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Spatial Mapping of Mini Purse Seine Fishing Grounds Associated with Fish Aggregating Devices (FADs) in the Coastal Waters of Buru Regency, Maluku Province, Indonesia

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ABSTRACT

This study aimed to identify the spatial distribution of Fish Aggregating Devices (FADs) within the fishing grounds of mini purse seine operations in the waters of Buru Regency, Maluku Province, and analyze the spatial relationship between FAD distribution, chlorophyll-a concentration, and sea surface temperature (SST) across different seasonal periods. A quantitative descriptive approach was applied, utilizing secondary oceanographic data derived from Aqua MODIS satellite imagery covering the period from December 2023 to November 2024. Chlorophyll-a and SST data were spatially analyzed using Geographic Information System (GIS) software and integrated with FAD coordinates obtained through field observations and interviews with 12 mini purse seine vessels, representing the entire population. The results indicate that FAD distribution remained consistently located from the northwestern to eastern waters of Buru Regency throughout the year, despite seasonal variations in environmental conditions. During the Southeast Monsoon (June–August 2024), chlorophyll-a concentrations peaked (0.22– 0.31mg/ m³), and SST values were relatively lower (27– 29°C) across most of the study area, indicating high primary productivity. Conversely, the West Monsoon and transitional seasons generally exhibited reduced productivity. However, fishers did not relocate their FADs, suggesting limited adaptation to oceanographic changes. The resulting spatial maps underscore that integrating oceanographic data with FAD distribution can serve as a foundational basis for spatial fishing zone policies and the sustainable management of small pelagic fish resources.

INTRODUCTION

Buru Regency is characterized by a tropical monsoonal climate, strongly influenced by surrounding oceanic conditions. The region experiences two main seasonal phases: the dry season (June–November) and the rainy season (December–May). More specifically, the local marine environment is shaped by four distinct seasonal periods: the West Monsoon (December–February), the First Transitional Season (March–May), the

Southeast Monsoon (June–August), and the Second Transitional Season (September–November) **(Sanaky, 2015)**.

These seasonal variations significantly influence the spatial distribution of fishing grounds, the safety of fishing operations, and the efficiency of fishing gear. According to **Kasmawati and Ardiana (2015)**, fishing seasons are closely linked to the presence and availability of target fish species. In Buru's waters, mini purse seine operations still rely heavily on Fish Aggregating Devices (FADs) to concentrate fish schools in localized areas. Most FADs are deployed as permanent installations in locations considered strategic by local fishers and are often passed down through generations.

Placing FADs in ecologically suitable zones can enhance fishing success, particularly when aligned with spatial and temporal oceanographic parameters such as chlorophyll-a concentration and sea surface temperature (SST). As noted by **Asmidar *et al.* (2023)**, the increasing availability of satellite-derived chlorophyll-a and SST data enables the development of predictive fishing ground maps, or Potential Fishing Zones (PFZs), which support more efficient fishing practices.

Asbar and Ihsan (2022) emphasized that PFZ maps integrate the spatial and temporal distribution of oceanographic parameters with actual catch data, providing fishers with valuable information to estimate catch potential and operational costs. However, there has been limited research explicitly integrating oceanographic data with the distribution of FADs in the waters of Buru Regency. Such integration is critical to support evidence-based policy for spatial fishing zoning and the sustainable utilization of small pelagic fish resources.

Based on this background, the objective of this study was to identify the spatial distribution of FADs used by mini purse seine fisheries in the waters of Buru Regency, Maluku Province and to analyze the spatial relationship between FAD distribution, chlorophyll-a concentration, and sea surface temperature across different seasonal periods.

In the context of national marine spatial planning, the utilization of scientific and oceanographic data has been prioritized under Indonesia's Coastal and Small Islands Zoning Plan (RZWP3K), as mandated by Law No. 27 of 2007 in conjunction with Law No. 1 of 2014, and further operationalized through Ministerial Regulation No. 23 of 2020. These frameworks emphasize the strategic use of remote sensing technologies and environmental indicators to inform fishing zone allocation and ensure resource sustainability. Accordingly, integrating chlorophyll-a concentrations and SST data with the spatial distribution of FADs is of particular importance for small-scale fisheries in eastern Indonesia, which are highly sensitive to climatic and seasonal variability. This study aimed to contribute scientific insights toward developing adaptive, data-driven spatial management strategies for pelagic fisheries in the region.

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MATERIALS AND METHODS

Time and location of the research

This study was conducted in the waters of Buru Regency, Maluku Province, Indonesia, from March to December 2024 (Fig. 1). The study area encompasses the fishing zones utilized by mini purse seine vessels operating with Fish Aggregating Devices (FADs).

