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RESEARCH ARTICLE ARAŞTIRMA MAKALESİ

# Fishing by numbers: Empowering Muara Kintap fisheries with data-driven fishing area forecast maps

# Sayılarla balıkçılık: Muara Kintap balıkçılığını veri odaklı balıkçılık alanı tahmin haritalarıyla güçlendirmek

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**Abstract:** The paper aims to enhance the fishing efficiency and sustainability of Muara Kintap fishers by using data-driven Fishing Area Forecast Maps (FAFM). This study makes significant contributions to the field of fisheries management by demonstrating the effective use of satellite data for local-scale fisheries management, bridging the gap between scientific research and practical applications, as well as promoting sustainable fishing practices and improving the fishers' livelihoods. The research ingeniously combined the wisdom of local fishers captured through the Fishing Points app with cutting-edge technology. Aqua MODIS satellite imagery captured detailed Muara Kintap waters condition, revealing sea surface temperature (SST) between 28.4 °C and 29.7 °C and chlorophyll-a (Chl-a) concentrations ranging from 0.38 to 6.27 mg/m³. The results strongly indicate that the distribution of Chl-a is a more influential predictor of fish catch than SST. This discovery underscores the intricate relationship between marine parameters and fish distribution. By providing FAFM, informed by Chl-a data, the fishers were able to make data-driven decisions, optimizing catches and promoting the long-term sustainability of their livelihoods. The study's impact transcends data analysis, highlighting the importance of collaboration and knowledge sharing among researchers, fishers, and policymakers in fostering sustainable fishing practices in Muara Kintap and beyond.

**Keywords:** FAFM, fishing efficiency, Muara Kintap, oceanographic data, sustainability

**Öz:** Bu çalışma veri odaklı Balıkçılık Alanı Tahmin Haritaları (FAFM) kullanarak Muara Kintap balıkçılarının balıkçılık verimliliğini ve sürdürülebilirliğini artırmayı amaçlamaktadır. Bu çalışma, yerel ölçekli balıkçılık yönetimi için uydu verilerinin etkili kullanımını göstererek, bilimsel araştırma ile pratik uygulamalar arasındaki boşluğu kapatarak, sürdürülebilir balıkçılık uygulamalarını teşvik ederek ve balıkçıların geçim kaynaklarını iyileştirerek balıkçılık yönetimi alanına önemli katkılarda bulunmaktadır. Araştırma, Fishing Points uygulaması aracılığıyla yerel balıkçıların bilgilerini son teknoloji ile ustaca birleştirdi. Aqua MODIS uydu görüntüleri ile Muara Kintap sularının ayrıntılı durumunu izlendi ve 28,4 °C ile 29,7 °C arasında deniz yüzey sıcaklığı (SST) ve 0,38 ila 6,27 mg/m³ arasında değişen klorofil-a (Chl-a) konsantrasyonları tespit edildi. Sonuçlar, Chl-a dağılımının SST'ye göre balık avının daha etkili bir öngörücüsü olduğunu güçlü bir şekilde göstermektedir. Bu bulgu, deniz parametreleri ile balık dağılımı arasındaki karmaşık ilişkiyi vurgulamaktadır. Chl-a verileriyle bilgilendirilen FAFM sağlanmasıyla, balıkçılar veri odaklı kararlar alabildi, avları optimize edebildi ve geçim kaynaklarının uzun vadeli sürdürülebilirliğini destekleyebildi. Çalışmanın etkisi veri analizinin ötesine geçerek, Muara Kintap ve ötesinde sürdürülebilir balıkçılık uygulamalarını teşvik etmede araştırmacılar, balıkçılar ve politikacılar arasındaki iş birliğinin ve bilgi paylaşımının önemini vurgulamaktadır.

**Anahtar kelimeler:** FAFM, balıkçılık verimliliği, Muara Kintap, oseanografik veri, sürdürülebilirlik

## INTRODUCTION

The global fishing industry is crucial for supporting fish processing and meeting the demands of both local and international markets. While commercial fisheries face challenges related to resource competition, small-scale fisheries grapple with the impacts of climate change (Heck et al., 2023). Various aid programs have been implemented to assist the small-scale fishers, including subsidized fuel (Shafari et al., 2019), fishing insurance (Syarif et al., 2019), and other technical assistance initiatives (Rusdiana et al., 2022). The success of fishing operations depends not only on the availability of fishing fleets, gear, and techniques, but also on the effective utilization of information and communication technologies (ICT) to locate and map potential fishing grounds (Natsir et al., 2020). The acceptance of new technologies by fishers is shown to be influenced by their socio-economic background (Rafi et al., 2020).

