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Review

Microplastic Contamination in the Genus *Litopenaeus*: A Systematic Review of Current Evidence and Future Perspectives

Saúl Silva-Reyna [1], Benigno Ortiz-Muñiz [1,*], María del Refugio Castañeda-Chávez [1], Fabiola Lango-Reynoso [1], Jesús Montoya-Mendoza [1], Antonio Huerta-Estévez [2] and Dalia Guadalupe Mendoza-López [1]

[1] Tecnológico Nacional de México/Instituto Tecnológico de Boca del Río. Km. 12, Carretera Veracruz-Córdoba, Boca del Río C.P. 94290, Veracruz, Mexico
[2] Tecnológico Nacional de México/Instituto Tecnológico de Veracruz. Calz. Miguel Ángel de Quevedo 2779, Veracruz C.P. 91897, Veracruz, Mexico
* Correspondence: benigno.om@bdelrio.tecnm.mx

Abstract

Microplastics have become contaminants of increasing concern in coastal environments and aquaculture systems because of their persistence, diversity of sizes and polymers, and capacity to interact with organisms and other pollutants. This systematic review critically synthesizes evidence on microplastic contamination relevant to the genus *Litopenaeus*, with emphasis on occurrence and characteristics, environmental exposure pathways, biological effects, anthropogenic sources, and methodological heterogeneity. Database searches covering 2013–2025 identified 537 records; after removal of 143 duplicates, title/abstract screening, and full-text eligibility assessment, 66 primary studies were included in the qualitative synthesis. Direct evidence is concentrated on *L. vannamei*, in which particles have been documented in the gastrointestinal tract, gills, hepatopancreas, muscle, and exoskeleton. Fibres and fragments recur frequently, with PE, PP, PET/polyester, PA/nylon, and PS among the commonly identified polymers. Experimental assays report oxidative stress, histological damage, dysbiosis, immunometabolism alterations; changes in growth, swimming, feeding and olfaction, and modified responses to co-exposed contaminants. Environmental studies identify sediments, water, feed, and aquaculture infrastructure as exposure compartments or pathways, while wastewater, solid waste, fishing, aquaculture, agriculture, industry, ports, rivers, and drainage networks emerge as potential pressure factors. Methodological differences in sampling, digestion, density separation, size limits, quantitative units, and chemical confirmation restrict quantitative comparability and preclude a global meta-analysis. This review integrates sources, entry routes, environmental matrices, shrimp exposure, and biological responses and identifies priorities for methodological standardisation and direct research on *L. setiferus*.

Keywords: microplastics; *Litopenaeus* shrimp; environmental exposure; biological effects; anthropogenic sources; methodological heterogeneity

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1. Introduction

Microplastics (MPs), defined as plastic particles smaller than 5 mm [1], are emerging contaminants of growing concern in coastal environments and aquaculture systems owing to their persistence, the wide range of sizes and polymer types they encompass and their capacity to interact with organisms and other pollutants. They are classified as primary,

when intentionally manufactured at these dimensions, or secondary, when derived from the fragmentation of larger items [1]. MPs have been documented in the water, sediments and biota of coastal lagoons worldwide [2]. Land-based inputs are a major source: in 2010 alone, an estimated 4.8–12.7 million tonnes of plastic waste generated in 192 coastal countries entered the ocean [3]. In aquaculture, the widespread use of nets, pipes, tanks, feeding systems and geomembrane liners constitutes an additional source [4,5], as the weathering of these materials by solar radiation, salinity and mechanical abrasion releases particles into the surrounding environment [6]. External inputs, such as urban runoff, domestic wastewater and contaminated intake water, further increase MP loads in these systems [7].

Once in the environment, MPs can be ingested by fish and crustaceans and accumulate in their tissues, where they have been associated with physical damage, oxidative stress, inflammatory responses, digestive and metabolic disturbances and impaired reproduction [8,9]. The severity of these effects varies with particle size and concentration [10,11]. MPs may also facilitate the transfer of chemical additives and hydrophobic pollutants to biota [12] and act as vectors for heavy metals, antibiotics and antibiotic-resistant bacteria [13]. Consequently, their occurrence in species intended for human consumption raises concerns regarding food safety; although evidence of adverse effects in humans remains limited and the current risks are generally considered low, environmental microplastic concentrations are projected to rise [14].

Among the commercially important organisms potentially exposed to these particles are shrimp of the genus *Litopenaeus*, which support both capture fisheries and aquaculture in tropical and subtropical regions. The genus *Litopenaeus* comprises the species *L. vannamei*, *L. setiferus*, *L. stylirostris*, *L. schmitti* and *L. occidentalis*. Its economic importance is most evident in *L. vannamei*: according to the Food and Agriculture Organization of the United Nations (FAO), global production of this species reached approximately 6.8 million tonnes in 2022, mainly through aquaculture [15]. This species accounted for nearly 83% of the global shrimp production analysed by Villarreal and Juarez [16], who also reported that Ecuadorian production exceeded one million tonnes in 2021, worth US$5.3 billion. The genus is also important for capture fisheries: the National Marine Fisheries Service of the US National Oceanic and Atmospheric Administration (NOAA Fisheries) recorded commercial landings of *L. setiferus* of approximately 48,500 tonnes in 2024, valued at US$159 million [17].

From an ecological perspective, shrimp of the genus *Litopenaeus* form part of the food webs in estuaries and coastal lagoons. Juveniles feed on small bottom-dwelling invertebrates and are in turn preyed upon by other aquatic animals, thereby contributing to the transfer of matter and energy; moreover, predation by juvenile *L. setiferus* can reduce the abundance of estuarine benthic macroinvertebrates [18]. The life cycle of this shrimp depends on a range of coastal habitats that provide feeding, refuge and nursery grounds [19]. The distribution of juvenile *L. setiferus* responds to habitat characteristics, with higher densities along flooded marsh edges [20]. In Louisiana salt marshes undergoing mangrove encroachment, the relative contribution of primary production sources to the diet of this species shifted with mangrove cover [21]. At earlier life stages, the recruitment of *L. setiferus* postlarvae into nursery areas is associated with selective tidal-stream transport: in Términos Lagoon (Mexico), tidal current velocity and water temperature jointly explained 86% of the variation in postlarval abundance [22]. These findings suggest that the development of this species depends on connectivity between marine and estuarine environments.

This close association with coastal environments, together with the widespread use of plastics in culture facilities, exposes *Litopenaeus* shrimp to MPs in both natural settings and aquaculture systems. As bottom foragers, they may ingest particles present in the sediment or in their prey, a pathway supported by field studies reporting MPs in the gastrointestinal tract of wild shrimp; the additional presence of MPs in the exoskeleton

suggests that exposure is not restricted to ingestion [23]. MPs have also been detected in the muscle, the edible portion, of farmed shrimp [24], and in *L. vannamei* reared in a super-intensive system with geomembrane-lined ponds, MP abundance increased over the culture cycle and exceeded that reported for shrimp from semi-intensive systems and the wild [5]. Laboratory experiments have further described adverse responses to exposure, including oxidative stress, histological damage and altered gut microbiota [10,25,26]. From a food safety perspective, estimated human intakes under different consumption assumptions were 280 and 647 MPs per person per year for wild shrimp consumed in Mexico [23] and shrimp reared in super-intensive systems [5], respectively.

