

DEVELOPMENT OF EAFM INDICATORS BASED ON BIOMETRIC AND SPATIAL PARAMETERS WITHIN THE FISH RESOURCE DOMAIN FOR THE EVALUATION OF SUSTAINABLE FISHERIES

Pengembangan Indikator EAFM Berbasis Biometrik dan Parameter Spasial pada Domain Sumber Daya Ikan untuk Evaluasi Perikanan Berkelanjutan

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ABSTRACT

The implementation of the Ecosystem Approach to Fisheries Management (EAFM) in Indonesian small-scale fisheries frequently encounters challenges regarding instrument sensitivity, primarily due to qualitative bias and operational data uncertainty in the field. This study aimed to analyze the weaknesses of existing EAFM indicators in the fish resource domain and reconstruct indicator formulations to be more valid, measurable, and operational. The research was conducted at the Pamayangsari Fish Landing Base (PPI), Tasikmalaya Regency, employing a Research, Design, Production, and Evaluation (RDPE) design with a descriptive qualitative-quantitative approach. Primary data were gathered through field observations, biometric catch sampling, and in-depth interviews with 35 key respondents (fishermen, port authorities, and fish traders). Findings revealed that the existing NWG-EAFM (2014) indicators suffer from critical fundamental subjectivities in qualitative assessment. This study successfully formulated two reconstructed indicator innovations: (1) a Biometric-Based Fish Size Trend Indicator, which converts qualitative perceptions into a quantitative matrix based on the ratio of Length at First Maturity (L_m) to mean catch length (L_c); and (2) a Spatial-Logistic Range Collapse Indicator, which converts fishing ground shift variables into a combined matrix of nautical mile distance, sailing time duration, and Fuel Consumption Ratio (FCR). The application of these reconstructed indicators effectively corrected the EAFM composite score for the Fish Resources domain at PPI Pamayangsari from a status of 2.25 (Moderate) to 1.75 (Critical). The sensitivity of this reconstructed instrument is able to eliminate compromise bias and provide a realistic representation of ecological threats. This study recommends the establishment of co-management institutions and fishermen's education programs based on participatory data collection, as well as the need for external validity testing (cross-location validation) in other regions and commodities.

Keywords: EAFM Indicator Development, Biometrics, Spatial Parameters, Fish Resources

ABSTRAK

Implementasi *Ecosystem Approach to Fisheries Management* (EAFM) pada perikanan skala kecil (*small-scale fisheries*) di Indonesia kerap menghadapi kendala sensitivitas instrumen, khususnya akibat tingginya bias kualitatif dan ketidakpastian data operasional di lapangan. Penelitian ini bertujuan untuk menganalisis kelemahan indikator eksisting EAFM pada domain sumber daya ikan serta merekonstruksi formulasi indikator agar lebih valid, terukur, dan operasional. Penelitian dilaksanakan di Pangkalan Pendaratan Ikan (PPI) Pamayangsari, Kabupaten Tasikmalaya, menggunakan desain *Research, Design, Production, and Evaluation* (RDPE) dengan pendekatan kualitatif-kuantitatif deskriptif. Data primer diperoleh melalui observasi lapang, sampling biometrik hasil tangkapan, serta wawancara mendalam terhadap 35 responden kunci (nelayan, otoritas pelabuhan, dan pedagang ikan). Hasil penelitian mengungkapkan bahwa indikator eksisting NWG-EAFM (2014) memiliki kelemahan mendasar pada aspek subjektivitas penilaian kualitatif. Penelitian ini berhasil merumuskan dua inovasi rekonstruksi indikator: (1) Indikator Tren Ukuran Ikan Berbasis Biometrik, yang mengonversi persepsi kualitatif menjadi matriks kuantitatif berbasis rasio *Length at First Maturity* (L_m) terhadap panjang rata-rata tangkapan (L_c); dan (2) Indikator *Range Collapse* Berbasis Parameter Spasial-Logistik, yang mengonversi variabel pergeseran *fishing ground* ke dalam matriks kombinasi jarak mil laut, durasi waktu tempuh (*sailing time*), dan rasio konsumsi Bahan Bakar Minyak (BBM). Penerapan indikator hasil rekonstruksi secara efektif mengoreksi nilai komposit EAFM domain Sumber Daya Ikan di PPI Pamayangsari dari status 2,25 (Sedang) menjadi 1,75 (Kritis). Sensitivitas instrumen yang direkonstruksi ini mampu mengeliminasi bias kompromistis dan memberikan gambaran ancaman ekologis secara riil. Penelitian ini merekomendasikan perlunya kelembagaan *co-management* dan program pendidikan nelayan berbasis pencatatan data partisipatif, serta diperlukan uji validitas eksternal (*cross-location validation*) pada wilayah dan komoditas lain.

