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Double trouble in the South Pacific subtropical gyre: Increased plastic ingestion by fish in the oceanic accumulation zone

Ana Markic[a,*], Clarisse Niemand[b], James H. Bridson[c], Nabila Mazouni-Gaertner[d], Jean-Claude Gaertner[e], Marcus Eriksen[f], Melissa Bowen[g]

[a] University of Auckland, Institute of Marine Science, Leigh 0985, New Zealand
[b] University of Waikato, School of Science, Hamilton 3216, New Zealand
[c] Scion, Manufacturing and Bioproducts, Rotorua 3010, New Zealand
[d] Université de la Polynésie Française, UMR-241 Ecosystèmes Insulaires Océaniens, BP 6570, Tahiti, French Polynesia
[e] Institut de Recherche pour le Development, BP 529, Papeete, Tahiti, French Polynesia
[f] The 5 Gyres Institute, Los Angeles, CA 90016, USA
[g] University of Auckland, School of Environment, Auckland 1010, New Zealand

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ABSTRACT

Fish are an important food source for South Pacific (SP) island countries, yet there is little information on contamination of commercial marine fish species by plastic. The aim of our study was to perform a broad-scale assessment of plastic ingestion by fish common in the diet of SP inhabitants. We examined 932 specimens from 34 commercial fish species across four SP locations, and some of the prey they ingested, for the presence of marine plastics. Plastic was found in 33 species, with an average ingestion rate (IR) of 24.3 ± 1.4% and plastic load of 2.4 ± 0.2 particles per fish. Rapa Nui fish exhibited the greatest IR (50.0%), significantly greater than in other three locations. Rapa Nui is located within the SP subtropical gyre, where the concentration of marine plastics is high and food is limited. Plastic was also found in prey, which confirms the trophic transfer of microplastics.

1. Introduction

Once a promising material of the future, plastic has gradually grown into a global environmental threat. Plastic is a versatile synthetic material used in all aspects of human existence, but since it is generally non-biodegradable in natural environments, it tends to accumulate. Although the mass production of plastics started only after WWII (Thompson et al., 2009), today there are no plastic-free natural environments. Plastic has been found in deep ocean trenches (Fischer et al., 2015) as well as in desert animals (Walde et al., 2007; Ahmed, 2011). While in the past some believed that '*littering is an aesthetic problem rather than an ecological one*' (p. 22, Bascom, 1974), others recognised plastic pollution as a potential environmental threat as early as the 1960s and 1970s (Carpenter et al., 1972; Rothstein, 1973). However, the attention of academia and media intensified only recently, and most likely due to concerns related to human health, since there is increasing evidence of plastic contamination of seafood (Galloway, 2015; Rochman et al., 2015; Santillo et al., 2017; Wright and Kelly, 2017).

Plastic debris is ubiquitous in all marine compartments, including coasts, surface waters, water column and seafloor (Galgani et al., 2015), where it occurs in various sizes, shapes, colours and specific gravities (Andrady, 2003). Due to such diversity, plastic debris poses a risk to a range of marine animals (Kühn et al., 2015). In the past decade, much of the research focus has shifted from macro debris to minute plastic particles, or microplastics, commonly defined as particles smaller than 5 mm (Auta et al., 2017; Avio et al., 2017a). Microplastics are particles either purposefully manufactured as miniscule particles (primary microplastics), such as plastic pellets and various abrasives (e.g. microbeads) or are formed by mechanical degradation of larger plastic debris (secondary microplastics) (Avio et al., 2017a). Due to the small particle size, microplastics are highly bioavailable and readily ingested by various marine organisms commonly consumed as seafood, such as mussels (De Witte et al., 2014), clams (Davidson and Dudas, 2016), shrimps (Devriese et al., 2015), lobsters (Murray and Cowie, 2011), squids (Rosas-Luis, 2016) and fish (Rochman et al., 2015). Plastic ingestion occurs directly (primary ingestion), or indirectly, by eating contaminated prey (secondary ingestion), and can be either intentional

* Corresponding author at: 160 Goat Island Rd, Institute of Marine Science, Leigh 0985, New Zealand.
E-mail address: amar926@aucklanduni.ac.nz (A. Markic).

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(mistaken prey identity) or unintentional (accidental ingestion through filter-feeding or grazing) (Ryan, 2016). There is evidence that ingested plastic debris causes an array of detrimental consequences, including the build-up of toxic compounds associated with plastic debris, either directly from ingested plastic (Rochman et al., 2013) or via trophic transfer from prey to predator (Batel et al., 2016). This justifiably creates concern among seafood consumers about their health and wellbeing (Santillo et al., 2017).

Plastic ingestion by marine fish has been studied intensively recently, with at least 39 studies published since 2017. Most studies were conducted in the North Atlantic region, while the South Pacific region has been poorly studied. In Pacific Island countries, seafood is an invaluable food source (Gillett, 2011) and the assessment of plastic contamination of fish in this vast ocean region is of crucial importance. At the time of the preparations for this study (2015), there was no information available on the state of the South Pacific fish. Meanwhile, six studies on plastic ingestion by fish in this region have been published. However, only one of those studies (Mizraji et al., 2017) used the recommended analytical method (Dehaut et al., 2016; Karami et al., 2017a), which includes chemical digestion of organic portion of the gut content for more effective detection and isolation of plastic debris. In the other five studies, the gut content was only visually inspected, by naked-eye or under a microscope (Cannon et al., 2016; Ory et al., 2017, 2018; Forrest and Hindell, 2018; Halstead et al., 2018).