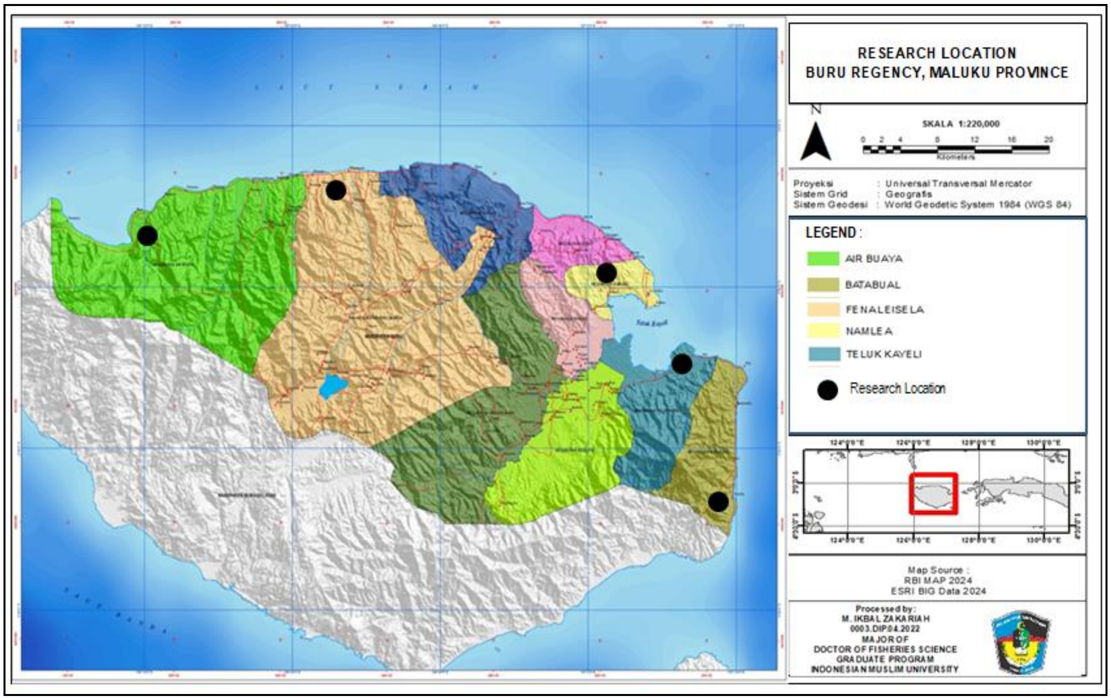

Fig. 1. Map of study sites

Data types and sources

A quantitative and spatial approach was employed, integrating both primary and secondary data to assess the distribution of FADs, oceanographic characteristics, and fisher behavior. Primary data included:

- Fishing catch volumes by mini purse seine vessels.
- Geographic coordinates of FAD locations and fishing spots per season.

These data were collected through field observations, structured interviews using questionnaires, and grid maps involving all 12 operational mini purse seine fishing units in Buru Regency.

Secondary data were obtained from relevant institutions and open-access sources, consisting of:

- Satellite-based oceanographic parameters, including chlorophyll-a concentration and Sea Surface Temperature (SST), from Aqua MODIS imagery.
- Bathymetric and base maps.
- Fisheries statistics from the Buru Regency Marine and Fisheries Office.

Population and sampling technique

The target population comprised all active mini purse seine fishing units in Buru Regency. Based on local fisheries records, a total of 12 vessels from five subdistricts (Air Buaya, Fena Leisela, Namlea, Teluk Kayeli, and Batabual) were identified. Although Slovin's formula was initially considered to determine minimum sample size with a 10% margin of error, a total sampling method was ultimately applied due to the small population size, ensuring full representation and minimizing sampling bias.

Data collection techniques

A survey method was used, consisting of:

1. **Field observations**: Direct visits to FAD sites were conducted using handheld GPS devices to record precise coordinates. Observations also included noting sea state, wind direction, wave conditions, and water depth near FAD locations.
2. **Structured interviews**: Conducted with fishers and FAD owners using validated questionnaires. Key information gathered included the rationale behind FAD placement, seasonal fishing schedules, average catch by season, and fishers' perceptions of environmental variability.

Secondary data collection involved literature reviews and extraction of oceanographic data (chlorophyll-a and SST) from MODIS satellite imagery, covering the period from December 2023 to November 2024. Raster-format datasets were downloaded from publicly available remote sensing platforms.

Data analysis

Spatial analysis of fishing grounds was carried out using a combination of Geographic Information System (GIS) tools and satellite image processing software. The analysis included:

1. **Fishing ground mapping**: Fisher-identified FAD and fishing locations were transferred from grid maps to ArcMap GIS to visualize fishing grounds per season (West Monsoon, Transition I, East Monsoon, and Transition II).
2. **Oceanographic parameter analysis**: Monthly chlorophyll-a and SST distributions were derived from processed Aqua MODIS imagery. Visual spatial analysis was used to identify distribution patterns, supported by time series analysis to detect seasonal trends. Image data were processed using SeaDAS software, and numerical data were exported to Microsoft Excel to calculate mean values.
3. **Spatio-temporal overlay**: Processed chlorophyll-a and SST maps were overlaid with FAD coordinate data to evaluate the spatial relationship between environmental conditions and FAD placement. Spatial contour mapping was performed using Ocean Data View (ODV) to visualize ocean productivity hotspots.

