microplastics

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Article

Do Newly Settled, Field-Collected Oysters and Other Common Sessile Marine Invertebrates Contain Microplastics?

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Abstract

Many filter-feeding invertebrates consume microplastics (MP) under laboratory conditions, but little is known about newly settled, field-collected juveniles. To address this information gap, we collected 3439 juvenile invertebrates in the Indian River Lagoon (IRL), FL, USA. Previous studies suggest that the IRL is a MP hotspot. A total of 70% of IRL adult oysters (*Crassostrea virginica*) contained MP (mean: 2.3 MP/individual), and MP number and MP length were positively correlated with animal size. We predicted that juvenile *C. virginica* and other sessile invertebrates would contain MP with a positive correlation to animal size. Five species were examined; 51% were *C. virginica* (mean shell length ± SD: 6.3 ± 4.7 mm). Overall, 117 (3.4%) animals contained potential MP (fibers: 90.7%). Of these particles that matched FTIR databases with a score of 70% or greater, 51% were plastic and 49% were anthropogenically modified particles. No correlations to animal size were found for particle presence (logistic regressions: $p \geq 0.20$ for all species) or particle length (linear regressions: $p \geq 0.23$ for all species). Thus, even though found in a MP hotspot, our extrapolated results suggest few juveniles (<1%) contained MP. This information is important for understanding the relationship between MP and the life histories of filter-feeding animals, especially for species considered biological indicators of MP.

Keywords: bivalve; *Crassostrea virginica*; oyster; mussel; barnacle; Indian River Lagoon; *Geukensia demissa*; *Amphibalanus eburneus*; *Anomia simplex*; *Crepidula fornicata*

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1. Introduction

Oysters are filter-feeding invertebrates that have a two-stage life cycle, which begins with the release of gametes into the water column which grows into a dispersal, feeding larval form, followed by radical metamorphosis into a sessile, benthic filter-feeding animal [1]. During metamorphosis, parts of the larva body are resorbed and the animal cements itself to a hard surface [1]. Larval feeding on particles in the size range of 2–30 microns starts 1–2 days post-fertilization and lasts for 2–4 weeks until metamorphosis occurs [2]. The newly metamorphosed individual lives off lipid reserves for ~6 days until adult feeding structures are functional [3]. Laboratory investigations of plastic pollution have focused on all life stages of oysters (e.g., gametes, larvae, adults) to quantify any negative impacts

on survival, growth rates, and reproductive outputs [4]. Although no acute toxicity values have been reported to date for any oyster species [5], documented negative plastic particle impacts include physical damage (e.g., gut blockage, perforation of the digestive tract, lysosomal stability), altered feeding behaviors, reduced energy allocation, reduced shell growth rates, chemical toxicity, and increased oxygen consumption and respiratory rates [4,6–8]). Many of these published studies focused on responses to polystyrene beads or high-density polyethylene (HDPE) particles in concentrations ranging from 0 (controls) to higher than environmentally relevant values with the commercially and ecologically important Pacific oyster *Crassostrea gigas* [5,9,10]. For example, Sussarellu et al. [9] reported in 2016 that when reproductive-age adults of *C. gigas* were exposed to polystyrene, results included significantly smaller and fewer oocytes, reduced sperm velocity, and reduced oyster survival. Exposure to polystyrene beads reduced survival and development in some, but not all, in additional studies with larvae of *C. gigas* [7,10–12]. Bringer et al. [13] fed HDPE particles to *C. gigas* larvae and found that these particles induced malformations, arrested development, and resulted in abnormal swimming behaviors as well as significantly slower spat growth post-settlement. Similar responses were reported in trials with juvenile and adult *C. gigas* with greater negative impacts, higher concentrations, and larger MP [4,7]. When larvae of the eastern oyster *Crassostrea virginica* were exposed to HDPE particles, Bhatt et al. [14] reported no impact on survival at 10 mg/L concentrations, but they did find delayed larval development.

