THE EFFECT OF MACROPLASTIC DEBRIS ON MARINE VERTEBRATES

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Abstract

Plastic pollution causes mortality of marine vertebrates, endangers populations, and affects entire ecosystems. This literature review examines the effects of macroplastic on marine animals. Through scholarly databases, the author researched how plastic negatively impacts ecosystems and marine vertebrates. The major themes (e.g. toxicity, hazardous ingestion or entanglement) of forty-eight sources were analyzed or evaluated in this paper. Plastic pollution is a major phenomenon that is affecting the health of the marine environment. Anthropogenic debris makes its way around the world via ocean currents and can affect coastal and oceanic animals. Macroplastics are plastics larger than 0.5 mm and are visible to the naked eye. Organisms such as marine mammals, seabirds, and fish are affected by macroplastics through ingestion, entanglement, or direct contact generally because plastics can contain many toxic additives. Solutions to plastic pollution effects on marine vertebrates include sustainable fishing practices and reduction/management of waste.

Keywords: macroplastics, plastic pollution, marine debris, ingestion, entanglement, bioaccumulation, biomagnification, toxins, marine vertebrates

1.0 Plastic as marine debris

Ocean pollution by plastic waste is a modern phenomenon of interest to scientists and civilians alike. Plants and animals are greatly affected by the presence of these unnatural oil-born products. This review articulates the concerns made by scientific researchers regarding plastic pollution effects on marine vertebrates in a variety of ecosystems. Plastic pollution is becoming well-studied because it is affecting marine ecosystems globally.

While plastics have some incredibly useful functions for humans, they also have equally dangerous qualities in the natural world. They are persistent polymers which means they can stay in an environment for many years (Bergmann et al., 2015). The fact that they are of light weight is also a consideration in their mobility. Some materials which are lost to the ocean (e.g., anchors) sink and have localized impacts on their surroundings, but plastic's low density allows it to be tossed and carried across the world impacting all sorts of organisms along the way (Laist, 1987). Plastic products which end up in the ocean can be incredibly hazardous to marine life. Marine vertebrates are not only subject to entanglement in macroplastics, but they are also threatened by starvation if they consume these non-degradable materials (Quayle, 1992). Plastic pollution can happen anywhere, whether it be at the center of an ocean gyre or along a public beach.

1.1 Case Study: White Horse Beach

To explore the abundance of plastic waste and trash on public beaches, on seven occasions from May 21 through July 19 of 2016, I collected all visible trash at White Horse Beach in Plymouth MA. I then sorted the trash into the following categories: glass bottles, plastic drink containers, various hard plastics, aluminum cans, paper products, fishing equipment, and plastic bags. I recorded the total weight of each grouping of items and calculated the percent composition of each type. I also documented the presence of other items such as Styrofoam, ribbons/balloons, straws, bottle caps, cigarettes, clothing and batteries, but their weights and percent compositions did not make up a significant proportion of the trash collected.

Figure 1. Typical pile of consumer goods left on beach, mainly alcoholic containers.

Figure 2. Section of beach surveyed in Plymouth, MA. Reeds and washed up organic material containing many hard plastics.

I took photos of the beach area that was surveyed. Figure 1 shows what I typically found on the beach. There were many alcoholic drink containers which were left behind, despite the beach having a "no alcohol" policy. Figure 2 shows how the beach was covered in reeds and other litter, such as small, hard plastics which may have been left behind or washed ashore. Figure 3 shows the average composition of the trash for all visits. The composition of trash was determined based on percentage of the total mass per visit. Glass bottle and plastic drinking containers made up the most items found on the beach. It should be noted that there were over thirty trash cans added to the site over the course of my seven-week study. Figure 4 shows the specific masses of the three main plastic categories per visit. Plastic drinking containers had the largest mass and therefore, we can assume it posed the biggest threat to the natural ecosystem. The presence of plastic on our beaches is evident through this research. Even with the presence of trash cans, people still leave behind their consumer items on the beach, whether it be plastic drink containers, plastic bags, or fishing equipment. Solutions to these issues will be addressed throughout this paper.

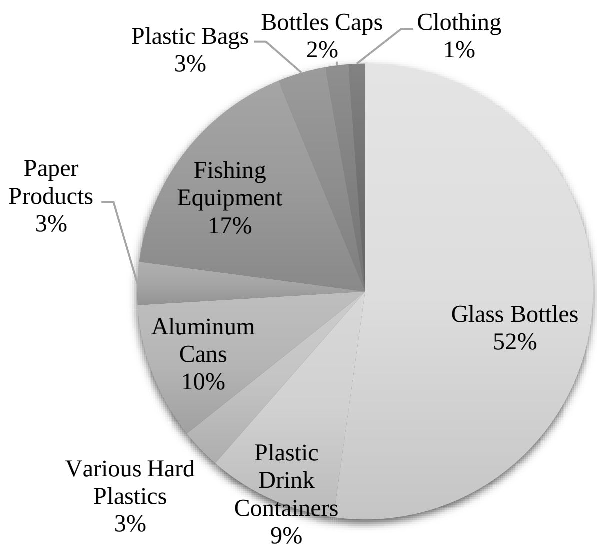

Figure 3. Average composition of trash found at White Horse Beach, Plymouth, MA over all seven visits to the site.