This integrated method allowed for the identification of spatial dynamics in FAD deployment and fishing ground suitability across different seasonal periods, contributing to informed spatial fisheries management.

RESULTS

1. Spatial distribution of fish aggregating devices (FADs)

Field observations and structured interviews with mini purse seine fishers in Buru Regency revealed that Fish Aggregating Devices (FADs) are predominantly deployed in the southwestern and northeastern waters of the region. These locations are considered strategic by local fishers based on longstanding experience and proximity to landing sites and ports.

A total of 27 anchored FADs were identified and georeferenced using GPS coordinates (Fig. 2). These devices are distributed across five subdistricts—Air Buaya, Fena Leisela, Namlea, Teluk Kayeli, and Batabual—within the geographical range of 3°15' to 3°38' South Latitude and 126°30' to 127°00' East Longitude (Fig. 2 & Table 1). Most FADs are located in waters with depths ranging from 30 to 70 meters, with moderate current velocities, making them suitable habitats for small pelagic fish species targeted by mini purse seine operations.

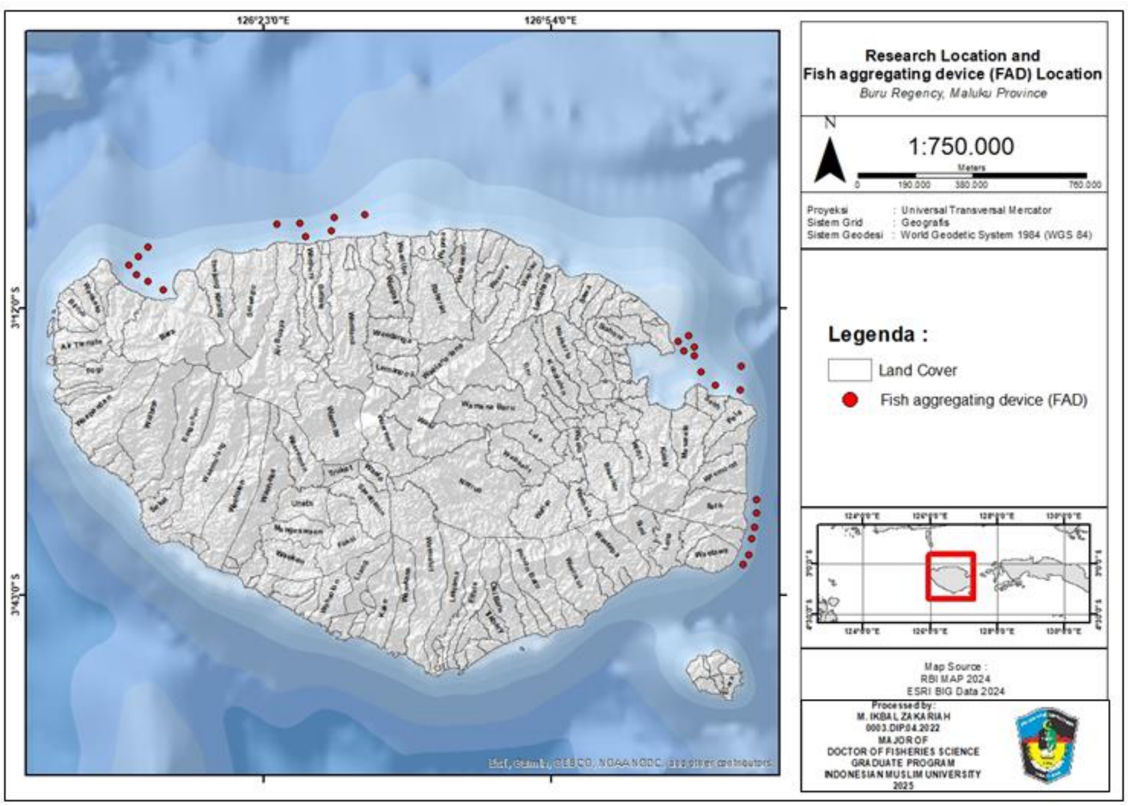

Fig. 2. Map of the distribution of Rumpon locations in the waters of Buru Regency

Table 1. Sets of coordinates of FADs in water of Buru Regency

No	Water Locations	Sets of Coordinates	Number of FADs
1	District of Air Buaya	3° 8'29.08"S-126°10'11.04"E	6
		3° 5'54.65"S-126°10'45.01"E	
		3° 6'54.60"S-126°10'17.35"E	
		3°9'4.57"S-126°11'1.39"E	
		3° 8'2.21"S-126° 9'23.25"E	
		3° 9'50.48"S-126°12'18.23"E	
2	District of Fena Leisela	3° 3'4.61"S-126°26'4.35"E	6
		3° 2'40.25"S-126°33'1.23"E	
		3° 2'34.21"S-126°30'53.73"E	
		3° 3'29.37"S-126°30'26.26"E	
		3° 3'51.27"S-126°28'17.37"E	
		3° 2'50.31"S-126°28'2.88"E	
3	District of Namlea	3°15'34.40"S-127° 8'8.68"E	5
		3°14'43.20"S-127° 9'3.52"E	
		3°15'28.04"S-127° 9'54.97"E	
		3°16'7.27"S-127° 8'50.89"E	
		3°16'17.67"S-127° 9'57.97"E	
4	District of Teluk Kaiely	3°18'3.36"S-127°10'39.62"E	4
		3°19'14.04"S-127°11'56.85"E	
		3°18'1.22"S-127°14'47.56"E	
		3°20'4.30"S-127°14'35.17"E	
5	District of Batabual	3°35'51.74"S-127°16'32.79"E	6
		3°36'40.31"S-127°16'40.89"E	
		3°34'26.57"S-127°17'16.22"E	
		3°37'54.98"S-127°16'18.76"E	
		3°33'34.54"S-127°17'26.65"E	
		3°38'36.60"S-127°15'53.48"E	
		Total	27