The capture fisheries sector is driven by digital innovation and is under Geographic Information System (GIS) software has become increasingly prevalent among capture fisheries, leveraging remote sensing applications to enhance operational efficiency and productivity (Sasmito et al., 2022). For instance, ArcGIS harnesses satellite data to generate fishing maps and disseminates valuable information directly to fishers and their vessels, exemplified by the Fishing Points app, which is accessible on Android smartphones. This app, available for free with basic features or through a premium subscription offering advanced functionality, enables users to locate fishing spots at sea using GPS without requiring an internet connection. It provides real-time data on maps, locations, catch records, fish activity forecasts, wave conditions, and weather updates, as well as significantly reduced fuel consumption and operational costs (Sukresno and Kusuma, 2021). QGPS, an open-source Quantum Geographic Information System, shares similar purposes and functionalities used for spatial analysis, visualization, and mapping for sustainable fisheries management (Yen and Chen, 2021).

At national level, fishing area forecast map (FAFM) served as a valuable tool, providing insight for fishers to predict potential fishing zones. However, FAFM requires a specific map-reading skill and the lack of high-resolution data that is critical to the success of local fishers highlights the need for user-friendly spatial data tools. Briefly, the preparation process for FAFM can be visualized in Figure 1.

FAFM is developed using satellite data on sea surface temperature and chlorophyll-a concentration, key indicators for identifying fish aggregation locations. These data are processed through an algorithm considering wave height and wind speed to predict potential fishing zones. Subsequently, FAFM information is disseminated to fishers, stakeholders, and policymakers via both print and electronic medias. Any feedback from users to enhance the quality of FAFM content is welcome. User feedback can offer valuable insights into the usability, accuracy, and relevance of the FAFM data. Suggestions for additional data sources, improved visualization techniques, or enhanced accessibility features can contribute to a more comprehensive and user-oriented FAFM experience. Moreover, feedback on FAFM's accuracy in predicting potential fishing zones is essential for refining forecasting algorithms and improving the tool's effectiveness.

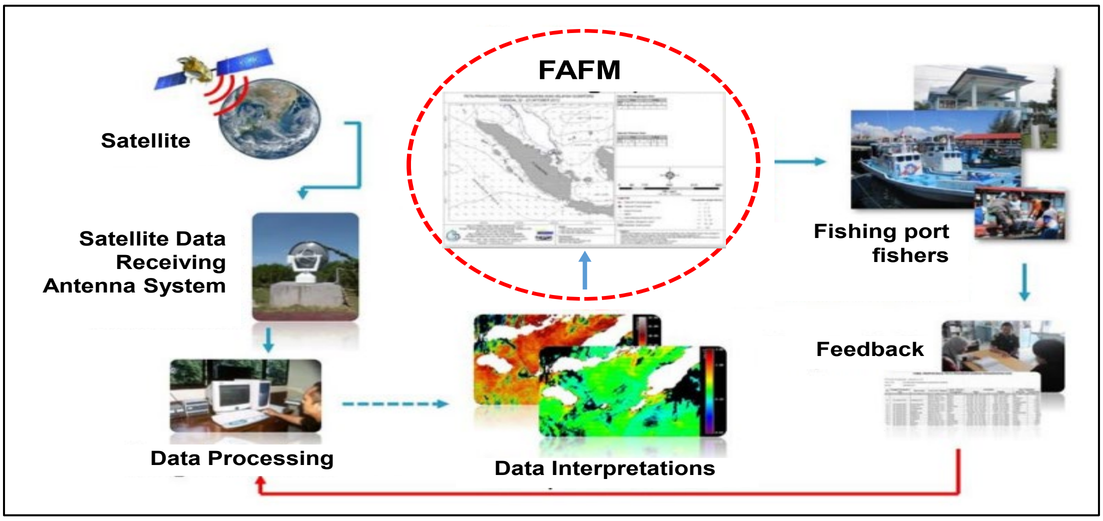


**Figure 1**. The preparation process for the national FAFM (Sukresno and Kusuma, 2021)

As other artisanal fishing communities (Rafi et al. 2020; Rusdiana et al. 2022), fishers in Muara Kintap Village also face crucial challenges in digital information technology, in addition to limited access to resources, skill gaps, affordability concerns, lack of trust in new technologies, inadequate infrastructure, and connectivity issues, which impact their ability to capitalize on regional economic potential. Limited access to oceanographic data and information hinders many fishers from understanding and sustainably managing their fishing grounds. Our field study empowered fishers to bridge this knowledge gap. By equipping the participants with GPS and user-friendly software (e.g., SeaDas, and ArcGIS/ArcMaps), we transformed them from passive observers into active participants. This newfound ability to analyze real-time data allows researchers to create personalized maps, promoting sustainable management of fishing grounds.

## MATERIALS AND METHODS

This research was conducted in Muara Kintap Village, Tanah Laut Regency, Indonesia (Figure 2). The village borders Mulia Village to the north, the Java Sea to the south, Kebun Raya and Sungai Cuka Villages to the east, and Pandansari and Kintap Villages to the west. With a total area of approximately 4,900 m$^2$, Muara Kintap boasts a coastal location that naturally attracts a large fishing community. Approximately 80% of Kintap sub-district's population relies on fishing for their livelihood. Although the village residents are not indigenous Banjar people of Borneo, most hail from the Bugis tribe. Despite their diverse origins, the community has a strong sense of cultural integration.

