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Plastic ingestion by planktivorous fishes in the North Pacific Central Gyre

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ABSTRACT

A significant amount of marine debris has accumulated in the North Pacific Central Gyre (NPCG). The effects on larger marine organisms have been documented through cases of entanglement and ingestion; however, little is known about the effects on lower trophic level marine organisms. This study is the first to document ingestion and quantify the amount of plastic found in the gut of common planktivorous fish in the NPCG. From February 11 to 14, 2008, 11 neuston samples were collected by manta trawl in the NPCG. Plastic from each trawl and fish stomach was counted and weighed and categorized by type, size class and color. Approximately 35% of the fish studied had ingested plastic, averaging 2.1 pieces per fish. Additional studies are needed to determine the residence time of ingested plastics and their effects on fish health and the food chain implications.

1. Introduction

The accumulation of marine debris, the majority of which is plastic (Derraik, 2002), has the potential to negatively impact marine organisms worldwide. On a broad scale, plastic debris can affect larger marine organisms and impair the quality of aquatic life. In more specific terms, large quantities of plastic pieces in the North Pacific Central Gyre (NPCG) are cause for concern as they mix with food sources for the area's planktivorous organisms. The NPCG is an ocean convergence zone that accumulates debris from the entire North Pacific (Ingraham and Ebbesmeyer, 2001). In 1999, Algalita Marine Research Foundation (AMRF) discovered that in the NPCG neuston plastics outweighed zooplankton by a ratio of 6:1 and averaged over 300,000 pieces per km^2 (Moore et al., 2001). In 2008, an AMRF neuston trawl survey of the same area found a dramatic increase in the number of particles per km^2 to 752,110 (unpublished data). This increase in particles per km^2 may affect the ability of fish to distinguish between plastic and their natural food.

Plastic debris accumulating in the marine environment is known to fragment into smaller pieces, which increases the potential for ingestion by smaller marine organisms (Browne et al., 2008). Additionally, the buoyancy of smaller pieces of plastic increases the likelihood for mixing with surface food sources. Although the ingestion of plastic debris by turtles, seabirds, marine mammals, and occasionally fish has been well documented (Balaz, 1985; Wallace, 1985; Ryan et al., 1990; Moser and Lee, 1992; Robards, 1993; Eriksson and Burton, 2003; Phillips et al., 2007), the amount and type of plastic ingested by lower trophic level marine organisms has not been investigated as vigorously.

The present study is the first conducted in the NPCG to confirm that small fish are ingesting accumulated plastic and to estimate the quantity of plastic ingested. More specifically the goal of this study is to determine if mesopelagic planktivorous fishes in the NPCG were ingesting small plastic fragments. The majority of fish species collected for this study are members of a family that comprise more than half of the world oceans' total fish biomass (Oizumi et al., 2001), allowing this study to make a significant contribution to wider understanding of marine debris' effects on ocean fish.

2. Methods

Eleven neuston samples were obtained by manta trawl from February 11 to 14, 2008. Sampling commenced at 34° 40.24′ N, 142° 04.534′ W and continued in a northerly direction to 36° 05.322′ N, 140° 41.118′ W, then sampling proceeded in an easterly direction from 36° 02.447′ N, 140° 19.875′ W to 35° 45.207′ N, 138° 21.45′ W (Fig. 1). Tows varied in time and distance, with tow time ranging from 1.5 to 5.5 h. The manta trawl had a 0.9 × 0.15 m rectangular opening and a 3.5 m long 333-μ net with a 30 × 10 cm collection bag. All samples were preserved for analysis by fixing in 5% formalin, then soaked in fresh water and transferred to 70% isopropyl alcohol.

