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Occurrence and amount of microplastic ingested by fishes in watersheds of the Gulf of Mexico

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ABSTRACT

Ingestion of microplastics by fishes could be an emerging environmental crisis because of the proliferation of plastic pollution in aquatic environments. Microplastics in marine ecosystems are well documented, however only one study has reported percent occurrence of microplastics in freshwater fishes. The purpose of this study was to quantify the occurrences and types of microplastics ingested by fishes within several freshwater drainages of the Gulf of Mexico and an estuary of the Gulf of Mexico. Among 535 fishes examined in this study, 8% of the freshwater fishes and 10% of the marine fishes had microplastics in their gut tract. Percentage occurrence of microplastics ingested by fishes in non-urbanized streams (5%) was less than that of one of the urbanized streams (Neches River; 29%). Percent occurrence of microplastics by habitat (i.e., benthic, pelagic) and trophic guilds (herbivore/omnivore, invertivore, carnivore) were similar. Low but widespread occurrences among drainages, habitat guilds, and trophic guilds indicate proliferation of plastic pollution within watersheds of the Gulf of Mexico, but consequences to fish health are unknown at this time.

1. Introduction

Globally, plastic pollution is ubiquitous on land and in water and is increasing. Plastic production continues to accelerate with developed and developing countries adopting the use-and-dispose culture. Annual plastic production has increased from 1.5 million tonnes in the 1950s to 288 million tonnes in 2012 (PlasticsEurope, 2013) with only 9% of plastics being currently recycled in the USA (EPA, 2014). Non-recycled plastics are disposed in landfills (Barnes et al., 2009) or in the environment as a pollutant (Cole et al., 2011). Marine plastic pollution has been of concern since the 1970s, when the first reports of microplastic ingestion in fishes were published (Carpenter et al., 1972). Plastic is prolific throughout the marine environment with as much as 80% of marine debris being plastic because of its durable nature (Barnes et al., 2009).

Plastic accounts for 92% of all encounters between organisms and marine debris, the effects of large plastic items (i.e., macroplastic), such as entanglement, ingestion and death, being widely reported in fish and wildlife (Gall and Thompson, 2015). However, a greater proportion of plastic pollution is microscopic (<5 mm; Arthur et al., 2009). Some microplastics, for instance microbeads, are manufactured to be of a microscopic size, typically polyethylene and polypropylene and used in skin exfoliators and cosmetics and in air-blasting technology (Derraik, 2002; Fendall and Sewell, 2009; Gregory, 2009). Additionally, microplastics are derived from macroplastic fragmenting and disintegrating into smaller particles through a process of photo-degradation caused by the ultraviolet rays of the sun, mechanical forces, and weather (Andrady, 2011; Cole et al., 2011; Derraik, 2002). These macroplastics are made of a variety of plastics; more abundant forms are polyolefins (polyethylene and polypropylene), which are primarily used for single-use packaging (Browne et al., 2010a, 2010b). A large proportion of the plastic fragments are lost from the surface due to hydrodynamic processes (Eriksen et al., 2014). Other sources of microplastics are acrylic, polyester, and polyamide fibers from textiles (Browne et al., 2011). Densities of plastic vary considerably, depending on the type of polymer and the manufacturing process. Size and density of plastic determine its position in the water column (Browne et al., 2011) and potentially its environmental effects including ingestion by fishes.

Occurrence of microplastics in the stomachs of fish poses several environmental concerns. Ingested microplastics are passed through in the feces, retained in the digestive tract, or translocated from the gut into body tissues via the epithelial lining (M. A. Browne et al., 2010a, 2010b). Negative effects on fish health are due to the toxic nature of the plastic itself and to other pollutants in the environment absorbed by plastic. Microplastics consist of synthetic organic polymers that are transport medium for persistent organic pollutants (POPs). Polymers act as a sponge and absorb toxins, such as polychlorinated biphenyls (PCBs), dioxins, pesticides, flame-retardants and carcinogens from the marine environment (Rochman, 2013). Toxic substances pass from microplastics to the carrier and accumulate in tissues, causing liver toxicity and lesions (Rochman et al., 2013).

