THE OCCURRENCE AND AMOUNT OF MICROPLASTICS INGESTED BY FISHES IN THE WATERSHEDS OF THE GULF OF MEXICO

by

Melissa B. Phillips, B.A.

A thesis submitted to the Graduate Council of
Texas State University in partial fulfillment
of the requirements for the degree of
Master of Science in Interdisciplinary Studies
with a Major in Interdisciplinary Studies
December 2014

Committee Members:

Timothy H. Bonner, Chair

Gwendolyn Hustvedt

Joseph Veech

FAIR USE AND AUTHOR'S PERMISSION STATEMENT

Fair Use

Duplication Permission

ACKNOWLEDGEMENTS

A very special thank you goes to my major advisor Dr. Timothy Bonner for welcoming me into his research lab, and being so supportive and encouraging throughout the data collecting, lab work, analysis and writing phase of this thesis. The fact that he took a chance on a student from another program with crazy ideas of looking for plastic in fish meant that I could pursue a long held dream and passion. I couldn't have wished for a better place to end up at Texas State than Dr. Bonner's lab. Not only have I been able to relate my studies in Sustainability to fish, but I have also been on countless research trips to the furthest reaches of Texas, which has made my experience here unforgettable.

I would also like to thank my committee members Dr. Veech and Dr. Gwendolyn Hustvedt for their guidance and contribution to my thesis and success as a graduate student. A special thanks goes to Dr. Hustvedt's continued support. Without her I probably would never have managed to maneuver the application process, let alone have such a fulfilling and exciting experience. She listened to my plastic pipe dreams, making them a reality by steering me towards Dr. Bonner. Her energy is contagious, she has been a joy to work with and as a strong woman scientist she is a huge inspiration to me.

I would like to thank all those who helped with the endless months of fish dissecting especially Michael Parham. Without Mike's enthusiasm and dedication I would still be dissecting fish. With that being said I must extend huge amounts of thanks to my colleagues in the Bonner lab: Cody Craig, David Ruppel, Harlan Nicholls, Ginny Dautreuil, Myranda Clarke, Chris Vaughn, Emily Cowles and Corey Scanes. They welcomed me into Freeman's with open arms and I have shared many laughs with them along the way.

Additionally I’d like to thank Port Mansfield Fishing Tournament for allowing me to gut hundreds of fish during the weigh in and Cerium Labs for the chemical analysis of the microplastics.

Next, my boyfriend, Jack, with whom there is never a dull moment. We embarked on our Texan adventure together and moving here has resulted in new horizons, new friends and wonderful memories. With that I would like to thank my wonderful family for being so supportive of my decision to move away and go back to school. My brother, Charles, especially has always been a friend, a joker and someone to lean on. I am lucky to have such inspirational parents, Sue and Mark Phillips, as mentors and I hope to make them as proud of me as I am of them. This is dedicated to them.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

Occurrence and types of microplastics in the digestive system of freshwater fishes could be an emerging environmental crisis because of the proliferation of plastic pollution in aquatic environments. Recent studies report increasing amounts of microplastics in marine systems and in the gut tracts of marine fishes. To date, only one study has reported percent occurrence of microplastics (12%) in the digestive system of freshwater fishes. Purposes of this study were to quantify occurrences and types of microplastics ingested by fishes within the western freshwater drainages of the Gulf Mexico and an estuary of the Gulf of Mexico. My study objectives were (1) to enumerate and identify microplastics from fishes taken from 10 sites and nine freshwater drainages of Texas and harbor, bay, and gulf sites within or near the Laguna Madre of southeast Texas, (2) to compare percent occurrence of microplastics among habitat and trophic guilds of fishes, and (3) to compare percent occurrence of microplastics between urbanized and non-urbanized streams and thus test the hypothesis that fishes from urbanized streams will have greater percent occurrence of microplastics than fishes from non-urbanized streams. Among 535 fishes examined in this study, percent occurrence of microplastics was 8% in freshwater fishes and 10% in marine fishes. Plastic types included polyester, polystyrene, polypropylene, acrylate, and nylon. Percent occurrence of microplastics ingested by fishes in non-urbanized streams (5%) was less than that of one urbanized streams (Neches River; 29%). Percent occurrence by habitat (i.e., benthic, pelagic) and trophic guilds (herbivore/omnivore, invertivore, carnivore) were similar. Percent occurrences of microplastics reported herein are similar for freshwater fishes and towards the lower end of the range of microplastic ingestion in marine fishes (range: 8 - 33%). Occurrences of microplastics in the fishes pose several environmental concerns. For fish health, microplastics absorb toxins and can be passed through the digestive system, into the circulatory system, and accumulate in tissue. Long-term effects are unknown for the fish or the effects on human consumers.