Kata kunci: Pengembangan Indikator EAFM, Biometrik, Parameter Spasial, Sumberdaya Ikan

INTRODUCTION

As the world's largest archipelagic nation, Indonesia possesses an exceptionally abundant potential for capture fisheries. However, the utilization of this potential has yet to fully deliver equitable and sustainable prosperity to coastal communities (Hutubessy & Mosse, 2015). The management of Indonesia's marine territories is divided into 11 Fisheries Management Areas (Wilayah Pengelolaan Perikanan Republik Indonesia/WPPRI), which encompass diverse ecosystem characteristics—ranging from shallow shelf waters to deep oceanic zones (KKP, 2022). The complexity of these resources—which include large pelagic, small pelagic, and demersal species, as well as crustaceans—demands a management paradigm that goes beyond merely maximizing the catch (Maximum Sustainable Yield/MSY) to also encompass the comprehensive protection of ecosystem integrity (Pomeroy *et al.*, 2015).

In response to global challenges and environmental uncertainties, the Food and Agriculture Organization (FAO, 2021) introduced the Ecosystem Approach to Fisheries Management (EAFM) framework. EAFM integrates five core principles: (1) limiting fishing impacts to within the ecosystem's tolerance thresholds; (2) maintaining ecological interactions and food web structures; (3) aligning governance mechanisms with the spatial distribution of resources; (4) applying a precautionary approach to decision-making; and (5) balancing the well-being of both ecological and human systems (Garcia & Cochrane, 2018; Ward *et al.*, 2012).

In Indonesia, the EAFM framework has been adopted at the national level through the development of an indicator module by the National Working Group on EAFM (NWG-EAFM, 2014). This method was developed as an improvement upon rapid evaluation techniques, such as the Rapid Appraisal for Fisheries (RAPFISH) (Pitcher & Preikshot, 2001). Nevertheless, the implementation of standard NWG-EAFM (National Working Group on Ecosystem Approach to Fisheries Management) protocols at the field level often encounters significant methodological challenges—particularly when applied to small-scale fisheries, which typically utilize motorized boats with a gross tonnage of less than 5 Gross Tonnage (GT) (Muawanah *et al.*, 2018).

Small-scale fisheries along the southern coast of Java—such as those at the Pamayangsari Fish Landing Site (PPI) in Tasikmalaya Regency (within Fisheries Management Area/WPPRI 573)—present a highly complex scenario. The Indian Ocean's challenging conditions—characterized by high waves, extreme seasonal cycles, and a multi-species environment—render the fishing behavior of local fishers highly dynamic (Widodo & Mahiswara, 2019). In this region, conventional EAFM indicators have proven insufficiently sensitive, frequently leading to assessment bias.

Within the "fish resources" domain, the indicators most susceptible to such bias are those concerning fish size trends and "range collapse" (Agustian *et al.*, 2021). In existing assessment instruments, fish size trends are often evaluated based on qualitative estimates and the recollections of fishers, lacking any comparison against biological benchmarks such as the length at first maturity (L_m). Consequently, the onset of "growth overfishing" is difficult to detect early (Froese, 2004). Meanwhile, the "range collapse" indicator—which tracks the contraction or shifting of fishing grounds—is assessed solely through verbal accounts, lacking quantitative parameters such as spatial displacement, operational duration, or fuel consumption (Charles, 2014).

The inaccuracy of these indicators has the potential to lead to policy failure, where the sustainability status of fisheries appears administratively secure ("green category"), even though in reality the ecosystem has experienced severe stock depletion. Therefore, this study aims to:

1. Analyzing methodological weaknesses and operational biases in existing EAFM indicators at small-scale fishery sites;
2. Developing and reconstructing fish size trend indicator formulation based on biological biometric parameters (L_m and L_c);
3. Formulating the standardization of spatial-logistic parameters for range collapse indicators;
4. Integrating perspectives on environmental education and participatory governance (co-management) to ensure the sustainability of EAFM data collection at the site level.