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Since the 1970s, occurrence of microplastic ingestion in marine environments has been well documented with a surge in research since 2000. Percent occurrences of plastics in the stomach contents of marine fishes range from 2.6% in the North Sea (Foekema et al., 2013) to 37% in the English Channel (Lusher et al., 2013). Reports from other areas include Brazilian estuaries (Possatto et al., 2011; Dantas et al., 2012) and North Pacific Gyre (Boerger et al., 2010). Reports of microplastic ingestion are limited for freshwater fishes with one study reporting 12% in urbanized streams of France (Sanchez et al., 2014).

Freshwater environments, like marine environments, are susceptible to microplastic pollution with rivers serving as major pathways of plastic transport from terrestrial environments to marine environments (Lechner et al., 2014). Microplastics occur in Laurentian Great Lakes of North America (Eriksen et al., 2013), freshwater inflows into Jade Bay, Germany (Dubaish and Liebezeit, 2013) and the remote Lake Hovsgol, Mongolia (Free et al., 2014) at amounts comparable to those in marine systems. Abundances of microplastic pollution and urban population density are directly related with microplastics coming from wastewater treatment effluents (Browne et al., 2011; Free et al., 2014). Concerns and subsequent effects of incidental ingestion by freshwater and marine aquatic animals are emerging environmental issues. Bioavailability of the smaller-sized microplastics is more likely than macroplastics, especially to fishes that mistakenly or incidentally ingest microplastic while feeding in the water column or along the benthos (Browne et al., 2010a, 2010b).

The objective of this study was to document occurrence, frequency, amount, and types of plastic ingested by fishes in freshwater drainages of the Gulf of Mexico and by marine fishes within a large bay system of the Gulf of Mexico. To further illustrate the link between highly human-altered areas and plastic pollution, this study compared ingestion amounts in fishes from urbanized and non-urbanized streams. Predictions were that percent occurrence of microplastics ingested by fish will be similar to the range of ingestion amounts reported in marine studies conducted in estuaries (8 to 33%; Possatto et al., 2011; Dantas et al., 2012) and freshwater (12%; Sanchez et al., 2014), will be greater in urbanized streams than in non-urbanized streams, and will differ among trophic and habitat guilds of fishes (e.g., benthic omnivore, pelagic piscivore), depending on the location of plastics within aquatic environments (i.e., benthic, pelagic, surface). Within the large bay system, Laguna Madre is naturally a hypersaline bay because of limited freshwater inflows. As such, microplastic availability might be lower than in other bay and estuary systems where plastic ingestion has been reported and therefore has lower incidents of microplastic ingestion among bay and offshore fishes.

2. Materials and methods

Gut contents of fishes were extracted from individuals harvested for purposes other than these study objectives. Freshwater fishes were obtained from teaching collections, taken between September 2013 and January 2014 and housed at Texas State University. Freshwater fishes were taken by permit (Texas Parks and Wildlife Scientific Collection Permit Number SPR-0601-159) and Institute of Animal Care and Use Committee (IACUC) protocols (Texas State University IACUC numbers 1036-1102-32 and 0530-0620-15). Freshwater fishes were taken from multiple sites and drainages within Texas (Fig. 1; see Phillips, 2014 for more specific site information). All sites were considered non-urbanized, except for Upper San Antonio River (City of San Antonio, Texas) and on Banita Creek (Neches River drainage, City of Nacogdoches, Texas). At each site, fishes were harvested with seines or electrofishing. Fishes were taken from all available habitats; however, a few larger specimens (>200 mm), usually ictalurids, centrarchids, and cichlids, were not retained. Otherwise, fishes retained were a representative sample of the community existing at the time of collection. Fishes were anesthetized with a lethal dose of MS-222 (>80 mg/l) and fixed in 10% buffered formalin. Later, fishes were transferred to 70% ethanol. In the laboratory, freshwater fishes were identified to species, weighed (g), and measured (mm; total length). Gastrointestinal (GI) tracts from esophagus to anus were removed. Marine fishes were donated by anglers in a bay and offshore fishing tournament held on the Laguna Madre along the southern coast of Texas in July 2013. Fishes were harvested by hook-and-line angling with live or plastic baits from the Laguna Madre (harbor and bay) or from the Gulf of Mexico near Laguna Madre. On the day of harvest, fishes were maintained in edible condition until reaching the weigh-in station at Port Mansfield, Texas, which usually includes holding fish in an ice bath. At weigh-in, fish were identified to species, weighed (g), and measured (mm; total length or fork length if caudal fin is lunate). The abdomen was opened,

