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Rethinking the plankton –plastic ‘crisis’

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Introduction

Micro- and nanoplastics have become signature pollutants of the Anthropocene, recorded from Arctic snowfields to hadal trenches and invoked routinely as an existential threat to planktonic life (Geyer et al., 2017; Botterell et al., 2019). The narrative is compelling: trillions of plastic fragments swirling in the sea, poised to clog the guts of zooplankton and collapse marine food webs. Yet a closer inspection of field evidence reveals a far more textured reality—one in which genuine hazards are geographically and taxonomically narrow, not ocean-wide. Here, we dissect the mismatch between experimental design and ecological reality, highlight the narrow windows of genuine vulnerability, and propose a path toward more targeted, field-anchored inquiry.

Laboratory risk versus oceanic reality

Roughly three-quarters of experimental studies that report harmful effects on copepods, euphausiids or larval fish deploy concentrations between 10^3 and 10^6 particles L^{-1} , often delivered as smooth, monodisperse polystyrene beads (Botterell et al., 2019). Such dosing regimes can be invaluable for illuminating mechanistic pathways—ingestion kinetics, oxidative stress, reproductive allocation—but they bear little resemblance to the sea. A synthesis of the ocean’s surface-water samples spanning every major basin places the range of microplastics from 10^{-4} to 10^4 particles per m^{-3} , with maxima in coastal and offshore gyres (Zhao et al., 2025).

This mismatch between laboratory and real-world matters because encounter probability scales with particle abundance: expose a copepod to one million beads per liter and every feeding appendage becomes a sieve; expose it to one particle per cubic meter and the animal may forage for weeks without meeting a single fragment. Interpreting high-dose experiments as ecological risk therefore overstates the likely influence of microplastics on most plankton populations. Moreover, recent studies show that copepods mostly reject microplastic particles after they contact the animals’ mouthparts (Xu et al., 2022). Therefore, even when microplastics are present in the water column, they are unlikely to become a substantial component of the zooplankton diet.

An ocean of gel and prey, not plastic

The gap between experimental dosing and ecological reality widens even further when the matrix in which plankton live is taken into account. The surface ocean is awash in naturally produced colloids—chief among them transparent exopolymer particles (TEPs) and related gels exuded by phytoplankton, bacteria and decaying detritus. These gummy aggregates routinely constitute 30–110% of the particulate-organic-carbon stock in Atlantic surface waters (Zamanillo et al., 2019), forming a three-dimensional buffet that dwarfs the synthetic debris load by orders of magnitude.

For a suspension feeder such as copepods, then, microplastics are statistical curiosities: a typical copepod must screen a million edible or at least bio-compatible particles before it meets a single plastic fragment (Zhao et al., 2025). Field gut-content surveys confirm this rarity; only ~3% of over 145,000 copepods examined across global studies contained microplastics, and just a quarter of studies reported ingestion rates above 10% (Fagiano et al., 2024). Crucially, no study has yet connected such verified *in-situ* burdens to demonstrable losses in growth, reproduction or abundance at the population scale.

The practical implication is straightforward. Today's pelagic grazers swim in a soup dominated by nutritious gels and live prey, not in a minefield of plastic shards. Until microplastic concentrations in open waters approach those of natural colloids—or unless synergistic stressors drastically lower tolerance thresholds—plastics will remain an energetically trivial component of most planktonic diets.

Feeding selectivity: a behavioral firewall against plastics

Suspension-feeding copepods provide the clearest evidence that encounter does not equal ingestion. In high-speed video and bottle-incubation experiments with *Temora longicornis*, roughly 80% of 20 µm polystyrene spheres that touched the maxillular “taste” setae were instantly rejected, regardless of polymer chemistry, bead shape, biofilm growth or sorbed pyrene (Xu et al., 2022). The same study reported electivity indices that were strongly positive for living algal prey (+0.21 to +0.33) but negative for plastics (−0.49 to −1.00), meaning that even when beads numerically outnumbered prey, actual ingestion of plastic lagged behind by one to two orders of magnitude. Scaled to open-ocean particle fields, where edible nano- and micro-plankton exceed microplastic fragments by at least 6 orders of magnitude, the consumption of microplastics by copepods should be merely anecdotic.

Microzooplankton add a second, often stronger, layer of discrimination. When presented with unrealistically equal mixtures of *Isochrysis galbana* cells and 2.5–4.5 µm beads, the heterotrophic dinoflagellates *Oxyrrhis marina* and *Gyrodinium* spp. still favored prey, while its congener *Protoperdinium bipe* rejected plastics completely (Fulfer and Menden-Deuer, 2021). Taken together, these behavioral sieves act on top of the numerical rarity of microplastics to drive the effective probability of plastic ingestion

by copepods and protozoans down into the parts-per-million range everywhere except the most polluted coastal embayments.

