Global Journal of Environmental Science and Management
(GJESM)

Homepage: https://www.gjesm.net/

Podcasts

ORIGINAL RESEARCH ARTICLE

Small-scale fisheries monitoring and fleet dynamics in a marine protected area

R. Firdaus[1,2], F. Yulianda[3,*], Z. Zairion[3]; G. Yulianto[3], C.M.N. 'Akla[1,4]

[1]Study Program of Coastal and Marine Resources Management, Department of Aquatic Resources Management, Faculty of Fisheries and Marine Sciences, IPB University, Jalan Raya Dramaga, Bogor 16680, West Java, Indonesia

[2]Department of Fisheries, Politeknik Indonesia Venezuela, Aceh Besar 23371, Aceh, Indonesia

[3]Coastal and Marine Resources Management, Department of Aquatic Resources Management, Faculty of Fisheries and Marine Sciences, IPB University, West Java 16680, Indonesia

[4]Department of Marine Science, Faculty of Agriculture, Malikussaleh University, Aceh 24351, Indonesia

ARTICLE INFO

Article History:
Received 19 July 2026
Revised 25 September 2026
Accepted 02 November 2026

Keywords:
Automatic Identification System
Data-limited fisheries
Fish length indicators
Fleet dynamics
Marine protected areas
Small-scale fisheries

DOI:
https://doi.org/10.22034.gjesm.2027.02.17

ABSTRACT

BACKGROUND AND OBJECTIVES: Monitoring fishing pressure in marine protected areas is difficult when small-scale vessels are not required to carry satellite transponders. Automatic Identification System data are used as a proxy for fishing activity, but their coverage of small-scale fleets is rarely checked against vessel registries and biological indicators. The study objectives were to determine the extent to which the registered fleet could be detected in the dataset, characterize temporal fluctuations in monthly vessel presence, and assess the size composition of landed reef fish in the Aceh Besar marine protected area, Indonesia.

METHODS: Fleet registry data (2019-2024) were combined with Global Fishing Watch presence records (February 2020-December 2024) and monthly mean lengths of ten reef-associated species (2020-2023). Monthly presence patterns were tested with the Friedman test. A coverage ratio compared distinct fishing vessels with registered vessels. The proportion of months wherein monthly mean lengths failed to exceed the threshold for first maturity was quantified for each species, with interannual variances assessed via Kruskal-Wallis and Dunn's post hoc tests.

FINDINGS: Registered vessels of 5 gross tonnage or less increased from 621 in 2019 to 979 in 2024, partly reflecting registry reclassification. Only 2-8 fishing vessels transmitted signals in each annual period, equal to 0.21-0.82 percent of the registered small-scale fleet, as expected because transponders are mandatory only for fishing vessels of 60 gross tonnage and above. Non-fishing vessels produced 99.2 percent of the 21,804 presence hours. Presence hours showed no significant monthly pattern, whereas distinct vessel counts peaked in August-September. Throughout nearly all sampled months, mean lengths for Carangoides ferdau, Variola albimarginata and Lutjanus quinquelineatus, failed to reach maturity thresholds, a condition observed in 73.3 percent of monthly samples for Caranx ignobilis. Length differed among years for six species without a consistent decline and was not correlated with registered fleet size.

CONCLUSION: The restricted coverage of the active fishing fleet by satellite surveillance limits its representativeness, rendering seasonal signals predominantly indicative of non-fishing maritime traffic. It should not be used alone to assess fishing pressure where small-scale fisheries dominate; registry audits, landing-site length-frequency surveys, community reporting and low-cost tracking of small boats offer a more realistic basis for monitoring.

This is an open access article under the CC BY license (http://creativecommons.org/licenses/by/4.0/)

NUMBER OF REFERENCES	NUMBER OF FIGURES	NUMBER OF TABLES
48	3	4

*Corresponding Author:
Email: fredinan@apps.ipb.ac.id
Phone: +6281 2914 4597
ORCID: 0000-0002-7547-6914

Note: Discussion period for this manuscript open until June 01, 2027 on GJESM website at the "Show Article".

INTRODUCTION

Marine protected areas (MPAs) can restore depleted fish stocks and protect marine biodiversity, but only if managers enforce regulations and monitor their performance year after year. According to Gill *et al*. (2017), MPAs equipped with robust staffing and monitoring capacity generate ecological benefits nearly threefold higher than inadequately monitored reserves. Fishing fleets and the fish they target change with the seasons, market conditions, and regulations. Assessing MPAs therefore requires a time-series perspective that tracks changes over the years. Most studies on fishing activity within Indonesian MPAs, including Aceh Besar, still rely on short-term surveys that capture only a single season. Indonesia's small-scale fisheries are notoriously data-poor, with catch and effort records too sparse to support robust stock assessments. A solitary survey is inadequate for capturing fleet dynamics, such as expansion, contraction, or spatial relocation, nor is it capable of resolving the incremental reductions in fish size indicative of overfishing. This gap leaves managers guessing about the actual trends in fishing pressure within MPAs. Therefore, MPA evaluations must link ecological changes to the human pressures that management aims to directly control. The systematic monitoring of anthropogenic stressors constitutes an essential foundation for appraising ecological dynamics, enabling researchers to isolate localized administrative deficiencies from overarching environmental determinants (Dunham *et al.,* 2020). Evaluating marine protected areas requires balancing ecological health with local socioeconomic dynamics (Arthatiani *et al.,* 2026). In the Indonesian setting, quantifying catch volume alone remains insufficient for defining small-scale fisheries; rather, the technological modernization of fishing gear and commercial organization critically condition overarching management imperatives (Halim *et al.,* 2019). Limited funding, facilities, and human resources continue to hinder the effectiveness of Indonesia's MPAs (Meilana *et al.,* 2023). Satellite tracking helps bridge some of this gap. The automatic identification system (AIS), processed through Global Fishing Watch, allows researchers to track individual vessels month by month. AIS data reveal when a vessel enters and exits an MPA and how many hours it is present inside the area; whether such visits involve transshipment or unreported catch cannot be determined from presence data. Integrated with longitudinal vessel registration records, these telemetry signals delineate the specific components of the registered fleet observable through satellite surveillance. While vessel tracking metrics alone remain insufficient to confirm whether monitored activities precipitate environmental harm, such interpretive capabilities must be critically contextualized within the operational limitations of the AIS system. AIS was originally designed for navigational safety, not for fisheries censuses. Therefore, installation requirements, transmission behavior, signal reception, identification errors, and classification can affect data representativeness (Robards *et al.,* 2016). The application of AIS in small-scale fisheries can support management, but its scope remains influenced by vessel size and regulatory requirements (James *et al.,* 2018). Under Indonesian regulatory frameworks, the mandatory carriage of AIS Class B transponders applies solely to fishing vessels displacing 60 gross tons and upward (MoT, 2022), leaving artisanal and small-scale fleets largely unmandated to broadcast telemetry data. Globally, about three-quarters of industrial fishing vessels are not publicly tracked (Paolo *et al.,* 2024). A comparison of AIS with vessel monitoring system (VMS) shows that differences in coverage and recording frequency can alter estimates of fishing tracks (Shepperson *et al.,* 2018; Thoya *et al.,* 2021). Biological indicators fill this critical gap because fish populations carry temporal signals. Escalating fishing pressure frequently induces a size-based truncation of catch assemblages toward smaller cohorts, thereby increasing the proportion of juvenile individuals harvested before reaching size-at-first- maturity (Froese, 2004). However,

length-based indicators must be interpreted while considering gear selectivity, recruitment variability, life history characteristics, and sample representativeness (Hordyk *et al.,* 2015; Chong *et al.,* 2020). These shifts occur slowly, so single-year length data cannot distinguish temporary fluctuations from declining trends. Validating recruitment overfishing requires longitudinal comparative data concerning size-at-maturity; accordingly, interpreting length-based indicators demands rigorous methodological prudence. The performance of length-based stock assessment methods is influenced by life history characteristics, exploitation rates, recruitment variability, and the length of the time series; therefore, simple length indicators are not always sufficient to definitively determine stock status (Chong *et al.,* 2020). Conducting length-based evaluations demands granular individual length frequency distributions and species-specific biological parameters, superseding the analytical utility of generalized monthly temporal averages (Halim *et al.,* 2020; Ernawati *et al.,* 2024). Uncertainties in recruitment and fishing mortality can also substantially affect length-based inferences (Rudd and Thorson, 2018; Pons *et al.,* 2020). Stock estimates are further sensitive to growth parameters, local maturity, and the representation of large fish in the sample (Herdiana *et al.,* 2025). The Aceh Besar MPA encompasses coral reef, seagrass, and open-water habitats under a multipurpose zoning system that includes no-take zones. Encompassing approximately 4,500 artisanal fishers, the study area experiences a bimodal monsoon regime that critically conditions local harvesting operations (Muhammad *et al.,* 2021). Without sustained monitoring and enforcement, such MPAs risk becoming “paper parks” legally protected but ecologically degraded. MPAs in developing countries often face weak enforcement, ineffective management, and resource constraints (de Oliveira Júnior *et al.,* 2021). Hitherto, existing literature lacks a comprehensive framework synthesizing tripartite temporal series encompassing fleet demographics, AIS telemetry, and ichthyological length data within an individual Indonesian marine protected area. Consequently, resource managers face critical analytical blind spots impeding evidence-based policy formulation, marine spatial planning, and compliance monitoring. Without this methodological integration, administrators cannot reliably distinguish between legitimate attenuation of fishing pressure and unrecorded evasion of fleets from surveillance frameworks. Previous studies have described the limited AIS coverage of small-scale fleets (James *et al.,* 2018; Thoya *et al.,* 2021) and applied length-based indicators to Indonesian reef fisheries (Halim *et al.,* 2020; Ernawati *et al.,* 2024), but the gap between AIS and an official fleet registry has rarely been quantified, and it is seldom tested whether AIS-derived seasonal signals reflect fishing or other maritime traffic. Four distinct methodological rationales dictated the selection of the Aceh Besar MPA: i) artisanal fishing represents the predominant extractive utilization across its multiple-use zoning; ii) the continuous transit of passenger and freight vessels facilitates comparative evaluations between fishing vessel telemetry (AIS) and baseline commercial maritime traffic; iii) customary marine governance administered by Panglima Laot, the institutionalized traditional sea-tenure framework of Aceh officially recognized within regional fisheries policy (Rizqi *et al.,* 2017), underpins participatory community-based surveillance; and iv) longitudinal convergence of multi-year vessel registries, AIS transmissions, and landing records is uniquely available for simultaneous assessment. This study aimed to i) quantify the AIS coverage of the registered fleet, ii) describe monthly patterns of AIS vessel presence and separate fishing from non-fishing traffic, iii) evaluate the monthly mean length of ten target species against length-at-maturity and analyze inter-annual variations, and iv) explore the association between registered fleet size and fish length in the Aceh Besar MPA, Indonesia, using fleet registry data (2019-2024). Research and data analysis were conducted from 2025 to 2026.

