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# Marine Waste Supply Management in Fishing Vessel Activities: A Study at the Nizam Zachman Ocean Fishing Port, Jakarta, Indonesia

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**Abstract:** This study examines the potential waste generation from medium-scale fishing vessels (30–100 GT) operating at the Nizam Zachman Ocean Fishing Port (PPSNZ) in Jakarta Bay and analyzes existing practices and regulatory gaps in marine waste management. The results indicate that provisioning activities are the primary source of plastic-based waste, including wrappers, bottles, and containers. The findings revealed that most vessels lacked onboard waste-handling systems and failed to return waste to port facilities, thereby contributing to unmonitored marine debris in coastal waters. Moreover, the regulatory framework for vessel waste management in Indonesia was fragmented and did not adequately address the operations of medium-scale vessels. Inadequate infrastructure, limited enforcement capacity, and low environmental awareness among crew members further hindered compliance. This study highlights the urgent need for vessel-specific waste return policies, the adoption of digital reporting systems, and the provision of adequate port reception facilities. It also emphasizes the importance of incentive-based compliance mechanisms, such as reduced port fees for vessels that return waste, and underscores the broader need to strengthen port governance in order to support a more inclusive marine waste management system aligned with Sustainable Development Goal (SDG 14).

**Keywords:** Fishing activities; Marine debris; System dynamics modeling; Waste management

## 1 Introduction

Marine debris is a global environmental issue receiving increasing attention due to its significant impact on the sustainability of marine ecosystems and the biota within them [1]. It is defined as solid waste originating from human activities that is intentionally or unintentionally discarded into marine and coastal environments [2]. This issue has become a key agenda item at various international forums, including the United Nations Ocean Conference, the Marine Debris Summit, and the World Ocean Summit [3]. As the second-largest archipelagic country contributing to marine plastic waste after China, Indonesia has set a national target to reduce plastic waste by 70% by 2025 and to achieve zero plastic pollution by 2040, as part of its commitment to the Sustainable Development Goals (SDGs) [4]. This global momentum has encouraged many countries to strengthen marine governance and onboard waste regulations. Nevertheless, Indonesia continues to face major implementation challenges, particularly in integrating vessel-based waste management into its national marine pollution framework.

Most marine debris originates from land; however, contributions from marine activities, particularly fishing, cannot be overlooked [5]. According to Chen and Liu [6], land-based sources account for approximately 80% of waste entering the sea, while maritime activities contribute the remainder, especially those associated with fishing vessels. As outlined in Annex [7], ships are recognized as sources of various types of waste, including plastics, food waste, domestic waste, operational waste, and fishing gear. However, most fishing vessels in Indonesia, particularly those under 100 GT, lack clear legal obligations regarding waste management [8]. Inconsistencies in national regulations, such as differing vessel size thresholds specified in Ministry of Transportation Regulation No. 29 of 2014 [9], Ministry of Marine Affairs and Fisheries Regulation No. 33 of 2021 [10], and MARPOL 73/78 [7], highlight policy gaps in managing waste from small- and medium-sized fishing vessels. These discrepancies reflect a fragmented regulatory landscape in which medium-sized vessels are effectively excluded from mandatory waste-handling protocols despite their significant operational footprint. This represents a critical shortcoming in Indonesia's marine environmental policy.

Waste generated from fishing vessel activities directly pollutes the marine environment and disrupts the ecological and economic balance of coastal communities [11]. Plastic waste can entangle or be ingested by marine organisms, leading to internal injury, population decline, and the accumulation of microplastics within the marine food chain [12, 13]. The behavior of fishing crews, who frequently dispose of waste at sea due to limited environmental awareness and inadequate waste management facilities on board or at ports, further exacerbates the problem [14]. Previous research indicates that only about 1% of crew members return waste to port [15], underscoring low environmental awareness and weak oversight systems at sea. These behavioral and infrastructural challenges demonstrate how the absence of vessel-specific regulations contributes to widespread non-compliance and uncontrolled waste disposal.

The Nizam Zachman Ocean Fishing Port (PPSNZ) in Jakarta Bay is one of the largest and most operationally active fishing ports in Indonesia, with 1,584 vessels of 30 GT currently operating [16]. The port plays a pivotal role in the distribution of marine catch and serves as a hub for marine economic activities. However, its waste management capacity remains focused on land-based waste and has yet to incorporate a comprehensive system for ship-generated waste. The polluted port environment, coupled with the absence of adequate ship waste treatment facilities, underscores the urgency of reformulating a port-based waste management strategy [17]. Given its national significance, PPSNZ provides a strategic case for examining the intersection of regulatory limitations, operational waste behaviors, and infrastructure constraints.