By virtue of its direct access to both the Java Sea (WPP-712) and the Makassar Strait (WPP-713), Muara Kintap Village boasts strategically located waters, making it a prime fishing area. This unique position allows fish populations from both sea regions to flourish in the surrounding waters. From November to April, westerly winds usher in a prime fishing season, while July to August, marked by south-easterly winds, brings a bountiful harvest of shrimp seeds, a valuable source of income for the local community. However, September and October represent a transitional period with rough seas and high waves, making fishing less ideal.

There were two types of data collected in this study, i.e. primary and secondary data. Primary data were collected directly from the surveyed within KUB Dermaga Bersama

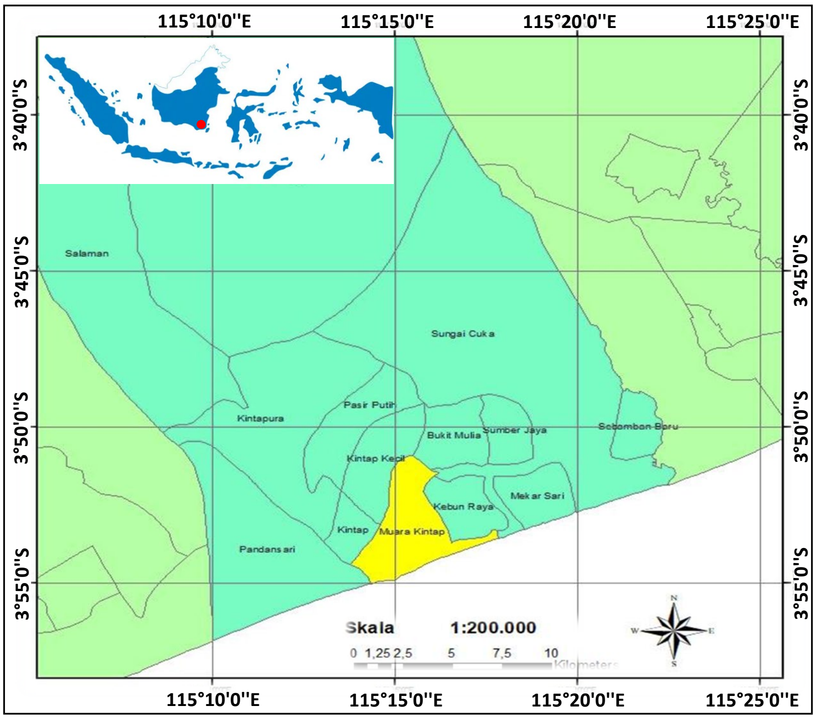


**Figure 2**. A map showing the study site in Muara Kintap Village, Indonesia

through questionnaires, interviews, and on-board observations (vessel dimension, fishing gear, season, main catch, coordinates of fishing areas), and also documentation (photos and videos). Secondary data were obtained from literature reviews and relevant government agencies (e.g., oceanographic data). Notably, KUB is officially registered with the Food Security and Fisheries Services of Tanah Laut District, and its members hold fishers' insurance cards. KUB was established on April, 3, 2020 with 10-member fishing group. A research vessel, KM. FATIH (15 GT), served as the platform for on-board data collection (Figure 3).

**Figure 3**. Mini purse seiner 'KM. FATIH' used for data collection

This fishing vessel, constructed from a blend of teak and ironwood, boasts impressive dimensions: 15.85 m long, 3.10 m wide, and 1.42 m depth. Powering the FATIH is a reliable Dongfeng main engine, ensuring efficient navigation throughout the research area. For seamless communication and precise positioning, the FATIH is well-equipped with a radio, compass, and GPS. Fishers usually use mini purse seine and drift gillnets to catch fish such as yellow mackerel (*Selaroides leptolepis*), and little tuna (*Euthynnus affinis*), Hairtail (*Trichiurus lepturus*). Unfortunately, KM. FATIH did not provide monthly catch data for this study. According to fisher's accounts, the fishing season for yellow mackerel peaked in March-April, while the season for little tuna occurs in September-October. Hairtail is considered incidental catch throughout the year.

Using the Fishing Points app, fishers can mark their own waypoints (coordinate points) with their Android phone's GPS to capture their fishing spot's location. Here is how to do this (Figure 4):

1. Download and Launch: Open the Fishing Points app and ensure it has permission to access the phone's location. The Fishing Points app collects data by capturing coordinates, time, and date of each location. These data are essential for subsequent analysis and mapping, and even optimize fishing strategy.

2. Dive into the Menu: Explore the app's menu and navigate to the "Add Location" function to mark the chosen fishing spot.

3. Capture the Coordinates: Now, pinpoint the perfect location. Navigate the map and tap the magnified image to capture the specific coordinates.

4. Share and convert: After confirming the coordinates, tap the "Share" button to export them as a GPX file, compatible, with most mapping software.

