Title. Plastics in estuarine fish and sediments at the mouth of an urban watershed.

Authors.

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Abstract.

The extent to which small plastics and potentially associated compounds are entering coastal foodwebs, especially in estuarine systems, is only beginning to be realized. Using estuarine fish and sediment collected during June 2015 from urbanized Chollas Creek in San Diego, California, we tested the hypotheses that small plastic composition in sediments would be reflected in fish guts (non-selective consumption), and that semi-volatile organic compounds (SVOCs) would be present in all fish. Sediments contained about 10,000 small plastic pieces per m^2, consisting mostly (90%) of fibers, and hard and soft pieces. Nearly 25% of fish contained small plastics, but prevalence varied with size and between species. Of the 39 types of small plastics found in sediment, fish preferred 10 types (distinct colors and forms). Several SVOCs, both water soluble and sediment-associated compounds, were found in the two species of fish tested. We conclude that a species' natural history may influence contamination levels with consequences, and lessons, for all consumers.

Keywords. Chollas Creek, ichthyofauna, plastics, San Diego Bay, water contamination, wetland fish

Introduction. Microplastics (plastic particles <5mm; Rochman 2018) are pervasive in our ocean and coastal ecosystems (Thompson 2015; Cole et al., 2011). These small plastics enter the environment as either primary microplastics (those manufactured as tiny pieces, such as microbeads) or secondary microplastics (those that form from the breakdown of larger plastic items) (de Sá et al. 2018; Auta et al. 2017). Microplastics are of concern not just because of their ubiquity, but because of the harmful effects they can have on biota. Microplastics can accumulate in the gut or gills of organisms, interfering with important life history processes such as feeding, growth, and reproduction (Chae and An 2017; Cole et al. 2015; Watts et al. 2014; Watts et al. 2015; Sussarellu et al. 2016). The monomers and additives that compose microplastics can be toxic to biota if they leach from their parent plastics into the environment (Smith et al. 2018; Thaysen et al. 2018; Teuten, et al. 2009). Furthermore, microplastics can sorb toxins such as metals, PCBs, PAHs, and DDT from the aquatic environment, and transmit these toxins to organisms, causing stress to internal organs, disruptions in normal bodily functions (e.g., enzyme inhibition, endocrine disruption), and reductions in organisms' abilities to defend themselves against predators and other threats (Chae and An 2017; Smith et al. 2018; Rochman et al. 2013a,b; Browne et al. 2013; Barboza et al. 2018b; Rochman et al. 2014). Microplastics have been found to transfer between trophic levels (Welden et al. 2018; Farrell and Nelson 2013; Setälä et al. 2014), and thus may pose health risks to humans via consumption of contaminated seafood (e.g., Van Cauwenberghe and Janssen 2014; Rochman et al. 2015a; Barboza et al.

2018a), though the impacts of microplastics on human health remain largely unknown (Wright and Kelly 2017; Smith et al. 2018).

One suite of contaminants of concern are semi-volatile organic compounds (SVOCs), which include additives commonly used in plastics manufacturing, such as phthalates, bisphenol A, and PBDEs, as well as PCBs, PAHs, and DDT (Lucattini et al. 2018; Weschler and Nazaroff 2008; Lusher et al. 2017b). SVOCs are susceptible not only to leaching out of plastics into the environment, but to resorbing to microplastics once present in the environment, due to their hydrophobic properties (Lusher et al. 2017b; Teuten et al. 2009; Cheng et al. 2013; Rochman et al. 2013a). SVOCs are a health concern for humans and wildlife because they are endocrine disrupting chemicals (EDCs) that have been linked with neurological, reproductive, metabolic, and behavioral abnormalities, as well as increased incidences of some forms of cancer (Koch and Calafat 2009; Xu and Zhang 2011; Gore et al. 2015). Microplastics facilitate the accumulation of SVOCs in organismal tissues (Rochman et al. 2013b; Besseling et al. 2013), however it is important to note that microplastics' role as a conduit for SVOCs into coastal foodwebs may be relatively unimportant when compared with other vectors, such as contaminated water, prey, or sediments (Lusher et al. 2017b; Koelmans et al. 2016). It is also important to note that, while often associated with plastics, SVOCs found in the environment may stem from a number of different sources, including household cleaning products, cosmetics, and pesticides (Luccattini et al. 2018; Weschler and Nazaroff 2008).

Much of the research conducted on the ecological impacts of microplastics over the last two decades has focused on marine systems, only recently shifting to include terrestrial and

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freshwater systems (Rochman 2018; Chae and An 2017). This shift in focus upstream is an important one, given the fact that significant portions of marine plastic pollution come from land-based sources, and rivers are major conduits of debris from land to sea (Rochman 2018; Jambeck et al. 2015; Lebreton et al. 2017). The effects of microplastics in urbanized riverine ecosystems may be particularly acute (e.g., Peters and Bratton 2016), as rivers that flow through densely populated, urban areas have been shown to carry higher loads of debris (Lebreton et al. 2017; SCCWRP 2016; Yonkos et al. 2014). This study contributes to the growing body of research on microplastics upstream from marine ecosystems by investigating the presence of microplastics and associated contaminants in estuarine sediments and fish in a brackish stretch of urbanized Chollas Creek, which empties into San Diego Bay. Understanding the types, fates, and effects of small plastics in coastal watersheds is necessary to develop natural and social science-based solutions to marine debris and declining watershed health (Rochman 2018).

Knowledge of seasonal precipitation patterns in Mediterranean climates, such as that found in Southern California, result in accumulation and breakdown of photodegradable plastics during the sunny, dry season, followed by wet season pulses of debris inputs and transport through coastal watersheds (Anderson et al., 2012; Lee, 2011; Chandler, 2012; Moore et al., 2011). A recent regional survey of the Southern California Bight, to which this study contributed, revealed that 92% of the total stream length of urban watersheds in the Southern California Bight contained debris, while 48% of undeveloped watersheds did (SCCWRP, 2016). More than 60% of the debris found was plastic (SCCWRP, 2016). Many coastal wetland fishes, such as killifish, intensively forage on the substratum (West and Zedler, 2000) where small plastics and contaminants accumulate, putting them at particularly high risk of contamination. These fish may

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in turn be important vectors in transferring small plastics and contaminants to the broader coastal food web given their abundance, their roles in connecting intertidal with both subtidal and terrestrial ecosystems, and their roles as forage fish for many species (Trexler et al., 1994; West et al., 2003; Able et al., 2012; Kang et al., 2015).

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Project goals. The goals of this study were to: a) determine the extent and magnitude of microplastics pollution in estuarine sediments and fish, and of SVOC contamination in estuarine fish, at the mouth of an urban coastal watershed, and b) determine whether sampled fish preferentially ingested certain types of microplastics, when compared with types and abundances of microplastics in sampled sediments.

Materials and Methods.

Study location. The Chollas Creek subwatershed (Fig. 1), considered one of the most impaired waterbodies in San Diego County, in part due to the large amounts of trash present in the creek (Anderson et al. 2012; State Water Board 2015), runs through a densely populated, urban section of the County and empties into San Diego Bay at one of the worst urban runoff sites of coastal San Diego (Pritchard 2014). In June 2015, we sampled sediments and fish along a 250-m long reach of intertidal Chollas Creek, located about 1 km upstream of the mouth (Fig. 1).

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Sample collection and processing. Microplastics in sediment were sampled at low tide by collecting nine 10-cm diameter x 5-cm depth cores (393 cu cm) throughout the reach, placing cores in clean, airtight bags, and freezing cores until analysis in the lab. Plastics were sorted from sediments by placing a single layer of sediment at a time into a Petri dish (about 1 tablespoon or 15 cu cm) along with a squeeze of milliQ water to slightly liquefy the moist sediment. The dish

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with mud was systematically examined at 25-45x power using a dissecting microscope; sorting of each dish took no more than 15 minutes. Particles that were clearly of anthropogenic origin, as determined by the shape and/or color of each particle (e.g., spherical microbeads, fibers with smooth surfaces and homogeneous thicknesses; often bright colors that stood out from the rest of the sample) were sorted out of the sample, classified according to the item from which they originated, when distinguishable (e.g., pieces of grocery bag, wrappers), or by hardness, shape and color (e.g., film, hard or soft pieces, fiber), and then counted and measured for maximum length. Particles that were not clearly of anthropogenic origin were examined using a compound microscope to check for lack of cell structure. Any particles that remained of uncertain origin were excluded from the analysis. It is important to note that because samples were only examined using microscopy (and not run through a spectroscope to chemically verify polymer types and particle counts), it is possible that the abundances of microplastics reported herein are either over- or underestimates of actual numbers, as both false positives and failures to identify very small plastic particles are relatively common when relying on microscopy to identify microplastics (Song et al. 2015; Lenz et al. 2015; Lusher et al. 2017a).

