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Risk and Safety Assessment of Purse Seine Operations in Small Fishing Ports of East Java

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ABSTRACT

Small-scale purse seine fisheries are a vital component of the economy and food security in East Java, Indonesia, but they also expose fishers to significant occupational hazards. The objective of this study was to identify and prioritize operational safety hazards and to assess ecological risk proxies (bycatch and fish maturity) in purse seine operations at small fishing ports in East Java. A combination of frequency and severity indices (a semi-quantitative Frequency Index–Severity Index (FI–SI) approach) was used to evaluate safety hazards, while bycatch and fish maturity data were analyzed to assess ecological risks. The results showed that incidents such as rope burns, slips, and entanglement were frequent but of low severity. Additionally, bycatch rates were minimal, with most of the catch being mature fish. The study highlights that while operational efficiency is high, safety risks remain a concern, particularly during net handling and hauling operations. The findings underscore the need for enhanced safety protocols and improved regulatory compliance to ensure both worker safety and ecological sustainability. This research contributes to the understanding of occupational risks in small-scale fisheries and offers a framework for integrating safety and sustainability in artisanal fisheries management. Because FI–SI scoring relies on reported experience and local operating conditions, risk levels should be interpreted as relative priorities within the studied ports. Future research should focus on evaluating the effectiveness of specific safety interventions and exploring the long-term impacts of these practices (including climate-related changes in sea conditions and work patterns) on fishers and marine ecosystems.

1. INTRODUCTION

Small-scale fisheries are a cornerstone of food security and socio-economic resilience in developing coastal regions, particularly in Indonesia, where millions rely on marine resources for livelihoods and nutrition. These fisheries provide direct access to affordable protein and indirect income opportunities that sustain local economies [1, 2]. Among them, small-scale purse seine operations play a pivotal role in East Java's coastal economy, supplying pelagic species such as sardines, mackerel, and tuna to domestic markets while providing employment for fishers, processors, and traders. Beyond their economic contribution, these fisheries reinforce social cohesion and cultural identity through shared labor and the communal distribution of catches [2]. Moreover, diversified livelihood strategies that integrate fishing with supplementary income activities enhance fishers' adaptive capacity to withstand environmental and market fluctuations [3-5]. Consequently, small-scale purse seine fisheries function not only as a critical source of food and income but also as a social safety net underpinning the resilience of coastal communities.

Despite this importance, small-scale purse seine operations remain among the most hazardous occupations worldwide. Fishers frequently work under unsafe conditions that heighten exposure to physical injury, fatigue, and unpredictable weather [6-8]. Common accidents include musculoskeletal strain from manual hauling, slips and falls on wet decks, rope entanglements, and drowning. These risks are compounded by inadequate protective equipment, limited vessel stability, and insufficient training in occupational safety [9, 10]. The absence of health insurance and weak enforcement of maritime safety regulations further exacerbate fishers' vulnerability [11]. Combined with fluctuating catches and unstable income, these challenges heighten socio-economic fragility among fishing-dependent communities [12, 13]. Thus, improving safety management in small-scale fleets is essential not only for occupational protection but also for sustaining livelihoods and community well-being.

The central dilemma in small-scale purse seine fisheries lies in the coexistence of economic dependency on fishing and high operational risk. Manual operations—setting, pursing, hauling, and sorting—expose crews to repetitive strain, collisions, and fatigue during high-intensity tasks. While mechanization could alleviate physical burdens, most small vessels lack the capital or technical capacity for such upgrades. This creates a paradox in which economic survival depends on activities that simultaneously threaten workers' safety.

Moreover, the absence of integrated, context-specific safety frameworks hinders systematic risk management. In East Java, many small ports have limited institutional capacity to monitor compliance or deliver technical training, underscoring the urgent need for structured approaches to identify, evaluate, and mitigate operational hazards while balancing productivity and safety.

