Plastic ingestion by fish in the South Pacific

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Introduction

Definition, sources, composition and distribution of marine debris

Contamination of oceans by marine debris, largely comprised of plastics, has been recognised as a serious threat to marine life, and consequently to coastal and island populations which heavily rely on marine food resources (UNEP 2009). Any persistent, manufactured or processed solid material that enters the ocean environment from any source is considered marine debris or marine litter (Coe and Rogers 1997). It includes all items discarded, disposed of, or abandoned in the marine and coastal environment (UNEP 2005). Sources of marine debris pollution can be related to a variety of land and ocean-based human activities, including street and beach littering, improper waste management, fishing and shipping, offshore drilling and at sea accidents; with land-based activities contributing up to 80% (Gregory and Andrady 2003; Trouwborst 2011). Marine debris is also generated by extreme natural events, such as tsunami, floods, king tides and cyclones, when various man-made objects are washed from the coastal areas into the marine environment (Lebreton and Borrero 2013).

The most prevalent (60-80%) types of marine debris are various plastic materials (Derraik 2002; Gregory and Andrady 2003). Plastics are positively, neutrally and negatively buoyant, and are ubiquitous in all marine compartments, from seashore to deep-sea, and surface to sea floor. Although the greatest densities of marine debris are usually found in highly populated coastal areas, ocean currents and winds disperse floating plastics to remote areas far from direct human influence, such as subtropical gyres, which are major oceanic accumulations zones where plastic debris is found in exceptionally high densities (Lebreton *et al.* 2012; Maximenko *et al.* 2012).

Marine plastic debris occurs in various sizes, and recently the so-called micro plastics have become of great concern (Andrady 2011). Small plastic particles manufactured to be miniscule, such as plastic pellets, micro abrasives in cosmetics, polishing and air-blast cleaning media, are considered primary micro plastics, while larger plastic objects, which degrade into tiny particles, are secondary micro plastics. There are disagreements regarding the sizes of micro plastics, which some authors define as particles smaller than 10 mm (Graham and Thompson 2009), 5 mm (Barnes *et al.* 2009), 2 mm (Ryan *et al.* 2009) and 1 mm (Browne *et al.* 2010; Claessens *et al.* 2011). Da Costa *et al.* (2016) recently drew attention to even smaller particles, less than one µm in size - marine nanoplastics.

Despite the constant increase in plastic production and disposal, and presumably input into the marine environment, the amount of floating plastics has not increased significantly over the past few decades (Cózar *et al.* 2014). This suggests 'loss' of plastic debris through nano-fragmentation, biofouling, shore deposition and ingestion by marine organisms.

Impacts of plastics on marine biota

A recent review provided a number of 693 species documented to be affected by marine debris pollution (Gall and Thompson 2015), which is almost three times than previously reported in 1997 (247 species) (Laist, 1997). Most adversely affected taxonomic groups are sea birds (174) and fish (114). A total number of 44,006 individuals from 395 species were reported to have either ingested or became entangled in marine debris. Plastic is the dominant material in most interactions with wildlife, reported in 76.5% of all publications.

Gall and Thompson (2015) reported that 50 species of fish were found to ingest plastics. Early documentation of plastic ingestion by fish indicated a quite high incidence of occurrence. Carpenter *et al.* (1972) investigated the pollution of surface waters of the northwest Atlantic by plastic polystyrene spherules and ingestion by fish. They examined 14 species and found that 8 ingested plastics, of which the greatest ingestion rate was observed in white perch and silversides (33%). They also reported ingestion by winter flounder and grubby larvae, only 5mm in size, which had ingested 0.5 mm large spherules. Kartar *et al.* (1976) reported the occurrence of polystyrene spherules in the intestines of 4 fish species (flounders, sand goby, sea-snail and five-bearded rockling). Some young flounders (2-5cm) ingested as much as 30 spherules.

Ingestion of plastics can occur directly (primary ingestion) or indirectly by ingesting prey which contain plastic (secondary ingestion). Eriksson and Burton (2003) proposed that plastic pieces found in feces of fur seals could be attributed to ingestion by their prey rather than themselves. Some studies experimentally demonstrated the trophic transfer of micro plastics and nanoplastics from lower to higher trophic levels in marine (Farrell and Nelson 2013; Setälä *et al.* 2014) and freshwater organisms (Cedervall *et al.* 2012).