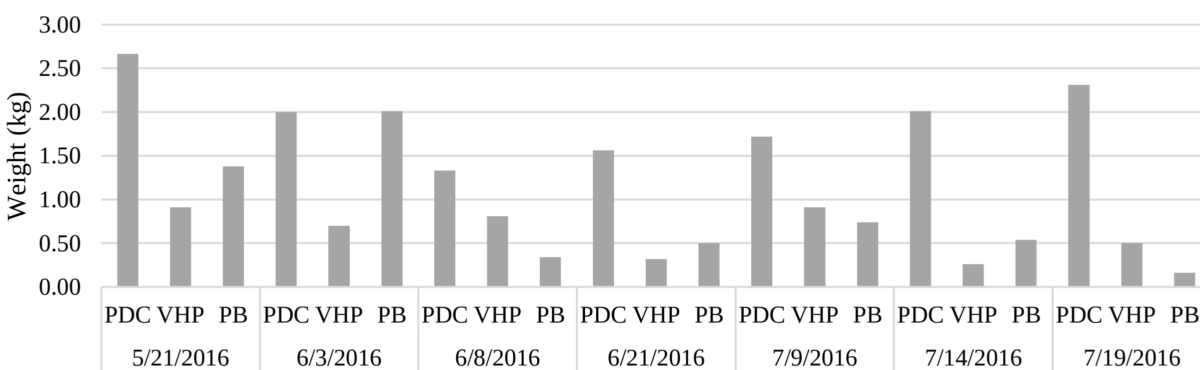

Figure 4. Masses of plastic drinking containers (PDC) various hard plastics (VHP) and plastic bags (PB) recorded at each visit to White Horse Beach, Plymouth, MA.

2.0 Macroplastic Facts and Figures

Plastics are becoming increasingly involved in modern lifestyles and industries. They are practically unavoidable day to day because they are used as beverage containers, food packaging, household products, wrappings, etc. The National Oceanic and Atmospheric Administration (NOAA) Office of Response and Restoration has published information on their website (www.noaa.gov) about plastic debris as a part of their effort to convey information about plastic pollution to the public and enpower everyday citizens to make changes. NOAA (2016) says that as new uses for plastic have developed, the variety and quantity of plastic items found in the marine environment has increased dramatically. When the wastes of society are not properly handled, trash enters the ocean, affecting the natural environment. Marine litter is a serious issue with serious consequences.

The United Nations Environment Programme (UNEP) describes marine litter as any persistent, manufactured, or processed solid that finds its way into the marine environment. Plastic is a synthetic material created from oil resin (UNEP, 2009; NOAA, 2011), it is persistent in the marine environment because it cannot be fully degraded in a way that biological materials can. There are many different types of common plastics found in the marine environment (NOAA, 2011). Polyethylene terephthalate (PET) is used to make water bottles and other drink containers. Polyethylene (PE) comes in two forms, high-density polyethylene (HDPE) and low-density polyethylene (LDPE). LDPE can be used to make the popular consumer plastic bag. Polypropylene (PP) is used to make common drinking straws. Expanded polystyrene (PS) is Styrofoam used in many take out containers. Others types of plastic such as polyvinyl chloride (PVC), polyamide (PA), and polyester (PES) exist.

The plastic forms found in the ocean that are “macroplastics” are larger than 0.5 mm and smaller than 1 m (Moore, 2008); macroplastics are visible to the naked eye. They can come in all types of shapes, sizes, densities and colors. Macroplastics can be in their original, full shapes or they can exist as pieces. Plastics in the ocean are exposed to some level of degradation whether it be by wave action, animal interactions, or photodegradation (UNEP, 2009). Perhaps one of the important qualities of a plastic in regards to its ability to affect marine vertebrates, is its density. According to a study by Morét-Ferguson et al. (2010), most plastics have densities which are less than the mean measured density of ocean water. They observed that the lightest plastics were derived from PP, HDPE, and PS. It is also important to understand that the densities of macroplastics can change; there is often some level of degradation to make it lighter, or biofouling which makes it heavier (Morét-Ferguson et al., 2010). When plastics float, they become a target item for ingestion by many marine vertebrates.

