonesian waters, particularly those of Bangka, remain reasonably warm. Mackerel populations in

Bangka waters remain largely constant (Bukhari *et al*. 2017). Bangka is a body of water whose annual wind pattern runs from south to north or vice versa. This leads to large current fluctuations, which cause nutrition distribution (Bukhari *et al.* 2017). Development of food chains and subsequent food webs in the area may be triggered by increased marine productivity, *i.e.,* production of phytoplankton following an increase in marine nutrients. The presence of prey may stimulate predatory fishers to concentrate in affluent phytoplankton areas (Kerckhove *et al.* 2015; Yu *et al.* 2015). CHL-a densities are important in this context. SSS is essential in regulating osmotic pressure that enables the solution exchange between the external and internal cells. If a fish species is less tolerant to SSS, it will be forced to move from the intolerable environment to more suitable areas. An adaptation strategy to find more appropriate places causes spatial and temporal distribution of targeted fish, including the narrow bar Spanish mackerels (Simbolon 2011).

CHL-a is essential in building marine food chains and food webs that originated from phytoplankton, zooplankton, plankton feeders, and subsequent predatory fishes. The main prey of the mackerels from southwest coast of India are small pelagic species, such as *Sardinella* and *Decapterus* (Rajesh *et al.* 2017), while from Korean waters. The present study, however, did not address this issue. Future studies should include collecting data on the prey of the mackerels, e.g., types and sizes of the prey. It means, identification of prospective fishing grounds for the mackerels must include the identification of prospective habitats for the prey. However, specific studies on the catch of the prey of target species have been rare. Therefore, the studies on the prey can be carried out by conducting gut content analysis of the target species.

The present study identified variations in the oceanographic conditions represented by SST, CHL-a and SSS between the northern waters (around Natuna islands) and the southern waters (around Bangka waters). During the western monsoon period (December to February), the northern waters are generally cooler than the southern waters. The lower SST in the northern waters is likely due to the water current from the South China Sea associated with north-east monsoon winds (Kok *et al.* 2015). In contrast, during the east monsoon (June to August), the northern waters are generally warmer than the southern waters because of the cooler waters from the Java Sea enter the region (Kok *et al.* 2015; Ambalika *et al.* 2019). Because of this north-south-north shift in water currents, the Kepulauan Riau waters were warmer in April, May, and June than in other months.

The relatively higher CHL-a in the northern waters can be attributed to the supply of nutrients which are carried by the waters from the north (South China Sea) and the upwelling in the north – near Luzon Island, the Philippines (Chen *et al.* 2015). In the areas adjacent to Sumatera's east coastal waters, such as around Lingga islands and Bangka islands, the CHL-a was relatively higher. Such higher CHL-a may be promoted by the supply of freshwater from rivers and runoff in the eastern coast of Sumatera during the northwest monsoon season, that is generally wet (Bukhari *et al.* 2017; Wirasatriya *et al.* 2021). The northwest monsoon in the region is also likely responsible for the low SSS of the waters around Lingga and Bangka (Lucas *et al.* 2016).

Table 2 Sea surface temperatures (℃), salinity (‰) and chlorophyll-a concentrations (mg/m^3) of fishing grounds where the Spanish mackerels (*Scomberemorus commerson*) were catched.

No	Location	Time	SST (℃)	SSS (‰)	CHL-a (mg/m^3)	Sources
1	Karimata Strait	East monsoon (May–Oct)	25.0-30.0	32.0-34.0	0.03-1.10	(Masturah *et al.* 2014; Kok *et al.* 2021)
		West monsoon (Nov–Apr)	26.0-32.9	32.4-33.0	0.04-0.99	
2	Maluku	-	26.0-32.0	-	-	(Tangke 2022)
3	Bangka	East monsoon (May–Oct)	29.0-31.0	-	0.50-1.00	(Bukhari *et al.* 2017)
		West monsoon (Nov–Apr)	28.0-31.0	-	0.30-1.30	
4	Karimun	-	29.0-30.0	32.0-33.0	-	(Noegroho 2019)
5	Kepulauan Riau	Sep-Dec	29.0-30.0	32.0-33.0	0.10-0.40	Figure 6.A, 6.B and 6.C

Jufri *et al.* (2014), Mursyidin *et al.* (2015), Bukhari *et al.* (2017), and Kuswanto *et al.* (2017) used CHL-a and SST for predicting or validating potential fishing grounds of pelagic species in different places in Indonesia. In contrast to the mentioned studies, the present study identified the optimum values of SST, CHL-a and SSS in the Kepulauan Riau waters where mackerels at acceptable sizes are available and successfully caught from September to December 2022. This SST, CHL-a and SSS were then used to assess the potency of each fishing ground in the study area as prospective fishing grounds for the mackerels. Most fishing grounds in the study area are highly prospective from August to November; the exception was only for the fishing grounds around Lingga Island. Among the five fishing grounds, the fishing season for the mackerels around Bangka Island is the longest which last from February to December. The fishing seasons around Lingga Island are prospective from February to June, while around Natuna Islands are prospective to highly prospective from August to December. The shifts in the locations of fishing grounds show spatial and temporal patterns governed by regional climates (i.e., monsoonal patterns) as described above.

The spatial-temporal patterns of the prospective fishing grounds for the mackerels can be used by the Agency for Marine and Fisheries Affairs to forecast the fluctuation of landings of the mackerels. The landings are expected to be high from September to December, medium from June to August, and low from January to May. The fisheries during the period of August to November is expected to be busy, i.e., more fishing trips for the mackerels. In implementing Precision Fisheries, the agency can estimate the amount of national income other than tax more precisely. The fish exporters can predict the fluctuation of landings of the mackerels so they can inform their customers overseas with more precise information on the supply of mackerels.

CONCLUSION

From August to November, all four fishing grounds around Natuna, Anambas, Tambelan, and Bangka are highly prospective for the mackerels, although Lingga islands is only prospective from February to June. The fishing season in Bangka Island waters has the longest duration (11 months). The spatial and temporal trends show a north-south-north shift in fishing grounds, linked to the regional climate, such as the monsoon.

RECOMMENDATIONS

This study can be extended to provide more information on the size composition of the mackerels from each fishing ground. Comparisons in size composition can be done to identify how the sizes of fish progress with time in each fishing ground. Such information will help to determine the locations of fish for the size group. Therefore, the fishing fleets can be suggested to operate in areas where fish of certain size groups concentrate in the Kepulauan Riau waters.

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