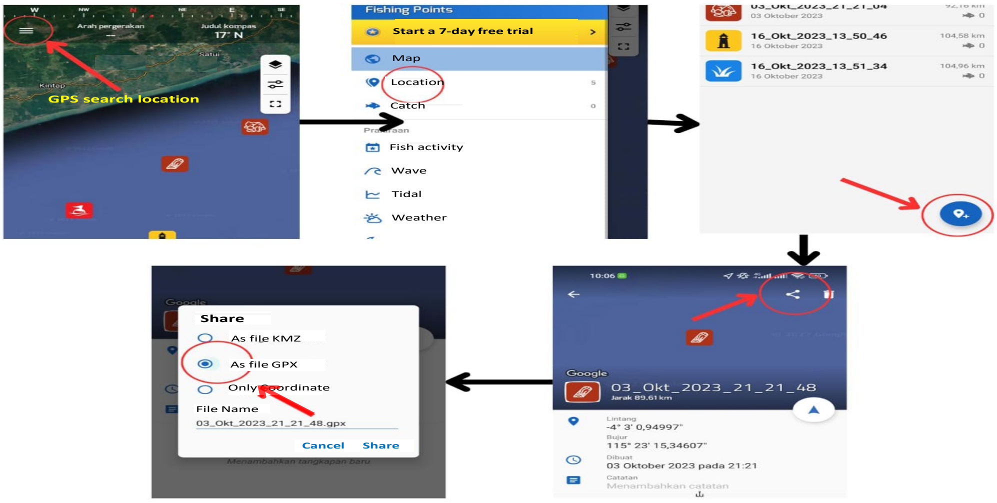


**Figure 4**. How to use Fishing Point on an Android phone (self-documentation)

GIS is a computer-based system used to collect, store, combine, organize, transform, manipulate, and analyze geographic data. It plays a vital role in environmentally sound resource management by providing insights for informed decision-making. Thematic maps visually represent specific themes or topics with a geographic component, and standardization ensures consistency and clarity in their creation (Darmawan, 2011).

The data requires a specialized software called SeaDAS (SeaWiFS Data Analysis System), established by NASA's ESDS Program (https://www.earthdata.nasa.gov/). The tool is made freely available through open-source software licensing. This program processes satellite imagery to extract valuable information for oceanographers, including sea surface temperature (SST) and chlorophyll-a (Chl-a) concentration. To extract valuable data from satellite imagery, we present a breakdown of the SeaDAS software workflow:

**a. Data acquisition**

This stage involved collecting Aqua MODIS (Moderate Resolution Imaging Spectroradiometer) satellite imagery from September 15 to October 15, 2023. The specific images chosen corresponded to the month of data collection and focused on capturing SST and Chl-a concentration.

**b. Image cropping**

To facilitate focused, detailed, and optimized data processing, the acquired Aqua MODIS images were cropped using SeaDAS software. This cropping process narrowed the image area to a specific research location within the Kintap District Fishing Ground.

**c. SST and Chl-a data processing**

The following image cropping, the relevant sea surface temperature data were extracted from the Aqua MODIS images. This involved processing the cropped data in ArcGIS to convert it from a raster format (gridded data) to vector format (points, lines, or polygons), or the data is exported to Mask Pixels. This conversion allows for easier manipulation and analysis of specific SST and Chl-a metadata within the research area.

ArcGIS, another powerful tool from ESRI (Environmental Systems Research Institute), complements the workflow. This comprehensive GIS software suite integrates various functionalities, allowing users to analyze, visualize, and manage spatial data.

**a. Data integration and projection**

This stage prepares all spatial data for analysis, which involves:

- *Georeferencing*: All data, including line maps (administrative boundaries) and fish catch coordinates from fishers, must have accurate geographic reference points.

- *Transformation*: All data are converted to a common coordinate system (datum) and projected for consistent spatial representation. This allows for a seamless overlay of different data layers.

**b. Fishing ground analysis**

The analysis phase uses the prepared data sets as follows:

- *Fish catch overlays*: The fish catch coordinates, obtained, from the "Fishing Points" application, were overlaid on the 1-month sea surface temperature map generated in the previous stage.

- *Field accuracy test*: The fish catch coordinates served as reference points for field studies, allowing researchers to verify the accuracy of the September-October 2023 Sea surface temperature data.

- *Spatial analysis boundary*: The coordinates also define the outer boundary of the Kintap sub-district fishing grounds. This boundary acts as a limit for spatial analysis, helping to determine and measure the potential fish catch zone within these waters.

Based on the SST and Chl-a concentrations, the suitability for fishing areas can be categorized. Waters with SSTs between 24 $^{0}$C and 27 $^{0}$C or Chl-a concentrations exceeding 0.2 mg/m$^3$ are considered most suitable (potential). Areas with SSTs between 27 $^{0}$C and 30 $^{0}$C or Chl-a levels between 0.1 and 0.2 mg/m$^3$ were categorized as moderately suitable (moderate potential). Conversely, conditions outside these ranges (SST below 24 $^{0}$C or above 30 $^{0}$C; Chl-a less than 0.1 mg/m$^3$) were considered less suitable (less potential), as described in Table 1.