2.1 Sources of plastic pollution in the marine environment

Plastic has the potential to degrade the quality of the natural environment like no other. According to Jambeck et al. (2015) 275 million metric tons of plastic waste was generated in 2010. Inputs of plastic into the ocean are significantly higher in the Northern Hemisphere due to the location of developed nations, such as the United States, whose demand for plastic is enormous (Eriksen et al., 2014). In the last two decades, there has been a dramatic increase in the amount of plastic produced and discarded. Barnes et al. (2009) noticed an increase in plastic marine debris in the 1990s specifically. The production of plastic is expected to rise in the coming decades if societal and infrastructural changes are not made (Jambeck et al., 2015). The more plastic produced, the more we potentially see in our ocean ecosystems. Only 9.5% of plastic waste is recovered and recycled in America (U.S. EPA, 2015), meaning 90.5% of plastic goes to a landfill, but it may get lost along the way. Over the past century, more of the world's population has moved to urban areas and major cities along coastlines, making the issues of plastic pollution and marine debris increasingly serious (Derraik, 2002).

Human activities directly relate to the input of plastic into the ocean, including urban development, fishing, and tourism (Pruter, 1987; Barnes et al., 2009). An estimated 80% of plastic waste in the ocean originated on land (Ryan et al., 2009), meaning the consumer plastics found their way to the ocean via watersheds (Reisser et al., 2013). The point source pollution of riverways which eventually lead to the ocean is a definite contributor to plastic pollution of the ocean (Ryan et al., 2009). Reisser et al. (2013) claims that storms can also exacerbate plastic pollution when storm drains collect discarded litter off flooded streets. Unmaintained and unclean beaches also present a problem as tides come in and take away plastics and other wastes (Ryan et al., 2009). Plastics left on beaches can either encounter marine vertebrates, such as sea birds, right away or they may get washed away into the ocean. The remaining 20% of plastic pollution that exists in the ocean is sea-based. Illegal dumping into the ocean and maritime activities, such as recreational or industrial fishing, can account for the pollution (Eriksen et al., 2014). Better recovery of plastics and recycling incentives would likely help to reduce the amount of plastic entering the oceans.

2.2 Effect of ocean currents on plastic distribution and "garbage patches"

The durability and light weight of most plastics enable them to travel and affect even the most remote marine ecosystems (Barnes et al., 2009). They are found floating in the middle of the ocean, along the coastlines, and sunken on the seabed. Anywhere from 250-1000 plastic pieces exist on every kilometer of the North and South Atlantic shorelines (Barnes et al., 2009). Other locations such as the South China Sea and the Mediterranean are also affected by dense plastic pollution. Eriksen et al. (2014) made estimates about the amount of plastic in the ocean by conducting visual analyses and plankton net tows in various locations. They believe that there are nearly 5.25 trillion plastic pieces weighing roughly 268,940 metric tons in the five subtropical gyres; nearly 92% of this may be considered "microplastic" (particles smaller than 0.5 mm) while 8% of this plastic qualifies as macroplastic (larger than 0.5 mm) (Eriksen et al., 2014). Wave action and the depth of the mixed layer can also affect the vertical distribution of plastics in the water column itself (Reisser et al., 2013). Overall, the distribution of this plastic is wide spread because it is largely moved by wind and surface currents created by abrasive, forceful winds, that circulate around the globe.

Differences in air and water temperature, salinity, depth and bathymetry, and high or low pressure systems can all have effects on the strength of an ocean current. The strongest ocean current is the Gulf Stream running south to north along the east coast of North America. The current brings heat from the equator up the shoreline, playing a significant role in the climate of the U.S. It also has major effects on the distribution of plastic in the North Atlantic Subtropical Gyre. A gyre is a large system of rotating ocean currents that spiral around a central point, clockwise in the Northern Hemisphere and counterclockwise in the Southern Hemisphere. There are five major ocean gyres: the North Pacific Subtropical Gyre, the South Pacific Subtropical Gyre, the North Atlantic Subtropical Gyre, the South Atlantic Subtropical Gyre, and the Indian Ocean Subtropical Gyre.

These gyres are important to understanding the distribution of plastic because they often pull plastic and trash into their centers (Eriksen et al., 2013). Reisser et al. (2013) conclude that the average plastic concentration in an ocean gyre is 4256.4 items for every square kilometer. A "garbage patch" is an area where the anthropogenic marine litter is abundant. One of the most notable garbage patches exists in the eastern half of the Northern Pacific Subtropical Gyre. About 38% of the 5.25 trillion plastic items in the ocean exist in this one garbage patch alone (Eriksen et al., 2014). Howell et al. (2012) noted that the sites of plastic pollution were semi-permanent and determined by climate, decadal events like El Nino, cyclonic wind patterns, and convergence zone locations. Within the gyres, there are subgyres and where they converge around the center of the larger gyre is where the plastic is more likely to accumulate (Howell et al., 2012). These garbage patches become a larger issue when marine vertebrates have direct interactions with potentially harmful macroplastics which amass in such large numbers.