Globally, structured risk assessment methodologies have been increasingly adopted to improve safety in artisanal fisheries. Frameworks such as Hazard Analysis and Critical Control Point (HACCP), originally designed for food safety, have been adapted to identify and manage hazards in fishing operations [14]. Similarly, the Marine Stewardship Council (MSC) certification framework links ecological sustainability with operational requirements, encouraging adherence to environmental and occupational best practices [15]. However, these frameworks differ in scope and data requirements, and they are not always directly transferable to data-limited, small-port contexts. In this study, HACCP/MSC are referenced as overarching examples of risk-based management, whereas the operational risk ranking is conducted using a simplified Frequency Index–Severity Index (FI–SI) matrix because it is feasible under limited incident records and can be implemented through structured observation and stakeholder reporting. Participatory safety programs that incorporate local ecological knowledge have also proven effective in increasing compliance, as they align interventions with cultural norms and economic realities [16]. The success of these integrated models underscores the value of combining scientific and community-based perspectives to achieve lasting safety and sustainability improvements.

However, in Indonesia, particularly within small fishing ports of East Java, there remains a lack of comprehensive assessment linking vessel characteristics, operational patterns, and occupational risk [17]. Prior research has primarily focused on biological sustainability, gear selectivity, and socio-economic outcomes, with limited empirical evaluation of the frequency and severity of work-related hazards specific to purse seine fisheries. Without such analyses, it is difficult to establish evidence-based frameworks or policy recommendations tailored to local operational contexts.

This study addresses this gap by conducting a structured risk and safety assessment of small-scale purse seine operations in East Java's coastal ports. The objective is to generate a port-level baseline that (1) identifies and ranks the most relevant operational hazards using an FI–SI risk matrix, (2) summarizes fleet and operational characteristics linked to hazard exposure, and (3) evaluates ecological risk proxies using bycatch and maturity composition. Using the FI and SI to quantify and classify operational hazards, the research evaluates fleet characteristics, fishing practices, and incident data to develop a baseline for port-level safety management. Given that FI and SI are semi-quantitative and depend on reported experience and observation, the resulting risk categories are intended for prioritization within the local artisanal context rather than as absolute probability estimates; this limitation is considered when interpreting results and formulating recommendations. The findings aim to provide critical insights into the interaction between operational safety, fishing behavior, and sustainability—offering a foundation for more integrated and adaptive management strategies in Indonesia's small-scale fisheries.

2. METHOD

This study employs a comprehensive approach to assess occupational safety and operational risks in small-scale purse seine fisheries operating in East Java (Figure 1). The methodology integrates several well-established risk assessment frameworks, tailored to the unique context of artisanal fisheries. The primary objective is to evaluate both the frequency and severity of operational hazards faced by fishers during their daily operations, ensuring a clear understanding of the safety challenges in this industry. The methodology follows a combination of qualitative and quantitative techniques, incorporating risk matrices, frequency and severity indices, and participatory hazard identification methods, adapted from previous studies and models applied to fishing communities [18, 19]. These tools allow for a structured analysis of risks, enabling the identification of critical hazards and the prioritization of safety interventions.

Figure 1. Map showing the study area in East Java, Indonesia

2.1 Risk assessment frameworks

Risk assessment in small-scale fisheries requires a framework that accounts for ecological, economic, and social factors. The extended Ecosystem-Based Fisheries Assessment (ECAF) framework was used as a conceptual structure to describe risk drivers and to ensure that hazard interpretation considers environmental and socio-economic context [19]. ECAF integrates environmental conditions, gear design, and socio-economic elements to provide a holistic risk evaluation, emphasizing the need to account for driving factors such as climate change and economic variability. In this study, ECAF is not used to generate quantitative risk scores; instead, it guides the organization of hazards and the discussion of broader drivers, while operational hazard prioritization relies on the FI–SI matrix. This positioning improves alignment with the realities of small-scale fisheries, where risks are operational but also influenced by broader conditions. Hazard Identification and Risk Matrices in the study incorporates hazard identification checklists and one risk matrix to systematically assess the operational risks associated with purse seine fishing activities. These tools, commonly used in industrial risk assessments, were adapted to the context of small-scale fisheries. The hazard identification checklist was informed by (i) structured input from fishers and local stakeholders and (ii) available documentation of prior incidents, enabling systematic screening of hazards that could lead to accidents or injuries. After hazard listing, risks were classified using a frequency–severity matrix (FI–SI) to generate a relative priority ranking (high/medium/low). Because the study's intent is prioritization rather than statistical inference, the matrix is used as a practical decision-support tool for small ports [20].