However, the evidence published between 2013 and 2025 has focused largely on *L. vannamei* in both natural environments and aquaculture systems [5,23,24], whereas other species of the genus *Litopenaeus* remain poorly characterised. Moreover, the detection of particles alone is insufficient to infer adverse biological effects, as the biological significance of such findings depends on dose, particle size and shape, polymer type, exposure route and experimental conditions [11,27]. In addition, the comparability of findings across studies is constrained by variations in sample preparation, minimum detectable particle size, quantitative units and the proportion of particles verified by Fourier-transform infrared (FTIR) spectroscopy, micro-FTIR (μFTIR), Raman spectroscopy or other analytical techniques, including the preliminary visual classification step [28,29]. Therefore, this systematic review aims to synthesise and critically evaluate the available evidence on MP contamination in the genus *Litopenaeus*, considering the occurrence and characteristics of MPs, environmental exposure pathways, biological effects, potential anthropogenic sources and the methodological approaches employed, in order to identify key knowledge gaps and establish priorities for future research.

2. Materials and Methods

2.1. Review Design and Search Strategy

A systematic literature review was conducted in accordance with the PRISMA 2020 (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) statement [30]. The completed PRISMA 2020 checklist is provided as Supplementary Material. The protocol for this review was registered on the Open Science Framework (OSF; DOI: https://doi.org/10.17605/OSF.IO/MFSNC). The procedure comprised identification, duplicate removal, screening, eligibility assessment, and final inclusion. The search covered publications from 2013 to 2025 and was performed across Scopus, SpringerLink, Google Scholar, and ResearchGate owing to their extensive coverage of environmental sciences, ecotoxicology, marine pollution, coastal ecosystems, fisheries, and aquaculture. Both English and Spanish terms related to the pollutant, target organism, environmental matrices, and potential sources of exposure were employed. Keywords included “microplastics”, “microplastic pollution”, “plastic contamination”, “coastal lagoons”, “estuaries”, “mangroves”, “sediments”, “anthropogenic sources”, “wastewater”, “aquaculture”, “shrimp”, “penaeid shrimp”, “*Litopenaeus*”, “*Litopenaeus vannamei*”, and “*Litopenaeus setiferus*”, combined using the Boolean operators AND and OR. Search strings were appropriately adapted for each platform. In Scopus, queries included combinations such as (“microplastics” OR “microplastic pollution” OR “plastic contamination”) AND (“coastal lagoon” OR “estuary” OR “mangrove” OR “coastal sediment”) AND (“shrimp” OR “penaeid shrimp” OR “*Litopenaeus*” OR “*Litopenaeus vannamei*” OR “*Litopenaeus setiferus*”). To broaden the identification of research concerning sources and effects, supplementary combinations focusing on “anthropogenic sources”, “aquaculture”, “accumulation”, “toxicity”, “oxidative stress”, and “microbiota” were applied. Equivalent expressions tailored to the specific search options of SpringerLink, Google Scholar, and ResearchGate were also utilised.

2.2. Eligibility Criteria and Organisation of Evidence

Original or empirical research was included if it evaluated microplastics in species of the genus *Litopenaeus*, other penaeid shrimp used for comparative reference, and coastal lagoons, estuaries, mangroves, sediments, water, or aquaculture systems capable of providing information on environmental exposure pathways. Experimental trials analysing accumulation, tissue distribution, oxidative stress, histological alterations, immunity, microbiota, metabolism, behaviour, growth, or the effects of co-exposed contaminants in shrimp were also considered.

Excluded records comprised duplicate documents, literature reviews used as primary evidence units, methodological protocols, book chapters, popular-science articles, conference abstracts, research proposals, studies focused exclusively on macroplastics, and publications without sufficient scientific information for data extraction. Reviews and methodological papers were retained only for contextual or procedural support and were not counted among the 66 primary studies.

For the synthesis, the corpus was functionally organised into: (a) direct evidence of presence, accumulation, or effects in *Litopenaeus*; (b) environmental evidence regarding water, sediment, lagoons, estuaries, mangroves, and aquaculture systems relevant to exposure pathways; and (c) experimental studies on toxicity and co-exposure. A single article could contribute to more than one analytical dimension but was counted only once as a unit of evidence.

2.3. Study Selection

The initial search identified 537 records, of which 143 duplicates were removed, leaving 394 records that underwent title and abstract screening. Following full-text retrieval and eligibility assessment, 66 primary studies met the inclusion criteria for qualitative synthesis. A detailed breakdown by source and the specific reasons for exclusion are presented in Figure 1.

2.4. Data Extraction and Synthesis

For each primary study, the following data were extracted: author and year; country and matrix/system; matrix type; species and wild or cultivated origin; number of sites and individuals; abundance units; size, shape, colour, and polymer type; sampling method; digestion and density separation; identification technique; blanks and controls; proposed anthropogenic sources; biological effects; and limitations. The unit of evidence was the study rather than the individual file; in cases where translations, exported pages, or differently named copies of the same article existed, only a single bibliographic reference and the most complete version were retained.

Abundance data were maintained in their original units and were directly compared only when the matrix, normalisation basis (dry mass, wet mass, volume, or individual), size range, and analytical technique matched. When chemical composition was not confirmed, items were interpreted as suspected microplastic particles rather than confirmed polymers. Due to the heterogeneity of units and detection limits, a general meta-analysis of abundances was not performed; quantitative synthesis was restricted to comparisons within methodologically compatible groups. The systematic synthesis comprises 66 primary studies selected via the PRISMA procedure for the search period spanning 2013 to 2025.

2.5. Methodological Quality Assessment

A ten-criterion methodological quality appraisal framework was used to structure the evaluation of study design, analytical control, and reporting transparency (Table 1). Each applicable criterion was defined as 0 points when unreported or inadequate, 1 point

when partially reported, and 2 points when complete; criteria genuinely not applicable were recorded as N/A rather than automatically scored as 0. The proposed total-score categories were low (0–7), moderate (8–14), and high (15–20) when all ten criteria were applicable. For controlled exposure studies, concentration relevance, particle characterisation, controls, and exposure duration were interpreted within the same framework. The matrix was used to support confidence judgments and identify recurrent limitations rather than as an automatic exclusion rule. Because the surviving audit record did not contain a complete per-study score sheet for all 66 studies, this review did not report an aggregate low/moderate/high distribution.