I. THE OCCURRENCE AND AMOUNT OF MICROPLASTICS INGESTED BY FISHES IN THE WATERSHEDS OF THE GULF OF MEXICO

Introduction

Plastic pollution is ubiquitous on land and in water globally and is increasing. The number of disposable plastic products created to date in the 21st century is greater than the number produced in the 20th century (MacBride 2012). Annual plastic production has increased from 1.5 million tonnes in the 1950s to 288 million tonnes in 2012 (PlasticsEurope 2013). In the U.S. only 9% of that was recycled (EPA 2014). Plastic production continues to accelerate and developing countries are starting to adopt the use-and-dispose culture now common in the developed world. Plastic litter in the ocean 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 (Barnes et al. 2009) and as much as 70% of marine debris is plastic where it persists and accumulates due to its durable nature (Derraik 2002, Lusher et al. 2013).

Effects of large plastic items (i.e., macroplastics), such as entanglement, ingestion and death, are widely reported in fish and wildlife (Moser and Lee 1992, Derraik 2002, Moore 2008, Witherington et al. 2012). However, a larger proportion of plastic pollution is microscopic (< 5 mm; Eriksen et al. In press). 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, Gregory 2009, Fendall and Sewell 2009, Eriksen et al. 2013). Additionally plastics 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 (Derraik 2002, Thompson et al. 2004, Cole et al. 2011). These macroplastics are made of a variety of plastics; the most abundant forms being polyolefins (polyethylene and polypropylene) primarily used for single-use packaging (Browne et al. 2010b). Another source of microplastics appears to be acrylic, polyester, and polyamide fibers from textile (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. 2010b) and potentially its environmental effects including ingestion by fishes.

Recent studies report the occurrence of microplastics in freshwater systems. Microplastics occur in Lake Geneva, Switzerland (Faure et al., 2012), the 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. Abundance of microplastic pollution and urban population density are directly related with one source microplastics coming from wastewater treatment effluent (Browne et al. 2011, Free et al. 2014). Concerns and subsequent effects of incidental ingesting 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 while feeding in the water column or along the benthos (Browne et al. 2010a).

Percent occurrence of plastics in the stomach contents of marine fishes range from 2.6% in the North Sea (Foekema et al. 2013) to 60% along the North Atlantic coast of USA (Carpenter et al. 1972). Other areas include Brazilian estuaries (percent occurrence: 8% among sciaenids, (Dantas et al. 2012); 18 to 33% among ariids, (Possatto et al. 2011), North Pacific Gyre (35% among meso- and epipelagic fishes, Boerger et al. 2010), and English Channel (37% among demersal and pelagic fishes, (Lusher et al. 2013). The studies of the percent occurrence of microplastics in freshwater fishes is limited with one study reporting 12% in urbanized streams in France (Sanchez et al. 2014).

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 (Browne et al. 2010a). Microplastics consist of synthetic organic polymers that can serve as a 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). More recently, research has also confirmed toxic substances pass from microplastics to the carrier and accumulate in tissues (Rochman et al. 2013). The negative effect that plastic can have on fish health can be due to the toxic nature of the plastic itself, or because of the pollutants absorbed (by plastic) from the environment. Due to the toxic consequences of microplastic ingestion to the food web and the ever increasing amount of plastic polluting a wide array of waterways, it is important to understand the extent of the problem, so as to effectively mitigate and take preventative measures. The implementation of effective resource recovery and waste management is crucial to ameliorate the negative effects of plastic ingestion by fish.