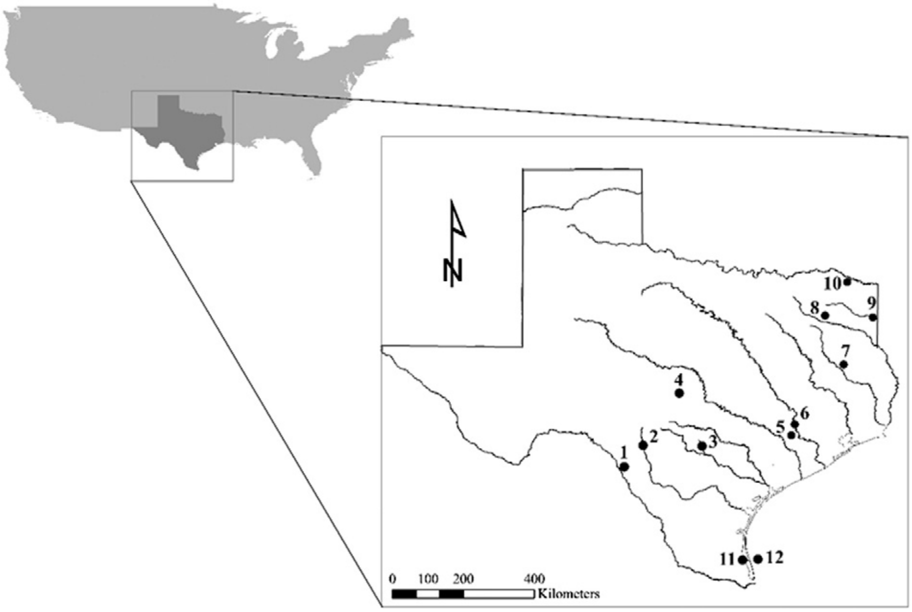

Fig. 1. Fishes were taken from 1) Las Moras Creek, Rio Grande drainage; 2) Nueces River, Nueces River drainage; 3) Upper San Antonio River, San Antonio River drainage; 4) James River, Colorado River drainage; 5) Mill Creek and 6) lower Brazos River, Brazos River drainage; 7) Banita Creek, Angelina River drainage; 8) Big Sandy Creek, Sabine River Drainage; 9) Caddo Lake, Cypress River–Red River drainage; 10) Red River, Red River drainage, 11) Laguna Madre; and 12) Gulf of Mexico.

and the alimentary canal from esophagus to anus was removed, placed in a plastic bag, and frozen.

Initially, all individuals collected from a site were targeted for GI tract examinations. After examining 67 Red Shiners *Cyprinella lutrensis* and 48 Pinfish *Lagodon rhomboides*, the selection process changed to selecting up to 10 individuals per species or habitat guild per site in order to capture variability among a greater number of species and habitat guilds, while restricting effort in examining a large number of the same species. For each individual selected, the GI tract was placed on a sterile petri dish underneath a dissecting scope with adequate lighting. Petri dish and sterilized dissecting utensils were examined for foreign material before each use. Stomach was delineated by a pyloric sphincter muscle. For fish without a distinct sphincter muscle, the upper GI tract to the first loop of the intestine was examined. Stomach or upper GI tracts were searched for any suspicious objects that did not resemble prey and removed with forceps. Search time depended on exhaustive sampling of the food contents.

Initially, a large number of white, red, and blue elongated fibers were found commonly in the first 100 individuals examined. A swipe of nearby countertops and dissecting scope surfaces contained identical white, red, and blue elongated fibers. Source of fibers was attributed to the settling of particles in the air. To avoid areal contamination, times were restricted to 10 min of continuous search. Occurrences of white, red, and blue elongated fibers, which were similar to length, diameter, and texture of room particles, were not considered ingested items. Once other suspected plastic items were found, the item was categorized following similar descriptions of Lusher et al. (2013) and Free et al. (2014): nurdle (e.g., irregularly shaped cube with smooth to jagged edges and without a flat plane), filament (e.g., thin thread-like structure), fragment (e.g., irregular shaped cube with at least one smooth plane), and film (e.g., thin with two smooth planes). For each item, the longest length and width were measured to estimate the area of the item. For each fish, the number and area of each plastic category were recorded.