**Table 1**. Assessment of potential fishing areas (PFAs) based on SST and Chl-a indicators

| No | PFA category | [1] SST ($^{0}$C) | [2] Chl-a (mg/m$^3$) |
|---|---|---|---|
| 1 | Potential | 24-27 | >0.2 |
| 2 | Moderate potential | 27-30 | 0.1-0.2 |
| 3 | Less potential | <24 or >30 | <0.1 |

Source: [1]Laevastu and Hela (1993), [2]Gower (1972)

## RESULTS

### GPS application

Muara Kintap fishers have successfully built their own personalized fishing resources and experiences using the Fishing Points app, which allows them to mark waypoints (coordinate points) using their Android phone's GPS. As shown in Figure 5, the integration of digital technologies in fisheries, particularly the Fishing Points app, is central to the workflow of small-scale fishers. This integration demonstrates how app data can enhance traditional fishing practices, potentially optimizing strategies and offering tangible benefits to fishers. This visualization most likely serves to illustrate the practical impact and potential advantages of incorporating digital tools within small-scale fishing operations. The Fishing Points app can track fishing locations and behavior, providing valuable insights into fish populations and migration patterns. By understanding these dynamics, fishers can adjust their practices to reduce bycatch, avoid overfishing certain species, and operate within sustainable limits.

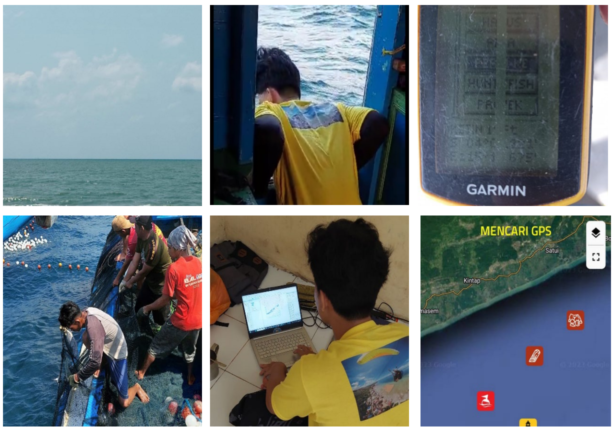


**Figure 5**. How digital technology is integrated into traditional fishing practices (self-documentation)

In contrast, the fishing area forecast map (FAFM) generated by the mini purse seiner KM. FATIH pinpointed five promising fishing locations within Muara Kintap's waters (Table 2). These measured fishing areas were relatively close together, with distances between the coordinate points ranging from 0.8 mile to 1 mile. The radius of the predicted fishing areas varied between 2.0 miles and 7.7 miles, consistent with the spatial dimensions of traditional fishing grounds. Meanwhile, fishing bases were located farther away, approximately 12-20 miles from these areas. The waters depth varied between 15 m and 20 m. Practically, FAFM stands as a crucial tool for fishers, providing precise guidance, improved efficiency, and long-term environmental benefits, enabling them to refine their fishing strategies, recognize patterns, and make well-founded decisions based on solid data rather than instinct alone.

**Table 2.** On-site coordinates of the predicted fishing areas in Muara Kintap waters

| On-site Coordinates | Actual measurements of fishing areas | SST ($^{0}$C) | Chl-a (mg/m$^3$) | Radius of fishing areas (mile) ^ | Water depth (m) |
|---|---|---|---|---|---|
| A | 3$^{0}$57'32.48"S - 115$^{0}$30'16.78"E | 29.4 | 1.9 | 4.3 | 15 |
| B | 4$^{0}$03'00.95"S - 115$^{0}$23'15.34"E | 29.3 | 2.2 | 7.4 | 18 |
| C | 4$^{0}$19'30.31"S - 115$^{0}$12'13.50"E | 28.9 | 1.8 | 7.7 | 18 |
| D | 4$^{0}$14'04.70"S - 115$^{0}$22'08.46"E | 28.8 | 0.6 | 2.4 | 20 |
| E | 4$^{0}$09'53.34"S - 115$^{0}$14'51.15"E | 28.7 | 0.5 | 2.0 | 20 |

^ aligning with the radius of commonly fished areas by fishers.

### SeaDas and ArcGIS applications

The foundation for our predicted fishing area maps was the analysis of monthly SST and Chl-a concentration data for Tanah Laut Regency. We used Aqua MODIS Level 3 satellite images, which are readily accessible through the NASA's OceanColor web (https://oceancolor.gsfc.nasa.gov/). The SeaDAS (Sea-viewing Wide Field-of-view Data Analysis System) software emerges as a critical asset in this mapping process. Its functionalities significantly enhance our workflow:

- *Efficient data collection*: SeaDAS streamlines the acquisition of time specific SST and Chl-a data, ensuring that we use the most up-to-date information.
- *Precise image cropping*: This software allows us to precisely crop satellite images, focusing solely on the relevant areas of Tanah Laut Regency.
- *Data processing versatility*: SeaDAS offers robust tools for processing both SST and Chl-a vector data, enabling effective analysis and integration into our mapping process.