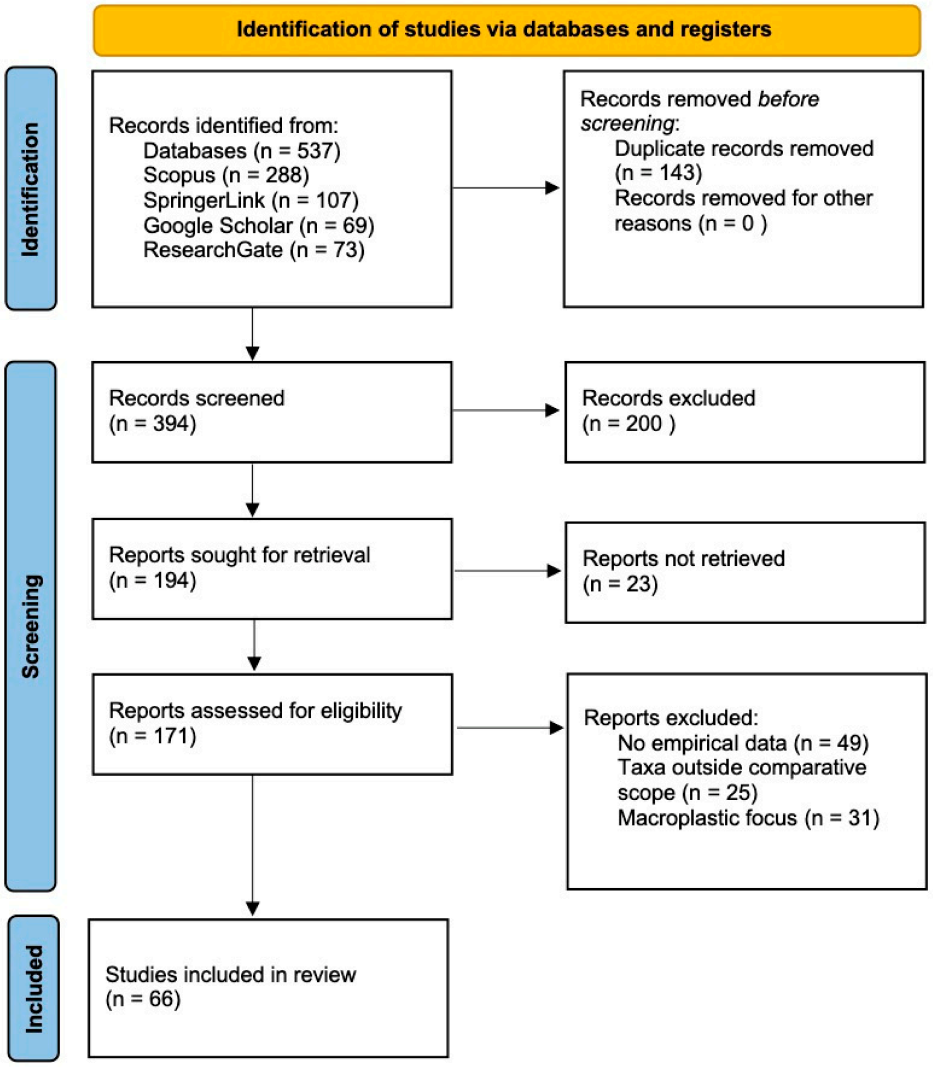


Figure 1. PRISMA 2020 flow diagram for identification, screening, eligibility assessment, and inclusion of the 66 primary studies.

Table 1. Methodological quality appraisal matrix for primary studies. Proposed classification: low (0–7), moderate (8–14), and high (15–20 points).

Criterion	0 Points	1 Point	2 Points
Sampling representativeness	Opportunistic sampling without justification	Limited coverage or insufficient replicates	Justified and replicated spatial/temporal design
Sample description	No data on mass, area, or individuals	Partial information	Mass/area, depth, size, and number clearly reported

Table 1. *Cont.*

Criterion	0 Points	1 Point	2 Points
Contamination control	No controls described	Some measures, without complete blanks	Field/process blanks and documented measures
Digestion/pre-treatment	Undescribed or incompatible	Described without validation	Compatible, validated, or recovery-tested method
Density separation	Not reported when required	Incomplete solution and density	Solution, density, and recovery reported
Size limit	Not reported	Partial range	Lower limit and size fractions clearly defined
Chemical confirmation	Visual only	Small subsample or limited technique	FTIR/Raman/thermal analysis in a representative proportion
Units and normalisation	Ambiguous units	Units reported without sufficient normalisation	Comparable units and defined dry/wet weight basis
Statistical analysis	Absent or inappropriate	Limited descriptive analysis	Analysis consistent with design and assumptions
Transparency and limitations	Does not discuss biases	Mentions some limitations	Explicit discussion of uncertainty and complete data

3. Results and Discussion

3.1. General Characteristics of the Evidence

The included evidence focuses on three main groups: environmental studies on microplastics in water, sediments, lagoons, estuaries, and mangroves; research on presence and accumulation in shrimp; and experimental toxicity assays. Geographic coverage is uneven, and studies specifically focusing on *Litopenaeus* centre primarily on *L. vannamei*, in both wild and farmed systems. In contrast, specific information on *L. setiferus* within the corpus was insufficient, preventing the direct extrapolation of exposure, retention, or sensitivity levels observed in other species.

A comprehensive review by Garcés-Ordóñez et al. [2] identified 57 publications containing data from 50 coastal lagoons and reported that 77% examined only a single environmental matrix. Although this review was not counted as a primary study within our set of 66 investigations, its findings align with a limitation observed here: few study designs simultaneously incorporate water, sediment, organisms, and potential sources, thereby hindering a complete reconstruction of transport and exposure pathways.

Across the included evidence, fibres and fragments are recurrent morphotypes, while PE, PP, and PET/polyester frequently occur among chemically identified polymers. Loads measured in shrimp vary with species, size, wild or farmed origin, organ analysed, and sample pretreatment. Experimental studies provide mechanistic evidence of oxidative stress, histological alterations, dysbiosis, immunometabolic changes, and behavioural effects, but environmental extrapolation requires consideration of concentration, particle size and ageing, exposure route, and co-occurring contaminants [25,31–35].

The analytical characterisation of the 66 included primary studies is presented in Supplementary Table S1, which compiles information regarding matrices, species or tissues, abundances or frequencies, morphotypes, polymers, sample preparation methods, identification techniques, potential sources, and main findings.

3.2. Presence and Characteristics of Microplastics in the Genus Litopenaeus

The developmental stage should not be considered a universal predictor of particle load. Valencia-Castañeda et al. [5] recorded an increase in particles per shrimp across culture stages in a super-intensive system, whereas Naidu et al. [31] documented a decrease during a different production cycle. These are not contradictory estimates derived from the same population; the systems, sampling times, size distributions, and exposure pathways differed. Variations apparently associated with age may also reflect body growth, continuous ingestion, depuration, or the specific anatomical compartment analysed; age-dependent patterns in *Litopenaeus* remain insufficiently elucidated.

Kim et al. [27] exposed *Penaeus vannamei* to polyethylene terephthalate (PET) microfibers in a benthic assay and observed alterations in molting patterns associated with molecular changes linked to molting hormones and chitin biosynthesis. An altered molting cycle does not, in itself, demonstrate that microplastics are eliminated via ecdysis. In another decapod, *Nephrops norvegicus*, Welden and Cowie [36] observed a lower microplastic load in recently molted individuals and found particles in the shed stomach lining; they proposed ecdysis as a potential elimination pathway for that species. This mechanism and its magnitude cannot be directly extrapolated to *Litopenaeus*. Evaluating this in the latter group requires studies that quantify particles in exuviae, digestive linings, faeces, and tissues before and after recorded molts, distinguishing elimination via molting from depuration [27,36,37].

Field studies on shrimp frequently analyse the gastrointestinal tract as an indicator of recent ingestion, whereas gills provide evidence of contact with suspended particles; hepatopancreas, muscle, and exoskeleton have also been examined to assess tissue distribution, retention, or externally adhered particles [5,24,31,32,38–40]. Comparisons among organs require attention to tissue mass, quantitative units, surface cleaning, digestion conditions, and analytical detection limits.