The purpose of my study is 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 compares ingestion amounts in fishes from urbanized and non-urbanized streams. Among freshwater drainages, I predict that plastic consumption will be similar to the range of ingestion amounts reported in marine studies conducted in estuaries (8 to 33%; Dantas et al. 2012,Possatto et al. 2011) and freshwater (12%; Sanchez et al. 2014). In addition, I predict that not all trophic guilds of fishes (e.g., benthic omnivore, pelagic piscivore) will ingest plastics equally but rather consume different amounts depending on the location of plastics within aquatic environments (i.e., benthic, pelagic, surface) where the fishes feed. Within the large bay system, I predict that fishes within and near the Laguna Madre (Southeast coast of Texas) will consume less plastic than reported elsewhere, given that the Laguna Madre is a hypesaline bay system which has limited freshwater inflows and is located next to the Wild Horse Desert. Study objectives are to quantify plastic ingestion among fish communities and among fish-feeding guilds, to compare amounts of plastic ingestion between urbanized and non-urbanized streams, and to chemically identify the primary sources of plastics consumed by fishes in freshwater drainages of the Gulf of Mexico and by marine fishes within or near the Laguna Madre.

Materials and Methods

Gut contents of fishes were extracted from individuals harvested for purposes other than these study objectives. Freshwater fishes were obtained from voucher and 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. Streams were upper Las Moras Creek (Rio Grande drainage) Nueces River (Nueces River drainage), upper San Antonio River (San Antonio River drainage), James River (Colorado River drainage), Mill Creek and lower Brazos River (Brazos River drainage), Banita Creek (Angelina River drainage), Big Sandy Creek (Neches River Drainage), Caddo Lake (Cypress River-Red River drainage), Red River (Red River drainage) (Figure 1). Sampling locations were within urban areas on the Upper San Antonio River (City of San Antonio, Texas) and on Banita Creek (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 time of collection. Fishes were anesthetized with a lethal dose of MS-222 (>80 mg/l) and fixed in 10% buffered formalin. After at least two weeks in 10% formalin, fish 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 the anus were removed. Marine fishes were donated by anglers in a bay and offshore fishing tournament (Port Mansfield 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 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). Abdomen was opened, 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*, 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 or upper GI tract was sliced longitudinally to expose the contents. 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. Care was taken to ensure that instruments did not scrape or generate plastic shavings on the bottom of the petri dish. 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 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 minutes 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), shard (e.g., irregular shaped cube with at least one smooth plane), and film (e.g., thin with two smooth planes). For each item, longest length and width were measured to estimate area of the item. For each fish, 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. Use of FTIR to identify all items was cost-prohibitive, so up to 8 representative samples from nurdle, filament, shard, and film categories were examined. All nurdle samples were identified as sand. The nurdle category was removed from subsequent analyses. Filament, shard, and film categories were confirmed as a 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 shard 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. These filaments did not appear to be similar to the filamentous air particles in the laboratory. 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 all fish examined in this study, for freshwater and marine fishes separately, for each freshwater drainage basin, and for each habitat and feeding guild. Percent occurrence is based on whether the fish ingested plastic. Habitat and feeding guilds were assigned following Goldstein and Simon's (1999) Guild Structure. 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-tail Z-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 any 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 (and 55.6% organic), shard category consisted of 75.0% 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. For example, 15 of the 419 freshwater fishes contained one or more film items and thus uncorrected percent occurrence for film in freshwater fishes would be 3.6% (15 out of 419). However, corrected percent occurrence would be 1.5% [e.g., (15 * 0.429) / 419 * 100)] because only 42.9% of the initially recorded film items actually were film items. Correction factors, using the same procedures, were developed for fishes that contained two and three categories of plastics. For example, a fish with at least one filament item (0.444) and one film item (0.429) would be corrected to 0.190 fish with a filament and film items, which is the product of 0.444 and 0.429. Counts and surface area of items reported herein were not corrected for the occurrence of organic tissue in the categories. Uncorrected total counts of plastics items are provided but should be viewed with caution. Organic tissue was not obviously distinct in size and therefore unlikely skews size estimates reported here but again should be viewed with caution.