The number of MP studies conducted on non-commercial sessile, filter-feeding species was historically more limited in the literature but is now rapidly increasing for both laboratory and field studies [15–17]. For example, the cosmopolitan barnacle *Amphibalanus amphitrite* ingested and egested polystyrene with no observed negative impacts on larval development at environmentally relevant concentrations in the laboratory [15]. Gut retention time, however, was increased with smaller microbeads [18]. Wang et al. [19] exposed the same species to MP particles with and without biofilms and found that the presence of the biofilm did not affect ingestion, while Xu et al. 2023 [20] found no difference in ingestion abundances for microspheres versus microfibers. Lo et al. 2018 [16] fed polystyrene beads to larvae of the slippersnail *Crepidula onyx* and found that at environmentally relevant concentrations, larval and juvenile *C. onyx* were not negatively affected. At higher concentrations of plastic, however, slower growth over 65 days, settlement at smaller sizes, and a negative legacy impact on post-larval juvenile individuals were reported. While these studies provide important data, few provide information on recently metamorphosed sessile invertebrates (shell length: $\leq$1 cm) that were not reared in a laboratory nor fed MP. Our research goal was to address this information gap in a Florida estuary, the Indian River Lagoon (IRL). This estuary was previously described as a microplastic (MP) hotspot [21], thus suggesting that invertebrate larvae and juveniles in these waters would likely encounter MP.

The IRL is a 251 km long subtropical estuary located along the east coast of central Florida, USA, and has been described as a MP hotspot based on studies of surface waters [8] and atmospheric deposition above and immediately surrounding the lagoon [22]. Water sampling documented 1.5 MP/L lagoon-wide with 1224 MP/m^2/day entering the system via atmospheric sources. Extrapolated, both sources of data yielded 1.1–1.4 trillion MP in the IRL [22]. These high levels of plastics in the water have translated into high densities of plastics in adult IRL organisms. Previously studied adult IRL organisms with high MP loads include crabs, coastal birds, and oysters [21,23,24]. Craig et al. [25] determined that 70% of adult IRL oysters contained MP (mean: 2.3 MP/individual). Some MP were excreted in feces (1 MP/h), while 1 MP was removed every 2 h in pseudofeces (particles captured and bound in mucus, but never entered the digestive tract). Craig et al. [25] also

reported that MP size was positively correlated to retention in oyster soft tissues; the larger the MP, the more likely that the MP were retained in *C. virginica* with egestion efficiency decreasing by 0.8% per 1 g increase in tissue weight. The average lengths of MP (±S.E.) in feces and pseudofeces were 1.5 ± 0.1 and 1.7 ± 0.2 mm, respectively, while the average length of MP collected from soft tissues of the same oysters was larger at 2.5 ± 0.2 mm.

Our research focused on understanding the abundances of MP in recently settled *C. virginica* and co-occurring sessile invertebrates under field conditions. MP data are very limited on sessile invertebrates in the early post-metamorphosis life-history stage for individuals not reared in the laboratory with exposure to high concentrations of a single polymer of virgin plastics of specific dimensions. Based on the results for adult IRL oysters [10], we asked the following: (1) Do juvenile oysters contain MP? (2) Are there increases in MP numbers with increases in oyster size? (3) Are there increases in the mean length of MP with increases in oyster size? As 49% of the collected recruits in this study were species other than *C. virginica*, we asked the same questions for all collected sessile invertebrates that were co-located on the oyster reefs. Moreover, we also report the results for anthropogenic particles (AP), defined here as human-modified natural materials, such as microfibrillated cellulose [9].

2. Materials and Methods

2.1. Sample Collection Location

All collections occurred in Mosquito Lagoon (ML), the northernmost region of the IRL system. Mosquito Lagoon is a shallow, microtidal, high-salinity (30+ ppt) estuary with restricted water movement due to a single ocean inlet [26]. Reefs of *C. virginica* in ML are intertidal. Boat wakes, boat strikes, hurricanes, sea level rise, algal blooms, mangrove encroachment and MP are some of the stressors that *C. virginica* encounter in this system [27].

2.2. Field Collections

Recruitment substrates were deployed for 96 days starting in September 2022. On the edge of each of ten oyster reefs (28°56′28.36″ N, 80°52′10.67″ W), two mats made from 23 × 46 cm non-plastic BESE-elements (Biodegradable EcoSystem Engineering Elements, Culemborg, The Netherlands) produced from the biopolymer Solanyl were deployed on bare sediment [28]. Solanyl is biodegradable, primarily composed of poly(lactic) acid from reclaimed starch, and considered to be non-toxic in the environment [29,30]. Eighteen recycled, adult oyster shells were attached to each mat with stainless-steel cable ties. Mats were held in place with cement weights and stainless-steel cable ties.