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At the time this study was conducted, the risk of sample contamination from airborne plastics was just beginning to be realized, and protocols to control for such contamination followed soon after although such QA/QC protocols have not yet been standardized and debate remains about how best to control and account for contamination of samples (NOAA, 2015; REF??; but see Hidalgo-Ruz et al., 2012). We therefore attempted a post-hoc control of environmental plastics contamination by conducting three trials separated in time on 20 June, 20 July and 19 August 2016 to determine average levels of contamination in the lab used during the

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study. During each trial, six clean Petri dishes were set out for 15 minutes on the lab countertops. Three or four people were present in the lab each time (during sample sorting in 2015, two or three people were present at any one time). At 15 minutes, dishes were covered with clean, clear lids and examined for particle settlement using a dissecting microscope. Only fibers were found at an average of 0.5±0.3, 0.5±0.2 and 0.5±0.3 fibers per dish for the June, July and August trials, respectively (grand average = 0.5±0.0 fibers per dish per 15 minute time period). Fiber contamination for each fiber color (type) was then calculated using the following steps: The average number of fibers per dish (0.5) was multiplied by the number of dishes likely sorted for each sample core (393 cu cm core / 15 cu cm spoonful per dish = ~26 dishes per core) for an estimated total of 13.1 fibers contaminating each sample core. Since the color of fibers causing contamination in 2015 could not be determined after the fact, the estimate of 13.1 fibers per core was divided by the seven fiber color categories for an estimate of 1.87 fibers contaminating each fiber color category. This value (1.87 fibers) was then subtracted from each fiber color category of each core before analyses and summary statistics were calculated. If the result of the subtraction was a negative number, the value was assigned a 0.

Common wetland fish (Boerger, et al. 2010; Rochman et al., 2013b) were trapped using metal minnow traps baited with cat food placed in nylon sleeves (to prevent fish from consuming it), and set throughout the reach. Three species were captured: the native marsh residents California killifish (*Fundulus parvipinnis*; n = 68) and longjaw mudsucker (*Gillichthys mirabilis*; n = 4), and the introduced sailfin molly (*Poecilia latipinna*; n = 82). In the field, all fish collected for gut analysis were placed in ziplock bags (one bag per trap). Additionally, two composite samples (7 California killifish and 8 sailfin molly) were collected and immediately placed into clean glass jars for analysis of SVOCs. Only four longjaw mudsucker individuals were captured,

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so all were used for gut analysis. The protocol of the AVMA Panel on Euthanasia (American Veterinary Medical Association, 2013) was followed, which recommends rapid chilling to euthanize warm-water fish. All fish remained frozen until analysis. Composite samples for SVOC analysis were analyzed for 67 SVOCs by a local analytical facility (Enviromatrix Analytical, Inc.) using EPA Method 8270C (EPA, 1996). Fish used for gut analysis were thawed, measured, weighed, and sexed in the lab. A ventral, longitudinal incision and two perpendicular ventral incisions (anterior and posterior) were made in each fish to expose the intact guts, and then the fish was placed in a clean glass dish under a dissecting microscope to complete the dissection and removal of gut contents. All contents were removed from inside the fish gut systematically as the gut was opened and analyzed a small section at a time for a total of ~15 min of exposure time (i.e., low risk of contamination). Since the post-hoc estimated contamination rates were $\leq$0.5 fibers per sample (0.5 fibers per dish divided by the one to four fiber color categories found in the fish samples equals 0.125-0.5 fibers contaminating each fiber color category) we did not use a correction but acknowledge that our fiber counts may be slight overestimates. Only materials drawn out of the gut were identified (or described) and counted. For items not feasibly counted (e.g., sand grains, organic debris, filamentous algae), presence in the gut was noted. Ten out of the 149 fish sampled had empty guts and were therefore excluded from further analyses. As with sediment samples, plastics were categorized by color and type (e.g., hard or soft pieces, fiber), then counted and measured for maximum length.

Data analyses. Descriptive statistics of sediment small plastics (average of all cores) and fish gut contents (average of small plastics and prey items for each species) were calculated to summarize findings. The concentrations of SVOCs, if present in at least one sample (at least one of the species), are reported. Fish diet preference was explored using Manly's alpha (Chipps and

Garvey, 2007), which compares the abundances of the types of plastic found in the environment and consumed by the fish. Differences in size and sex ratios of all fish sampled to those that had consumed plastics were tested using t-tests (size variables) and Chi Square (sex ratios) in JMP 12.

Results

Small plastics in sediment. All sediment cores collected contained small plastics; the average abundance (±1SE) was 9,638±1,636 pieces m^2 and average lengths (±1SE) of small plastics ranged from 1.8±0.3 to 4.6±1.1 mm. Common categories of plastics were plastic film pieces, such as film from bags and wrappers, polystyrene pieces, soft pieces, hard pieces, synthetic fibers, and a few miscellaneous items, such as strands of carpeting and synthetic turf (Fig. 2, Table 1). Synthetic fibers, hard pieces, and soft pieces were the most common types of plastics found across all sediment cores, together making up 90% of the fragments found (Fig. 2).

Fish gut contents.

Fish species present. Add short paragraph about ranges, and natural history characteristics of fundulus, sailfin molly, and mudsucker. *Mention species captured here, put natural history in discussion.*

Prey and non-plastics in guts. Half or more of these bottom feeding fish species had fed on sand or silt particles, and filamentous green algae (Table 2). Roughly 10% of both California killifish and sailfin molly also contained red algal filaments (Table 2). California killifish, primarily an

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invertebrate predator, contained remnants of small crustaceans (e.g., exoskeleton pieces, amphipod appendages), scales, unidentifiable fishes and insects, snails, tubificid oligochaetes, nematodes, and a sea cucumber (Table 2). The sailfin molly, although predominantly an herbivore, also commonly ingested tubificid oligochaetes and nematodes, and to a lesser extent, crustaceans and snails (Table 2). The predatory longjaw mudsucker contained scales, a digested fish, and nematodes (Table 2).

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Characteristics of plastic eating fish. None of the longjaw mudsucker guts contained plastics, which may have been due to the small sample size of only four individuals. California killifish individuals that had plastics in their guts were, on average, 25% longer and 79% heavier than those free of plastics ($p \leq 0.03$, Table 3). The ratio of males to females (to unknown sex) was similar between fish with and without gut plastics (Table 3). Neither size nor sex of sailfin molly individuals differed between those that contained plastics and those that did not (Table 3).

Small plastics in guts. Almost one quarter of fish examined contained small plastics, with 12% of California killifish (7 of 61) and 32% of sailfin molly (24 of 75) having consumed plastic (Table 3). Of the 39 types of plastic available in the environment, the California killifish and sailfin molly each consumed 10-11 different types of plastic items, mostly consisting of fibers and hard pieces (Fig. 2, Table 1). California killifish also ingested clear microbeads. The consumed items ranged in average length from 0.05±0.0 to 3.25±2.75 mm for California killifish and from 0.10±0.01 to 2.58±1.10 mm for sailfin molly.

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Of the 10-11 types of small plastics that were consumed by the fishes, 7-8 types were selectively eaten (Manly's alpha ≥0.025; Table 1), meaning the fishes' guts contained higher proportions of these items than were found in the environment (Fig. 2). The items the fishes selected included blue, yellow, orange and/or red hard plastic pieces, and all colors of synthetic fibers (Table 1).

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SVOCs in fish.