Páez-Osuna et al. [38] found 5.5 ± 0.5 particles per individual in wild *L. vannamei* across the analysed tissues, with a predominance of fibers and fragments. In Cau Hai Lagoon, My et al. [32] recorded 8.6 ± 3.5 particles per individual in *L. vannamei*, with a higher load in the gastrointestinal tract than in other tissues. Reunura and Prommi [39], as well as Vitheepradit and Prommi [24], also documented microplastics in farmed shrimp. During a culture cycle, Naidu et al. [31] detected microplastics in 93.7% of shrimp samples and simultaneously analysed feed, water, and sediment. Taken together, these studies demonstrate the recurrence of fibers and fragments and the frequent identification of PE, PP, PET/polyester, PA/nylon, and PS.

The observed loads do not depend solely on ambient concentration. The production system, duration of exposure, water exchange rate, feed, infrastructure wear, organism size, particle geometry, and the tissue analysed can all influence the quantified load. Studies covering different culture stages and production durations show distinct temporal trajectories [5,31], and depuration under controlled conditions has been documented [37]. Molting could alter externally adhered particles and shed digestive structures, yet its independent contribution to the elimination of internal particles in *Litopenaeus* has not yet been established. Consequently, comparisons between wild and farmed shrimp must take into account the developmental stage, exposure environment, analytical units, and tissue selection.

Findings regarding *L. vannamei* identify organs of interest and candidate variables but do not establish equivalent particle loads, retention, or sensitivity for *L. setiferus*, *L. stylirostris*, *L. schmitti*, or *L. occidentalis* (Table 2).

Table 2. Representative studies on microplastics in penaeid shrimp, with emphasis on *Litopenaeus vannamei*. Differences in organ, minimum size, processing, and quantitative units preclude direct ranking by contamination level.

Environment	Species and Matrices	Sample/Abundance	Shape, Colour, and Polymers	Confirmatory Method	Main Interpretation
Cultured pond, Thailand [39]	*L. vannamei*; gastrointestinal tract (GIT) (study also included *M. rosenbergii*)	150 *L. vannamei*; 11.00 ± 4.60 MP/individual; 100% positive	Fibres, fragments, and films; white/transparent frequent; PE predominant, with PCL, PVA, and ABS	Stereomicroscopy + FTIR	Aquaculture-associated materials and feed were plausible sources; *M. rosenbergii* had the higher load
Cau Hai Lagoon, Vietnam [32]	Farmed *L. vannamei*; GIT and tissues (wild and farmed penaeids compared)	8.6 ± 3.5 MP/individual; 1.1 ± 0.4 MP/g	Fibres and fragments; rayon 61.9%, PA 10.5%, PET 6.7%, PE 5.7%, polyacrylic ~5%, and PS 3.8%	ATR-FTIR	Farmed shrimp showed higher loads than wild shrimp; GIT > tissues
SAMARE Lagoon, Mexico [38]	Wild *L. vannamei*; GIT, gills, exoskeleton, and muscle	5.5 ± 0.5 MP/individual	Fibres 74.7%, fragments 22.7%; transparent/blue; cotton and PET predominated	Polymer identification + metal analysis	Positive MPs-Zn association in gills; observational evidence does not establish a plastic-mediated metal pathway
Cultured pond, Thailand [24]	*L. vannamei*; GIT, hepatopancreas, muscle, and exoskeleton	105/105 positive; 66.17 ± 29.19 MP/individual; GIT 137.78 ± 16.48 MP/g; hepatopancreas 16.31 ± 1.87; muscle 1.69 ± 0.13; exoskeleton 4.37 ± 0.27 MP/g	Fragments 62.07%, fibres 37.31%; blue 43.69%; PET, PVAc, and CAB frequent	Stereomicroscopy + FTIR	The GIT carried the highest load; pond infrastructure, aquaculture activities, and runoff were plausible pathways
12 culture ponds, India [31]	*L. vannamei*; shrimp, feed, water, and sediment	93.7% positive shrimp; 4.07 MP/individual; 1.24 MP/g; MPs detected in all associated matrices	Fragments and fibres dominant; particles <100 µm frequent in shrimp; PE and PP dominant	µFTIR	Shrimp load decreased over culture time while particle size shifted upward; feed was identified as the main source
Huizache-Caimanero Lagoon, Mexico [23]	Wild *L. vannamei*; GIT, gills, and exoskeleton	GIT 114.7 ± 33.2 MP/g; gills 13.7 ± 5.3 MP/g; exoskeleton 3.0 ± 0.5 MP/g; 13.3 ± 1.1 MP/shrimp	Fibres 92.3%, fragments 6.0%, films 1.0%; transparent dominant; no integral polymer identification	Stereomicroscopy + Nile Red fluorescence	GIT showed the highest load; fishing and agricultural/urban activities were discussed as potential sources
Super-intensive system, Gulf of California [5]	*L. vannamei*; post-larvae and juveniles; GIT, gills, and exoskeleton	PL25: 0.2 ± 0.0 MP/individual; ~10.0 ± 0.3 to 40.3 ± 3.6 MP/individual from 1 to 7 months	Fibres 42.1–68.7%; transparent 46.1–65%; 15–4686 µm; PE 37.4%, nylon 21.1%, PET 18.5%	Spectroscopic polymer identification	MP abundance and particle size increased with age/culture stage; plastic infrastructure was a probable source
Korean market/seafood [40]	*L. vannamei*; whole samples and samples without head/intestine	1.73–3.80 MP/10 g by size; 11.83 MP/10 g with head/intestine vs. 3.16 MP/10 g without them	77–92% <100 µm; blue dominant; PE and PP, followed by PET, PS, nylon, and PVC	FTIR + digital microscopy	Removing the head and intestine substantially reduced estimated exposure; sample preparation strongly influenced the result
Arabian Sea [41]	*F. indicus*, *P. monodon*, *P. semisulcatus*, and *M. affinis*; GIT	100, 100, 100, and 200 individuals; 0.74–1.91 MP/individual among species	Spheres 33.38%, pellets 32.4%, fibres 31.8%; PE, PVC, nylon 66, ABS, and PS	ATR-FTIR + Raman (10% subsample)	Interspecific differences indicate that feeding ecology and habitat should be considered when comparing shrimp exposure

3.3. Environmental Exposure Pathways and Relationship with Environmental Matrices

Rainfall, run-off, and fluvial discharges can introduce particles from river basins, whereas wind, wave action, currents, and storms can redistribute or resuspend deposited particles. An increased input does not necessarily result in a higher local concentration when dilution, water exchange, or export rates are also high. İslek et al. [42] recorded greater abundance in sediments during the rainy winter season in Küçükçekmece Lagoon; however, this represents environmental evidence specific to that system rather than a measured seasonal shift in *Litopenaeus* tissues. Naidu et al. [31] sampled shrimp and culture matrices at different periods, although variations across a production cycle could not be automatically interpreted as climate-driven seasonality. Robust seasonal inference requires paired, repeated sampling of water, sediment, and specific shrimp tissues, alongside data concerning precipitation, flow rate, salinity, temperature, hydrodynamics, and developmental stage.

Exposure of *Litopenaeus* must be interpreted within the environmental context in which particles are transported and retained. Rivers, canals, drains, runoff, and discharges connect inland sources to lagoons, estuaries, and coastal zones, whereas hydrodynamics, residence time, suspended solids, salinity, and inlet morphology influence retention or export. Sediments can act as sinks for denser, biofouled, or aggregated particles, while waves, currents, storms, dredging, and bioturbation can promote resuspension [33,42–44].