Results

Among 535 individuals, 51 species, and 17 families examined, plastics were detected in stomach contents of 46 individuals (8.6%), 33 species (65%), and 13 families (71%) taken from freshwater and saltwater environments (Table 1). Filamentous plastics occurred in 2.6% of individuals and consisted of polyester and polystyrene. Mean surface area (± 1 SD) of filamentous plastics was 222 um^2 (± 372.2) with a maximum size of 4,500 um^2. Maximum number of filamentous plastics in a stomach was 4. Shard plastics occurred in 3.4% of individuals and consisted of polystyrene, polypropylene, acrylate, and nylon (polyamide). Mean surface area (± 1 SD) of shard plastics was 147.6 um^2 (± 192.2) with a maximum size of 1,500 um^2. Maximum number of shard plastics in a stomach was 12. Film plastics occurred in 3.9% of individuals and consisted of polyester and cellulosic materials. Mean surface area (± 1 SD) of film plastics was 576 um^2 (± 2,940.4) with a maximum size of 22,500 um^2. Maximum number of film plastics in a stomach was 10. Among the 46 individuals with a plastic item, 22 (48%) contained at least 2 plastic types and

4 (9%) contained three plastic types. Maximum number of plastic types in a stomach was 12.

A total of 419 freshwater fishes was examined, representing 44 species and 12 families (Table 2). Among these, plastics were detected in 34 individuals (8.2%), 26 species (59%), and 9 families (75%). Percent occurrence among individuals by plastic type was 1.3% for filament plastics, 2.7% for shard plastics, and 3.1% for film plastics. Percent occurrences of plastics were 6.8 and 29% in the two urbanized streams and ranged from 0.0 to 11% in non-urbanized streams. Percent occurrence of plastics in fishes from urbanized area of the Neches River (29.2%) was greater ($P > 0.95$) than those taken from non-urbanized streams (mean ± 1 SD; 4.6 ± 3.9). Percent occurrence of plastics in fishes from urbanized area of the San Antonio River (6.8%) did not differ ($P = 0.90$) than those taken from non-urbanized streams.

Among urban streams, percent occurrences among individuals by plastic type were 0.5 and 2.1% for filament plastics, 4.5 and 13% for shard plastics, and 1.8 and 20% for film plastics. Mean surface area (± 1 SD; maximum area) was 286 um^2 (± 345.3; 1380 um^2) for filament plastics, 129.8 um^2 (± 133; 1,500 um^2) for shard plastics, and 192.1 um^2 (± 240; 1,400 um^2) for film plastics. Maximum number within a stomach was 2 for filament plastics, 12 for shard plastics, and 10 for film plastics. Among the 20 individuals with a plastic item, 12 (35%) contained at least two plastic types. Percent occurrence within the benthic habitat guild was 19%, ranging from 13% in herbivores-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-urban streams, percent occurrences among individuals by plastic type ranged from 0 to 5.0% for filament plastics, from 0 to 4.5% for shard plastics, and from 1.3

to 3.9% for film plastics. Mean surface area (± 1 SD; maximum area) was 73 um^2 (± 98.6; 400 um^2) for filament plastics, 160 um^2 (± 245.2; 694 um^2) for shard plastics, and 235 um^2 (± 332.2; 1,400 um^2) for film plastics. Maximum number within a stomach was 2 for filament plastics, 4 for shard 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. Maximum number of plastic types in a stomach was 5. 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.

A total of 116 marine fishes was examined, representing eight species and five families (Table 3). Among these, plastics were detected in 12 individuals (10.4%), seven species (58%), and four families (80%). Percent occurrence among individuals by plastic type was 3.8% for filament plastics, 2.6% for shard plastics, and 2.6% for film plastics. Percent occurrences of plastics were 5.9% in the harbour fishes, 13.5% in the bay fishes and 22% in the offshore fishes.