Despite seasonal variations in oceanographic conditions, the spatial distribution of FADs remained largely static throughout the year. This indicates that the deployment of FADs in Buru's waters is based primarily on traditional ecological knowledge and fisher preference rather than dynamic environmental indicators such as chlorophyll-a concentration or sea surface temperature. The fixed nature of these FADs, often referred to as anchored FADs, reflects a high level of dependence on established fishing zones.

From an operational standpoint, the use of permanent FAD sites enhances efficiency in terms of time and fuel costs. However, this static deployment strategy may limit adaptive capacity in response to shifting environmental conditions **(Tukan *et al.*, 2024)**. Satellite-derived data showed that chlorophyll-a and SST levels vary significantly by season, yet FADs relocation was rarely observed. This suggests a gap between environmental variability and spatial fishing effort, potentially resulting in suboptimal catches during less productive seasons.

The concentration of FADs in ecologically productive zones during certain periods—such as the northeastern waters during the southeast monsoon—demonstrates some degree of alignment between traditional knowledge and scientific observation. Nevertheless, a more responsive strategy that integrates remote sensing data could improve catch efficiency and sustainability. Spatial planning for FAD deployment, informed by oceanographic parameters, would allow for more adaptive, data-driven fisheries management in the face of seasonal environmental dynamics.

2. Zoning of fishing grounds based on seasonal variability

Spatial analysis of oceanographic parameters—specifically chlorophyll-a concentration and sea surface temperature (SST)—combined with the GPS-based coordinates of FADs, revealed clear spatiotemporal variation in potential fishing grounds across the waters of Buru Regency. The seasonal zoning of fishing activity was categorized into four distinct periods: West Monsoon**,** Transition I**,** Southeast Monsoon, and Transition II. Each season exhibited unique oceanographic characteristics that directly influenced primary productivity and the spatial distribution of small pelagic fish habitats.

West monsoon season (December 2023 – February 2024)

As shown in Fig. (3), chlorophyll-a concentrations during the West Monsoon season were the highest (> 0.3mg/ m^3) in the northeastern and eastern waters of Buru. These areas also displayed lower sea surface temperatures (approximately 29°C), indicating upwelling phenomena that bring nutrient-rich deep waters to the surface, thus enhancing marine productivity. The clustering of FAD coordinates in this region suggests that mini purse seine fishers actively utilize these productive areas during this season. In contrast, the northwestern and northern waters showed lower chlorophyll-a levels (< 0.3mg/ m^3) and higher SSTs (~31°C), indicating reduced productivity.