Collected mats were individually wrapped in aluminum foil to prevent contamination. All mats were kept wrapped in foil at room temperature in University of Central Florida Biology laboratory (20 °C) until processing.

2.3. Laboratory and Data Processing

To minimize contamination, standard MP protocols were followed throughout processing [22]. All researchers in the field and laboratory wore 100% natural fiber clothing. All Petri dishes, filtration units, ceramic pestles, metal probes and forceps were first triple-rinsed with deionized (DI) water filtered to 0.45 µm. Additionally, while microscopy was underway, five "blank" Petri dishes were placed in a half-circle around each microscope, with new blanks used for each individual [22]. Each blank dish contained a 0.45 µm filter to which 2 mL of filtered water was added to dampen the filter and promote atmospheric particle capture. Blank dishes were open to the environment throughout the duration of

microscopy. Once an individual animal was completed, all particles in blank dishes were recorded and a contamination rate per sample was calculated [25].

For sample processing, all mats, including the external surfaces of all individual animals, were first triple-rinsed with 0.45 µm filtered, deionized water to remove any external particles. Next, all sessile animals were identified to the species level, and the shell length of each settled individual was recorded with calipers. Individuals were then removed from the settlement substrate using stainless-steel forceps and probes. All individuals were placed into separate dishes. Additional gentle crushing with a ceramic pestle was used, if necessary, to expose all of the animal's soft tissue. While chemical digestion is required with larger organisms (e.g., adult oysters) to enable scientists to accurately view all soft tissue under a microscope, this step was not needed with these small individuals (mean length: <1 cm), as the small amount of tissue present was liquid and transparent after crushing [25].

Filtered DI water (0.45 µm) was added to each dish containing a single animal, and all contents were then filtered through gridded (3 mm^2) 0.45 µm filter paper using a GAST vacuum pump (Gast Manufacturing, Inc., Benton Harbor, MI, USA). Each dish was rinsed and filtered three additional times, using a total of ~100 mL of filtered water per animal. Filters were then placed in washed, labeled Petri dishes for microscopy. All samples were examined under a Leica EZ4 dissecting microscope (Leica Microsystems, Wetzlar, Germany) at 20–40X magnification to allow for observation of particles as small as 4–10 µm. Due to the small size of some particles, it was not possible to always test for the breakage of particles to separate natural materials from potential MP. Data were collected for all potential MP as particle type (fiber, fragment, film, foam, bead, pellet) and particle length (mm).

Attenuated Total Reflection Fourier Transform Infrared Spectroscopy (ATR-FTIR) was performed on all potential MP particles to identify polymers. Polymer composition analysis was performed using a Shimadzu IR Spirit-T spectrometer (Shimadzu, Kyoto, Japan). Particles were scanned in the 400 to 4000 cm^{-1} range. Spectra were matched with a qualitative approach, in which the acquired spectra were compared against reference spectra from the KnowItAll FTIR Spectral Database Collection™.

Each spectrum was baseline-corrected and smoothed using a Savitzky–Golay filter with an average of three prior to library matching. Only responses that had a 70% or higher match with the standards database were deemed reliable and categorized as plastic. The matching score was derived from the Euclidean distance between the sample and the reference spectra, representing a nonlinear metric, as variations in environmental or instrument conditions can influence the similarity value. Additionally, the library was designed to match to many types of cellulose/modified cellulose. Modified cellulose particles are reported here as anthropogenic cellulose and include materials such as rayon. Any remaining particles were reported as natural materials (e.g., cellulose).

All statistical analyses were conducted in R version 4.4.1 [31]. Each species was analyzed separately. Organism length and particle length were log transformed to account for the significant positive skew in the data. Models for particle presence/absence were logistic regressions (glm() function with family = "binomial" from the stats package version 4.4.1). Models for MP length used the linear model lm() function from the R statistical package. Confidence intervals for logistic regressions and linear models were determined using the confint() function [31]. Confidence intervals for logistic regressions are reported as odds ratios. Logistic regression model fits were assessed using the Hosmer–Lemeshow test (hoslem.test() function in the ResourceSelection package version 0.3–6)]. Linear model assumptions were assessed visually using diagnostic plots, and no major violations were observed.