Studies conducted in Venice, Küçükçekmece, Urías, Setiu, and the Pearl River Estuary demonstrate marked spatial variation and the recurrence of fibres and fragments; however, their abundance values are not directly comparable. İslek et al. [42] reported 2922.32 ± 517.35 particles/kg in sediments of Küçükçekmece Lagoon, whereas Zuo et al. [43] recorded 100–7900 particles/kg of dry sediment in mangroves of the Pearl River Estuary. These contrasts must be interpreted by taking into account sampling depth, analysed mass, density separation efficiency, minimum detectable size, and the proportion of chemically confirmed particles (Table 3).

Table 3. Representative studies on microplastics in coastal lagoons, sediments, and biota. Abundance values are retained in their original units and should not be compared without considering method and matrix.

Region	System and Matrix	Design or Main Abundance	Dominant Characteristics	Highlighted Pressures or Sources	Contribution to This Review
Italy [33]	Venice Lagoon; surface sediments from 10 sites	672–2175 MP/kg dry weight; MPs in 100% of samples	93% of particles 30–500 µm; PE and PP > 82%; 10 polymer types identified by µFTIR	Continental inputs and anthropogenic gradient; urban, industrial, and aquaculture activities considered	Demonstrates spatial gradients, sediment-size effects, and the value of chemical confirmation
México [45]	Four coastal lagoons in Veracruz; sediments	MPs in all four lagoons; Alvarado showed the highest levels across size fractions	Fibres were more abundant than particles; PP, acrylic, and PE were reported by IR; BPA was co-assessed	Solid waste, wastewater, urban/industrial inputs, and fishing activities	Provides regional evidence for Veracruz lagoons and illustrates the need to separate occurrence from source attribution
Türkiye [42]	Küçükçekmece Lagoon; sediments from 5 stations over 12 months	2922.32 ± 517.35 MP/kg	Fibres 59%; black 42%; ~50% between 1 and 100 µm	Highest abundance in the rainy winter season; maximum at the station where anthropogenic pressures converged	Integrates spatial and seasonal variation
México [35]	Urías Lagoon; surface beach sediments from 4 sites	317 ± 153 to 1100 ± 750 particles/kg; mean 654 ± 326 particles/kg	Fibres 99 ± 1.52%; blue/transparent dominant; cotton + polyester ≥81%	Wastewater, fishing, aquaculture, industry, thermoelectric activity, and textile-related inputs	Mexican example of cautious source attribution linked to hydrodynamic exchange and polymer/morphotype evidence

Table 3. *Cont.*

Region	System and Matrix	Design or Main Abundance	Dominant Characteristics	Highlighted Pressures or Sources	Contribution to This Review
Egypt [44]	Burullus Lake; surface water + GIS modelling	Mean 452.4 ± 606.2 MP/m^3; open water 165.0 ± 199.6 vs. near drains 835.6 ± 758.1 MP/m^3	Eight thermoplastics identified instrumentally	Drains, wastewater, agriculture, urban development, waterways, and roads	Demonstrates the value of integrating GIS, drainage, land use, and environmental variables
México [46]	Alvarado Lagoon; gills and digestive tract of *D. maculatus*	1134 MP in 127 fish; 8.9 MP/individual; 100% positive	Fibres 97.53%; blue 62%	Textile laundering and fishing linked to nearby populations as plausible sources	Recent biological evidence of particle availability in a Mexican coastal lagoon
Malaysia [47]	Setiu Wetlands; mangrove sediments	2292 MP/kg dry sediment	>80% fibres; mainly transparent and black; many particles <1 mm; PP dominant	Aquaculture; degradation of packaging, fishing nets, and ropes	Relates abundance and polymer composition to productive activity while retaining source-attribution caution
China [43]	Pearl River Estuary; 48 sediment samples from three mangroves	100–7900 MP/kg; mean 851 ± 177 MP/kg dry weight	69.4% < 500 µm; fibres and fragments; PP-PE copolymer dominant	Urbanisation and industrialisation; correlations with population and economic activity	Strong spatial association with human pressure, without attribution to a single emission source

For benthic and detritivorous shrimp, sediment represents a plausible route of exposure through contact and ingestion. However, a correlation between sediment and intestinal loads does not by itself demonstrate direct transfer because both compartments may respond to the same source or retention regime. Stronger inference requires paired sampling by site and date, environmental covariates, and coherence in particle shape, colour, and polymer composition between sediment and shrimp [31,32,38,44].

Alonso et al. [48] examined the relationship between microplastics in sediment and in the tissues of *Macrobrachium amazonicum* within a tropical reservoir; their results are neither attributed to *Litopenaeus* nor utilised to establish a causal transfer between matrices.

3.4. Biological and Toxicological Effects

The presence of microplastics in an organism does not automatically equate to an adverse effect. Controlled assays are useful for identifying mechanisms and target organs, but environmental interpretation depends on whether the concentrations, particle sizes, shapes, polymers, ageing state, and exposure routes are environmentally plausible. In *L. vannamei*, experimental studies have described oxidative stress, intestinal and hepatopancreatic lesions, changes in microbiota, immunity and metabolism, reduced growth and swimming performance, altered feeding and olfaction, and modified exoskeletal properties [10,11,25,26,49,50].

At the molecular level, Han et al. [51] investigated the transcriptomic response of experimentally exposed *P. vannamei* and detected 1251 differentially expressed genes (685 upregulated and 566 downregulated), with functional changes related to stress, immune response, and muscle-associated processes. This study was already included in the submitted literature, although its findings have not been integrated into the main discussion. Duan et al. [25] reported complementary proteomic and metabolomic responses, whereas Kim et al. [27] included transcriptomic findings from a size-dependent PET exposure study. Differential gene expression documents a transcriptional response but does not, in itself, demonstrate DNA mutations, heritable damage, or adverse effects under field conditions.

Microplastics and nanoplastics must be interpreted separately because particle size alters the fractions recovered by analytical methods and can influence uptake, tissue distribution, and biological response. The experiment involving trophic exposure of shrimp to nanoplastics [34] provides complementary mechanistic context rather than an interchange-

able estimate of environmental microplastic exposure. Cross-study interpretation must explicitly consider size definition, polymer type, shape, dose metric, exposure route, and the limit of detection [11,27,34].

Duan et al. [25] reported changes in microbiota, proteomic profiles, and haemolymph metabolism following microplastic exposure; Hsieh et al. [26] documented oxidative stress and histopathological damage; and Zhou et al. [11] demonstrated size-dependent responses. Trophic exposure to nano-polystyrene (nano-PS) via contaminated mussels altered gut microbiota and nutritional composition [34], whereas Shan et al. [50] recorded reduced food intake, delayed olfactory response, dysbiosis, and digestive disturbances.

Mixtures with other contaminants add further complexity. Co-exposure to PS and hexabromocyclododecane altered toxicity and HBCD accumulation in the hepatopancreas [52] while aged PE modified several responses associated with a glyphosate-based herbicide [53]. These findings indicate that microplastics can modify responses to co-occurring contaminants, but they do not support the assumption that all microplastics invariably act as vectors of increased toxicity (Table 4).

Table 4. Physiological and toxicological effects of microplastics in *Litopenaeus vannamei*.