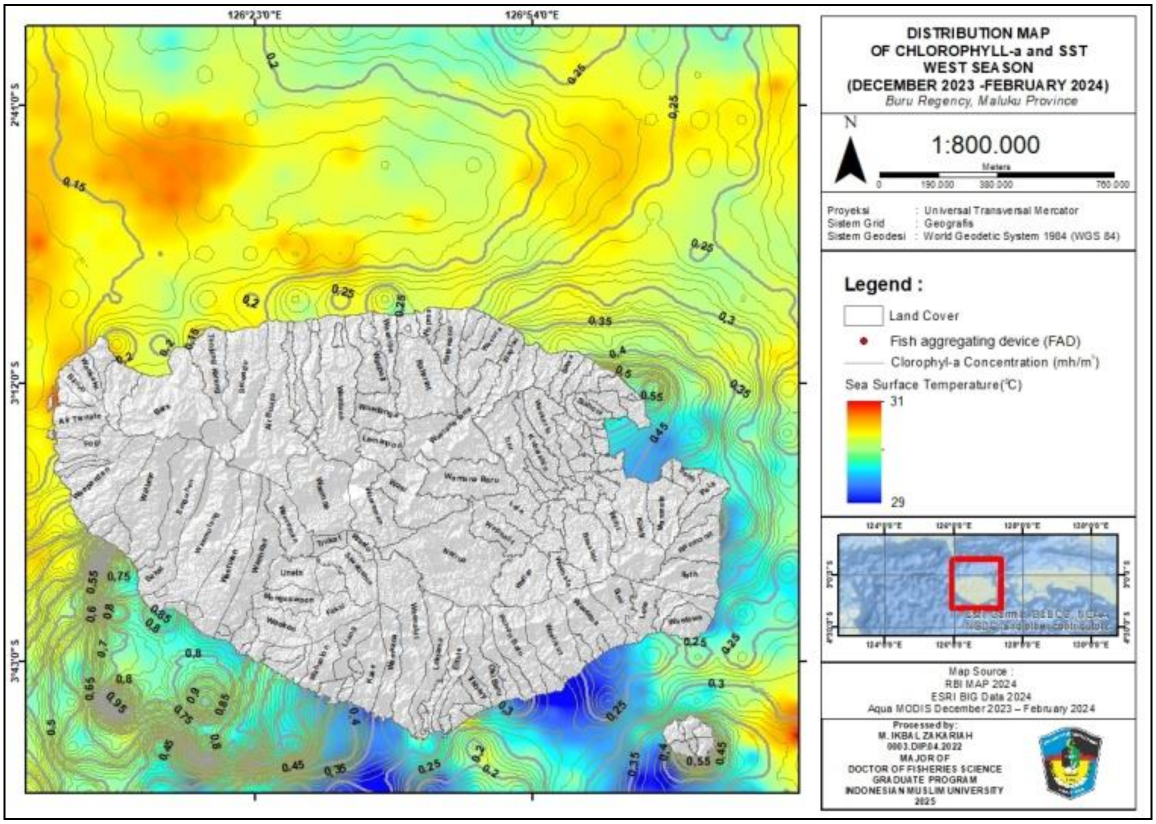

Fig. 3. Distribution of chlorophyll-a and SST in the west monsoon season

Transition season I (March – May 2024)

During the first transitional season **(**Fig. 4), a notable decline in chlorophyll-a concentration was observed, with values ranging from 0.13 to 0.18mg/ m^3. Concurrently, SSTs increased to between 30.5 and 31°C, particularly in the northern and eastern waters. This condition signifies a decrease in phytoplankton activity, which may reduce the availability of pelagic fish. Despite this, FAD locations remained unchanged, still concentrated in historically productive areas. The persistence of static FAD placement under changing conditions indicates limited adaptation to oceanographic variability. Without adjustments to gear location or fishing strategy, catch efficiency during this season may decline.

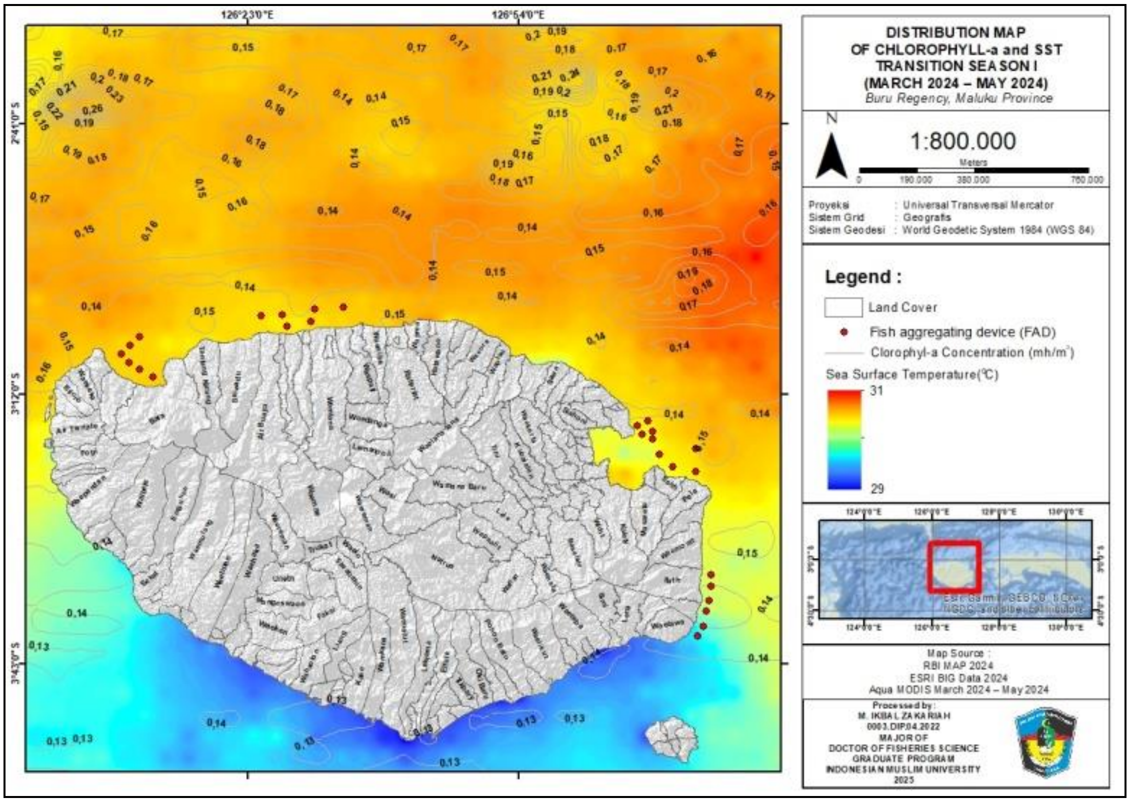

Fig. 4. Distribution of chlorophyll-a and SST in the transition season

Southeast monsoon season (June – August 2024)

According to Fig. (5**)** the southeast monsoon represented the peak period of marine productivity in Buru's waters. Chlorophyll-a concentrations increased significantly, reaching values between 0.22 and 0.31 mg/m³, especially in the northwestern and northeastern zones. This seasonal productivity surge was accompanied by a drop in SST (27–29°C), associated with widespread upwelling processes. These favorable environmental conditions created optimal habitats for small pelagic species, as also observed in similar studies in the Java Sea and Makassar Strait **(Larasati *et al*., 2024)**.