MATERIALS AND METHODS

Study area

This study was conducted in the Aceh Besar MPA, Aceh Province, Indonesia, approximately 5°25′-5°58′ north (N) and 95°10′-95°25′ east (E) (Fig. 1). The MPA covers 29,615.63 hectares (ha) and comprises nine management units (Zones I-IX) containing no-take, sustainable fisheries, utilization, and other zones. Zones I-VI form a contiguous cluster around the offshore islands and the western coast, whereas Zones VII-IX are small nearshore units on the northern coast. Spatial analysis of AIS data was deliberately bounded to Zones I–VI, as these sectors constitute the principal contiguous core of the MPA and are situated immediately adjacent to artisanal fishing communities along the offshore islands and western shoreline. Zones VII-IX were excluded because they are small units separated from the main cluster; the implications of this exclusion are considered with the other limitations of the study.

Data sources

Vessel presence data were obtained from Global Fishing Watch (GFW) for the period February 2020- December 2024 and downloaded on 22 January 2025. The data were spatially filtered to Zones I-VI of the nine active management zones within the Aceh Besar MPA. The classification of fishing vessels versus non-fishing vessels relies entirely on GFW's built-in algorithm (based on speed, track patterns, and behavior) (Kroodsma *et al.,* 2018). Longitudinal registry data concerning the commercial and artisanal fishing fleet of Aceh Besar were compiled from the Ministry of Marine Affairs and Fisheries (KKP) of the Republic of Indonesia for the 2019–2024 monitoring period. This dataset includes the number of registered fishing vessels classified by gross tonnage (GT): ≤5 GT, 6-10 GT, 11-20 GT, 21-30 GT, 31-50 GT, and 51-100 GT. The registry also reported non-motorized boats (perahu tanpa motor, PTM) and, in 2019-2020, a combined ">30 GT" class, and the class boundaries were not fully consistent between years (Table 1). Encompassing the entirety of Aceh Besar Regency without recording specific fishing locations or vessel-level AIS identities, the registry reflects the aggregate fleet potentially active within and adjacent to the MPA. Accordingly, individual AIS tracking records precluded direct cross-referencing with specific registered vessels. Fish length surveys were conducted monthly (2020-2023), whenever small-scale fishers landed their catch around the Aceh Besar MPA. There was no fixed landing site; the fish were measured directly at the landing point at the time of landing. No sampling was conducted in April-June 2020, and *Lethrinus lentjan* and *Lethrinus rubrioperculatus* were recorded only in 2021-2022. Measurements were taken individually for all target species present on the survey day (opportunistic sampling) using a ruler with a precision of 0.1 cm. Archived as taxa-specific monthly mean lengths, the data lacked individual length records, monthly sample sizes, and sex determinations; consequently, all length-based indicators were computed directly from aggregated monthly means. Ten target species, selected based on their commercial significance as reef-associated fisheries frequently harvested by small-scale fishers around the MPA vicinity, were evaluated; corresponding length at first maturity (Lm) values referenced from FishBase (Froese and Pauly, 2023) or derived empirically where documented values were lacking. AIS vessels were grouped into three categories according to the GFW vessel type: fishing vessels (type FISHING, with gear types such as trawlers, drifting longlines, set longlines and pole-and-line), fishing-gear buoys (type GEAR, AIS devices attached to fishing gear) and non-fishing vessels (cargo, passenger, bunker, carrier, seismic and OTHER). The OTHER class, which denotes vessels of unspecified type, was treated as non-fishing because the vessels with the longest presence in this class were tugboats and other service or transport vessels; this class accounted for 65.7% of all presence hours. Owing to the absence of empirical cross-

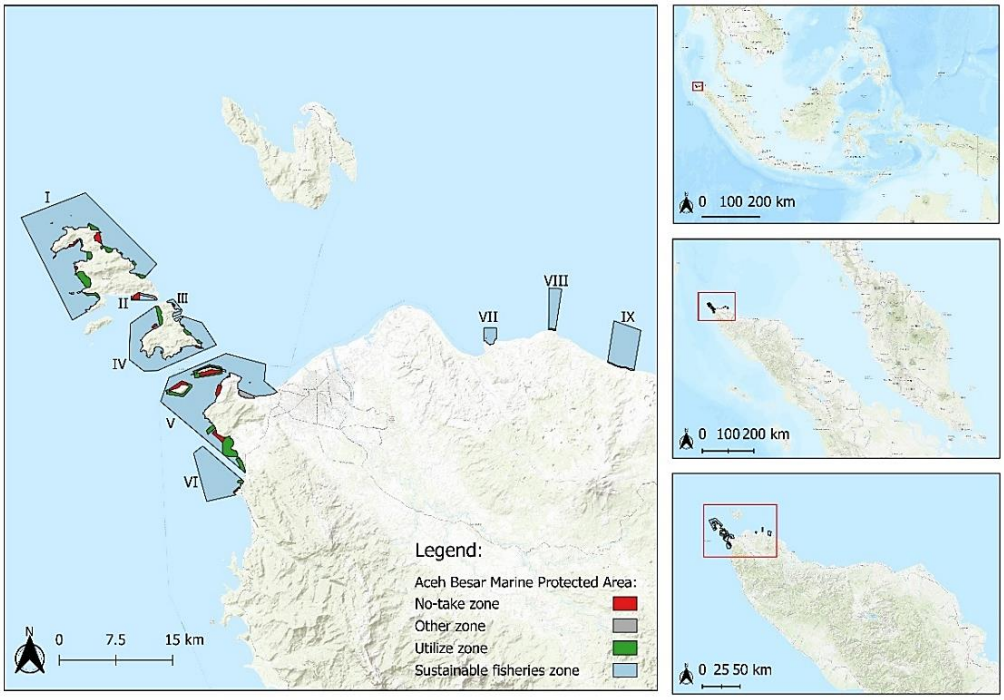

Fig. 1: Geographical location of the study area in Aceh Besar MPA showing the spatial distribution of management zones (no-take zone, sustainable fisheries zone, utilization zone, and other zone) across nine management areas

validation between GFW classifications and on-the-ground vessel inspections, minor instances of vessel misclassification cannot be precluded (Kroodsma *et al.,* 2018). AIS records were grouped into five periods running from February of year t to January of year t + 1, each matched to the registry count of year t (e.g., February 2020–January 2021 with the 2020 registry; the last period covers February–December 2024), and the fish length series (2020–2023) was matched to registry years by calendar year. Because the AIS data refer to Zones I–VI, the registry to the whole Aceh Besar Regency and the length data to landing points around the MPA, the three datasets were compared through annual totals and seasonal patterns rather than vessel by vessel.

Vessel activity metrics

Four distinct metrics extracted from GFW presence records were utilized to quantify vessel presence. Individual records capture discrete vessel incursions—documenting entry and exit timestamps as well as the aggregate duration of the vessel was present within Zones I-VI (designated as presence hours, D_i). The download contained 526 visit records after three non-data rows were removed; no duplicate records with the same vessel identity, entry time and exit time were found, and one record without a vessel identity (2 presence hours) was kept in the presence-hour totals but excluded from vessel counts. Because AIS positions are not transmitted or received continuously, the presence hours were usually much shorter than the entry-exit span (median 2 versus 52.5 hours), and 191 visits consisted of a single position with identical entry and exit times. Accordingly, cumulative duration of Presence, as opposed to gross entry-exit elapsed time, was adopted as the primary metric for quantifying temporal presence within the designated zones. First, the length of the visit window (T_i) was calculated as the difference between the exit and entry timestamps, using Eq. 1 (Kroodsma *et al.,* 2018):

$$T_i = t_{exit,i} - t_{entry,i} \quad (1)$$

Where: T_i is the visit window in hours, $t_{exit,i}$ is the time vessel i exited Zones I-VI, and $t_{entry,i}$ is the time it entered. Second, the monthly presence hours ($PH_{m,p}$) for month m of AIS period p were obtained by apportioning the presence hours of each visit (D_i) to calendar months in proportion to the overlap between the visit window and each month, using Eq. 2 (Kroodsma *et al.,* 2018; Guiet *et al.,* 2019):

$$PH_{m,p} = \sum_{i=1}^{n_p} D_i \times \frac{o_{i,m}}{T_i} \quad (2)$$

Where: n_p is the number of visit records in period p, $o_{i,m}$ is the number of hours of the visit window of vessel i that fall within month m, and T_i is the visit window from Eq. 1. When T_i = 0, D_i was assigned entirely to the month of entry. This apportionment procedure presupposes a uniform temporal distribution of presence hours throughout the visitation interval, thereby precluding redundant enumeration and ensuring mutually exclusive hourly accounting. Third, to compare seasonal patterns independently of inter-annual differences in traffic, a seasonal index (SI, $SI_{m,p}$) was computed by dividing the presence hours of each month by the mean monthly presence hours of the corresponding period p, because January 2025 was excluded which ends in December 2024 using Eq. 3 (Guiet *et al.,* 2019):

$$SI_{m,p} = \frac{PH_{m,p}}{\overline{PH}_p} \quad (3)$$

Where: $\overline{PH}_p$ is the mean monthly presence hours across all 12 months within period p. (11 months for 2024-2025, because January 2025 was excluded); by construction, the SI values of each period average 1.00. Values above 1.0 indicate months with above-average activity, while values below 1.0 indicate below-average activity. In addition, *unique vessel counts* ($UV_{m,t}$) were determined as the number of distinct vessels (based on the Maritime Mobile Service Identity (MMSI) detected at least once within each month, using Eq. 4 (Robards *et al.,* 2016; Kroodsma *et al.,* 2018):

$$UV_{m,t} = |\{\text{vessel ID} \mid \text{active in month } m \text{ of year } t\}| \quad (4)$$

Presence hours and unique vessel counts serve as indicators of aggregate vessel activity rather than direct fishing effort, as AIS transmissions within Zones I–VI encompass transiting, anchoring, or fishing behaviors. Accordingly, both metrics were analyzed across three distinct categories: fishing vessels, fishing-gear buoys and non-fishing vessels. Due to low monthly sample sizes within the fishing vessel class (0–5 vessels per month), the seasonal index was evaluated using the aggregated ensemble of all AIS-tracked vessels.