The present study addresses this knowledge gap by estimating the potential waste generated from fishing vessel activities, particularly those related to provisions carried during voyages. The analysis focuses on vessels in the 30–100 GT class, which occupy a regulatory gray area in waste management despite their substantial contribution to national fisheries production. To date, no empirical data exist on the waste volumes generated by this vessel segment, nor are there targeted policy instruments to mitigate their cumulative pollution impacts. The volume of waste produced by vessels is significantly affected by crew size and voyage duration, as longer trips require greater supplies and inevitably result in increased waste generation. Accordingly, this study examines the potential for waste generation and the prevailing practices of marine waste management within this context.

## 2 Method

### 2.1 Research Design

This study employed a descriptive quantitative design to estimate the potential waste generated from fishing vessel activities at PPSNZ. The primary objective was to calculate the volume of waste produced during fishing voyages, taking into account the number of crew members, voyage duration (trips), and the types of fishing gear used. Waste was classified according to the categories outlined in MARPOL Annex V [7]: plastics, metals, paper, and other domestic residues. The study focused on vessels within the 30–100 GT category due to their regulatory ambiguity and operational significance. Although these vessels contribute substantially to fishery production, they fall below the 500 GT threshold that is typically subject to international and national waste management regulations. This regulatory gap positions them as a relevant yet underexplored subject for empirical investigation.

Structured questionnaires were used as the primary data collection tool, ensuring uniformity across respondents and enabling the generation of comparable quantitative data on waste production, provisioning patterns, and crew practices. This method also minimized interviewer bias and facilitated subsequent statistical analyses.

### 2.2 Research Location and Period

The research was conducted at PPSNZ, located in Jakarta Bay, Penjaringan District, North Jakarta (see Figure 1). PPSNZ is Indonesia's largest ocean fishing port in terms of vessel activity, landing volume, and strategic economic value. The port functions as a central hub for industrial and medium-scale fisheries, accommodating more than 1,500 fishing vessels, approximately 447 of which fall within the 30–100 GT category targeted in this study. The site was selected due to its critical role in national fishery logistics, proximity to urban markets, and high susceptibility to marine debris accumulation. Moreover, PPSNZ represents coastal ports in developing countries that face pressures from intensive fishing activities and limited waste management infrastructure. Data collection was conducted from March to September 2024, covering both the east and west monsoon periods. This timeframe was deliberately chosen to capture seasonal variations in fishing activities, vessel frequency, and waste generation patterns, thereby providing a more comprehensive representation of annual operational dynamics and waste outputs.

The spatial location of PPSNZ along Jakarta's heavily urbanized northern coast places it at the confluence of land-based and marine pollution sources, making it an appropriate site for assessing ship-generated waste within a complex environmental and regulatory context.


**Figure 1.** Location of the Nizam Zachman Ocean Fishing Port (PPSNZ) in Jakarta Bay

### 2.3 Population and Sampling Technique

The target population in this study comprised fishing vessels in the 30–100 GT class that were actively operating at PPSNZ and held a valid Fishing Permit issued by the Ministry of Marine Affairs and Fisheries. According to the official vessel registry of the PPSNZ Port Authority, a total of 447 active vessels met these criteria during the study period. To obtain a statistically valid and representative sample, the study applied a probability sampling approach using simple random sampling, ensuring that each vessel had an equal likelihood of selection. The sample size was determined using the Krejcie and Morgan formula, a widely recognized method for calculating sample size from a finite population. This formula incorporates key statistical parameters such as population size, confidence level, and margin of error. Using a 95% confidence level and a 5% margin of error for a population of 447 vessels, the minimum required sample size was calculated to be 210 vessels. The final sample size was increased to 214 vessels to account for potential non-response or incomplete data. The unit of analysis in this study was the primary operational crew member on board, specifically the captain or crew leader, who was directly responsible for provisioning logistics, consumption decisions, and waste disposal practices during fishing voyages. These individuals were selected as respondents due to their managerial roles and comprehensive knowledge of vessel operations, making them reliable informants for assessing waste generation behaviors and decision-making processes. This sampling approach ensures that the data are representative and relevant for understanding waste patterns within the operational context of Indonesia's medium-scale fishing fleet.