In marine fish, percent occurrences among individuals by plastic type ranged from 2.9% in the harbour fishes to 14.8% in the offshore fish for filament plastics, 1.9% in harbour fishes to 4.3% in bay fishes for shard plastics, and 2.8% in barbour fishes to 7.1% in offshore fishes for film plastics. The mean surface area (± 1 SD; maximum area) was 313 um^2 (± 473.9; 4,500 um^2) for filament plastics, 186 um^2 (± 290.1; 832 um^2) for shard plastics, and 1,565 um^2 (± 5,588.7; 22,500 um^2) for film plastics. Maximum number within a stomach was 4 for filament plastics, 2 for shard 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 occurrence within the pelagic habitat guild was 10%, ranging from 6% in invertivore trophic guild to 17.5% in carnivore trophic guild.

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 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 streams (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 the all 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. In press). 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 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 (Luther 2012). 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 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), polyethulacrylate, 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 shard are reported to be from packaging and sturdy plastic material (Browne et al. 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). Combination of all three categories in fishes examined in this study supports that land-base and water-base sources of plastics are entering the aquatic systems.

The extent of the effect of plastic contamination on fish health is not yet completely understood. All of the polymers identified in this study possess harmful monomers of varying degrees. The crude oil derived chemicals, released during production, use and disposal of plastics, are hazardous to the foodweb and the environment and (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, 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). Pesticides and organic pollutants such as polychlorinated biphenyls, known to disrupt physiological processes, such as cell division and immunity, are found in high concentrations in plastic in the marine environment (Teuten et al. 2009). The negative effects of toxins on fish health is demonstrated in a study, in which Japanese Medaka *Oryzias latipes* were exposed to small particles of low-density polyethylene (LDPE), a polymer that has a high affinity to organic pollutants and is most commonly found in aquatic debris, making it of high environmental relevance. The LDPE had previously been deployed in an urban bay for three months and after a two-month exposure the fish tissues were analyzed showing a greater concentration of PBTs. The fish showed signs of liver stress, including glycogen depletion, fatty vacuolation and single cell necrosis (Rochman et al. 2013).

On the whole, microplastic found in freshwater and marine fishes is in relatively low abundance; however, as the population of Texas grows, plastic consumption will increase resulting in more plastic pollution. I present this study as an early indication of an environmental concern that can be avoided with mitigation. Freshwater fishes in Texas are consuming microplastic waste that has been shown to have detrimental effects to fish health. Whilst more research into the effects of plastic ingestion on fish in the wild is necessary, the data thus far sufficiently emphasizes both the physical and chemical threats of plastic pollution. The information in the present study, along with the extensive research into the many hazardous impacts of plastic pollution in our environment, is sufficient evidence to compel more effective action and mitigation. The next step for the scientific community is to verify whether once the associated toxins are ingested, they are translocating to fish tissues and entering the food chain, and thus a concern for human consumption.

Sustainability and Management

This study has implications for fishery and wildlife management. What follows is a discussion of the implications of the study for public policy. It is hoped that the following types of policy makers and could benefit from an understanding of the results (municipal and federal governments, environmental advocacy groups, intergovernmental organizations). One suggestion to reduce the amount of unrecovered plastic entering our waterways is to phase out the production of the more harmful plastics. PVC, for example, is the third most produced plastic world-wide and due to the carcinogenic monomer involved in its production it is one of the most hazardous. It is estimated that as the global population increases, there will be another 33 billion tonnes of plastic produced by 2050. If the most toxic, least recyclable single-use plastics were to be classified as hazardous and replaced with more durable, safer and recoverable plastics it is estimated that this amount could be reduced to 4 billion tonnes (Browne and Rochman 2013). The phasing out of toxic and problematic plastics will force producers to adopt a closed-loop system where plastics would be continuously reused. A cradle-to-cradle approach promotes an extended producer responsibility through the consideration of the total life-cycle assessment of a plastic, and the appreciation of the total costs, from production to disposal, incurred.

Furthermore, asides from the detrimental effects to the environment, cities and local governments have historically borne the cost associated with the end of life cycle of throwaway plastics. A total of 288 million tonnes of plastic was generated globally in 2013, and 32 million tonnes of plastic waste were generated in 2012 in the United States, of which 14 million tonnes was containers and packaging. Only nine percent of the total plastic waste generated was recovered for recycling (EPA 2014). Just three percent of the 87 million tonnes of municipal solid waste (MSW) recovered in the United States in 2012 was plastic. Though the growth of recycling has increased since 1990, only 14% of plastic containers and packaging were recycled in 2013. The most recycled plastics are plastic bottles made of polyethylene terephthalate (PET; 31% recycled) and high density polyethylene (HDPE; 28% recycled). The numbers are even less impressive in Texas, where of the 1.2 million tonnes (0.8%) of plastic material reported as diverted from MSW facilities.