Country/ Reference	Exposure	Organ/System	Observed Response	Limitations for Environmental Extrapolation
China [25]	PE, PS, PVC, PTFE, and PP; 1 mg/L; 14 days	Intestine and hemolymph	Dysbiosis and immune, proteomic, and metabolic changes	Commercial model particles and an experimental concentration; not directly equivalent to environmental exposure
Taiwan [26]	Fluorescent red PE microspheres; 0.1, 0.2, 0.5, and 1.0 µg/g shrimp; 7 days	Muscle, hepatopancreas, and gills; histology and survival	Tissue accumulation, oxidative stress, histopathological damage, and reduced survival at higher doses	Intramuscular injection of PE microspheres differs from environmental ingestion or contact and from naturally occurring particle morphologies
China [10]	PS; 0.02–1 mg/L	Hepatopancreas and behaviour	Accumulation, reduced growth, abnormal swimming, lipid peroxidation, hepatopancreatic injury, and metabolic alterations	Controlled exposure to a single polymer
China [54]	Microplastics + nitrite; controlled co-exposure	Intestine, digestion, immunity, and microbiota	Intestinal barrier damage, oxidative stress, enzymatic alterations, immune effects, and dysbiosis	Specific interaction with nitrite under controlled conditions
Mexico [38]	Environmental exposure	Gills and other tissues	Positive association between microplastics and Zn in gills	Observational design: the association does not demonstrate causality or plastic-mediated metal transport
China [49]	Microplastics at environmentally realistic concentrations	Exoskeleton, muscle, and hemolymph	Increased exoskeletal hardness and modulus, together with fractures and embedded microplastics; reduced chitin acetylation and alterations in Ca-related functions	Requires validation in wild populations, with other particle types and in other species
China [11]	Spherical PS particles of 0.1, 1, 5, and 20 µm; 24 at 10 mg/L and 12 days at 1 mg/L	Gills, intestine, microbiota, and metabolome	Particles of 1 and 5 µm induced greater oxidative stress and tissue damage; size-dependent microbial and metabolic responses	Spherical model particles; environmental fibers and fragments may behave differently

Table 4. *Cont.*

Country/ Reference	Exposure	Organ/System	Observed Response	Limitations for Environmental Extrapolation
South Korea [27]	PET fragments of 9.09, 49.00, and 158.59 µm; 21 days	Gastrointestinal tract, growth, swimming, histology, and transcriptomics	Small- and medium-sized PET reduced growth and movement and damaged the intestine; the largest size showed partial recovery	Controlled single-polymer assay; responses are size-dependent and do not, by themselves, establish environmental risk
South Korea [34]	Nano-PS via contaminated mussels; 21 days	Intestine, microbiota, antioxidant enzymes, and nutritional composition	Changes in microbiota, GST, and SOD; decreases in some essential amino acids and fatty acids	Trophic model involving nanoplastics and a controlled diet; not equivalent to direct exposure to environmental microplastics
China [55]	Microplastics; 0, 50, 500, and 5000 µg/L; 48 h	Survival, immune-related genes, and microbiota	High concentrations induced immune responses, dysbiosis, and reduced survival; low concentrations altered bacterial balance	Acute exposure; the abstract consulted does not specify the polymer, and the highest concentration may exceed many environmental scenarios
India [37]	Aged PE; 0.1–0.5 mg; 25 days plus 5 days of depuration	Growth and antioxidant system	Growth inhibition, lipid peroxidation, changes in GST, GSH, and catalase, and depuration of ~60% of particles after 5 days	Aged particles improve environmental realism, but the assay remains controlled and covers limited size and dose ranges
China [52]	PS + hexabromocyclododecane (HBCD), separately and combined	Hepatopancreas	Oxidative stress, alterations in metabolic and detoxification pathways, and higher HBCD accumulation during co-exposure	One specific particle–contaminant combination was assessed; the results cannot be generalized to all co-occurring contaminants
Germany [53]	Aged PE + glyphosate-based herbicide; 96 h	Acetylcholinesterase (AChE), immunity, oxidative stress, and hepatopancreatic histology	Aged PE alone caused mild effects but modified several herbicide-associated responses	Short exposure to a specific herbicide formulation
China [50]	PS microplastics (5 µm) and PS nanoplastics (50 nm) at environmentally relevant levels	Feeding, olfaction, microbiota, and digestion	Specific feed intake decreased by 24.92% and 28.48%, respectively; delayed olfactory response, dysbiosis, and oxidative and digestive alterations	Recent controlled assay; confirmation in production systems is needed

Consumer Exposure and Potential Health Implications

The presence of particles in shrimp does not equate to a quantified risk to human health. Yoon et al. [40] found distinct particle burdens when analysing seafood products with and without heads or intestines, which highlights the importance of the edible fraction and culinary preparation. Chen et al. [56] evaluated the polymer composition and potential health implications in estuarine *P. vannamei*, indicating the need for more direct evidence regarding human exposure. Gao et al. [57] modelled consumer exposure in other edible wild shrimp taxa; their estimates provide a comparative approach rather than a risk assessment specifically for *Litopenaeus*. A defensible evaluation requires chemically identifying the particles present in the portion actually consumed, quantifying the portion size and consumption frequency, and obtaining toxicological references relevant to human exposure; the effects documented in experimentally exposed shrimp cannot be directly extrapolated to human consumers [40,56,57].

3.5. Anthropogenic Activities as Potential Sources of Contamination

Potential sources of microplastics in environments where shrimp live or are farmed include wastewater, urbanisation, solid waste, fishing, aquaculture, agriculture, industry, ports, navigation, tourism, roads, and atmospheric deposition (Table 5). Domestic discharges can transport fibres and fragments; fishing and aquaculture materials can release particles through loss and wear; and larger plastic debris can fragment through weathering and abrasion. Spatial or temporal gradients associated with drains, rivers, land use, and productive activities provide stronger source evidence than polymer identity alone [31,33,35,44,45,47].

Aquaculture represents a particular case because it combines external inputs with potential internal sources. Feed, pipes, nets, hoses, containers, and other plasticised infrastructure can contribute particles. Naidu et al. [31] identified feed as a significant source signal during a production cycle, whereas other studies in ponds support water and infrastructure as potential exposure pathways [5,24,39]. Fishing activities can also contribute fibres or fragments composed of PA, PP, and PE resulting from the wear of nets, lines, and ropes, although these polymers are not exclusive to fisheries.

Attributing a specific particle to a particular activity requires caution. Polyester fibres near domestic discharges are compatible with textile-derived inputs but may also originate from ropes, nets, or atmospheric deposition; likewise, PE and PP are too widely used to identify a unique source on their own. Confidence increases when spatial or temporal gradients, locally used materials, hydrological connectivity, land use, and polymer profiles converge. GIS-based integration of drains, roads, land use, and environmental variables can strengthen this attribution framework [35,44,47].

Table 5. Anthropogenic activities as potential sources of microplastics and evidence required for cautious source attribution.

