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Note

Incidence of plastic fragments among burrow-nesting seabird colonies on offshore islands in northern New Zealand

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ABSTRACT

Marine plastic pollution is ubiquitous throughout the world's oceans, and has been found in high concentrations in oceanic gyres of both the northern and southern hemispheres. The number of studies demonstrating plastic debris at seabird colonies and plastic ingestion by adult seabirds has increased over the past few decades. Despite the recent discovery of a large aggregation of plastic debris in the South Pacific subtropical gyre, the incidence of plastics at seabird colonies in New Zealand is unknown. Between 2011 and 2012 we surveyed six offshore islands on the northeast coast of New Zealand's North Island for burrow-nesting seabird colonies and the presence of plastic fragments. We found non-research related plastic fragments (0.031 pieces/m^2) on one island only, Ohinau, within dense flesh-footed shearwater (*Puffinus carneipes*) colonies. On Ohinau, we found a linear relationship between burrow density and plastic density, with 3.5 times more breeding burrows in areas with plastic fragments found. From these data we conclude that plastic ingestion is a potentially a serious issue for flesh-footed shearwaters in New Zealand. Although these results do not rule out plastic ingestion by other species, they suggest the need for further research on the relationship between New Zealand's pelagic seabirds and marine plastic pollution.

1. Introduction

Rates of plastic production and pollution into marine systems have increased steadily since the 1950s (Barnes et al., 2009). Plastics constitute the majority of anthropogenic debris occurring throughout the global marine environment (Derraik, 2002). Among the many negative impacts of plastic pollution is the endangerment of marine wildlife through entanglement or ingestion (Mattlin and Cawthorn, 1986; Gregory, 2009).

Ingestion of plastic by adult seabirds and offloading to chicks has been widely documented from the high Arctic and northern Pacific Ocean (Provencher et al., 2010; Van Franeker et al., 2011) to the sub- and continental Antarctic (Furness, 1985; Van Franeker and Bell, 1988) and most places in-between (Laist, 1997). The potential effects of plastic consumption on seabirds include: internal and external wounds, blockage of the digestive tract, impairment of feeding capacity, reduction in reproductive capacity, and poisoning from the absorption of toxic compounds (Gregory, 2009). Due to the regurgitation of plastic to chicks, the death of chicks or fledglings with large loads of plastic in their stomach, and the regurgitation of large indigestible materials (i.e. plastic) by chicks, seabirds can act as vectors, introducing plastic fragments to their breeding grounds (Huin and Croxall, 1996).

The New Zealand archipelago has the highest diversity of seabird species' in the world, dominated by burrow-nesting procellariiforms (Taylor, 2000). They are however, threatened by human disturbance, habitat alteration, and introduced predators, which have resulted in the extirpation of most species from the mainland (Taylor, 2000; Holdaway et al., 2001). The impact of plastic pollution on the conservation status of New Zealand's seabirds and the amount of plastic deposited at their breeding grounds are currently unknown. Plastic debris and pellets wash up frequently onto beaches around New Zealand (Gregory, 1977; Gregory, 1999); furthermore, plastic pellets have been documented in the stomachs of prions (*Pachyptila spp.*) found wrecked around New Zealand as early as 1960 (Harper and Fowler, 1987). Given the large populations of procellariiform seabirds found in New Zealand, as well as the tendency for birds of this order to ingest more plastic than others (Azzarelo and Van Vleet, 1987), the potential for plastic affecting seabirds in New Zealand is likely to be high.

While surveying burrow-nesting seabird colonies on islands with 'nature reserve' status in northern New Zealand, we noted the presence of non-research related plastic fragments. We therefore recorded the presence/absence and number of fragments in all surveyed colonies. We then compared the distribution of plastic fragments with the presence, local density, and occupancy of

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breeding burrows in order to test whether plastic was associated with seabird colonies.

