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Microplastic exposure in anchovies: baseline evidence from small-island waters of Indonesia

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ABSTRACT

Microplastics are emerging contaminants in aquatic environments and may enter human exposure pathways through seafood consumption. However, baseline exposure data for small pelagic fish in small-island settings remain limited, particularly in Indonesia. Anchovy (*Stolephorus spp.*), which is commonly consumed whole, may represent a direct dietary exposure pathway. This study aimed to quantify and characterize microplastic contamination in anchovy collected from Dendun Island waters. A descriptive cross-sectional study was conducted in 2025 using 100 anchovy samples obtained from local catches. Microplastics were extracted using oxidative digestion followed by density separation, filtration, and stereomicroscopic observation. Data were analyzed descriptively. A total of 109 microplastic particles were identified, with a mean abundance of 1.09 particles per individual. Fibres dominated (67.0%), followed by films (20.2%) and fragments (12.8%). Various colours were observed, indicating heterogeneous particle characteristics. This study provides baseline evidence of microplastic contamination in anchovy from a small-island coastal setting, highlighting its potential as a dietary exposure pathway. These findings support the need for routine monitoring and strengthened plastic pollution control strategies to protect seafood safety and public health.

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1. INTRODUCTION

Plastics have become ubiquitous in modern life due to their versatility, low cost, and durability; however, these same properties have contributed to the long-term accumulation of plastic waste in the environment. Global assessments indicate that cumulative plastic production has reached several billion tonnes, while only a small fraction has been recycled; the remainder has been disposed of in landfills or leaked into natural ecosystems [1]. Large quantities of mismanaged waste continue to enter rivers and coastal zones and ultimately reach the ocean, particularly in densely populated coastal regions where solid-waste services and behavioural practices remain inadequate [2]. This persistent leakage helps explain why marine plastic stocks remain substantial despite uncertainty in bottom-up inventories, as suggested by top-down mass budgeting approaches [3]. In aquatic environments, weathering processes such as ultraviolet radiation, mechanical abrasion, and chemical degradation fragment larger plastic items into smaller particles known as microplastics, which are increasingly recognised as cross-compartment contaminants occurring in water, sediment, and biota [4].

Microplastics are commonly operationalised as synthetic polymer particles smaller than 5 mm, although definitions differ across studies in terms of size thresholds and classification criteria, highlighting the need for harmonisation to improve comparability [1], [5]. Their small size and persistence enhance mobility and bioavailability to aquatic organisms through direct ingestion, filtration, and trophic transfer. Beyond physical presence, microplastics may carry plastic additives and adsorbed environmental contaminants, positioning them not only as an environmental pollution issue but also as a concern for environmental health and food safety [6], [7]. Critically, data quality and methodological variability remain recurring concerns in the microplastics field, reinforcing the importance of transparent reporting and quality assurance when interpreting exposure-relevant findings [8], [9].

From an environmental health perspective, dietary exposure through seafood consumption has become a key pathway of concern [10], [11]. Evidence synthesis suggests that exposure can occur through multiple routes, with food—including seafood—being a plausible contributor, although human health evidence remains emergent and exposure baselines are still being refined [6]. Importantly, reviews emphasise that organisms consumed whole may pose higher exposure potential because the gastrointestinal tract—where microplastics are frequently detected—is not removed prior to consumption [7]. Consistent with this, recent reviews on fish and fishery products highlight that microplastics have been detected in various seafood commodities and may contribute to dietary exposure; reported biological effects in experimental models depend on particle size, polymer type, and exposure burden [5]. More recent hazard- and risk-oriented syntheses also stress that exposure estimates depend heavily on analytical thresholds and reporting consistency [12], [13].

Small pelagic fish such as anchovy (*Stolephorus spp.*) are ecologically susceptible due to their feeding behaviour in the water column and the likelihood of confusing microplastics with prey items of similar size and appearance. Studies in marine systems, including the Mediterranean, have reported microplastic ingestion in anchovy and sardine, reinforcing that small pelagic species can serve both as indicators of contamination and as potential vectors for transfer to humans [14]. In Indonesia, multi-location studies have also documented microplastic contamination in anchovies, suggesting that contamination is not limited to single hotspots and may occur across diverse fishing grounds [15]. This concern is further supported by broader evidence that microplastic occurrence in fish gastrointestinal tracts is widespread globally, with high heterogeneity across settings [16].

