The Effects of Plastic Debris and Toxins on Black-footed and Laysan Albatrosses in the North Pacific.

ABSTRACT

Plastic and toxins have a negative impact on the health and reproductive success of Black-footed and Laysan albatross birds breeding on islands in the Hawaiian Island chain. These islands lie within the North Pacific Gyre, which, due to its circulation patterns, accumulates massive amounts of plastic. Since plastics are permeable, lipophilic structures, they are able to absorb and accumulate pollutants with ease. Albatrosses are exposed to these toxins either through direct consumption of contaminated plastic or via bioaccumulation. Ingestion of this pollution can negatively impact feeding habits, fitness, fat deposition, and embryo and chick development. Varying affects from both plastic and toxins have been found depending on the foraging ranges, feeding habits, and trophic levels of the seabirds. Although plastic and toxin accumulation within both Black-footed and Laysan albatrosses has been shown to negatively impact their health and fitness, the mortality rates and impact on population success is still unclear.

PLASTIC

Plastic constitutes the majority of marine debris worldwide, making up 60-80% of the total by mass (Derriak, 2002; Rios et al., 2007; Titmus & Hyrenbach, 2011). Many of the products we produce are made from plastic, especially single use items, which generate a large amount of waste. There's a variety of plastic, but the basis of them all is synthetic organic polymers derived from petroleum, which make plastic lightweight, cheap, and long lasting (Rios et al., 2007; Derriak, 2002). Polyethylene (PE) and polypropylene (PP) based plastic are two common types found in the marine environment, both of which are highly
resistant to aging and degradation (Rios et al., 2007; Titmus & Hyrenbach, 2011) and both have a density less than seawater (Rios et al., 2010). Plastics are divided into pre-production plastics (virgin pellets) and post-consumer plastics.

The polymers of plastic become embrittled due to photodegradation and oxidation, and about 2-3 years after entering the sea the pieces begin to break into smaller fragments (Azzarello et al., 1987; Titmus & Hyrenbach, 2011). The lifespan of plastic in the ocean is highly variable depending on the type and qualities of the plastic. Estimates have been made that fishing nets submerged in the ocean may persist for 50 years (Azzarello et al., 1987), while a plastic bottle is estimated to take 450 years to completely break down (Rios et al., 2007). The process is much slower in ocean environments than on land due to cooler temperatures and reduced UV exposure (Ryan et al., 2009).

The term ‘biodegradable’ plastics is also a bit of a misnomer. Plastics are made with only a portion of biodegradable materials, such as starch, which, after broken down, leaves the microscopic plastic fragments that constituted the rest of the structure (Ryan et al., 2009).

The main sources of plastic debris are garbage dumped from ships at sea and land-based sources, which are usually carried out by rivers and storm-water [Figure 1] (Ryan et al., 2009). Densely populated and industrial areas contribute a large amount of land-based litter which enters via rivers (Derriak, 2002). The actual amount entering the marine environment has been difficult to quantify, since it's often not flowing out at a constant rate. Litter will build up between rain events, and then if the water flow becomes large enough, all is flushed at once (Ryan et al., 2009). Merchant ships and fishing boats dump large
amounts of plastic into the oceans every year including items such as ropes and fishing nets (Azzarello et al., 1987).

![Diagram showing the main sources and movement of plastics in the marine environment. Sinks occur (1) on beaches, (2) in coastal waters and their sediments and (3) in the open ocean. Curved arrows indicate wind-blown litter, grey arrows water-borne litter, stripped arrows vertical movement through the water column, and black arrows ingestion by marine organisms. From Ryan et al. (2009).](image)

**Figure 1.** Diagram showing the main sources and movement of plastics in the marine environment. Sinks occur (1) on beaches, (2) in coastal waters and their sediments and (3) in the open ocean. Curved arrows indicate wind-blown litter, grey arrows water-borne litter, stripped arrows vertical movement through the water column, and black arrows ingestion by marine organisms. From Ryan et al. (2009).

