SDG UNDERGRADUATE RESEARCH GROUP
SPRING 2021

MICROPLASTICS IN THE BAY AREA

AND ITS EFFECTS ON SEA LIFE AND HUMAN HEALTH

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EXECUTIVE SUMMARY

The introduction of microplastics into aquatic ecosystems has caused detrimental effects onto both sea life and human health. Our oceans are now home to over 5.2 trillion pieces of macro and microplastics and everyday this number increases by 8 million. In a study published in October 2019 by the San Francisco Estuary Institute (SFEI) and Five Gyres Institute, it was found that the San Francisco Bay has some of the highest recorded concentrations of microplastics anywhere in the world. This project aims to compile research on 1) its ways of travel through the water column and how that impacts local sea life, and 2) the effects of consuming microplastics in food on human health and how it relates to environmental justice.

The transport of microplastics in the Bay is regulated by the estuarine circulation between the freshwater and seawater currents. Freshwater enters the Bay from the tributaries that make up the Sacramento-San Joaquin River Delta. These freshwater currents flow out of the Bay, while saltwater from the ocean flows into the Bay. The fate of microplastics, like how far they travel and its position in the water column, is dependent on the particle's buoyancy. Only some buoyant or passive particles followed surface freshwater to exit and travel a considerable distance past the Golden Gate Bridge. Denser particles with settling velocities were mostly retained in the Bay and could be found in sediment.

Understanding the distribution of microplastics in the water column and how it is transported could help us determine the possible effects microplastics have on sea life, like the species we see in this San Francisco Bay food web. Microplastics ingested by smaller organisms at the bottom of the food chain could cause accumulation of particles and more significant health problems for their predators, though some research has shown how microplastics mainly remain in the stomach or guts of animals and there is not enough research on higher predators to make a final conclusion. The two modes of impact microplastics can have are physical (ex: inflammation), from the particle itself, and chemical (ex: cytotoxicity), from the additives that can leach from the plastic.

Microplastics can enter our bodies through three mechanisms: ingestion, inhalation, and skin contact. The most understood mechanism is inhalation, which is split into three stages: deposition, clearance, and inflammation/cancer. Once these microplastics have accumulated in our bodies, it can cause some serious health effects, mainly attributed to inflammation caused by the particles. This may eventually result in more serious effects such as the promotion of cancer due to damages in the DNA. A large part of the results are dependent on the size, shape, density and chemicals in the plastics, as that determines the extent to which the human excretory system eliminates consumed microplastics. However, due to most research being concentrated in mice, more research is needed to determine the true impacts on human health. Polystyrene nanoparticles, in particular, are of huge concern to the health of the human respiratory system and have many current studies examining those risks.

In looking at the Cal Dining order information, we analyzed the exposure levels of Berkeley students. Crab cakes made up the largest percentage of the seafood order, with relatively little scallops ordered. Crustaceans and molluscs can be more predisposed to microplastic exposure due to their feeding habits and consumption of certain prey. Because it was difficult to come up with accurate approximations of average microplastics consumed, we conducted a survey of Berkeley students.

The results of our survey showed that on average, Berkeley students consume about 57.059 microplastic particles per day from beer, plastic bottled beverages, salt, and seafood. At the 95th percentile, or in rare circumstances, Berkeley students consume about 22,234.171 microplastic particles per day from beer, plastic bottle beverages, salt, and seafood. In any case, these values could vary significantly between different types of students and even between different days for the same student. We also compared these values to global averages to gain a better understanding on how our Berkeley student data compares to the rest of the world, as well as minority and lower income communities. Non-Hispanic (NH) Black and Hispanic adults had much higher odds of consuming tap water, and consumed less tap water than NH White adults. For NH Black, Hispanic and non-US-born adults, the majority of drinking water intake came from bottled water, whereas for NH White, NH Asian, and US-born adults, most drinking water came from tap water. Higher percentages of Hispanic and Black communities perceive their tap water to be unsafe for drinking, and turn to bottled water instead. However, though free of other pollutants that are common in low-quality water areas, the bottled water had approximately twice as many plastic particles compared to tap water on average. Furthermore, the type of packaging process also has a significant impact on microplastic concentrations in bottled water.

We also found that another vulnerable demographic in many communities was at high risk for consuming microplastics: babies. Babies that are fed with formula that is prepared in polypropylene (PP) instant feeding bottles (IFBs) are exposed to greater amounts of microplastic than babies who are breastfed. While sterilizing and preparing feeding bottles at high temperatures, more microplastics are prone to being released into the baby formula.

Microplastics are a large anthropogenic problem that requires a two-pronged approach. Much of the real long-term effects of microplastics are largely unknown, as a lot of the vital research in the scientific community is still ongoing. In the meantime, we can focus our efforts on reducing the upstream problems of plastic usage in order to prevent microplastics, the downstream product, from affecting the health of local sea life and vulnerable communities.

INTRODUCTION

The SDG Undergraduate Research Group (SURG) is an undergraduate-led research group affiliated with the UC Berkeley Office of Sustainability and guided by the UN Sustainable Development Goals. Through student-led research, SURG aims to take action on the major challenges of our time, expand undergraduate leadership in topics of interest, and increase transdisciplinary learning of these issues. SURG was founded by Kung Chen, Mikayla Tran, Varsha Madapoosi, and Rohith Moolakatt, and its inaugural semester took place in Fall of 2020.

The Microplastics Research Committee was created to investigate the impact of microplastics in the Bay Area and its effects on sea life and human health. The team consisted of co-leads Britney Wu and Sarah Harte, and researchers Megan Hur, Audrey Williams, Ranjini Nair, Romi Takara, Mary Wang, Sabi Can Ruso, and Sindre Carlsen. Our academic mentor, Dr. Scott Coffin, guided us through our research process.

Because of difficulties with the COVID-19 pandemic, much of our research was desktop based. Over the span of a semester, our research group perused through many published research papers and literature reviews focusing on the harm microplastics cause in natural and social environments. With microplastics being a developmental topic in recent years, much vital research in the scientific community is still ongoing. In addition to desktop research, our team also analyzed data belonging specifically to the Berkeley community. With our student survey that delved into potential microplastic exposure of Cal students, and an evaluation of Cal Dining's seafood menu, we were able to provide a snapshot of what microplastic consumption might look like on the UC Berkeley campus.

Guided by SDG 3 ("good health and wellbeing"), SDG 12 ("responsible consumption and production"), and SDG 14 ("life below water"), we determined the foundational questions that our research would target. Our team focused on 1) how the spread of various microplastics impacts local sea life, and 2) how the accumulation of microplastics is detrimental to the health of local communities, with an emphasis on Berkeley students and vulnerable populations.

Through our report, we will address what this means for our oceans, our resources, and our health. We hope to provide a greater understanding of how microplastics, one of the smallest pollutants in the ocean, wreak damage on a global scale, and the mitigative steps we can take to prevent it.

BACKGROUND

Our oceans are now home to over 5.25 trillion pieces of macro and microplastics. Everyday this number increases by 8 million, as plastic continues to flow into our oceans and waterways. (Parker, 2015) As research has revealed, this is likely to have catastrophic effects on both human and sea life as large quantities of plastics are left unchecked in our oceans and rivers. Importantly, with the introduction of **microplastics** into the aquatic system both sea life and human health have been, and will be, adversely affected as plastic continues to break down, and commercial products are ineffectively disposed of. (Rogers, 2020)

'Microplastics' is an emerging field of study with little known of their true impacts on both marine ecosystems and human health. By definition, microplastics are tiny particles less than five millimetres (0.2 inches) in diameter, or smaller than a standard pearl. These tiny particles are the result of the immense plastic pollution described above. (Rogers, 2020)

There are two different categories of microplastics: primary and secondary. Primary microplastics are tiny particles that result from commercial use, such as micro-beads found in cosmetics, microfibres from fishing nets, and clothing e.g nylon. Primary microplastics can enter into the environment through many different avenues such as personal care products being washed into the wastewater system from households, unintentional loss from product manufacturing, or synthetic material from clothing.

Whereas, secondary microplastics form when larger macro plastics break-down, and this occurs when larger plastic weathers through exposure to wind abrasion and ultraviolet radiation from sunlight in the ocean. (Liitschwager, 2019)

In our marine and freshwater ecosystems microplastics have been found in more than 114 aquatic species digestive tracts and stomachs, a startling statistics that proves the urgent need for this field of study to be addressed. It is now clear that microplastics have worked their way into our food chains, with the ingestion of fish and birds containing microplastics likely to cause neurological and reproductive toxicity in humans. (Rogers, 2020)

Additionally, it is also likely that microplastics have worked their way into everyday household items and food products. With microplastics being detected in drinking water, bottled water, beer and food products including seafood and table salt. In short, microplastics are not biodegradable. Thus, once in the environment, primary and secondary microplastics accumulate and persist in our ecosystems, with their true effects largely unknown. (Smith et al. 2018)

MICROPLASTICS IN THE SEA & SEA LIFE

TRANSPORT AND DISTRIBUTION

MICROPLASTICS TRANSPORT

Microplastics are ubiquitous and can be found everywhere: up and down the water column, in deep-sea sediments, and our estuaries, rivers, and beaches. Studies by Browne et al. (2011), Hidalgo-Ruz et al. (2012), and Van Cauwenberghe et al. (2013) show large amounts of microplastics in surface waters, shallow waters, and sediments, as well as in the guts of many organisms living in these ecosystems (as cited in Bergmann et al., 2015). Studying how these microplastics have been transported and what their distribution looks like is important in understanding what impacts different types of plastic in different areas of our waters have on what organisms.

Once released into the ocean, microplastics follow the same oceanographic features as macroplastics, resulting in a distribution consisting of accumulation at upwelling convergence zones, such as the Great Pacific Garbage Patch in the North Pacific Gyre (Bergmann et al., 2015). It has been determined that plastics discharged into the sea are taken up by ocean currents, like the California Current for the northeast Pacific Ocean, transporting them to the open ocean (Doyle et al., 2011; Bergmann et al., 2015). As a result of the surface ocean's wind-driven circulation, the rotational pattern of the currents make convergence zones and ocean gyres where plastics accumulate, persist, and fragment, affecting sea life up and marine ecosystems (Karl, 1999, as cited in Bergmann et al., 2015). On a related note Kukulka et al. (2012), has concluded that microplastics' vertical movement in the surface wind-mixing layer of the water column is influenced by wind, which causes a downward flux in buoyant particles that have an upward flux (as cited in Bergmann et al., 2015).

In studies by Doyle et al. (2011), Lattin et al. (2004), and Desforges et al., 2014, the microplastic abundance was higher in sampling sites closer to the shore, rather than in offshore subsurface waters, and the difference was especially pronounced near high population southern cities Los Angeles and San Diego (as cited in Bergmann et al., 2015). Microplastics are then taken from these coastal areas by ocean currents to convergence zones (Reisser et al., 2013, as cited in Bergmann et al., 2015). For similar reasons of the urbanized areas on the coast, studies that sampled ocean water before and after rain events show that samples after storms have more microplastics, as a result of land-based runoff (Lattin et al., 2004; Moore et al., 2002; Sutton et al., 2019).

The distribution of microplastics in the water column is known to be dependent on the particle's density. Plastics in the ocean are usually not pure plastics (that are often used in microplastic experimental studies), since pure plastics are altered during manufacturing with additives and chemicals that make plastic the convenient material it is, as well as weathering and biofouling. Biofouling is the accumulation of microorganisms on a surface, likely causing particles to become negatively buoyant and sink: assuming that when the density of the particle with the addition of biofilm is greater than the density of seawater, the particle will start to settle and then stay suspended at the depth where the microplastic's density is equivalent to the density of the seawater or sink all the way to sediment (Kooi et al., 2017). When considering biofilm's effect on microplastics' position in the water column, Kooi et al. (2017) reports how communities of algae can form within a day and cause the particle to start sinking depending on characteristics of the microplastic, environmental conditions, and the amount of biofilm that can accumulate on the particle, which is demonstrated by collision, growth, respiration, and mortality, but can also defoul due to light limitation and other factors. With these in mind, the general pattern of buoyant microplastic movement can be further elaborated on by including how after particles start to settle, they can move up again, possibly resurfacing, then settling, resulting in an oscillation up and down the water column, with the periodicity and amplitude depending on microplastic characteristics, as seen in **Figure 4.1-1** (Kooi et al., 2017).

