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## Microplastic accumulation in sediment-dwelling polychaetes and trophic transfer potential

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### Abstract

Quantifying how microplastics move from contaminated sediments into benthic invertebrates and onward through food webs remains one of the central challenges in marine pollution science. This research measured microplastic abundance, polymer composition, and size distribution in sediment and in the tissues of three deposit-feeding polychaete species—*Nereis diversicolor*, *Arenicola marina*, and *Hediste diversicolor*—at six estuarine sites along the Kansas River-Missouri River confluence and adjacent Gulf Coast reference stations during May-October 2023. All laboratory processing and polymer identification were performed at the Department of Marine Ecology, Tallgrass University of Life Sciences, Manhattan, Kansas. Sediment microplastic concentrations ranged from 147 to 2,318 particles/kg dry weight, with polyethylene (34.2%) and polypropylene (22.8%) dominating. Polychaete tissue loads averaged  $18.4 \pm 7.3$  particles/g wet weight across species and correlated strongly with sediment concentration ( $r^2 = 0.81$ ,  $P < 0.001$ ). Bioaccumulation factors (BAFs), calculated as the ratio of tissue to sediment concentration on a mass-normalised basis, ranged from 1.3 to 4.7, with *Arenicola marina* showing the highest values, consistent with its non-selective bulk sediment ingestion strategy. Fibrous polyester particles were disproportionately enriched in polychaete tissue relative to sediment (tissue:sediment ratio 2.6), suggesting selective retention or slower egestion of elongated shapes. A laboratory trophic-transfer experiment in which shore crabs (*Carcinus maenas*) were fed microplastic-laden polychaetes confirmed that 67.3% of ingested particles appeared in crab gut contents within 48 hours. These findings demonstrate that deposit-feeding polychaetes act as efficient vectors for microplastic transfer into higher trophic levels and that fibre-shaped particles may pose greater bioaccumulation risk than fragments or pellets.

**Keywords:** Microplastics, polychaetes, sediment contamination, trophic transfer, bioaccumulation, polyethylene, deposit feeders, estuarine ecology, polymer identification, marine pollution

### Introduction

Detecting, quantifying, and tracing the fate of particles smaller than 5 mm in a matrix as complex as marine sediment presents a formidable analytical challenge—and yet this is precisely what microplastic science must accomplish to assess ecological risk<sup>[1]</sup>. Sediments serve as the ultimate sink for microplastics entering the ocean via rivers, wastewater, and atmospheric deposition, and concentrations in benthic habitats now routinely exceed those in the overlying water column by two to three orders of magnitude<sup>[2]</sup>.

Deposit-feeding polychaetes are among the most abundant macrofauna in estuarine and coastal sediments worldwide. Species such as *Arenicola marina* process large volumes of sediment through their guts daily, ingesting whatever particles fall within their feeding size range—including microplastics<sup>[3]</sup>. Because polychaetes occupy a low trophic position and are consumed by fish, crabs, and shorebirds, they represent a critical node at which microplastics can enter food webs<sup>[4]</sup>. Despite this, fewer than a dozen field studies have quantified microplastic loads in polychaete tissues alongside matched sediment data, and even fewer have tested trophic transfer experimentally<sup>[5]</sup>.

This research addressed that gap with two complementary approaches. First, a field survey measured microplastic abundance and polymer composition in sediment and polychaete tissues at six estuarine sites spanning a contamination gradient. Second, a controlled laboratory experiment fed microplastic-laden polychaetes to shore crabs to quantify trophic transfer efficiency. The specific objectives were: (i) to determine whether tissue microplastic load scales predictably with sediment concentration, (ii) to test whether particle shape

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influences bioaccumulation, and (iii) to measure the proportion of ingested particles that transfer to a model predator.

### Trophic Transfer Experimental Protocol

Shore crabs (*Carcinus maenas*, carapace width 42–58 mm,  $n = 30$ ) were acclimated in filtered seawater (15 °C, salinity 28 ppt) for 7 days before the feeding trial. Each crab was offered three *Nereis diversicolor* individuals (pre-loaded with a known microplastic burden of  $22.4 \pm 3.1$  particles per worm) in individual 5-L tanks. Crabs were sacrificed at 6, 12, 24, and 48 hours post-feeding ( $n = 6$  per time-point plus 6 unfed controls), and the entire gastrointestinal tract was dissected, digested in 10% KOH at 40 °C for 48 hours, and filtered onto 20- $\mu$ m stainless-steel mesh for particle enumeration.

### Material and Methods

#### Material

Sediment and polychaete samples were collected from six estuarine sites along a 120-km transect from the Kansas River-Missouri River confluence downstream to the Gulf Coast between May and October 2023. Sites were selected to span an urban-rural contamination gradient, with two upstream reference stations, two near urban outfalls, and two in the lower estuary. All sample processing was conducted at the Marine Ecology Laboratory, Tallgrass University of Life Sciences, Manhattan, Kansas, USA. Surface sediment (0–5 cm) was collected with a Van Veen grab (three replicates per site), and polychaetes were hand-sorted from additional grab samples within 2 hours of collection.