The proportion of plastic in litter increases the further it gets from the source, due to its buoyancy and longevity which makes it more easily transported as compared to more dense waste such as glass or metal (Ryan et al., 2009; Titmus & Hyrenbach, 2011). Plastic debris appears to be increasing in abundance even though some countries have instated regulations regarding dumping plastic. In 2008, 245 million tons of plastic was produced worldwide, as compared to 1.5 million tons that was produced in 1950 (Rios et al., 2010). More plastic produced, means more opportunity for waste accumulation at sea.

In an attempt to control the amount of plastic being dumped in oceans, MARPOL Annex V was put into effect in 1988 (Ryan et al., 2009). It is an international protocol that restricts the amount of garbage that can be discharged at sea, and bans at sea disposal of plastic and synthetics such as fishing nets and ropes (Derriak, 2002). Even though MARPOL
was ratified by 79 countries, the legislation appears to be ignored. Almost 10 years after it was implemented, it was estimated that 6.5 million tons per year of plastic were still being dumped by ships at sea (Derriak, 2002).

**TOXINS**

There are a variety of persistent organic compounds (POPs) found in the marine environment two of which are polychlorinated biphenyl’s (PCBs), found in storage materials and electronics, and DDT, an organo-chlorine pesticide (Rios et al., 2007). Both of these POPs were banned in Canada and the US in the 1970s (Finkelstein et al., 2006).

POPs are considered by Rios et al. (2007) to be the most persistent organic compound that humans have introduced to the environment. They are very chemically stable and are able to bioaccumulate in the food chain. They have varying contamination concentrations throughout the oceans, which produces significant variation in the amount of contamination to which marine life is exposed (Finkelstein et al., 2006). POPs are known mutagens, carcinogens, and endocrine disruptors (Rios et al., 2007) and PCB has been found to lead to reproductive disorders or death (Derriak, 2002).

POPs are lipophilic, and when they are in ocean surface waters, they get absorbed into lipophilic, permeable particulate materials, such as plastic debris (Rios et al., 2007; Rios et al., 2010). Normally POPs found in the water column are absorbed by sediments, which then settle on the sea floor. Plastic behaves like sediments in that they absorb the hydrophobic POPs (Rios et al., 2010), but rather than sinking they remain in the surface waters, becoming a floating accumulation of toxins, within reach of marine life (Rios et al., 2010). The concentration of pollutants in plastic steadily increases with exposure time (McDermid & McMuller, 2004). The combination of plastic absorbing contaminants and
remaining accessible for consumption in the surface waters poses a real threat to the health of marine species (Rios et al., 2010).

OCEANS

The North Pacific Ocean is a complex circulation system, but it’s primarily made up of a rotating gyre system (Howell et al., 2012). It can be divided into the Subpolar Gyre (SPG) and Subtropical Gyre (STG), which are separated by the North Pacific Transition Zone (NPTZ). The NPTZ is bordered by two frontal systems, the Subarctic Frontal Zone (SRFZ) and the Subtropical Frontal Zone (STFZ). The Subtropical Convergence Zone (STCZ) forms at the southern edge of the transition zone [Figure 2] (Howell et al., 2012). This paper will focus mainly on debris in the Subtropical Gyre and the Subtropical Convergence Zone, which is where the island of Midway and the Hawaiian Island chain are located. Studies have found this region to be important regarding the concentration and transportation of marine debris (Howell et al., 2012).

Figure 2. Schematic representing the major ocean currents and zones of the North Pacific. The orange lines represent frontal zones. The shaded green areas are locations where high debris accumulation occurs. WPG - Western Garbage Patch. EPG - Eastern Garbage Patch. From Howell et al. (2012).
Plastic debris is now ubiquitous throughout the world’s ocean, although the
distribution is patchy due to differences in current patterns, wind, and differences in
geographic input (Azzarello et al., 1987). Within the NPG scientists have found the ratio by
mass of plastic to plankton to be 6:1 (McDermid & McMullen, 2004). The highest densities
of plastic in the NPG occur between 20°-40° N (Young et al., 2009), with Midway Atoll
situated at 28°12’ N (Guruge et al., 2001). Modeling studies have found that plastic debris
can remain within the NPG for more than 12 years (Rios et al., 2010).

The majority of studies done on the amount of plastic in oceans have involved
evaluating the surface waters. However, in the open ocean, denser plastics will sink to the
denser, colder midwater layer, where they will float neutrally buoyant (Azzarello et al.,
1987). This means there is likely a large amount of plastic being unaccounted for, and the
amount of plastic in the ocean has been greatly underestimated (Azzarello et al., 1987).