Three SVOCs of 67 tested were found in the tissues of these species. Both the California killifish and sailfin molly contained diethyl phthalate and benzyl alcohol, and the sailfin molly additionally contained 4-(3-) methylphenol (Fig. 3). The sources of these compounds in this creek are uncertain. The phthalate is a synthetic compound, while benzyl alcohol and 4-(3-) methylphenol have natural, albeit small, localized sources (PubChem, 2019 a,b,c). All three have common industrial applications, including additives in plastics, solvents, antiseptics, preservatives, pesticides, and/or additives in cosmetics and perfumes (WHO, 2003; Wade, 2019; Wiki, 2019; PubChem, 2019a,b,c).

Discussion.

Small debris in sediment and fish. This study, along with other recent studies (Moore et al., 2011; Rochman et al., 2015a; Rochman et al., 2016), illustrate the risk of plastic and plasticizer (SVOC) pollution to coastal food webs. A concurrent regional study of debris in the Southern California Bight found that sediments in embayments exhibited the highest abundance of small plastics, while continental shelf sediments exhibited the lowest abundance of small plastics (SCCWRP, 2016). Bay sediments, for example, were found to have a mean of 140 pieces/m^2, and continental shelf sediments were found to have ≤20 pieces/m^2 (SCCWRP, 2016). By

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While there is much knowledge about the presence of small plastics in coastal ecosystems, the extent to which/pathways through which small plastics and potentially associated compounds are being integrated into coastal foodwebs remains an emerging area of research.

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contrast, our study of the debris at the mouth of an urban stream emptying into San Diego Bay revealed a much denser concentration of small plastics, with almost 10,000 pieces/m^2. This may be because the mouth of Chollas Creek is in a highly urbanized area, in close proximity to roads, which are responsible for large inputs of debris (SCCWRP, 2016). Streams like Chollas Creek are conduits for plastics, carrying them into embayments and eventually to the ocean, where they accumulate at high densities in marine sediment (SCCWRP, 2016).

While we found a greater variety of small plastics in wetland fish than were observed in select species of pelagic and demersal fish sold in California for human consumption (Rochman et al., 2015a), both sets of fish predominantly ingested fibers (~60% of the plastics ingested by wetland fish, ~80% of market fish). Further, all of the small debris found in California-grown Pacific oysters were fibers (Rochman et al., 2015a). It is important to note that the fibers found within aquatic organisms, while undoubtedly anthropogenic, could be either synthetic or organic. We were unable to perform spectroscopic analysis to identify their composition.

Natural history and contamination risk. The extent that contaminants impact food webs depends upon the types of plastics and contaminants present, the environment (Renick et al. 2015), and the natural history of the organisms present (e.g., Renick et al. 2016), including feeding behavior, and changes associated with ontogeny and sex (Temming and Hammer, 1994; Smith et al., 2000; Talley, 2000; Borg et al., 2014).

The marsh fish in this area selectively fed on most of the small plastics found in their guts including all colors of fibers, blue and warm colors of hard pieces, and, in the case of California

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killifish, microbeads. Anecdotally, these items often resembled prey, especially a similar morphology between fish eggs and microbeads, and between synthetic fibers and filamentous algae, oligochaetes and nematodes (e.g., Fig. 4), further raising the concern that fish may mistake small plastics as food (Corley, 2014). The likelihood of plastics ingestion or the ability to pass plastics may change throughout the life of an organism, as revealed by the higher incidence of plastics ingestion in larger (older) California killifish individuals during this study. This is consistent with other ontogenetic dietary shifts observed in California killifish, including changes in prey type, prey size and different microhabitat use with time (Smith et al., 2000; Talley, 2000).

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As with the patterns of plastics ingestion, contamination by SVOCs varied with fish species. Diethyl phthalate, a water-insoluble, sediment-penetrating compound (PubChem 2019a), was found in both species but was almost three times higher in the California killifish. Both species ingest sediment while feeding (e.g., Table 3), so an explanation for the higher phthalate concentration in California killifish is uncertain but may be linked to diet, with higher abundances of benthic deposit feeders observed in the guts of killifish in this study (i.e., potentially more diethyl phthalate-laden sediment), or an artifact of small sample size (n=1). The reasons underlying the presence of 4-(3-) methylphenol and the 3.5 fold greater benzyl alcohol concentration in the sailfin molly compared with the California killifish are also uncertain. These compounds, which are used as solvents, pesticides, antiseptics, anesthetics, and additives in cosmetics and fragrances, are water soluble, have fairly rapid degradation rates in water, and do not tend to accumulate in tissues (PubChem 2019b,c). Again, stomach contents (i.e., water content) or small sample size could explain this observed difference. Although the sources and

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pathways of exposure are uncertain (Weschler and Nazaroff, 2008), the presence of these compounds in our two samples reveals that transfer of contaminants, even those that are relatively transient, from the environment to food webs is a real risk. Further study is needed to understand the interactions among these contaminants, the species' natural history, and other environmental stresses (e.g., predation, parasitism; Renick, et al., 2015; Renick et al. 2016).

Health effects of small plastics and SVOCs. The effects of small plastics and SVOC contamination on organisms may be complex (e.g., Renick et al., 2015) and remain largely uncertain, but knowledge of these effects is needed to understand the consequences of exposure to the organisms themselves and those that eat them. The acute and chronic effects of the three SVOCs found in this study have been observed on the growth, reproduction, enzyme activity, metabolic activity, respiration, kidney function and/or liver function in animals, while the effects on humans are less well known and are of concern (NIOSH, 1997; Lithner et al., 2011; Groshart and Okkerman, 2000; Ghorpade et al., 2002; Okkerman and van der Putte, 2002; Gore et al., 2015; NIH, 2018; PubChem 2019a,b,c). Dietary guidelines and warnings about the risks of contamination in higher trophic level and longer-lived seafood species due to bioaccumulation are common, but studies like this illustrate that smaller and/or lower trophic level fish may have hazards of their own. There is increasing realization that plastics (Murray and Cowie, 2011; Van Cauwenberghe and Janssen, 2014; Rochman et al., 2015a; Sussarellu et al., 2016) and SVOCs (Windward Environmental, 2010) occur in species consumed by humans. Improved knowledge of the types and distributions of contaminants in an area, as well as of the biology and natural history of organisms, are needed to improve predictions of contamination risks of fish, shellfish and dependent higher trophic levels, including humans.

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Acknowledgements

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References

Able, K.W., Vivian, D.N., Petruzzelli, G., Hagan, S.M., 2012. Connectivity among salt marsh subhabitats: Residency and movements of the mummichog (*Fundulus heteroclitus*). Estuaries and Coasts 35, 743-53. doi:10.1007/s12237-011-9471-x

Ackerman, L.K., Schwindt, A.R., Massey Simonich, S.L., Koch, D.C., Blett, T.F., Schreck, C.B., Kent, M.L., Landers, D.H., 2008. Atmospherically deposited PBDEs, pesticides, PCBs, and PAHs in Western U.S. National Park fish: Concentrations and consumption guidelines. Environmental Science and Technology 42(7), 2334-2341. doi:10.1021/es702348j

American Veterinary Medical Association, 2013. AVMA Guidelines for the Euthanasia of Animals: 2013 Edition. https://www.avma.org/KB/Policies/Documents/euthanasia.pdf

Anderson, B., Phillips, B., Markiewicz, D., Stillway, M., 2012. Toxicity in California Waters: San Diego Region. California Water Board Surface Water Ambient Monitoring Program. http://www.waterboards.ca.gov/water_issues/programs/swamp/docs/reglrpts/rb9_toxicity_2012_new.pdf

Andrady, A.L., 2011. Microplastics in the marine environment. Marine Pollution Bulletin 62(8):1596-1605. https://doi.org/10.1016/j.marpolbul.2011.05.030

Auta, H. S., C. U. Emenike, and S. H. Fauziah. 2017. Distribution and importance of microplastics in the marine environment: A review of the sources, fate, effects, and potential solutions. Environmental International 102: 165-76.

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Barboza, L.G.A., A.D. Vethaak, B.R.B.O. Lavorante, A-K. Lundebye, and L. Guilhermino. 2018a. Marine microplastic debris: An emerging issue for food security, food safety and human health. Marine Pollution Bulletin 133: 336-48.