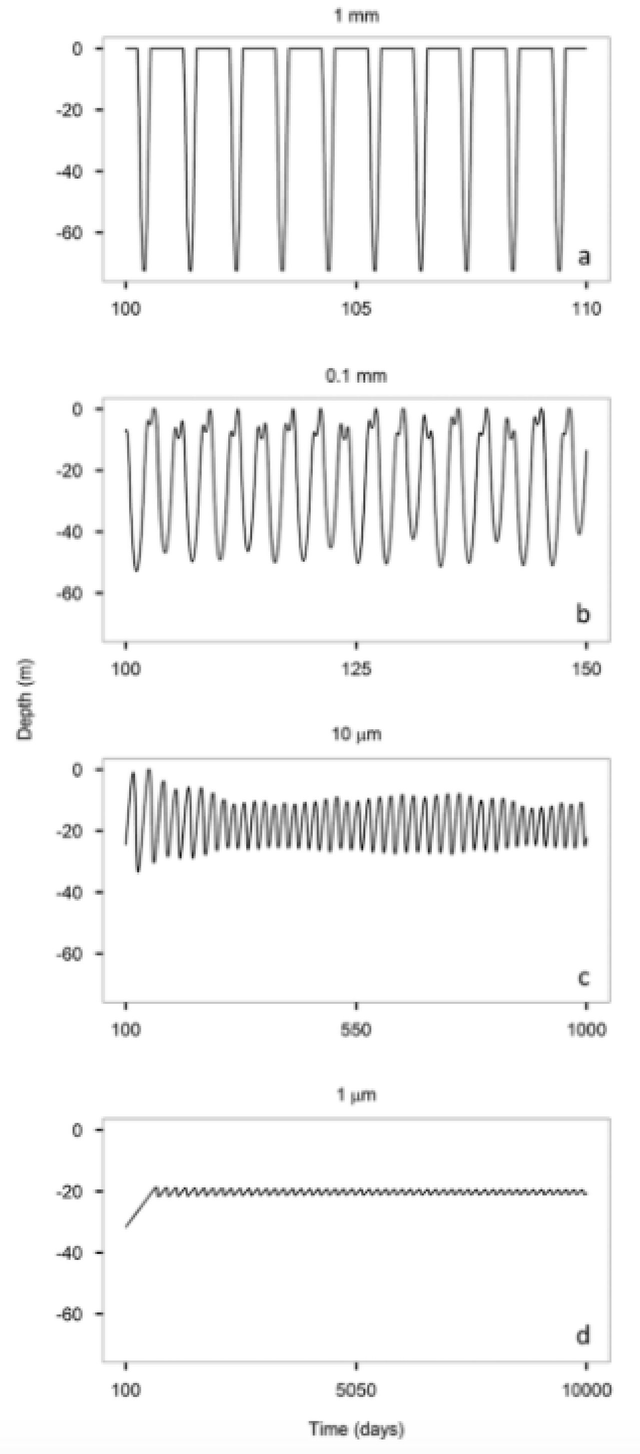

Figure 4.1-1: "Oscillations of a LDPE particle of (a) 1 mm, (b) 0.1 mm, (c) 10 µm, and (d) 1 µm. Note the different time scales on the x-axis. Oscillation periods increase with decreasing particle size." (Kooi et al., 2017)

The 2012 review by Hidalgo-Ruz et al. says that most microplastics particles float at the sea surface at 0.022–8,654 items m−3, because most polymers are lower in density than sea water, "but occur to a lower extent suspended in the water column (0.014–12.51 items m−3)" (as cited in Bergmann et al., 2015). Negatively buoyant particles can settle in sediment (18,000–125,000 items m−3 in subtidal sediments) and sinking and neutrally buoyant particles can sometimes accumulate in beaches (Hidalgo-Ruz et al., 2012, as cited in Bergmann et al., 2015).

Alternatively, a 2019 study by Choy et al. researched the concentrations and types of microplastics in the pelagic water column and found that concentrations of microplastics were highest in samples from depths right below the mixed layer: 15 particles m−3 at 200 m deep. Concentrations were lowest at the sea surface (5 m deep) and deepest waters sampled (1000 m deep), with medians of about 2.9 particles L−1 (Choy et al., 2019). In this particular study, microplastics concentrations were higher at offshore locations, which are thought to have been transported through "wind forcing and upwelling dynamics" of the California Current. (However, the Choy et al. (2019) study wasn't focused on the differences between microplastic concentration in nearshore and offshore sites, and other studies have found that more plastic is accumulated closer to the coast, as stated previously.) As for the types of plastic, Polyethylene terephthalate (PET) and polyamide (PA) were found at all depths sampled, as well as in the "gastrointestinal tracts of pelagic red crabs" and "from discarded larvacean sinkers" (Choy et al., 2019).

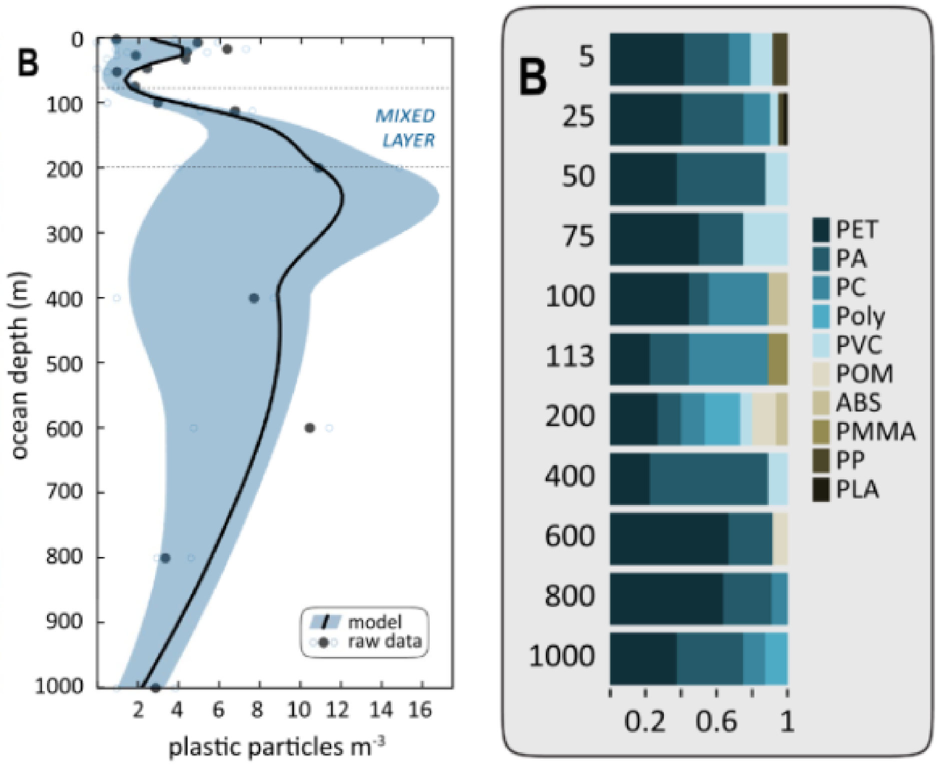

Figure 4.1-2: (Left) "Microplastic concentrations varied across sample depths and peaked just below the mixed layer." (Right) A diversity of plastic material types were represented in the water column. (Choy et al., 2019)

MICROPLASTICS IN THE SAN FRANCISCO BAY

In the 2019 report by the San Francisco Estuary Institute (SFEI) and Five Gyres Institute, the transport of microplastics and microplastics were simulated by developing a model that tracks the movement of particles, as well as a hydrodynamics model of the San Francisco Bay. Knowing that the determining factor of microplastic transport is the rate at which the particle moves up or down the water column depending on its density, settling and rising velocities were estimated based on the methods of Wäldschlagger and Schüttrumpf, which considers the parameters of bulk density, Corey Shape Factor, and Powers Roundness. SFEI calculated settling and rising velocities for various materials found in stormwater and wastewater datasets, such as rubber, polyethylene, nylon, and foam (Sutton et al., 2019). The main hydrodynamics that characterize the Bay is the estuarine circulation between the freshwater and seawater currents, which are the main forces in the SFEI hydrodynamic model that combined a few existing models to create one that would accurately represent the forces in the Bay and neighboring sanctuaries. Freshwater enters the Bay from the tributaries that make up the Sacramento-San Joaquin River Delta, which then flow out of the Bay, while saltwater currents from the ocean flow into the Bay through the narrow channel under the Golden Gate Bridge. Microplastics that are released from stormwater and treated wastewater are subject to the currents that are ebbing, or emptying, and flooding, or filling, the Bay. As for the particle tracking model, seven velocities were used: rising at 50 mm/s, 5 mm/s, 0.5 mm/s; passive (0 mm/s); and settling at 50 mm/s, 5 mm/s, 0.5 mm/s (Sutton et al., 2019).

Likewise with other studies on microplastic transport, the San Francisco Estuary Institute finds that the fate of microplastics (whether particles released within the Bay stay in the Bay or flow out into the ocean) is largely dependent on particle buoyancy or density. In the simulation where particles were released in the South Bay, shown in Figure 4.1-3, only 20% of the passive particles were able to travel past the Golden Gate Bridge, following a surface freshwater plume leaving the Bay, directing particles north or south, depending on winds and local currents (Sutton et al., 2019). Conversely, denser particles with settling velocities were contained in the Bay, finding themselves grounded in the sediment among benthic organisms (Sutton et al., 2019).

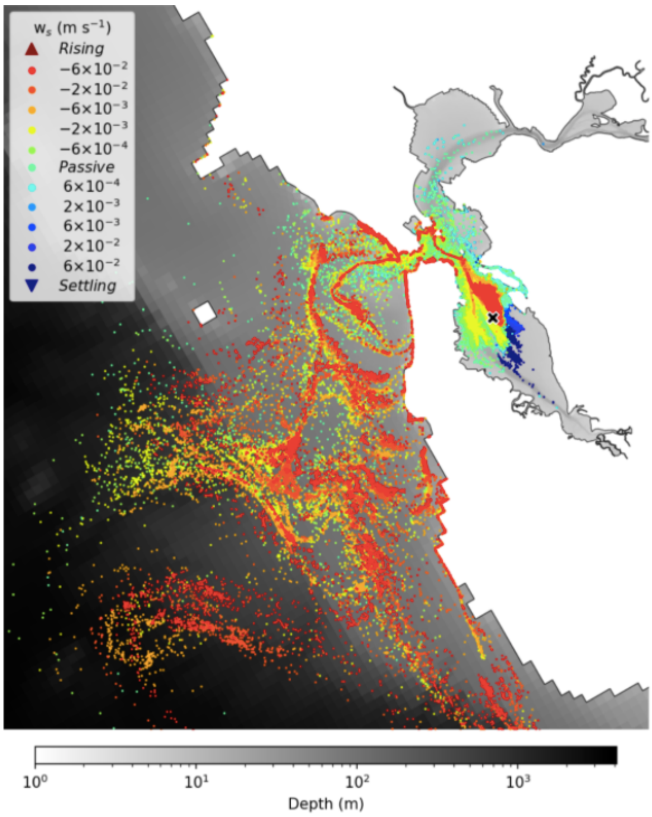

Figure 4.1-3: "Particle distribution after 30 days, South Bay release at X. w_s represents a rising velocity when negative and a settling velocity when positive." (Sutton et al., 2019)

The model also gives insight on convergence zones in the San Francisco Bay and marine sanctuaries that have resulted in accumulation of particles: estuarine convergence of near-bed currents at the point where freshwater and brackish water meet, South Bay shoals with long residence times and influenced by prevailing winds, and the coastal plume that directs a buoyant flux northward by the Coriolis Effect (Sutton et al., 2019).

As presented above, biofilm on microplastics is widely known, but biofouling is not considered in SFEI's hydrodynamic model: the particles are given one rising or settling velocity, which the model uses to predict its transport depending on weather conditions and time period. The SFEI Report does note that running their model for a 44-day period is long enough for biofilm to grow, but velocities of individual particles were not changed to account for it. Another related aspect of microplastic transport that is not included in the hydrodynamic model is the oscillation of particles up and down the water column (as researched in the 2017 biofouling study by Kooi et al.), as the exact depth of certain particles based on their settling or rising velocities wasn't a focal point of the report.