The concentration of FADs in areas with high chlorophyll-a levels suggests that some fishers have begun to adjust their fishing patterns based on environmental knowledge. This seasonal alignment of FAD deployment with oceanographic hotspots enhanced catch efficiency during the most productive period of the year. Nevertheless, a full optimization of this season's potential remains limited, as many FADs were still not relocated based on real-time oceanographic data.

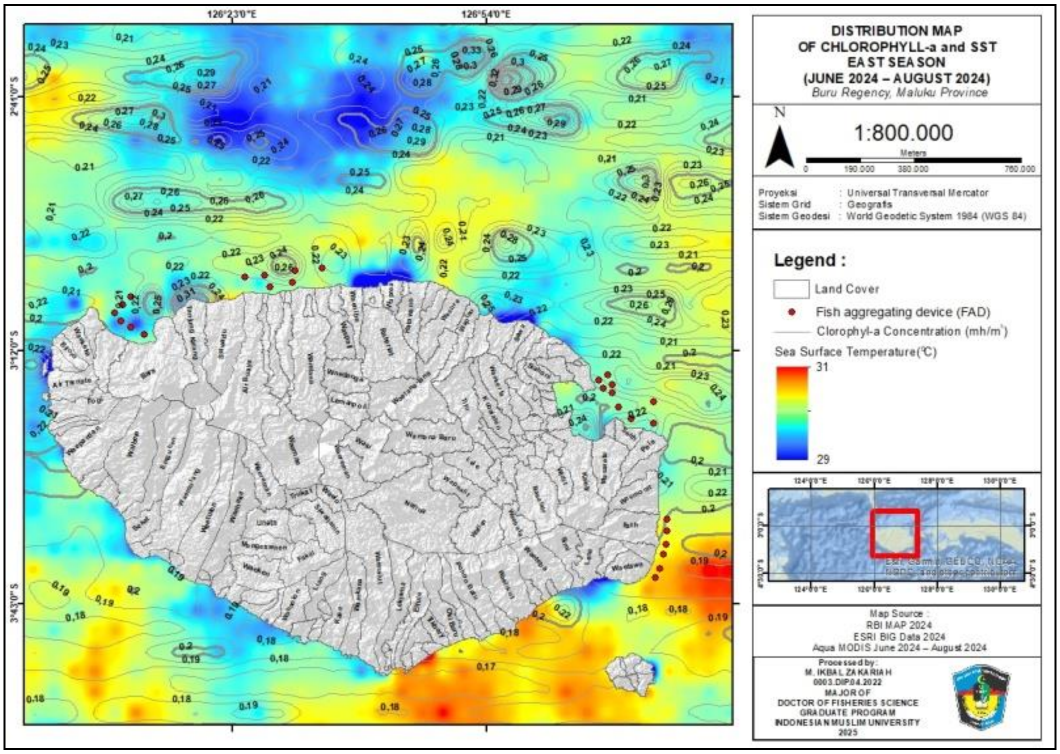

Fig. 5. Distribution of chlorophyll-a and SST in the southeast monsoon season

Transition season II (September – November 2024)

As illustrated in Fig. (6), oceanographic conditions during the second transitional season mirrored those of Transition I but showed early indicators of change toward the west monsoon phase. Chlorophyll-a concentrations declined again, ranging from 0.13 to 0.17mg/ m³, particularly from the northwest to the eastern waters of Buru. Meanwhile, SST remained relatively stable between 27 and 30°C. This intermediate condition suggests recovering productivity, though still below optimal levels.

The FAD distribution during this period remained largely unchanged, concentrated in the same southwestern and northeastern zones. This lack of mobility in FAD deployment, despite observable shifts in productivity, could affect fishing success due to spatial mismatch with pelagic fish distribution. As pelagic species become more dispersed, catch efficiency may decline. Therefore, the application of seasonal chlorophyll-a and SST maps is essential for guiding temporary or mobile FAD deployments during transitional phases.

These seasonal dynamics emphasize the need for adaptive fishing strategies based on reliable spatial-temporal environmental data. Incorporating oceanographic indicators into FAD placement and fishing zoning policies can significantly enhance the resilience and sustainability of small pelagic fisheries in Buru Regency.

