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Physical and chemical effects of ingested plastic debris on short-tailed shearwaters, *Puffinus tenuirostris*, in the North Pacific Ocean

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Abstract

We investigated the plastics ingested by short-tailed shearwaters, *Puffinus tenuirostris*, that were accidentally caught during experimental fishing in the North Pacific Ocean in 2003 and 2005. The mean mass of plastics found in the stomach was 0.23 g per bird (n = 99). Plastic mass did not correlate with body weight. Total PCB (sum of 24 congeners) concentrations in the abdominal adipose tissue of 12 birds ranged from 45 to 529 ng/g-lipid. Although total PCBs or higher-chlorinated congeners, the mass of ingested plastic correlated positively with concentrations of lower-chlorinated congeners. The effects of toxic chemicals present in plastic debris on bird physiology should be investigated.

Keywords (6 words): Marine plastic debris, Polychlorinated biphenyls (PCBs), North Pacific Ocean, plastic ingestion, plastic contaminants, short-tailed shearwater

Plastic wastes have become distributed around the world ocean during the past four decades (Carpenter and Smith 1972; Derraik 2002), and their ingestion by seabirds has been well documented (Day 1980; Day et al. 1985; Azzarello and van Vleet 1987; Ryan 1987; Moser and Lee 1992; Spear et al. 1995; Robards et al. 1997; Vlietstra and Parga 2002; van Franeker et al. 2011). However, assessment of the effect of ingested plastic on seabirds is insufficient. The effect can be divided between injury leading to starvation (Connors et al. 1982; Ryan 1988; Sievert and Sielo 1993; Pierce et al. 2004) and chemical exposure (Ryan et al. 1988; Colabuono et al. 2010). Plastics sorb potentially hazardous hydrophobic chemicals such as polychlorinated biphenyls (PCBs) from the surrounding water (Mato et al. 2001; Tuten et al. 2008, Hirai et al., 2011). The mass of plastic in the stomach of seabirds had a weak but significant correlation with PCBs in their abdominal adipose tissue (Ryan et al. 1988).

The present study assessed the physical and chemical effects of ingested plastic on short-tailed shearwater, *Puffinus tenuirostris*, among which plastics have been frequently detected in the stomach (Day et al. 1985; Ogi 1990; Robards et al. 1997; Vlietstra and Parga 2002).

Short-tailed shearwaters breed mainly in Tasmania, Australia (from October to March) and spend their non breeding season (from May to September) in the northern North Pacific (Brooke 2004).

Short-tailed shearwaters were accidentally caught in driftnets by the research vessel *Wakatake-maru* (Hokkaido Prefectural Government) in the northern North Pacific Ocean (mainly central Bering Sea; Fig. 1) during June to July in 2003 and 2005. The carcasses were stored at –30 °C until analysis. In the laboratory, the carcasses were thawed and blotted dry with tissue paper repeatedly until the body weight did not change. Body weights were measured on an electronic balance. The carcasses were then dissected with a solvent-rinsed stainless steel knife. The samples could not be sexed because the size of the genital is quite reduced during the non-breeding season (Proctor and Lynch 1993), so all samples were combined for statistical analyses. Stomachs were removed to examine the contents.

In 2003, plastics were sorted out from the stomach contents of 87 shearwaters. The pieces were washed in distilled water and dried at room temperature. Each sample was weighed on an electronic balance. Plastics were categorized into plastic resin pellets, fragments of plastic products, fibers, foam (all pieces appeared to be polystyrene), or plastic sheets.

In 2005, plastics were removed from the stomachs of 12 birds, weighed as in 2003 and sorted by polymer type, i.e., polyethylene [PE], polypropylene [PP], Polystyrene [PS], and polycarbonate / acrylonitrile-butadiene-styrene resin [PC/ABS] by near-infrared spectrometry (PlaScan-W, OPT Research Inc., Tokyo, Japan). Due to the properties of instrument, plastics that were line-shaped, smaller than ~2 mm, and/or black could not be analyzed, and were classified as ‘not identified [NI]’.