Overall, the comprehensive 2019 report by San Francisco Estuary Institute (SFEI) and Five Gyres Institute adequately provides a depiction of particle distribution and helps to understand possible implications the transport of microplastics have on marine biota and humans in the Bay Area.

HEALTH EFFECTS ON BAY SEA LIFE

SEA LIFE IN THE SAN FRANCISCO BAY

Understanding the distribution of microplastics in the water column and how it is transported helps determine the possible effects microplastics have on sea life. In a study by Choy et al. (2019) on transport of microplastics along the water column, the authors find that organisms that had the highest amount of microplastics were found in the depths with the highest concentrations of microplastics, suggesting the degree of problems for organisms. As noted in the San Francisco Estuary Institute's report, the distribution of plastic particles that leave and settle in the Bay are a risk to these organisms. A conclusion found in the report points to the large amount of microplastics that have settling velocities and don't make it past the Golden Gate Bridge, becoming a concern for benthos organisms and their predators (Sutton et al., 2019).

Although very altered by the surrounding urban environment, the San Francisco Bay supports thousands of species in its many ecosystems, like the open bay and tidal zones. Common invertebrates include ghost shrimp (Neotrypaea californiensis), bivalves, like mussels, clams, and oysters, and various zooplankton. Topsmelt and northern anchovy are prey to larger fish, such as Chinook salmon, the introduced striped bass, and the leopard shark, as seen in **Figure 4.2-1**.

The Bay ghost shrimp is only one example of the many crustaceans in the San Francisco Bay. They make burrow systems in the mudflats, home to crabs, other shrimp, and copepods, causing bioturbation and having a negative effect on oysters. Oyster beds are also a habitat for many other species and they help with nutrient cycling and water filtration, making them a keystone species. Both ghost shrimp and bivalves are benthic organisms in the intertidal or subtidal zones of the Bay, and some species of both groups are filter feeders, ingesting the organic matter and plankton that flow into their gills (Mooi et al., 2007).

Topsmelt is a key species for monitoring contaminants, mostly residing in the sloughs or embayments while feeding on invertebrates, plants and diatoms. As the most abundant fish species, the Northern Anchovy are located in the pelagic waters of the Bay and ocean and consume everything from plankton and zooplankton to crustaceans (Sutton et al., 2019). These fish species are prey to various predators. The harmless leopard shark swims close to the bottom of the Bay or intertidal zone and feeds on benthic shellfish and smaller fish near the mudflats (Mooi et al., 2007). The striped bass is an introduced species from the Atlantic coast of North America who diet on types of herring and shad.

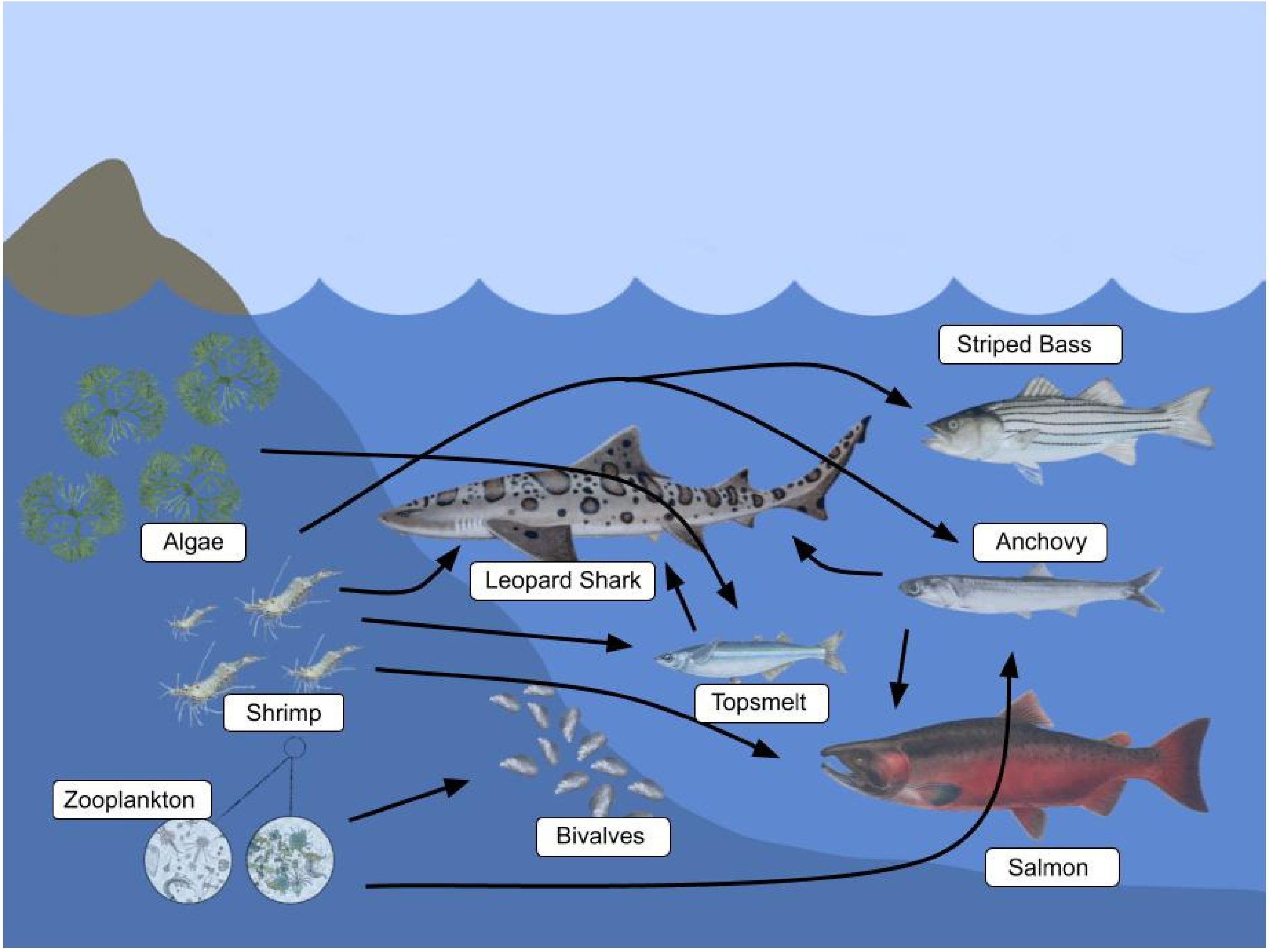

Figure 4.2-1: Food web with common San Francisco Bay species.

The Chinook salmon population in the Pacific has decreased substantially due to harvest and habitat loss, but usually feed on insects and crustaceans in their early year(s), while older salmon eat smaller fish. Both striped bass and Chinook salmon are anadromous, migrating from the ocean through the Bay to the freshwater delta and rivers to spawn, making the conditions of the San Francisco Bay ecosystem important for restoring Pacific salmon populations (Mooi et al., 2007).

As research on microplastics in marine ecosystems and its possible effects increases, it is important to note the varying conclusions of these new studies. More research is needed to make a definitive conclusion on trends, especially because of the many differing factors, like location, method of microplastic measuring, etc. With the following research, consider this disclaimer.

Bivalves

Because of the status of bivalves as filter feeders, bivalves have been proposed to be a bioindicator of microplastic pollution in marine ecosystems. However, in a March 2020 study, researchers found that the selective uptake of bivalves may not be representative of all the microplastics present in the ecosystem, as bivalves take in particles based on their size and shape. Bivalves take in a disproportionate amount of fibers (98% of the particles researchers found) compared to fragments and films, and typically do not absorb larger microplastic fragments (Miller et. al 2020).

In analyzing the particles in bivalve tissue, researchers compared San Francisco Bay specimens of California Mussels (M. californianus) with samples from Bodega Head, an area less affected by the urban environment. Samples from Bodega Head averaged 0.18–0.29 plastic fibers per individual, while samples from the San Francisco Bay averaged 0.87–1.38 plastic fibers per individual. The San Francisco Bay results from this study were on par with worldwide data on microplastics in bivalves, but researchers indicated that their microplastic data from the samples are likely to be conservative numbers. Though this report indicates bivalves are not representative of the total microplastic concentration in the Bay, it confirms that the urban center of the Bay Area is certainly a contributing factor to the microparticle pollution in marine habitats (Miller et. al 2020).

In a study by Sussarellu et al. (2016), researchers exposed economically important adult Pacific oysters (Crassostrea gigas) to virgin polystyrene microplastics for 2 months during a reproductive cycle, looking at various ecophysiological parameters. They found that the oysters preferentially ingested 6- µm micro-PS over 2- µm; both sizes were found in the stomach and intestine, but there were no signs of cellular inflammatory features. A large part of their research was done on the reproductive effects: after the 2 month cycle, they found that exposed female oysters had decreased numbers of oocytes and oocyte diameter, while sperm velocity in exposed males decreased. D-larval yield was “estimated after making crosses by mixing oocytes collected from exposed and control females with control spermatozoa” and results show that there was a decrease in yield and slower larval development of offspring (Sussarellu et al., 2016).

Figure 4.2-2: California mussels (M. californianus), a common bivalve in the Bay Area.

Salmon

A study from Seattle found that the main culprit to the increased mortality of Coho salmon populations in the U.S. Pacific Northwest is 6PPD-quinone, a toxicant that protects tires from ozone (Tian et al., 2020). 6PPD-quinone can leach out of tire rubber as the particles enter stormwater that have been washed from pavement by rain, and even small doses of the chemical proved to be lethal to salmon in the study by Tian et al. (2020). San Francisco Estuary Institute (SFEI) researchers who also co-authored the Seattle study, Sutton and Gilbreath (2020), found that out of nine samples from streams and storm drains after a storm in the Bay, four had levels that would cause half the salmon to die after a few hours in the lab. Although Coho salmon are not found in the San Francisco Bay, species like the steelhead trout and Chinook salmon may be similarly sensitive to 6PPD-quinone. This continues to be a concern, since almost half of the seven trillion microplastic particles in urban stormwater could be from tire wear particles (Sutton & Gilbreath, 2020).

Prey Fish

As microplastics drift through the ocean, transported through various currents and water columns, they enter the organisms that make up our marine ecosystems. Microplastics tend to work their way up the food chain, accumulating in the guts of aquatic organisms. As prey fish are typically consumed whole, compared to human consumption, there is a higher risk for microplastic build up in larger predators (Smith et al., 2018). Researchers from the San Francisco Estuary Institute (SFEI) identified two types of prey fish — northern anchovy (Engraulis mordax) and topsmelt (Atherinops affinis) — that constitute the diets of

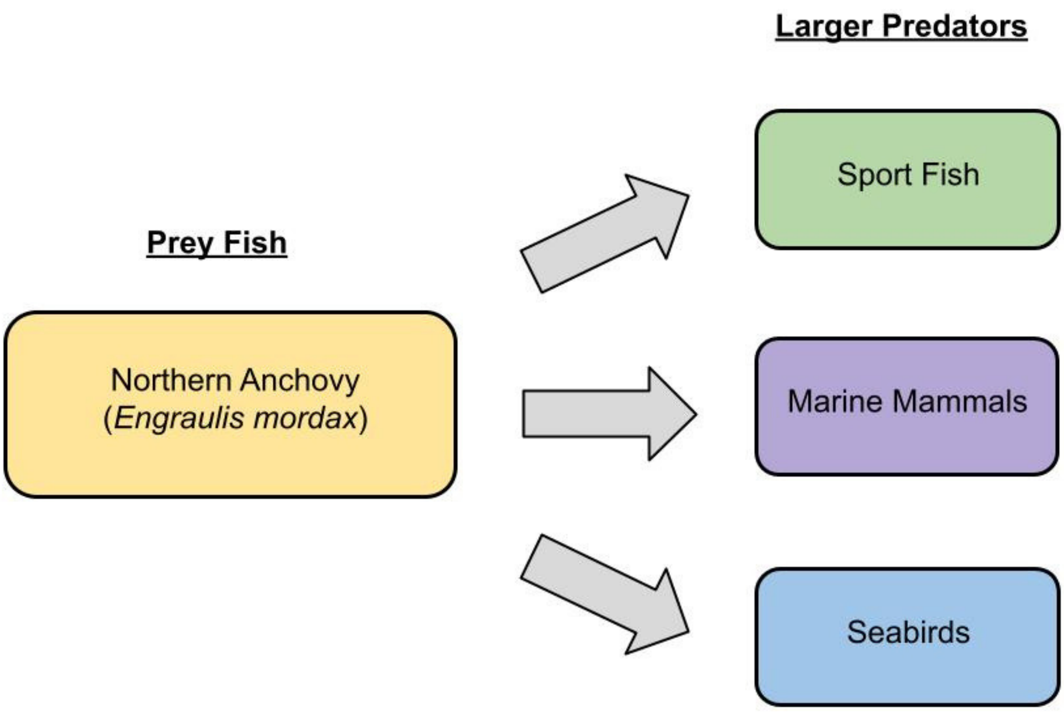

Figure 4.2-3: Food chain for the Northern Anchovy (Engraulis mordax).

numerous larger predators, such as sport fish, marine mammals, and seabirds (**Figure 4.2-3**). These two species were utilized to gain a bigger picture on how microplastics affect marine life in the San Francisco Bay. Selected samples from the Bay Area (more prone to pollution from stormwater and wastewater) were compared with a control reference area in Tomales Bay, an area with less urban pollution.