3. Results

A total of 3439 sessile invertebrates representing five species settled within 96 days on the deployed oyster shell substrate (Table 1). Overall, 117 (3.4%) of the 3439 individuals contained 118 potential MP. Of these 118 particles, 107 were fibers (90.7%), 9 were fragments (7.6%), and 2 were films (1.7%). No foams or beads/pellets were found. A total of 100% of the particles were fibers for the Atlantic ribbed mussel *Geukensia demissa*, while the ivory barnacle *Amphibalanus eburneus* and the Atlantic jingle shell *Anomia simplex* contained both fibers and fragments. Fibers, fragments, and films were found in *Crassostrea virginica* and *Crepidula fornicata* (Table 1). Overall particle length ranged from 0.1 to 12 mm, with mean lengths for *C. virginica* at 1.5 mm (n = 58 particles) and *C. fornicata* at 1.7 mm (n = 47 particles) (Table 1).

Table 1. Animal and particle metrics. Particle lengths were only calculated when particles were detected (no zeros). SD = standard deviation.

Species	*Crassostrea virginica*	*Crepidula fornicata*	*Amphibalanus eburneus*	*Geukensia demissa*	*Anomia simplex*
Common name	Eastern oyster	Common Atlantic slippersnail	Ivory barnacle	Atlantic ribbed mussel	Common jingle shell
# Individuals (% total Individuals)	1741 (50.6%)	1337 (38.9%)	284 (8.3%)	55 (1.6%)	22 (0.6%)
Mean shell height ± SD (mm)	6.3 ± 4.7	5.0 ± 3.8	4.2 ± 2.4	3.7 ± 2.1	5.3 ± 5.7
Range: shell height (mm)	0.5–33.0	0.5–19.0	0.5–18.0	1.0–9.5	2.0–30.0
# Individuals with particles (% by species)	58 (3.3%)	46 (3.4%)	8 (2.8%)	2 (3.6%)	3 (13.6%)
# Particles per individual ± SD	0.04 ± 0.21	0.04 ± 0.28	0.03 ± 0.19	0.04 ± 0.19	0.10 ± 0.30
Mean length of particles ± SD (mm)	1.5 ± 1.4	1.7 ± 1.6	2.8 ± 3.6	2.5 ± 0.0	1.0 ± 1.7
Range: length of particles (mm)	0.1–6.0	0.1–8.0	0.5–12.0	2.5–2.5	0.1–5.0
Particle Types (#)	Fiber: 53 Fragment: 4 Film: 1	Fiber: 43 Fragment: 3 Film: 1	Fiber: 7 Fragment: 1 Film: 0	Fiber: 2 Fragment: 0 Film: 0	Fiber: 2 Fragment: 1 Film: 0
FTIR-validated particles	MP: 10 AP: 12	MP: 9 AP: 9	MP: 3 AP: 0	MP: 1 AP: 0	MP: 0 AP: 1

We found no significant relationships between organism size and anthropogenic particle presence or size for the three species with ≥5 individuals containing particles (Tables 2 and 3). We observed no relationship between the presence/absence of particles and shell height (logistic regression, p-values ≥ 0.05; Table 2). All Hosmer–Lemeshow (HL) test p-values for our logistic regression models were not significant (p values > 0.05), suggesting our models appropriately fit the data. We also observed no relationship between shell length and the particle size in these three species (linear model, p-value ≥ 0.05; Table 3, Figure 1).

All particles from all individuals were examined using ATR-FTIR. Due to the small size of many particles and their states of degradation, many of these particles produced scores that were below the 70% matching threshold. This resulted in usable results from 45 of the 118 particles (38.1% of the total). The breakdown of totals of MP versus AP by species is included in Table 1. For each species, the percentage of MP to AP was similar. A total of 51.1% of these confirmed particles were plastic polymers (PET: 17 particles, 37.8%; nylon: 3, 6.7%; HDPE: 1, 2.2%; acrylonitrile film: 1, 2.2%; modified rubber: 1, 2.2%). A total of 48.9% of particles were anthropogenic cellulose fibers (microfibrillated cellulose:

20, 44.4%, Tencel: 1, 2.2%). The only other anthropogenic compound observed was one calcium stearate particle. Contamination rates associated with atmospheric particles in blanks were very low (0.009/sample) and thus not included in the FTIR data analyses [9]. In the contamination blanks, there were seven fibers that produced FTIR matches at 70% or higher; included was one PET fiber and six microfibrillated cellulose fibers.