Fish length analysis

Because the available length data were monthly means, two indicators were calculated for each species: the ratio between the overall mean length (Lmean) and Lm (Lmean/Lm), and the percentage of sampled months in which the monthly mean length was below Lm, using Eq. 5 (Froese, 2004; Cope and Punt, 2009):

$$P_{<Lm} = \frac{k_{<Lm}}{N} \times 100 \quad (5)$$

Where: $P_{<Lm}$ is the percentage of sampled months with a mean length below Lm, $k_{<Lm}$ is the number of sampled months in which the monthly mean length was below Lm, and N is the number of months sampled for the species. Because a monthly mean below Lm can occur even when part of the catch is mature, $P_{<Lm}$ describes the typical size of landed fish relative to Lm and is not an estimate of the proportion of immature individuals (Froese, 2004). Lm values were assigned in the following order of priority: i) the Lm reported in FishBase (Froese and Pauly, 2023); ii) where FishBase reported only a range, the lower bound of that range; and iii) where no maturity

data were available, an empirical estimate from the maximum total length (L_{max}) reported in FishBase, using the relationships of Froese and Binohlan (2000): log L_∞ = 0.044 + 0.9841 log L_{max} and log Lm = 0.8979 log L_∞ − 0.0782, where L_∞ is the asymptotic length. Because sex determinations were absent from the length-frequency records and localized maturity studies for these taxa in Aceh waters are lacking, sex-disaggregated parameters could not be incorporated; respective data sources are enumerated in Table 4. Because Lm values from other regions or from empirical relationships are uncertain, the sensitivity of $P_{<Lm}$ to a 10% decrease or increase in Lm was also examined.

Registry-AIS coverage analysis

In order to evaluate the correspondence between the registered fleet and AIS-detected fishing vessels, an AIS coverage ratio (CR) was derived for each monitoring interval by dividing the count of unique MMSIs identified as fishing vessels by the aggregate number of registered vessels, using Eq. 6 (Shepperson *et al.,* 2018):

$$CR_p(\%) = \frac{UV_{F,p}}{R_p} \times 100 \quad (6)$$

Where: $UV_{F,p}$ is the number of distinct fishing-vessel MMSIs in AIS period p and R_p is the number of registered vessels in the matched registry year, calculated both for vessels ≤5 GT and for the total fleet. Owing to the inability to disaggregate AIS vessels by gross tonnage classes, the coverage ratio (CR) functions as a comparative metric of fleet coverage rather than an absolute detection rate for small-scale vessels (≤ 5 GT). This distinction is particularly critical given that Indonesian regulations mandate AIS carriage solely for fishing vessels of 60 GT and upward (MoT, 2022).

Temporal correlation analysis

The association between the number of registered vessels ≤5 GT and fish length was examined for 2020-2023, the only years covered by both datasets (n = 4). To control for temporal variability in species composition, multispecies mean length was derived by averaging annual means from eight species sampled continuously across all four years, excluding *Lethrinus lentjan* and *Lethrinus rubrioperculatus*. Both Pearson's correlation coefficient (r) and Spearman's rank correlation coefficient (ρ) were determined, while a leave-one-out sensitivity analysis (successively recalculating r upon the removal of individual years) was employed to evaluate inter-annual influence. With n = 4, only correlations with $|r| > 0.95$ are significant at $\alpha = 0.05$, so this analysis is exploratory.

Statistical analysis

Differences in monthly mean length among years were tested separately for each species with the Kruskal-Wallis test, because each year group contained only 9-12 monthly means and normality was rejected for some species-year groups (Shapiro-Wilk test, $p < 0.05$). Because the two *Lethrinus* species were sampled across only two distinct annual intervals, the corresponding statistical test simplifies to a two-group comparative analysis. When the Kruskal-Wallis test was significant, pairwise differences between years were examined with Dunn's post-hoc test with Bonferroni correction. Monthly differences in the seasonal index and in unique vessel counts were tested with the Friedman test, using months as treatments and AIS periods as blocks. To ensure full annual representation across all twelve months, the primary analysis incorporated four complete monitoring periods (2020–2021 through 2023–2024); subsequently, the test was re-evaluated for the February–December interval across all five periods to confirm methodological robustness through a sensitivity analysis. Kendall's coefficient of concordance (W) was reported as the effect size, and pairwise comparisons among months were not performed because of the small number of blocks. Test results are reported as the Kruskal-Wallis statistic (H) or the Friedman statistic (χ^2), with degrees of freedom (df) and p values. While presupposing the independence of

monthly mean observations, we acknowledge that intra-annual temporal autocorrelation cannot be entirely precluded. Uncertainty was further evaluated by calculating coverage ratios against both the ≤5 GT fleet and the total fleet, by reporting fishing vessels, fishing-gear buoys and non-fishing vessels separately, by recalculating $P_{<Lm}$ with Lm decreased and increased by 10%, and by the leave-one-out correlation analysis. The significance level was set at α = 0.05 for all tests. All analyses were performed in Python 3.

RESULTS AND DISCUSSION

Temporal transformation of the registered fleet

The number of registered vessels ≤5 GT increased by 57.6%, from 621 in 2019 to 979 in 2024, and this class made up 84.0% of the registered fleet in 2024 (Table 1). The total fleet decreased by 7.4% over the same period (from 1,258 to 1,165 vessels), but this decrease resulted almost entirely from the change between 2019 and 2020, when the “>30 GT” class fell from 264 to 28 vessels and the number of PTM from 334 to 3. The “>30 GT” class overlaps the 31-50 and 51-100 GT classes, and the 6-10, 11-20 and 21-30 GT classes were all recorded as zero in 2021, whereas 87 vessels of 6-10 GT were recorded in both 2020 and 2022. Rather than indicating genuine demographic shifts within the fleet, these observed patterns predominantly stem from administrative modifications in registry classification. Consequently, the PTM time series (comprising 334, 3, 15, 45, 46, and 32 vessels) demonstrated pronounced temporal fluctuations rather than a monotonic downward trend. When only the more consistent 2020-2024 series is considered, vessels ≤5 GT increased by 16.7% (from 839 to 979) and the total fleet by 20.7% (from 965 to 1,165). The registry data do not allow a real increase in the number of boats to be distinguished from the registration of previously unregistered boats or from administrative reclassification, a known difficulty in defining and recording small-scale fleets in Indonesia (Halim *et al.,* 2019). Owing to the omission of aggregate gross tonnage (GT) and engine power specifications within the registry data, inferences concerning temporal fluctuations in fishing capacity remain precluded. Values as reported in the KKP registry. The “>30 GT” class (2019-2020) overlaps the 31-50 and 51-100 GT classes, and the zero values for 6-10, 11-20 and 21-30 GT in 2021 indicate missing or reclassified records; the change (%) column (2019-2024) is therefore indicative only. PTM = non-motorized boats.

AIS coverage of the registered fleet

Only 2-8 distinct vessels classified as fishing vessels transmitted AIS signals in Zones I-VI in each period, against 839-979 registered vessels ≤5 GT (Table 2). The resulting coverage ratio ranged from 0.21% to 0.82% of the ≤5 GT fleet (mean ± standard deviation (SD) = 0.49 ± 0.26%) and from 0.21% to 0.69% of the total fleet (0.42 ± 0.21%). These values should not be read as a detection rate of small-scale vessels. In accordance with Indonesian regulations mandating AIS carriage solely for fishing vessels 60 GT (MoT, 2022), the 13 distinct fishing MMSIs identified across the five monitoring intervals largely consisted of Indonesian-flagged motor vessels deployed with gear configurations characteristic of larger-scale operations (e.g., trawlers, drifting longlines, set longlines, and pole-and-line). Exceptions included a single foreign-flagged vessel and one vessel lacking registry flag data. Without MMSIs in the KKP registry, vessel GT classes remain unverified. Consequently, low coverage reflects AIS carriage regulations rather than small-scale fisher behavior, confirming AIS cannot represent fleets operating predominantly below the mandatory threshold. Conversely, monitoring intervals yielded between 66-117 unique non-fishing vessels and 0-3 fishing-gear buoys per period. Temporal analysis revealed that non-fishing vessels dominated presence, accounting for 99.2% of the 21,804 aggregate presence hours, whereas commercial fishing vessels and gear buoys constituted negligible shares at 0.48% and 0.28%, respectively.

Table 1: Structure of the Registered Fishing Fleet by Gross Tonnage (GT) Class in Aceh Besar, Indonesia (2019-2024)

GT Class	2019	2020	2021	2022	2023	2024	Change (%)
≤5 GT	621	839	950	940	944	979	+57.6
6-10 GT	32	87	0	87	97	101	+215.6
11-20 GT	5	6	0	21	21	31	+520.0
21-30 GT	1	1	0	0	0	5	+400.0
31-50 GT	0	0	0	0	0	5	-
51-100 GT	1	1	1	2	2	12	+1,100.0
>30 GT	264	28	0	0	0	0	-100.0
PTM (non-motorized)	334	3	15	45	46	32	-90.4
Total	1,258	965	966	1,095	1,110	1,165	-7.4

Table 2: Registered fleet and distinct AIS vessels in Zones I-VI of the Aceh Besar MPA by AIS period (2020-2024)

AIS period (registry year)	Registered ≤5 GT	Registered total	AIS non-fishing vessels	AIS fishing vessels	AIS gear buoys	CR ≤5 GT (%)	CR total (%)	Fishing share of presence hours (%)	GFW gear types of fishing vessels
Feb 2020-Jan 2021 (2020)	839	965	74	2	0	0.24	0.21	0.06	Trawlers
Feb 2021-Jan 2022 (2021)	950	966	66	2	2	0.21	0.21	0.45	Trawlers, unspecified
Feb 2022-Jan 2023 (2022)	940	1,095	97	5	3	0.53	0.46	1.15	Drifting longlines, pole-and-line, set longlines, unspecified
Feb 2023-Jan 2024 (2023)	944	1,110	117	6	3	0.64	0.54	0.24	Drifting longlines, trawlers, unspecified
Feb-Dec (2024)	979	1,165	110	8	1	0.82	0.69	0.63	Drifting longlines, trawlers, unspecified, inconclusive
Mean ± SD						0.49 ± 0.26	0.42 ± 0.21		

AIS vessel numbers are distinct MMSIs per period. CR = AIS coverage ratio (Eq. 6), calculated against registered vessels ≤5 GT and against the total registered fleet; it is a coverage contrast rather than a detection rate, because AIS vessels could not be matched to registry GT classes and AIS carriage is mandatory only for fishing vessels ≥60 GT (MoT, 2022). Gear buoys = GFW vessel type GEAR. Non-fishing vessels include the GFW types CARGO, PASSENGER, BUNKER, CARRIER, SEISMIC_VESSEL and OTHER. One record without an MMSI (2 presence hours, 2022-2023) was excluded from the vessel counts, the 2024–2025 period covers February–December 2024. SD = sample standard deviation. These results agree with previous studies showing that AIS represents small-scale fleets poorly (de Souza *et al.,* 2016; Kroodsma *et al.,* 2018; Park *et al.,* 2020). At the global scale, about three-quarters of industrial fishing vessels are not publicly tracked (Paolo *et al.,* 2024), and small vessels below national carriage thresholds are even less likely to be visible (James *et al.,* 2018). Due to inherent limitations in the dataset, disentangling unequipped vessels, signal propagation failures, algorithmic classification errors, and deliberate transmissions disabling remains precluded (Robards *et al.,* 2016). Because ≤5 GT boats are not obliged to carry AIS, their absence from the data cannot be interpreted as a behavioral choice or as evidence of illegal fishing. Activity that is not monitored nevertheless adds to the uncertainty of catch statistics (Agnew *et al.,* 2009) and limits the use of AIS for spatial management (Kroodsma *et al.,* 2018), and combining AIS with vessel monitoring systems or other tracking sources has been proposed to fill such gaps (Shepperson *et al.,* 2018; Thoya *et al.,* 2021). In Indonesia, VMS data have been used to identify the fishing activity, suspected infringements and logbook mismatches of tuna longliners, but VMS is mandatory only for vessels above 30 GT (Tawaqal *et al.,* 2019), so it does not cover the ≤5 GT fleet either. Accordingly, the derived coverage ratio serves predominantly as a

transparent and replicable index quantifying the fraction of the registered fleet uncaptured by AIS surveillance, rather than as an analytical measure of opaque, unreported, or illegal fishing activities.