RESEARCH METHODS

Place and Time

This research was conducted at the Pamayangsari Fish Landing Site (PPI Pamayangsari), located in Cikawungading Village, Cipatujah District, Tasikmalaya Regency, West Java (Figure 1). Geographically, PPI Pamayangsari faces the open waters of the Indian Ocean (WPPRI 573). Field data collection was carried out intensively over a three-month period, from June to August 2023.

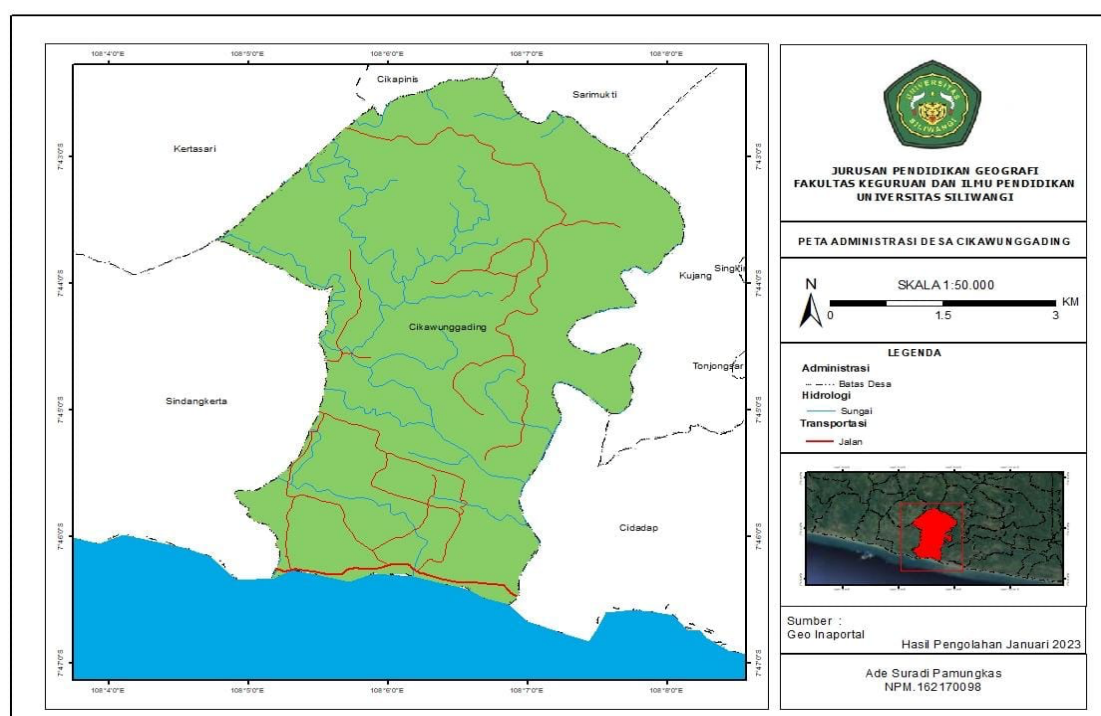


Figure 1. Map of the Research Location

Research Design

The research design model employed is the Research, Design, Production, and Evaluation (RDPE) framework, adapted from the instructional development and scientific instrument models proposed by Richey and Klein (2009). During the Research phase, an assessment of the NWG-EAFM (2014) indicators was conducted through interviews with 35 key respondents; the findings revealed that the indicators for fish size trends and range collapse were highly subjective, as they relied on fishers' recall rather than measurable parameters. Subsequently, the Design phase involved formulating a biometric indicator for fish size trends by converting qualitative estimates into a quantitative matrix based on the ratio of L_c (mean catch length) to L_m (length at first sexual maturity). This phase also included the design of a logistic spatial index to track shifts in fishing grounds without the use of GPS. In the third phase—Production—an evaluation matrix prototype was developed, resulting in an operational scoring table ready for testing through the calculation of integrated biometric and spatial data. Finally, the Evaluation phase involved simulations and a comparative analysis, contrasting the EAFM composite scores for the fish resources domain derived from the existing instrument against those from the reconstructed instrument. Thus, this approach integrates descriptive qualitative analysis—to explore the socio-ecological phenomena surrounding the fishers—with quantitative biometric and spatial analyses (Siyoto & Sodik, 2015).