The circulation of the North Pacific Ocean is highly variable over spatial and
temporal scales. The Subtropical Frontal Zone (STFZ) is a permanent region of the North
Pacific, which shifts latitudinally with the seasons (Howell et al., 2012) due to changes in
wind, weather conditions, water temperature and salinity (Young et al., 2009). The air and
water currents directing horizontal convergence in this zone are also what cause buoyant
organic and inorganic materials, whether passive or active, to aggregate there (Howell et al.,
2012).

The region around the Northwestern Hawaiian Islands and Midway are impacted by
the seasonal change in latitude of the STCZ and NPTZ. As the zones move closer to the
island in winter and early spring, the islands are bombarded with biological material and
marine debris, due to increased retention at the surface (Howell et al., 2012). The egg
laying and early chick rearing months of both Black-footed and Laysan albatrosses on these islands are from November to February (Kappes et al., 2010), which puts them in close proximity to a large aggregation of marine debris. As the NPTZ moves further south in early spring and summer, marine debris is reported at its highest concentration around the Hawaiian island chain (Young et al., 2009). This corresponds to the late stage of chick rearing with birds starting to disperse across the Pacific around June (Young et al., 2009).

A study by Mc Dermid & McMullen (2004) examined plastic debris on 9 beaches throughout the Hawaiian Archipelago and found that Midway Atoll, one of the most remote beaches at the Western end of the island chain, had the highest quantity of plastic as seen in Table 1. Of the total debris collected, 72% by weight was plastic particles, totaling 19,100 pieces from the 9 beaches (McDermid & McMullen, 2004). 43% of the plastic pieces collected were 1-2.8mm in size, which is small enough to be ingested by planktivores as well as surface feeding birds such as albatross (McDermid & McMullen, 2004). This study points out how, regardless of proximity to dumping zones, or how dense the human population is in the area, plastic debris is likely to affect all beaches in the North Pacific (McDermid & McMullen, 2004). It is also important to note, that pre-production pellets are known to be found in high densities on beaches near industry, but in McDermid and McMullen’s study, they were abundant on even these remote beaches far from cities and industry.
The main threats to marine life from plastic are ingestion and assimilation of persistent organic pollutants (Derriak, 2002; Azzarello et al., 1987). Seabirds are highly susceptible to plastic ingestion due to their expansive foraging ranges, and high trophic level (Titmus & Hyrenbach, 2011; Blight & Burger, 1997). Plastic can be ingested directly, or acquired via bioaccumulation through secondary ingestion of their prey (Titmus & Hyrenbach, 2011). Seabirds are able to assimilate the chemicals from plastic in their stomachs, which can lead to harmful accumulation in tissues such as the liver and subcutaneous fat (Derriak, 2002).

44% of all seabird species have been confirmed to ingest plastic (Titmus & Hyrenbach, 2011; Rios et al., 2007), however Procellariiformes, the order of surface feeding seabirds including Black-footed albatrosses (BFA) and Laysan albatrosses (LA), tend to accumulate more plastic than other seabirds (Azzarello et al., 1987). This is influenced by

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**PLASTIC, TOXINS, AND ALBATROSSES**

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migratory patterns, and where their feeding and breeding grounds are located (Azzarello et al., 1987).

Ryan et al. (2009) found that seabirds tend to be selective in the types of plastic they ingest, choosing pieces based on colours and shapes which they mistake for prey. Light brown plastic particles have been found to resemble pelagic fish eggs, which are a source of food for albatrosses (Azzarello et al., 1987). Although BFA and LA are top predators and surface feeders, they tend to seek out different prey and both, especially BFA, are known to be scavengers of trash from ships (Azzarello et al., 1987). LA primarily eat Ommastrephis squid while BFA largely consume flying fish eggs (Kappes et al., 2010). This places BFA higher in the food web, so they may experience higher bioaccumulation of both plastic and toxins, neither of which they are able to degrade (Guruge et al., 2001).