2.2 Frequency and severity indices

To quantify operational risks, the study employed an FI and an SI, which are commonly used as semi-quantitative tools to evaluate the relative likelihood and impact of specific hazards [21]. FI summarizes how often a hazard is encountered, while SI summarizes the typical consequences when it occurs. FI and SI information was compiled from triangulated sources, including (where available) accident/incident records, fisher interviews, and operational notes/logbooks, to reflect the regularity of events during fishing trips. SI reflects consequences such as injury outcomes and equipment damage [22, 23]. FI and SI scores were combined in a single FI–SI matrix to classify risks into low/medium/high priority for intervention. To reduce unnecessary technical detail, the full scoring rubric and category thresholds should be provided in a supplementary table/appendix. Importantly, FI–SI is appropriate for data-limited artisanal fisheries as a prioritization method, but its outputs are context-specific and should be interpreted as relative rankings rather than absolute probabilities.

2.3 Participatory risk assessment

In line with modern approaches to community-based fisheries management, this study adopted participatory methods for hazard identification. Engaging fishers in the assessment process has been shown to improve the accuracy and relevance of risk assessments, as local knowledge provides valuable insights into the daily risks encountered by workers in these operations [24]. Fishers were actively involved through interviews and group discussions. To limit common biases, participatory inputs were cross-checked with direct observations and any available incident documentation. This approach supports both contextual accuracy and ownership of proposed safety interventions, which can improve compliance.

2.4 Data collection

The data collection process involved direct observation, interviews, and review of incident reporting (where available and accessible at the port level). Direct observation was carried out during fishing operations to monitor safety practices and identify hazards across work stages (net setting, hauling, and fish handling), documenting unsafe conditions and behaviors. Interviews with fishers captured experiences of occupational risks, existing safety measures, and prior accidents, providing context for interpreting FI and SI. Because small ports may have incomplete or inconsistent reporting systems, the study treats incident records as supportive evidence rather than the sole data source and relies on triangulation to improve reliability.

2.5 Data analysis and risk categorization

The data collected from interviews, observations, and incident documentation were analyzed using complementary qualitative and quantitative methods. The frequency of hazards was summarized using FI, while severity was summarized using SI. FI and SI scores were mapped onto the FI–SI risk matrix to classify risks into low, medium, or high priority. To keep the Methods section non-duplicative with Results, specific hazard rankings and examples are reported in the Results section; here, "high priority" refers to hazards with the highest combined FI–SI category requiring immediate attention. Given the semi-quantitative nature of FI–SI, recommendations are framed as practical controls (training, ergonomics, and weather-related decision protocols) that can be implemented under small-port constraints, and the approach is intended for periodic updating as operating conditions (including long-term climate variability) evolve.

3. RESULT

3.1 Fleet characteristics and operations

Small-scale purse seine fleets in East Java operate nearshore with wooden vessels (10–30 GT) and compact crews (3–8 persons), undertaking mostly one-day trips as shown in Figure 2. Two-boat coordination is common, improving net deployment and retrieval efficiency while shortening time at sea. These patterns are consistent with regional profiles for Southeast Asian small-scale fleets and support rapid turnover to local markets [25, 26]. However, the compressed tempo of one-day trips can concentrate high-intensity deck tasks into short time windows, which is relevant when interpreting the hazard profile reported.

3.2 Catch composition and bycatch

Landings were dominated by small pelagics: *Rastrelliger kanagurta, Auxis rochei, Scomberoides tol, Katsuwonus* *pelamis, and Euthynnus affinis*. The catch was highly selective, with very low non-target take (Table 1). Overall bycatch rate measured 0.4% and discards were negligible, aligning with evidence that purse seines—when properly operated—produce lower bycatch than many alternative gears [27, 28]. From a safety perspective, low discard volumes also imply less time spent sorting unwanted catch, which can modestly reduce exposure to cuts/punctures during handling.