This research also leverages ArcGIS, a comprehensive GIS software developed by ESRI (Environmental Systems

Research Institute). The proposed goes beyond being a single program; it acts as a platform that integrates functionalities from various specialized GIS software tools. For fishers, ArcGIS can revolutionize their understanding of fishing grounds. The software's ability to generate maps based on spatial information provides valuable insights into a seasonal, monthly, and even daily basis. This enables fishers to make data-driven decisions about where and when to deploy their efforts.

ArcGIS played a central role in preparing potential FAFMs. This involved incorporating data obtained from SeaDAS software, likely including processed SST and Chl-a data, for spatial analysis within ArcGIS. This analysis contributed to the creation of informative and actionable FAFM. The development of the FAFM relies on a two-pronged approach:

- *Satellite imagery analysis*: Aqua/Terra MODIS satellite data plays a crucial role. By analyzing the SST and Chl-a derived from these images, we can identify promising fishing areas. The Single Image Edge Detection (SIED) method is particularly effective in pinpointing thermal fronts, which often mark the convergence of water masses with differing temperatures. These thermal zones are often associated with intensified currents and fluctuations in sea level within the surrounding waters.

- *Oceanographic data integration*: National and port-specific FAFMs were further refined by incorporating additional oceanographic factors. Satellite-derived data provided insights into parameters like SST, Chl-a concentration, and sea level anomalies. SST data are especially valuable for analyzing thermal fronts, as these zones often indicate cooler waters rich in nutrients, a prime indicator of high fish productivity.

**SST and Chl-a distributions**

Our analysis of Aqua MODIS satellite images provided informative fishing area forecast maps depicting the distribution of SST and Chl-a concentration in Muara Kintap's waters. The SST across the study area spanned 28.4 °C to 29.7 °C (Figure 6), while the SSTs measured within the five fishing areas ranged from 28.7 °C to 29.4°C (Table 2), and were categorized as moderately suitable (moderate potential). This slight variation can be attributed to the use of different images within the analysis timeframe.

As shown in Figure 7, the predicted Chl-a concentrations across the study area ranged from 0.38 mg/m³ to 6.27 mg/m³, with Chl-a levels within the identified five fishing areas varying from 0.5 mg/m³ to 2.2 mg/m³, as outlined in Table 2. High Chl-a concentration in Muara Kintap waters indicates a productive marine environment. The abundance of phytoplankton in the area plays a crucial role as a primary food source for zooplankton, which further sustains populations of pelagic fish. This interdependent ecosystem highlights the high potential for sustainable fisheries in the region, presenting promising opportunities for long-term productivity and prosperity for Muara Kintap's fishing communities.

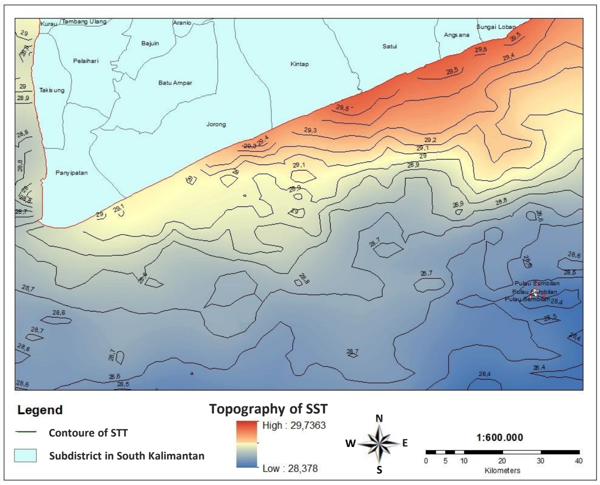


**Figure 6**. Sea surface temperature distribution in Muara Kintap waters

Emphirical studies confirmed that sustainable fisheries are essential for small-scale fishers, providing livelihoods, boosting local economies, and ensuring food security for communities, even potentially contributing to national food supplies that was fully underpinned by information technology, government policy, and additional technical support (Stacey et al., 2021; Simmance et al., 2022). However, small-scale fishers confront a multitude of challenges, including limited access to essential resources, infrastructure, and technology. They are also exposed to risks associated with climate change and overfishing (Ferrer et al., 2022; Heck et al., 2023). Additionally, small-scale fishers often experience a lack of social and economic protection (Giron-Nava et al., 2021; Virdin et al., 2023).