2. Methods

2.1. Study area and search method

We surveyed burrow-nesting seabird colonies on six islands located in the Hauraki Gulf, off the northeastern coast of the North Island of New Zealand: Taranga, Mauitaha, Ruamaahuanui, Ohinau, Korapuki, and Kawhitu (Fig. 1). All study islands had long histories of human occupation and modification through burning and terracing, and/or the introduction of Pacific rats (*Rattus exulans*) by Māori (Skegg, 1963, 1964; Atkinson, 2004), but have been protected as nature reserves and have remained undisturbed since the mid-19th Century. We visited the islands between September and December in 2011 and 2012. This period represented the pre-breeding to egg hatching stages of the breeding cycles of burrow-nesting seabirds present on our study islands. Those species included grey-faced petrel (*Pterodroma macroptera gouldi*), flesh-footed shearwaters (*Puffinus carneipes*), common diving petrels (*Pelecanoides urinatrix*), fluttering shearwaters (*Puffinus gavia*), little shearwater (*Puffinus assimilis*), Pycroft's petrel (*Pterodroma pycrofti*), sooty shearwater (*Puffinus griseus*), and little blue penguin (*Eudyptula minor*).

In order to survey the seabird colonies and the distributions of colony-associated plastic fragments, we spread colony survey plots along evenly-spaced transects which ran from coast to coast, parallel to the short edge of each island. Approximately 35 transects per island resulted in distances of 10–40 m between transects, depending on island size (Table 1). The transect method was not employed on two islands: Ruamaahuanui, due to high burrow density and thus high risk of burrow collapse; and Taranga, due to hazardous terrain. Instead, previously selected, randomly generated GPS (Global Positioning System) points were used on Ruamaahuanui; and modified transects constrained by proximity to existing tracks, were employed on Taranga.

Depending on the transect length, one to six random distances (chosen from a random numbers table) were measured from the transect start. This distance was measured using a handheld GPS (Garmin 60CSx). At each random distance, the centre of a 3 m radius circular plot was marked with a metal stake. Within the 28.27 m^2 we counted all seabird burrows whose entrances fell more than halfway inside the plot limits. The contents of each burrow were assessed using an infrared burrow camera (Taupe professional 'burrowscope', Sextant Technology Ltd.). Generally, different petrel species do not use the same burrow during the same breeding season, thus we assumed that burrow occupancy by a species was indicative of seasonal occupancy. While surveying a plot, RTB performed a visual search for the presence of plastic fragments (no leaf litter or other natural debris were displaced). Equal search effort (<5 min) was made within each plot on each island. Any fragments found were counted and collected.

2.2. Statistical analysis

To determine if more plastic fragments were observed in plots with seabird burrows present we used a general linear model