Activity	Associated Materials	Compatible Morphotypes/Polymers	Entry Route	Recommended Evidence Level	Pressure Indicators and Attribution
Urban/domestic	Sewage, textiles, packaging, and mixed solid waste	Polyester/rayon/PET and PA fibres; PE/PP/PET fragments may be compatible but are not source-specific	Drains, rivers, runoff, and discharges	Probable only when gradients, hydrological connectivity, and compatible particle characteristics converge	Population, discharge points, drainage, waste accumulation, and distance/connectivity
Fishing	Nets, ropes, lines, buoys, boxes, and sacks	PA/nylon, PE, and PP fibres + fragments are compatible but also occur in other sources	Direct loss and wear/weathering	Probable with documented gear use, fishing intensity, spatial gradients, and chemical/shape coherence	Number of vessels, gear types, fishing grounds, landing sites, and lost/damaged gear
Aquaculture	Feed, geomembranes, pipes, nets/meshes, hoses, packaging, and other plasticised infrastructure	PE, PP, PET, and PA/nylon recur in the corpus; other polymers vary among systems	Internal wear, feed input, water exchange, and effluents	High when feed, water, sediment, shrimp, and infrastructure are sampled within the same production system	Number/area of farms or ponds, materials, stocking/culture stage, water exchange, feed, and effluents

Table 5. *Cont.*

Activity	Associated Materials	Compatible Morphotypes/Polymers	Entry Route	Recommended Evidence Level	Pressure Indicators and Attribution
Agricultural/ livestock	Films, irrigation hoses, sacks, containers, and transported residues	Films/fragments often compatible with PE/PP, but polymer identity alone is insufficient	Runoff, drainage canals, and flood transport	Suggested to probable when land use, hydrological connection, rainfall seasonality, and gradients are documented	Agricultural area, channels, distance, slope, runoff direction, and seasonal activity
Industrial/ petroleum	Pellets, packaging, cables, coatings, pipes, process residues, and plastic handling	Site-specific fibres, fragments, or pellets; no single polymer in the reviewed corpus is diagnostic of this source	Effluents, spills, handling losses, and runoff	Requires site-specific polymer/additive fingerprinting, a coherent spatial gradient, or direct source matching	Facilities, discharge points, process/material type, distance, and hydrological connection
Port/navigation	Ropes, paints/ coatings, packaging, vessel waste, and maintenance materials	Fibres, fragments, coatings, and paint-like particles; composition must be confirmed instrumentally	Operations, repair, runoff, dredging, and direct losses	Suggested to probable only with port-use information and compatible spatial/chemical evidence	Vessel traffic, docks, shipyards, dredging, maintenance areas, and drainage
Tourism/ recreational	Bottles, bags, utensils, packaging, and synthetic clothing	PET, PE, and PP fragments and films; fibres may also occur	Littering, beach use, runoff, and drainage	Suggested to probable when a seasonal visitor/use pattern coincides with particle distribution	Visitors, services, beach use, season, waste generation, and collection capacity
Transport/roads	Tyre wear, road markings, vehicle-related particles, and urban dust	Elastomeric/dark particles require specific chemical or thermal identification	Road runoff and atmospheric deposition	Only when analytical identification and road/runoff linkage support the attribution	Road density, traffic, distance, drainage, and runoff direction
Waste management	Landfills, open dumping, burning, and informal disposal	Mixtures of fibres, films, foams, and fragments	Wind, flooding, runoff, and leachate	Cross-cutting source; confidence increases with mapped accumulation areas and transport pathways	Disposal sites, waste volume/ type, distance, flood/ runoff pathways, and connectivity

3.6. Integrative Synthesis: From Sources to Biological Response

The primary contribution of this review is the integration of components that are frequently studied in isolation: anthropogenic sources, entry pathways, environmental matrices, *Litopenaeus* exposure, biological effects, and the methodological decisions that condition their interpretation. This integration allows for a clear distinction between the mere co-occurrence of microplastics and human activities, the evidence of exposure in shrimp, and the demonstration of a biological response (Table 6).

Primary evidence converges on a general sequence: human activities release particles or debris; hydrological and atmospheric pathways transport them; hydrodynamics and particle properties determine persistence in water or sediment; shrimp are exposed through ingestion, branchial contact, and surface contact; and, under some conditions, sublethal responses may occur. Causal inference is strengthened by spatial and temporal continuity, agreement in morphotypes and polymers, paired environmental and biological samples, and analyses that rule out plausible alternatives [25,31–33,43].

Table 6. Integrative causal chain linking anthropogenic activities, environmental matrices, shrimp exposure, and biological response.

Component	Observable Indicators	Evidence Strengthening the Relationship	Main Limitation
Source	Type/intensity of activity; materials used; discharges and waste	Local inventory, direct observation, interviews, georeferencing, and material characterisation	Presence of an activity does not prove that it emitted the detected particles
Route	Rivers, drains, runoff, effluents, wind, atmospheric deposition, and direct loss	Flow direction, distance, hydrological connectivity, and rainfall/seasonal timing	Routes and connectivity change among seasons and hydrometeorological events
Water	Particles/m^3 or particles/L; shape, size, colour, and polymer	Gradient from an entry point toward the receiving system, with matched particle characteristics	High temporal variability and strong dependence on sampling volume, mesh/filter, and flow
Sediment	Particles/kg dry weight; depth, grain size, and organic matter	Spatial coincidence with sources/routes and particle characteristics; accumulation in low-energy zones	Sediment integrates different time periods and may later be resuspended
Shrimp	Prevalence; particles/individual and particles/g; organ/tissue and body size	Paired sampling with water/sediment and morphological/chemical coherence across compartments	Ingestion may be transient and depends on size, diet, molt/depuration, and organ analysed
Response	Oxidative stress, histology, microbiota, immunity/metabolism, growth, feeding, swimming, and behaviour	Dose–response evidence, appropriate controls, exposure characterisation, and mechanistic consistency	Laboratory assays do not always represent field concentrations, morphotypes, ageing, or exposure routes
Mixtures	Zn/other metals, BPA, HBCD, nitrite, glyphosate-based herbicide, and other co-occurring contaminants	Co-occurrence plus sorption/chemical evidence, statistical association, and controlled co-exposure where appropriate	Association or enhanced toxicity does not prove that microplastics are the dominant environmental vector

3.7. Methodological Comparability

The primary cross-cutting limitation across the evidence base was methodological heterogeneity (Table 7). In sediments, sampling involved either surface or core samples, variable sample masses, and different density separation solutions; in water, varying mesh sizes, filters, and volumes were employed; and in shrimp, analyses ranged from whole organisms to specific anatomical parts, such as the gastrointestinal tract, gills, hepatopancreas, muscle, or exoskeleton. These procedural choices directly influence the fraction of particles recovered and, consequently, the apparent magnitude of contamination.

Digestion treatments also vary. Reagents such as KOH and H_2O_2 differ in digestion efficiency and polymer compatibility, and reported lower size limits range from sub-micrometre fractions to millimetres. Visual identification can misclassify natural or regenerated fibres in the absence of chemical confirmation. FTIR, μFTIR, Raman, and thermal techniques increase confidence, but studies differ in the proportion of suspected particles that are chemically analysed [24,33,39–41].

Table 7. Sources of methodological heterogeneity and recommendations for generating comparable data in coastal environment and shrimp studies.