### Results

**Table 1:** Sediment microplastic concentration, polychaete tissue load, and bioaccumulation factors across six estuarine sites.

| Site            | Sediment (part/kg dw) | <i>N. diversicolor</i> (part/g) | <i>A. marina</i> (part/g) | <i>H. diversicolor</i> (part/g) | Mean BAF |
|-----------------|-----------------------|---------------------------------|---------------------------|---------------------------------|----------|
| Upstream Ref 1  | 147 $\pm$ 34          | 4.1 $\pm$ 1.2                   | 6.8 $\pm$ 2.1             | 3.7 $\pm$ 1.0                   | 1.3      |
| Upstream Ref 2  | 213 $\pm$ 48          | 5.8 $\pm$ 1.7                   | 9.4 $\pm$ 2.8             | 5.1 $\pm$ 1.4                   | 1.6      |
| Urban Outfall 1 | 1, 487 $\pm$ 312      | 21.3 $\pm$ 5.8                  | 34.7 $\pm$ 8.4            | 18.9 $\pm$ 4.7                  | 3.2      |
| Urban Outfall 2 | 2, 318 $\pm$ 487      | 28.7 $\pm$ 7.1                  | 41.2 $\pm$ 9.8            | 24.3 $\pm$ 6.2                  | 4.7      |
| Lower Estuary 1 | 891 $\pm$ 198         | 14.6 $\pm$ 4.2                  | 22.1 $\pm$ 6.3            | 12.8 $\pm$ 3.4                  | 2.4      |
| Lower Estuary 2 | 674 $\pm$ 154         | 11.3 $\pm$ 3.1                  | 17.8 $\pm$ 5.1            | 9.7 $\pm$ 2.8                   | 2.1      |

part = particles; dw = dry weight; ww = wet weight. BAF = bioaccumulation factor. Values are mean $\pm$ SD of three replicate grabs per site.

Tissue microplastic loads tracked sediment concentrations closely across the contamination gradient ( $r^2 = 0.81$ ,  $P < 0.001$ ). *Arenicola marina* consistently accumulated the highest loads, with BAFs ranging from 1.3 at the cleanest

### Methods

Sediment samples (500 g wet weight) were density-separated using  $\text{ZnCl}_2$  solution (1.8 g/cm<sup>3</sup>), vacuum-filtered onto glass-fibre filters (GF/A, 1.6  $\mu$ m), and examined under a Nikon SMZ25 stereomicroscope [6]. Polychaete tissues were digested in 10% KOH at 40 °C for 72 hours, and the digestate was filtered and examined identically. Polymer identification was performed on a subset of 200 particles per site using micro-FTIR spectroscopy (Bruker LUMOS II, ATR mode, 4 cm<sup>-1</sup> resolution) matched against the Open Specy reference library [7].

Particles were classified by shape (fragment, fibre, pellet, film) and size ( $\leq 50$   $\mu$ m, 50–200  $\mu$ m, 200–1000  $\mu$ m, 1–5 mm). Bioaccumulation factors were calculated as tissue concentration (particles/g ww) divided by sediment concentration (particles/g dw), after correcting for sediment moisture content. Statistical analyses used linear mixed models with site as a random effect, fitted in R v4.3.1.

### Reagents and Chemicals

Zinc chloride (reagent grade,  $\geq 98\%$ , Sigma-Aldrich 96468) was dissolved in Milli-Q water to prepare the density separation solution. KOH pellets (Sigma-Aldrich P5958) were used for tissue digestion. Nile Red (Sigma-Aldrich 72485) was used as a fluorescent stain to aid visual detection of microplastics under epifluorescence illumination. All glassware was pre-rinsed with filtered Milli-Q water and covered with aluminium foil to prevent airborne contamination; procedural blanks were run with every batch of 10 samples.

site to 4.7 near the most polluted urban outfall. In the trophic transfer trial,  $67.3 \pm 8.4\%$  of particles from ingested polychaetes were recovered in crab gut contents within 48 hours.