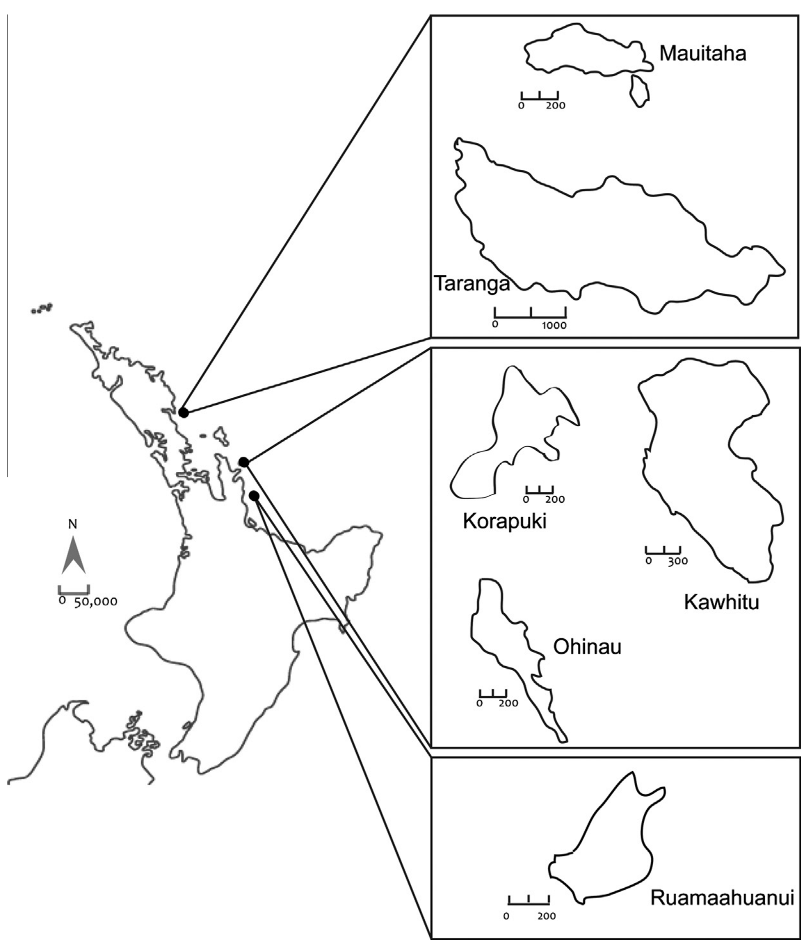

Fig. 1. Location of study islands which were surveyed between September to December in 2011 and 2012. The main map is of the North Island of New Zealand.

Table 1
Details of transects and plots surveyed on islands in the Hauraki Gulf, New Zealand.

	Taranga[a]	Mauitaha	Ohinau	Kawhitu	Korapuki	Ruamaahuanui[b]
Number of transects	61	31	33	33	38	n/a
Number of plots	120	68	100	132	101	76
Area searched (m^2)	3392.4	1922.4	2827	3731.6	2855.3	2148.5
% Island searched	0.072	0.961	0.883	0.373	1.586	1.023

[a] A modified transect method, constrained by proximity to existing tracks, was employed on Taranga.
[b] Randomly positioned points were used to survey burrow density and occupancy and plastic occurrence on Ruamaahuanui.

Table 2
Burrow density, plastic density, and burrow-nesting seabird species found within plots in the Hauraki Gulf, New Zealand. Y = species was present (GFPE-grey-faced petrel, LISH-little shearwater, PYPE-Pycroft's petrel, LBPE-little blue penguin, FLSH-fluttering shearwater, CDPE-common diving petrel, FFSH-flesh-footed shearwater, SOSH-sooty shearwater).

Island	Mean burrow density (m^{-2})	Mean plastic density (m^{-2})	Species present							
			GFPE	LISH	PYPE	LBPE	FLSH	CDPE	FFSH	SOSH
Taranga	0.053 ± 0.005	0	Y	Y	Y	Y	Y			
Mauitaha	0.034 ± 0.006	0	Y	Y	Y		Y		Y	
Ohinau	0.058 ± 0.006	0.031 ± 0.001	Y	Y					Y	
Kawhitu	0.075 ± 0.008	0.001 ± 0.001	Y	Y	Y	Y		Y		
Korapuki	0.088 ± 0.010	0.004 ± 0.002	Y	Y	Y	Y		Y		Y
Ruamaahuanui	0.229 ± 0.031	0	Y	Y	Y	Y	Y	Y		

(GLM) with a binomial error structure and logit link. To determine if areas with plastic had a higher burrow density than areas with no plastic we used a GLM with a Poisson error structure and log link. Finally, to examine the relationship between burrow density and plastic density we used a GLM with a Gaussian error structure and an identity link. Analyses were performed in R version 2.11.1 (R Development Core Team 2010), statistical significance is assumed at $\alpha < 0.5$, and unless specified, all data are presented as mean ± SE.

3. Results

The most common species, found nesting on all islands, were grey-faced petrel and little shearwater. Also common were little blue penguin and Pycroft's petrel (Table 2).

The majority of plastic fragments that we detected were found were on Ohinau (Table 2; Fig. 2). We observed three plastic fragments on Kawhitu (0.0008 pieces/m^2) and ten on Korapuki (0.0035 pieces/m^2), all of which appeared to have been associated with previous research-related activities (e.g. small pieces of flagging tape or plot markers). No plastic fragments were found on Taranga, Mauitaha, and Ruamaahuanui.

On Ohinau, we found 89 plastic fragments (0.031 pieces/m^2), all but two of which were found in plots with burrows ($Z = 2.154$, $P = 0.0312$). There was a significantly higher density of burrows in plots with plastic observed than in plots without plastic ($Z = 7.346$, $P < 0.001$), and a positive relationship between burrow density and plastic density ($T = 2.795$, $P < 0.006$; Fig. 3). Although burrow occupancy was low on Ohinau (7.4%), flesh-footed shearwaters were the most commonly detected species found within burrows (67% of birds detected; Table 3).