Figure 2. The small-scale purse seine used in Tambakrejo

Table 1. Main and bycatch categories for purse seine landings

Species (Scientific Name)	Catch (kg)	Relative Abundance (%)	Category
Auxis rochei	6,833	35.3	
Rastrelliger kanagurta	5,480	28.3	
Scomberoides tol	4,645	24.0	Main catch
Katsuwonus pelamis	1,735	9.0	
Euthynnus affinis	570	2.9	
Tylosurus acus	75	0.4	Bycatch

3.3 Size distribution and maturity structure

The length distributions of the main target species provided significant insights into the maturity structure of the catch (Table 2). For *Auxis rochei* (Length of maturity/Lm = 25.8 cm), the length distribution showed a peak at 26.94–28.74 cm, with a substantial proportion of fish caught at or above the size at first maturity; approximately two-thirds of sampled individuals were ≥ Lm, resulting in a mature-skewed profile. For *Scomberoides tol* (Lm = 26 cm), the size distribution ranged from 24.0 cm to 51.5 cm, with the catch overwhelmingly composed of mature fish (≈ 98% ≥ Lm). In contrast, for *Euthynnus affinis* (Lm = 42.3 cm), all observed individuals in this dataset were below Lm (Table 2), indicating a potential growth-overfishing concern for this species within the sampled landings. *Katsuwonus pelamis* was fully composed of individuals exceeding the size at first maturity, with dominant length modes in the range of 56.42–58.82 cm. Collectively, these outcomes indicate species-specific differences in maturity composition: several targets were mature-skewed, while *Euthynnus affinis* requires attention from a size-management perspective.

Table 2. Percentage of immature individuals in the catch for the main target species (based on Lm)

Species (Scientific Name)	Lm (cm)	Im-Mature (%)	Mature (%)	Basis in Manuscript
Rastrelliger kanagurta	21.0	0	100	From length classes; all ≥ Lm
Auxis rochei	25.8	34	66	From length-frequency counts vs. Lm
Euthynnus affinis	42.3	100	0	All observed < Lm
Scomberoides tol	26.0	2	98	From length-frequency counts vs. Lm
Katsuwonus pelamis	41.3	0	100	All observed ≥ Lm
Tylosurus acus (bycatch)	47.3	0	100	All observed ≥ Lm

Although the majority of catches were within or above maturity thresholds for several species, the retention of all fish—including individuals below Lm—remains a concern. The absence of release practices for undersized fish increases the long-term risk of growth overfishing and may shift fishing behavior toward more sets and/or longer searching effort to maintain landings. This can increase operational intensity and cumulative exposure time on deck, thereby elevating the probability of onboard accidents. This feedback may be further amplified under long-term climate variability (e.g., more frequent rough-sea windows and disrupted seasonality), which can constrain safe operating days and pressure crews to fish during marginal conditions. This finding underscores the need to integrate biological sustainability with occupational safety considerations in the management of small-scale purse seine fisheries.

3.4 Occupational risk profile (Frequency Index–Severity Index–matrix)

The risk-scoring framework used in this study applies a semi-quantitative FI–SI matrix to prioritize safety controls across purse-seine deck operations. FI summarizes how often a hazard is encountered, and SI summarizes typical consequences; combining them yields a relative risk category (low/medium/high) used for prioritization (Table 3). Because this approach is designed for small-port, data-limited settings, the risk levels are interpreted as practical priorities for control measures rather than absolute probabilities.

Table 3. Operational risk and safety management matrix for small-scale purse seine operations in East Java