Seasonal patterns of vessel activity

After presence hours were apportioned to calendar months (Eq. 2), the mean seasonal index ranged from 0.79 in February to 1.41 in January, but it varied widely between periods (Table 3; Fig. 2b); the February index, for example, ranged from 0.29 to 1.60. The Friedman test detected no significant difference among months (χ^2 = 11.19, df = 11, p = 0.43, W = 0.25), and the result was similar when February-December was tested across all five periods (χ^2 = 9.82, df = 10, p = 0.46). Accordingly, temporal distributions of presence hours lack a discernible seasonal cycle. Because 70.2% of cumulative presence hours were contributed exclusively by ten non-fishing vessels exhibiting the longest residence durations, monthly aggregates were governed largely by sporadic, extended port or zonal stays. In contrast, monthly counts of unique vessels displayed a markedly more regular pattern (Fig. 2a). Relative to the mean of each period, counts were highest in August-September (1.23-1.25) and lowest in January-February (0.72-0.73), and this pattern was significant (χ^2 = 28.67, df = 11, p = 0.003, W = 0.65). The difference between the two metrics shows that the number of vessels present followed a seasonal pattern, whereas the intensity of presence depended on the length of stay of individual vessels. Because 99.2% of presence hours came from non-fishing vessels, both patterns describe mainly transport, passenger and service traffic. Encompassing the semi-monsoonal climatic regime of northwestern Indonesia (Aldrian and Susanto, 2003), Aceh experiences distinct seasonal monsoonal patterns: the northeastern regime governs conditions from December through March, whereas the southwestern regime prevails from June to September. The lower vessel counts in January-February coincide with the northeast monsoon, but the AIS data alone cannot show how sea conditions affected small-scale fishing. Because the AIS signal is dominated by non-fishing traffic, it cannot identify peak fishing months and does not support a seasonal closure in February-March. Seasonal closures can protect spawning aggregations, which are highly vulnerable to fishing (Sadovy de Mitcheson and Erisman, 2012; Erisman *et al.,* 2017), and a spawning aggregation of *Caranx ignobilis* has been shown to benefit from protection (da Silva *et al.,* 2015). However, the spawning seasons of the ten target species remain undocumented for Aceh waters, and the socioeconomic impacts of fishery closures on local fishers were not evaluated in this study. Any temporal closure should therefore be based on local evidence from gonad sampling, fishers' knowledge and landing records rather than on AIS presence. The monthly SI values of each AIS period are presented in Table 3. While each period exhibits a methodological mean of 1.00 by design, corresponding standard deviations indicate an absence of inter-annual recurrence in the monthly temporal patterns.

Length-based indicators

The length indicators of the ten target species are summarized in Table 4 and Fig. 3. Mean length was below Lm in all or almost all sampled months for *Carangoides ferdau* (44 of 44 months), *Variola albimarginata* (45 of 45) and *Lutjanus quinquelineatus* (44 of 45), with Lmean/Lm ratios of 0.78-0.81. For *Caranx ignobilis*, mean length was below Lm in 73.3% of months (33 of 45; Lmean/Lm = 0.82), and for *Lethrinus lentjan* in 54.2% (13 of 24). Lower values were found for *Cephalopholis sonnerati* (31.1%), *Lethrinus rubrioperculatus* (16.7%) and *Lutjanus gibbus* (2.2%), and mean length was never below Lm for *Epinephelus fasciatus* and *Lutjanus lutjanus*. Because LM values for the three leading species are absent from FishBase, they were derived empirically; nevertheless, 10% perturbation analysis demonstrated that species classification was robust, with 86.7% to 100% of monthly means

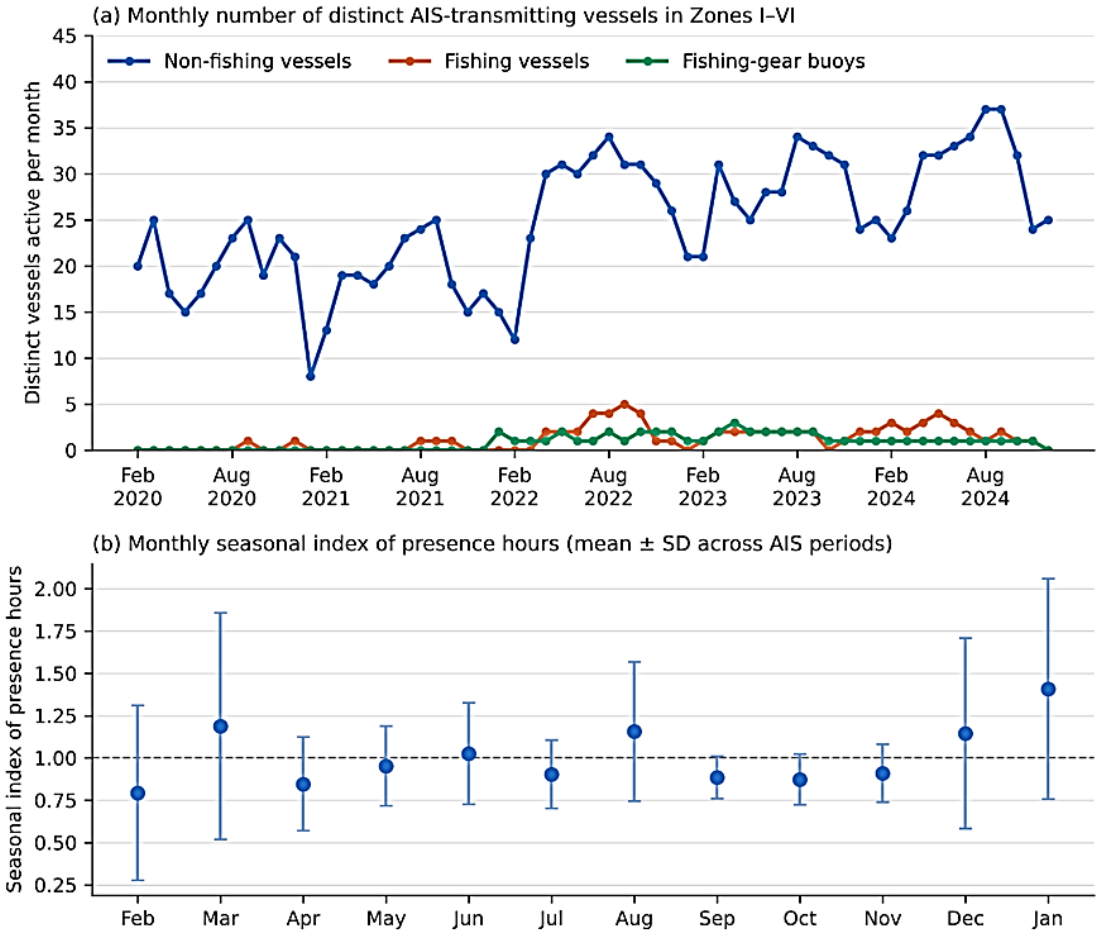

Fig. 2: AIS-derived vessel activity in Zones I-VI of the Aceh Besar MPA. (a) Monthly number of distinct AIS-transmitting vessels by GFW category (non-fishing vessels, fishing vessels and fishing-gear buoys), February 2020-December 2024; (b) monthly seasonal index of presence hours (mean ± SD across AIS periods; January based on four periods), calculated with Eqs. 2-3. The dashed line marks SI = 1.0

Table 3: Seasonal index of AIS presence hours in Zones I-VI of the Aceh Besar MPA by AIS period (February 2020-December 2024)

Month	2020-2021	2021-2022	2022-2023	2023-2024	2024-2025	Mean	SD
Feb	1.60	0.43	0.29	0.92	0.72	0.79	0.52
Mar	2.18	1.49	0.45	0.95	0.87	1.19	0.67
Apr	1.16	0.60	0.54	0.85	1.07	0.85	0.28
May	0.60	1.24	0.91	0.95	1.05	0.95	0.23
Jun	0.56	1.34	1.01	0.98	1.23	1.03	0.30
Jul	0.61	0.78	1.01	1.00	1.11	0.90	0.20
Aug	0.63	1.69	1.03	0.98	1.44	1.16	0.41
Sep	0.69	0.84	0.97	1.01	0.91	0.88	0.13
Oct	0.66	0.77	0.94	1.01	0.98	0.87	0.15
Nov	0.87	0.65	0.90	1.06	1.06	0.91	0.17
Dec	1.76	0.72	1.71	0.98	0.55	1.14	0.56
Jan	0.65	1.45	2.23	1.31	-	1.41	0.65

SI values were calculated with Eqs. 2-3 from presence hours apportioned to calendar months; each period averages 1.00. The 2024–2025 period ends in December 2024 (the GFW query window ended on 1 January 2025), so the January mean and SD are based on four periods. Friedman test across months (four complete periods): $\chi^2 = 11.19$, df = 11, p = 0.43.