Barboza, L. G. A., L. R. Vieira, V. Branco, N. Figueiredo, F. Carvalho, C. Carvalho, and L. Guilhermino. 2018b. Microplastics cause neurotoxicity, oxidative damage and energy-related changes and interact with the bioaccumulation of mercury in the European seabass, *Dicentrarchus labrax* (Linnaeus, 1758). Aquatic Toxicology 195: 49-57.

Barnes, D.K.A., Galgani, F., Thompson, R.C., Barlaz, M., 2009. Accumulation and fragmentation of plastic debris in global environments. Philos. Trans. Roy. Soc. B: Biol. Sci. 346(1526), 1985–98. doi:10.1098/rstb.2008.0205

Besseling, E., A. Wegner, E.M. Foekema, M.J. van den Heuvel-Greve, and A.A. Koelmans. 2013. Effects of microplastic on fitness and PCB bioaccumulation by the lugworm *Arenicola marina* (L.). Environmental Science & Technology 47(1): 593-600.

Blais, J.M., Schindler, D.W., Muir, D.C.G., Kimpe, L.E., Donald, D.B., Rosenberg, B., 1998. Accumulation of persistent organochlorine compounds in mountains of western Canada. Nature 395, 585-588. doi:10.1038/26944

Boerger, C.M., Lattin, G.L., Moore, S.L., Moore, C.J., 2010. Plastic ingestion by planktivorous fishes in the North Pacific Central Gyre. Marine Pollution Bulletin 60(12), 2275-2278. doi:10.1016/j.marpolbul.2010.08.007

Borg, J.P.G., Westerbom, M., Lehtonen, H., 2014. Sex-specific distribution and diet of *Platichthys flesus* at the end of spawning in the northern Baltic Sea. Journal of Fish Biology 84(4), 937-51. doi:10.1111/jfb.12326

Browne, M.A., Dissanayake, A., Galloway, T.S., Lowe, D.M., Thompson, R.C., 2008. Ingested microscopic plastic translocates to the circulatory system of the mussel, *Mytilus edulis* (L.). Environ. Sci. Technol. 42(13), 5026−5031. doi:10.1021/es800249a

Browne, M.A., Niven, S.J., Galloway, T.S., Rowland, S.J., Thompson, R.C. 2013. Microplastic moves pollutants and additives to worms, reducing functions linked to health and biodiversity. Current Biology 23(23), 2388-2392. doi:10.1016/j.cub.2013.10.012

Chae, Y., and Y-J. An. 2017. Effects of micro- and nanoplastics on aquatic ecosystems: Current research trends and perspectives. Marine Pollution Bulletin 124(2): 624-32.

Chandler, N., 2012. How can we speed up plastic photodegradation? HowStuffWorks.com. http://science.howstuffworks.com/environmental/green-science/speed-up-plastic-photodegradation.htm. Accessed 16 March 2016.

Cheng, Z., X-P. Nie, H-S. Wang, and M-H. Wong. 2013. Risk assessments of human exposure to bioaccessible phthalate esters through market fish consumption. Environment International 57-58: 75-80.

Chipps, S.R., Garvey, J.E., 2007. Assessments of diets and feeding patterns. In: Guy, C.S., Brown, M.L., eds. Analysis and Interpretation of Freshwater Fisheries Data. Bethesda, MD: American Fisheries Society, 473-514. http://pubstorage.sdstate.edu/wfs/502-F.pdf

Chua, E.M., Shimeta, J., Nugegoda, D., Morrison, P.D., Clarke, B.O., 2014. Assimilation of polybrominated diphenyl ethers from microplastics by the marine amphipod, *Allorchestes compressa*. Environ. Sci. Technol. 48(14), 8127-8134. doi:10.1021/es405717z

Cole, M., Lindeque, P., Halsband, C., Galloway, T.S., 2011. Microplastics as contaminants in the marine environment: A review. Marine Pollution Bulletin 62(12): 2588-2597. doi:10.1016/j.marpolbul.2011.09.025

Formatted: Right: 0.25"

Cole, M., P. Lindeque, E. Fileman, C. Halsband, and T. S. Galloway. 2015. The impact of polystyrene microplastics on feeding, function and fecundity in the marine copepod *Calanus helgolandicus.* Environ. Sci. Technol. 49(2): 1130-37.

Corley, C., 2014. Why those tiny microbeads in soap may pose problem for Great Lakes. NPR. www.npr.org/2014/05/21/313157701/why-those-tiny-microbeads-in-soap-may-pose-problem-for-great-lakes

de Sá, L. C., M. Oliveira, F. Ribeiro, T. L. Rocha, and M. N. Futter. 2018. Studies of the effects of microplastics on aquatic organisms: What do we know and where should we focus our efforts in the future? Science of the Total Environment 645: 1029-39.

EPA (Environmental Protection Agency), 1996. Method 8270C Semivolatile organic compounds by gas chromatography/mass spectrometry (GC/MS). https://www3.epa.gov/wastes/hazard/testmethods/sw846/pdfs/Method%208270C,%20Revision%203%20-%201996.pdf

Farrell, P., and K. Nelson. 2013. Trophic level transfer of microplastic: *Mytilus edulis* (L.) to *Carcinus maenas* (L.). Environmental Pollution 177: 1-3.

Ghorpade, N., Mehta, V., Khare, M., Sinkar, P., Krishnan, S., Rao, C.V., 2002. Toxicity study of diethyl phthalate on freshwater fish *Cirrhina mrigala*. Ecotoxicology and Environmental Safety 53(2): 255-258. doi:10.1006/eesa.2002.2212

Gore, A.C., Chappell, V.A., Fenton, S.E., Flaws, J.A., Nadal, A., Prins, G.S., Toppari, J., Zoeller, R.T., 2015. Executive Summary to EDC-2: The Endocrine Society's Second Scientific Statement on Endocrine-Disrupting Chemicals. Endocrine Reviews 36(6): 593-602. doi: http://dx.doi.org/10.1210/er.2015-1093

Formatted: Right: 0.25"

Groshart, Ch., Okkerman, P.C., 2000. Towards the establishment of a priority list of substances for further evaluation of their role in endocrine disruption - preparation of a candidate list of substances as a basis for priority setting. Final Report, Annex 15 List of 66 substances with categorisation high, medium or low exposure concern. EUROPEAN COMMISSION DG ENV. http://ec.europa.eu/environment/archives/docum/pdf/bkh_main.pdf; http://ec.europa.eu/environment/archives/docum/pdf/bkh_annex_15.pdf

Hirai, H., Takada, H., Ogata, Y., Yamashita, R., Mizukawa, K., Saha, M., Kwan, C., Moore, C., Gray, H., Laursen, D., Zettler, E.R., Farrington, J.W., Reddy, C.M., Peacock, E.E., Ward, M.W., 2011. Organic micropollutants in marine plastics debris from the open ocean and remote and urban beaches. Marine Pollution Bulletin, 62(8), 1683–1692. doi: 10.1016/j.marpolbul.2011.06.004

Heudorf, U., Mersch-Sundermann, V., Angerer, J., 2007. Phthalates: Toxicology and exposure. International Journal of Hygiene and Environmental Health 210(5), 623-634. doi:10.1016/j.ijheh.2007.07.011

Hidalgo-Ruz, V., Gutow, L., Thompson, R. C., and Thiel, M., 2012. Microplastics in the marine environment: a review of the methods used for identification and quantification. Environmental Science & Technology 46: 3060-3075.

Holmes, L.A., Turner, A., Thompson, R.C., 2012. Adsorption of trace metals to plastic resin pellets in the marine environment. Environ. Pollut. 160, 42-48. doi:10.1016/j.envpol.2011.08.052

Imam J., 2015. Microbead ban signed by President Obama. CNN. http://www.cnn.com/2015/12/30/health/obama-bans-microbeads/

Formatted: Right: 0.25"

Integrated Laboratory Systems, 2006. Chemical Information Profile: Diethyl Phthalate [CAS No. 84-66-2]. Prepared for National Toxicology Program. http://ntp.niehs.nih.gov/ntp/htdocs/chem_background/exsumpdf/diethyl_phthalate_508.pdf

Jambeck, J.R., R. Geyer, C. Wilcox, T.R. Siegler, M. Perryman, A. Andrady, R. Narayan, and K.L. Law. 2015. Plastic waste inputs from land into the ocean. Science 347(6223): 768-71.