2.3 Plastic Toxicity and Bioaccumulation

Plastics are not subject to biological degradation and they are persistent synthetic materials (Gregory, 1991), but they can be physically broken down into smaller pieces by wave action and exposure to sunlight or saltwater can cause the material to leach its ingredients into the water (Moore, 2008). According to Reisser et al. (2013) more than half of modern plastics contain at least one hazardous ingredient. Plastics are not just made from refined oils; there are also many additives in the material that are used to harden or soften the product. In a study by Reisser et al. (2013), of all the plastic that was found, 67.5% was PE, hard plastic, and roughly 31% was PP, soft plastic. Moore (2008) suggests that plastic additives and softeners like bisphenol-A (BPA) and nonyphenol (NE) are potentially harmful in the marine environment. These “plasticizers” have known detrimental effects on the endocrine systems of humans and they likely affect marine animals in a similar fashion.

Plastics in the ocean also have the ability to adsorb persistent organic pollutants, or POPs (Koelmans et al., 2014). POPs cannot be excreted or metabolized; instead they are incorporated into the tissues of the organism which consumes them. Continuous ingestion of these materials helps to biomagnify the effects of these harmful chemicals (Koelmans et al., 2014). Bioaccumulation is the accumulation of toxins in one organism. For example, if one fish consumes pieces of plastic which contain a harsh chemical, and that chemical cannot be excreted, then it will accumulate in the fatty tissue of the individual organism. Biomagnification is the accumulation of toxins through trophic levels. This happens when a predatory fish secondarily consumes toxic chemicals, by preying on fish that originally ate the plastic, so species in the upper levels of the food chain are more likely to contain these non-excretal chemicals. Macroplastics have also been observed to contain heavy metals, pesticides, and others chemicals such as polychlorinated biphenyls (PCB) and polycyclic aromatic hydrocarbons (PAHs) (Rios et al., 2010). Rios et al. (2010) found that about 40% of plastic samples from the North Pacific Subtropical Gyre contained organochlorine pesticides such as DDT. These are endocrine disrupting chemicals which will bind to estrogen and androgen, halting development in some organisms (Rios et al., 2010). These substances have been observed to biomagnify through the food chain.

3.0 Plastic Pollution and Marine Vertebrates

In the past century humans have expanded our reach around the globe as new technologies have advanced. We now have access to even the most remote ecosystems, but with our advancement, we have severely damaged marine and terrestrial ecosystems alike. In our wake we have affected habitats of the millions of species that we share this planet with. Our impacts may be direct or indirect, direct meaning any physical altercation between the organism and a human (i.e trawling or hunting), and indirect meaning any secondhand interaction (i.e competition for resources) (Vincent et al., 2016). Plastic pollution provides an excellent example of how our presence is affecting organisms, habitats, food webs, and ecosystems as a whole. Pollution of the marine environment represents an indirect impact on organisms because we are not present when organisms encounter our waste. Whether through accidental or intentional release, our macroplastics have made it to the ocean and they are now impacting marine vertebrates which may be important keystone species in their ecosystems. Vertebrates are members of the Subphylum Vertebrata in the Phylum Chordata and Kindgom Animalia. Typically, vertebrates are broken down into seven classes: Agnatha (jawless fish), Chondrichthyes (cartilaginous fish), Osteichthyes (bony fish), Amphibia, Reptilia, Aves (birds), and Mammalia (Avissar et al., 2012). Their vertebral column, or spine, makes them a versatile group of animals which inhabitat land and sea. Vertebrate history stretches back 500 million years on this planet where their ancestors' fossils can be found in the Burgess Shale of Canada. Today the number of extant vertebrate species is about 62,000. The fish are some of the oldest and most numerous organisms, respresenting half of all vertebrates with roughly 31,000 living species. Fish are certainly a group of interest when talking about marine vertebrates that are potentially affected by the presence of macroplastic in the oceans. Marine reptiles such as iguanas, sea turtles, and snakes, sea birds such as albatrosses, and mammals such as seals are also at risk when it comes to plastic pollution.

3.1 Entanglement

Entanglement happens when an animal becomes caught by an object, whether that means being wrapped in a rope or stuck with a fish hook (NOAA, 2014). Over 135 different species of oceanic animals have been recorded as entangled in debris (Allen et al., 2012). Pinnipeds (seals, sea lions, and walruses) as well as cetaceans (toothed and baleen whales) are the most likely types of marine animals to be entangled (NOAA, 2014). Floating macroplastic debris can exist along coastlines and endanger marine mammals which swim near the shore. The animals breathe air and after diving, they potentailly have to swim through the debris to get to the surface. Allen et al.