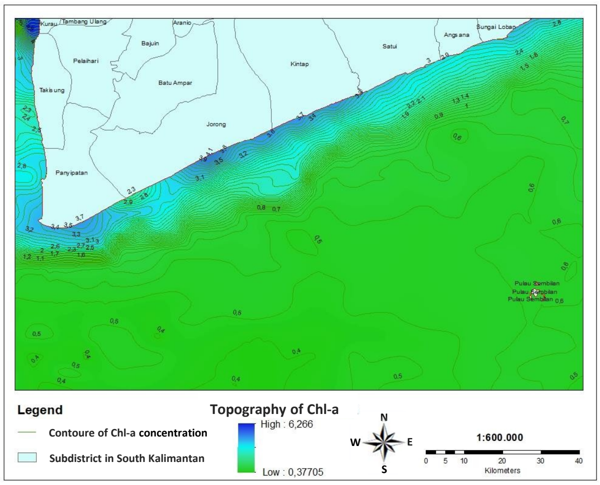


**Figure 7**. Chlorophyll-a distribution in Muara Kintap waters

**Mapping of predicted fishing areas**

Aqua MODIS satellite imagery was used to generate fishing area forecast maps (FAFM) for the waters surrounding Muara Kintap (Figure 8). These FAFMs were meticulously constructed by analyzing two critical parameters: SST and Chl-a concentration. The shift in SST patterns in the study area is largely driven by global climate change, while Chl-a concentration remains relatively stable due to a consistent flow of nutrients across the study area. Chl-a content may hold a greater influence on fish catch than SST and, presents an opportunity to refine FAFMs for enhanced effectiveness.

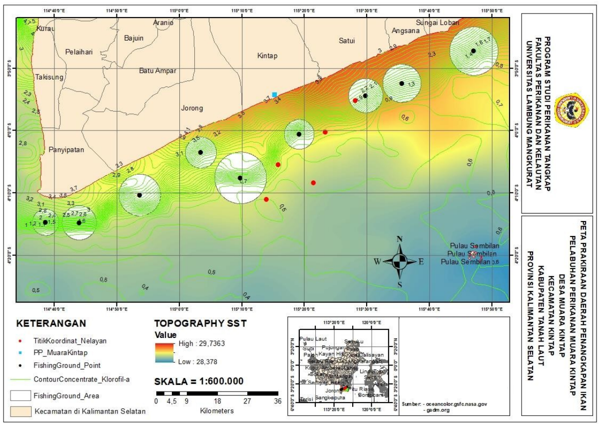


**Figure 8.** FAFM for small pelagic fish in Muara Kintap waters

## DISCUSSION

Muara Kintap's fishers have adopted FAFMs, a transformative digital tool that empowers them with data-driven insights, which promise a brighter future for fisheries. However, despite the potential benefits, local fishers in Muara Kinta Village still contend with some obstacles that hinder their ability to fully embrace these new technologies, including:

1. Access and Skills

- *Technology access*: Not all fishers have access to mobile devices or an adequate internet connection to use fishing apps.

- *Digital skills*: A lack of digital literacy and training for using new technologies can hinder the adoption of apps and digital platforms by fishers.

2. Costs

- *Subscription fees*: Subscription fees for premium apps or certain digital platforms can be a burden on local fishers.

- *Technology costs*: The upfront cost of purchasing mobile devices and internet data plans can also be a barrier for fishers.

3. Trust and Adoption

- *Doubt in information*: Some fishers are still skeptical of the information and recommendations provided by digital apps, preferring to rely on their knowledge and experience.

- *Lack of education*: Lack of education and awareness of the benefits of digital technology for fishers may hinder wider adoption.

4. Infrastructure and Connectivity

- *Internet network*: In some coastal areas, internet connectivity may be limited or unstable, making it difficult to use application and digital platforms.

- *Lack of infrastructure*: A lack of supporting infrastructure, such as mobile device charging stations in ports and fishing villages, can hinder the use of digital technology.

5. Environmental Impact

- *Overfishing concerns*: Some parties worry that using fish finder apps can make it easier to overfish, leading to damage to marine ecosystems.

- *Reliance on technology*: Overreliance on digital technology to find fish is feared to cause fishers to lose their knowledge and local wisdom in sustainable fishing practices.

Bridging the gap in the fishing industry requires a collaborative effort from various parties, such as governments, NGOs, technology companies, and fishing communities to work together to create a more sustainable and prosperous future for fisheries. Alternative solutions to the problem can be considered as follows:

a. Increase access and education: Provide training programs and affordable internet access for fishers to improve digital literacy and encourage technology adoption.

b. Develop fisherman-friendly apps: Design easy-to-use apps and digital platforms that consider the needs and limitations of fishers.

c. Build trust: Provide accurate and transparent information about the benefits of digital technology and involving fishers in the technology development process.

d. Improve infrastructure: Build supporting infrastructure such as internet networks and charging stations in coastal areas.

e. Promote sustainable fishing: Encourage the use of digital technology to support sustainable and responsible fishing practices.

One of the key datasets employed in this research was Aqua MODIS imagery, which provided valuable insights into both the SST and Chl-a distributions. The Muara Kintap coastline has warm waters, ranging from 28.4 °C to 29.7 °C, and high Chl-a concentrations between 0.38 and 6.27 mg/m³. These characteristics, particularly high Chl-a content, serve as valuable indicators of productive fishing grounds for local fishers. Sasmito et al. (2022) pointed out that over 60% of fish caught in the Java Sea came from areas with Chl-a concentrations of 0.2-0.5 mg/m³ and SST of 28-31 °C. These studies reinforced the importance of mapping coastal suitability based on biophysical parameters like SST and Chl-a content. Nugraha et al. (2019) found a strong positive correlation between these parameters and catch per unit effort (CPUE) of the Spanish mackerel (*Scomberomorus commerson*) caught in the coastal region Kejawanan Cirebon, West Java. Time series data like this, encompassing SST and Chl-a variations over time, can be instrumental in developing descriptive models to assess long-term potential fishing area (Clinton et al., 2022).