Plastic ingestion has detrimental physical and chemicals effects on animals. These include lethal and sub-lethal effects, of which the latter is difficult to quantify, especially on a level higher than an individual organism (Kühn *et al.* 2015). Ingestion of plastic objects can cause direct mortality by gut obstruction and perforation. Indirect physical impacts include decreased mobility and feeding, reduced body condition and overall performance.

Chemical effects include introduction of various plastic-related xenobiotics to marine organisms. Marine plastics adsorb the toxic compounds already present in the ambient water such as pesticides, fertilisers and industrial chemicals (e.g. PCBs, DDTs, PAHs) (Rochman, 2015). Furthermore, various toxic chemicals are added to plastics during their production to change their properties (e.g. BPA, phthalates, PBDEs) and they can leach out of the material. Some organic compounds, such as styrene which is a building block of polystyrene, are also known to leach. When an organism ingests marine plastics, these externally- and internally-bound chemicals, including their metabolites which are sometimes more detrimental than the parent compound (Geyer *et al.* 2000), can cause numerous physiological disruptions (Rochman 2015). In populations prone to plastic ingestion, all this may lead to lowered survival and reproductive success (Kühn *et al.* 2015).

Plastic ingestion by fish has been extensively studied in European waters and the North Pacific. However, there is little data on plastic ingestion by fish in the South Pacific region. The aim of this study was to examine several fish species most commonly consumed by the residents of three South Pacific Island countries, Samoa, French Polynesia and Easter Island.

Methods

Sample collection

Samples of fish guts were collected from three locations in the South Pacific: Apia, Samoa (September-October 2015), Tahiti, French Polynesia (February-March 2016) and Easter Island, Chile (April 2016). In Samoa, 406 samples from 12 species were collected from the local fish market with a sample size $N \geq 30$. The samples were kept frozen and subsequently shipped to New Zealand with an MPI permit for import of biological samples. They were stored in the containment facility at the University of Auckland, fixed in absolute ethanol and transferred to Institute of Marine Science for analysis. In Tahiti, 327 samples from 9 species were collected in collaboration with the local fishermen and sellers (Marina Paea and road side stands). The sample size was $N \geq 30$. In Easter Island, 148 samples from 6 species were collected exclusively from fishermen. Local market is very small and all fish are sold cleaned and gutted. The sample size in Easter Island was $N \geq 10$. Samples from French Polynesia and Easter Island were fixed in absolute ethanol at the University of French Polynesia and brought back to NZ.

Sample processing

The analysis includes the following steps:

- Rough visual examination of each sample by naked-eye for the presence of plastic debris,
- Homogenisation of gut content of larger fish and entire gut of smaller fish,
- Chemical digestion in 15 % hydrogen-peroxide (H_2O_2) at 60 °C until organic matter is digested
- Vacuum filtration of undigested remains through a set of 3 stainless steel filters of the following apertures: 63 µm, 260 µm, 500 µm,
- Visual inspection of the filters under a dissecting microscope for the presence of micro plastics,
- Polymer characterisation of recovered plastics using Fourier Transform Infrared Spectroscopy (FTIR).

We aimed to analyse as much gut content as possible. For smaller digestive system (e.g. parrot fish, rabbitfish) the entire viscera was homogenised and chemically digested in 15 % H_2O_2. The ample gut content of larger individuals (e.g. tuna, mahi mahi) was scraped out of the stomach, pyloric caeca and intestines, homogenised and chemically digested. If intact, prey was present in the stomach, it was removed and separately examined for the presence of plastics in its gut content (i.e. secondary ingestion). To avoid sample contamination, H_2O_2 and water used for digestion and subsequent filtration were filtered on Grade 1 paper filter (11 µm). The samples were allowed to digest in H_2O_2 in the oven at 60 °C for minimum 24h. Digestion time was not equal for all samples and it depended on the size of the sample. After digestion, all samples were heated in the microwave, vacuum filtered on a set of 3 stainless filters and washed out with filtered hot water at the end of filtering. Each stainless steel was visually examined under a dissecting microscope with magnification between 6 and 40 times. All plastic particles or objects were stored in glass vials for further FTIR analysis. Additionally, 'stain' and 'float' tests were applied for particles which were not easily identified. Rose Bengal stain dyes organic matter in pink, while $CaCl_2$ solution with specific gravity of 1.4 keeps most plastic materials afloat.