SFEI researchers found that fish collected from areas closer to the San Francisco Bay, compared to Tomales Bay, had higher levels of microplastics through analysis of fish guts. 38% of the fish samples from the San Francisco Bay had microplastics within their tissue. Within those samples, 86% were fibers, 11% were fragments, and 3% were films. 16% of the fragments and 6% of the fibers were smaller than 150 micrometers, a size of particle that is able to translocate to other tissues in the body besides the gut, theoretically resulting in bioaccumulation and exposing larger organisms that prey upon these species (Sutton et al., 2019). However, though bioaccumulation is a well-accepted hypothesis, more field and laboratory data is required to support this idea of bioaccumulation across the food web (Miller et al., 2020). We recommend more research be conducted on the guts and tissues of larger predators to determine to what extent microplastics are transferred from varying trophic levels.

SEA LIFE HEALTH PROBLEMS

As demonstrated in the preceding species-specific research, scientists have been finding microplastics in marine life, as well as the multitude of health problems imposed by them. Various marine biota ingest microplastics — either intentionally consuming and confusing it with prey or unintentionally through a lower-trophic organism that has ingested it. Once microplastics are ingested by sea life, the modes of impact can be physical (from the inflammation the particle could cause or

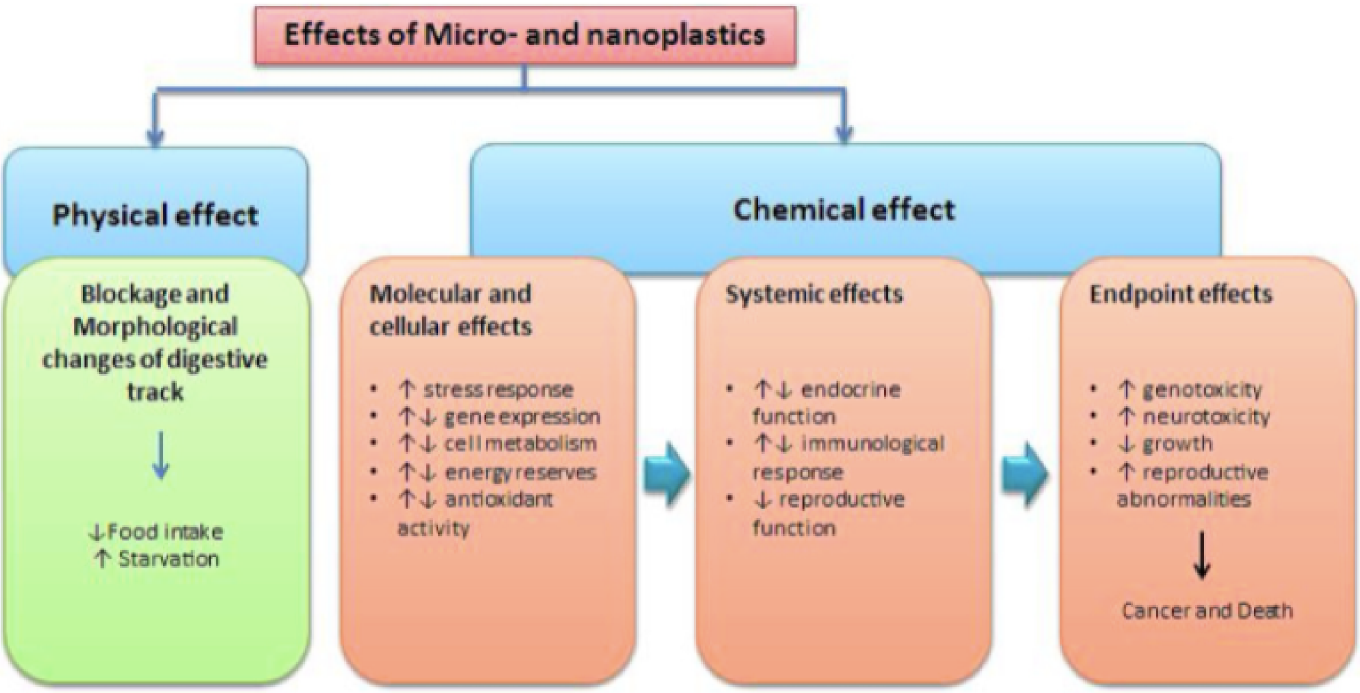

Figure 4.2-4: Adverse effects of microplastic on marine animal health. (Pirsaheb et al., 2020)

possible translocation between organs) and/or chemical (due to the additives from the plastics' manufacturing or pollutants that may have leached into degrading plastic).

As regularly revealed in macroplastics research, microplastics can also cause starvation by blocking food from moving through the digestive system and inducing a pseudo-satiety sensation. These problems continue to escalate with physiological stress, a decrease in fertility, and increase in mortality (Cole et al., 2015; Ryan, 1987; Van Franeker, 1985; Welden and Cowie, 2016; Wright et al., 2013, as cited in Pirsaheb et al., 2020).

Once consumed, microplastics can accumulate in organs, translocate between tissues, or are excreted. Translocation of microplastics would mean the movement of particles from the digestive track to other parts of the organism, causing the possibility of bioaccumulation. Through fluorescence microscopy and histological examination, there is evidence of microplastic translocation in humans, rodents, and mussels (Browne et al., 2008, as cited in Pirsaheb et al., 2020).

Accumulation of microplastics in intestines have been linked to inflammation, metabolic disorder, and possible gut microbiota dysbiosis. The gut microbiota consists of all the microorganisms, like bacteria, fungi, and archaea, in the digestive system of organisms that help the host body carry out various physiological and biochemical functions. This complex system helps the host maintain its ability for development and normal activity, making it sensitive to any dysbiosis or imbalance in its composition. Studies have shown how foreign compounds, such as heavy metals, persistent pollutants, antibiotics, and pesticides, could alter the microbiota's structure, causing physiological dysfunction, making the host more vulnerable to diseases, and decreasing their fitness (Lu et al., 2019; Carding et al., 2015; DeGruttola et al., 2016, as cited in Pirsaheb et al., 2020). Although research on the effects of the chemicals in microplastics on gut microorganisms is limited, other studies have shown plastic-induced scratches in the intestine (Grigorakis et al., 2017; Lu et al., 2016; Vendel et al., 2017, as cited in Pirsaheb et al., 2020). Experimental studies of zebrafish and larval fish that were exposed to polystyrene microplastics showed gut inflammation and metabolism disorder, possibly altering gut microbiota by increasing the amount of a certain bacteria known to cause disease in some fish species (Jin et al., 2018b; Wan et al., 2019; Rawls et al., 2006, as cited in Pirsaheb et al., 2020). In addition, Qiao et al. (2019b) found a reduction in gut microbiota diversity and changes in intestinal permeability, as a result of prolonged gut inflammation and elevated oxidative stress.

Continuing with the inflammation, experimental studies show evidence of inflammation from microplastics, but the varying factors of plastics (i.e., size, shape, type, additives, etc.) can affect organisms in different ways. Although the microplastics found in digestive tracts have been mixed in its roughness and shape, it has been found that spherical shapes cause less injury and reduced reaction to the gut than the irregular shapes that result from weathering and fragmentation (Mazurais et al., 2015, as cited in Pirsaheb et al., 2020). Research in this area often uses polystyrene (PS) for its high demand in industry and zebrafish for its genetic similarity to humans (Pirsaheb et al., 2020). A study by Jin et al. (2018) that exposed zebrafish to different sizes of PS resulted in staining of the gut from an increase in mucus, giving evidence for changes in microbiota diversity through decreases and increases of particular bacteria. Similarly, in the order of most to least, fibers, fragments, and then spherical beads accumulate in the gut pathway, as fibers with larger aspect ratios get embedded in tissue more than fragments and beads (Qiao et al., 2019a, as cited in Pirsaheb et al., 2020). Vacuolization and cilia defects in gut mucosa, as a result of microplastic fibers in the gut, is thought to have been caused by the fibers' rougher surfaces (Qiao et al., 2019a, as cited in Pirsaheb et al., 2020).

The toxic compounds that are added to or seep into microplastics from the environment inflicts adverse effects on organisms that ingest them. Chemical additives, persistent organic pollutants, pesticides, pathogens, and others can cause lower immune response, oxidative stress, cancer, decrease fertility, and increase mortality (Aliko et al., 2018; Blahova et al., 2020; Pagano et al., 2017; Qyli et al., 2020; Vajargah et al., 2020, as cited by Pirsaheb et al., 2020). If able to bioaccumulate, the particle and pollutants could be transferred up the food chain, possibly causing problems for humans as well (Van Cauwenberghe and Janssen, 2014; Wright et al., 2013; Yang et al., 2015, as cited by Pirsaheb et al., 2020).

As research into the health impacts by microplastics to marine life increases, similar questions ensue for possible effects on human health. The wide range of health problems on sea life are problems we may see for humans as well.

IMPACTS ON HUMAN HEALTH

IMPLICATIONS OF MICROPLASTICS IN THE HUMAN BODY

While it is known that microplastics can cause a variety of human health effects, it is still unknown whether the microplastic particle, chemicals that are absorbed by the plastics, or some interaction of the particle and the chemical that causes these effects. Some researchers have stated that microplastic particles have the ability to accumulate PCBs and other toxic chemicals that can have several damaging health effects when in contact with tissues. This includes cancer, weakened immunity, and endocrine disruption. On the other hand, based off of studies done on plastics, it is known that larger pieces of plastic consumed can block digestive tracts. Plastics in our digestive tract can reduce our desire to eat, and alter feeding behavior as a whole. In some animal species, it has been shown that if their stomachs are filled with plastics, they may feel full, but will starve to death (Reports 2019). These conclusions are further limited by the fact that studies have primarily involved mice and other organisms and only certain types of particles have been studied so far.

There are three known mechanisms in which microplastics enter into our bodies. There's ingestion where microplastics simply enter our bodies as we consume food or drink. Next, there's inhalation which is when we breathe in something like aerosols, fertilizers, or dust which contain microplastics. There's also the mechanism of skin contact where microplastic particles can enter our bodies through an area of skin that has a weaker skin barrier or wound.

As far as research goes, the most understood mechanism is inhalation which can be described in three main parts: deposition, clearance, and inflammation/cancer. Deposition occurs after inhalation when the upper airways endure impaction due to the microplastics collision in the walls of the throat. The next step is clearance where the mucous helps to carry microplastic particles, exposing itself to the digestive system. Then once these microplastics have accumulated in our bodies, it can cause some serious health effects. These effects are mainly attributable to inflammation caused by the microplastic particles. If there is an over-accumulation of dust particles, this can cause serious damage to the respiratory system. Furthermore, the irritation and inflammation caused by the microplastics may result in more serious effects such as the promotion of cancer due to damages in the DNA.

In general, during this process, the microplastic particles move down our respiratory tract which could eventually lead to dust overload or oxidative stress and toxicity which can then lead to inflammation (Prata 2018).

While the human excretory system eliminates over 90% of the ingested microplastics and nanoplastics consumed through food (as explained previously), the results are dependent on the size, shape, density, and chemicals in these plastics. Prior studies on mice can provide a basic understanding of the possible effects. One such study found using fluorescence spectrometer measurements of lyophilized tissues that certain microplastics (depending on particle size) accumulated in three main tissues of mice: liver, gut, and kidney. Changes to chemical biomarkers in mice were also recorded, identifying changes in energy metabolism and lipid metabolism (Deng et al. 2017).