### 2.4 Data Collection Techniques

Data were collected using a structured questionnaire administered to selected crew members. The questionnaire captured quantitative information on: (1) the number of crew members and voyage duration; (2) the types and volumes of logistical supplies brought on board; (3) the types and quantities of waste generated during voyages; and (4) waste handling and disposal practices. Secondary data were obtained from official documents of the PPSNZ Port Authority and the Ministry of Marine Affairs and Fisheries, as well as from recent statistical reports and fisheries-related policy documents.

### 2.5 Data Processing and Analysis Techniques

Data were analyzed descriptively using Microsoft Excel and SPSS software. Waste generation estimates were calculated by comparing the volume of supplies loaded onto vessels at departure with the volume of waste returned upon arrival.

In cases where waste was not returned, the consumed supplies were assumed to have been discarded at sea. Waste was categorized according to material composition (i.e., plastic, paper, metal, and organic) and analyzed in terms of weight (kg), type, and frequency of occurrence per trip. Annual estimates were derived by multiplying the average waste generated per trip per vessel by the average number of voyages conducted annually for each vessel category and fishing gear type.

### 2.6 Waste Generation Estimates

Waste generation estimates were based on the difference between the amount of potential waste, derived from the supplies carried by each vessel upon departure, and the waste physically returned to port. If no waste was returned, it was assumed that the entire volume of consumed supplies had been disposed of at sea. Waste types were identified through direct visual observation and subsequently validated through crew interviews. Waste was classified according to material type (plastic, paper, metal, and organic), weight, and frequency of use during a single voyage. The estimation model incorporated two key factors, namely voyage duration and crew size, as both significantly affect the quantity of provisions consumed and the volume of waste generated.

### 2.7 Comparative Review of International Ship Waste Management Practices

A comparative analysis of international ship waste management practices demonstrates significant variation in policy effectiveness, institutional capacity, and compliance mechanisms across countries. Reviewing these practices provides valuable insights for contextualizing Indonesia's regulatory framework and identifying best practices that may inform national policy reform. In Norway, ship-generated waste management, including waste from fishing vessels, is governed by a comprehensive legal and operational framework. Compliance with MARPOL Annex V is reinforced through national legislation that mandates the provision and use of port reception facilities (PRFs) for vessels of all sizes. The implementation of the "No Special Fee System", in which waste disposal costs are embedded within port service fees, has significantly improved compliance by eliminating financial disincentives for waste return. In addition, routine inspections and a centralized waste tracking mechanism, administered by the Norwegian Environment Agency, enhance transparency and strengthen enforcement of onboard waste-handling protocols [18].

In Japan, regulatory enforcement is integrated with cooperative-based monitoring systems, resulting in high compliance among fishing vessels. Port authorities, in collaboration with fisheries cooperatives, implement waste return incentive schemes that subsidize the provision of onboard waste storage containers, compactors, and sorting bins. Furthermore, digital waste monitoring platforms allow the central government to collect disaggregated data on waste types and volumes by port and fleet segment. This system has enabled Japan to implement targeted interventions and refine marine waste policies over time [19]. Taiwan enforces shipboard waste management through its Fisheries Agency, which requires vessels to submit logbooks containing detailed records of provisioning supplies and waste generated during voyages. Compliance is further supported by periodic inspections and localized training programs for vessel crews. Importantly, smaller vessels are not exempt from these requirements. Instead, waste-handling procedures are adapted to vessel size, thereby promoting inclusive enforcement without undermining ecological objectives [20]. By contrast, Indonesia's regulatory framework remains underdeveloped in several key areas related to vessel-based waste management, particularly for medium-sized fishing vessels in the 30–100 GT category. Although Indonesia has ratified MARPOL Annex V and incorporated its provisions into national regulations, such as Ministry of Transportation Regulation No. 29 of 2014 and Ministry of Marine Affairs and Fisheries Regulation No. 33 of 2021, these instruments differ in definitions, enforcement standards, and compliance thresholds. Consequently, medium-scale vessels are often excluded from formal waste management obligations, and no mandatory systems currently exist for onboard waste storage, waste logbooks, or port-based waste return. This regulatory ambiguity creates a significant governance gap, allowing a substantial portion of the fishing fleet to operate without adequate oversight or accountability regarding waste discharge.