Airborne contamination by fibres readily occurs. For this reason, all fibres that resemble synthetic textile fibres, were not included in the analysis. All instruments were rinsed with tap water which was previously tested by filtering 15 L of tap water through a 5 µm stainless steel filter. No plastic contamination of tap water was found.

Results

Here we present the results of a portion of samples from Apia, Samoa. Out of 295 samples analysed, marine plastic debris was found in 62 samples, with average ingestion rates of 21.2 %. The greatest ingestion rates were found in yellowfin tuna (*Thunnus albacares*) and ambon emperor (*Lethrinus amboinensis*). With respect to the trophic level, greater ingestion rates were found in carnivorous predators than in herbivorous fish. Plastic debris recovered from the guts was all of microscopic sizes, usually less than 1 mm in length (Fig. 1).

Table 1. List of species collected in Apia fish market, Samoa.

Species	Sample size (N, #)	Av. total length (cm) ± SE	Av. weight (g) ± SE	Ingestion rates (%)	Samples analysed (N, #)	Samples with plastics (N, #)
Thunnus albacares	31	78.0 ± 2.0	6210.3 ± 450.0	**31.8**	22	7
Lethrinus amboinensis	32	37.5 ± 1.2	632.0 ± 62.2	**30.4**	23	7
Katsuwonus pelamis	34	70.2 ± 1.4	6055.6 ± 387.6	**23.8**	21	5
Lutjanus gibbus	32	32.2 ± 1.1	485.0 ± 50.3	**23.1**	26	6
Naso unicornis	32	26.3 ± 1.7	404.7 ± 84.1	**22.7**	22	5
Naso lituratus	30	24.7 ± 1.0	244.7 ± 19.7	**20.0**	20	4
Scarus oviceps	47	25.3 ± 0.4	237.2 ± 13.7	**19.4**	36	7
Lethrinus obsoletus	31	26.9 ± 0.3	244.0 ± 9.7	**19.2**	26	5
Scarus niger	31	25.3 ± 0.6	337.6 ± 21.7	**19.1**	21	4
Ctenochaetus striatus	38	22.0 ± 0.23	181.9 ± 6.2	**17.2**	29	5
Acanthurus lineatus	37	22.6 ± 0.33	163.1 ± 6.1	**16.7**	30	5
Siganus punctatus	31	21.4 ± 0.6	170.7 ± 11.6	**10.5**	19	2

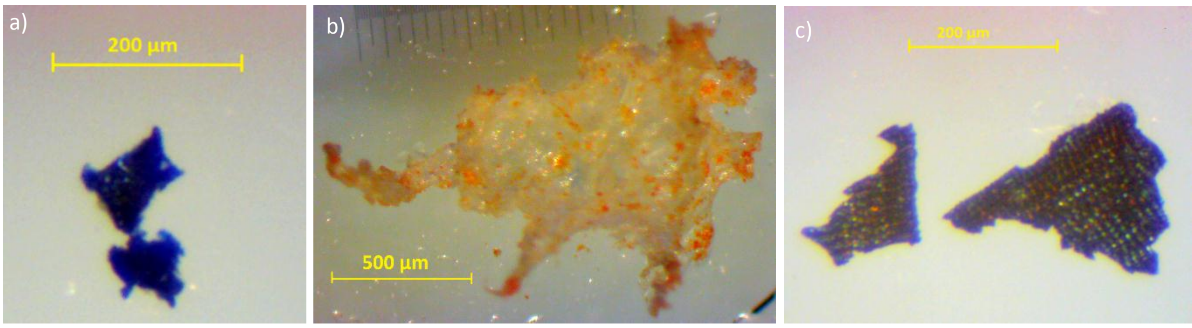

Fig. 1. Micro plastics recovered from a) *Thunnus albacares*, b) *Lethrinus obsoletus* and c) *Lutjanus gibbus*.

Recommendations

The problem of plastic ingestion by marine fish should be addressed as mitigating plastic pollution in general, through green procurement, sustainable living practices and sound waste management. More research on this issue is needed to gain insight into the extent of the contamination of commercial and non-commercial marine fish species in the Pacific region, as well as to better understand the impacts of plastic ingestion on fish, and consequently humans.

The following recommendations are to:

1. Monitor plastic ingestion by marine fish on regular basis covering the most common species consumed in the Pacific region.
2. Examine the tissue of commercial fish species for the presence of persistent organic pollutants associated with plastic debris.
3. Raise awareness and continue improving waste management.

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