A commercial company (Cerium Laboratories, Austin, Texas) used Fourier transform infrared (FTIR) spectroscopy to identify and confirm categories of suspicious items found in the gut contents of fish. The use of FTIR to identify all items was cost-prohibitive, so 8 representative samples from nurdle, filament, fragment, and film categories were examined. All nurdle samples were identified as sand and removed from subsequent analyses. Filament, fragment, and film categories were confirmed as plastic but not in all samples tested. Organic tissue (i.e., non-plastic) was found in 55% of the filament samples tested, 25% of the fragment samples tested, and 57% of the film category tested. Organic tissue was largely prey or fish tissues that appeared to be a plastic item. The remaining organic tissue was cellulosic filaments. The source of cotton items still could be from contamination or ingested from aquatic sources. Regardless, issues surrounding plastics in the environment are likely not the same for cotton fibers in the environment. As such, cotton and other organic tissues were excluded from subsequent analyses.

Percent occurrence of microplastics was calculated for freshwater and marine fishes separately, for each freshwater drainage basin, for fish taken from harbor, bay, and offshore, and for habitat and feeding guilds. Percent occurrence is based on whether the fish ingested plastic. Habitat and feeding guilds were assigned following Goldstein and Simon (1999). Percent occurrences of microplastics from fishes in each urbanized stream (Upper San Antonio River and Banita Creek) were compared to those from non-urbanized streams ($N = 5$) with a one sample t-test ($\alpha = 0.05$) to test the prediction that percent occurrence of microplastics was greater in fish within urbanized streams than in non-urbanized streams. Since FTIR spectroscopy was conducted on only a representative sample of the categories, a correction factor was developed and applied to the raw data before analysis. The correction factor was necessary to adjust for organic tissue being selected and considered as a plastic. Percent occurrences with correction factor consisted of calculating a correction for each plastic category. Among items tested with FTIR spectroscopy, filament category consisted of 44.4% confirmed plastic items, fragment category consisted of 75% confirmed plastic categories, and films consisted of 42.9% confirmed plastic categories. Each of these percentages was converted to a proportion and multiplied by the numbers of fish reported to contain a plastic item. Number and surface areas of items reported herein were not corrected for the occurrence of organic tissue in the categories. Uncorrected number and surface areas of plastic items are provided but should be viewed with caution.

3. Results

3.1. Freshwater fishes

A total of 419 freshwater fishes was examined, representing 44 species and 12 families (Table 1). Plastics were detected in 34 individuals (8.2%) from urban and non-urbanized streams. Percent occurrence was 1.3% for filament plastics, 2.7% for fragment plastics, and 3.1% for film plastics for all fishes. Percent occurrence of plastics in fishes from urbanized area of the Neches River (29.2%) was greater (one-sample t-test; $P > 0.01$) than those taken from non-urbanized streams (mean $\pm$ 1 SD; 4.6 $\pm$ 3.9). Percent occurrence of plastics in fishes from an urbanized area of the San Antonio River (6.8%) did not differ ($P = 0.90$) than those taken from non-urbanized streams.

Between the two urban streams, maximum percent occurrences were 2.1% for filament plastics, 13% for fragment plastics, and 20% for film plastics (Table 2). The mean surface area ($\pm$1 SD) was 286 μm^2 ($\pm$345.3) for filament plastics, 129.8 μm^2 ($\pm$133) for fragment plastics, and 192.1 μm^2 ($\pm$240) for film plastics. The maximum number within a stomach was 2 for filament plastics, 12 for fragment plastics, and 10 for film plastics. Among the 20 individuals with a plastic item, 12 (35%) contained at least 2 plastic types. Percent occurrence within the benthic habitat guild was 19%, ranging from 13% in herbivore–omnivore trophic guild to 21% in invertivore trophic guild. Percent occurrence within the pelagic habitat guild was 7.7%, ranging from 6.3% in invertivore–carnivore trophic guild to 21% in herbivore–omnivore trophic guild.

Among non-urbanized streams, maximum percent occurrences were 5.0% for filament plastics, 4.5% for fragment plastics, and 3.9% for film plastics. The mean surface area ($\pm$1 SD) was 73 μm^2 ($\pm$98.6) for filament plastics, 160 μm^2 ($\pm$245.2) for fragment plastics, and 235 μm^2 ($\pm$332.2) for film plastics. The maximum number within a stomach was 2 for filament plastics, 4 for fragment plastics, and 5 for film plastics. Among the 13 individuals with a plastic item, 4 (12%) contained at least two plastic types and 1 (3%) contained three plastic types. Percent occurrence within the benthic habitat guild was 5.9%, ranging from 5.8% in invertivore trophic guild to 7.5% in invertivore–carnivore trophic guild. Percent occurrence within the pelagic habitat guild was 5.6%, ranging from 2.4% in invertivore–carnivore trophic guild to 8% in herbivore–omnivore trophic guild.