Table 2. Results of logistic regression analysis of particle detection (presence/absence of particles) versus organism shell length. Beta 0 and Beta 1 values are reported as odds ratios. CI = confidence intervals.

	Crassostrea virginica	*Crepidula fornicata*	*Amphibalanus eburneus*
N	1741	1337	284
p-value	0.884	0.199	0.785
β0 + CI	0.033 (CI: 0.017–0.061)	0.050 (CI: 0.027–0.087)	0.024 (CI: 0.0034–0.0924)
β1 + CI	1.065 (CI: 0.459–2.481)	0.543 (CI: 0.212–1.374)	1.428 (CI: 0.127–23.077)

Table 3. Results of linear regression analysis of shell length versus particle length. CI = confidence interval.

	Crassostrea virginica	*Crepidula fornicata*	*Amphibalanus eburneus*
N	58	46	8
p-value	0.939	0.483	0.231
β1 + CI	−0.013 (CI: −0.346–0.320)	0.119 (CI: −0.218–0.456)	0.983 (CI: −0.787–2.751)
R^2	< 0.01	< 0.01	0.083

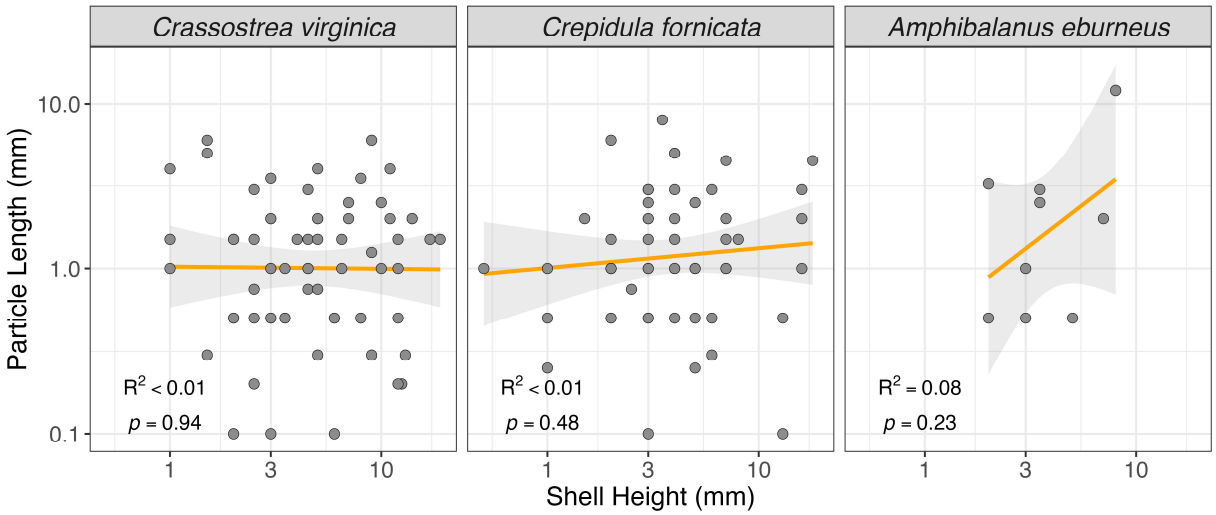

Figure 1. Relationship between shell height and particle length for each *C. virginica*, *C. fornicata*, and *A. eburneus*. Note $\log_{10}$ scaling of both axes. Orange lines are the log-log linear line of best fit, and the gray shaded areas show the 95% confidence interval for each line. R^2 and *p*-values are also reported for each species.