Kang, C.K., Park, H.J., Choy, E.J., Choi, K.S., Hwang, K., Kim, J.B., 2015. Linking intertidal and subtidal food webs: Consumer-mediated transport of intertidal benthic microalgal carbon. PLoS One. doi:10.1371/journal.pone.0139802

Koch, H.M., Calafat, A.M., 2009. Human body burdens of chemicals used in plastic manufacture. Philos. Trans. Roy. Soc. B: Biol. Sci. 364(1526), 2063–2078. doi:10.1098/rstb.2008.0208

Koelmans, A.A., A. Bakir, G.A. Burton, and C.R. Janssen. 2016. Microplastic as a vector for chemicals in the aquatic environment: Critical review and model-supported reinterpretation of empirical studies. Environmental Science & Technology 50(7): 3315-26.

Koelmans, A.A., Besseling, E., Wegner, A., Foekema, E.M., 2013. Plastic as a carrier of POPs to aquatic organisms: A model analysis. Environ. Sci. Tech. 47(14), 7812-7820. doi:10.1021/es401169n

Lebreton, L.C.M., J. van der Zwet, J-W. Damsteeg, B. Slat, A. Andrady, and J. Reisser. 2017. River plastic emissions to the world's oceans. Nature Communications 8: 15611.

Formatted: Right: 0.25"

Lee, M., 2011. Using trash to track Tijuana's trash. San Diego Union Tribune. http://www.utsandiego.com/news/2011/feb/13/tracking-trash-trash/

Lenz, R., K. Enders, C.A. Stedmon, D.M.A. Mackenzie, and T.G. Nielsen. 2015. A critical assessment of visual identification of marine microplastic using Raman spectroscopy for analysis improvement. Marine Pollution Bulletin 100(1): 82-91.

Lithner, D., Larsson, A., Dave, G., 2011. Environmental and health hazard ranking and assessment of plastic polymers based on chemical composition. Science of the Total Environment 409(18), 3309-3324. doi:10.1016/j.scitotenv.2011.04.038

Lorz, P.M., Towae, F.K., Enke, W., Jäckh, R., Bhargava, N., Hillesheim, W., 2007. Phthalic Acid and Derivatives. Ullmann's Encyclopedia of Industrial Chemistry. Weinheim: Wiley-VCH. doi:10.1002/14356007.a20_181.pub2

Lucattini, L., G. Poma, A. Covaci, J. de Boer, M.H. Lamoree, and P.E.G. Leonards. 2018. A review of semi-volatile organic compounds (SVOCs) in the indoor environment: Occurrence in consumer products, indoor air and dust. Chemosphere 201:466-82.

Lusher, A.L., N.A. Welden, P. Sobral, and M. Cole. 2017a. Sampling, isolating and identifying microplastics ingested by fish and invertebrates. Analytical Methods 9: 1346-60.

Lusher, A.L., P.C.H. Hollman, and J.J. Mendoza-Hill. 2017b. Microplastics in fisheries and aquaculture: Status of knowledge on their occurrence and implications for aquatic organisms and food safety. FAO Fisheries and Aquaculture Technical Paper. No. 615. Rome, Italy.

Mato, Y., Isobe, T., Takada, H., Kanehiro, H., Ohtake, C., Kaminuma, T., 2001. Plastic resin pellets as a transport medium for toxic chemicals in the marine environment. Environ. Sci. Tech. 35(2), 318-324. doi:10.1021/es0010498

Formatted: Right: 0.25"

Moore, C.J., 2008. Synthetic polymers in the marine environment: A rapidly increasing, long-term threat. Environmental Research 108(2), 131-139. doi:10.1016/j.envres.2008.07.025

Moore, C.J., Lattin, G.L., Zellers, A.F., 2011. Quantity and type of plastic debris flowing from two urban rivers to coastal waters and beaches of Southern California. Journal of Integrated Coastal Zone Management 11(1), 65-73.

Murray, F., Cowie, P.R., 2011. Plastic contamination in the decapod crustacean *Nephrops norvegicus* (Linnaeus, 1758). Marine Pollution Bulletin 62(6), 1207–1217. doi:10.1016/j.marpolbul.2011.03.032

Napper, I.E., Bakir, A., Rowland, S.J., Thompson, R.C., 2015. Characterisation, quantity and sorptive properties of microplastics extracted from cosmetics. Marine Pollution Bulletin 99(1-2): 178-185. https://doi.org/10.1016/j.marpolbul.2015.07.029

NIH (National Institute of Health), 2018. Hazardous Substances Data Bank (HSDB online database). National Toxicology Information Program, National Library of Medicine, Bethesda, MD. http://toxnet.nlm.nih.gov

NIOSH (U.S. National Institute of Occupational Safety and Health), 1997. Registry of Toxic Effects of Chemical Substances (RTECS online database). National Toxicology Information Program, National Library of Medicine, Bethesda, MD. https://www.cdc.gov/niosh/docs/97-119/default.html

NOAA, 2015. Laboratory methods for the analysis of microplastics in the marine environment: Recommendations for quantifying synthetic particles in waters and sediments. NOAA Marine Debris Program Technical Memorandum NOS-OR&R-48. July 2015. https://marinedebris.noaa.gov/sites/default/files/publications-files/noaa_microplastics_methods_manual.pdf

Formatted: Right: 0.25"

NTP (National Toxicology Program), 2014. *Report on Carcinogens, Thirteenth Edition.* Research Triangle Park, NC: U.S. Department of Health and Human Services, Public Health Service. http://ntp.niehs.nih.gov/pubhealth/roc/roc13/

OEHHA (California Office of Environmental Health Hazard Assessment), 2019. Library of Chemicals: Di-n-butyl Phthalate. https://oehha.ca.gov/chemicals/di-n-butyl-phthalate

Okkerman, P.C., van der Putte, I., 2002. Endocrine disrupters: Study on gathering information on 435 substances with insufficient data. Final Report. Annex 13, The summary profiles of (41) Category 1 chemical groups. EUROPEAN COMMISSION DG ENV. http://ec.europa.eu/environment/chemicals/endocrine/pdf/bkh_report.pdf#page=148

Peters, C.A., and S.P. Bratton. 2016. Urbanization is a major influence on microplastic ingestion by sunfish in the Brazos River Basin, Central Texas, USA. Environmental Pollution 210: 380-87.

Pritchard, T., 2014. These ten locations featuring urban runoff pollution will shock you. San Diego Coastkeeper. https://www.sdcoastkeeper.org/blog/urban-runoff/these-ten-locations-featuring-urban-runoff-pollution-will-shock-you

PubChem, 2019a. Compound Summary: Diethyl phthalate. National Center for Biotechnology Information. https://pubchem.ncbi.nlm.nih.gov/compound/6781

PubChem, 2019b. Compound Summary: m-Cresol. National Center for Biotechnology Information. https://pubchem.ncbi.nlm.nih.gov/compound/m-cresol

PubChem, 2019c. Compound Summary: Benzyl alcohol. National Center for Biotechnology Information. https://pubchem.ncbi.nlm.nih.gov/compound/244

Renick, V.C., Anderson, T.W., Morgan, S.G., Cherr, G.N. 2015. Interactive effects of pesticide exposure and habitat structure on behavior and predation of a marine larval fish. Ecotoxicology 24 (2): 391-400.

Renick, V.C., Weinersmith, K.L., Vidal-Dorsch, D.E., Anderson, T.W., 2016. Effects of a pesticide and a parasite on neurological, endocrine, and behavioral responses of an estuarine fish. Aquatic Toxicology 170: 335-343.

Rochman, C. M. 2018. Microplastics research: From sink to source. Science 360(6384): 28-29.

Rochman C.M., 2013. Plastics and priority pollutants: A multiple stressor in aquatic habitats. Environ. Sci. Tech. 47(6), 2439-2440. doi:10.1021/es400748b

Rochman, C. M., 2015. The complex mixture, fate and toxicity of chemicals associated with plastic debris in the marine environment. In *Marine anthropogenic litter* (pp. 117-140). Springer International Publishing.