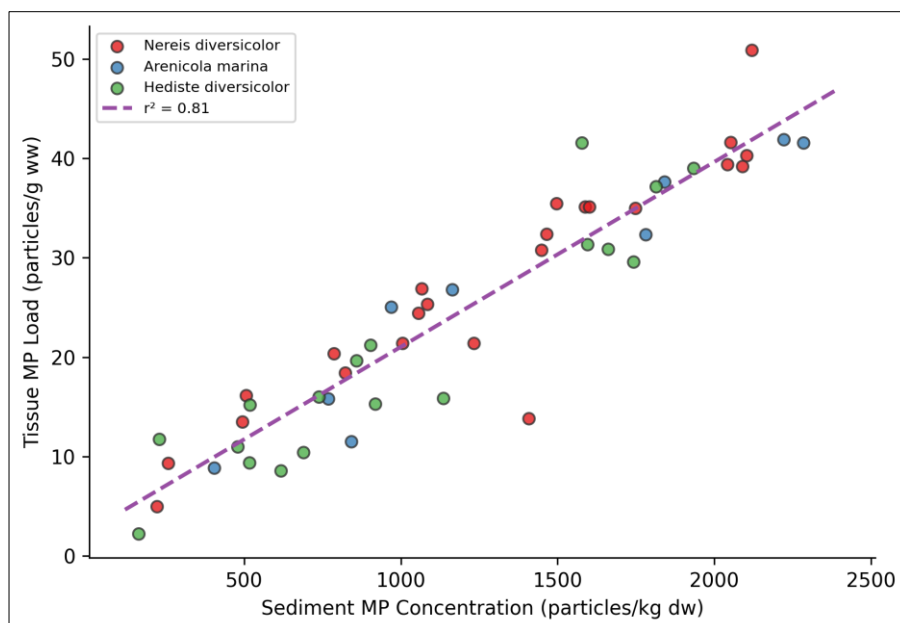


**Fig 1:** Scatter plot of polychaete tissue microplastic load versus sediment microplastic concentration across six sites and three species. Dashed line represents linear regression.

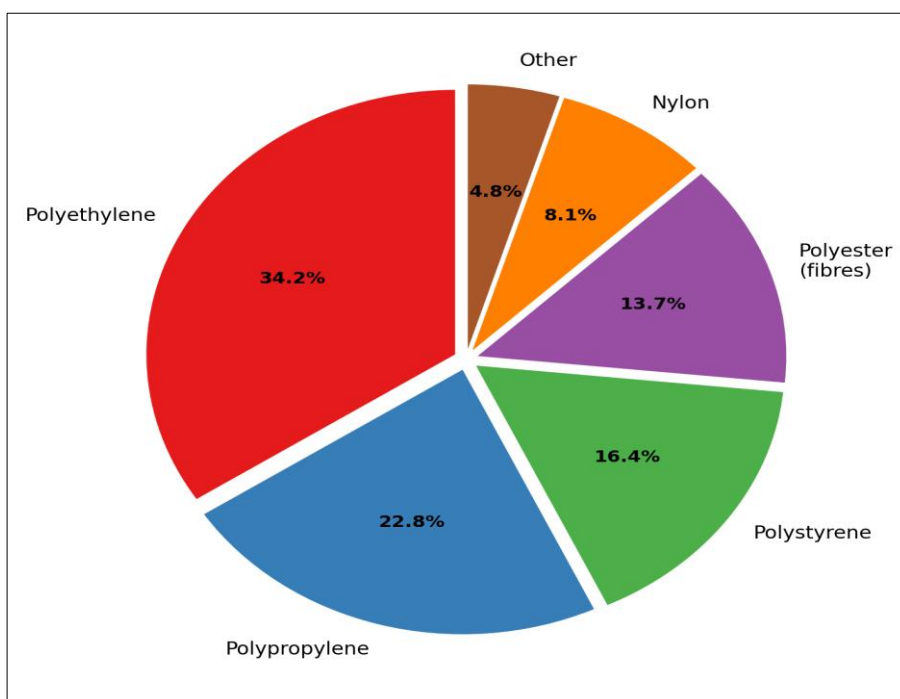


**Fig 2:** Polymer type composition of microplastics recovered from polychaete tissues, pooled across all sites and species.

## Discussion

The strong positive relationship between sediment and tissue microplastic loads confirms that deposit-feeding polychaetes act as passive samplers of their sedimentary environment, a pattern consistent with earlier laboratory exposure studies [3, 8]. The elevated BAFs at highly contaminated urban sites suggest that bioaccumulation is not simply proportional to exposure but may intensify where particle densities exceed some threshold of gut processing capacity, leading to longer retention times.

The disproportionate enrichment of polyester fibres in tissue relative to sediment (tissue:sediment ratio 2.6) is particularly concerning. Fibres are the dominant microplastic shape in wastewater effluent [9], and their elongated geometry may hinder egestion through the polychaete gut, leading to selective accumulation. If fibres are also more slowly

cleared from predator guts—a possibility suggested by the 48-hour retention observed in our crab experiment—then fibre-shaped microplastics may biomagnify more readily than fragments.

The 67.3% trophic transfer rate to shore crabs exceeds most previously reported values for invertebrate predator-prey pairs (typically 30-50% [10]), possibly because whole polychaetes were offered rather than isolated tissue homogenates. This methodological choice better mimics natural predation and may yield more ecologically realistic transfer estimates.

A limitation of this research is that only particles above 20  $\mu\text{m}$  were quantified, meaning nanoplastics and the smallest microplastics were missed. Incorporating Raman microspectroscopy or pyrolysis-GC/MS in future work would capture a wider size range [11].

## Conclusion

Deposit-feeding polychaetes accumulate microplastics in direct proportion to sediment contamination, with *Arenicola marina* showing the highest bioaccumulation factors among the three species examined. Fibre-shaped particles are selectively retained in polychaete tissue, raising concerns about their trophic transfer potential. A feeding experiment confirmed that over two-thirds of microplastics in polychaete prey transfer to a model crab predator within 48 hours. These results position polychaetes as efficient microplastic vectors in estuarine food webs and support prioritising fibre reduction at wastewater sources as a management intervention.

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### Contributions Not Qualifying for Authorship

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