The aim of our study was to perform a broad-scale assessment of plastic ingestion by commercial fish species, from different habitats and trophic levels, commonly present in the diet of South Pacific Islanders. Additionally, we were interested in investigating the differences in plastic ingestion by fish inhabiting the centre of convergence of the subtropical gyre (near Rapa Nui, or Easter Island) and other sampling locations in the South Pacific. A subtropical gyre is an oceanic convergence zone where plastic debris accumulates in great abundance (Eriksen et al., 2013), and where the organisms are exposed to much higher concentrations of plastic debris than outside of the gyre. Furthermore, the transfer of plastic debris along the food web has been demonstrated experimentally (Farrell and Nelson, 2013), but there is no previous evidence of trophic transfer in field subjects. We intended to investigate this route of plastic contamination in fish by also examining the gastrointestinal tract of undigested prey items from the stomach of predatory fish. Lastly, we aimed to develop a cheap analytical method which could be easily replicated in developing countries. Thus, the questions we address in our field study are:

1. Is there a significant difference in plastic ingestion between the fish from the South Pacific subtropical gyre (accumulation zone) and the other three locations?
2. Is there evidence of trophic transfer of plastics, or secondary ingestion?
3. Are there patterns in the occurrence of plastic ingestion among examined species with respect to trophic levels, feeding preferences and habitats?
4. Is there a common size, type, colour, opacity and polymer type of marine plastics ingested by South Pacific fish?

2. Methods

2.1. Sample collection

Samples of gastrointestinal (GI) tracts of 34 marine fish species (Table 1) were collected from four study locations (Auckland, Samoa, Tahiti, Rapa Nui) in the South Pacific region between September 2015 and October 2016 (Fig. 1). The sampling locations were selected based on their population size or their geographical position in the South Pacific. Greater concentrations of plastic debris are usually associated with human population centres (Andrady, 2017), or accumulation zones of subtropical gyres (Eriksen et al., 2013). Samoa, Tahiti and New Zealand are some of the major population centres in the South Pacific region, while Rapa Nui has a low population, but was chosen due to its position within the South Pacific subtropical gyre. We aimed to collect locally caught species from various habitats and trophic levels. Although there is always a degree of uncertainty to the origin of the fish, we made sure all the specimens were fresh, caught by local fishermen and not imported. No ethical permit was needed for sample collection as the fish were not caught specifically for research, but were obtained from local markets or fishermen. The species were identified by fisheries officers, fishermen and fellow scientists. Further identification was confirmed using Fishbase (Froese and Pauly, 2016), FAO (2016) and New Zealand Ministry of Fisheries identification keys (McMillan et al., 2011). The number of collected species varied across locations and depended on the availability of the local fish. The sample size (i.e. the number of specimens per species) on all locations was $N \geq 10$. The collection was as random as possible, with specimens of the same species being collected from various sources on various days. The entire GI tracts were removed from the fish, from the oesophagus to the vent. The samples where the stomachs were everted, or the regurgitation occurred, were not collected. A detailed description of the methods is provided in the Supplementary information (Table S1). Biometrics data (standard, total and fork length (cm), and mass (g)) of individual fish were taken where possible prior to evisceration (Table S2).

2.2. Diet analysis and gut fullness

A basic diet analysis was done to be able to place each species into a distinct trophic group, based on their feeding strategy. When much of the stomach content was digested or unidentifiable, additional information was extracted from Fishbase (Froese and Pauly, 2016) and FAO (2016). It should be noted that some stomach content might not be representative of the fish usual diet as it can easily be confounded by bait items (e.g. bread, fish heads). The guts with the items identified as bait were not included in the analysis to avoid the potential contamination from bait. Additionally, gut fullness index (GF, from 1 to 5) was recorded for each digestive tract based on visual assessment, one being empty and five being completely full. We acknowledge that this type of analysis is subjective, but since only one person examined all the guts and assigned the GF index, the estimation was consistent throughout the entire examination.

2.3. Method testing

We established an analytical protocol which was a combination of previously published methods (Avio et al., 2015; Rochman et al., 2015). The protocol was tested on the gut content of two genera, *Scaber* spp. (Scaridae, parrotfish) and *Lethrinus* spp. (Lethrinidae, emperor), on five specimens of each genus. Each sample was spiked with 15 polyethylene microbeads of three different colours (five red, five blue and five transparent) and sizes ranging from 100 to 500 μm (more details in Table S1). These two genera were selected due to the difference in their gut content, which represent the two extreme types of the gut content with respect to their ability to dissolve in H_2O_2 and the subsequent detectability of plastics during the microscopic analysis. The gut content of parrotfish dissolves almost entirely, while the gut content of emperor usually contains plenty of undissolvable residue, such as shells, bones, scales and sediment, which makes the microscopic analysis more difficult.

2.4. Sample processing

The samples were processed randomly, rather than consecutively per species or per location, to avoid potential systematic errors due to tired eye or lack of concentration. The gut content was extracted from the stomachs and the intestines onto a clean metal or ceramic plate using a metal spatula. The content was first examined by naked-eye for