From 12 birds, approximately 300 mg (wet weight) of abdominal adipose tissue was dissected using a stainless steel knife. Analysis of PCB concentrations in the tissue followed the method described in Yamashita et al. (2009). PCBs were analyzed on a Hewlett-Packard 5890 series II gas chromatograph equipped with an electron capture detector. Twenty-four PCB congeners (IUPAC numbers 8/5, 18, 28, 52, 44, 66/95, 90/101, 110/77, 118, 132/153, 105, 138/160, 187, 128, 180, 170/190, and 206) were quantified. The total concentration of these congeners was expressed as total PCBs in the present study. A procedural blank was run with every batch (5 and 7 samples). The limit of quantification was set at 3 times the amount detected in the procedural blank (which was normally ~4 ng/g-lipid). Reproducibility and recovery were confirmed through four replicate analyses of a sample with and without spiking. The relative standard deviations of concentrations of individual PCB congeners were <5.8% and the recoveries were >96%. After aliquots of the sample extracts were evaporated to complete dryness, the lipid contents were determined gravimetrically.

To estimate PCB concentrations in the ingested plastics, we used data from Hirai et al. (2011), who collected plastic fragment from the Central Pacific Gyre, and analyzed them using gas chromatography-ion-trap mass spectrometers (GC-ITMS; Thermo Fisher ITS) on MS/MS mode. We selected the 17 congeners from Hirai et al. (2011) (i.e., IUPAC numbers 8, 18, 28, 52, 44, 66, 101, 110, 118, 105, 153, 138, 128, 187, 180, 170, and 206) and calculated the weighed average concentrations of each congener using the mean mass of PE and PP (see Table 2). For statistical analysis, SPSS 14.0J software was used in the statistical analyses.

The mean (±SE) number and mass of ingested plastics per bird were 15.1 (±2.9) pieces and 0.226 (±0.185) g (n = 99, Table 1). These values were higher than those recorded in the same regions (northern North Pacific Ocean and Bering Sea) during the 1970s to the 1990s (Day 1980; Ogi 1990; Robards et al. 1995; Vlietstra and Parga 2002). The mean mass of ingested plastic was 0.04% of the body weight. The highest load was 0.896 g in one bird (0.21% of its body mass). In both years, the two most abundant types of plastic ingested fragments (Table 1) and resin pellets (in terms of mass). These results are similar to reports from previous studies (e.g., Vlietstra and Parga 2002; Ryan 2008; Colabuono et al. 2010; van Franeker et al. 2011). Vlietstra and Parga (2002) reported that the dominant type of plastic in the stomach of shearwaters shifted from resin pellets to fragments in the Bering Sea. In the

North Pacific, the proportion of plastic fragments has increased during the last three decades (Day and Shaw 1987; Moore et al. 2001; Yamashita and Tanimura 2007) and was predominant in the 2000s (Yamashita and Tanimura 2007). These shifts are likely to reflect the reduction of the spillage of industrial plastics and the increase in the discharge of user plastics to marine environments. However, the short-tailed shearwaters migrate widely, between the North Pacific and the South Pacific (where it breeds)(Brooke 2004), and limited information is available on where shearwaters ingest plastics and on the abundance and types of plastics in the South Pacific.

Among the polymer types, PE was most abundant (number 51% of total number, mass 68% of total mass), followed by PP (number 23%, mass 22%; Table 2). These results are similar to those reported by Mosel and Lee (1982). PE and PP are buoyant (gravity; PE 0.91-0.965, PP 0.91-0.92, seawater 1.03). The ingestion of floating plastics is consistent with the pursuit-plunging foraging behavior of the short-tailed shearwater (Ashmole 1971). However, PS (number 0.6%; gravity 1.04-1.07) and PC/ABS (number 3.4%; PC gravity 1.1-1.4, ABS gravity 1.06), which are not buoyant, were also detected in the stomachs. Short-tailed shearwaters can dive up to 71 m depth (Weimerskirch and Cherel 1998), so they may ingest plastics not only at the sea surface, but also in deeper waters. The form and apparent gravity of plastics in seawater should be considered in future studies.

Pearson correlation was used to determine if body weight and mass of ingested plastic were related, and no relationship was found (n_{2003}=87, r_{2003}=-0.046, P_{2003}=0.674; n_{2005}=12, r_{2005}=0.044, P_{2005}=0.891; $n_{2003\ and\ 2005}$=99, $r_{2003\ and\ 2005}$=0.044, $P_{2003\ and\ 2005}$=0.891; Fig. 2).