Sampling and Respondent Selection Techniques

Respondents were selected using a purposive sampling technique based on criteria such as expertise, experience at sea, and authority in fisheries governance (Sugiyono, 2013). The key respondents consisted of 35 individuals, drawn from a total population of 750 active fisheries stakeholders at PPI Pamayangsari, comprising:

1. Port Manager / Harbor Master PPI Pamayangsari (3 people);
2. Key Fishermen who own or use vessels <5 GT with the criteria of >5 years of sea experience (20 people);
3. Fisheries Cooperative Managers and Coastal Community Leaders (4 people);
4. Wholesalers/Traders and Fish Processors at TPI (6 people).

The number of key respondents is considered representative of the population; rather than being selected randomly, they were chosen based on their expertise to elicit in-depth information. Biometric sampling was conducted on three primary commodities: largehead hairtail (*Trichiurus lepturus*), frigate tuna (*Auxis thazard*), and black pomfret (*Formio niger*), with a total sample size of 450 specimens (150 per species). To ensure the biometric data accurately represented catch dynamics throughout the study period, sampling was carried out periodically—twice a week for 12 weeks (June–August 2023)—covering 24 landing days at the Pamayangsari Fish Landing Port (PPI Pamayangsari).

On each sampling day, 3–5 jukung (traditional outrigger boats) were randomly selected upon arrival. From the catch baskets of each boat, 5–7 individuals per species were collected using a simple random sub-sampling technique, regardless of the fish's physical size. This randomized sampling approach—distributed across different fishing trips and time periods—was employed to eliminate clustering bias and to ensure that the quota of 150 individuals per species could objectively reflect the population size structure (total length, TL) of the catches landed by fishers in Pamayangsari.

Data Analysis

1. Biometric Analysis of Fish.

Total length (TL) data for the fish were measured using a measuring board with a precision of 0.1 cm. These measurements were then processed to determine the mean length at first capture (L_c). The L_c value was subsequently compared with the length at first maturity (L_m), obtained from accredited fisheries biology literature concerning the relevant species within WPPRI 573.

The percentage of fish of a catchable size (P_{mature}) is calculated using the formula:

$$P_{mature} = \left(\frac{N(TL > L_m)}{N_{total}} \right) \times 100\%$$

Description:

$N(TL > L_m)$ = The number of individual fish with a total length greater than the L_m value.

N_{total} = Total number of individual fish sampled.

2. Analysis of Spatial-Logistical Parameters

The variable of fishing-ground range collapse is converted from a qualitative estimate into a spatial-logistic index (SLI) matrix that incorporates three operational parameters:

- Changes in the geographical distance of the fishing area in nautical miles (D);
- Changes in the duration of the round trip journey at sea in hours (T);
- Fuel Consumption Ratio (FCR).

Since the three operational parameters have different units, a normalization of their ratios relative to the 2020 baseline value (X_0) is performed. The Spatial-Logistic Index (SLI) equation is formulated as follows:

$$ISL = w_1 \left(\frac{\Delta D}{D_0} \right) + w_2 \left(\frac{\Delta T}{T_0} \right) + w_3 \left(\frac{\Delta FCR}{FCR_0} \right)$$

Where ΔD , ΔT , and ΔFCR represent the difference in parameters between the current condition and the baseline condition from 3 years prior, while w_1 , w_2 , and w_3 are the weighting factors for the indicators ($w_1=0.4$, $w_2=0.3$, $w_3=0.3$), such that:

$$\sum_{i=1}^3 w_i = w_1 + w_2 + w_3 = 0,4 + 0,3 + 0,3 = 1,0.$$

Table 1. Variable Definitions, Units, Direction of Change, and Weighting for the Spatial-Logistic Index (SLI)

Symbol	Variabel	Original Unit	Units after Normalization	Direction of Change	Weight
<i>D</i>	Change in Detection Range	Nautical Mile	Without units (Ratio)	Positive (+) = Greater distance	0,4
<i>T</i>	Change in Travel Time	Hours	Without units (Ratio)	Positive (+) = Duration at sea increases	0,3
<i>FCR</i>	Fuel Consumption Ratio	Liter/ Trip	Without units (Ratio)	Positive (+) = Fuel consumption increases	0,3