Moreover, infrastructure constraints exacerbate the issue. Unlike ports in Norway and Japan, which maintain dedicated PRFs capable of receiving, sorting, and processing multiple waste streams, major Indonesian fishing ports such as PPSNZ continue to prioritize land-based municipal waste, with minimal integration of ship-generated waste systems. This infrastructural limitation hampers proper waste disposal and reduces incentives for voluntary compliance among vessel operators. The experiences of other maritime nations highlight several actionable strategies that could be adapted to the Indonesian context. These include: (1) establishing mandatory requirements for onboard waste storage and segregation for all vessels exceeding 30 GT; (2) integrating waste logbooks into the fishing permit system to support routine monitoring and reliable data collection; and (3) developing port-based reception and reporting infrastructure, coupled with economic incentives for waste return and stricter penalties for non-compliance. Such reforms would align Indonesia's practices with international standards while strengthening its commitment to marine pollution reduction, sustainable fisheries management, and the achievement of SDG 14 (Life Below Water).

## 3 Results

### 3.1 Waste Generation by Vessel Size

Fishing vessel operations at PPSNZ were found to generate substantial amounts of waste, primarily originating from the packaging of logistical supplies and consumables used by crew members during voyages. The most frequently encountered waste types included plastic sacks, food and beverage wrappers, jerry cans, plastic bottles, cigarette filters, and paper. These findings align with the categories outlined in MARPOL Annex V and reflect the strong reliance of fishing operations on single-use packaging and plastic-based products. Based on field measurements, plastic food wrappers accounted for the largest share of waste generated, reaching an estimated 6.46 tons per trip. This was followed by plastic jerry cans (6.26 tons per trip) and cigarette filters and paper products (4.36 tons per trip). The breakdown of total waste by type for vessels sized 30–100 GT is presented in Figure 2.

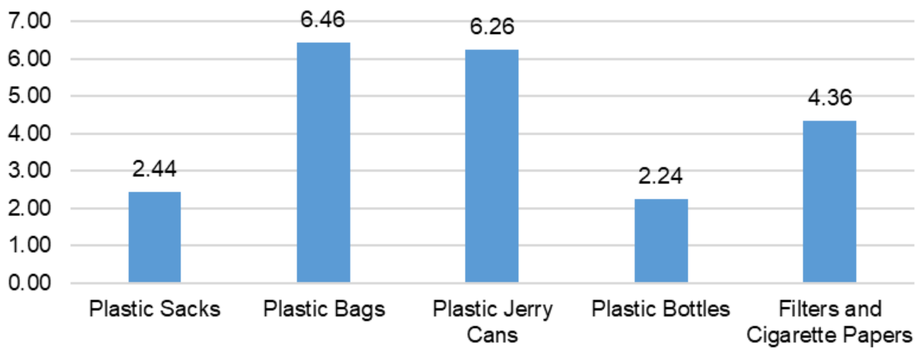


**Figure 2.** Total waste potential from fishing vessels of 30–100 GT by waste type (tons/trip)
Source: Researchers, processed in 2024.

When analyzed by vessel size, waste generation exhibited a clear increasing trend. Vessels in the 30–60 GT category produced an average of 49.37 kg of waste per trip, while vessels in the 61–100 GT category generated approximately 54.29 kg per trip. This difference is primarily due to the larger storage capacity and longer voyage durations of larger vessels, which require greater quantities of supplies and generate higher volumes of waste. The average waste values per trip by vessel size are shown in Figure 3.