3.2. Marine fishes

A total of 116 marine fishes was examined, representing eight species and five families (Table 3). Plastics were detected in 12 individuals (10.4%). Percent occurrences by plastic type were 3.8% for filament plastics, 2.6% for fragment plastics, and 2.6% for film plastics for all fishes. Percent occurrences by location were 5.9% in harbor fishes, 13.5% in the bay fishes and 22% in the offshore fishes. The mean surface area ($\pm$1 SD) was 313 μm^2 ($\pm$473.9) for filament plastics, 186 μm^2 ($\pm$290.1) for fragment plastics, and 1565 μm^2 ($\pm$5588.7) for film plastics. The maximum number within a stomach was 4 for filament plastics, 2 for fragment plastics, and 6 for film plastics. Among the 12 individuals with a plastic item, 6 (50%) contained at least two plastic types and 3 (33%) contained three plastic types. Percent occurrence within the benthic invertivore–carnivore trophic guild was 12%. Percent

Table 1
Species, number, and maximum (max) sizes of individuals examined from 10 sites and nine freshwater drainages of Texas and the Laguna Madre, an estuary along the southeast coast of Texas. Symbols: F = freshwater, M = marine, x = occurrence of plastic.

Family	Species	Common name	Max length (mm)	Site	N	Plastic present
Clupeidae	*Brevoortia patronus*	Gulf Menhaden	83	F	9	
	Dorosoma cepedianum	Gizzard Shad	40	F	16	x
	Dorosoma petenense	Threadfin Shad	81	F	5	x
Cyprinidae	*Campostoma anomalum*	Central Stoneroller	90	F	31	x
	Cyprinella lepida	Plateau Shiner	71	F	5	
	Cyprinella lutrensis	Red Shiner	62	F	67	x
	Cyprinella venusta	Blacktail Shiner	79	F	38	x
	Notemigonus crysoleucas	Golden Shiner	88	F	7	
	Notropis amabilis	Texas Shiner	63	F	16	x
	Notropis volucellus	Mimic Shiner	60	F	32	x
	Opsopoeodus emiliae	Pugnose Minnow	58	F	2	
	Pimephales promelas	Fathead Minnow	68	F	1	
	Pimephales vigilax	Bullhead Minnow	89	F	3	x
	Notropis sabinae	Sabine Shiner	62	F	12	x
	Notropis stramineus	Sand Shiner	49	F	7	x
Catostomidae	*Erimyzon oblongus*	Creek Chubsucker	75	F	1	
	Minytrema melanops	Spotted Sucker	100	F	1	
Characidae	*Astyanax mexicanus*	Mexican Tetra	85	F	12	x
Ictaluridae	*Ameiurus melas*	Black Bullhead	61	F	1	
	Ameiurus natalis	Yellow Bullhead	55	F	7	x
	Ictalurus punctatus	Channel Catfish	98	F	10	x
	Noturus gyrinus	Tadpole Madtom	64	F	2	x
Mugilidae	*Mugil cephalus*	Striped Mullet	75	F	9	
Fundulidae	*Fundulus notatus*	Blackstripe Topminnow	70	F	2	x
Poeciliidae	*Gambusia affinis*	Western Mosquitofish	53	F	5	x
Centrarchidae	*Lepomis auritus*	Redbreast Sunfish	118	F	8	x
	Lepomis cyanellus	Green Sunfish	142	F	6	x
	Lepomis gulosus	Warmouth	85	F	1	
	Lepomis humilis	Orangespotted Sunfish	42	F	4	x
	Lepomis macrochirus	Bluegill	120	F	12	x
	Lepomis megalotis	Longear Sunfish	120	F	23	x
	Lepomis microlophus	Redear Sunfish	200	F	5	x
	Lepomis miniatus	Redspotted Sunfish	105	F	6	
	Micropterus punctatus	Spotted Bass	116	F	1	
	Micropterus salmoides	Largemouth Bass	145	F	12	x
	Pomoxis annularis	White Crappie	75	F	4	
	Pomoxis nigromaculatus	Black Crappie	250	F	3	
Percidae	*Etheostoma artesiae*	Redspot Darter	53	F	11	x
Carangidae	*Caranx hippos*	Crevalle Jack	84	F	9	
Lutjanidae	*Lutjanus campechanus*	Red Snapper	635	M	2	x
	Lutjanus griseus	Mangrove Snapper	213	M	5	x
Sparidae	*Lagodon rhomboides*	Pinfish	248	M	48	x
Sciaenidae	*Pogonias cromis*	Black Drum	654	M	1	
	Micropogonias undulatus	Atlantic Croaker	175	M	1	
	Sciaenops ocellatus	Redfish	702	M	28	x
	Cynoscion nebulosus	Spotted Seatrout	654	M	20	x
Cichlidae	*Herichthys cyanoguttatus*	Rio Grande Cichlid	127	F	6	x
	Oreochromis aureus	Blue Tilapia	103	F	4	x
Scombridae	*Scomberomorus cavalla*	King Mackerel	959	M	1	
Paralichthyidae	*Paralichthys lethostigma*	Southern Flounder	464	M	8	x
Coryphaenidae	*Coryphaena hippurus*	Dolphinfish	1238	M	2	x