Rochman C.M., Browne, M.A., Underwood, A.J., van Franeker, J.A., Thompson, R.C., Amaral-Zettler, L.A., 2016. The ecological impacts of marine debris: Unraveling the demonstrated evidence from what is perceived. Ecology 97(2): 302-312. doi: 10.1890/14-2070.1

Rochman C.M., Hoh, E., Hentschel, B.T., Kaye, S., 2013a. Long-term field measurement of sorption of organic contaminants to five types of plastic pellets: Implications for plastic marine debris. Environ. Sci. Tech. 47(3), 1646-1654. doi:10.1021/es303700s

Rochman C.M., Hoh, E., Kurobe, T., Teh, S.J., 2013b. Ingested plastic transfers hazardous chemicals to fish and induces hepatic stress. Scientific Reports 3: 3263. doi:10.1038/srep03263

Formatted: Right: 0.25"

Rochman, C.M., Kross, S.M., Armstrong, J.B., Bogan, M.T., Darling, E.S., Green, S.J., Smyth, A.R., Veríssimo, D., 2015b. Scientific evidence supports a ban on microbeads. Environ. Sci. Tech. 49, 10759−10761. doi:10.1021/acs.est.5b03909

Rochman, C.M., Tahir, A., Williams, S.L., Baxa, D.V., Lam, R., Miller, J.T., Teh, F.C., Werorilangi, S., Teh, S.J., 2015a. Anthropogenic debris in seafood: Plastic debris and fibers from textiles in fish and bivalves sold for human consumption. Scientific Reports 5. doi:10.1038/srep14340

Rochman, C. M., T. Kurobe, I. Flores, and S. J. Teh. 2014. Early warning signs of endocrine disruption in adult fish from the ingestion of polyethylene with and without sorbed chemical pollutants from the marine environment. Science of the Total Environment 493: 656-61.

Rios, L. M., Moore, C., Jones, P. R., 2007. Persistent organic pollutants carried by synthetic polymers in the ocean environment. Mar.Pollut. Bull. 54, 1230−1237.

SCCWRP (Southern California Coastal Water Research Project), 2013. Southern California Bight 2013 Regional Monitoring Program: 2013 Planning Documents. http://www.sccwrp.org/Documents/BightDocuments/Bight13Documents/Bight13PlanningDocuments.aspx

SCCWRP (Southern California Coastal Water Research Project), 2016. Southern California Bight 2013 Regional Monitoring Program: Volume III. Trash and Debris. Draft Report. http://www.sccwrp.org/Documents/BightDocuments.aspx

Setälä, O., V. Fleming-Lehtinen, and M. Lehtiniemi. 2014. Ingestion and transfer of microplastics in the planktonic food web. Environmental Pollution 185: 77-83.

Formatted: Right: 0.25"

Sheavly, S.B., Register, K.M., 2007. Marine debris and plastics: Environmental concerns, sources, impacts and solutions. Journal of Polymers and the Environment 15(4), 301-305. doi:10.1007/s10924-007-0074-3

Smith, K.J., Taghon, G.L., Able, K.W., 2000. Trophic linkages in marshes: Ontogentic changes in diet for young-of-the-year mummichog, *Fundulus heteroclitus*. In: Weinstein, M.P., Kreeger, D.A. Concepts and Controversies in Tidal Marsh Ecology. Kluwer Academic Publishers, The Netherlands, 221-237.

Smith, M., D. C. Love, C. M. Rochman, and R. A. Neff. 2018. Microplastics in seafood and the implications for human health. Current Environmental Health Reports 5(3): 375-86.

Song, Y.K., S.H. Hong, M. Jang, G.M. Han, M. Rani, J. Lee, and W.J. Shim. 2015. A comparison of microscopic and spectroscopic identification methods for analysis of microplastics in environmental samples. Marine Pollution Bulletin 93(1-2): 202-09.

Stanley, K.A., 2008. Semi-volatile organic compounds and developing organisms: Accumulation in California Mountain Tadpoles in the field and fish embryo exposures in the laboratory. PhD Dissertation. Oregon State University. 149 pp.

State Water Resources Control Board (State Water Board). 2015. Final 2012 California Integrated Report (Clean Water Act Section 303(d) List/305(b) Report). Category 5. https://www.waterboards.ca.gov/water_issues/programs/tmdl/2012state_ir_reports/category5_report.shtml

Sussarellu, R., Suquet, M., Thomas, Y., Lambert, C., Fabioux, C., Pernet, M.E.J., Le Goïc, N., Quillien, V., Mingant, C., Epelboin, Y., Corporeau, C., Guyomarch, J., Robbens, J., Paul-Pont, I., Soudant, P., Huvet, A. 2016. Oyster reproduction is affected by exposure to polystyrene microplastics. PNAS 113(9), 2430-2435. doi:10.1073/pnas.1519019113

Formatted: Right: 0.25"

Tanaka, K., H. Takada, R. Yamashita, K. Mizukawa, M., Fukuwaka, and Y. Watanuki. 2013. Accumulation of plastic-derived chemicals in tissues of seabirds ingesting marine plastics. Marine Pollution Bulletin 69:219–222.

Temming, A., Hammer, C., 1994. Sex specific food consumption of dab (*Limanda limanda L.*) based on a 24th fishery. Archive of Fisheries and Marine Research 42(2), 123-36.

Teuten, E.L., Saquing, J.M., Knappe, D.R.U., Barlaz, M.A., Jonsson, S., Bjorn, A., Rowland, S.J., Thompson, R.C., Galloway, T.S., Yamashita, R., Ochi, D., Watanuki, Y., Moore, C., Viet, P.H., Tana, T.S., Prudente, M., Boonyatumanond, R., Zakaria, M.P., Akkhavong, K., Ogata, Y., Hirai, H., Iwasa, S., Mizukawa, K., Hagino, Y., Imamura, A., Saha, M., Takada, H., 2009. Transport and release of chemicals from plastics to the environment and to wildlife. Philos. Trans. R. Soc. B: Biol. Sci. 364(1526), 2027−2045. doi:10.1098/rstb.2008.0284

Thaysen, C., K. Stevack, R. Ruffolo, D. Poirier, H. De Frond, J. DeVera, G. Sheng, and C. M. Rochman. 2018. Frontiers in Marine Science 5: 71. doi: 10.3389/fmars.2018.00071

Thompson, R. C. 2015. Microplastics in the marine environment: Sources, consequences and solutions. Pp. 185-200 *in* Bergmann, M., and M. Klages (eds.). Marine Anthropogenic Litter. Springer, Cham.

Trexler, J.C., Tempe, R.C., Travis, J., 1994. Size-selective predation of sailfin mollies by two species of heron. Oikos 69(2), 250-258. doi:10.2307/3546145

Usenko, S., Landers, D.H., Appleby, P.G., Simonich, S.L., 2007. Current and historical deposition of PBDEs, pesticides, PCBs and PAHs to Rocky Mountain National Park. Environ. Sci. Tech. 41(21), 7235-7241. doi:10.1021/es0710003

Van Cauwenberghe, L., Janssen, C.R., 2014. Microplastics in bivalves cultured for human consumption. Environmental Pollution 193, 65–70. doi:10.1016/j.envpol.2014.06.010

Wade, L.G. 2019. Cresol: Chemical Compound. Encyclopedia Britannica. https://www.britannica.com/science/cresol

Watts, A.J.R., Lerwis, C., Goodhead, R.M., Beckett, S.J., Moger, J., Tyler, C.R., Galloway, T.S., 2014. Uptake and retention of microplastics by the shore crab *Carcinus maenas*. Environ. Sci. & Tech. 48, 8823-30. dx.doi.org/10.1021/es501090e

Watts, A.J.R., Urbina, M.A., Corr, S., Lewis, C., & Galloway, T.S. 2015. Ingestion of plastic microfibers by the crab Carcinus maenas and its effect on food consumption and energy balance. Environ. Sci. & Tech. 49(24): 14597-604.

Welden, N.A., B. Abylkhani, and L.M. Howarth. 2018. The effects of trophic transfer and environmental factors on microplastic uptake by plaice, *Pleuronectes plastessa*, and spider crab, *Maja squinado.* Environmental Pollution 239: 351-58.