Fish, plankton, and anthropogenic debris were sorted and processed at Southern California Coastal Water Research Project (SCCWRP) in Costa Mesa, CA. For each fish, basic metrics were recorded, including: standard length (mm), standard weight (g),

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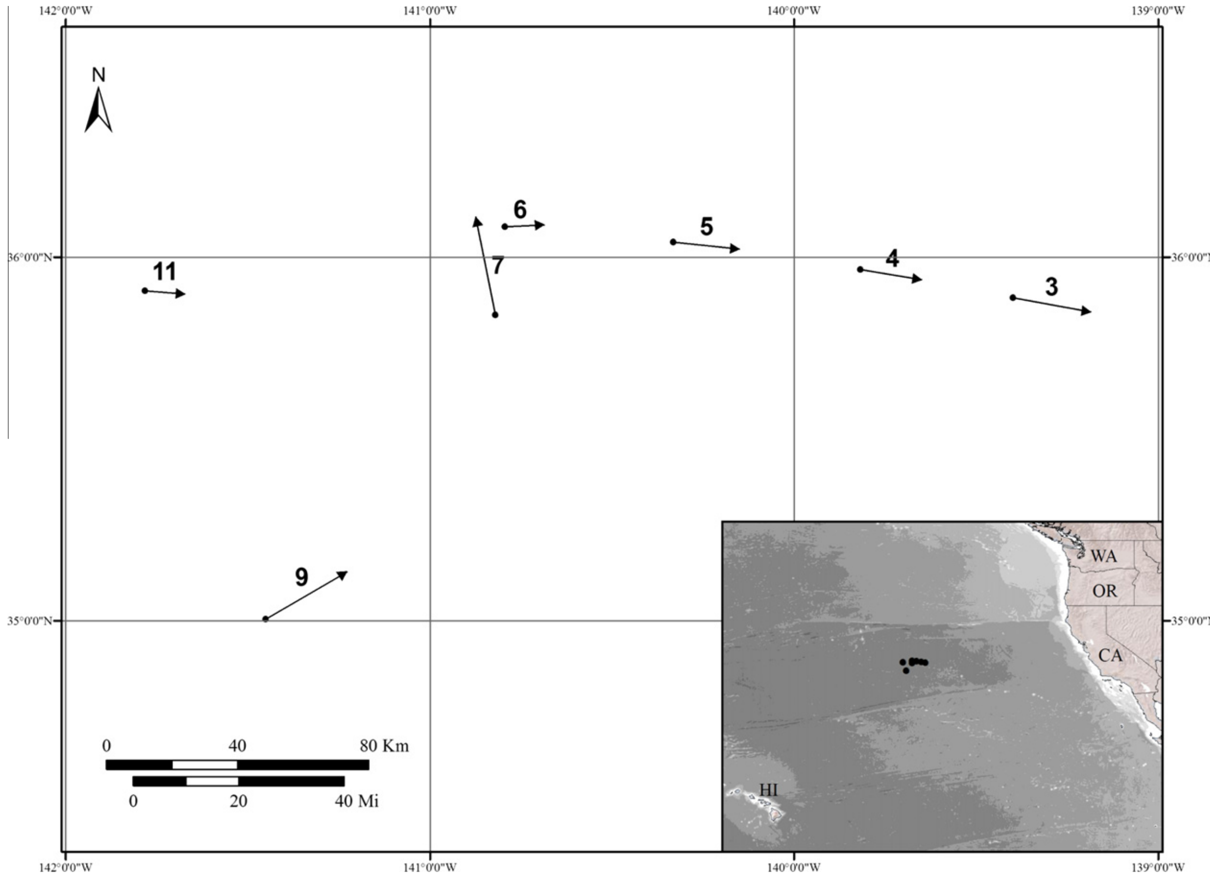

Fig. 1. Neuston trawls locations in the North Pacific Central Gyre.

and sex (male, female, or immature). Each stomach was removed and examined under a dissecting microscope (see Fig. 2). Stomach contents were sorted into natural (plankton) and non-natural (plastic) food source groups, then dried at 65 °C for 24 h. Dry weight of the plankton was recorded in grams using a Sartorius MC1 balance. Plastic pulled from each fish stomach was categorized by size, color and type (fragment, line, foam, pellet or film), then weighed using a C31-Microbalance.