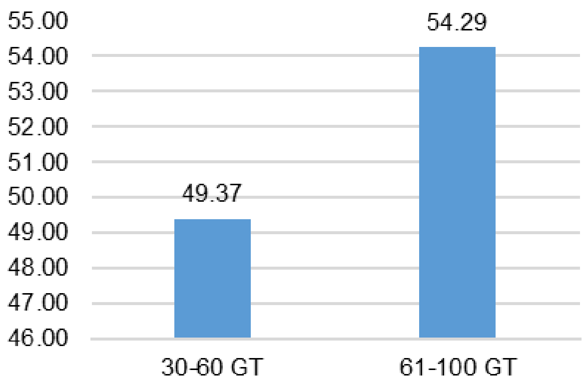


**Figure 3.** Average waste from fishing activities (kg/trip/vessel)
Source: Researchers, processed in 2024.

The estimation of annual waste generation, based on the average waste produced per trip and the frequency of sailing operations, revealed a significant contribution from fishing vessels to marine pollution. Specifically, vessels in the 30–60 GT category were estimated to generate between 19.16 and 28.73 tons of waste per year, with a mean value of 23.95 tons/year. In contrast, vessels in the 61–100 GT category exhibited even higher outputs, ranging from 23.65 to 35.47 tons/year, with an average of 29.56 tons/year. These projections, presented in Figure 4, provide a comparative overview of total annual waste output across vessel size categories. The findings highlight the disproportionately high contribution of medium-sized fishing vessels to marine waste, particularly plastic waste, which poses long-term ecological risks in semi-enclosed waters such as Jakarta Bay. Given their frequent operational cycles and extended voyage durations, vessels in this class represent a critical yet under-regulated source of ocean pollution. Furthermore, the high levels of waste generation documented in this study reveal a clear mismatch between current waste production trends and existing port-based waste handling capacities. Facilities such as PPSNZ often lack adequate infrastructure, enforcement mechanisms, and institutional protocols to effectively capture, process, or monitor waste returned from vessels in this segment. This gap increases the likelihood of direct waste discharge into the sea, exacerbating the environmental burden and undermining Indonesia's marine conservation targets.

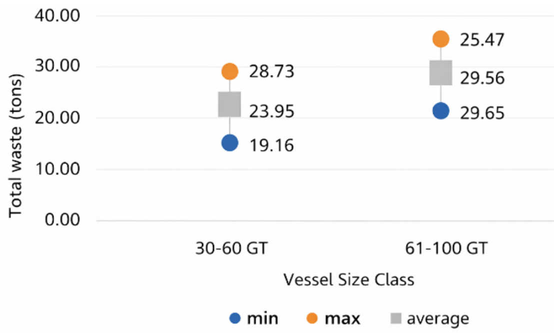


**Figure 4.** Total annual waste potential from fishing vessels by size category (tons/year)
Source: Researchers, processed in 2024.

These results are broadly consistent with findings from previous studies conducted in other regions. For instance, Lee et al. [20] reported that Taiwanese coastal fishing vessels under 100 GT, typically operating on shorter voyages of 2–3 weeks with 5–12 crew members, generated approximately 22.5 kg of waste per trip, which is less than half of the average recorded in this study. In the Barents Sea, Silber and Adams [21] found that vessels in the 100–500 GT category produced around 45–60 kg per trip, with volumes significantly affected by voyage duration and onboard storage capacity. Meanwhile, in small-scale fisheries in Pangandaran, Indonesia, Purba et al. [22] estimated waste generation at only 12.7 kg per trip for vessels below 30 GT, reflecting their shorter voyage durations of 3–5 days.

This cross-regional comparison demonstrates that vessels operating out of PPSNZ, although classified as medium-scale, generate waste at intensities comparable to, or even exceeding, those of larger fleets in other regions. This trend is closely linked to their prolonged voyages, which may last up to four months, as well as the absence of institutionalized waste segregation, storage, and return mechanisms on board. These findings indicate a critical need for policy interventions that incorporate medium-scale fishing vessels into Indonesia's maritime waste governance framework. Measures such as mandatory waste logbooks, standardized onboard handling protocols, and structured port-based waste return systems are essential to mitigate this unmanaged source of marine debris.

In contrast to larger vessels, which are subject to more stringent MARPOL compliance requirements, many Indonesian medium-scale fishing vessels remain largely outside formal regulatory oversight. As a result, their waste output constitutes a regulatory blind spot that significantly exacerbates marine pollution in coastal areas such as Jakarta Bay [23]. Overall, the analysis confirms that vessel size is a strong predictor of marine waste generation, particularly when combined with operational variables such as voyage frequency and provisioning needs. These insights underscore the importance of extending robust waste management policies and infrastructure to medium-scale vessels, which are currently under-regulated but contribute substantially to environmental degradation.

### 3.2 Waste Generation by Type of Fishing Gear

Waste generation by fishing vessels also varied significantly by the type of fishing gear used. Different gear types correspond to specific fishing methods, crew activities, and provisioning practices, all of which affect the volume and composition of waste produced. The analysis revealed that, within the 30–60 GT category, vessels equipped with squid jigging gear generated the highest amount of waste, averaging 61.94 kg per trip, whereas those using tuna longline gear produced only 37.66 kg per trip. Similarly, in the 61–100 GT category, small pelagic purse seiners recorded the highest waste generation at 72.77 kg per trip, while tuna longliners again generated the lowest, at 38.60 kg per trip. These variations, as illustrated in Figure 5, highlight the effect of fishing practices and gear configurations on waste output.