Weschler, C.J., Nazaroff, W.W., 2008. Semivolatile organic compounds in indoor environments. Atmospheric Environment 42(40), 9018–9040. doi:10.1016/j.atmosenv.2008.09.052

West, J., Zedler, J.B., 2000. Marsh-creek connectivity: Fish use of a tidal salt marsh in Southern California. Estuaries 23(5), 699-710. http://www.jstor.org/stable/1352896

West, J.M., Williams, G.D., Madon, S.P., Zedler, J.B., 2003. Integrating spatial and temporal variability into the analysis of fish food web linkages in Tijuana Estuary. Environmental Biology of Fishes 67(3), 297-309.

WHO (World Health Organization), 2003. Concise International Chemical Assessment Document 52: Diethyl phthalate. http://www.who.int/ipcs/publications/cicad/en/cicad52.pdf?ua=1

Formatted: Right: 0.25"

Wiki (Wikipedia). 2019. Benzyl alcohol. https://en.wikipedia.org/wiki/Benzyl_alcohol#Applications

Windward Environmental, 2010. East waterway operable unit supplemental remedial investigation/feasibility study: Final data report: Fish and shellfish tissue collection. Prepared for U.S. Environmental Protection Agency, Region 10. Windward Environmental LLC, Seattle, WA. https://www3.epa.gov/region10/pdf/sites/harborisland/east_waterway/fish_shellfish_data_report_0410.pdfs

Wright, S.L., and F.J. Kelly. 2017. Plastic and human health: A micro issue? Environmental Science & Technology 51: 6634-47.

Xu, Y., Zhang, J.S., 2011. Understanding SVOCs. American Society of Heating, Refrigerating and Air-Conditioning Engineers Journal 53(12), 121-125.

Yonkos, L.T., E.A. Friedel, A.C. Perez-Reyes, S. Ghosal, and C.D. Arthur. 2014. Microplastics in four estuarine rivers in the Chesapeake Bay, U.S.A. Environmental Science & Technology 48(24): 14195-202.

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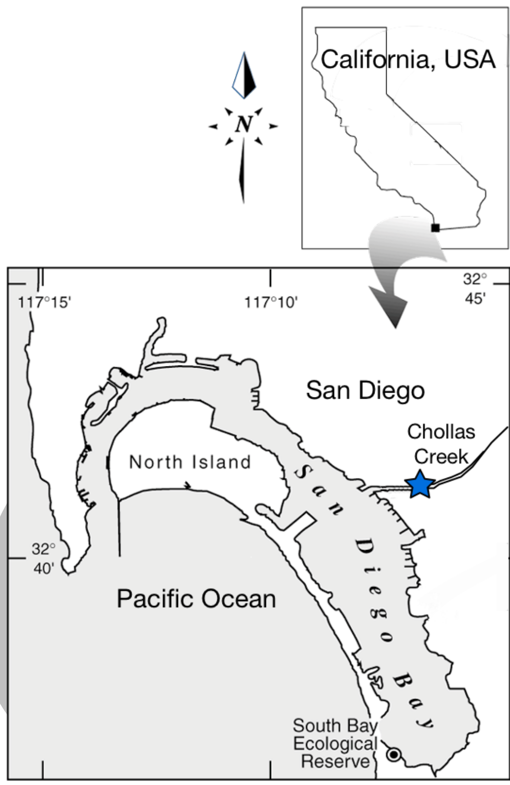

Fig. 1. Study site located in lower Chollas Creek near the mouth with San Diego Bay, California, USA.

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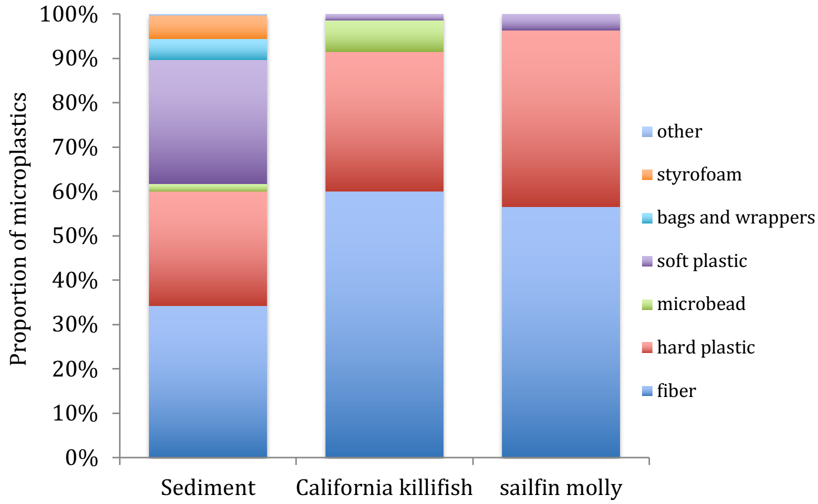

Fig. 2. Relative abundance and composition of microplastics found in sediments (0-5 cm depth) and the guts of two common wetland resident fish in lower Chollas Creek. N= 9 soils, 7 California killifish, 23 sailfin molly. Data are from June 2015.

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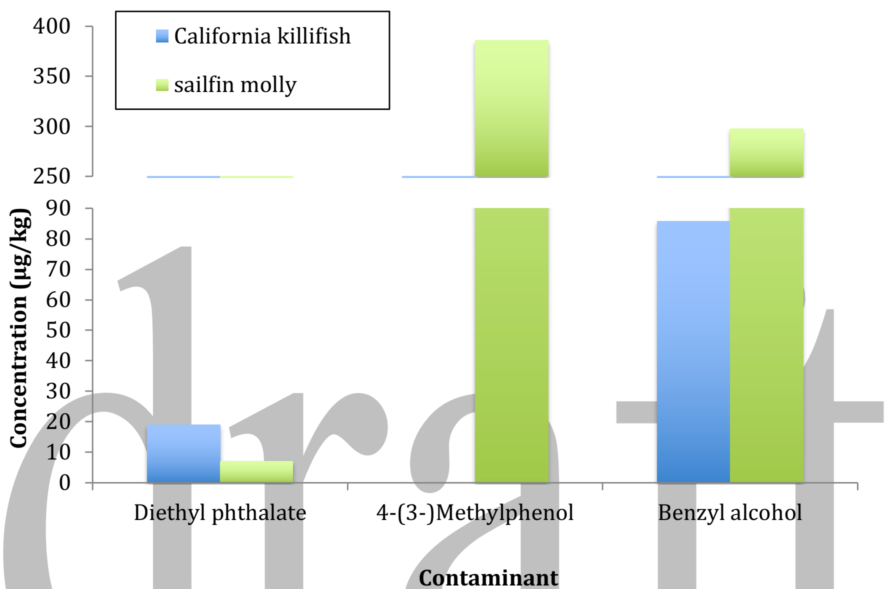

Fig. 3. Semi-volatile organic compounds found in wetland resident fish in lower Chollas Creek, San Diego, California, USA. N=1 composite sample consisting of 3 California killifish and 2 sailfin molly individuals. Data are from June 2015.

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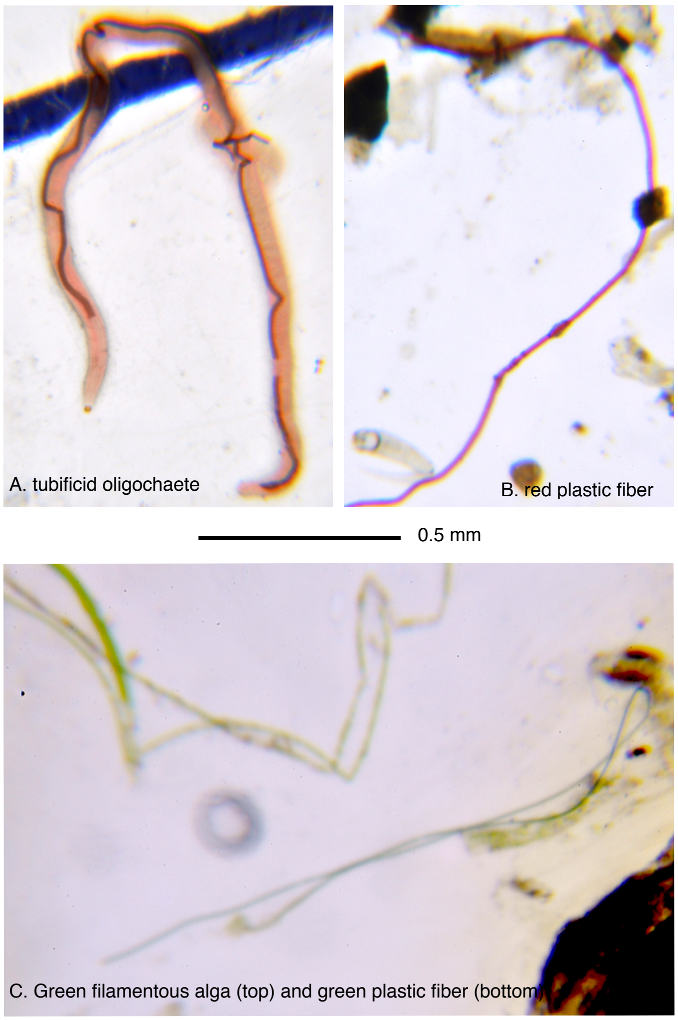

Fig. 4. Similar looking microplastic fibers and prey items in guts of wetland resident fish. Contents of California killifish guts included (A) a tubificid oligochaete and (B) a red plastic fiber. Contents of a sailfin molly guts included (C) a filament of green algae (top) and a green plastic fiber (bottom). Scale shown applies to all photos.