In another experiment, pregnant mice exposed to the microplastics suffered from problems with their gut microbiome and metabolic disorders. These effects seemed to appear in the F1 and F2 generations as well, indicating that these adverse outcome pathways may also have impacts on offspring and future generations (Yee et al. 2021). While this may provide a blanket understanding of the toxic effects of microplastic accumulation over time, it cannot be used to determine the specific and the extent of the effects of microplastics on humans.

Polystyrene nanoparticles, of the size 50 nm and smaller, were demonstrated to be a potential risk to the human respiratory system (Xu et al. 2019). The effects of polystyrene nanoparticles from the atmosphere in the alveolar epithelial cell were toxic based on the duration of exposure, diameter of particle, and concentration. These nanoparticles can also enter the bloodstream because of the thin tissue barrier of the human lung. These particles were shown to be toxic to cells and can also damage genetic information, which could possibly lead to cancer (i.e. pulmonary cancer).

U.S. government scientists express caution towards polystyrene because it's "reasonably anticipated to be a human carcinogen", or having the potential to cause cancer. While one study showed no evidence of increased cancer risk from workers in nylon flock plants who've had increased exposure to synthetic fibers, the workers did have more respiratory irritations (like asthma) (Wright, 2017). However, that does not necessarily mean to disregard its effects. Research on the absorption of microplastics/nanoplastics on the human body and its specific organs/tissues is still being tested.

Other chemicals in microplastics, such as phthalates and bisphenol A, can have toxic effects on reproductive health. BPA mimics estrogen by bonding to estrogen receptors and exposure to BPA can cause liver function changes and insulin resistance, a factor that contributes to development of diabetes, obesity, and heart disease (Yee et al. 2021). Phthalate esters like BBP and DEHP also disrupt hormonal activity and can increase the risk of tumors (Yee et al. 2021).

Research on microplastics and their effects on human health are not very extensive. As a result, most people are unaware of the toxic effects of microplastics. Awareness campaigns, such as those explaining the cardiovascular or neurological effects of microplastics, could possibly contribute to the public's knowledge of microplastics. In addition, drinking water treatment processes should be assessed to determine whether they can remove microplastics. Research should also be taken to understand the extent to which chemicals in microplastics can have toxic effects on neurological systems (especially considering children who are exposed to bisphenol A and/or ortho-phthalates have been linked to inhibited brain development and risk for learning disabilities and behavioral disorders) (Engel et al. 2021).

CAL DINING SEAFOOD CONSUMPTION

The Cal Dining order information provides more information on the exposure levels of Berkeley students. The fish ordered the most was crab cakes and there were relatively little scallops ordered. Based on preliminary studies, molluscs (including bivalves like scallops) appear to have up to 40 times the microplastics concentrations found in fish with 50th and 95th percentiles of 8.07 particles/g TWW and 428.4 particles/g TWW compared to 0.18 particles/g BWW, median overall concentration for microplastics within fish muscle (Mohamed Hur 2021). Both crustaceans and molluscs may also be more predisposed to microplastic exposure due to their feeding habits of filter feeding and consumption of floating food sources. Compared to pelagic fish such as salmon, pollock, tuna, and cod, molluscs and crustaceans such as shrimp, crab, and bivalves may have more microplastics (Mohamed Hur 2021).

Due to limited research about microplastic concentrations in specific fish species and variance in these concentrations in different areas as well as variance in student eating habits, it is difficult to come up with numerical exposure estimates based on this data. In order to come up with more accurate evaluations of the average number of microplastics consumed by Berkeley students, we conducted a survey.

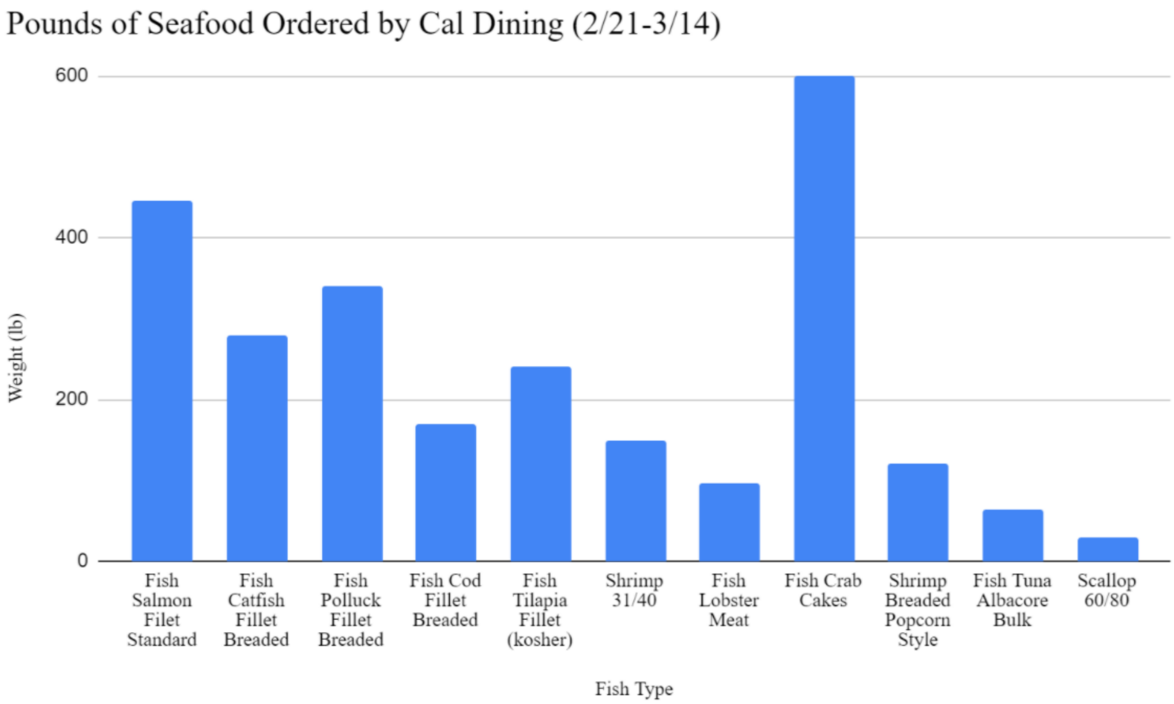

Figure 5.1-1. Pounds of fish ordered by Cal Dining (2/21/2021-3/14/2021).

BERKELEY SURVEY AND RESULTS

We conducted a survey with Berkeley community members to examine how much microplastic they are consuming on a day to day basis. The survey was distributed by members of our team through social media and in group chats for various classes. All respondents responded voluntarily. Our survey included 59 respondents and they were not required to answer all questions. All respondents were between the ages of 17-23. Out of the 59 respondents, 36 were in the College of Letters & Sciences, 17 were in the College of Natural Resources, 3 were in the College of Environmental Design, and 1 each in the College of Chemistry, College of Engineering, and other. Histograms of the data from each survey question was created. The 50th percentile (median) and 95th percentile values were found to show who is exposed to various toxicants "on average" and "in rare circumstances." These percentiles were compared to global median and 95th percentile values in cases where global values were available. The paper that was referenced for global consumption values was from the journal “Lifetime Accumulation of Microplastic in Children and Adults” by Mohamed Nor et al 2021.

To see if our survey data values were far off from global normal values, we asked a survey question regarding students’ consumption of sugar over the course of two days. The results are displayed in a histogram (**Figure 5.2-1**). The large majority of our survey respondents consumed between 17.5-20 grams+ grams of sugar per day. According to the American Health Association, American adults consume 77 grams per sugar a day and the suggested intake is 25-36 grams per day. The disparity between these numbers should be taken into consideration for this section.

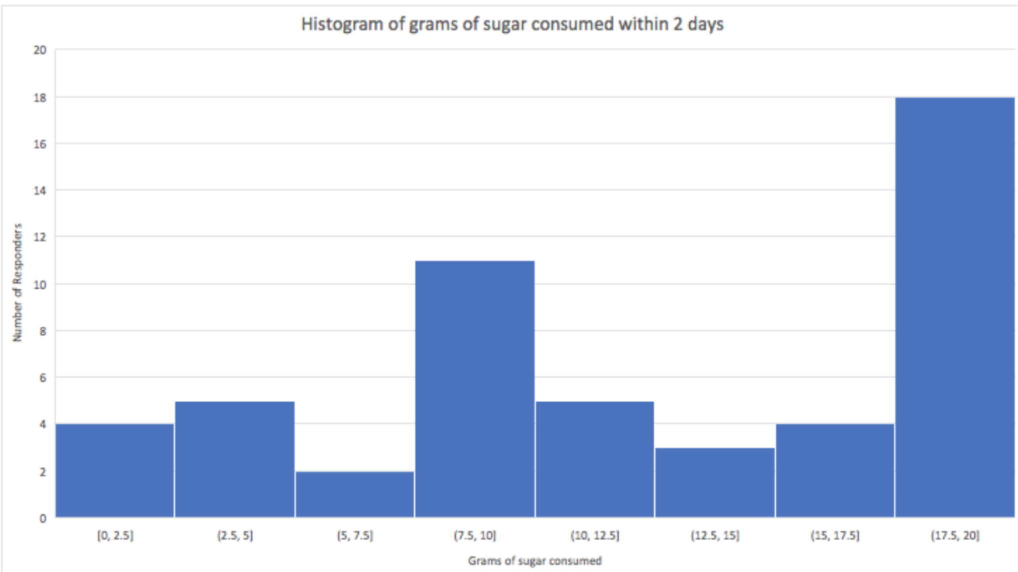

Figure 5.2-1: Histogram of grams of sugar consumed within 2 days by Berkeley students Note: survey answer of 20 or more was shortened to 20. (thus, 20 grams is the largest number of grams in this chart)

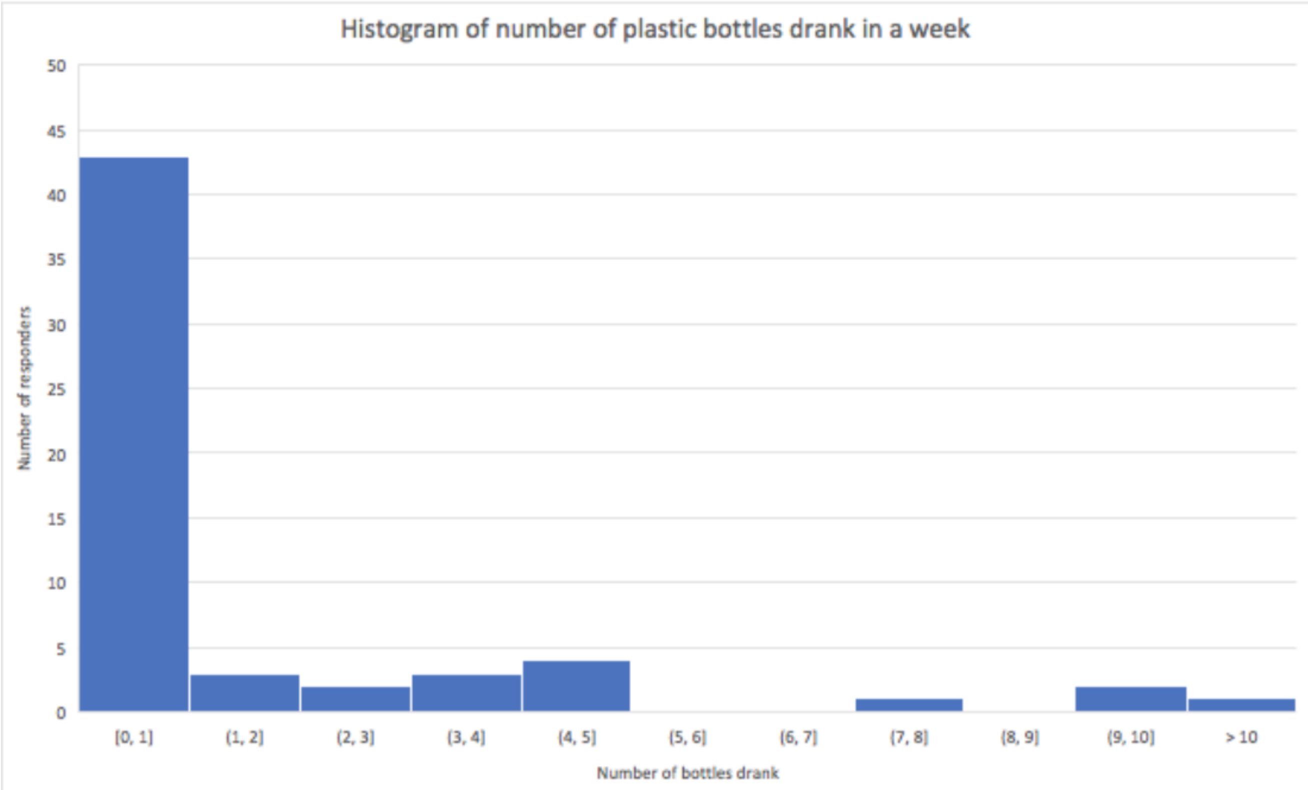

Figure 5.2-2: Histogram of plastic bottles used in week by Berkeley students

The median value was 0 plastic bottles a week (0 g/capita-day) and the 95th percentile was 9 bottles per week, equivalent to 1.286 bottles per day (643 g/capita-day). Compared to the global median and 95th percentile (Mohamed Nor et al 2021), Berkeley students median consumption of plastic bottles is lower than that of the global median value (37.154 g/capita-day) and Berkeley students 95th percentile values were higher than that of the global 95th percentile (436.516 g/capita-day).