Nationally, publications in the Journal of Environmental Health have reinforced that microplastics are an emerging contaminant relevant to environmental health, with potential toxicological implications and a clear need for stronger exposure evidence to support prevention strategies [10], [17]. Microplastic contamination has also been reported in edible shellfish in coastal settings, underscoring seafood as a potential exposure route [18]. Furthermore, evidence of microplastics in dug-well water [19] and karst underground river systems [20] indicates that contamination may occur in environmental media closely linked to domestic activities and water resources—strengthening the rationale for an integrated upstream-to-downstream environmental health approach [1], [11].

Despite increasing evidence of microplastic contamination in seafood, important gaps remain in understanding exposure pathways in small-island environments where coastal ecosystems and local food systems are closely interconnected. Previous studies in Indonesia have reported the presence of microplastics in anchovies. However, most studies lack localized baseline data and do not explicitly link environmental contamination with dietary exposure risk [4], [21], [22].

In particular, small pelagic fish such as anchovy (*Stolephorus spp.*), which are commonly consumed whole, may represent a more direct exposure pathway compared to larger fish species. Therefore, this study aims to provide baseline data on microplastic contamination in anchovies collected from Dendun Island waters, representing a small-island coastal setting [18]-[20]. This study contributes to the existing literature by contextualizing microplastic contamination within a public health and seafood safety framework, particularly in relation to dietary exposure risk in coastal communities [5], [7], [14].

2. METHOD

2.1. Study design and setting

The sample size of 100 individuals was selected based on commonly applied sampling ranges in microplastic studies on marine biota, which are considered sufficient to provide representative baseline data for descriptive analysis. This laboratory-based cross-sectional study was conducted in 2025 at the Laboratory of Poltekkes Kemenkes Tanjungpinang, Indonesia. Microplastic extraction and visual identification followed a NOAA-recommended workflow adapted for biota digestion and particle enumeration. The protocol rationale and critical controls were aligned with established guidance for microplastic monitoring and inter-laboratory harmonization to improve comparability and reduce contamination bias [23]-[26].

2.2. Study area and sample collection

Anchovy *Stolephorus spp.* locally known as *teri nasi/bilis nasi*) were obtained from local fishers operating in Dendun Island waters, Riau Islands, Indonesia. A total of 100 individual fish were collected, as sampling at this order of magnitude is commonly recommended to support meaningful inference in comparative biota microplastic studies. Specimens were placed in clean containers and transported to the laboratory for analysis. Anchovies were collected using purposive sampling from local fishers, with inclusion criteria including fresh condition and typical consumption size commonly found in local markets.

2.3. Sample preparation and microplastic extraction

Each fish sample was prepared in a clean workspace. Samples were placed into a glass beaker and covered with aluminium foil to minimize airborne contamination. Organic matter digestion was performed using an oxidizing digestion assisted by iron catalyst (Fenton-type oxidation), which is widely used for removing biological matrices while preserving plastic particles [24], [27]. Briefly, 20 mL of 30% H_2O_2 and 5 drops of 0.05 M $FeSO_4$ were added to the sample. The beaker was covered with aluminium foil and incubated for 24 h at room temperature. After incubation, the digestate was centrifuged at 3,000 rpm, then heated using a steam bath for 30 min and allowed to cool. The cooled digestate was filtered using Whatman No. 1 filter paper, and the residue was rinsed with NaCl solution to assist particle recovery and reduce residual debris. The retained material was transferred to a Petri dish for microscopic examination.