3. Evaluation of EAFM Sustainability Status

The sustainability status scoring adopts the NWG-EAFM composite standard, modified into a 3-point ordinal scale consisting of integer values: 1 (poor), 2 (moderate), and 3 (good). The total range is $3.00 - 1.00 = 2.00$; thus, when divided equally into three sustainability status categories, the resulting class interval length is 0.67. Further details are presented in Table 2 below:

Table 2. Sustainability Condition Scale

Score	Condition	Composite Score	Status
3	Good	2,34 - 3,00	Highly Sustainable
2	Medium	1,67 - 2,33	Sufficiently Sustainable
1	Bad	1,00 - 1,66	Unsustainable

RESULT AND DISCUSSION

General Overview of the Research Site

The Pamayangsari Fish Landing Port (PPI Pamayangsari) is located at coordinates 7° 38' 45" S and 108° 04' 12" E. From a hydrodynamic perspective, the waters of Pamayangsari are strongly influenced by the Indonesian Throughflow and the dynamics of periodic upwelling phenomena triggered by the Southwest and Northeast Monsoons (Satria, 2015). Sea waves in this region are considered extreme, with average heights ranging from 1.5 to 4.0 meters during certain months (July–September).

Fishing activities at PPI Pamayangsari are dominated entirely by small-scale fisheries. The fishing fleet consists of 185 fiberglass *jukung* (outrigger) boats equipped with outboard motors, each measuring less than 5 Gross Tonnage (GT). The primary fishing gear employed includes drift gill nets, hand lines, and bottom longlines. A multi-species characteristic is highly prominent; rather than focusing on a single target species, fishers adjust their choice of fishing gear according to the seasonal availability of various marine commodities.

Table 3. Characteristics of Fisheries at PPI Pamayangsari

No	Operational Parameters	Actual Conditions in the Field
1	Fleet/Boat Size	Jukung Boat (<5 GT)
2	Types of Fishing Gear	Drift Gillnet, Handline, Bottom Longline
3	Primary Catch Commodities	Hairtail, Tuna (Mackerel Tuna), Black Pomfret

4	Range	2–12 miles from the coastline
5	Fishermen's Institutions	Fisheries Cooperatives and Fishermen Groups
6	Local Knowledge (TEK)	Sea Gratitude Rituals and Signs from Nature

The fishing community of Pamayangsari possesses strong social-ecological ties rooted in indigenous knowledge, manifested through the "Syukur Laut" (Sea Gratitude) tradition. This ritual serves as a cultural adaptation mechanism that internalizes norms regarding fishing restrictions and respect for the marine environment (Erwin, 2018). However, in recent decades, the pursuit of short-term economic needs and the pressures of climate change have eroded adherence to these local norms.

Analysis of Weaknesses in Existing Indicators and the Urgency for Reconstruction

Initial evaluation results indicate that the conventional EAFM (Ecosystem Approach to Fisheries Management) assessment instrument—based on the NWG-EAFM Indicator Module (2014)—faces significant challenges regarding data reliability when applied in Pamayangsari. A fundamental issue lies in the subjectivity of the assessment criteria. For instance, within the "Fish Resources" domain, the indicator for fish size trends requires interviewers to assign a score based on fishers' recollections of average fish sizes over the past 3–5 years.

In the context of Pamayangsari, where fishers target multiple species, such perceptions are highly subjective. Fishers tend to recall their best catches (from peak seasons) rather than the annual average—a phenomenon known as "recall bias." Furthermore, the absence of biometric parameters means that "growth overfishing"—a scenario where fish are caught at a young age before they can reproduce—goes undetected as an ecological threat (Froese, 2004). Meanwhile, regarding the "range collapse" indicator, a key limitation stems from the lack of digital navigation tools, such as GPS, among the fishing fleet (vessels <5 GT). Consequently, fishers struggle to quantify shifts in their fishing grounds in terms of nautical miles. Moreover, the existing indicators lack a conversion mechanism to link changes in fishing locations to increases in operational costs (such as fuel consumption) and extended time spent at sea. As a result, the assessment of "range collapse" is often speculatively assigned a "moderate/yellow" score, which fails to accurately reflect the actual conditions on the ground (Agustian, 2022).