Hazard/Exposure	Operation Phase	FI	SI	Risk Level	Main Causes/Triggers	Existing Controls	Recommended Improvements
Rope burns and hand injuries	Net pursing/hauling	4	2	Medium	Manual handling of high-tension lines	Use of gloves (irregular)	Provide rubberized gloves; train on safe rope handling
Slips and falls on the deck	Sorting/washing	3	2	Medium	Wet decks, fish slime	Periodic cleaning	Apply anti-slip mats; mark safe walk zones
Entanglement in a net	Setting/hauling	2	3	Medium	Net or bridle snag during hauling	Skipper supervision	Designate exclusion zones; establish clear crew signals
Back strain/musculoskeletal disorders	Lifting/brailing	3	2	Medium	Repetitive heavy lifting	Task rotation (informal)	Introduce lifting aids; ergonomic training
Cuts and punctures from fish/knives	Sorting/cleaning	3	1	Low–Medium	Sharp fins, improper knife use	Personal knives used	Use cut-resistant gloves; implement a knife control standard operating procedure (SOP)
Drowning/man overboard	All sea operations	1	5	High	Loss of balance, rough weather	Swimming ability only	Require personal flotation devices (PFDs); conduct quarterly man-overboard (MOB) drills
Weather and sea hazards	Navigation/setting	2	4	High	Sudden squalls, high waves	Skipper experience	Weather-window criteria; pre-trip safety checklist
Eye/facial injuries	Hauling/sorting	3	1	Low–Medium	Recoil of lines, fish spines	Caps only	Provide wrap-around eye protection
Heat stress/dehydration	Day operations	2	2	Low–Medium	Prolonged sun exposure	Drinking water available	Hydration schedule; canopy shading
FAD retrieval entanglement	FAD recovery	2	3	Medium	Fouled lines or submerged debris	Knife available	Telescopic cutting pole; retrieval SOP
Electrical/mechanical hazards	Power-block use	1	4	Medium–High	Snag or short circuit	Skipper oversight	Install guards; lock-out/tag-out procedure
Cold-chain failure/food safety	Post-capture handling	2	2	Low–Medium	Inadequate icing or temp control	Ice carried on board	Implement 3C+Q system; temperature checks
Poor night visibility	Night sets/navigation	2	3	Medium	Insufficient lighting	Basic deck lights	Add headlamps, reflective vests, and horn signals
Bycatch handling injuries	Sorting	2	2	Low–Medium	Contact with spiny bycatch	Gloves (inconsistent)	Species handling cards; mandatory glove use

Note: Frequency Index (FI); Severity Index (SI); Fish Aggregating Device (FAD).

3.5 Safety–sustainability linkages

Two-boat systems can raise catching efficiency and improve maneuvering/situational awareness, yet also compress high-intensity tasks that elevate entanglement and strain risks if coordination falters [29, 30]. In this study, length–frequency profiles show mature-skewed catches for several targets; however, all fish, including individuals < Lm, were retained. Persistent retention of sub-Lm fish is a classic pressure toward growth overfishing and is often exacerbated by small mesh or non-selective settings [31]. If sub-Lm fish increasingly dominate the stock, maintaining the same landed volume will likely require longer time at sea and more sets, thereby increasing exposure to rope burns, slips, and entanglement incidents on wet, cluttered decks [32, 33]. Strengthening release practices for obvious juveniles, aligning mesh to selectivity targets, and scheduling shorter, daily trips can therefore link biological sustainability with reduced accident exposure [34].

3.6 Risk profile and prioritization

Observed injury patterns in comparable fleets are dominated by frequent minor events (rope/hand abrasions, slips) and rare but severe outcomes (man-overboard (MOB), crush injuries) [35, 36]. Applying the FI–SI matrix standardizes prioritization across crews: frequent/moderate injuries receive near-term ergonomic and procedural controls, while low-frequency/high-severity events trigger critical safeguards such as PFD adoption, exclusion zones, and call-and-response during pursing/brailing [37]. This aligns with adaptive, participatory risk assessment that blends local practice with structured tools to reduce subjectivity and sustain compliance [18, 24].

3.7 Operational practices that co-deliver quality, safety, and value

For one-day trips typical of East Java ports, rigorous 3C+Q handling (clean, careful, cool-chain, quick), layered icing, and rapid landing minimize deck time spent on deteriorating fish and reduce knife/fin handling injuries—while protecting freshness, histamine safety, shelf life, and price [38-41]. Where bathymetry is complex, keeping sets off sensitive shallow features lowers snag/entanglement risk and avoids habitat contact, while deeper deployments reduce benthic interactions without shifting risk onto unprepared crews [42]. Finally, aligning mesh size to minimum size regulations helps limit juvenile retention at the source, lowering future effort requirements and cumulative exposure hours. Taken together, these adjustments integrate stock protection with occupational risk reduction—an approach consistent with co-management and continuous improvement in small-scale purse-seine fisheries [43].