occurrence within the pelagic habitat guild was 10%, ranging from 6% in invertivore trophic guild to 17.5% in carnivore trophic guild.

4. Discussion

Although percent occurrences were low, occurrences of microplastic ingestion was ubiquitous among all water bodies, taxonomic groups, and trophic guilds quantified in this study. Predictions about percent occurrence of microplastic ingestion among freshwater and marine fishes, between non-urbanized and urbanized streams, and among trophic guilds were generally supported. Percent occurrence of microplastic ingestion among freshwater fishes (8%) and marine fishes (10%) in the study area was within the low range of reported plastic ingestion elsewhere (8 to 33%; Dantas et al., 2012; Possatto et al., 2011). Percent occurrence of microplastics ingested by fishes in non-urbanized streams (5%) was less than that of one urbanized stream (Neches River; 29%). Estimates within urbanized streams (6.8 to 29%) were similar to percent occurrence of microplastic ingestion in other urbanized streams (12%; Sanchez et al., 2014). Within urbanized streams, 19% of all the fishes of the benthic habitat guild ingested microplastics, whereas only 8% of all fishes with the pelagic habitat guild ingested microplastics. Benthic and pelagic guilds were similar (<6%) within non-urbanized streams and within the marine system (10–12%) and consistent with other studies that did not detect differences among habitat or trophic guilds (Boerger et al., 2010).

Sizes of microplastics reported in this study were similar to those reported as the most abundant in the environment and in the stomach contents of fish. Though reported in area, the maximum linear length was 5.5 mm. Microplastics, ranging in linear length from 0.33 to 4.75 mm, comprise up to 92% of the available plastics in marine environments, although estimates of the smaller microplastics were constrained by mesh size of tow (0.33 mm; Eriksen et al., 2014). As such, estimates of available microplastics likely underrepresented the total amounts of water column microplastics available. Size distributions of microplastics within the aquatic systems assessed in this study are not known at this time although it would be useful to know the amount of ingestion

Table 2
Percent occurrences and types of microplastic ingestion in freshwater habitats, among urbanized and non-urbanized streams, and trophic guilds, taken from 10 sites and nine freshwater drainages of Texas. Symbols: herb = herbivore, omn = omnivore, invert = invertivore, carn = carnivore.

	Total N	% of total	% of fish with a plastic type*		
			Filament	Fragment	Film
Freshwater fishes	419	8.1	1.9	3.6	3.9
Urbanized streams					
Neches River	41	29.2	0.5	13.1	20.1
San Antonio River	119	6.8	2.1	4.5	1.8
Benthic	63	19.0	2.3	10.1	10.7
invert/carn	9	16.8	3.7	12.0	4.8
invertivore	40	21.2	0.9	10.7	15.1
herb/omn	14	13.0	4.5	5.4	4.4
Pelagic	91	7.7	1.2	3.6	3.4
invert/carn	7	6.3	6.3		
invertivore	84	7.8	0.8	4.0	3.7
herb/omn	6	21.0	3.2	17.9	8.5
Non-urbanized streams					
Brazos River	100	3.7	0.9	1.5	1.3
Colorado River	11	3.9			3.9
Nueces River	73	4.4	1.5		3.2
Red River	61	10.8	5.0	4.5	3.0
Rio Grande	14	0			
Benthic	113	5.9	2.7	1.7	2.4
invert/carn	10	7.5		7.5	
invertivore	88	7.2	2.5	4.8	1.1
herb/omn	15	5.9	17.8		
Pelagic	151	5.6	1.3	2.0	2.4
invert/carn	18	2.4			2.4
invertivore	107	5.2	1.8	1.4	2.2
herb/omn	26	8.0	3.4	2.9	1.6