(2012) observed that nearly 5% of the grey seal population in Cornwall, UK, was affected by entanglement. Hanni & Pyle (2000) observed 27 Stellar sea lions who were entangled at Farallon Island in California, and also recorded entanglement cases involving Californian sea lions and Northern elephant seals. To endangered seals, such as Hawaiian and Mediterranean monk seals, entanglement in macroplastic can have major, negative effects on the already critical population sizes because, in most cases of entanglement, survivorship is unlikely (Allen et al., 2012). Macroplastic debris entanglement can increase drag and make swimming more difficult, which means that the animals expend more energy to move while foraging (Allen et al., 2012). Marine animals are also at risk of strangulation and suffocation by debris. Entanglement can cause visible wounds or constriction which have potentially fatal impacts through blood loss or infection (Allen et al., 2012).

Juveniles and subadults are the most likely age groups to be entangled in macroplastics (Arnould & Croxall, 1995; Hanni & Pyle, 2000). Seals have a natural curiosity that often puts them in danger as they investigate and interact with marine debris (Allen et al., 2012). It has also been observed that more females are caught in macroplastics than males; this may be because females hunt/forage more often to meet their higher energy demand for raising young (Hanni & Pyle, 2000).

Sharks are also at risk for entanglement in macroplastic debris (Laist, 1997) because these curious fish likely bite and poke at inanimate objects, testing to see if they are edible, and that puts them in harm's way. Some people call these shark bitten plastics "sharkastics" (Maui Nui Marine Resource Council, 2016). In a study by Sazima et al. (2002), three juvenille sharpnose sharks were found entangled in plastic rings. Juvenile sharks often live along coastlines, among mangroves or in inlets, making them more exposed to direct inputs of plastic pollution. These fish were all encircled by the plastic rings causing tissue damage, gill restriction, and even emaciation, as the fish could not open their mouths to feed (Sazima et al., 2002)

Evidence for how marine mammals, specifically pinnipeds, and a variety of other animals are often entangled in plastic debris found in their environment is abundant. Plastic pollution’s ability to entangle are greater than previously imagined. Arnould & Croxall (1995) observed that materials entangling seals were principally polypropylene bands and fishing net fragments. Plastic bags, plastic bands, packaging straps, plastic fishing lures, plastic belts, and synthetic fishing lines are just some of the items which researchers have seen animals entangled in (Arnould & Croxall, 1995; Hanni & Pyle, 2000; Raum-Suryana et al., 2009; Allen et al., 2012). It has been recorded in several studies (eg. Arnould & Croxall, 1995; Allen et al., 2012) that the intentional or accidental dispersal of plastic debris by the fishing industry is the cause for most cases of entanglement of marine vertebrates (Arnould & Croxall, 1995). Figure 5 shows images of pinneped entanglement in marine debris. More sustainable fishing practices, such as responsible long line fishing, use of biodegradable fishing nets, or better waste management techniques at sea would likely reduce the occurrence of entanglement.

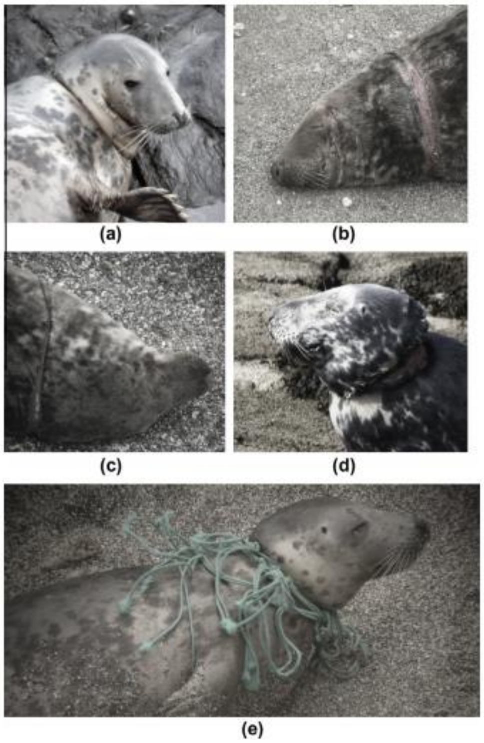

Figure 5. "Categories of net entanglement injuries: (a) 'constriction', (b) 'wound', (c) 'evident' and (d) 'constriction and wound', (e) 'trailing material evident'" (Allen et al., 2012)

3.2 Presence in nesting materials

Marine macroplastics may affect birds through incorporation of litter into nests (Ryan et al., 2009). Laist (1997) found that more than 44% of seabird species studied were impacted by marine debris via ingestion and entanglement. There have been several studies conducted to observe the correlation between plastic presence in nesting material of seabirds and their plastic-related casualties. De Souza Petersen et al. (2016) describes how plastic debris was selected by sooty terns in 54 of 1800 nests in Trinidad. The birds seemed to have a preference for the blue plastic pieces as they occurred in higher frequency (Verlis et al., 2014; de Souza Petersen et al., 2016). Similar observations have been made in post-mortem examinations of sea turtles, as they more often ingest blue colored plastics (Hoarau et al., 2014).