Most plastic fragments were too damaged to be identifiable. Of the pieces whose source was recognizable however, two appeared to be fragmented rope, several were fragments of bottle caps, and two were fragments of coffee lids (Fig. 2).

4. Discussion

We found little evidence of plastic fragments on most of the islands we surveyed in northeastern New Zealand. Plastic was common on one island only: in a relatively large flesh-footed shearwater colony on Ohinau.

Flesh-footed shearwaters are known to ingest large amounts of plastic (Reid et al., 2013). For example, on Lord Howe Island, 96% of breeding flesh-footed shearwaters were found to have ingested plastic (J. Lavers unpub. data). In a study by Hutton et al., (2008), plastic fragments made up at least 31% of the volume of proventricular cavities of all failed flesh-footed shearwater fledglings on Lord Howe Island. Furthermore, plastics were found in 79% of the proventricular cavities of near-fledged chicks, in volumes of up to 15%.

We found large numbers of plastic fragments in flesh-footed shearwater colonies on Ohinau, but not on Mauitaha, despite the presence of flesh-footed shearwaters on both islands. One possible explanation for the difference between islands is the higher burrow density and occupancy of flesh-footed shearwaters on Ohinau (Table 3). Our occupancy estimates on Ohinau were likely lower because we surveyed burrows during the pre-breeding season (October), rather than during incubation (Baker et al., 2010). However, previous surveys during incubation and chick rearing (January) confirm very few flesh-footed shearwaters on Mauitaha and much larger and denser colonies of this species on Ohinau (Baker et al., 2010).

Possible explanations for the lack of plastics found in other procellariiform species' colonies could be: (1) inter-specific differences in plastic ingestion due to different concentrations of plastic at respective foraging grounds, (2) differences in each species ability to regurgitate plastic to chicks, and thus for plastic to accumulate at nesting sites and (3) different detectability of plastics by visual survey because of, e.g. different patterns in plastic deposition from inside a burrow to the areas surrounding a burrow.

Evidence suggests that plastic loads often differ between species of seabird breeding at the same colony. On Lord Howe Island, plastic levels were significantly lower in wedge-tailed shearwater stomachs than flesh-footed shearwater stomachs, possibly due to different densities of plastic within foraging locations (Hutton et al., 2008) and differences in foraging behavior (Young et al., 2009). Foraging ranges differ between the species' present on our study islands. Common diving petrels, fluttering shearwaters, little shearwaters, and little blue penguins feed mostly within the inshore region, while, grey-faced petrels, flesh-footed shearwaters,

Table 3
The total number of burrows occupied (N occ.) and percent occupancy (% occ.) by species on each study islands in the Hauraki Gulf, New Zealand in 2011 and 2012. (GFPE-grey-faced petrel, LISH-little shearwater, PYPE-Pycroft's petrel, LBPE-little blue penguin, FLSH-fluttering shearwater, CDPE-common diving petrel, FFSH-flesh-footed shearwater, SOSH-sooty shearwater).

	Mauitaha		Taranga		Ohinau		Kawhitu		Korapuki		Ruamaahuanui	
	N occ.	% occ.	N occ.	% occ.	N occ.	% occ.	N occ.	% occ.	N occ.	% occ.	N occ.	% occ.
GFPE	10	18.18	64	36.78	5	3.09	69	30.40	40	15.81	68	16.83
LISH	3	5.45	2	1.15	1	0.62	1	0.44	9	3.56	8	1.98
LBPE	0	0	2	1.15	0	0	2	0.88	3	1.19	1	0.25
PYPE	1	1.82	1	0.57	0	0	8	3.52	3	1.19	1	0.25
FLSH	1	1.82	2	1.15	0	0	0	0	0	0	36	8.91
CDPE	0	0	1	0.57	0	0	0	0	4	1.58	19	4.70
FFSH	2	3.64	0	0	12	7.41	0	0	0	0	0	0
SOSH	0	0	0	0	0	0	0	0	2	0.79	0	0
Unknown	1	1.82	1	0.57	0	0	5	2.20	2	0.79	7	1.73