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Table 1. Abundance of microplastics in surface sediments and the guts of common marsh resident fish, and Manly's alpha where a ≥0.025 (in bold) indicates a dietary selective preference for microplastics compared to what were available in the environment. Only individuals with microplastics present in the gut were included in this summary. Samples were collected from lower Chollas Creek, San Diego, California, USA during June 2015.

Type of microplastic	Sediment	California killifsh	sailfin molly	California killifsh	sailfin molly
n=	9 cores	7 individuals	23 individuals	7 individuals	23 individuals
	Abundance (no. m^{-2})	**Abundance (no. gut^{-1})**		**Manly's alpha (α ≥ 0.026)**	
	Avg ± 1 SE	**Avg ± 1 SE**	**Avg ± 1 SE**	**Avg ± 1 SE**	**Avg ± 1 SE**
Bag and packaging pieces					
mylar wrapper	28 ± 19	0	0	0	0
clear or opaque wrapper	127 ± 60	0	0	0	0
grocery bag	85 ± 37	0	0	0	0
thick, opaque (retail bag)	14 ± 14	0	0	0	0
thin translucent (produce bag)	14 ± 14	0	0	0	0
thick, clear, soft (bread or zip bag)	28 ± 28	0	0	0	0
clear, thin crinkly wrapper	42 ± 30	0	0	0	0
thick, clear, crinkly (nut, pasta bag)	14 ± 14	0	0	0	0
strapping or packaging tape	42 ± 30	0	0	0	0
clear hard plastic shell packaging	14 ± 14	0	0	0	0
styrofoam piece	467 ± 116	0	0	0	0
jar or bottle label	28 ± 28	0	0	0	0
rubber or foam piece	14 ± 14	0	0	0	0
Soft plastic pieces					
clear or white	467 ± 108	0	0	0	0
green	241 ± 109	0	0	0	0
blue	467 ± 192	0.14 ± 0.14	0.13 ± 0.13	0.004 ± 0.004	0.012 ± 0.009
red	1089 ± 399	0	0	0	0
yellow	410 ± 137	0	0	0	0
orange	99 ± 59	0	0	0	0
Hard plastic pieces					
clear or white	552 ± 209	0	0.04 ± 0.08	0	0.005 ± 0.005
green	368 ± 157	0.14 ± 0.14	0.04 ± 0.08	0.005 ± 0.005	0.020 ± 0.020
pink	28 ± 28	0	0	0	0
blue	311 ± 150	0.29 ± 0.18	0.65 ± 0.52	**0.027 ± 0.021**	**0.220 ± 0.080**
red	424 ± 133	0.14 ± 0.14	0.17 ± 0.19	0.005 ± 0.005	**0.057 ± 0.044**
yellow	1019 ± 376	0.14 ± 0.14	0.13 ± 0.13	**0.143 ± 0.143**	**0.046 ± 0.043**
black	14 ± 14	0	0	0	0
silver	14 ± 14	0	0	0	0
orange	14 ± 14	0	0.04 ± 0.08	0	**0.042 ± 0.042**
microbead	212 ± 124	0.29 ± 0.18	0	**0.066 ± 0.043**	0
Fibers					
clear or white	2716 ± 1008	0.57 ± 0.43	0	**0.145 ± 0.145**	0
black	85 ± 56	0	0.39 ± 0.36	0	**0.108 ± 0.054**
blue	57 ± 43	0.43 ± 0.30	0.43 ± 0.25	**0.213 ± 0.148**	**0.239 ± 0.079**
green	14 ± 14	0.14 ± 0.14	0.13 ± 0.13	**0.138 ± 0.138**	**0.130 ± 0.072**
red	71 ± 37	0.57 ± 0.30	0.22 ± 0.20	**0.254 ± 0.127**	**0.121 ± 0.061**
net or thick line	396 ± 312	0	0	0	0
Pieces of other items					
sponge	14 ± 14	0	0	0	0
toys: Lego, beads	28 ± 28	0	0	0	0
artificial grass, astro turf	28 ± 28	0	0	0	0
synthetic carpet	42 ± 30	0	0	0	0
Total per core or gut:	9638 ± 1638	2.86 ± 1.22	2.43 ± 0.68		

Table 2. Abundance of prey and other non-plastics found in the guts of common marsh resident fish from lower Chollas Creek, San Diego, California, USA. Data are from June 2015.

Gut content items	California killifsh	sailfin molly	longjawed mudsucker
n (number of individuals)=	61	74	4
Items that could not be counted	**Avg ± 1 SE**	**Avg ± 1 SE**	**Avg ± 1 SE**
	% of fish with items present		
sand or silt	48%	99%	50%
scales	5%	0%	25%
unknown exoskeleton pieces	53%	1%	0%
unknown amphipod or shrimp pieces	2%	0%	0%
unknown decapod pieces	0%	1%	0%
unknown organics or digested pieces	18%	0%	0%
green filamentous algae	75%	85%	50%
red filamentous algae	10%	11%	0%
Enumerated items	**Avg ± 1SE**	**Avg ± 1SE**	**Avg ± 1SE**
	(no. gut-1)	**(no. gut-1)**	**(no. gut-1)**
snails (*Barleeia californica, Assiminea californica*)	0.49 ± 0.40	0.04 ± 0.03	0
tubificid oligochaetes, nematodes	1.66 ± 0.28	0.12 ± 0.05	1.75 ± 0.75
unnown whole digested-fish	0.02 ± 0.02	0.01 ± 0.01	0.25 ± 0.25
unknown fish eggs or larvae	0.05 ± 0.05	0	0
unknown insect larvae or adult parts	0.05 ± 0.03	0	0
sea cucumber (*Leptosynapta* sp.)	0.05 ± 0.03	0	0

Table 3. Comparison of fish that had and did not have small plastics in their guts with all fish analyzed in this study. Results of t-tests (fish morphological variables) and Chi square (sex ratios) are shown.

	California killifsh					**sailfin molly**				
	Fish without plastics	**Fish with plastics**	**t-test/Chi square results**			**Fish without plastics**	**Fish with plastics**	**t-test/Chi square results**		
n=	61	7				74	23			
Variable	**Avg ± 1 SE**	**Avg ± 1 SE**	**P**	**t/ Chi sq**	**df**	**Avg ± 1 SE**	**Avg ± 1 SE**	**P**	**t/ Chi sq**	**df**
standard length (cm)	4.34 ± 0.16	5.50 ± 0.32	0.003	2.52	59	4.05 ± 0.12	4.15 ± 0.29	0.655	0.55	72
total length (cm)	5.12 ± 0.18	6.40 ± 0.40	0.005	2.41	59	4.96 ± 0.14	5.08 ± 0.34	0.624	0.58	72
weight (g)	2.35 ± 0.27	4.20 ± 0.32	0.005	2.25	59	2.05 ± 0.19	2.39 ± 0.38	0.466	1.04	72
sex: female / male / unknown	24/23/6	3/3/1	0.571	1.13	2	28/21/2	15/7/1	0.677	0.78	2

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