The presence of plastic material in bird nests can affect the survivability of chicks because they may consume or entangle themselves in the debris (de Souza Petersen et al., 2016). The presence of plastic in rookeries are indicative of the presence of plastics in the natural environment. When these animals are exposed to the plastics so consistently, they are also exposed to the associated dangers. In a study by Verlis et al. (2014), 96 brown booby nests were surveyed at Swain Reef, Australia. Figure 6 shows examples of the presence of plastic material in brown booby nests in this study. They found that more than half of the nests contained one or more plastic pieces; large, hard plastics made up the biggest percentage of present synthetic material and these plastics were likely debris deposited by fishing activity. Plastic finds its way to even the most isolated, undeveloped locations where it affects all organisms, even visiting sea birds.

Figure 6. Incidence of plastic in booby nests (Verlis et al., 2014)

3.3 Ingestion

Marine vertebrates are affected by the presence of plastic pollution through direct and indirect interactions with the waste. There is abundant research supporting the occurrence of plastic in the digestive tracts of marine vertebrates such as the loggerhead sea turtle, bluefin tuna, and big eye moonfish (eg. Choy & Drazen, 2013; Romeo et al., 2015). These are all ecologically important species, and there are even more that have been studied. When researchers focus on the frequency of marine debris in the stomachs, intestines, and fecal matter of marine vertebrates, they are really studying the frequency of marine debris in the ocean. This phenomenon is called bioindication, meaning that the species who inhabit the ecosystem are indicating potential problems with the environment itself (van Franeker et al., 2011). Marine debris and macroplastics found in the marine environment have effects on the entire ecosystem, not just individual organisms, ranging from zooplankton to apex predators (Romeo et al., 2015). Ingestion of synthetic materials is one of the most critical ways in which plastic pollution affects marine vertebrates.

Marine debris is abundant throughout the water column and even the seabed of the ocean, and so plastic can affect all types of organisms regardless of their feeding strategies (Choy & Drazen, 2013). Marine vertebrates may feed on many types of organisms such as neuston, which are prey items that float at the surface, and also nekton, which are organisms that can swim well enough to overcome ocean currents. Some may even be herbivorous, feeding on marine plants or phytoplankton, although most planktivores also eat zooplankton. Marine vertebrates may also feed on benthic creatures and invertebrates which live in or on the seafloor. These animals have a wide variety of prey items which they will hunt or eat at different locations in the ocean, whether that is coastal, oceanic, underwater, at the surface, or in the sediment (Choy & Drazen, 2013). In any case, marine animals are at risk for plastic ingestion because the occurance of plastic in the ocean is increasing.

Over the past three decades, seabirds such as fulmars have been observed to ingest plastics. Van Franeker et al. (2014) suggested that the incidence of plastic in fulmars averaged 91% in the 1980s in the North Sea. The number of plastic particles per bird, as well as the average frequency of ingestion, has increased since this time as their foraging areas become more littered with user plastics (van Franeker et al., 2011). The floating plastics are ingested more frequently by seabirds which forage using "surface siezing" and diving methods (van Franeker et al., 2011; Kühn et al., 2015). It is also probable that the seabirds ingest the plastic secondarily through their prey. Van Franeker et al. (2011) says that the potential toxic danger of plastic ingestion affects the higher food web levels not only directly, but also indirectly through the consumption of contaminated prey. Plastic pollution likely affects seabirds with more generalized appetites; seabirds with specific prey items will only consume plastic items which resemble their prey (Kühn et al., 2015).

Chicks are also threatened by plastic pollution, as their parents may unknowingly feed them the indigestible material. The debris may block their intestines, or remain in their stomachs creating a false sense of satiation and therefore starvation. If the lives of chicks are threatened before reaching a reproductive age, then future generations of the organism are also endangered. Figure 7 shows how, when plastic material is passed on to chicks, the consequences are fatal (Moore, 2008). In a study by Lavers et al. (2014), it was noted that puffin chicks who consumed plastic debris fed to them by their parents had altered body sizes which were likley result of the additives associated with plastic debris.

Figure 7. Plastic in the decayed body of an albatross chick. (Moore, 2008)

There is also much evidence for the ingestion of marine debris and macroplastics by fish. In a study by Choy & Drazen (2013), in the Mediterranean 19% of 595 fish contained plastic particles. The big eye moonfish, lancetfish, dogfish, mackerel, swordfish and big eye tuna were all affected by marine debris (Choy & Drazen, 2013). The average plastic found was colored and had a length of 56 mm, which is easily defined as a macroplastic. They concluded that planktivorous fish and fish who consumed micronekton are the most likely to contain plastics. These fish likely feed in the mixing layer, where plastic is abundant. Some predators will even vertically migrate from a depth to the surface to hunt, potentially putting them at risk of ingesting floating plastic (Choy & Drazen, 2013). Davison & Asch (2011) had similar results in their study as 9.2% of the fish they sampled had ingested plastic. There was a higher frequency of ingestion in mesopelagic fishes which migrated throughout the water column (Davison & Asch, 2011). When these fish ingest plastics, they are likely to receive less nutrition due to intestinal blockage, although the totality of the exposure remains uncertain (Choy & Drazen, 2013).