Reconstruction of EAFM Indicator Formulation

1. Reconstruction of Indicator 1: Biometric-Based Fish Size Trends (L_m)

To eliminate qualitative perception bias, this study transforms fish size trend indicators into a biometric indicator based on a "maturation-at-capture" matrix ($\$P_{\{mature\}}\$$). This indicator requires a direct comparison between the mean length of the fish in the catch ($\$L_c\$$) and the length at first sexual maturity ($\$L_m\$$). The biometric parameters of three key species at the Pamayangsari Fish Landing Port (PPI Pamayangsari) were analyzed based on field data and biological references for the waters off the southern coast of Java (Table 4).

Table 4. Biological Biometric Parameters and Catch Sampling Results at PPI Pamayangsari

Commercial Name	Scientific Name	L_m Value (cm) and Reference	Mean Length of Catch (cm) & Sex Category	Percentage Suitable for Catching (%)	Biological Status of the Catch
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Hairtail Fish	Trichiurus lepturus	72,5 (Agustian <i>et al.</i> , 2021)	61,2 Combined sex	34,6%	Growth Overfishing Severely Detected
Krai Tuna	Auxis thazard	29,8 (Froese, 2004)	32,4 Combined sex	78,2%	Moderate / Near Sustainable
Black Pomfret	Formio niger	24,0 (Widodo & Mahiswar a, 2019)	19,8 Combined sex	28,0%	Growth Overfishing Severely Detected

Table 4 shows that the determination of the Length at First Maturity (L_m) value—used as a biological threshold—is based on fisheries literature concerning regions with ecological conditions similar to the study site in WPPRI 573 (the Indian Ocean south of Java). To accommodate operational constraints at the Pamayangsari Fish Landing Site (PPI)—where sampling is conducted using non-destructive (non-lethal) methods, without the dissection of gonads—a combined-sex L_m value was adopted. The use of this combined-sex L_m has proven both effective and practical for rapidly classifying the proportion of fish that have reached maturity (P_{mature}) at the fish landing site, without compromising the market value of the fishermen's catch.

Based on this biometric formulation, the operational scoring criteria for fish size trend indicators have been quantitatively reconstructed, as presented in Table 5.

Table 5. Reconstruction Matrix for Scoring Fish Size Trend Indicators Based on Biometrics

EAFM Score	Status Category	Formulation of Biometric Parameters	Ecological Interpretation
3	Good	$P_{\text{mature}} > 80\%$ of the total catch	The majority of the catch consists of adult fish that have spawned at least once. Stock recruitment is secure.
2	Medium	$50\% \leq P_{\text{mature}} \leq 80\%$ of the total catch	There is a moderate level of fishing pressure. Regulation of mesh size is required.
1	Bad	$P_{\text{mature}} < 50\%$ of the total catch	Severe growth overfishing is occurring. The catch is dominated by juvenile/young fish. The stock is at risk of collapse.

2. Reconstruction of Indicator 2: Standardization of Spatial Parameters for Range Collapse

To address the absence of GPS navigation data on small-scale fishing boats, the "range collapse" variable is reconstructed by transforming geographic spatial variables into three operational logistics variables that can be concretely and easily measured by fishers: estimated distance in nautical miles (D), duration of time spent at sea (T), and Fuel Consumption Ratio (FCR). The Spatial-Logistics Index (SLI) formulation developed is as follows:

$$ISL = 0.4 \left(\frac{\Delta D}{D_0} \right) + 0.3 \left(\frac{\Delta T}{T_0} \right) + 0.3 \left(\frac{\Delta FCR}{FCR_0} \right)$$

Based on this equation, the scoring criteria for the range collapse indicator are reconstructed into a standard operational matrix (Table 6).