Total PCB concentrations in abdominal adipose tissue ranged from 45 to 529 ng/g-lipid. The congener profile was dominated by higher-chlorinated congeners, such as CB132/153, CB138/160, and CB118 (Fig. 3). This profile is similar to those observed in various oceanic seabirds (Yamashita et al., 2007). Higher-chlorinated congeners become enriched in the fat of seabirds through biomagnification owing to their resistance to basic metabolism.

The mass of ingested plastic was not correlated with total PCB concentrations (n = 12, Pearson's r = 0.33, P = 0.30; Fig. 4a). However, the mass was positively correlated with tissue concentrations of lower-chlorinated congeners (Cl number from 2 to 4, see Fig.3), but not with those of higher-chlorinated congeners (Cl number from 5 to 9; Fig. 4b, c). This difference may have been due to the two main exposure routes. Seabirds are exposed to PCBs through both their natural prey and the ingested plastics. The natural prey, such as krill, small fish, and squid, concentrate the higher-chlorinated congeners through biomagnifications, so birds the fed on these prey would show no correlation with higher chlorinated congeners.

However, plastics found in the open ocean are rich in lower-chlorinated congeners and depleted in higher-chlorinated congeners (Fig. 5; Hirai et al., 2011), which could explain they contribution of ingested-plastic-derived PCBs was more recognizable in the lower-chlorinated congeners. These results suggested this is how lower-chlorinated congeners were transferred to short-tailed shearwaters. These results are consistent with the results of a feeding experiment in which we fed shearwaters chicks with contaminated plastic resin pellets together with natural food (Tueten et al., 2009): the lower chlorinated congeners were transferred from the ingested plastics to chicks. More research is necessary to better understand the transfer of chemicals from ingested plastics to tissues and their potential for adverse effects on seabirds.

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Figure captions

Figure 1. Locations where short-tailed shearwaters was collected in 2003 and 2005. Solid circle ; sampling in 2003, square ; sampling in 2005, and double circle ; sampling in 2003 and 2005.

Figure 2. Relationship between ingested plastic mass and body weight of short-tailed shearwaters. Open circle: 2003, solid circle : 2005.

Figure 3. PCB congener compositions in abdominal adipose tissues of short-tailed shearwaters that ingested plastics. Cl Number ; numbers of chlorines substituted in the biphenyl.

Figure 4. Relationships between ingested plastic mass and concentrations of (a) total PCBs, (b) lower-chlorinated congeners (Cl Number 2–4, see Fig.3), and (c) higher-chlorinated congeners (Cl Number 5–9, see Fig.3) in abdominal adipose tissues of shearwaters that ingested plastics.

Figure 5. PCB congener compositions of plastic fragments (data from Hirai et al. 2011).

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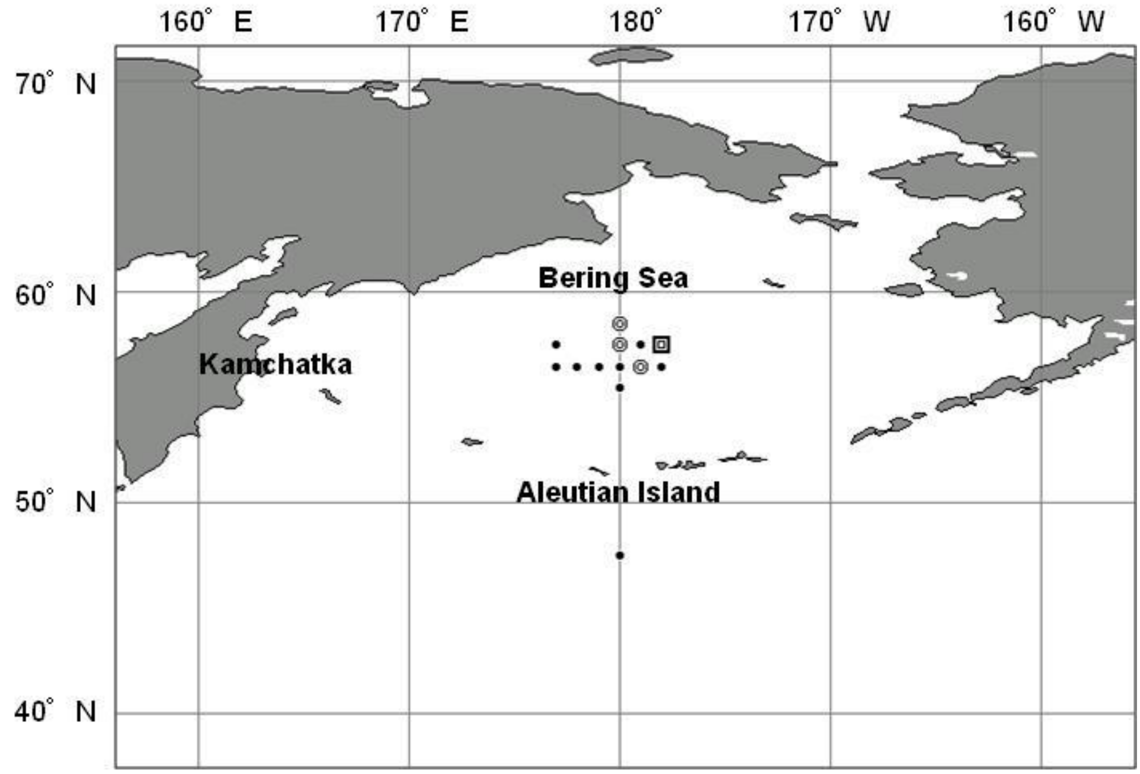