The median percent difference was 100%, meaning that Berkeley students' median is distinct from the global median. The 95th percentile percent difference was 47.3%, meaning that Berkeley students' 95th percentile is distinct from the global 95th percentile value. In regards to concentrations of microplastics consumed, the median particle concentration is 338 particles/L and the 95th percentile particle concentration is 9,332 particles/L (Mohamed Nor et al 2021). This means that Berkeley students at the 50th percentile are consuming 0 microplastics per day from plastic bottles and Berkeley students at the 95th percentile are consuming about 6,000.48 particles per day from plastic bottles.

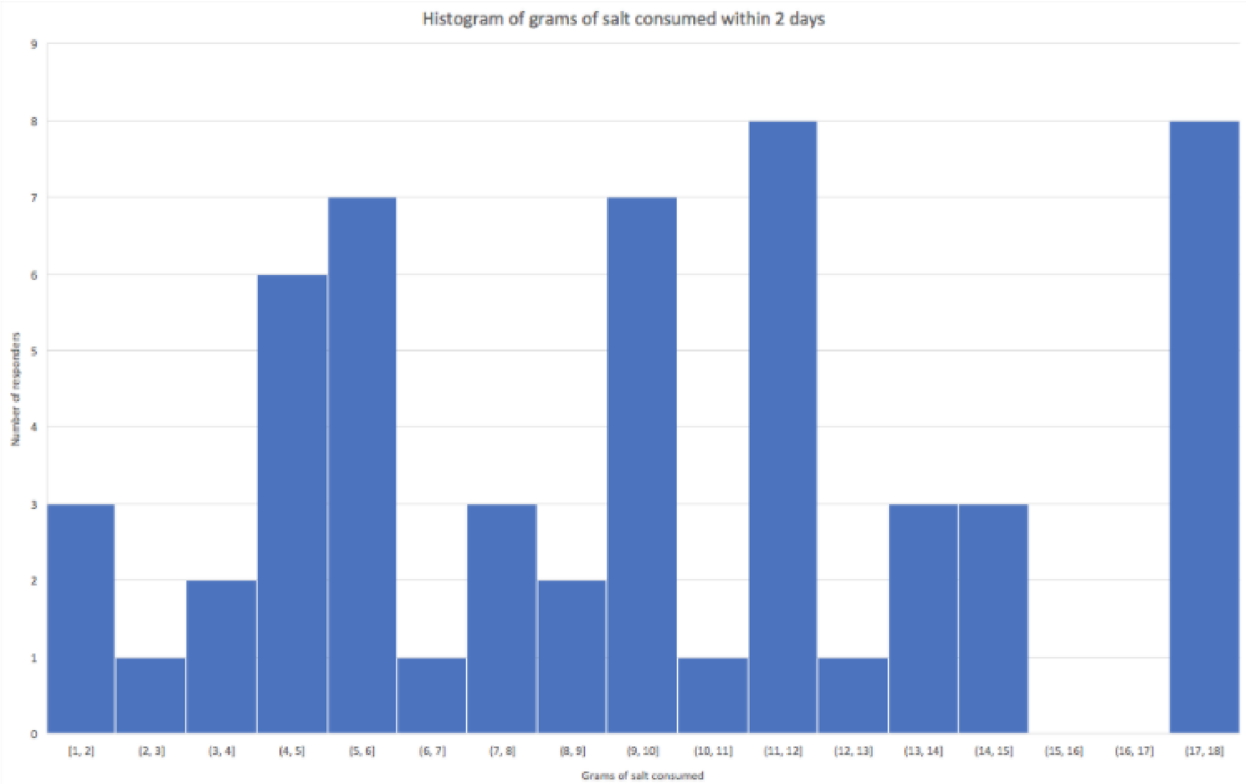

Figure 5.2-3: Histogram of grams of salt consumed within 2 days by Berkeley students
(Note: survey choice of 18 or more was shortened to 18; thus, 18 grams is the largest number of grams.)

The median value reported was 10 grams of salt in 2 days (5 g/capita-day) and the 95th percentile was 18 grams of salt in 2 days (9 g/capita-day). Compared to the global median and 95th percentile (Mohamed Nor et al 2021), Berkeley students had a much higher median than the global median (0.57 g/capita-day). Berkeley students had a higher 95th percentile value, but closer than the median, than the global 95th percentile (7.25 g/capita-day).

The median percent difference was 88.6%, meaning that Berkeley students' median is distinct from the global median. The 95th percentile percent difference was 19.44%, meaning that Berkeley students' 95th percentile is distinct from the global 95th percentile value.

In regards to concentrations of microplastics consumed, the median particle concentration is 1,288.25 particles/kg and the 95th percentile particle concentration is 120,226 particles/kg (Mohamed Nor et al 2021). This means that Berkeley students at the 50th percentile are consuming 6.44 particles per day from salt and Berkeley students at the 95th percentile are consuming about 1082.03 particles per day from salt.

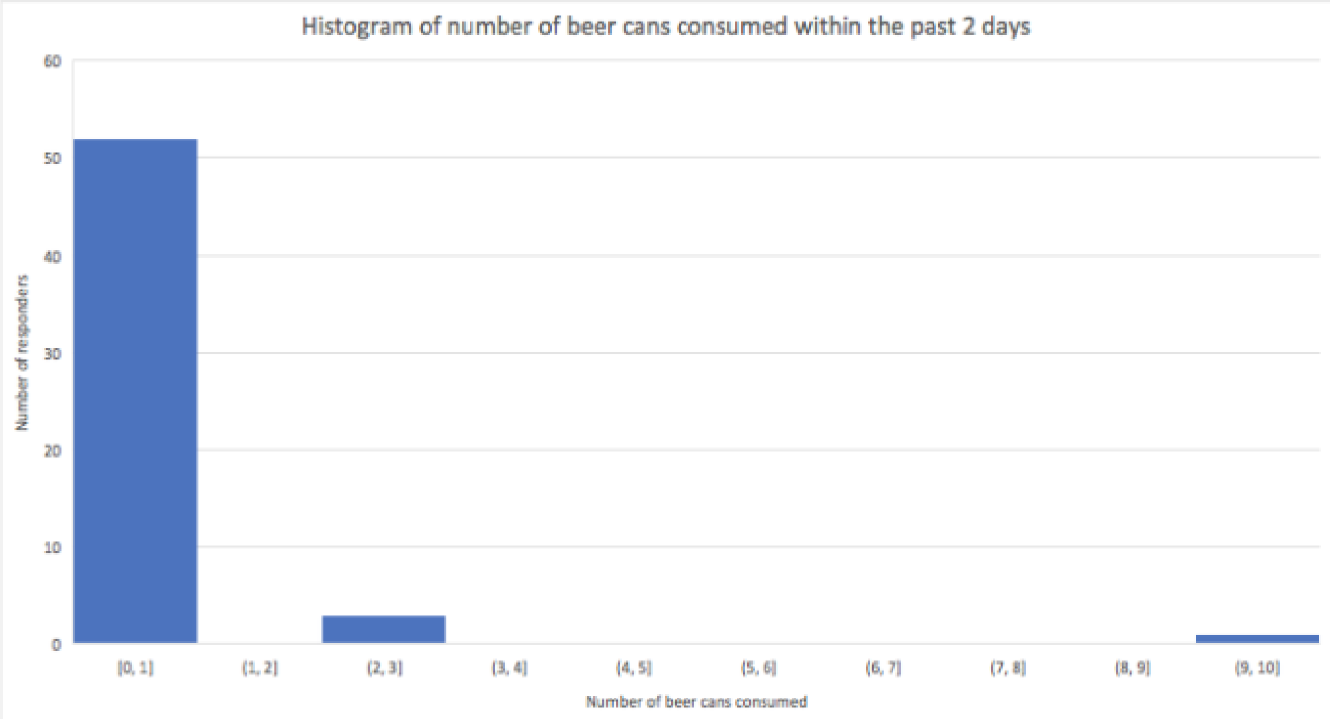

Figure 5.2-4: Histogram of beer cans consumed by Berkeley students within the past 2 days

The median value reported was 0 cans in 2 days (0 g/capita-day) and the 95th percentile reported was 3 cans in 2 days, equivalent to 1.5 cans in 1 day (519 g/capita-day). Compared to the global median and 95th percentile (Mohamed Nor et al 2021), Berkeley students had a lower median than the global median (16.6 g/capita-day) and Berkeley students had a higher 95th percentile compared to the global 95th percentile (161.7 g/capita-day).

The median percent difference was 100%, meaning that Berkeley students' median is distinct from the global median. The 95th percentile percent difference was 68.84%, meaning that Berkeley students' 95th percentile is distinct from the global 95th percentile value.

In regards to concentrations of microplastics consumed, the median particle concentration is 131.83 particles/L and the 95th percentile particle concentration is 3,548.13 particles/L (Mohamed Nor et al 2021). This means that Berkeley students at the 50th percentile are consuming 0 microplastics per day from beer and Berkeley students at the 95th percentile are consuming about 573.73 particles per day from beer.

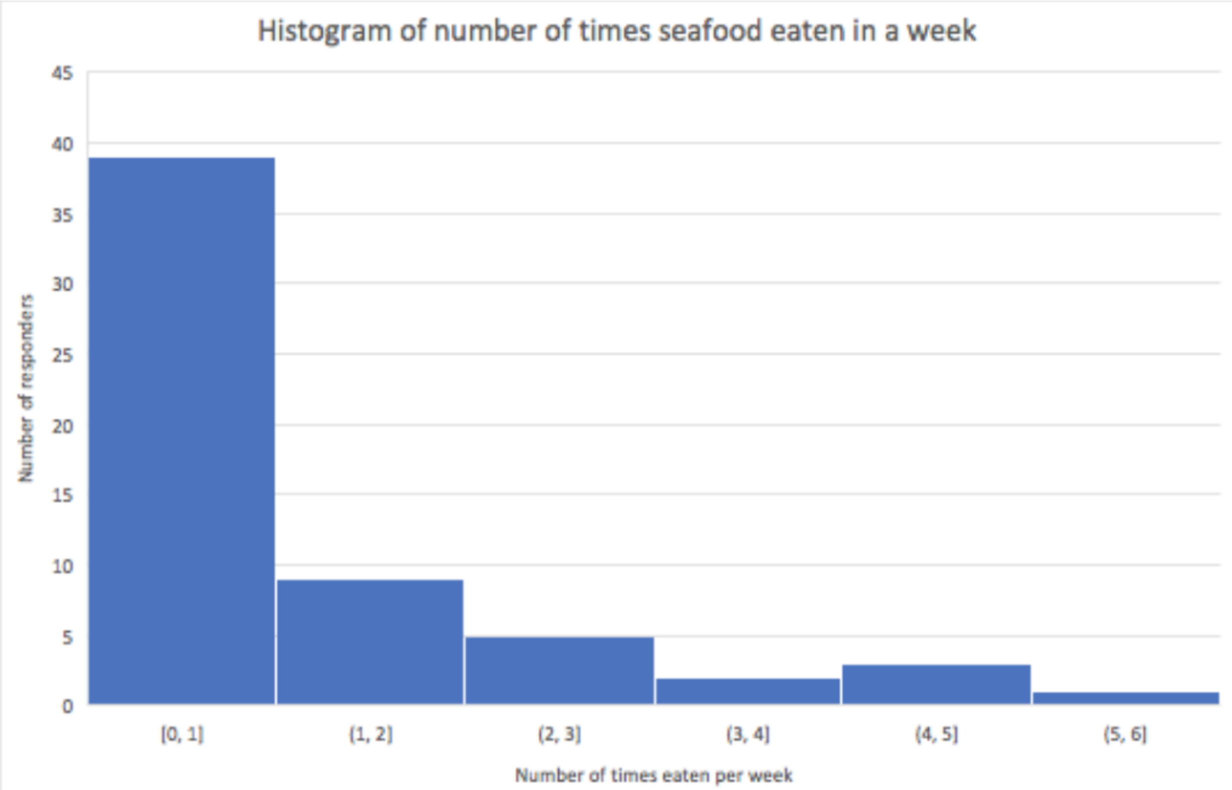

Figure 5.2-5: Histogram of weekly seafood consumption by Berkeley students
Note: seafood values from Mohamed Nor et al 2021 used for comparison were taken as an average of the data from fish, mollusc, and crustaceans.