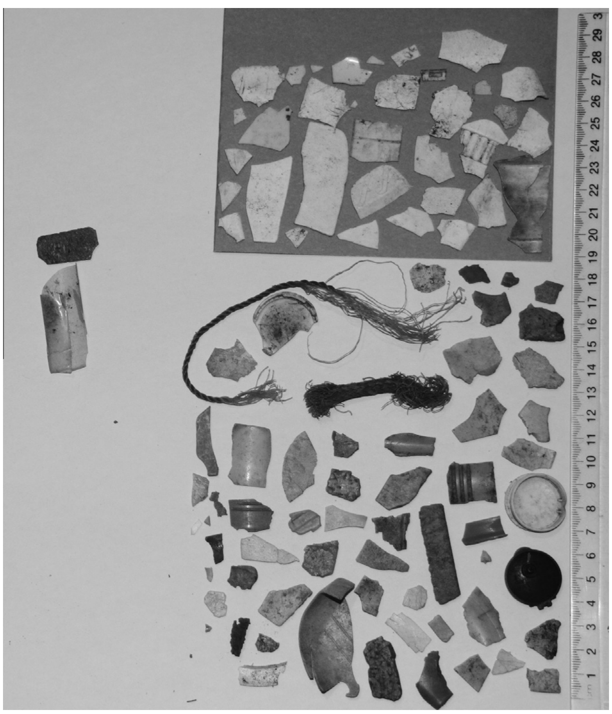

Fig. 2. Plastic fragments found on the island of Ohinau. The two plastic fragments on the left were observed in survey plots with no burrows; plastic fragments on the right were observed in plots containing flesh-footed shearwater (*Puffinus carneipes*) burrows.

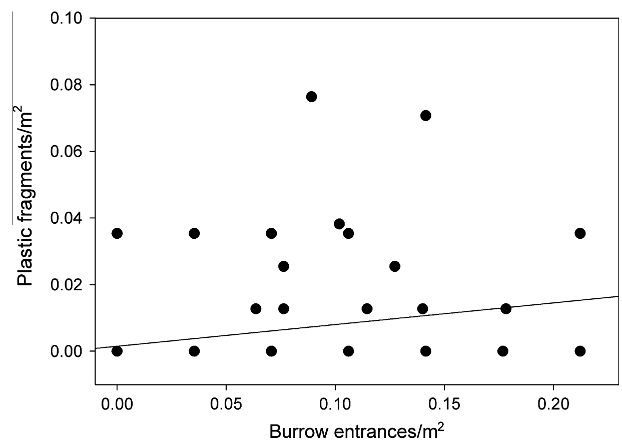

Fig. 3. The linear regression line shows a positive relationship between the density of burrow entrances (of all species) and the density of plastic fragments within 3 m circular plots on Ohinau in northern New Zealand.

and sooty shearwaters forage far offshore over a much wider area (Marchant and Higgins, 1990). A large aggregation of plastic has been located in the southern pacific gyre, with the centre approximately 450 km southeast of Easter Island spreading west to Pitcairn Island (Eriksen et al., 2013). The fact that plastic was only found in flesh-footed shearwater colonies may reflect a wider foraging strategy, where birds are feeding closer to this south-eastern gyre.

In seabirds, the regurgitation of plastic is restricted by the size of the constriction between the proventriculus and gizzard. There is a tendency for procellariiforms to retain hard indigestible objects, due to the size limitation of this constriction (Azzarelo and Van Vleet, 1987). Thus, the lack of plastic fragments found at other species colonies could reflect different sizes of constriction, rather than a true lack of plastic.

The large amount of plastic found strewn about a forested, rarely visited nature reserve in this study suggests the need for more research into plastic ingestion by New Zealand's seabirds. Seabirds throughout the New Zealand archipelago are benefitting from large-scale predator removal projects (Towns et al., 2006), but the impact of other factors, such as plastic ingestion, may put hitherto unaccounted for constraints on the recovery of seabird populations.

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