4. Discussion

Overall, 117 of 3439 (3.4%) sessile, filter-feeding, field-collected animals from the Indian River Lagoon, a shallow estuary on the east coast of central Florida, contained potential MP (fibers: 90.7%). Of these particles that matched FTIR databases with a score of 70% or greater (38.1%), 51.1% were plastic and 48.9% were anthropogenically modified. However, particles at the lower end of the size range observed in this study are typically identified using μ-FTIR rather than ATR-FTIR. The use of ATR-FTIR for smaller particles could add uncertainty to our results. Additionally, we did not sample surface waters at oyster

reefs during the study, which limits our ability to discern if the particles observed were ingested or were present in larvae prior to settlement. No correlations to animal size were found for particle presence (logistic regressions: $p \geq 0.20$ for all species) nor particle length (linear regressions: $p \geq 0.23$ for all species). Thus, even though found in a MP hotspot, our extrapolated results suggest few juveniles (<1%) that were less than 1 cm in shell length contained MP. No published articles found during our literature review focused on newly metamorphosed, wild-caught individuals, and only a few laboratory-based studies tracked these sessile filter-feeders post-metamorphosis [13,16]. Chiani et al. (2025) [32] did, however, report from field-collected animals that smaller individuals of the mussel *Mytilaster lineatus* and barnacle *Amphibalanus improvisus* had significantly more MP than larger individuals. Although the animal size ranges were not large (mussel: 1.0–1.4 cm; barnacle: 0.66–1.07 cm), the authors suggest that future studies on MP biomonitoring include size-related variables. Moreover, they thus suggested that small individuals have greater potential as biological indicators.

Good biological indicators of ecosystem health should focus on cosmopolitan species that are common, easy to identify, have limited mobility, feed at lower trophic levels, and resist ecological change [33,34]. Sessile, filter-feeding invertebrates have been suggested as potentially being good bioindicators of MP pollution in many studies (bivalves: [34–36]; mussels: [17]; barnacles: [37,38]; gastropods including *Crepidula*: [39]). As mentioned in the previous paragraph, it is important to consider the size of the potential biological indicator, as our results document that very few (3.4%) of the 3439 study individuals contained any visible particles and <1% contained MP. It is likely that nanoparticles would have been found in these animals as well. However, the tools needed to quantify nanoparticles are less available, making nanoplastic metrics less useful for a biological indicator.

Ward et al. [40,41] suggested that bivalves (oysters, mussels, clams) are poor biological indicators due to their selective feeding capabilities. Although both filter-feeders, bivalves and barnacles feed in different ways that may impact their ingestion of MP. Bivalves actively feed by bringing water into their body, sorting and selecting particles on their gills, followed by additional sorting on their labial palps before the particles enter their mouth [40,41]. Sorting is based on many particle criteria including size, shape, density, chemical, and nutritional properties [40,41]. Unselected particles are removed as pseudofeces. The selected particles are then transported to the bivalve's mouth for ingestion. MP have been reported in both pseudofeces and feces in oysters [25]. Alternatively, barnacles are considered passive, mechanical feeders with no, or very limited, pre-ingestive particle sorting [19]. Barnacles create water movement by rhythmic movement of their cirri [19]. The cirri have fine setae on them that collect all particles and transfer them to the barnacle's mouth with limited sorting or selection [19]. Another non-selective feeder is the slippersnail *Crepidula* sp.; this genus uses a mucus net to capture particles and then consumes this mucus [42]. Sponges, tunicates, and suspension-feeding polychaetes are also non-selective filter-feeding animals in estuarine and marine waters [43]. Khan and Rountos (2025) [43] evaluated 144 publications (133 species) and compared MP metrics in selective versus non-selective filter-feeders. They found similar percentages of fibers and fragments, as well as the same dominant polymers (PE, PET, and PP). However, higher concentrations of MP were found in the non-selective feeding species [43]. While *C. virginica* takes ~6 days until filter-feeding commences post-metamorphosis, this duration is not known for most sessile invertebrates [3]. Nor is it known how selective the "selective" filter feeders are when the animal sizes are <1 cm. Our reported data suggest similar numbers of particles per individual regardless of whether the species was a selective or non-selective feeder.

Unlike our results with newly settled *C. virginica* from the IRL, Craig et al. [25] found positive correlations with adult IRL oysters for both particle counts and particle lengths.