For Berkeley student consumption estimation purposes, 3.5 ounces (99.2233 grams) of cooked fish was used as an approximation for a one time consumption amount (3.5 ounces is considered one single serving by the American Heart Association).

The median value reported was consumption of seafood 1 time per week (14.175 g/capita-day) and the 95th percentile value reported was 5 times per week (70.874 g/capita-day). Compared to the global median and 95th percentile (Mohamed Nor et al 2021), Berkeley students had a higher median than the global median (2.12 g/capita-day) and Berkeley students had a higher 95th percentile compared to the global 95th percentile (7.46 g/capita-day).

The median percent difference was 85.04%, meaning Berkeley students' consumption values and global consumption values are distinct and the 95th percentile difference was 89.47%, meaning Berkeley students' consumption values and global consumption values are distinct.

In regards to concentrations of microplastics consumed, the median particle concentration is 3.571 particles/g and the 95th percentile particle concentration is 205.688 particles/g (Mohamed Nor et al 2021). This means that Berkeley students at the 50th percentile are consuming about 50.619 microplastics per day from seafood and Berkeley students at the 95th percentile are consuming about 14,577.931 particles per day from seafood.

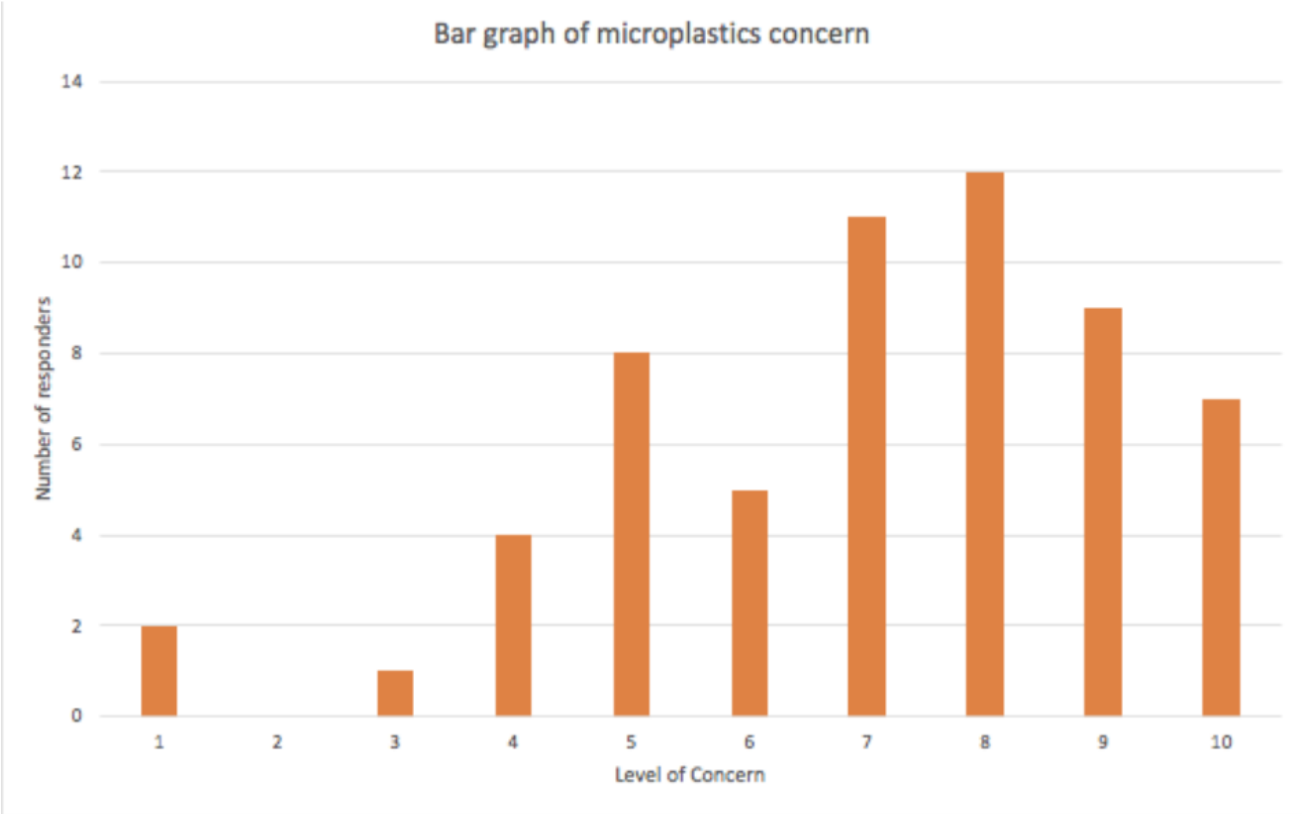

Figure 5.2-6: Bar graph of Berkeley students' concern over microplastics

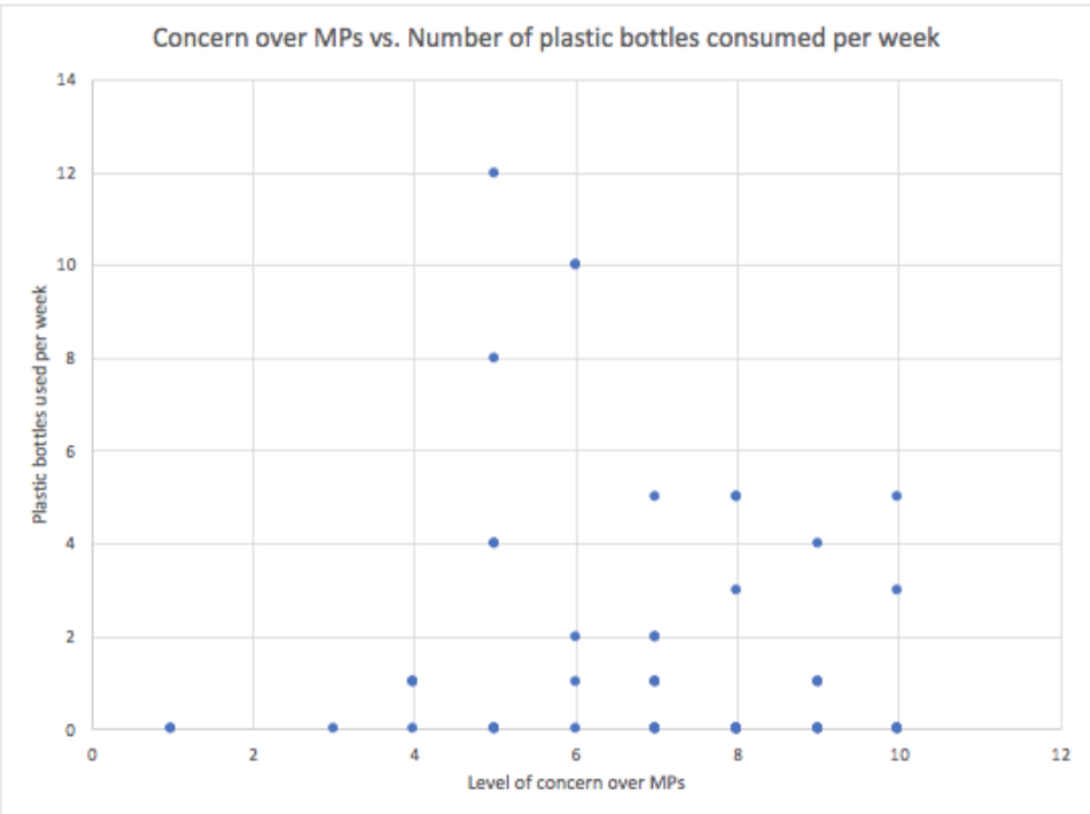

Figure 5.2-7: Scatterplot of students' concern over microplastics vs. weekly plastic bottle consumption

We wanted to test whether a respondent's concern over microplastics (**Figure 5.2-6**) was related to one's consumption of water bottles. We plotted a scatterplot of the two data sets (**Figure 5.2-7**). From the linear regression run between the respondents' level of concern over MP's and their plastic bottle usage per week, it was found that the R2 value was 0.0239 and the calculated p-value was 0.246, which is greater than the alpha significance level; thus, the relationship between the variables is not statistically significant.

CONCLUSIONS FROM THE DATA

The results of our survey showed that on average, Berkeley students consume about 57.059 microplastic particles per day from beer, plastic bottled beverages, salt, and seafood. At the 95th percentile, or in rare circumstances, Berkeley students consume about 22,234.171 microplastic particles per day from beer, plastic bottle beverages, salt, and seafood. In any case, these values could vary significantly between different types of students and even between different days for the same student. It is important to note that respondents self reported all values, creating a large margin of error for each possible question.

In comparison to global values, Berkeley students' consumption and intake of microplastics through different media are distinctly different for all measured factors, including seafood, plastic drink bottles, salt, and beer. These differences occurred in 2 ways: Berkeley students consumed more than the global average and Berkeley students consumed less than the global average.

There are many possible explanations for the big differences between Berkeley students' consumption and global consumption. On average, Berkeley students used less plastic bottles per week; this could possibly be explained by a greater amount of awareness around the topic of reducing plastic consumption. On the other hand, this could also be explained by plastic bottles being more expensive for college students than filling a reusable bottle with tap water. As noted in Figure 5.2-7, there was no statistical significance between the number of plastic bottles consumed per week and the concern over microplastics by the student. This could show that perhaps plastic consumption varies between different people for different reasons and there is no one reason to explain all disparities. For example, some groups of people are dependent on bottled water as their main source of drinking water. A further look into how environmental justice plays a role in microplastic consumption in different communities is necessary.

IN RELATION TO ENVIRONMENTAL JUSTICE

TAP WATER VERSUS BOTTLED WATER

In a 2018 study on bottled water microplastic contamination, 93% of the 259 total bottles processed showed some sign of microplastic contamination (Mason et al. 2018). For the brand Gerolsteiner, two samples were tested. One was in a glass bottle and the other was in a plastic bottle. Even though they were taken from the same water source, the water in the plastic bottle had significantly more microplastic contamination (204 vs. 1,410 MPP/L, respectively). This suggests that the packaging process has a significant impact on microplastic concentrations in bottled water.