It is not only lower level trophic fish which are affected by plastic pollution, but also upper level predators. Romeo et al. (2015) provided evidence for plastic presence in fish at the top of the food chain such as swordfish, bluefin tuna, and albacore. The 12.5% of sampled swordfish which consumed macroplastics ate fragments ranging in size from 3.69-55.40 mm. Albacore had a similar frequency of 12.9% of individuals, but they consumed mostly microplastics, whereas 32.4% of bluefin tuna had consumed plastics pieces ranging from 0.63-164.50 mm (Romeo et al., 2015). It should be noted that bluefin tuna is an endangered keystone species, meaning it is a critical predator that is important to the food web and ecosystem. The tuna is an opportunistic feeder which hunts schools of fish in shallow waters where plastic fragments are abundant (Romeo et al., 2015). Again, it is also possible that this species ingests plastics secondarily, biomagnifying through the food chain as the toxic plasticizers and fragments bioaccumulate in the smaller fish (Romeo et al., 2015). Fish are likely to ingest plastic due to their hunting and feeding strategies. They use contrast to see their prey and they are not careful to avoid any non-prey items as they hunt (Schuyler et al., 2014).

Marine reptiles such as sea turtles are at risk for plastic consumption as well. Turtles are visually selective when it comes to prey capture; they can see some colors and they differentiate their prey based on luminance, flexibility and translucancy (Schuyler et al., 2014). Schuyler et al. (2013) compiled evidence from studies over the past few decades regarding sea turtle plastic consumption, and they found that the majority of marine debris ingested was soft plastics, styrofoam, fishing equpment, and even balloons. They saw that the liklihood of loggerhead sea turtles consuming plastic had increased from nearly 30% in 1985 to 50% in 2012 (Schuyler et al., 2013). Campani et al. (2013) confirm that the incidence of plastic in sea turtles is increasing as they found that nearly 71% of their sampled loggerheads ingested debris, and about 91% of that debris was user plastic.

The endangered loggerhead sea turtle is a generalist that hunts a diverse range of prey, so it will often mistake plastic items for prey. Oceanic sub-adults will follow ocean currents which also carry plastics, meaning their environment is consistently littered (Schuyler et al., 2013). Inexperienced juveniles are more likely to consume things like plastic bags which are sheetlike and float, making them visually similar to neustonic jellyfish which are a major food of loggerheads (Campani et al., 2013; Hoarau et al., 2014). Hoarau et al. (2014) observed that the primary cause of death for the sea turtles was abrasions in the esophogus and stomach which likely became infected. The 51.4% of sea turtles they sampled contained hard plastics, caps, plastic bags, and fishing gear in their guts and feces. They found that while some of the debris may be excreted, it most likely obstructs the bowels or causes ulcerations and injuries while it is inside the turtle. While the debris is not always lethal, its plasticizers may still impact the endocrine system, development, and reproductivity of the sea turtle, thus affecting the entire population (Campani et al., 2013; Hoarau et al., 2014). Chemicals such as bisphenol-A (BPA) are not excretable and will biomagnify through the food chain if the oranism that originally consumed the plastic is eaten (Campani et al., 2013).

Marine mammals also ingest marine debris; there are at least 26 species of cetaceans that have been documented with ingestion of plastic debris (Denuncio et al., 2011). Di Beneditto & Ramos (2014) observed that the stomach contents of two species of dolphin contained nylon yarn fragments and flexible plastics which were likely found in the sediment where they hunted. Denuncio et al. (2011) noticed that 28.1% of Franciscana dolphins had plastic in their digestive system, including cellophane bands, bags, rubber, and hard plastic fragments. Figure 8 breaks down the types of macroplastics seen ingested by Franciscana dolphins in that study. The proportion of estuarine dolphins ingesting plastic was greater than that of oceanic dolphins (Denuncio et al., 2011). Much like the sea turtle, juveniles were also more likely to ingest plastics, as they are more inexperienced in hunting. But it is important to note that because these cetaceans use echolocation along with vision to hunt, it is unlikely that visual mistakes are the only cause of ingestion (Secchi & Zarzur, 1999). Dolphins are incredibly curious and playful creatures; they probably approach the plastic to get a better look and feel for what it is (Denuncio et al., 2011).