The at sea foraging habitat of Laysan and Black-footed albatrosses is segregated, with LA foraging more northwesterly and BFA northeasterly primarily due to differences in prey type (Kappes et al., 2010). Similar patterns of segregation are seen during egg incubation, chick rearing, and non-breeding periods, with Laysan albatross traveling farther and for longer periods than Black-footed albatross, overall. In Kappes et al. (2010) study, only 47.6% of their foraging ranges overlapped, with both foraging extensively in the North Pacific Transition Zone (NPTZ) during the breeding season, but LA were also foraging further north than BFA, utilizing the Subarctic Frontal Zone (SAFZ) [Figure 3]. These differences in foraging ranges and prey are directly correlated to the amount of plastic ingested, which related to the amount of toxins assimilated from the plastic (Derriak, 2002).
A study by Finkelstein found that Black-footed albatross have 370-460% higher organochlorine (i.e. PCB and DDT) concentrations than Laysan Albatross. Both species now have 130-360% higher concentrations of PCB and DDE than a decade ago as can be seen in Table 2 (Finkelstein et al., 2006). The North American coast, where BFA frequent, has a history of high contaminant discharge from industry and agriculture, and the geographic separation of their foraging ranges would explain the higher concentration of contaminants in BFA as compared to LA (Finkelstein et al., 2006).
By examining the stomach contents of albatross chicks, scientists have been able to confirm that parents are regurgitating plastic to their young (Azzarello et al., 1987; Derriak 2002). Although the land around the birds’ nests is often littered with plastic, young chicks rarely eat scraps off the ground (Azzarello et al., 1987). Laysan albatross chicks, aren’t able to regurgitate plastic their parents accidentally feed to them, and only pieces of plastic <0.1g can pass through the gizzard opening in albatrosses (Azzarello et al., 1987). This causes it to accumulates in their stomachs (Derriak, 2002) putting them at risk for dehydration or starvation (Auman et al., 1997)

Foraging patterns appear to differ in birds of the same species living in different colonies. This in turn impacts their exposure and ingestion of plastic debris and POPs. A study by Young et al. (2009) examined Laysan albatross colonies on different islands in the Hawaiian Island chain, Oahu and Kure, which are 2150 km apart. During the breeding season both LA colonies foraged close to their respective nesting islands. As they moved into the late chick rearing stage, they both began expanding their range northward (Young et al., 2009). Albatrosses on Oahu foraged mainly in the North Pacific Transition Zone, and

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<td>PCBs</td>
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<td>BFAL</td>
<td>110 ± 17</td>
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<td>LAAL</td>
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most did not reach the Eastern Garbage Patch. Kure’s albatross foraged more north/northwest of the island, frequently foraging in the Western Garbage Patch (Young et al., 2009).

Chick boluses examined from both islands contained plastic, however chicks on Kure Atoll were fed ten times the amount of plastic as those on Oahu (Young et al., 2009). Every bolus from Kure contained fishing line or tools, whereas only a couple from Oahu had fishing paraphernalia, even though there is a high amount of recreational fishing right next to the Oahu colony (Young et al., 2009).

Similar to how levels of plastic ingestion vary between regions, POP concentrations vary between species in the Northern and Southern ocean. The concentration of PCBs in the subcutaneous fat of BFA in the North Pacific was 92 µg/g, while White-capped albatrosses living in the Southern ocean had concentrations of 1.4 µg/g (Guruge et al., 2001). BFA had the highest concentration out of all the 8 species examined from the North and South Pacific, illustrating the significance of foraging range and prey type on toxin accumulation (Guruge, et al. 2001).

Comparing studies on Laysan chicks, shows an increase in ingested plastic over the decades. In 1966, a study on Hawaii found 74% of 91 chicks examined contained plastic (Auman et al., 1997). A 1989 study found plastic in 90% of the chicks (Derriak, 2002). In 1995, Auman’s study found 97.6% of the 251 chicks examined contained plastic. This increase in plastic ingestion from the 1960s, as well as the high proportion of consumer to pre-production plastic being ingested, corresponds to an increase in plastic production and thus plastic debris concentrations in the North Pacific (Auman et al., 1997; Blight & Burger, 1997).
**IMPACT**

Ingested plastic is not broken down in the intestinal tract of albatrosses, which results in accumulation in the proventriculi and gizzards (Auman et al., 1997). This can lead to diminished feeding stimulus, reduced food intake, lower steroid hormone levels, blockage of gastric enzyme secretion, obstruction of the gut, starvation, dehydration, decreased fat deposition, delayed ovulation, reproductive failure, and increased POP assimilation (Derriak, 2002; Auman et al., 1997; Azzarello et al., 1987; McDermid & McMullen, 2004).