The chemical vector question

Another oft-voiced fear is that plastics act as Trojan horses for additives and adsorbed pollutants—bisphenols, phthalates, brominated flame retardants or legacy POPs. Laboratory work confirms that leachates can provoke oxidative stress, enzyme inhibition, or even death in copepods (Lehtiniemi et al., 2021), and that microplastics can sorb hydrophobic chemicals from seawater (Lee et al., 2014). Yet mass-balance analyses reveal a limiting constraint: the partitioning capacity of plastics is finite, and equilibrium with the surrounding water is reached quickly, thus microplastic ingestion is not likely to increase the exposure to hydrophobic organic chemicals (Koelmans et al., 2016). Moreover, real-world debris are typically aged and bio-filmed, factors that slow additive release and reduce surface reactivity. Coastal embayments with contaminated sediments remain legitimate concerns, but basin-scale toxic shadows over plankton are not borne out by present evidence.

Nevertheless, microplastics rarely operate alone. Zooplankton already contend with warming, deoxygenation, acidification and shifting prey fields, all of which squeeze their energy budgets (Espinel-Velasco et al., 2023; de Juan et al., 2024). Under these combined stresses even small plastic loads might push vulnerable populations past their metabolic margin, whereas plentiful food shortens gut residence time and blunts the effect (Rodríguez-Torres et al., 2020). Sensitivity is trait-specific: raptorial feeders with slow gut turnover (for example, chaetognaths) are inherently at higher risk of microplastics' effects than fast-grazing copepods, although they are unlikely to “attack” inert fragments. Experiments that embed such co-stressors and species traits are therefore essential for credible hazard appraisal.

Discussion

Overall, plastics unquestionably disfigure coastlines and entangle megafauna, but at the microscale, for the vast majority of plankton living in today's ocean, microplastics remain an energetically diluted exposure, not a functional hazard. Laboratory evidence to the contrary stems largely from hyper-dose experiments that simulate food deprivation rather than natural seawater. Integrating exposure abundances, energetic theory and chemical realism paints a more moderate, but more actionable, picture: genuine risk is geographically patchy, trait-dependent and often overshadowed by climate-driven stressors.

A first step is, then, to anchor exposure regimes to nature (Figure 1). Equally important is using particles that resemble what plankton actually encounter: most ocean plastics are rough, weather-worn and covered with microbial biofilms, and these features strongly influence how often the particles are swallowed, expelled or release chemicals. Nevertheless, fewer than 10% of

Rethinking experimental design for microplastics research



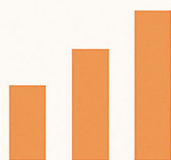
Match doses to reality.

Experimental ranges need to include field-representative concentrations (<math><10\text{ particles L}^{-1}</math> in the open ocean,



Use weathered, irregular particles with biofilms.

Shape, roughness and microbial coatings alter ingestion and egestion patterns, yet ca. <math><10\text{ \%}</math> of published work simulates such complexity.



Adopt energetic endpoints.

Growth efficiency, reproductive output and carbon assimilation link directly to population fitness, unlike single-time-point mortality curves.



Embed co-stressors.

Add warming, food scarcity or hypoxia to reveal synergistic and antagonistic interactions that dominate natural settings.



Minimize contamination.

When using bulk-digestion methods on field samples, first rinse and clean each specimen individually to minimise contamination.

FIGURE 1

Summary of the suggested actions to obtain accurate plastic-zooplankton related data.

laboratory studies have used such realistic particles. Experimental endpoints also need to be rethought. Replacing single-time mortality snapshots with evaluations of growth efficiency, reproductive output and carbon assimilation links microplastic effects directly to population fitness and ecosystem carbon flow.

Embedding co-stressors such as episodic food scarcity, sub-lethal warming or transient hypoxia will expose the synergistic and antagonistic interactions that dominate natural settings (Figure 1). Finally, credible monitoring and toxicology share a common prerequisite: rigorous contamination control. Each plankton specimen

should be rinsed and processed individually before chemical digestion to avoid laboratory fibers masquerading as field ingestion events.

Embracing these upgrades will align laboratory insight with oceanic reality. Only then can we quantify microplastic hazards with the precision needed to steer mitigation toward the true hotspots and away from symbolic but low-yield gestures. While the open ocean appears safe for now, certain zones merit heightened vigilance. Estuaries downstream of megacities, semi-enclosed seas with sluggish flushing and high-density shellfish farms can all trap microplastics at concentrations orders of magnitude above ambient medians. In such areas, targeted mitigation—storm-water filtration, improved wastewater treatment, gear-loss reduction—could yield disproportionately large ecological gains.

In short, the seductive image of a single ocean “drowning in plastic” can scatter effort and funding far too thinly. Policymakers should concentrate on true hotspots—places where microplastics coincide with sensitive life stages, high biodiversity, or critical ecosystem services. Scientists, for their (our) part, must adopt realistic protocols that mirror natural conditions. Only with this realism can we judge the actual risk microplastics pose to plankton and respond proportionately.

Author contributions

AC: Validation, Project administration, Investigation, Conceptualization, Methodology, Supervision, Writing – review & editing, Funding acquisition, Visualization, Formal Analysis, Resources, Data curation, Writing – original draft.

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