Table 6. Reconstruction Matrix for the Standardization of Spatial-Logistic Parameters for the Range Collapse Indicator

Condition Score	Condition Score (D)	Change in Travel Time (T)	Fuel Consumption Ratio (FCR)	Ecosystem Status
Score 3 (Good/Green)	A shift of <2 nautical miles from the baseline	Additional travel time $\Delta T < 1$ hour	Fuel consumption is relatively stable ($\Delta FCR < 10\%$)	Fishing grounds are nearby and stable; inshore stocks are abundant.
Score 2 (Medium/Yellow)	The D shift ranges from 2 – 5 nautical miles	The additional travel time (ΔT) ranges from 1 to 3 hours	Fuel consumption increases by $\Delta FCR 10\% - 30\%$	There is moderate fishing pressure; fishers are beginning to look for alternative areas.
Score 1 (Bad/Red)	Shift D>5 Nautical Miles towards the open sea	Additional travel time $\Delta T > 3$ hours	Fuel consumption has surged ($\Delta FCR > 30\%$)	A range collapse has occurred—a scarcity of fish stocks in nearshore coastal areas.

Operational fishing data for jukung (traditional outrigger boat) fishers at the Pamayangsari Fish Landing Center (PPI Pamayangsari) from 2020 to 2023 reveal a significant increase in logistical parameter values (Table 7). The operational figures presented in Table 7 are derived from two distinct data collection approaches. Data for the current period (2023) were obtained quantitatively through direct field observations conducted at the jukung landing site at PPI Pamayangsari between June and August 2023. The 2023 mean values were calculated based on routine records of approximately 480 fishing trips undertaken by 20 key sample fishers. Conversely, the baseline data (2020) were obtained through a qualitative, retrospective approach, utilizing in-depth interviews based on the "recall method" with the same 20 key fishers.

The researchers acknowledge a methodological disparity between the direct, real-time recording in 2023 and the retrospective recall from 2020, which may introduce "recall bias" into the baseline data. The absence of historical logbook records for small-scale fisheries at PPI Pamayangsari constitutes a limitation of this study. Nevertheless, the observed upward trend in the logistical parameters shown in Table 7 provides an empirical overview of the shifting fishing grounds as experienced by the fishers themselves. This scarcity of historical data underscores the urgent need for the Spatial-Logistical Index (SLI) innovation and the Participatory Logbook-based co-management framework proposed in this study.

Table 7. Dynamics of Operational Fishing Parameters for Jukung Fishers at PPI Pamayangsari (2020 vs. 2023)

Operational Parameters	Baseline Condition (Year 2020)		Current Condition (Year 2023)		Difference in Change (Δ)	Percentage Increase (%)
Average Capture Distance (D)	3.2 Miles	Nautical	7,8 Miles	Nautical	+ 4,6 Nautical Miles	+ 143,7%
Round-trip Travel Time (T)	2.5 hours		5,8 hours		+ 3,3 hours	+ 132,0%
Fuel Consumption per Trip (FCR)	8,5 Liter		15,0 Liter		+ 6,5 Liter	+ 76,5%

Table 7 illustrates a significant expansion in fishing effort within the *jukung* (traditional boat) fleet at the Pamayangsari Fish Landing Center (PPI) during the 2020–2023 period. An average increase of 143.7% (+4.6 nautical miles) in operational range, coupled with a 76.5% rise in fuel consumption (+6.5 liters per trip), confirms a shift in fishing grounds—a "range collapse"—moving away from nearshore coastal zones toward more distant waters. Although this study does not explicitly calculate the Catch Per Unit Effort (CPUE) ratio based on daily catch weight, the observed dynamics in the spatial-logistical parameters presented in Table 6 objectively demonstrate a decline in operational efficiency and an increased production cost burden that small-scale fishers must bear to reach their fishing grounds.

Comparison of EAFM Evaluation Results: Existing vs. Reconstructed

The integration of the reconstructed indicator formulation substantially alters the sustainability assessment landscape for the EAFM "Fish Resources" domain. A comparison of the composite values is presented in Table 8.

Table 8. Comparison of EAFM Assessments for the Fish Resources Domain: Existing Method vs. Reconstruction Method

Indicator	Existing Score	Existing Category	Reconstruction Score	Reconstruction Category	Sources of Sensitivity Variation
Species Composition	2	Medium	2	Medium	Relatively Stable
Fish Size Trends	2	Medium	1	Bad	The application of the L_m biometric standard has been shown to detect growth overfishing
Range Collapse	2	Medium	1	Bad	The application of spatial-logistic parameters confirms a shift in distance and an inflation in fuel consumption
Endangered Species	3	Good	3	Good	Rarely entangled (low bycatch)

Indicator	Existing Score	Existing Category	Reconstruction Score	Reconstruction Category	Sources of Sensitivity Variation
Domain Composite Score	2,25	Medium	1,75	Critical/ Near Red	Reconstruction enhances precision and eliminates compromise-based bias.