Figure 1.

Locations where short-tailed shearwaters was collected in 2003 and 2005. Solid circle means sampling in 2003, square means sampling in 2005, and double circle means sampling in 2003 and 2005.

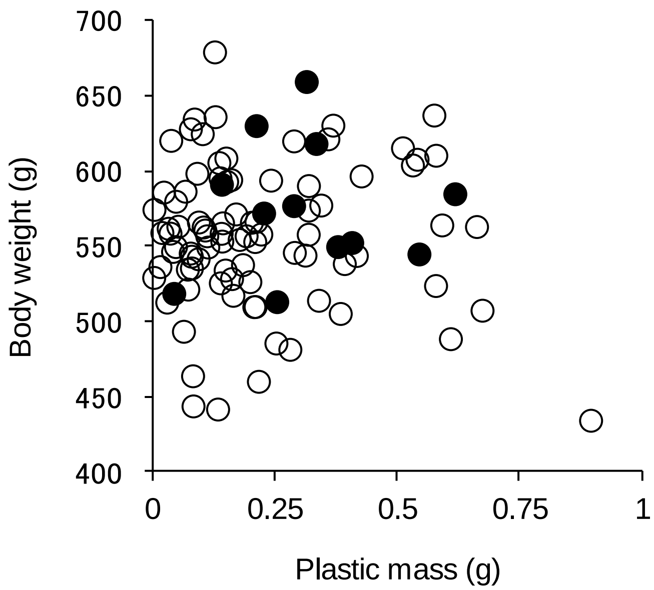

Figure 2

Relationship between ingested plastic mass and body weight of short-tailed shearwaters.

Open circle: 2003, solid circle: 2005.