Like many anthropogenic effects, the issue of plastic pollution and microplastic contamination of fauna is recognized as problematic. However, sufficient action and prevention are yet to be put into place. Though there is no international regulation surrounding plastic production, there are those that recognize the extent to which plastic pollution poses a threat to our environment. An outcome of the Fifth International Marine Debris Conference (5IMDC) was the Honolulu Strategy, a framework for a comprehensive and global effort to reduce the ecological, human health, and economic impacts of marine debris globally (NOAA and UNEP 2011). Though not intending to impose regulations on the international community, the framework goal is to improve collaboration and coordination among concerned stakeholders across the globe, employing strategies to reduce land-based sources of marine debris, such as education of solid waste management and minimization, as well as regular cleanups of coastal watersheds and waterways.

On a more local level, City of Austin, Texas, has adopted the goal of becoming Zero Waste and has put a Universal Recycling Ordinance (URO) in place, setting October 2017 as a deadline by which all residential and commercial properties will be required to provide recycling services to their tenants and employees. Banning plastic shopping bags is another measure Austin has taken to reach the overall 2040 deadline to divert 90% of MSW from the landfill. The reduction of the ecologic and economic impacts from plastic pollution is being increasingly addressed on both a local and global scale. Aggressive goals like those aforementioned are needed, without which as the population in Texas and globally rapidly increases the incidence of plastic pollution and microplastics finding their way into the rivers, streams and oceans will become more prolific.

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

Table 1 continued

Family	*Species*	Common name	Max Length (mm)	Site	N	Plastic Present
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

Table 1 continued

Family	*Species*	Common name	Max Length (mm)	Site	N	Plastic Present
	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	1,238	M	2	x

Table 2. Percent occurrences and types of microplastic ingestion in freshwater habitats, amongst 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	Shard	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

Table 3. Percent occurrence and types of microplastic ingestion in marine habitats, amongst harbour, 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.

			% of fish with a plastic type*		
	Total N	% of total	Filament	Shard	Film
Marine Fishes	116	10.4	3.8	2.6	2.6
Harbour	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/car	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