3. Results

Out of 11 neuston trawls, 6 night trawls and 5 day trawls, 7 trawls contained fish. Notably, only the 6 night trawls yielded fish

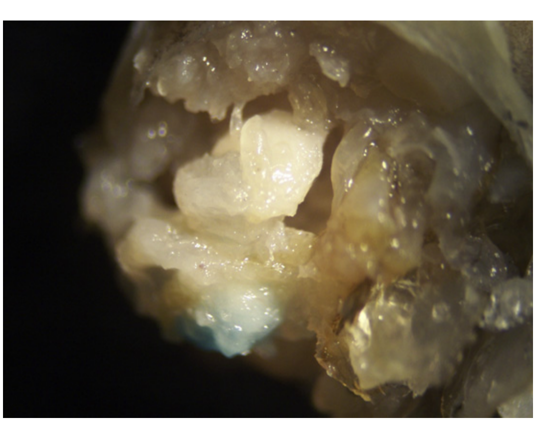

Fig. 2. Stomach under a dissecting microscope with plastic and plankton.

that had ingested plastic. A total of 670 fish, representing five mesopelagic and one epipelagic species, were obtained from 7 trawl samples. The mesopelagic species were: *Symbolophorus californiensis*, *Myctophum aurolanternatum*, *Loweina interrupta* and *Hygophum reinhardtii* (Family Myctophidae), and *Astronesthes indopacifica* (Family Stomiidae). The epipelagic species was *Cololabis saira* (Family Scomberesocidae). The most commonly caught species was *M. aurolanternatum* (69%), followed by *S. californiensis* (11%), *C. saira* (8%), *H. reinhardtii* (7%), *L. interrupta* (4%) and finally *A. indopacifica* (1%).

Approximately 35% of the fish examined had plastic pieces in their guts. A total of 1375 pieces of plastic, ranging from 1 to 83 pieces per fish and averaging 2.1 pieces (±5.78) per fish, were collected from fish guts. *M. aurolanternatum* and *S. californiensis*, had the highest average number of pieces at 6.0 pieces (±8.99) and 7.2 pieces (±8.39), respectively (Table 1). The average weight of plastic retrieved from fish followed a similar pattern, with the average mass of total plastic 1.57 mg (±4.755) per fish. The two most common species sampled had ingested the highest masses of plastic; *M. aurolanternatum* averaged 4.66 mg (±7.385) and *S. californiensis* averaged 5.21 mg (±7.487) of plastic per fish.

Quantitatively, the average number of plastic pieces ingested increased as the size of the fish increased, reaching a maximum average of seven pieces per fish for the 7-cm size class (Fig. 3). A dramatic drop in average pieces per fish observed for the 8-cm size class may be attributed to the limited sample size; only two sample fish were assigned to this class size. For the 9- and 10-cm size classes, the average pieces per fish decreased only slightly from the maximum average.

Qualitatively, ingested plastic consisted primarily of fragments (94%), film (3%), fishing line (2%), and finally rope (woven

Table 1
Mean count and mass of plastic retrieved from gut of fish by species.

Species	Abundance		Weight (mg)	
	Mean	Standard deviation	Mean	Standard deviation
Astronesthes indopacifica	1.0	–	0.03	–
Cololabis saira	3.2	3.05	1.97	2.245
Hygophum reinhardtii	1.3	0.71	1.82	1.830
Loweina interrupta	1.0	–	0.64	–
Myctophum aurolanternatum	6.0	8.99	4.66	7.385
Symbolophorus californiensis	7.2	8.39	5.21	7.847
Overall	2.1	5.78	1.57	4.755

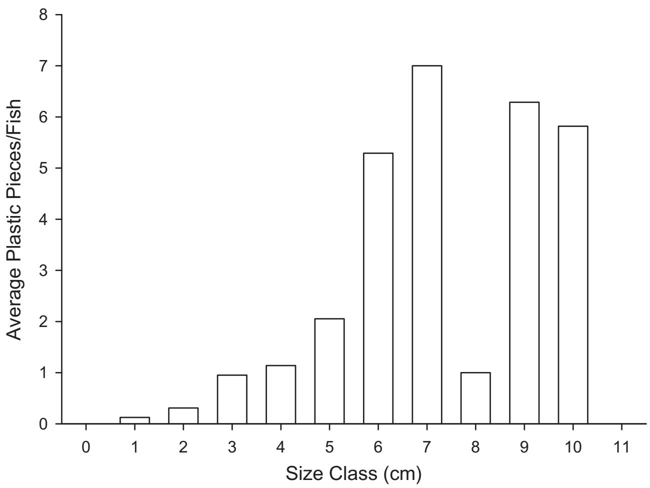

Fig. 3. Average number of plastic pieces per fish.