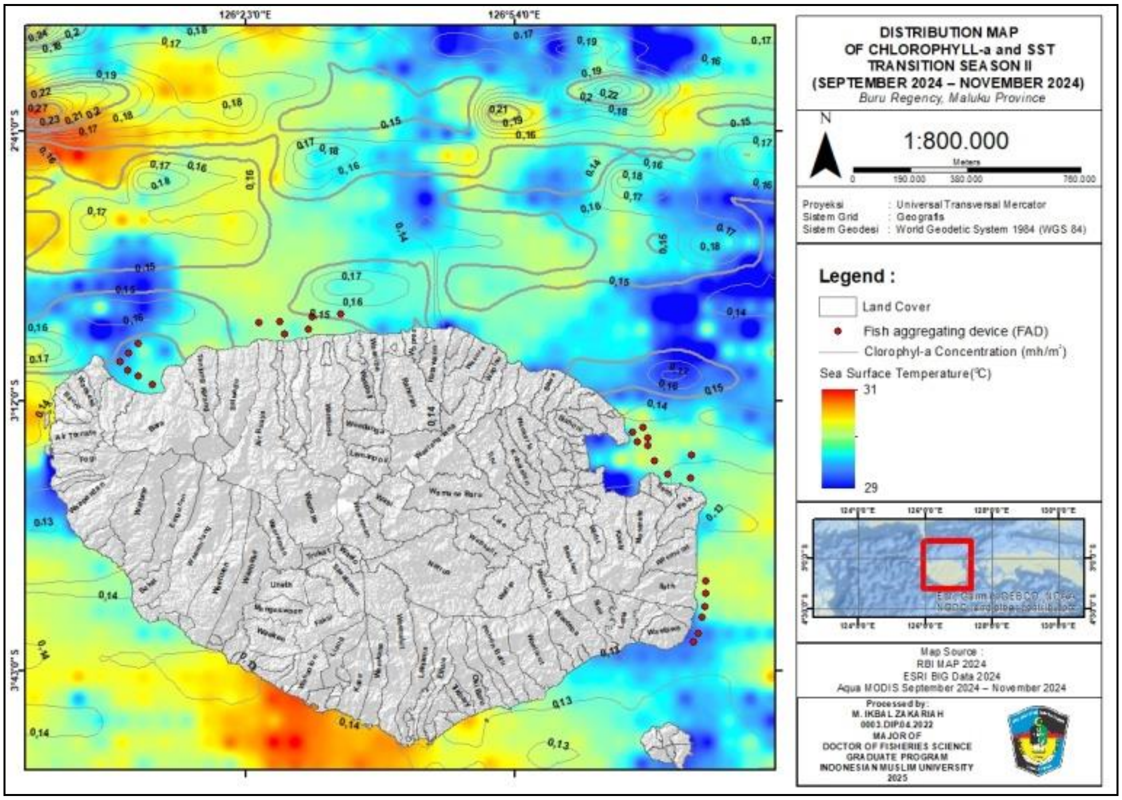

Fig. 6. Distribution of chlorophyll-a and SST in the transition season II

DISCUSSION

The spatial pattern of FAD deployment observed in the waters of Buru Regency illustrates a strong reliance on traditional ecological knowledge rather than adaptive responses to environmental dynamics. Fishers consistently positioned their FADs in the southwestern and northeastern coastal areas—locations historically perceived as productive due to generational experience and proximity to landing sites. This static pattern persisted across all seasonal transitions, even though satellite-derived oceanographic data revealed significant variability in both chlorophyll-a concentration and sea surface temperature (SST) throughout the year.

During the West Monsoon season, elevated chlorophyll-a levels (>0.3 mg/m³) and cooler SST (~29 °C) in the northeastern waters coincided with the densest FAD presence, suggesting partial overlap between fisher intuition and actual productivity. However, in less productive seasons, such as Transition I and Transition II, chlorophyll-a values declined reaching below 0.18mg/ m³, while SSTs rose above 30.5°C—signaling decreased phytoplankton biomass and primary productivity. Despite this, FAD locations remained unchanged. Such rigidity in spatial fishing effort may result in decreased catch efficiency, particularly in seasons where ecological productivity is not aligned with traditional fishing grounds.

Interestingly, during the Southeast Monsoon season, environmental conditions became most favorable, with chlorophyll-a concentrations peaking between 0.22–0.31mg/ m³ and SST dropping to 27– 29°C—indicative of upwelling processes that enhance nutrient availability and attract pelagic species. Yet, fishers did not markedly adjust their FAD placements to optimize these conditions, pointing to a limited capacity or willingness to incorporate environmental cues into operational decisions. Similar studies in small pelagic fisheries in the Java Sea and the Makassar Strait confirm that even when productivity peaks seasonally, the mobility of mini purse seine units tends to be constrained by economic, logistical, and cultural factors **(Capello *et al.*, 2012; Larasati *et al.*, 2024)**.

This behavior aligns with findings across the Indonesian archipelago, where fishers are often constrained by vessel range, fuel costs, and time—leading to a preference for fixed FAD installations **(Hibata *et al.*, 2018)**. Moreover, the perceived reliability of "customary" fishing zones and the financial cost of FAD relocation may outweigh potential catch gains, particularly among small-scale operators with limited adaptive capacity. As a result, a spatial mismatch arises between areas of high productivity and actual fishing effort, potentially diminishing catch-per-unit-effort (CPUE) during suboptimal seasons.