The observed disparity in waste volumes can be explained by the operational characteristics associated with different fishing gear types. Purse seine and squid jigging vessels generally undertake longer voyages, require larger quantities of bait and ice, and rely heavily on single-use packaging for food and provisions. These factors, combined with larger crew sizes and continuous harvesting practices, contribute to higher levels of both organic and plastic waste. In contrast, tuna longliners typically operate with smaller crews, use more selective fishing methods, and target high-value species across broader fishing areas. Their gear deployment and retrieval processes are less frequent, which reduces packaging turnover and overall material consumption on board. These results are consistent with previous studies. For instance, Grøsvik et al. [18] reported that waste generation in the Barents Sea varied not only by vessel size but also by gear type, with trawlers and longliners producing less daily waste per crew member compared to vessels using seine nets. Similarly, in Taiwan, Richardson et al. [24] observed that vessels employing gillnets or longlines generated lower waste volumes than those engaged in purse seining, which requires more intensive provisioning and frequent gear handling. In the Indonesian context, Wibawa [25] emphasized that differences in both waste types and quantities across artisanal fishing vessels were strongly influenced by fishing methods and trip duration, significantly affected than vessel tonnage alone.

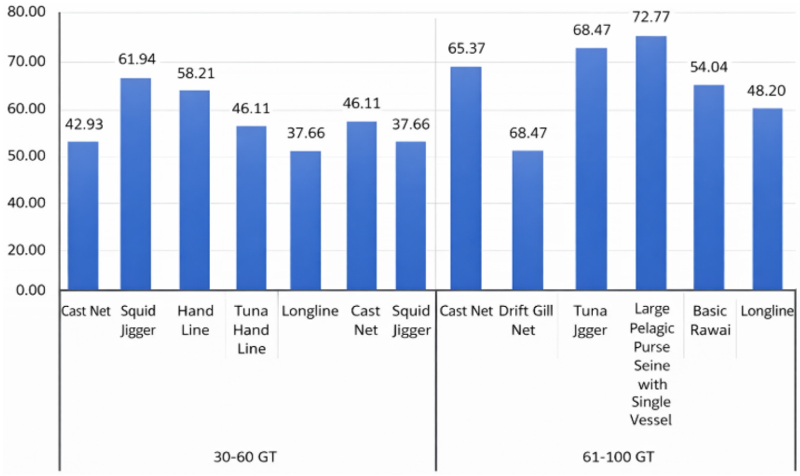


**Figure 5.** Estimated average waste from fishing vessels by gear type (kg/trip/vessel)

Source: Primary data, processed by the researchers, 2024.

Collectively, these findings highlight that fishing gear type is a critical determinant of waste generation behavior. Despite this, current waste management regulations in Indonesia rarely differentiate between specific fishing methods or operational practices [26]. This study underscores the importance of adopting gear-specific interventions, such as tailored waste-handling protocols for squid jigging and pelagic purse-seine fleets, which were identified as producing the largest waste volumes. Furthermore, incorporating fishing gear categories into port-based waste monitoring systems could improve enforcement of waste return requirements and optimize the allocation of waste management facilities, such as bins, compactors, and segregation units [27]. Such targeted approaches are particularly crucial in high-volume fishing hubs such as PPSNZ, where diverse fleet compositions and operational practices intensify the environmental challenges associated with marine waste.

### 3.3 Operational Factors Affecting Waste Generation

Operational characteristics, particularly crew size and voyage duration, were found to exert a direct effect on the volume and composition of waste generated aboard fishing vessels. Analysis of primary data from 214 vessels in the 30–100 GT category showed that most vessels operated with 10–18 crew members and undertook voyages averaging four months. These two parameters were strongly correlated with waste output per trip. Specifically, larger crew sizes and longer voyages significantly increased the consumption of logistical supplies (e.g., food, drinking water, and packaging materials), thereby generating greater quantities of plastic wrappers, bottles, jerry cans, and organic waste. These findings are consistent with previous studies. Lee et al. [20] reported that waste generation from Chinese fishing vessels was closely related to provisioning requirements and operational duration. Similarly, Silber and Adams [21] found that limited onboard storage during extended voyages in the Barents Sea often led to illegal waste disposal at sea.

A comparative summary of waste generation across different regions and vessel characteristics is presented in Table 1.