Table 4: Length indicators and inter-annual differences of the ten target species (2020-2023)

Species	Years	N	Lmean ± SD (cm)	Lm (cm)	Lmean/Lm	k/N	$P_{<Lm}$ (%)	$P_{<Lm}$ at 0.9/1.1 Lm (%)	H (df)	p
Carangoides ferdau	2020-2023	44	31.6 ± 2.5	39.1[b]	0.81	44/44	100.0	90.9/100.0	9.44 (3)	0.024*
Caranx ignobilis	2020-2023	45	49.3 ± 13.2	60.0[a]	0.82	33/45	73.3	66.7/88.9	3.53 (3)	0.316
Cephalopholis sonnerati	2020-2023	45	28.7 ± 2.2	28.0[c]	1.02	14/45	31.1	6.7/82.2	8.79 (3)	0.032*
Epinephelus fasciatus	2020-2023	45	21.3 ± 1.0	16.0[c]	1.33	0/45	0.0	0.0/0.0	2.27 (3)	0.517
Lethrinus lentjan	2021-2022	24	25.0 ± 7.7	24.1[a]	1.04	13/24	54.2	37.5/58.3	3.85 (1)	0.0496*
Lethrinus rubrioperculatus	2021-2022	24	24.5 ± 1.3	23.0[a]	1.07	4/24	16.7	0.0/75.0	4.08 (1)	0.043*
Lutjanus gibbus	2020-2023	45	28.3 ± 2.5	21.5[a]	1.32	1/45	2.2	0.0/8.9	7.73 (3)	0.052
Lutjanus lutjanus	2020-2023	44	16.8 ± 1.7	12.2[a]	1.38	0/44	0.0	0.0/0.0	19.54 (3)	<0.001*
Lutjanus quinquelineatus	2020-2023	45	18.5 ± 2.1	22.8[b]	0.81	44/45	97.8	86.7/100.0	11.17 (3)	0.011*
Variola albimarginata	2020-2023	45	28.7 ± 2.1	36.6[b]	0.78	45/45	100.0	97.8/100.0	2.64 (3)	0.451

N = number of months sampled; Lmean ± SD = mean ± standard deviation of monthly mean lengths; k/N = months with mean length below Lm/months sampled; $P_{<Lm}$ = percentage of sampled months with mean length below Lm (Eq. 5); $P_{<Lm}$ at 0.9/1.1 Lm = sensitivity of $P_{<Lm}$ to a 10% decrease/increase in Lm; H = Kruskal-Wallis statistic among years; * $p < 0.05$. Lm sources: a, Lm reported in FishBase (Froese and Pauly, 2023); b, estimated from the maximum total length reported in FishBase (*C. ferdau* 70 cm, *V. albimarginata* 65 cm, *L. quinquelineatus* 38 cm) with the equations of Froese and Binohlan (2000); c, lower bound of the maturity range reported in FishBase. Dunn's post-hoc test with Bonferroni correction: *C. ferdau* 2023 > 2020 ($p = 0.033$); *L. quinquelineatus* 2023 > 2021 ($p = 0.006$); *L. lutjanus* 2023 > 2020 ($p = 0.001$) and 2023 > 2021 ($p < 0.001$); no significant pair for *C. sonnerati*. *C. ferdau* is listed as *Ferdauia ferdau* in recent versions of FishBase.

remaining below the adjusted length-at-maturity thresholds. In contrast, the values for *C. sonnerati* (6.7-82.2%) and *L. rubrioperculatus* (0-75.0%) were highly sensitive to Lm, because their mean lengths were close to Lm (Lmean/Lm = 1.02 and 1.07). These findings warrant cautious interpretation. Although a monthly mean length below Lm denotes that the median landed specimen was smaller than the population's average size at first maturity, it cannot quantify the proportion of immature individuals due to the absence of underlying length-frequency distributions for each monthly mean. Froese (2004) recommended that ideally all fish in the catch should be mature; the month-based indicator used here is not equivalent to that criterion and should not be compared with thresholds defined for individuals. Small mean lengths may result from fishing pressure, but they may also reflect gear selectivity, fishing in habitats used by young fish, or pulses of recruitment (Hordyk *et al.,* 2015; Rudd and Thorson, 2018). For *C. ignobilis*, a large predator that reaches 170 cm total length (Froese and Pauly, 2023), monthly mean lengths ranged from 24.5 to 76.9 cm, so landings were dominated by fish far below the maximum size of the species. Comparable apprehensions regarding the harvest of juvenile groupers and snappers have emerged across alternative Indonesian fisheries, wherein length-based stock assessments relied upon disaggregated individual length-frequency data (Halim *et al.,* 2020; Ernawati *et al.,* 2024; Herdiana *et al.,* 2025). In Taka Bonerate National Park, a length-based assessment of snappers landed by small-scale fishers indicated an overfished status for *L. gibbus* and an optimal level of exploitation for *L. quinquelineatus* (Sari *et al.,* 2024). The asymptotic lengths reported there (L_∞ = 46.8 cm for *L. gibbus* and 29.5 cm for *L. quinquelineatus*) correspond to Lm values of about 26.4 and 17.4 cm with the relationship of Froese and Binohlan (2000). With these regional values, mean length in the present data would be below Lm in 8 of 45 months (17.8%) for *L. gibbus* and in 13 of 45 months (28.9%) for *L. quinquelineatus*, compared with 2.2% and 97.8% with the FishBase-based values; the result for *L. quinquelineatus* in particular should therefore be regarded as uncertain until local maturity data are available. Even so, the present indicators can identify the species that deserve priority in monitoring, particularly *C. ferdau*, *V. albimarginata*, *L. quinquelineatus* and *C. ignobilis*, but they cannot

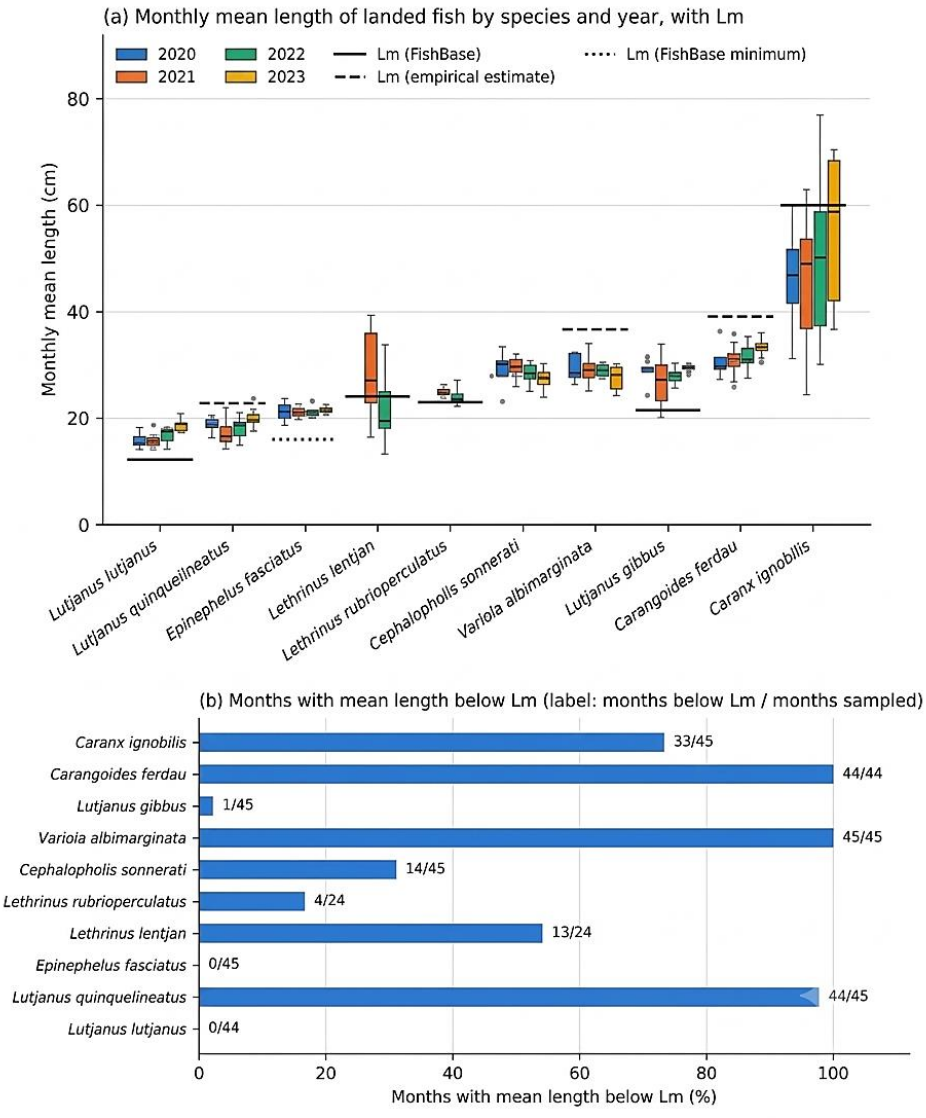

Fig. 3: Length indicators of the ten target species landed around the Aceh Besar MPA (2020-2023). (a) Distribution of monthly mean length by species and year; horizontal lines show Lm from FishBase (solid), empirical estimates (dashed; Froese and Binohlan, 2000) and the lower bound of the FishBase maturity range (dotted). (b) Percentage of sampled months in which the mean length was below Lm; labels give months below Lm/months sampled

establish recruitment overfishing. Mean length differed significantly among years for *C. ferdau* ($H = 9.44$, $df = 3$, $p = 0.024$), *C. sonnerati* ($H = 8.79$, $df = 3$, $p = 0.032$), *L. quinquelineatus* ($H = 11.17$, $df = 3$, $p = 0.011$) and *L. lutjanus* ($H = 19.54$, $df = 3$, $p < 0.001$), and between 2021 and 2022 for *L. rubrioperculatus* ($H = 4.08$, $df = 1$, $p = 0.043$) and *L. lentjan* ($H = 3.85$, $df = 1$, $p = 0.0496$) (Table 4). Dunn's test showed that fish were larger in 2023 than in 2020 for *C. ferdau* ($p = 0.033$), than in 2021 for *L. quinquelineatus* ($p = 0.006$), and then in both 2020 and 2021 for *L. lutjanus* ($p = 0.001$ and $p < 0.001$, respectively), whereas no pairwise difference remained significant for *C. sonnerati* after Bonferroni correction. The two *Lethrinus* species were smaller in 2022 than in 2021. No significant inter-annual difference was found for *C. ignobilis*, *E. fasciatus*, *V. albimarginata* or *L. gibbus*. The data therefore do not show a consistent decline in fish length between 2020 and

2023. Due to the opportunistic nature of data collection, observed inter-annual variations likely encapsulate underlying shifts in spatial, temporal, and technical sampling attributes (e.g., landing sites, gear configurations, fishing grounds, and monthly coverage, such as the omission of April–June samples in 2020). Consequently, these variations cannot be interpreted as direct manifestations of changing fishing pressure. The AIS and length indicators describe different parts of the fishery and cannot be linked causally: the AIS data do not cover the ≤5 GT boats that land most of the sampled fish, whereas the length data give no information on where and by which vessels the fish were caught. Collectively, these findings highlight that the non-detection of small-scale vessels within AIS monitoring networks does not imply a cessation of fishing operations; this is evidenced by the continuous landing of small reef fish across all monitored intervals of the study.

Association between fleet size and fish length

The multispecies mean length of the eight species sampled in all four years was 27.4, 27.0, 27.8 and 29.2 cm in 2020-2023, while the number of registered vessels ≤5 GT was 839, 950, 940 and 944. The two series were not significantly correlated ($r = 0.27$, $p = 0.73$; $\rho = -0.20$, $p = 0.80$), and the leave-one-out coefficients ranged from −0.47 to 0.70, which shows that even the direction of the relationship depended on which year was included. Accordingly, empirical findings indicate an absence of any demonstrable relationship between structural modifications in the registered fleet and temporal shifts in fish length. For *C. ignobilis*, the annual mean length increased from 45.4 cm in 2020 to 55.1 cm in 2023, and its correlation with fleet size was also not significant ($r = 0.50$, $p = 0.50$). With only four years, the test has very low statistical power, and the registry changed little between 2021 and 2023 (940-950 vessels). A multispecies mean is also affected by the species and sizes present in opportunistic samples, by environmental variability that influences fish production (Lumban-Gaol *et al.,* 2021), and by market demand and changes in fishing practices, none of which could be controlled in this study. consequently, variations in fleet magnitude and fish length should be interpreted as complementary indicators evaluated across long-term monitoring frameworks, rather than as demonstrable proof of underlying causation.