			Average microplastic densities (MPP/L)				
			NR + FTIR confirmed particles	NR tagged particles	Total		
Brand	Lot	Purchase location	(>100 um)	(6.5–100 um)	Average	Minimum	Maximum
Aqua	IB 101119	Jakarta, Indonesia	6.68	30.4	37.1	3	133
Aqua	BB 311019 08:11 PSRL6	Bali, Indonesia	10.5	695	705	1	4,713
Aqua	BB 311019 09:50 STB1	Medan, Indonesia	6.93	397	404	0	3,722
Aquafina	Oct0719 0121PF100375	Amazon.com	14.8	237	252	42	1,295
Aquafina	BN7141A04117	Chennai, India	11.6	162	174	2	404
Bisleri	HE.B.No.229 (BM/AS)	Chennai, India	18.0	808	826	39	5,230
Bisleri	MU.B.No.298 (MS/AD)	Mumbai, India	8.85	204	213	2	1,810
Bisleri	SO.B.No.087 (AS/LB)	New Delhi, India	0.57	3.15	3.72	0	32
Dasani	Oct 0118NHBRB	Amazon.com	14.6	150	165	85	303
Dasani	P18NOV17CG3	Nairobi, Kenya	6.28	68.3	74.6	2	335
E-Pura	17.11.18	Mexico City, Mexico	22.3	664	686	11	2,267
E-Pura	14.10.18	Tijuana, Mexico	7.76	12.2	20.0	3	92
E-Pura	09.08.18	Reynosa, Mexico	0.21	37.1	37.3	0	149
Evian	PRD 03 21 2017 14:02	Amazon.com	26.0	171	197	126	256
Evian	PRD 05 24 17 11:29	Fredonia, NY, USA	1.51	56.7	58.2	0	256
Gerolsteiner	07.142018 2 07.07.2017	Fredonia, NY, USA	14.8	1,396	1,410	11	5,106
Gerolsteiner	NV No. AC-51-07269	Amazon.com	8.96	195	204	9	516

Figure 5.3-1: Microplastic contamination data in bottled water brands.

In another 2018 research study on anthropogenic contamination of tap water, beer, and salt, anthropogenic debris was found in 81% of the 159 samples tested (Kosuth et al. 2018). There were approximately twice as many plastic particles (>100 um) within bottled water as compared to tap water on average (10.4 vs. 5.45 particles/L). It can be suggested that due to contamination during the packaging process, people can be more at risk of microplastic contamination when drinking bottled water compared to tap water. So, which demographics consume more bottled water?

According to data from the National Health and Nutrition Examination Survey published by Cambridge University Press, Non-Hispanic (NH) Black and Hispanic adults had 0.44 (95 % CI 0.37, 0.53) and 0.55 (95 % CI 0.45, 0.66) times the odds of consuming tap water, and consumed less tap water than NH White adults. For NH Black, Hispanic and non-US-born adults, the majority of plain water intake came from bottled water, whereas for NH White, NH Asian, and US-born adults, most plain water came from tap water.

	Drank plain water§		Drank tap water§		Drank bottled water§	
Independent variable‖	OR	95 % CI	OR	95% CI	OR	95% CI
Race/Hispanic origin						
NH White	1·00	Ref.	1·00	Ref.	1·00	Ref.
NH Black	0·94	0·79, 1·10	0·44**	0·37, 0·53	2·20**	1·79, 2·69
NH Asian	1·21	0·88, 1·67	1·01	0·82, 1·26	1·26	0·99, 1·61
Hispanic	1·21	0·97, 1·51	0·55**	0·45, 0·66	2·37**	1·91, 2·94
Nativity status						
US-born	1·00	Ref.	1·00	Ref.	1·00	Ref.
Born outside fifty US states or Washington, DC	1·67**	1·25, 2·21	0·88	0·72, 1·08	1·46**	1·19, 1·79
Education						
Less than high school	1·00	Ref.	1·00	Ref.	1·00	Ref.
High-school graduate/GED or equivalent	1·17	0·94, 1·46	1·26*	1·06, 1·50	0·89	0·75, 1·05
Some college or associates degree	1·71**	1·38, 2·12	1·69**	1·44, 1·98	0·97	0·85, 1·11
College graduate or above	2·63**	2·05, 3·38	2·72**	2·26, 3·28	0·80*	0·66, 0·98
Age						
20–39 years	1·00	Ref.	1·00	Ref.	1·00	Ref.
40–59 years	0·91	0·80, 1·05	0·94	0·83, 1·07	1·02	0·91, 1·14
≥60 years	0·97	0·84, 1·13	1·17	1·03, 1·34	0·78*	0·64, 0·95
Sex						
Male	1·00	Ref.	1·00	Ref.	1·00	Ref.
Female	1·39**	1·17, 1·65	1·03	0·90, 1·17	1·28**	1·11, 1·47
n	9666		9666		9666	

Figure 5.3-2: Consumption data of tap and bottled water for different races and ethnicities.

Bottled water contains microplastics significantly, and while tap water has less microplastic contamination than bottled water, it still has some nonetheless. Lower-income communities are more likely to consume bottled water than tap water, and are more at risk of microplastic contamination, making this an environmental justice issue. Only 5% of non-Hispanic whites perceive their water source to be unsafe, in contrast to over 8% of African Americans and over 16% of Hispanics. While more Hispanic households perceive tap water as unsafe, avoidance of the tap water is higher in African American communities relative to Hispanic communities (Javidi Pierce 2018).

This environmental justice issue creates unequal financial burdens for minorities as they have to find a substitute for tap water. As the data illustrates, bottled water is the most popular substitute for African American and Hispanic households. The negative perception of tap water places significant financial burdens on households. According to data from Dig Deep, a human rights nonprofit, minorities can feel unsafe for a number of reasons.

Disproportional access to clean tap water causes minorities to perceive it as unsafe, and have to purchase bottled water as substitutes. Not only does this create a financial burden for these households, but as research has found, bottled water contains more microplastics on average than tap water. As a result, they are also disproportionately being affected by microplastic contamination.

Race and ethnicity	Perception of tap water as unsafe (%)	Alternative choices among those perceiving the tap to be unsafe (*n* = 2,859)			
		Unfiltered tap water (%)	Filtered tap water (%)	Bottled water (%)	Other (%)
Non-Hispanic White (*n* = 26,407)	5.07 (*n* = 1338)	6.52	33.22	55.33	4.93
Black (*n* = 5,132)	8.48 (*n* = 434)	4.42	14.22	78.63	2.72
Hispanic (*n* = 5,048)	16.39 (*n* = 876)	1.86	22.14	73.78	0.22
Other (*n* = 2,498)	8.43 (*n* = 211)	2.48	38.15	52.91	6.46
Proportion of Total (*n* = 39,085)	7.31 (*n* = 2,859)	4.31	26.72	65.41	3.56

Figure 5.3-3: Perception of tap water and alternate preferences of different races and ethnicities.

Figure 5.3-4: Closing the Water Access Gap in the United States: A National Action Plan Executive Summary reflecting disparities in access to clean water.

THE USAGE OF POLYPROPYLENE INSTANT FEEDING BOTTLES

A 2020 study published in the online journal, Nature Food, found that babies that are fed with formula that is prepared in polypropylene (PP) instant feeding bottles (IFBs) are exposed to greater amounts of microplastic than babies who are breastfed (Li et al. 2020, 746). In a liter of formula prepared in a PP IFB, if following WHO's recommendations for proper sterilization, microplastics exposure can be as much as 16,200,000 particles.

The amount of particles released into the formula increases with high-temperature, sterilization, and preparation (shaking). The researchers found differences in temperature when sanitizing the IFBs was the biggest determinant of the number of particles released into the formula. They tested the IFBs at different temperatures, filling them with water and shaking them at 25°C, 70°C and 95°C. At 25°C, 600,000 particles / liter was released into the solution; at 70°C, which is the WHO's recommended temperature for correct sterilization, 16.2 million particles / liter was released into the solution; and at 95°C, 55 million particles / liter, was released into the solution. The researchers continued testing the bottles daily for three weeks, finding that the IFBs continued to release microplastics at similar rates even with repeated sterilization (Li et al. 2020, 750).

The study surveyed 48 regions to find the amount of microplastics babies are exposed to at 12 months old. The values ranged from 14,600 to 4,550,000 particles per day; these findings show a greater spread than earlier anticipated, also having greater values than previously recognised. Infants in richer countries / areas are less likely to be breastfed, and consequently will have a greater exposure to MPs. In Figure 5.3-5, we see the daily MP exposure at 12 months plotted against the local breastfeeding rates. Breastfeeding rates at 12 months for Americans fell at 35.3%, and in California this number is 43.3%, both numbers significantly lower than the world average of 74% per year (CDC 2020).

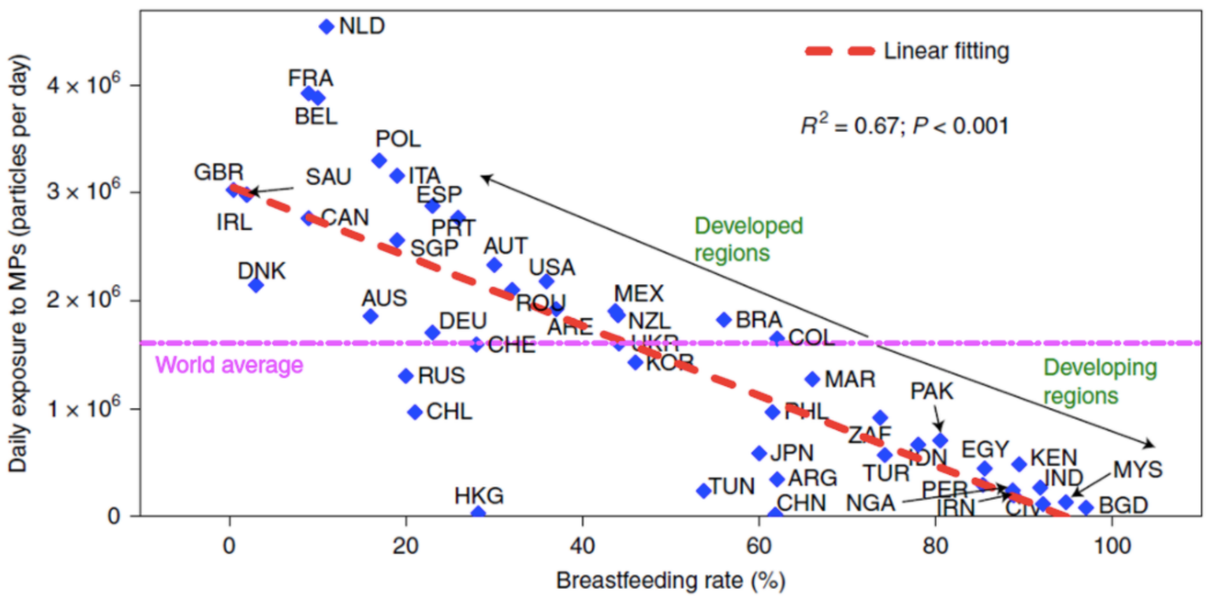

Figure 5.3-5: Plot of daily MP exposure for 12 month old babies vs. local breastfeeding rate

CONCLUSION

Microplastics are a large anthropogenic problem that requires a two-pronged approach. Much of the real effects of microplastics are largely unknown, as a lot of the vital research in the scientific community is still ongoing. In the meantime, we can focus our efforts on reducing the upstream problems of plastic usage in order to prevent microplastics, the downstream product, from affecting the health of local sea life and vulnerable communities. As much of our research reveals, microplastics must be addressed through the implementation of a robust management plan that includes increasing awareness within the public, particularly within groups that are vulnerable to the effects of microplastics.

Currently, Much of the conversation around solving the plastic pollution problem relies on the idea of bioplastics, plastics that microbes are able to fully break down and be released into the environment without adverse effects (Shen et al. 2020). These bioplastics are either completely biodegradable and made of polymers like cellulose or starch or are a hybrid of a natural polymer and a synthetic polymer.

However, while bioplastics may be helpful in the transition from single-use plastic culture, they face many of the same problems that plague typical plastics. For example, as they break down, they can also fragment into small pieces that can absorb chemicals and transport harmful compounds (Shen et. al 2020). They also seem to be less effective as barriers. Finally, the same lack of infrastructure that creates problems with conventional plastics affects management of bioplastics.

To address the plastic problem at its root, creation of more robust waste management systems and global discussions and policies like those that have been created for chlorofluorocarbons (CFCs) and greenhouse gas emissions must be created (Shen et al. 2020, Borrelle et al. 2017). Over 50% of the world’s oceans lie outside nations’ boundaries, and while plastic dumping is not allowed by ships, 80% of the plastic in the ocean comes from the land (Borrelle et al. 2017). An increase in legislation and creation of policies that create value for recycled plastic and cut back on government fossil fuel subsidies could drastically improve the situation (Borrelle et al. 2017, Thompson 2018).

Consequently, in order to move forward and create sustainable change within our communities it is clear that further research must be targeted toward increasing public awareness, and furthering our understanding of microplastics within our communities: something we hope we have achieved through this report.

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