2.4. Quality assurance and contamination control

Given the high risk of secondary contamination in microplastic analysis, contamination control measures were applied following widely adopted best practices for microplastic monitoring and harmonization efforts [25], [26]. These measures include: i) preference for glassware over plastics; ii) covering samples with aluminium foil during digestion and processing; iii) using clean lab coats and gloves; iv) rinsing equipment with filtered deionized water; and v) performing procedural blanks (reagent blank processed alongside samples) to detect potential airborne or reagent-derived fibres [23], [25], [26]. Procedural blanks were included during analysis to assess potential contamination from laboratory procedures.

2.5. Microplastic identification and classification

Suspected microplastics were observed under a stereo microscope at 40–100× magnification. Particles were classified morphologically into fibre, fragment, film, foam, and pellet/granule, following common categorical schemes used in monitoring guidelines and empirical studies. Colours were recorded descriptively. Because visual identification can misclassify non-plastic particles, polymer confirmation using FTIR/Raman is recommended where instrumentation is available; if not performed, this limitation should be stated explicitly in the manuscript [24]-[26]. Microplastics were operationally defined as synthetic particles smaller than 5 mm. Visual identification was based on criteria including the absence of cellular or organic structures, consistent coloration, and uniform morphology under magnification.

2.6. Outcome measures

The primary outcome was microplastic abundance expressed as particles per individual fish (particles/individual). The secondary outcomes were particle shape category. They also included colour distribution, reported as counts and proportions.

2.7. Data analysis

Data were summarized using descriptive statistics (total particle count, mean particles/individual, and frequency distributions for shape and colour). Where supporting variables exist (e.g., fish length/weight), stratified summaries or non-parametric comparisons may be added, consistent with common analytical approaches in microplastic biota studies when distributional assumptions are not met [25], [26]. All analyses were conducted descriptively, and no inferential statistical tests were applied due to the exploratory nature of the study.

3. RESULTS AND DISCUSSION

3.1. Microplastic occurrence and abundance

Microplastics were detected in anchovy (*Stolephorus spp.*) samples collected from Dendun Island waters. From 100 individuals examined, a total of 109 microplastic particles were recovered, corresponding to a mean abundance of 1.09 particles per fish. The distribution of microplastic abundance across individuals is presented in Table 1.

Microplastic contamination in a frequently consumed small pelagic fish is environmentally and public-health relevant because it links coastal plastic leakage with a plausible dietary exposure pathway in the observed population. In small-island and nearshore settings, domestic waste handling, fisheries-related activities, and hydrodynamic retention can occur in close spatial proximity, allowing local seafood to reflect the surrounding exposure environment. This supports the value of generating locality-specific baselines to inform seafood safety surveillance and risk communication, rather than relying on extrapolation from distant sites with different source profiles or analytical thresholds [2], [4], [8].

Evidence from multiple regions indicates that anchovies and other small pelagic fish frequently ingest microplastics, yet reported burdens vary widely by location, sampling context, and analytical resolution. Mediterranean studies have documented ingestion in anchovy and sardine and emphasized that ingestion patterns can co-vary with ecological and spatial factors, reinforcing that local conditions matter for interpreting exposure [14]. In Indonesia, anchovy contamination has been reported across numerous locations, suggesting that the phenomenon is not restricted to isolated hotspots [15]. A global systematic review and meta-analysis of microplastics in fish gastrointestinal tracts similarly highlights high heterogeneity and methodological drivers of reported burdens, which cautions against direct numerical comparison across studies without harmonised protocols [16]. Moreover, anchovy-/Stolephorus-specific work from other coastal settings indicates that contamination profiles can vary by tissue focus and local exposure conditions, reinforcing the need to interpret results in a site-specific context rather than as universal benchmarks [28]. Accordingly, the primary contribution of the present dataset is best framed as a baseline for Dendun Island, suitable for local monitoring and hypothesis-building tarher than definitive inter-regional ranking.