Integrated evidence and management implications

The combined use of registry, AIS and length data gives a more complete picture of fishing in the Aceh Besar MPA than any single source, mainly by showing what each source cannot capture. The dataset presents a tripartite methodological constraint: first, the official registry delineates an extensive small-scale fleet lacking spatial fishing ground data; second, AIS surveillance captures larger vessels and non-commercial maritime traffic while failing to resolve the registered fleet; and third, catch-composition metrics reveal that multiple species are harvested primarily below Lm independently of vessel identification. These findings agree with earlier work showing that AIS gaps are largest where small-scale fisheries dominate (Kroodsma *et al.,* 2018; Park *et al.,* 2020). The contribution of this study lies in quantifying this gap against an official registry, in showing that an apparent AIS seasonal signal can arise from non-fishing traffic and from the way presence hours are aggregated, and in setting these results beside independent biological indicators. Although assessments of MPA performance frequently rely on fishing pressure indicators to account for ecological responses (Lester *et al*., 2009; Edgar *et al*., 2014), such metrics derived from AIS surveillance are inherently prone to severe methodological bias in areas characterized by artisanal and small-scale fleet dominance. Monitoring data become useful only when they are linked to management decisions. Evidence from Indonesian multipurpose MPAs shows that community participation, equitable governance and fair enforcement contribute to ecological benefits (Fidler *et al.,* 2022), that fishing restrictions and no-take zones

are associated with higher reef fish biomass (Campbell *et al.,* 2020), and that repeated reef fish surveys can document the effect of protection, as shown in the Banda Islands MPA (Welly *et al.,* 2020). In addition to effective enforcement, strategic management frameworks, and active stakeholder participation (Di Franco *et al*., 2016), the efficacy of artisanal and small-scale fisheries MPAs is fundamentally contingent upon the harmonious integration of fishing activities with concurrent maritime uses (Tranter *et al.,* 2022). Building on these principles, a monitoring framework for the Aceh Besar MPA could include five components: i) an annual audit of the fleet registry with consistent GT classes, home ports and, where available, MMSIs; ii) monthly landing-site surveys that record individual lengths, the number of fish measured, gear and fishing ground, so that length-based methods such as the spawning potential ratio or length-based Bayesian biomass estimation can be applied (Hordyk *et al.,* 2015; Froese *et al.,* 2018); iii) community-based catch and effort reporting through Panglima Laot and fishers' groups; iv) supplementary tracking of a sample of ≤5 GT boats with low-cost global positioning system (GPS) trackers to map their fishing grounds within the zones (James *et al.,* 2018; Thoya *et al.,* 2021); and (v) annual calculation of the AIS coverage ratio as a simple indicator of monitoring completeness. Prior to implementation, management frameworks formulated upon such empirical data must be rigorously tested against defined operational objectives and operational constraints (Herdiana *et al*., 2023), most notably where fishing intensity intersects with dynamic oceanographic variability (Sakti *et al.,* 2026). These components can be translated into measurable actions. Landing inspections could be targeted at the species and months with the highest share of small fish, starting with *C. ferdau*, *V. albimarginata*, *L. quinquelineatus* and *C. ignobilis*. Compliance with minimum landing sizes set close to Lm could be tracked as the annual percentage of measured fish below the minimum size of each species, and the tracks of monitored small boats could be used to verify whether the registered fleet fishes inside the no-take and sustainable fisheries zones. These metrics correspond directly with the performance-oriented evaluative criteria established for Indonesian MPAs (Meilana *et al.,* 2023), while reinforcing the decentralized management paradigms that have historically sustained reef fisheries throughout the region (Muallil *et al.,* 2019). The approach can be applied to other tropical MPAs where small-scale fleets fall below national AIS carriage thresholds, because registry, AIS and landing data of the kind used here are routinely available in many countries. Nevertheless, because these exact quantitative values are governed by localized regulatory frameworks, fleet configurations, and maritime traffic dynamics, validating their broader applicability necessitates comparative investigations across diverse MPAs, empirical local maturity assessments, and rigorous validation (ground-truthing) of AIS vessel categories.

CONCLUSION

This study combined the official fleet registry, AIS presence records from Global Fishing Watch and length data from landed reef fish to examine how well fishing activity in the Aceh Besar MPA can be monitored with the data that are currently available. The registry showed a large and growing fleet of small boats: vessels ≤5 GT increased from 621 in 2019 to 979 in 2024 and made up 84.0% of the registered fleet in 2024. Part of this increase, however, coincided with changes in registry classification, and for the more consistent 2020-2024 series the increase was 16.7%. Accordingly, while official registry records outline the potential numerical magnitude of the fleet operating within and surrounding the MPA, they remain insufficient for evaluating temporal increases in fishing capacity or resolving the precise spatial distribution of fishing effort. AIS, by contrast, recorded only 2-8 fishing vessels in each annual period between February 2020 and December 2024, equal to 0.21-0.82% of the registered vessels ≤5 GT. This gap is not unexpected, because transponders are mandatory only for fishing

vessels of 60 GT and above, and the few fishing vessels that did transmit were mostly trawlers, longliners and pole-and-line vessels, gear types usually operated from larger boats. Accordingly, the overarching inference from the AIS telemetry indicates that satellite surveillance predominantly characterizes larger craft and non-commercial maritime traffic in the region, rather than illuminating the artisanal and small-scale fleet that sustains the MPA's fisheries. The seasonal analysis led to a similar conclusion. Non-fishing vessels produced 99.2% of the 21,804 presence hours, and once the presence hours of each visit were assigned correctly to calendar months, no consistent seasonal peak remained. Only the number of distinct vessels followed a regular pattern, with more vessels in August-September and fewer in January-February. Consequently, as these observed patterns primarily capture maritime transport, passenger movement, and service vessel operations, they are unsuited for delineating peak fishing seasons or substantiating temporal fishery closures. The length data provided a different and complementary signal. Mean length was below Lm in every sampled month for *Carangoides ferdau* and *Variola albimarginata* and in about three-quarters of the months for *Caranx ignobilis*, whereas *Epinephelus fasciatus* and *Lutjanus lutjanus* were landed above Lm throughout the study period. *Lutjanus quinquelineatus* was also landed below Lm in almost all months when the FishBase-based value was used, but not when regional growth parameters were applied, so its status remains uncertain. Inter-annual variations in mean length among six species lacked a consistent directional trend; consequently, the observation of larger specimens across multiple taxa in 2023 is more plausibly attributed to sampling artifacts than to a genuine relaxation of fishing pressure. The registered fleet and the multispecies mean length were not correlated ($r = 0.27$, $p = 0.73$), and with only four overlapping years no relationship between fleet size and fish size can be inferred. In the context of Aceh Besar MPA management, these results demonstrate that AIS data is insufficient on its own for characterizing fishing intensity or appraising the performance of restricted and sustainable fisheries zones. Consequently, a more comprehensive evaluation necessitates the synthesis of diverse, cost-effective monitoring sources. The fleet registry can be audited every year with consistent GT classes, home ports and, where available, MMSIs, so that real changes in the number of boats can be separated from administrative changes. Landing surveys should record the length of each fish, the number of fish measured, the gear and the fishing ground, which would allow the proportion of immature fish to be estimated and length-based stock assessments to be applied. Integrating catch and effort monitoring via Panglima Laot and community fisher groups with cost-effective position trackers deployed across a sample of artisanal boats would enable high-resolution spatial mapping of ≤5 GT fleet operations, thereby clarifying their intrusion dynamics within marine reserve no-take zones. The AIS coverage ratio can be recalculated each year at almost no cost as a simple check on how much of the registered fleet remains outside satellite monitoring. For the species most often landed below Lm, especially *C. ferdau*, *V. albimarginata* and *C. ignobilis*, minimum landing sizes close to Lm and landing inspections in the months with the smallest fish could be considered when the MPA management plan is next revised. The formulation of such management rules exhibits a higher probability of widespread compliance and social legitimacy when co-designed alongside artisanal fishers and established customary governance institutions operating within Aceh's fisheries sector. Several limitations should be kept in mind when these conclusions are applied. The AIS analysis covered only Zones I-VI and depended on the GFW vessel classification, which was not validated locally. The length data were monthly means from opportunistic sampling at varying landing points, without individual lengths, sample sizes or information on fishing grounds, and the Lm values were taken from FishBase or estimated from empirical relationships rather than from local

maturity studies. Official registry data are compiled at the regency level and exhibit inter-annual inconsistencies in vessel classifications, with only a four-year temporal overlap shared with the length-frequency dataset. Future studies should therefore collect individual length-frequency data and local estimates of length at first maturity for the main target species, extend the time series of registry, AIS and landing data, and validate AIS vessel classes against port and field records. Comparative studies in other tropical MPAs where small-scale fleets fall below national AIS carriage thresholds would show how widely these findings apply. Synthesized collectively, the findings indicate that official registry, satellite and catch landing data characterize disparate dimensions of the fishery. Therefore, robust quantification of fishing pressure within artisanal-dominated MPAs necessitates the methodological integration of these data streams, underpinned by participatory community monitoring.

AUTHOR CONTRIBUTIONS

R. Firdaus, contributed to conceptualization, data curation, formal analysis, investigation, methodology, visualization, writing the original draft, and review and editing of the manuscript. F. Yulianda, contributed to conceptualization, methodology, supervision, and review and editing. Zairion contributed to methodology, supervision, and review and editing. G. Yulianto, contributed to methodology, supervision, validation, and review and editing. C.M.N. 'Akla, contributed to investigation, data curation, and review and editing.

ACKNOWLEDGEMENT

The authors would like to sincerely thank the Indonesian Education Scholarship (BPI), the Center for Higher Education Funding and Assessment, the Ministry of Higher Education, Science, and Technology of the Republic of Indonesia (PUSLAPDIK-KEMDIKTISAINTEK), and the Indonesia Endowment Fund for Education (LPDP) for their support in funding this doctoral under contract No. [00581/J5.2.3./BPI.06/9/2022].

CONFLICT OF INTEREST

The authors declare that there is no conflict of interest regarding the publication of this manuscript. In addition, the authors have completely observed the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, and redundancy.