Table 2
Percent of plastic pieces by color.

Ingested plastic		Neuston trawl plastic	
Color	Percent	Color	Percent
White	58.2	White	53
Clear	16.7	Clear	21
Blue	11.9	Blue/Grn	15
Green	5.2	Blk/Grey	7
Black	3.6	Black	3.6
Yellow	1.0	Brn/Tan	1
Grey	0.9	Yellow	1
Pink	0.7	Or/Pnk/Red	1
Red	0.7		
Orange	0.6		
Tan	0.4		
Peach	0.2		

filaments), Styrofoam and rubber (all <1%). These plastics represented a wide variety of colors, with white, clear, and blue (87% total) being most prevalent. Similar percentages were observed in the analysis of non-ingested plastics obtained from the 11 neuston trawls. Analysis of non-ingested samples found that 89% of the plastic fragments were white, clear and blue (Table 2). The most common size class of plastic ingested by the fish was 1–2.79 mm.

4. Discussion

Plastics, both large and small pieces, are a complex problem in the marine environment, with poorly understood consequences (Moore, 2008). Although studies have documented the effects of large anthropogenic debris, predominantly plastic, as potentially lethal to marine mammals through entanglement and ingestion, the overall impact of smaller plastic debris on the marine environment will require more extensive investigation. Similarly, while the ingestion of smaller plastic pieces by turtles, seabirds, and some fish has been well documented, the impacts of the ingested plastic have not been widely analyzed.

The present study examines and confirms the ingestion of plastic by lower trophic level fish in the NPCG. Quantification of ingested plastic with respect to fish species and size class offers important insights into the characteristics of potential impacts. More than one-third of the fish examined had ingested small plastic pieces, however, it is not possible to fully understand the effects of ingestion until it can be determined if the fish are able to pass this plastic through the gut, and whether some plastic remains in the gut for the life span of the fish.

In the NPCG, the colors of the most commonly found plastics were white, clear, and blue. These colors are similar to those of the area's plankton, a primary food source for surface feeding fish. This similarity may explain a propensity for ingestion by fish. The majority of the fish examined in the present study were part of the family Myctophidae a mesopelagic fish commonly found in the NPCG. These fish have diurnal feeding habits and come to the surface at night to feed on small plankton (Watanabe and Kawaguchi, 2003). Impacts of ingested plastic may increase as an increasing amount of small plastic pieces mix with natural food sources in the NPCG. Subsequently, if fish are not able to pass the ingested plastic through their digestive tracts, the accumulation of non-nutritive elements may lead to malnutrition and eventual starvation, which could lead to significant reductions in world fish populations. Additionally, the buoyancy of the plastic may increase the difficulty of mesopelagic fish to return to deeper waters.

The present study's analysis of ingestion quantities based on fish size class across species establishes a foundation for further research related to long term impacts of marine debris. The larger fish had more pieces of plastic on average in their guts than smaller fish; however, it is unknown if the plastic had been recently consumed. Consequently, without knowing the residence time of the plastic found in fish guts, it was not possible to assess differences in ingestion rates for fish at different stages of life. Notably, this residence time may be an important area for future research as recent studies indicate that plastic in the marine environment can sorb extremely high levels of persistent organic pollutants (Rios et al., 2007; Mato et al., 2001), which are capable of being transferred to wildlife (Teuten et al., 2009). This may pose an additional threat to planktivorous fish and their predators at higher levels of the food chain, such as: tunas, squid, toothed whales, seabirds, and fur seals (Eriksson and Burton, 2003; Phillips et al., 2001; Oizumi et al., 2001, and Perrin, 1975).

The confirmation of plastic ingestion and quantification of plastics consumed by five mesopelagic and one epipelagic fish makes an important contribution to understanding the problem of plastic debris in the marine environment. Further study is needed to understand the impacts of plastic debris on the general health and life cycle of these fish, to investigate the potential for pollutant transfer to higher trophic levels, and to explore possible actions to protect aquatic life from plastic pollution.

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