The verification process for the change in the composite value of the "Fish Resources" domain—shifting from the existing method to a reconstruction method—is calculated using the linear average formula for standard EAFM indicators ($NK_{\text{Domain}} = 1/4 \sum S_i$). In the existing method, the accumulated indicator scores (2+2+2+3) yield a composite value of 2.25 (Moderate/Yellow category). Following a reconstruction based on biometric parameters (where S_{TU} decreases to 1) and spatial-logistical parameters (where S_{RC} decreases to 1), the total accumulated score becomes 2+1+1+3 = 7. This results in a final composite value of 1.75 (7/4). The reconstruction of these two indicators provides a sensitivity correction of 22.22% ($\Delta NK = -0.50$), which transparently shifts the sustainability status toward the critical category ("Near Red") and eliminates the "smoothing effect" inherent in conventional instruments. Conversely, this reconstruction method—grounded in biometric and spatial parameters—effectively exposes threats such as growth overfishing and the shrinkage of fishing grounds, presenting them clearly to fisheries policymakers.

The findings of this study underscore that the successful implementation of sensitive and accurate EAFM instruments cannot rely solely on a top-down, administrative approach from the government. Two primary supporting pillars are required: Environmental Education and Participatory Governance (Co-Management) (Pomeroy *et al.*, 2015; Satria, 2015). Environmental education plays a crucial role in shifting the paradigm of fishers from an extractive orientation toward a conservation-minded perspective. In the context of indicators concerning fish size trends, such education is directed toward concrete actions, specifically the autonomous modification of fishing gear mesh sizes. Fishers are being taught to increase the mesh size of their gillnets from 1.5 inches to a minimum of 2.5–3.0 inches. This adaptive measure has been shown, both theoretically and practically, to allow juvenile fish (with a total length, TL, less than the length at maturity, L_m) to escape, thereby ensuring the sustainability of natural stock recruitment (Froese, 2004).

A primary challenge in applying "range collapse" indicators—based on spatial-logistical parameters—is the availability of consistent, daily data. To address the limited number of port personnel, a co-management strategy has been implemented by empowering local fisher cooperatives and community-based surveillance groups.

Fishers are trained to complete a simple "participatory logbook" before landing their catch at the Pamayangsari Fish Auction Place (TPI). The recorded data includes three key variables: the fishing zone/location, the duration of the trip, and the volume of fuel (in liters) consumed. This participatory recording process not only ensures a continuous flow of data for the annual Ecosystem Approach to Fisheries Management (EAFM) evaluation but also fosters a sense of ownership among fishers regarding the conservation of their own aquatic ecosystems (Muawanah *et al.*, 2018).

CONCLUSION

This study concludes that the existing conventional EAFM evaluation instrument (NWG-EAFM, 2014) possesses fundamental weaknesses regarding sensitivity and data reliability, particularly when applied to small-scale fisheries such as those at the Pamayangsari Fish Landing Center (PPI Pamayangsari). The study successfully formulated two innovative,

operational, and valid indicator reconstructions: the Biometric-Based Fish Size Trend indicator—which converts qualitative perceptions into a quantitative matrix representing the ratio of L_c (length at first capture) to L_m (length at first maturity)—and the Spatial-Logistic Parameter-Based Range Collapse indicator. The latter transforms variables related to shifts in fishing grounds (in the absence of GPS) into a Spatial-Logistic Index (SLI), calculated based on changes in nautical miles, travel time (sailing time), and increased fuel consumption (Fuel Consumption Rate/FCR).

Applying these reconstructed indicators effectively adjusted the EAFM composite score for the "Fish Resources" domain at PPI Pamayangsari from 2.25 (Moderate) to 1.75 (Critical). The enhanced sensitivity of these reconstructed instruments eliminates "compromise bias" and provides a realistic assessment of ecological threats. To ensure the continued use of these indicators, it is recommended that they be supported through co-management institutions and educational programs for fishers focused on participatory data recording. Furthermore, external validity testing (cross-location validation) in other regions and for different commodities is advised.

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