* Percentages do not sum to % of total because of consumption of multiple plastic types.

relative to the amount available in the environment. As reported in other studies, plastic sizes in fish stomachs ranged from <5 mm (Foekema et al., 2013) to 14.3 mm, with the most common size class being 1 to 2 mm (Lusher et al., 2013). A large proportion of fishes examined in this study are small-bodied fishes (<100 mm). Gape size among the most common family (Cyprinidae) is <6% of the total length (calculated from three representative species within the family; Perkin et al., 2009), which constrains consumption of microplastics >6 mm.

Polymers ingested by fish in this study were polypropylene (PP), polyester (PET), polymethacrylate, polystyrene, and nylon (polyamide). Similar polymers were present in the gut tracts of fishes taken from the English Channel (Lusher et al., 2013) and the North Sea (Foekema et al., 2013). Sources of polymers classified as film and fragment are reported to be from packaging and sturdy plastic material (Browne et al., 2010a, 2010b). Sources of polymers classified as filament (e.g. nylon) are reported to be from wastewater treatment facilities and soil from terrestrial habitats where sewage sludge had been applied (Browne et al., 2011; Dubaish and Liebezeit, 2013). A combination of all three categories in fishes examined in this study supports that land-based and water-based sources of plastics are entering and affecting freshwater and marine systems.

Table 3
Percent occurrence and types of microplastic ingestion in marine habitats, among harbor, bay and offshore fishes and trophic guilds taken from the Laguna Madre, an estuary along the southeast coast of Texas. Symbols: invert = invertivore, carn = carnivore.

	Total N	% of total	% of fish with a plastic type*		
			Filament	Fragment	Film
Marine fishes	116	10.4	3.8	2.6	2.6
Harbor	54	5.9	2.9	1.9	2.8
Bay	56	13.5	6.4	4.3	4.7
Offshore	6	22.0	14.8		7.1
Benthic-invert/carn	9	11.8	7.1		6.9
Pelagic	107	10.2	5.0	3.2	3.7
carnivore	5	17.5	8.9		8.6
invert/carn	49	14.1	6.9	4.9	4.1
invertivore	53	6.0	2.9	2.0	2.9

* Percentages do not sum % of total because of consumption of multiple plastic types.

The extent of the effect of plastic contamination on fish health is not fully understood at this time. All of the polymers identified in this study possess harmful monomers of varying degrees. Crude oil derived chemicals are hazardous to the food web and the environment (Lithner et al., 2011). Polystyrene, used in food packaging, is made of the endocrine disrupter styrene, which is used in many other polymers, including polyester (Lithner et al., 2011). Two of the polymers, polyester and poly(methylacrylate), are made with hazard level IV (out of five levels) monomers, which are associated with cell mutation and respiratory irritation and are hazardous to the aquatic environment (Lithner et al., 2011). Though polymers such as polyethylene and nylon (polyamide) are thought to be more benign, these materials are likely to absorb pollutants in the environment (Rochman, 2013). The negative effects of toxins on individual fish health are demonstrated by Rochman et al. (2013). Small particles of low-density polyethylene (LDPE) were exposed to environmental bay conditions for three months, and then fed to fish. After two-months, fish tissues had a greater concentration of PBTs, and individuals showed signs of liver stress, including glycogen depletion, fatty vacuolation and single cell necrosis (Rochman et al., 2013). However, further research is necessary to detect if microplastics and associated toxins accumulate within the food web and if microplastics are associated with population-level declines of fish species. Some encouraging information from a fish health perspective is that low numbers of plastic items reported herein suggest that ingested microplastics are not accumulating within the stomach of fishes (i.e., short residency time), which could minimize exposure to toxins and lessen the likelihood of compound translocation to fish tissue.

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