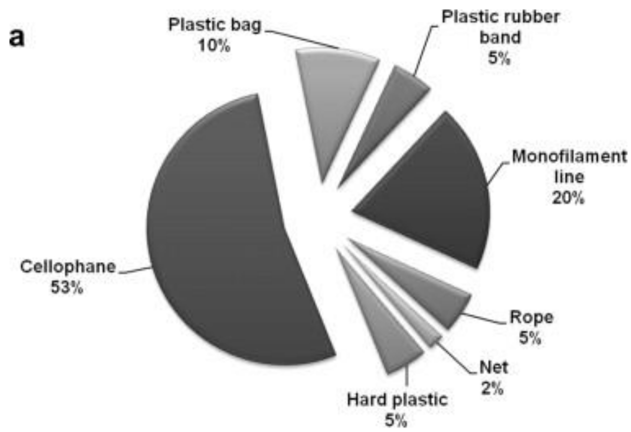

Figure 8. Macroplastics found in Franciscana dolphins in a study by Denuncio et al. (2011)

Secchi & Zarzur (1999) published a note about a Blainville's beaked whale that they found washed up with blue plastic bundles in its stomach. Interestingly, the whale's stomach contained only the plastic and no food, meaning that the whale had a "false sense of satiation [which] reduced [the] whale's appetite and meal size" (Secchi & Zarzur, 1999). This accidental consumption likely lead to the whale's death. Plastic ingestion, even at low levels, can have sublethal effects, by obstructing the gastronintestinal tract and reducing the feeding stimulus (Denuncio et al., 2011). With this being said, the magnitude of the effects of plastic on marine organisms is not well studied and there is far more work to be done (Di Beneditto & Ramos, 2014).

4.0 Effects on marine ecosystems as a whole

It is not just marine vertebrates which are impacted by the presence of plastic pollution, but ecosystems generally. Plastics can leach their aditives, such as bisphenol-A and nonyphenol, into the marine environment as they slowly degrade (Koelmans et al., 2014). These additives can make their way into the water column, then into the food chain via filterfeeding invertebrates, which are then eaten by the vertebrates and so on, biomagnifying the harmful effects of the nonexcretal chemicals through the food chain (Kühn et al., 2015). These additives pose serious health risks to the individual and can affect its fitness and ability to survive and reproduce. This in turn impacts entire populations and their demography (Kühn et al., 2015). Kühn et al. (2015) suggests that the presence of plastic pollution can even affect coral colonies and therefore highly productive and globally important-reef ecosystems which hundreds of marine vertebrate species rely on as their habitat.

Plastics ingestion and entanglement by marine animals such as seals and whales increase rates of mortality among populations to unsustainable levels and can therefore affect the entire food chain (Williams et al., 2011). Marine vertebrates such as these are commonly keystone species, umbrella species, or flagship species (Zacharias & Roff, 2001). Keystone species are often predatory animals which keep populations of other species in check in an ecosystem; they are critical to ecological function and community structure. Umbrella species are organisms whose conservation would save other associated species, similar to how saving a prey item would save its predator. And flagship species are charismatic megafauna which are regularly used as propoganda to get communties to support an issue (Zacharias & Roff, 2001). One can imagine how marine vertebrates such as seabirds, sharks, and dolphins fit these categories.

It has been documented that plastics can travel the oceans, inadvertantly providing habitats for fouling organisms and acting as a vector for microorganisms as well. They may exacerbate the issue of invasive species, as they carry non-natives to new locations around the globe (Kiessling et al., 2015). Gregory (1991) noted that organisms such as bryozoans, algae, annelids, barnacles and even some corals used macroplastics to circulate the oceans and find new ecosystems to inhabit. Invasive species such as these may affect natural populations through competition for resources and shelter. Pathogenic bacteria may also be stored on plastics until it finds a vertebrate host to infect, and so plastic fragments may also cause the spread of disease (Kiessling et al., 2015).

4.1 Solutions

The effects of plastic pollution are far-reaching, but there are solutions to reduce the amount of plastic entering our oceans. Moore (2008) suggests beach cleanups to remove plastic waste before it enters the ocean as a simple way for the average citizen to get involved. Government intervention through legislation and taxation could also be helpful (Moore, 2008; Lebreton et al., 2012). Taxing the consumption of plastic beverage containers, banning the use of plastic bags, or implementing more responsible techniques for waste management would all impede the flow of plastics into the marine environment. Large scale reycling practices at consumer and commercial levels are suggestons to reduce the amount of waste generated (Moore, 2008; Ryan et al., 2009). The Natural Resources Defense Council, or NRDC, suggests using eco-friendly products which are made of natural fibers and are biodegradable (NRDC, 2016). But the most effective solution would be to educate all people on the issue of plastic pollution and the problems it poses to all marine organisms. When citizens are more educated on the issue, they become more resposible consumers. People should be encouraged to reduce the amount of plastic they consume, reuse what items they can, and recycle what they cannot reuse. If all of these suggestions become reality, they would certainly benefit the natural and productive oceanic ecosystems we require for life on earth.

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