OPEN ACCESS

©2027 The author(s). This article is licensed under a Creative Commons Attribution 4.0 International License, which permits use, sharing, adaptation, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons license, and indicate if changes were made. The images or other third-party material in this article are included in the article's Creative Commons license, unless indicated otherwise in a credit line to the material. If material is not included in the article's Creative Commons license and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder. To view a copy of this license, visit: http://creativecommons.org/licenses/by/4.0/

PUBLISHER'S NOTE

GJESM Publisher remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

POSITIVE AI STATEMENT

During the preparation of this work the author(s) have used Artificial Intelligence (AI) Claude AI Pro and DeepL Pro to assist with language proofreading and refinement of the academic English phrasing of the manuscript. After using this tool/service, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

ABBREVIATIONS

%	Percent
α	Significance level
χ^2	Friedman test statistic
ρ	Spearman's rank correlation coefficient
AIS	Automatic identification system
BPI	Indonesian Education Scholarship (Beasiswa Pendidikan Indonesia)
cm	Centimeter
CR	AIS coverage ratio
df	Degrees of freedom
D_i	Presence hours of visit i reported by GFW (hours)
E	East
Eq.	Equation
Fig.	Figure
GFW	Global Fishing Watch
GPS	Global Positioning System
GT	Gross tonnage
H	Kruskal-Wallis test statistic
ha	Hectare
KEMDIKTI SAINTEK	Ministry of Higher Education, Science, and Technology of the Republic of Indonesia (Kementerian Pendidikan Tinggi, Sains, dan Teknologi)
KKP	Ministry of Marine Affairs and Fisheries, Indonesia (Kementerian Kelautan dan Perikanan)
$k_{<Lm}$	Number of sampled months with mean length below Lm
L_m	Length at first maturity
L_{max}	Maximum total length
L_{mean}	Mean length
L_∞	Asymptotic length
LPDP	Indonesia Endowment Fund for Education (Lembaga Pengelola Dana Pendidikan)
m	Month
MMSI	Maritime Mobile Service Identity
MoT	Ministry of Transportation of the Republic of Indonesia
MPA	Marine protected area
n	Number of years in the correlation analysis
n_p	Number of visit records in AIS period p
N	North; number of months sampled
$o_{i,m}$	Hours of the visit window of vessel i that fall within month m
p	Probability value; AIS period in Eqs. 2, 3 and 6
$P_{<Lm}$	Percentage of sampled months with mean length below Lm
PH	Presence hours
PTM	Non-motorized boats (perahu tanpa motor)
PUSLA PDIK	Center for Higher Education Funding and Assessment
r	Pearson correlation coefficient
R_p	Number of registered vessels in the registry year matched to AIS period p
SD	Standard deviation
SI	Seasonal index
t	Year
T_i	Visit window of vessel i (hours)
$t_{entry,i}$	Time at which vessel i entered the MPA
$t_{exit,i}$	Time at which vessel i exited the MPA
UV	Unique vessel counts
$UV_{F,p}$	Number of distinct fishing-vessel MMSIs in AIS period p
VMS	Vessel monitoring system
W	Kendall's coefficient of concordance

REFERENCES

Agnew, D.J.; Pearce, J.; Pramod, G.; Peatman, T.; Watson, R.; Beddington, J.R.; Pitcher, T.J., (2009). Estimating the worldwide extent of illegal fishing. PLoS ONE. 4(2): e4570 **(8 pages).**

Aldrian, E.; Susanto, R.D., (2003). Identification of three dominant rainfall regions within Indonesia and their relationship to sea surface temperature. Int. J. Climatol., 23(12): 1435-1452 **(18 pages).**

Arthatiani, F.Y.; Putri, M.R.; Bernawis, L.I.; Gusmawati, N.F.; Trenggono, S.W.; Kasim, K.; Yuwono, T.; Hidayat, F., (2026). Ocean health index status and the conservation priorities associated with marine protected park. Global J. Environ. Sci. Manage., 12(2): 603-624 **(22 pages).**

Campbell, S.J.; Darling, E.S.; Pardede, S.; Ahmadia, G.; Mangubhai, S.; Amkieltiela; Estradivari; Maire, E., (2020). Fishing restrictions and remoteness deliver conservation outcomes for Indonesia's coral reef fisheries. Conserv. Lett., 13(2): e12698 **(9 pages).**

Chong, L.; Mildenberger, T.K.; Rudd, M.B.; Taylor, M.H.; Cope, J.M.; Branch, T.A.; Wolff, M.; Stäbler, M., (2020). Performance evaluation of data-limited, length-based stock assessment methods. ICES J. Mar. Sci., 77(1): 97-108 **(12 pages).**

Cope, J.M.; Punt, A.E., (2009). Length-based reference points for data-limited situations: Applications and restrictions. Mar. Coast. Fish., 1(1): 169-186 **(18 pages).**

da Silva, I.M.; Hempson, T.; Hussey, N.E., (2015). Giant trevally spawning aggregation highlights importance of community fisheries management no-take zone. Mar. Biodivers., 45(2): 139-140 **(2 pages).**

de Oliveira Júnior, J.G.C.; Campos-Silva, J.V.; Santos, D.T.V.; Ladle, R.J.; da Silva Batista, V., (2021). Quantifying anthropogenic threats affecting marine protected areas in developing countries. J. Environ. Manage., 279: 111614 **(12 pages).**

de Souza, E.N.; Boerder, K.; Matwin, S.; Worm, B., (2016). Improving fishing pattern detection from satellite AIS using data mining and machine learning. PLoS ONE, 11(7): e0158248 **(14 pages).**

Di Franco, A.; Thiriet, P.; Di Carlo, G.; Dimitriadis, C.; Francour, P.; Gutiérrez, N.L.; Jeudy de Grissac, A.; Koutsoubas, D.; Milazzo, M.; Otero, M.M.; Piante, C.; Plass-Johnson, J.; Sainz-Trapaga, S.; Santarossa, L.; Tudela, S.; Guidetti, P., (2016). Five key attributes can increase marine protected areas performance for small-scale fisheries management. Sci. Rep., 6: 38135 **(9 pages).**

Dunham, A.; Dunham, J.S.; Rubidge, E.; Iacarella, J.C.; Metaxas, A., (2020). Contextualizing ecological performance: Rethinking monitoring in marine protected areas. Aquat. Conserv., 30(10): 2004-2011 **(8 pages).**

Edgar, G.J.; Stuart-Smith, R.D.; Willis, T.J.; Kininmonth, S.; Baker, S.C.; Banks, S.; Barrett, N.S.; Becerro, M.A.; Bernard, A.T.F.; Berkhout, J.; Buxton, C.D.; Campbell, S.J.; Cooper, A.T.; Davey, M.; Edgar, S.C.; Försterra, G.; Galván, D.E.; Irigoyen, A.J.; Kushner, D.J.; Moura, R.; Parnell, P.E.; Shears, N.T.; Soler, G.; Strain, E.M.A.; Thomson, R.J., (2014). Global conservation outcomes depend on marine protected areas with five key features. Nature. 506(7487): 216-220 **(5 pages).**

Erisman, B.; Heyman, W.; Kobara, S.; Ezer, T.; Pittman, S.; Aburto-Oropeza, O.; Nemeth, R.S., (2017). Fish spawning aggregations: Where well-placed management actions can yield big benefits for fisheries and conservation. Fish Fish., 18(1): 128-144 **(17 pages).**

Ernawati, T.; Boer, M.; Kamal, M.M.; Butet, N.A.; Satria, F.; Perdanahardja, G.H., (2024). Length-based stock assessment for Malabar blood snapper in Makassar Strait-Indonesia: Status and recommendation for sustainability. Reg. Stud. Mar. Sci., 73: 103485 **(14 pages).**

Fidler, R.Y.; Ahmadia, G.N.; Amkieltiela; Awaludinnoer; Cox, C.; Estradivari; Glew, L.; Handayani, C.N.; Mahajan, S.L.; Mascia, M.B.; Pakiding, F.; Andradi-Brown, D.A., (2022). Participation, not penalties: Community involvement and equitable governance contribute to more effective multiuse protected areas. Sci. Adv., 8(18): eabl8929 **(11 pages).**

Froese, R., (2004). Keep it simple: Three indicators to deal with overfishing. Fish Fish., 5(1): 86-91 **(6 pages).**

Froese, R.; Binohlan, C., (2000). Empirical relationships to estimate asymptotic length, length at first maturity and length at maximum yield per recruit in fishes, with a simple method to evaluate length frequency data. J. Fish Biol., 56(4): 758-773 **(16 pages).**

Froese, R.; Pauly, D. (eds.), (2023). FishBase. World Wide Web electronic publication.

Froese, R.; Winker, H.; Coro, G.; Demirel, N.; Tsikliras, A.C.; Dimarchopoulou, D.; Scarcella, G.; Quaas, M.; Matz-Lück, N., (2018). A new approach for estimating stock status from length frequency data. ICES J. Mar. Sci., 75(6): 2004-2015 **(12 pages).**

Gill, D.A.; Mascia, M.B.; Ahmadia, G.N.; Glew, L.; Lester, S.E.; Barnes, M.; Craigie, I.; Darling, E.S.; Free, C.M.; Geldmann, J.; Holst, S.; Jensen, O.P.; White, A.T.; Basurto, X.; Coad, L.; Gates, R.D.; Guannel, G.; Mumby, P.J.; Thomas, H.; Whitmee, S.; Woodley, S.; Fox, H.E., (2017). Capacity shortfalls hinder the performance of marine protected areas globally. Nature, 543(7647): 665-669 **(5 pages).**

Guiet, J.; Galbraith, E.; Kroodsma, D.; Worm, B., (2019). Seasonal variability in global industrial fishing effort. PLoS ONE. 14(5): e0216819 **(17 pages).**

Halim, A.; Loneragan, N.R.; Wiryawan, B.; Hordyk, A.R.; Sondita, M.F.A.; Yulianto, I., (2020). Evaluating data-limited fisheries for grouper (Serranidae) and snapper (Lutjanidae) in the Coral Triangle, eastern Indonesia. Reg. Stud. Mar. Sci., 38: 101388 **(44 pages).**

Halim, A.; Wiryawan, B.; Loneragan, N.R.; Hordyk, A.; Sondita, M.F.A.; White, A.T.; Koeshendrajana, S.; Ruchimat, T.; Pomeroy, R.S.; Yuni, C., (2019). Developing a functional definition of small-scale fisheries in support of marine capture fisheries management in Indonesia. Mar. Policy, 100: 238-248 **(11 pages).**

Herdiana, Y.; Coulson, P.G.; Tweedley, J.R.; Wiryawan, B.; Wisudo, S.H.; Loneragan, N.R., (2025). Growth, reproductive parameters and stock status of brown-marbled grouper *Epinephelus fuscoguttatus*, a commonly targeted grouper in Saleh Bay, Indonesia. Fishes, 10(12): 611 **(25 pages).**

Herdiana, Y.; Wiryawan, B.; Wisudo, S.H.; Tweedley, J.R.; Yulianto, I.; Natsir, M.; Agustina, S.; Hordyk, A.; Loneragan, N.R., (2023). Application of the Method Evaluation and Risk Assessment Tool for a small-scale grouper fishery in Indonesia. Fishes, 8(10): 498 **(26 pages).**