4. DISCUSSION

The findings of this study provide significant insights into the complexities of small-scale purse seine operations in East Java, with particular focus on operational risks, safety concerns, and the sustainability challenges these fisheries face. This discussion examines the relationship between selective fishing, seasonal environmental factors, operational safety, and management strategies, providing a comprehensive understanding of the ecological and socio-economic consequences of purse seine operations.

Selective fishing practices, designed to target specific species or size classes of fish, have become integral to enhancing fishery sustainability. However, as highlighted by Kolding et al. [44], the selective removal of certain fish species can inadvertently alter the dynamics of marine ecosystems. In the context of small-scale purse seine fisheries, this phenomenon is evident in the selective targeting of small pelagic species, such as sardines and anchovies, which have been crucial for local food security and livelihoods [26, 44]. While these practices minimize bycatch, they also disrupt marine community structures and may contribute to long-term ecological imbalances. The removal of larger, predatory fish species can result in the unchecked proliferation of smaller species, which in turn affects the ecological balance and reduces the resilience of the entire ecosystem.

In East Java, the tendency to capture fish below their length at first maturity (Lm) is a critical concern. The capture of juvenile fish, particularly under Lm, has implications for the reproductive health of these species, potentially leading to stock depletion and the need for longer fishing trips to achieve the same catch yield. This trend not only puts pressure on the fish populations but also increases the operational time and risks associated with these longer trips, thereby compromising both sustainability and safety [44]. Furthermore, the lack of release for undersized fish further exacerbates the risk of overfishing, presenting a fundamental challenge for future fisheries management.

Seasonal and environmental factors, particularly oceanographic variability, have profound effects on school behavior, bycatch levels, and operational safety in purse seine fisheries. Oceanographic conditions such as temperature, salinity, and nutrient availability influence the behavior of target fish species, leading to variations in fish distribution and school dynamics [45]. Upwelling zones and areas with mesoscale activity often exhibit higher prey availability, causing fish to aggregate around these productive regions, making them prime locations for purse seine operations [46]. However, the presence of Fish Aggregating Devices (FADs), while enhancing catch rates, also increases bycatch rates by attracting non-target species [15]. This seasonality in fish availability and bycatch levels must be considered when assessing the long-term ecological impacts of purse seine fishing in coastal waters.

Operational safety is directly influenced by seasonal changes in weather patterns, including the occurrence of storms and monsoons [47]. During adverse weather conditions, fishers are exposed to heightened risks, including capsizing, injuries from gear mishandling, and drowning. The unpredictability of weather can force fishers into dangerous situations, exacerbating safety hazards onboard. Furthermore, shifts in oceanographic conditions can alter the behavior of fish schools, requiring fishers to adjust their operational patterns and gear deployment methods [30]. The dynamic nature of seasonal and environmental changes underscores the importance of adaptive management strategies that can address these fluctuating risks [48].

Incorporating risk matrices, hazard identification tools, and the Frequency-Severity Index (FSI) approach has proven effective in evaluating operational risks in small-scale purse seine fisheries. By categorizing accidents according to their frequency and severity, fishers and managers can prioritize high-risk areas and implement safety interventions. The data collected using these frameworks provides a clear picture of the most critical hazards, such as slips and falls, rope burns, entanglement, and weather-related accidents, which commonly occur onboard small-scale fishing vessels [33, 49]. The combination of risk indices enables stakeholders to design targeted safety training and risk mitigation strategies that improve crew members' well-being while reducing the occurrence of accidents during operations.

Furthermore, risk matrices allow for continuous evaluation of safety interventions. By tracking changes in injury rates after implementing safety measures, stakeholders can identify effective practices and areas requiring further attention [50]. This iterative process supports the continuous improvement of operational safety within small-scale fisheries, reinforcing the role of comprehensive risk management in achieving sustainable fisheries practices [23].

The integration of participatory governance and adaptive management strategies is essential for enhancing both safety and sustainability outcomes in small-scale fisheries. By involving fishers in the decision-making process, local knowledge and insights can be incorporated into the development of safety protocols and sustainable management practices. This collaborative approach fosters a sense of ownership and responsibility among fishers, ensuring that safety measures are adhered to and that resource management practices align with local realities [43].