**Table 1.** Comparative waste generation from fishing vessels based on operational characteristics

| Location/Study | Vessel Size and Voyage | Crew Size | Waste Generation (kg/trip) |
|---|---|---|---|
| PPSNZ, Jakarta (This study) | 30–100 GT, ∼4 months | 10–18 | 49.37–54.29 |
| China [20] | <100 GT, 2–3 weeks | 5–12 | ∼22.5 |
| Norway [21] | 100–500 GT, 1–2 months | 8–20 | ∼45–60 |
| Pangandaran, Indonesia [22] | <30 GT, 3–5 days | 3–6 | ∼12.7 |

These cross-regional comparisons reinforce the conclusion that waste generation scales with operational intensity rather than solely with vessel tonnage. Vessels undertaking longer voyages with larger crews tend to generate greater volumes of waste due to increased consumption [28]. Importantly, this study provides novel empirical evidence from PPSNZ, Indonesia's largest fishing port, where data on vessel-based waste generation have previously been scarce. The findings indicate that medium-scale vessels (30–100 GT) in PPSNZ produce waste volumes exceeding those of smaller vessels (e.g., <30 GT in Pangandaran) and approaching levels observed in larger international fleets. This suggests that medium-scale fishing vessels, despite being largely excluded from stringent MARPOL regulations, represent a critical regulatory blind spot with significant implications for marine environmental sustainability.

## 4 Discussion

The results of this study indicate that waste generated from fishing vessels at PPSNZ has reached a considerable level, with plastics such as food wrappers, bottles, sacks, and jerry cans emerging as the dominant waste type. Most of this plastic originates from crew consumption activities. These findings are consistent with previous studies, which have identified plastic as the primary component of marine debris in tropical coastal areas [29, 30]. In addition to plastic waste, food residues and other domestic waste also contributed substantially, particularly on vessels with larger crew sizes and longer voyage durations.

Two main factors were found to affect waste generation: the number of crew members and the voyage length. A larger crew on board and longer fishing trips lead to higher consumption of supplies, which, in turn, increases waste production. This finding supports environmental behavior theory [31], which posits that individual consumption behavior in closed systems, such as vessels, is directly associated with the volume of waste generated. Within this framework, crew members function not only as operational actors but also as the primary sources of waste generation.

From a regulatory perspective, ship-generated waste management is formally governed by MARPOL Annex V [7] and has been incorporated into national policies, including Ministry of Transportation Regulation No. 29 of 2014 [9] and Ministry of Marine Affairs and Fisheries Regulation No. 33 of 2021 [10]. However, implementation remains limited in practice. Vessels below 500 GT, particularly those in the 30–100 GT range that were the focus of this study, are not yet strictly required to provide onboard waste management facilities. This regulatory gap contributes to low compliance with marine waste management practices. In contrast, countries such as Norway and Japan require vessels to maintain onboard waste logs, return all waste to PRFs, and provide economic incentives to promote compliance. The absence of integrated enforcement mechanisms and adequate infrastructure in Indonesia has weakened the effectiveness of existing regulations, leaving medium-scale fishing vessels largely unregulated.

Furthermore, most surveyed crew members reported rarely returning waste to port. Instead, waste is commonly disposed of at sea, primarily due to limited onboard storage capacity and insufficient monitoring. This finding reinforces the argument that the current port management system remains overly focused on land-based waste and has not yet fully adopted an integrated, port-based approach to waste management. Beyond structural limitations, behavioral factors also play a critical role in shaping these practices. According to the theory of planned behavior, individual actions are affected by attitudes, for example, the perception that returning waste is burdensome, subjective norms, such as minimal social pressure to comply, and perceived behavioral control, including limited knowledge or resources for waste management. These dimensions help explain the normalization of sea dumping and highlight that regulatory frameworks alone may be insufficient without complementary behavioral interventions.

These findings highlight the urgency of policy reforms addressing several key areas. First, there is a need to develop and enforce technical guidelines for onboard waste management, including digital reporting systems and standardized waste processing procedures, particularly for vessels in the 30 to 100 GT class. Second, locally based educational curricula should be integrated into fisheries crew competency certification programs, complemented by regular training on waste management practices. Third, the implementation of a Return Waste Policy (RWP) is essential, requiring vessels to document and return all waste to PRFs upon arrival. Fourth, the development of visual and digital communication media is necessary to raise awareness and reinforce compliance among fishing crews. Fifth, the supervisory role of port authorities in maritime environmental protection should be strengthened, in accordance with Government Regulation No. 27 of 2021 [32]. Sixth, economic incentives should be provided for vessels that consistently return waste to land-based facilities [19]. In addition to regulatory and infrastructural measures, behavioral interventions are crucial for achieving sustainable outcomes. Strategies such as peer accountability mechanisms, onboard visual reminders, and reward-based compliance systems can complement formal policies by directly affecting crew behavior.