Table 1. Microplastic abundance in anchovy (*Stolephorus spp.*) from Dendun Island waters

Indicators	Result
Number of fish examined (n)	100
Total microplastic particles (n)	109
Mean abundance (Particles/individual)	1.09

3.2. Microplastic morphotypes (shape distribution)

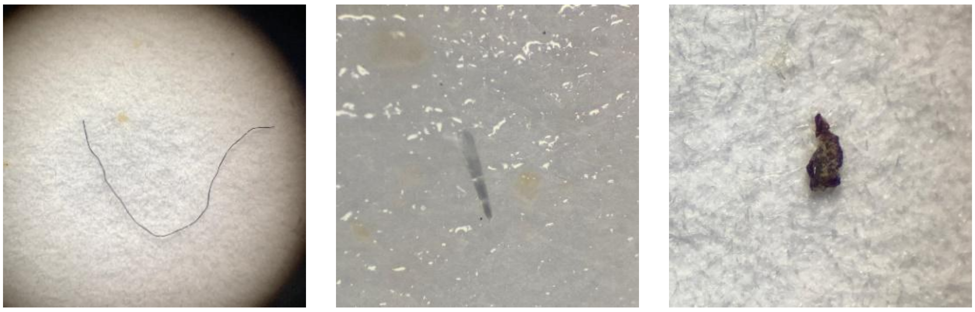
The distribution of microplastic morphotypes identified in anchovy samples is presented in Table 2. Three morphotypes were identified (Fibre, film a fragment). Overall, fibres dominated the recovered particles (67.0%), followed by films (20.2%) and fragments (12.8%). The predominance of fibres is consistent with global patterns in fish ingestion datasets. A meta-analysis synthesizing fish studies reported fibres as the most frequently reported morphotype across species and regions, with fragments often ranking second [26], [29]. This is compatible with multiple exposure pathways, including textile-derived fibres transported via domestic wastewater and atmospheric fallout, as well as fisheries-related materials (e.g., ropes and nets). At the same time, the literature cautions against treating any single morphotype profile as universal; several datasets show appreciable contributions from films or fragments depending on local plastic use patterns, degradation stage, and nearshore activities [26], [30]. Therefore, fibre dominance should be interpreted as an exposure descriptor consistent with mixed nearshore inputs, while source attribution should be treated as provisional unless supported by polymer-level confirmation.

Table 2. Shape composition of microplastic recovered from achovy (*Stolephorus spp.*)

Morphotype	Frequency (n)	Result
Fibre	73	67.0
Film	22	20.2
Fragment	14	12.8
Total	109	100.0

3.3. Microplastic morphology (shape categories)

Microplastic particles observed in anchovy samples comprised three main morphotypes, with fibres as the dominant type, followed by films and fragments. Representative morphotypes are shown in Figure 1. Several limitations should be acknowledged to ensure an honest and balanced interpretation. First, visual identification based on microscopy and morphology can misclassify non-plastic particles, particularly natural fibres, as microplastics; polymer confirmation using FTIR/Raman is increasingly expected to strengthen validity and enable more credible source inference [9], [24]-[26]. Second, contamination control is a well-recognized challenge in microplastic analysis: procedural blanks and blank-corrected reporting are important because airborne fibres and laboratory background can contribute to false positives [25], [26], [31]. If procedural blanks were not performed or not reported, the possibility of upward bias—especially in fibre counts—cannot be ruled out and should be stated as a limitation. Third, differences in size cut-offs and filter characteristics strongly influence particle counts, which is one reason cross-study comparisons should be treated cautiously [4], [8], [9], [16]. Finally, the results reflect a single period and location; seasonal rainfall, runoff intensity, and changes in local activity patterns may alter contamination pressure over time, which reinforces the need for repeated sampling to establish temporal stability [2], [8], [32].



(a) (b) (c)

Figure 1. Representative microplastic morphotypes: (a) fibre, (b) film, and (c) fragment observed in anchovy (*Stolephorus spp.*)

3.4. Microplastic colour characteristics

Microplastics recovered from anchovy (*Stolephorus spp.*) displayed a heterogeneous colour profile. Across the examined samples, particles were observed in multiple colours, including brown, yellow, black, dark blue, grey, light blue, red, and green. The presence of both dark-toned (e.g., black, dark blue, grey) and brighter-coloured particles (e.g., red, green, yellow, light blue) indicates substantial variability in the visual characteristics of microplastics ingested by anchovies in Dendun Island waters. Overall, the identified colours suggest that the recovered particles likely originated from diverse plastic products and underwent differing degrees of surface alteration prior to ingestion. The colour categories recorded in this study are provided as a qualitative description of the recovered particles and are intended to complement the morphotype classification (fibre, film, fragment) reported above.