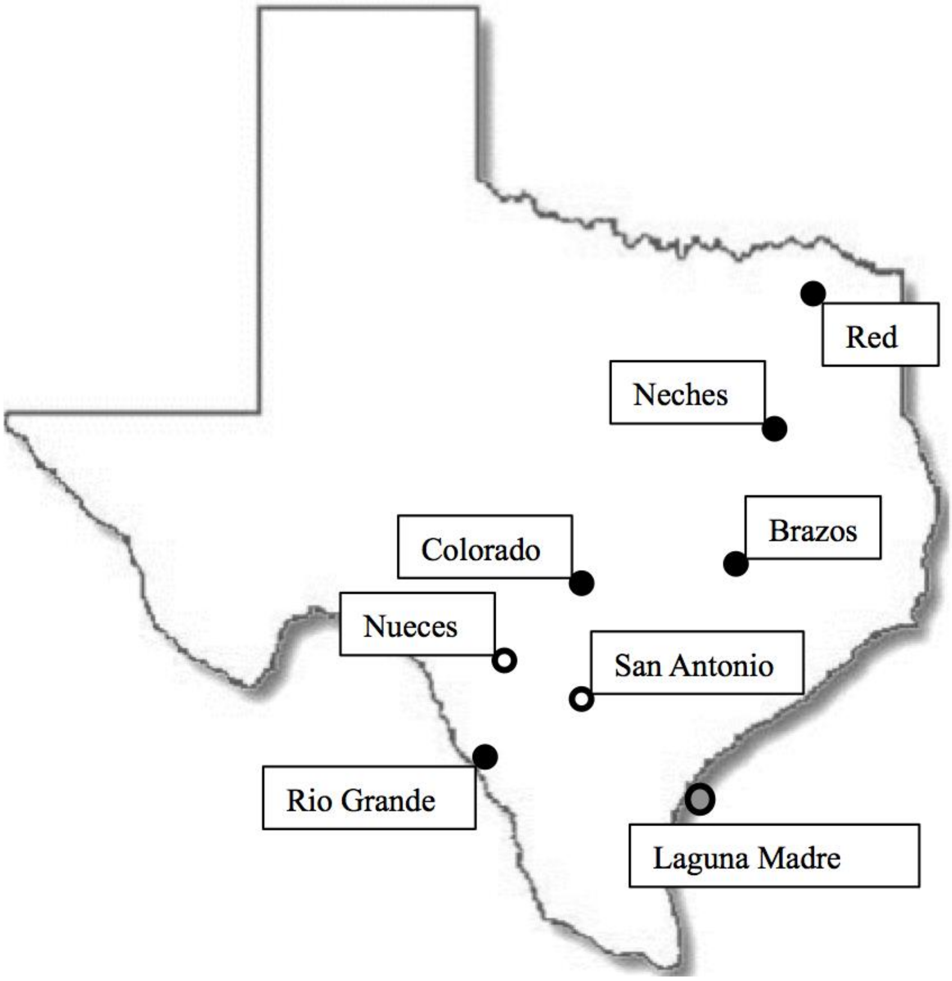

Figure 1. Generalized locations (freshwater and marine) by drainage of fishes harvested for gut content examination. Symbols: full circle = non-urbanized freshwater, hollow circle = urbanized freshwater, shaded circle = marine

LITERATURE CITED

Barnes, D. K. A., F. Galgani, R. C. Thompson, and M. Barlaz. 2009. Accumulation and fragmentation of plastic debris in global environments. Philosophical transactions of the Royal Society of London. Series B, Biological sciences (364):1985–1998.

Boerger, C. M., G. L. Lattin, S. L. Moore, and C. J. Moore. 2010. Plastic ingestion by planktivorous fishes in the North Pacific Central Gyre. Marine Pollution Bulletin 60(12):2275–2278.

Browne, M. A., P. Crump, S. J. Niven, E. Teuten, A. Tonkin, T. Galloway, and R. Thompson. 2011. Accumulation of microplastic on shorelines woldwide: Sources and sinks. Environmental Science and Technology 45(21):9175–9179.

Browne, M. A., A. Dissanayake, T. S. Galloway, D. M. Lowe, and R. C. Thompson. 2010a. Ingested Microscopic Plastic Translocates to the Circulatory System of the Mussel , Mytilus edulis (L .) 42(13):5026–5031.

Browne, M. a., T. S. Galloway, and R. C. Thompson. 2010b. Spatial patterns of plastic debris along estuarine shorelines. Environmental Science and Technology 44(9):3404–3409.

Browne, M. A., and C. M. Rochman. 2013. Classify plastic waste as hazardous:6–8.

Cole, M., P. Lindeque, C. Halsband, and T. S. Galloway. 2011. Microplastics as contaminants in the marine environment: A review. Marine Pollution Bulletin 62(12):2588–2597.

Dantas, D. V., M. Barletta, and M. F. da Costa. 2012. The seasonal and spatial patterns of ingestion of polyfilament nylon fragments by estuarine drums (Sciaenidae). Environmental Science and Pollution Research 19(2):600–606.

Derraik, J. G. B. 2002. The pollution of the marine environment by plastic debris : a review. Marine Pollution Bulletin 44:842–852.

Dubaish, F., and G. Liebezeit. 2013. Suspended microplastics and black carbon particles in the Jade system, southern North Sea. Water, Air, and Soil Pollution 224(2):1352.

EPA. 2014. Plastics Common Wastes & Materials US EPA.

Eriksen, M., S. Mason, S. Wilson, C. Box, A. Zellers, W. Edwards, H. Farley, and S. Amato. 2013. Microplastic pollution in the surface waters of the Laurentian Great Lakes. Marine Pollution Bulletin 77(1-2):177–182.