Hordyk, A.; Ono, K.; Valencia, S.; Loneragan, N.; Prince, J., (2015). A novel length-based empirical estimation method of spawning potential ratio (SPR), and tests of its performance, for small-scale, data-poor fisheries. ICES J. Mar. Sci., 72(1): 217-231 **(15 pages).**

James, M.A.; Mendo, T.; Jones, E.L.; Orr, K.; McKnight, A.; Thompson, J., (2018). AIS data to inform small scale fisheries management and marine spatial planning. Mar. Policy, 91: 113-121 **(9 pages).**

Kroodsma, D.A.; Mayorga, J.; Hochberg, T.; Miller, N.A.; Boerder, K.; Ferretti, F.; Wilson, A.; Bergman, B.; White, T.D.; Block, B.A.; Woods, P.; Sullivan, B.; Costello, C.; Worm, B., (2018). Tracking the global footprint of fisheries. Science. 359(6378): 904-908 **(5 pages).**

Lester, S.E.; Halpern, B.S.; Grorud-Colvert, K.; Lubchenco, J.; Ruttenberg, B.I.; Gaines, S.D.; Airamé, S.; Warner, R.R., (2009). Biological effects within no-take marine reserves: A global synthesis. Mar. Ecol. Prog. Ser., 384: 33-46 **(14 pages).**

Lumban-Gaol, J.; Siswanto, E.; Mahapatra, K.; Natih, N.M.N.; Nurjaya, I.W.; Hartanto, M.T.; Maulana, E.; Adrianto, L.; Rachman, H.A.; Osawa, T.; Rahman, B.M.K.; Permana, A., (2021). Impact of the strong downwelling (upwelling) on small pelagic fish production during the 2016 (2019) negative (positive) Indian Ocean Dipole events in the eastern Indian Ocean off Java. Climate, 9(2): 29 **(11 pages).**

Meilana, L.; Fang, Q.; Susanto, H.A.; Widiastutik, R.; Syaputra, D.E.; Ikhumhen, H.O.; Sholihah, R.; Hakim, A.; Yang, S.; Liu, Z., (2023). How Indonesian marine protected areas (MPAs) are doing: A management performance-based evaluation. Biol. Conserv., 282: 110033 **(13 pages).**

MoT, (2022). Regulation of the Minister of Transportation of the Republic of Indonesia No. PM 18 of 2022 on the automatic identification system for vessels operating in Indonesian waters. Ministry of Transportation of the Republic of Indonesia, Jakarta **(12 pages).**

Muallil, R.N.; Tambihasan, A.M.; Enojario, M.J.; Ong, Y.N.; Roldan, M.J.L.; Anantan, A.; Muallil, M.N.; Cleland, D.; Albasin, B.S.; Geronimo, R.C., (2019). Effectiveness of small locally-managed marine protected areas for coral reef fisheries management in the Philippines. Ocean Coast. Manage., 179: 104831 **(7 pages).**

Muhammad, M.; Firdaus, R.; Kurnianda, V.; Jalil, Z.; 'Akla, C.M.N.; Dewi, I.J.P., (2021). Coral reef and reef fishes of core zone in the marine proctected areas of Aceh Besar, Indonesia. IOP Conference Series: Earth Environ. Sci., 674(1): 012078 **(8 pages).**

Paolo, F.S.; Kroodsma, D.; Raynor, J.; Hochberg, T.; Davis, P.; Cleary, J.; Marsaglia, L.; Orofino, S.; Thomas, C.; Halpin, P., (2024). Satellite mapping reveals extensive industrial activity at sea. Nature, 625(7993): 85-91 **(7 pages).**

Park, J.; Lee, J.; Seto, K.; Hochberg, T.; Wong, B.A.; Miller, N.A.; Takasaki, K.; Kubota, H.; Oozeki, Y.; Doshi, S.; Midzik, M.; Hanich, Q.; Sullivan, B.; Woods, P., (2020). Illuminating dark fishing fleets in North Korea. Sci. Adv., 6(30): eabb1197 **(8 pages).**

Pons, M.; Cope, J.M.; Kell, L.T., (2020). Comparing performance of catch-based and length-based stock assessment methods in data-limited fisheries. Can. J. Fish. Aquat. Sci., 77(6): 1026-1037 **(12 pages).**

Rizqi, R.; Simbolon, D.; Mustaruddin, (2017). Interaction between capture fisheries policy and local wisdom in the northern waters of Aceh (In Indonesian). ALBACORE J. Penelit. Perikan. Laut, 1(3): 257-264 **(8 pages).**

Robards, M.D.; Silber, G.K.; Adams, J.D.; Arroyo, J.; Lorenzini, D.; Schwehr, K.; Amos, J., (2016). Conservation science and policy applications of the marine vessel Automatic Identification System (AIS)-A review. Bull. Mar. Sci., 92(1): 75-103 **(29 pages).**

Rudd, M.B.; Thorson, J.T., (2018). Accounting for variable recruitment and fishing mortality in length-based stock assessments for data-limited fisheries. Can. J. Fish. Aquat. Sci., 75(7): 1019-1035 **(17 pages).**

Sadovy de Mitcheson, Y.; Erisman, B., (2012). Fishery and biological implications of fishing spawning aggregations, and the social and economic

importance of aggregating fishes. In: Sadovy de Mitcheson, Y.; Colin, P.L. (eds.), Reef Fish Spawning Aggregations: Biology, Research and Management. Springer, Dordrecht. 225-284 **(60 pages).**

Sakti, W.I.; Radjawane, I.M.; Latief, H.; Meilano, I.; Trenggono, S.W.; Diantara, S.D.; Wahyudin, R.A.; Radiarta, I.N.; Ketaren, D.G.K.; Winata, I.N.P.; Gusmawati, N.F.; Syamdidi; Yuwono, T.; Arthatiani, F.Y.; Fahira, N., (2026). Balancing ecological stability and economic growth under oceanographic variability and coastal interventions in fisheries systems. Global J. Environ. Sci. Manage., 12(3): 1263-1286 **(24 pages).**

Sari, A.F.R.; Pranajaya, A.; Anam, K.; Marliana, I.; Tarigan, S.A.; Kartawijaya, T.; Agustina, S.; Kembaren, D.D.; Natsir, M.; Prasetia, R., (2024). Length-based stock assessment of snappers (*Lutjanus* spp.) in Taka Bonerate National Park waters (In Indonesian). Mar. Fish. J. Teknol. Manaj. Perikan. Laut, 15(1): 37-53 **(17 pages).**

Shepperson, J.L.; Hintzen, N.T.; Szostek, C.L.; Bell, E.; Murray, L.G.; Kaiser, M.J., (2018). A comparison of VMS and AIS data: The effect of data coverage and vessel position recording frequency on estimates of fishing footprints. ICES J. Mar. Sci., 75(3): 988-998 **(11 pages).**

Tawaqal, M.I.; Yusfiandayani, R.; Imron, M., (2019). Analysis of the fishing activity of tuna longline vessels based in Benoa, Bali, using a vessel monitoring system (In Indonesian). J. Teknol. Perikan. Kelaut., 10(1): 109-119 **(11 pages).**

Thoya, P.; Maina, J.; Möllmann, C.; Schiele, K.S., (2021). AIS and VMS ensemble can address data gaps on fisheries for marine spatial planning. Sustainability. 13(7): 3769 **(14 pages).**

Tranter, S.N.; Estradivari; Ahmadia, G.N.; Andradi-Brown, D.A.; Muenzel, D.; Agung, F.; Amkieltiela; Ford, A.K.; Habibi, A.; Handayani, C.N.; Iqbal, M.; Krueck, N.C.; Lazuardi, M.E.; Muawanah, U., (2022). The inclusion of fisheries and tourism in marine protected areas to support conservation in Indonesia. Mar. Policy, 146: 105301 **(11 pages).**

Welly, M.; Fahrudin, A.; Bengen, D.G.; Damar, A., (2020). Impact of marine protected area on reef fish population in Ay and Rhun Islands, Banda Islands, Maluku Province. J. Ilmu Teknol. Kelaut. Trop., 12(1): 223-233 **(11 pages).**

AUTHOR (S) BIOSKETCHES

Firdaus, R., Ph.D. Candidate, Study Program of Coastal and Marine Resources Management, Department of Aquatic Resources Management, Faculty of Fisheries and Marine Sciences, IPB University, Jalan Raya Dramaga, Bogor 16680, West Java, Indonesia.
- Email: *rianfirdaus@apps.ipb.ac.id*
- ORCID: 0000-0003-3394-6962
- Web of Science ResearcherID: GQH-6056-2022
- Scopus Author ID: 57212384351
- Homepage: https://scholar.google.com/citations?user=PQQVWlMAAAAJ&hl=id

Yulianda, F., Ph.D., Professor, Coastal and Marine Resources Management, Department of Aquatic Resources Management, Faculty of Fisheries and Marine Sciences, IPB University, West Java 16680, Indonesia.
- Email: *fredinan@apps.ipb.ac.id*
- ORCID: 0000-0002-7547-6914
- Web of Science ResearcherID: NA
- Scopus Author ID: 56103753300
- Homepage: https://msp.ipb.ac.id/lecturers-msp/

Zairion, Z., Ph.D., Associate Professor, Coastal and Marine Resources Management, Department of Aquatic Resources Management, Faculty of Fisheries and Marine Sciences, IPB University, West Java 16680, Indonesia.
- Email: *zairion@apps.ipb.ac.id*
- ORCID: 0000-0002-4707-6702
- Web of Science ResearcherID: NA
- Scopus Author ID: 59318954000
- Homepage: https://msp.ipb.ac.id/lecturers-msp/

Yulianto, G., Ph.D., Associate Professor, Coastal and Marine Resources Management, Department of Aquatic Resources Management, Faculty of Fisheries and Marine Sciences, IPB University, West Java 16680, Indonesia.
- Email: *gyo@apps.ipb.ac.id*
- ORCID: 0000-0003-4946-3877
- Web of Science ResearcherID: NA
- Scopus Author ID: 57221489619
- Homepage: https://msp.ipb.ac.id/lecturers-msp/

'Akla, C.M.N., Ph.D. Candidate, Study Program of Coastal and Marine Resources Management, Department of Aquatic Resources Management, Faculty of Fisheries and Marine Sciences, IPB University, Jalan Raya Dramaga, Bogor 16680, West Java, Indonesia.
- Email: *cutmeurahnurulakla@apps.ipb.ac.id*
- ORCID: 0000-0002-7422-6286
- Web of Science ResearcherID: GQI-1539-2022
- Scopus Author ID: 57212387654
- Homepage: https://scholar.google.com/citations?hl=id&user=VNyZuHAAAAAJ

HOW TO CITE THIS ARTICLE:
Firdaus, R.; Yulianda, F.; Zairion; Yulianto, G., 'Akla, C.M.N., (2027). Small-scale fisheries monitoring and fleet dynamics in a marine protected area. Global J. Environ. Sci. Manage., 13(2): …-…

DOI: https://doi.org/10.22034/gjesm.2027.02.17
URL: https://www.gjesm.net/article_736377.html