Colour heterogeneity is frequently reported in microplastic ingestion studies and can be useful for descriptive reporting and internal consistency checks [26]. However, colour is not a reliable proxy for source: photodegradation, biofouling, surface oxidation, and adsorption of organic matter or contaminants can alter apparent colour and texture over time [4], [27]. For this reason, colour should be presented as a descriptive characteristic that complements morphotype classification; stronger inferences about sources are more appropriately supported by polymer confirmation (FTIR/Raman) and triangulation with local environmental matrices (water/sediment) [9], [24]-[26].

Despite these constraints, the present study contributes exposure-relevant baseline evidence for a locally important seafood commodity in an archipelagic setting. The most immediate priorities for strengthening inference in subsequent work include: i) implementing and reporting procedural blanks with blank-corrected counts [25], [26], [31]; ii) reporting particle size classes using standardized thresholds to improve comparability (3,20,21); iii) confirming polymer composition on a representative subset of particles [24]-[26]; and iv) triangulating seafood findings with nearshore water and sediment sampling to support a source–pathway–receptor interpretation [8], [9]. If the study scope is expanded, meta-analytic evidence on fish responses to microplastic exposure may help prioritize risk-relevant endpoints and contextualize ecological plausibility [33], [34]. These improvements would increase confidence in contamination estimates, support more defensible local risk communication, and provide a stronger evidence base for prevention-oriented environmental health governance.

4. CONCLUSION

This study confirms the presence of microplastic contamination in anchovies (*Stolephorus spp.*) collected from Pulau Dendun waters, with a mean abundance of 1.09 particles per individual and a predominance of fibre-type particles. These findings indicate that small pelagic fish in small-island environments may serve as a pathway for microplastic exposure through seafood consumption.

Importantly, this study provides baseline exposure data in a small-island coastal context, addressing a critical gap in the current literature. As practical implications, these findings support the need for routine monitoring of microplastics in small pelagic fish as part of seafood safety surveillance in archipelagic settings, alongside upstream measures to reduce plastic leakage from coastal settlements and fisheries-related activities. Future studies are recommended to strengthen validity and comparability by applying procedural blanks and blank-corrected reporting, documenting particle size classes, and confirming polymer composition using FTIR/Raman, as well as triangulating biota findings with nearshore water and sediment sampling to better characterise local source–pathway relationships.

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AUTHOR CONTRIBUTIONS STATEMENT

This journal uses the Contributor Roles Taxonomy (CRediT) to recognize individual author contributions, reduce authorship disputes, and facilitate collaboration.

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C : **C**onceptualization
M : **M**ethodology
So : **So**ftware
Va : **Va**lidation
Fo : **Fo**rmal analysis
I : **I**nvestigation
R : **R**esources
D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

CONFLICT OF INTEREST STATEMENT

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

INFORMED CONSENT

Not applicable because this study did not involve human participants as study subjects.

ETHICAL APPROVAL

Ethical clearance for this study was granted by the Health Research Ethics Committee, Universitas Bakti Tunas Husada Tasikmalaya (Komite Etik Penelitian Kesehatan Universitas Bakti Tunas Husada Tasikmalaya), under the Ethical Exemption/Approval letter No. 381-01/E.01/KEPK-BTH/IX/2025. The approved protocol title was “Identification of Microplastics in Anchovies (*Stolephorus spp.*) Found in the Waters of Dendun Island,” with Veronika Amelia Simbolon, M.K.M. (Poltekkes Kemenkes Tanjungpinang) as the principal investigator. The approval is valid from 23 September 2025 to 23 September 2026.

DATA AVAILABILITY

The data supporting the findings of this study are available from the corresponding author upon reasonable request.

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