Stage	Observed Variation	Risk	Standardisation Recommendation
Sediment	Spatula, core, or grab; different depths; variable mass/area	Sampling of non-equivalent sediment strata and surfaces	Use a predefined surface depth, report dry mass, collect replicates, and record coordinates
Shrimp	Grouped individuals or tissues; different sizes/ages and organs	Loss of individual variation and confounding by body size or tissue choice	Record size, weight, sex/stage, origin, and site; analyse individuals where feasible and report organ explicitly
Digestion	H_2O_2, KOH, NaOH, acids, enzymes, or combinations	Polymer damage, incomplete organic-matter removal, or method-specific recovery	Validate recovery with representative polymers and select a tissue-compatible reagent
Density separation	NaCl, $ZnCl_2$, NaI, and other solutions	Low-density solutions such as NaCl may under-recover denser polymers	Report solution and density, recovery efficiency, repetitions, and use a sufficiently dense medium when justified
Filtration	Lower limits from sub-microns to millimetres; different meshes/filters	Strong size-selection bias and non-comparable particle fractions	Report the lower detection limit, filter/mesh size, and standardised size fractions
Identification	Visual inspection, hot needle, FTIR/μFTIR, Raman, or thermal methods	False positives and confusion between synthetic, natural, and regenerated fibres	Chemically confirm all particles or a representative proportion and report spectral-match criteria/proportion confirmed
Blanks	Field, laboratory, and process blanks reported inconsistently	Airborne, clothing, water, and reagent contamination	Use field/process blanks where applicable, filtered solutions, covered glassware, cotton clothing, and blank correction/reporting
Units	Particles/kg, m^2, m^3, L, g, individual, or occurrence/prevalence	Direct numerical comparison can be misleading across normalisation bases	Use particles per individual only when the whole shrimp is analysed. For a specific organ, report particles per whole organ or particles per gram of that organ (specifying whether wet or dry weight is used). Identify the examined fraction; do not equate tissue-specific measurements with the total burden of the organism
Statistics	Descriptive summaries or non-equivalent statistical designs	Over-interpretation of unreplicated, non-independent, or incomparable data	Use models consistent with replication, sites, systems, seasons, body size, and relevant environmental covariates

Quantitative units hinder direct comparison between matrices and, frequently, even within the same matrix. Sediments may be expressed as particles/kg of dry mass; water as particles/L or particles/m^3; whole shrimp as particles/individual only when the entire organism is examined; and isolated organs or tissues as particles/organ, particles/sample, or particles/g of tissue, specifying whether wet or dry weight is used. A figure obtained from an isolated intestine cannot be equated with the particle burden of a whole shrimp. Consequently, numerical contrasts must take into account the anatomical fraction analysed, the normalisation basis, the minimum detectable size, the proportion of chemical confirmation, and the analytical method. Future studies should report sample mass or volume,

examined organs, recovery controls, blanks, and confirmation rates; when studying only a part of the shrimp, units normalised by tissue mass and the explicit identification of the organ are preferred.

3.8. Knowledge Gaps

Several critical knowledge gaps remain. Direct evidence for *L. setiferus* is scarce, and comparable exposure ranges for wild populations are lacking [5,23,24,31,32,38,39]. Few designs integrate water, sediment, shrimp, and anthropogenic sources at the same sites and times [31,32]. Methodological standardisation remains incomplete for lower size limits, quantitative units, digestion, density separation, contamination controls, and spectroscopic confirmation [24,33,39–41]. Source attribution is often inferred from proximity or land use rather than demonstrated through converging evidence [35,44,47]. Retention, clearance, translocation, and the role of molting in wild shrimp are also poorly resolved [5,10,24,37], as are complex mixtures under environmentally realistic conditions [38,52–54]. Finally, comprehensive seasonal and event-based sampling remains uncommon [31,42].

3.9. Perspectives and Development Opportunities

The next stage of research should move from studies focused solely on the question 'Are there microplastics in shrimp?' toward designs capable of answering where they come from, what environmental factors control exposure, what fraction is retained or cleared, what effects they produce, and to what extent these results can be compared across regions and species. This requires integrated designs that sample water, sediment, and shrimp at the same sites and dates, record environmental parameters, and explicitly characterise anthropogenic activities.

Standardisation is a priority opportunity. The use of harmonised protocols for minimum size, digestion, density separation, blanks, chemical confirmation, and quantitative units would allow for the transformation of a currently fragmented literature into a more comparable evidence base. Identification using FTIR, μFTIR, Raman, or equivalent techniques should be accompanied by information on the proportion of confirmed particles and, where possible, by analyses that distinguish synthetic polymers from natural or regenerated fibres.

Spatiotemporal studies and experiments with greater environmental realism are also needed. Including rainy seasons, droughts, and hydrometeorological events would allow for the assessment of changes in transport and retention, while tests should consider aged fibres and fragments, polymer mixtures, and environmentally plausible concentrations. In parallel, evaluating co-exposed contaminants, purification, and transfer between internal compartments could improve the understanding of the mechanisms of effect.

Given that shrimp are widely consumed, future research should also consider the implications of these findings for food safety. In particular, forthcoming studies should ideally distinguish between the edible fraction and the tissues that are normally discarded, quantifying microplastics separately in the muscle, hepatopancreas and gastrointestinal tract, and accounting for the way in which the species is customarily consumed (whole, headless, peeled or deveined). Such data could allow dietary exposure to be estimated from consumption rates and could provide a basis for future risk assessments, for which the available evidence on fishery products remains limited [14]. Depuration trials, together with evaluations of the effects of cooking and processing on particle retention, may further help to establish whether the exposure reaching the consumer differs from that measured in field-collected organisms.

Finally, source attribution can be strengthened by combining field observations, GIS, land use, hydrological connectivity, locally used materials, and polymer profiles. This

approach can move interpretation from broad associations with 'anthropogenic activity' toward testable source hypotheses and can guide prevention measures targeting discharges, waste management, fishing gear, aquaculture infrastructure, and other dominant pathways [31,35,44,47]. Generating direct evidence for *L. setiferus* and other understudied species of the genus remains a priority for improving the ecological validity of the evidence base.

4. Conclusions

The available evidence confirms the presence of microplastics in different compartments of *Litopenaeus*, but it is markedly concentrated in *L. vannamei*. Fibres and fragments are the most recurrent morphotypes, and PE, PP, PET/polyester, PA/nylon, and PS appear among the most frequently identified polymers. Specific information for *L. setiferus* remains insufficient; therefore, the results obtained in other species should not be extrapolated without direct verification.

Experimental studies show plausible mechanisms of effect, including oxidative stress, histological damage, dysbiosis, immunometabolic alterations, changes in growth, swimming, feeding, olfaction, and exoskeleton properties. However, translating these results to the environment requires considering concentration, size, shape, ageing, exposure route, and coexisting contaminants, and explicitly distinguishing between presence, association, and causality.

The main limitation for a comprehensive quantitative synthesis is the methodological heterogeneity among studies. Differences in matrix, sampling, digestion, density separation, minimum size, chemical confirmation, and quantitative units can generate apparent contrasts that do not necessarily reflect real differences in contamination. Standardisation of these components is essential.

Supplementary Materials: The following supporting information can be downloaded at https://www.mdpi.com/article/10.3390/microplastics5040237/s1, Supplementary Material PRISMA 2020 checklist and Supplementary Table S1 provide the analytical characteristics of the 66 primary studies included in the qualitative synthesis [5,10,11,23–27,31–35,37–89].

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Abbreviations

The following abbreviations are used in this manuscript:

Abbreviation	Definition
AChE	Acetylcholinesterase
BPA	Bisphenol A
FTIR	Fourier-transform infrared spectroscopy
GIS	Geographic information system
GIT	Gastrointestinal tract
GSH	Glutathione
GST	Glutathione S-transferase
HBCD	Hexabromocyclododecane
MPs	Microplastics
PA	Polyamide/nylon
PE	Polyethylene
PET	Polyethylene terephthalate
PP	Polypropylene
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-Analyses
PS	Polystyrene
PTFE	Polytetrafluoroethylene
PVC	Polyvinyl chloride
SOD	Superoxide dismutase
μFTIR	Micro-Fourier-transform infrared spectroscopy

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