Adaptive management strategies enable fisheries to respond flexibly to changing environmental conditions, stock availability, and socio-economic pressures. These strategies allow for the continuous adjustment of fishing practices based on real-time data and observations, improving safety protocols and ensuring ecological sustainability. The application of adaptive management frameworks, in conjunction with local knowledge, facilitates the creation of safety systems tailored to the specific needs of small-scale purse seine fisheries, enhancing both the safety and economic stability of fishing communities.

Long-term climate change may further amplify the safety risks identified in this study by altering sea-state conditions and narrowing safe weather windows for small-scale purse seine trips. As wind, wave, and rainfall extremes become more frequent, fishers may face greater exposure to rough-sea operations and time-pressure to complete sets during short “weather windows,” which can increase the likelihood of high-consequence events such as MOB and other weather-related incidents, as well as secondary risks (fatigue, slips, and entanglement) during hurried hauling and sorting. Although this study did not model climate trends, these results suggest that port-level safety management should be adaptive—periodically re-evaluating FI–SI priorities by season/year, strengthening go/no-go criteria and pre-trip checklists, and reinforcing critical controls (personal flotation device (PFD) use, MOB drills, and weather-informed decision-making protocols) to maintain both occupational safety and operational sustainability under increasingly variable conditions.

5. CONCLUSIONS

This study highlights the significant risks and safety challenges faced by small-scale purse seine fisheries in East Java, focusing on operational hazards, bycatch issues, and the ecological impacts of selective fishing practices. The findings show that while selective fishing methods have been designed to improve sustainability, they often inadvertently cause shifts in marine community structures and reduce genetic diversity, which may impact the long-term health of fish stocks. Moreover, seasonal environmental factors, such as oceanographic variability, further complicate the safety of fishing operations and increase the likelihood of accidents at sea.

The study contributes to the existing body of knowledge by integrating risk management frameworks with participatory governance strategies, offering practical recommendations for improving safety outcomes and ensuring the sustainability of these fisheries. The use of risk matrices and adaptive management approaches could help mitigate operational risks and enhance the resilience of fishing communities. Future research should focus on refining these safety management frameworks and exploring the impacts of climate change on the safety and sustainability of small-scale fisheries in the region.

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APPENDIX

Table A1. Accident severity scale (Severity Index (SI))

SI	Descriptor	Medical Outcome and Lost Time	Typical Examples in Purse-Seine Operations
1	Very minor	First-aid only; no lost time	Superficial rope burn; small abrasion; minor eye splash with no corneal injury
2	Minor	Outpatient/clinic treatment; ≤ 1 day restricted duty	Deeper cut from fish spine/knife; mild sprain/strain from hauling; minor slip without impact trauma
3	Moderate	Medical treatment; 1–3 days lost or restricted duty	Entanglement causing moderate laceration or contusion; back strain requiring rest; slip/fall with bruising
4	Major	Hospitalization and/or > 3 days lost time; temporary disability	Fracture or dislocation from fall; severe cut requiring sutures; crush injury in power-assisted hauling
5	Severe	Permanent disability or fatality	Man-overboard (MOB) drowning; severe head injury; amputation or life-threatening trauma

Table A2. Accident frequency categories (Frequency Index (FI))

FI	Descriptor	Approximate Frequency Benchmark	Data Anchor and Examples
1	Very rare	≤ 1 event per 1,000 trips (or < 1 per fleet-year)	Unprecedented events in logs; e.g., catastrophic mechanical failure causing injury
2	Rare	> 1 per 1,000 up to 1 per 100 trips	Isolated seasonally: e.g., FAD retrieval entanglement incident; moderate weather-related injury
3	Occasional	> 1 per 100 up to 1 per 20 trips	Intermittent: e.g., knife cuts during sorting; isolated back strains
4	Frequent	> 1 per 20 up to 1 per 5 trips	Common: e.g., rope burns during pursing/hauling; minor slips on wet deck
5	Very frequent	≥ 1 per 5 trips (multiple per month for active vessels)	Recurrent: e.g., minor hand abrasions during net handling; eye/facial splash from scales