From a fisheries management perspective, this mismatch underscores the need to integrate real-time or seasonal oceanographic data—particularly chlorophyll-a and SST distributions—into local fishing strategies. In many regions, such data have already been used to create Potential Fishing Zone (PFZ) forecasts, enhancing fisher efficiency and reducing unnecessary effort. Incorporating PFZ mapping into Buru's local fishing system could provide an evidence-based decision-making tool, allowing for dynamic FAD deployment in alignment with oceanographic variability. Studies have shown that such tools can increase CPUE by up to 40 % while reducing operating costs **(Capello *et al.*, 2012; Potin *et al.*, 2022)**.

Furthermore, the static nature of FAD use presents ecological risks, including localized overfishing and potential habitat degradation. Mobile or seasonal FAD strategies have been shown to distribute fishing pressure more evenly, reduce bycatch, and allow for periodic recovery of fish stocks **(Dagorn *et al.*, 2013)**. In the context of climate variability and increasing uncertainty in marine ecosystems, adaptive spatial management—including seasonal zoning and FAD mobility incentives—becomes even more critical.

Another notable finding is the evident disconnect between scientific data and fisher behavior. While oceanographic data clearly point to seasonal shifts in productivity, this information is rarely accessed or applied by local fishers in Buru. Bridging this gap requires not only technological tools but also participatory extension efforts. Training programs that incorporate satellite image interpretation, mobile app-based PFZ services, and collaborative monitoring can empower fishers to adjust their behavior in response to ecological signals. Success in similar settings has been observed in India and the Philippines, where fisher cooperatives partnered with research institutions to co-develop spatial fishing calendars based on remote sensing inputs **(FAO, 2021)**.

Lastly, integrating local ecological knowledge with scientific data holds potential for co-management approaches **(Berhitu *et al.*, 2025)**. The strategic value of traditional FAD placements should not be dismissed, as they may already reflect long-term patterns in productivity. However, validating and complementing these insights with chlorophyll-a and SST data could refine spatial planning and support sustainable harvest strategies. Adaptive management frameworks that embed FAD placement within broader ecosystem-based approaches—such as marine spatial planning or seasonal effort limitations—are increasingly seen as vital tools in managing small pelagic fisheries under pressure from both environmental and anthropogenic forces.

In conclusion, while the mini purse seine fishery in Buru demonstrates strengths in localized knowledge and operational consistency, its current static FAD deployment model lacks the flexibility needed to match dynamic ocean productivity patterns. Integrating satellite-based environmental data into FAD deployment strategies and fishing ground zoning could enhance ecological sustainability and economic resilience. This requires not only access to data but also to institutional support and fisher engagement in co-creating adaptive, spatially informed management strategies for the long-term viability of Buru's small pelagic resources.

Furthermore, the findings could be enriched by comparing the spatial behavior of FAD deployment in Buru Regency with similar small-scale fisheries in other regions of Indonesia or Southeast Asia, such as the Maluku Sea, Sulawesi, or the Philippines. Such comparative perspectives would help determine whether the static deployment reflects a localized tradition or a broader structural constraint across archipelagic fisheries. Additionally, socio-economic factors—such as fuel prices, fisher income, and limited institutional support—may significantly influence the fishers' capacity to adapt to oceanographic variability. Incorporating these dimensions into future research would enhance understanding of the systemic barriers to adopting more dynamic, data-driven fishing strategies.

CONCLUSION

The findings of this study reveal that the spatial distribution of Fish Aggregating Devices (FADs) in the coastal waters of Buru Regency is predominantly concentrated in two main zones: the northwestern and northeastern areas. The placement of these devices is primarily guided by local fishers' traditional knowledge and the operational range of small-scale mini purse seine vessels. This static deployment pattern reflects a relatively fixed use of marine space, despite seasonal variations in environmental conditions.

Spatial analysis of oceanographic parameters—particularly chlorophyll-a concentration and sea surface temperature—indicates that the Southeast Monsoon season (June to August 2024) represents the most productive period for fisheries. During this time, chlorophyll-a concentrations ranged from 0.22 to 0.31mg/ m³, while sea surface temperatures fell to 27– 29°C, creating favorable ecological conditions for small pelagic fish. In contrast, the West Monsoon and transitional periods exhibited lower productivity, characterized by reduced chlorophyll-a levels and higher sea surface temperatures.

Despite these seasonal fluctuations, FAD locations remained unchanged throughout the year, suggesting a limited degree of adaptation by fishers to shifting oceanographic conditions. This highlights a disconnect between environmental variability and fishing practices. Nevertheless, integrating remote sensing data with FAD distribution provides a valuable spatial understanding of fishing patterns and productive zones. These insights serve as a foundational step toward developing more adaptive, efficient, and sustainable spatial zoning strategies for managing small pelagic fisheries in eastern Indonesian waters.

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