This difference is not a sample size issue as a large number of *C. virginica* were examined in both studies; 70.0% (981 of 1402) of adults contained MP, versus our 3.3% (58 of 1741) of juvenile *C. virginica*. The type of particle was similar in both Craig et al. [25] and our study. Ninety-five percent of particles were fibers for Craig et al. [25] and 91.4% of *C. virginica* for our study. However, the mean number of particles per individual in our study for juvenile *C. virginica* was two orders of magnitude smaller (0.04) versus 2.3 particles for Craig et al. [25] in adult oysters from the same area. Moreover, the mean length of particles was 1 mm shorter (1.5 mm) in our juvenile *C. virginica*, while it was 2.5 mm in the adult IRL oysters [25]. We initially predicted that individuals $\leq$ 96 days old would follow similar patterns to adult *C. virginica*, but this was not the case. To better understand the capability of each species of these size ranges to consume MP, it would have been necessary to culture each species in a laboratory, and that was out of scope for this observational field study.

Because the days since settlement was only known to be <96 days, our focus was on animal size (e.g., shell length) rather than age. Shell length and wet weight are widely adopted indicators of bivalve growth [7,44]. As our invertebrates all averaged less than one centimeter in mean length ($\leq$6.3 mm) and were tightly cemented to the substrate, as is common in newly settled animals, we focused on shell length as our proxy to enable comparisons with global populations of each genus and species. Using shell length additionally makes sense with these sessile animals collected in the fall in warm Florida waters, as growth rates in the field are dependent on temperature and food availability rather than the number of days since settlement [45].

Although much more research is needed, concerns are rising over the wide-ranging negative impacts of plastic particles on humans (e.g., microplastic syndrome) [46]. Humans unintentionally consuming plastic is an important source of pollution [47,48]. Shellfish, mussels and, in some locations, barnacles, are consumed whole, so whatever was contained in the invertebrate moves to the human consumer. Ribeiro et al. 2020 [49] calculated that ~0.7 mg of plastic are consumed by humans eating just 10 adult oysters. Recent studies suggest that humans consume up to 11,000 MP particles annually by consuming shellfish [50]. This type of bioaccumulation via predation represents an important vector for trophic transfer of MP from sessile, filter-feeding invertebrates to humans and to many other animals in food webs. Common predators of oysters and mussels in estuaries include crabs, coastal birds, fish, and small vertebrates such as raccoons [17,24,51]. Additionally, egestion of MP by bivalves onto the sediment surface can provide MP that are ingested by nearby deposit-feeding organisms such as worms [25,52]. MP loads in shellfish may increase if grown in aquaculture settings, especially for those industries reliant on plastic tanks, cages, ropes, or bags [53]. Bringer et al. 2020 [13] found slower initial growth of *C. gigas* larvae when grown in tanks spiked with aged aquaculture plastics. Moreover, liquid algal feed for shellfish that is packaged in plastic bottles may increase MP concentrations in tanks [L. Nguyen, pers. comm]. A future research area should focus on understanding the "tipping point" at which field-collected filter-feeding invertebrates go from being mostly MP-free to being a valuable bioindicator and potential source of microplastic syndrome in humans.

In conclusion, we found very small numbers of small plastic particles (23 MP, 0.7% of total animals) and 22 anthropogenically modified particles (0.6% of total animals) in filter-feeding invertebrates that averaged less than 1 cm in length in this shallow, subtropical Florida estuary. Extrapolated to all individuals from this study, we suggest that 1.3% of the total invertebrates contained some sort of human-produced particles (MP + AP). Further research is needed to understand and distinguish if any observed particles were larval legacy particles retained post-metamorphosis or if they were captured post-settlement via filter-feeding. Moreover, additional research is needed to better understand juvenile

capture and egestion rates of various sized fibers, fragments, and films under realistic conditions. Only with this information will we begin to understand the impact of plastics on newly recruited animals that are ecologically and economically important in Florida, throughout the temperate and subtropical western Atlantic estuaries, and beyond.

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Abbreviations

The following abbreviations are used in this manuscript:

MP	Microplastics
IRL	Indian River Lagoon
FTIR	Fourier Transform Infrared Spectroscopy
ML	Mosquito Lagoon
ATR-FTIR	Attenuated Total Reflection Fourier Transform Infrared Spectroscopy
AP	Anthropogenic Particle (non-plastic, human-modified)

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