The Chl-a concentration in Muara Kintap's waters exceeded the 0.1-1.9 mg/m³ threshold established by Clinton et al. (2022). It excellently highlights the richness of biological activity in the area. This is due to geophysical processes that play a significant role in regulating nutrient flow from land through rivers. Although these processes can cause fluctuations in specific nutrient levels, the overall Chl-a concentration in the Muara Kintap remained relatively stable. The distribution of Chl-a, a key indicator of marine productivity, exhibits a distinct pattern within the bay. The concentrations are highest in waters closest to land, such as rivers, river mouths, and bay margins. As we moved toward the center of the bay and then outwards, Chl-a levels gradually decreased (Marlian et al., 2015). This trend mirrors the distribution of nitrate and phosphate, essential nutrients for phytoplankton growth. Ayuningsih et al. (2014) demonstrated a strong positive correlation between Chl-a levels and these nutrients, with higher concentrations found in the estuaries and progressively lower values toward the open sea. These rich nearshore waters benefit not only from riverine nutrient runoff but also from the presence of mangrove vegetation. As mangrove leaves decompose and fall into the water, they release vital nutrients, further enriching the coastal environment and promoting phytoplankton growth (Hidayah et al., 2016).

The compelling evidence from this study strongly indicates that the distribution of Chl-a is a more influential predictor of fish catch than SST, highlighting the ecological importance of Chl-a in relation to fish populations. This finding underscores the importance of prioritizing Chl-a data in future FAFMs to enhance the effectiveness of fishing practices. The positive impact of Chl-a on fish catches can be attributed to a phenomenon known as upwelling (Narvekar et al., 2021). Upwelling occurs when wind and water currents cause the mixing of deep, nutrient-rich cold-water masses with the surface layer. This process increases Chl-a concentration, which is often accompanied by a decrease in SST due to the influx of cooler water from below. Although strong winds can contribute to a decrease in the SST (the uppermost warm layer), the overall impact on fish seems less pronounced than the surge in Chl-a. By analyzing the SST and Chl-a distributions, researchers can pinpoint areas where upwelling might occur, providing valuable insights into targeted fishing practices.

The FAFM, utilizing in-situ SST data, identified a temperature range of 28.9°C to 29.5°C along the Muara Kintap coastal waters. The analysis indicates that the southern region has slightly higher temperatures than the southwest. The SST significantly influences the schooling behavior and migration pattern of small pelagic fish, which prefer warmer waters between 29 °C and 33 °C (Safruddin et al., 2014). These fish inhabit the surface layer of the water column and often reside in relatively shallow areas like estuaries (Safruddin, 2013). The SST values fell within the empirical range (25-31°C) considered optimal for high pelagic fish presence (Clinton et al., 2022). Sobatnu and Irawan (2022) also conducted similar research using Aqua MODIS image processing to generate fishing zone maps.

The importance of comprehensive and up-to-date data for informed decision-making on fisheries management is also patamount. Here are some suggestions to be built upon in future studies:

1. Detailed data collection: This step expands data collection efforts to capture more granular details. This involves the following step.

- Employing standardized data collection protocols across the entire research area.
- Recording a wider range of parameters than those currently measured (e.g., fish species composition, catch sizes, gear types used).
- Finer spatial and temporal resolutions are implemented for data collection to account for potential variations within the Muara Kintap waters.

2. Direct observation and source diversification: Satellite data are supplemented with on-the-ground observations and a broader range of data sources:

- Regular field surveys were conducted to validate satellite data and gather real-time information on fish behavior and distribution.
- Collaborate with local fishers to leverage their practical knowledge and experience of the fishing grounds.
- Explore the potential of citizen science initiatives to engage the community in data collection.

3. Data management and sharing establish robust data management practices:

- Implement a centralized data repository to realize efficient storage, organization, and accessibility of collected information.
- Develop data sharing protocols to facilitate collaboration between researchers, fisheries management agencies, and the fishing community.

## CONCLUSION

The implementation of digital technology such as the Fishing Area Forecast Map (FAFM) has enhanced the ability of Muara Kintap's fishers to identify productive fishing grounds, leading to more targeted and efficient fishing practices that promote sustainable fisheries and improve the fisher's livelihoods. The results strongly indicate that the distribution of Chl-a is a more influential predictor of fish catch than SST.

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## AUTHORSHIP CONTRIBUTION

All authors contributed equally, ensuring the accuracy, authenticity, and ethical integrity of the research.

## CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

## ETHICS APPROVAL

Ethics Committee approval certificate was not required for this study.

## DATA AVAILABILITY

All relevant data are in the article.

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