Waste management policies that are purely reactive, such as ocean cleanup initiatives, have proven to be costly and unsustainable. Preventive approaches grounded in crew behavior should therefore be prioritized. In this context, the integration of the theory of planned behavior [33], as discussed in the dissertation, is essential for understanding the behavioral intentions of crew members. Attitudinal factors, social norms within the ship community, and perceived behavioral control collectively affect whether crew members are willing to return waste to port. Targeted behavioral interventions, reinforced through education, communication, and onboard leadership, can foster long-term reductions in at-sea waste disposal.

The effects of waste generation extend beyond ecological concerns to include significant socio-economic consequences. Waste discharged into the sea can pollute the waters of Jakarta Bay, which serves as a critical national fishing route [34]. Plastic that fragments into microplastics may enter the marine food chain and pose risks to human health [35]. Furthermore, a poor environmental reputation of the port can diminish the market value of fishery products, particularly in export markets [36]. Declining environmental quality may also reduce fish abundance, disproportionately affecting small-scale fishers who depend on nearshore fishing grounds. In addition, reputational damage to Indonesian seafood in international markets, especially those with traceability standards, may pose long-term economic risks.

This situation also undermines the government's blue economy agenda, as the sustainability of marine ecosystems is a fundamental prerequisite [37]. As outlined in Law No. 32 of 2009 [38] and the triangular sustainability theory [39], sustainable development requires synergy among environmental, economic, and social dimensions in marine resource management. Compared with countries such as Norway, Japan, and Taiwan, which have implemented mandatory waste-return policies, digital monitoring systems, and well-developed port reception facilities, Indonesia's regulatory framework remains fragmented and weakly enforced. These international examples underscore the urgency of developing integrated, vessel-specific policies alongside infrastructure improvements to support compliance and reduce marine pollution in the fisheries sector.

## 5 Limitations

This study has several limitations that should be acknowledged. First, waste generation estimates were based on self-reported data from crew members via questionnaires and interviews, making them susceptible to perception bias and inaccuracies in reporting waste quantity and composition. Second, no direct onboard measurements were conducted during voyages, which limited the ability to empirically verify waste generation, storage, and disposal practices. Third, the study was constrained by time and location, which limits the generalizability of the findings, as they may not fully represent conditions at other fishing ports in Indonesia, particularly those with different geographical characteristics, vessel types, and operational practices.

## 6 Conclusion

This study demonstrates that fishing vessels of 30–100 GT operating in PPSNZ generate substantial waste, with plastic as the dominant component. Most plastic waste originates from crew consumption, including food wrappers, jerry cans, and bottles. The average waste generated per trip ranged from 49.37 to 54.29 kg, while the estimated total annual waste from vessels in this class ranged from 19.16 to 35.47 tons. Factors such as vessel size, crew size, fishing gear type, and voyage duration significantly influenced waste generation. However, most vessels lacked adequate storage facilities and onboard waste management systems.

These findings reveal critical gaps in ship waste management policies and practices in Indonesia, particularly for medium-sized vessels that are not yet required to implement onboard waste treatment systems. Limited port supervision, the absence of incentives for waste return, and low environmental awareness among crew members contribute to the direct discharge of waste into the sea. If left unaddressed, this issue may exacerbate marine pollution in strategic coastal areas such as Jakarta Bay and hinder Indonesia's efforts to advance a blue economy and achieve SDG 14 (Life Below Water).

Accordingly, this study recommends systemic reform of ship waste management policies. The government should develop and enforce technical guidelines for onboard waste handling, digital reporting, and waste processing for vessels within the 30–100 GT class. In addition, locally tailored educational curricula should be integrated into fishing crew certification programs, supported by regular training on waste management practices. To enhance compliance, practical incentives such as reduced port service fees or priority berthing for vessels that return waste to port reception facilities should be introduced. When combined with stricter supervision, these economic instruments can encourage behavioral change among vessel operators and align operational practices with environmental objectives. Furthermore, strengthening port authorities' capacity and supervisory functions, ensuring adequate port-based waste collection facilities, and providing continuous education for crew members are essential. Through this integrated approach, ship waste management can evolve from a regulatory obligation into a broader framework for behavioral change and sustainable marine environmental governance.

## Author Contributions

Conceptualization and writing—original draft preparation, W.H.; methodology, S.W.U.; supervision, T.E.B.S.; writing—review and editing, E.F. All authors have read and agreed to the published version of the manuscript.

## Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

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**Conflicts of Interest**

The authors declare no conflict of interest.

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