Fendall, L. S., and M. a Sewell. 2009. Contributing to marine pollution by washing your face: microplastics in facial cleansers. Marine pollution bulletin 58(8):1225–8.

Foekema, E. M., C. de Gruijter, M. T. Mergia, J. a van Franeker, a T. J. Murk, and a a Koelmans. 2013. Plastic in north sea fish. Environmental science & technology 47(15):8818–24.

Free, C. M., O. P. Jensen, S. a. Mason, M. Eriksen, N. J. Williamson, and B. Boldgiv. 2014. High-levels of microplastic pollution in a large, remote, mountain lake. Marine Pollution Bulletin 85(1):156–163.

Gregory, M. R. 2009. Environmental implications of plastic debris in marine settings--entanglement, ingestion, smothering, hangers-on, hitch-hiking and alien invasions. Philosophical transactions of the Royal Society of London. Series B, Biological sciences 364(1526):2013–2025.

Lithner, D., A. Larsson, and G. Dave. 2011. Environmental and health hazard ranking and assessment of plastic polymers based on chemical composition. The Science of the total environment 409(18):3309–24.

Lusher, a. L., M. McHugh, and R. C. Thompson. 2013. Occurrence of microplastics in the gastrointestinal tract of pelagic and demersal fish from the English Channel. Marine Pollution Bulletin 67(1-2):94–99.

MacBride, S. 2012. Recycling reconsidered [electronic resource]: The present failure and future promise of environmental action in the United States. Cambridge, Mass.: MIT Press, c2012

Moore, C. J. 2008. Synthetic polymers in the marine environment: A rapidly increasing, long-term threat. Environmental Research 108(2):131–139.

Moser, M., and D. Lee. 1992. A fourteen-year survey of plastic ingestion by western North Atlantic seabirds. Colonial Waterbirds 15(1):83–94.

NOAA, and UNEP. 2011. The Honolulu Strategy.

PlasticsEurope. 2013. Plastics-The Facts 2013: An analysis of European latest plastics production, demand and waste data. Pages 1–40 Octubre 2013. Plastic Europe.

Possatto, F. E., M. Barletta, M. F. Costa, J. a. Ivar do Sul, and D. V. Dantas. 2011. Plastic debris ingestion by marine catfish: An unexpected fisheries impact. Marine Pollution Bulletin 62(5):1098–1102.

Rochman, C. M. 2013. Plastics and priority pollutants: A multiple stressor in aquatic habitats. Environmental Science and Technology 47(6):2439–2440.

Rochman, C. M., E. Hoh, T. Kurobe, and S. J. Teh. 2013. Ingested plastic transfers hazardous chemicals to fish and induces hepatic stress. Scientific reports 3:3263.

Sanchez, W., C. Bender, and J. M. Porcher. 2014. Wild gudgeons (Gobio gobio) from French rivers are contaminated by microplastics: preliminary study and first evidence. Environmental research 128:98–100.

Teuten, E. L., J. M. Saquing, D. R. U. Knappe, M. a Barlaz, S. Jonsson, A. Björn, S. J. Rowland, R. C. Thompson, T. S. Galloway, R. Yamashita, D. Ochi, Y. Watanuki, C. Moore, P. H. Viet, T. S. Tana, M. Prudente, R. Boonyatumanond, M. P. Zakaria, K. Akkhavong, Y. Ogata, H. Hirai, S. Iwasa, K. Mizukawa, Y. Hagino, A. Imamura, M. Saha, and H. Takada. 2009. Transport and release of chemicals from plastics to the environment and to wildlife. Philosophical transactions of the Royal Society of London. Series B, Biological sciences 364(1526):2027–45.

Thompson, R. C., Y. Olsen, R. P. Mitchell, A. Davis, S. J. Rowland, A. W. G. John, D. McGonigle, and A. E. Russell. 2004. Lost at sea: where is all the plastic? Science (New York, N.Y.) 304(5672):838.

Witherington, B., S. Hirama, and R. Hardy. 2012. Young sea turtles of the pelagic Sargassum-dominated drift community: habitat use, population density, and threats. Marine Ecology Progress Series 463:1–22.