The albatross’ brain requires stimuli to regulate its food intake. Appetite stimulation occurs via contraction of the stomach, low temperatures, and sight of food. Inhibition of the appetite results from dehydration, and distention of the proventriculus, gizzard, and intestines (Azzarello et al., 1987; Auman et al., 1997). Therefore, large amounts of plastic accumulated within the GI of the bird can suppress feeding by keeping the stomach distended and preventing stomach contraction - this would signal the brain that the bird is satisfied (Azzarello et al., 1987). Albatross chicks already have a high incidence of death due to dehydration, so the additional displacement of food by plastic may accelerate the process of dehydration and starvation, especially in those birds that are already in poor health (Auman et al., 1997).

Albatrosses have relatively small gizzards and can suffer serious internal injuries and possible death if intestinal blockages become significant (Derriak, 2002; Azzarello et al., 1987). Studies have found dead birds with solid pieces of plastic completely blocking the opening between the oesphagus and proventriculus. Blockages such as this can impede movement of food to the intestine (Azzarello et al., 1987).
Plastic ingestion also appears to cause large amount of stress to individuals, which affects their overall health and fitness (Auman et al., 1997). Research has concluded that seabirds carrying large loads of plastic have lower food consumption, which limits the fat deposits they can lay down (Derriak, 2002). Reduction in deposits can have detrimental effects on albatross’ migratory abilities, and their reproductive success once they reach breeding grounds (Derriak, 2002). Again, the amount of harm varies among species, but Procellariiformes are more vulnerable, because they lack the ability to regurgitate ingested plastic (Derriak, 2002). It’s been found that Laysan albatross on Midway Atoll contain a wider variety, greater incidence, and larger volume of plastic than other seabirds (Auman et al., 1997).

POPs are able to be assimilated and absorbed into different tissues of the albatrosses (Derriak, 2002). The toxic effect of POPs becomes evident during high energy activities, such as breeding and migration. PCB and DDT are lipid pollutants, so when lipids become mobilized during high energy activity, the toxins become redistributed throughout tissues due to subcutaneous fat reserves being metabolized (Colabuono et al., 2012). The toxins then move through the bloodstream, causing increases in concentration in other organs, such as the liver. It’s shown that birds in poor body condition will have an increase in these compounds in the liver and muscle tissue due to depleting fat reserves (Colabuono et al., 2012).

POPs can have adverse effects that result in malformations of fetuses, embryo mortality, chick edema, and egg shell thinning, which causes hatchling failure. In the study by Guruge et al. (2001), the subcutaneous fat of female BFAs had a range of 13-73 µg/g and LA ranged from 3.3 to 7.8 µg/g. Previous studies have shown that as little as 4 µg/g of DDE
in eggs can cause greater than 5% shell thinning. According to Guruge et al. (2001), the concentrations of contaminants are high enough to threaten population levels of albatrosses.

Even with all the evidence of the negative impact plastic ingestion can have, it is difficult for researchers to prove that plastic is the cause of death or ill health in the albatrosses studied. As a result, it's still unclear what the levels of mortality are due to plastic and POP consumption (Young et al., 2009).

**CONCLUSION**

Although the research cannot say conclusively whether plastic and toxins are contributing to death or declining populations, it’s clear that the pollutants are reducing the overall health and fitness of Black-footed and Laysan albatrosses. There are clear trends that plastic consumption is increasing in both species. The impact however varies with the rate of consumption, which depends on the island used for breeding, where the birds forage, and the type of prey consumed. Due to the movement of the North Pacific Gyre, the regions most negatively impacted are not close to the sources of pollution. The issue of plastic waste and organic pollutants is therefore not a local problem, but a global one, and needs to be addressed to prevent further increases in accumulation rates of both plastic and toxins.
Reference