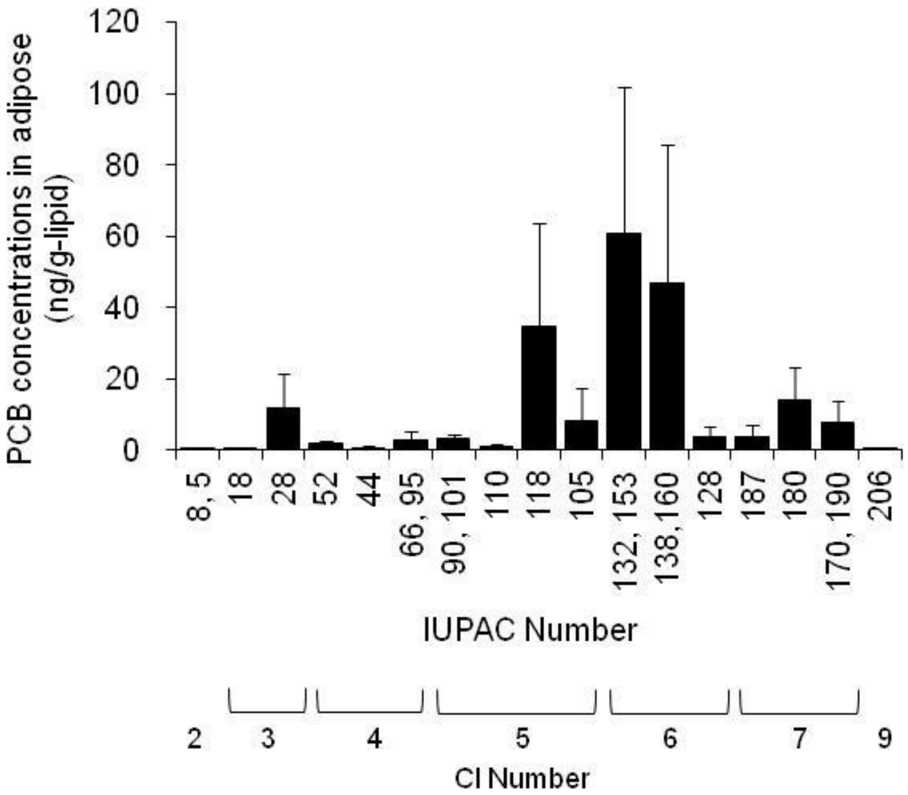

Figure 3

PCB congener compositions in abdominal adipose tissues of short-tailed shearwaters that ingested plastics. Cl Number : numbers of chlorines substituted in biphenyl.

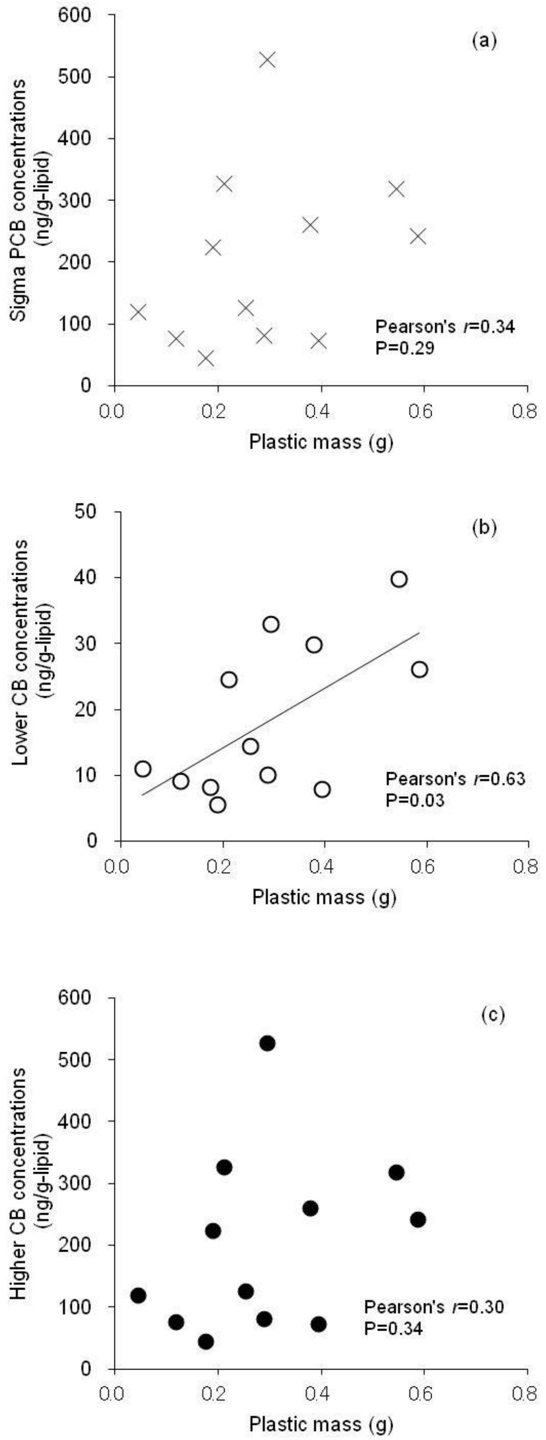

Figure 4

Relationships between ingested plastic mass and concentrations of (a) total PCBs, (b) lower-chlorinated congeners (Cl Number 2–4), and (c) higher-chlorinated congeners (Cl Number 5–9) in abdominal adipose tissues of shearwaters that ingested plastics.

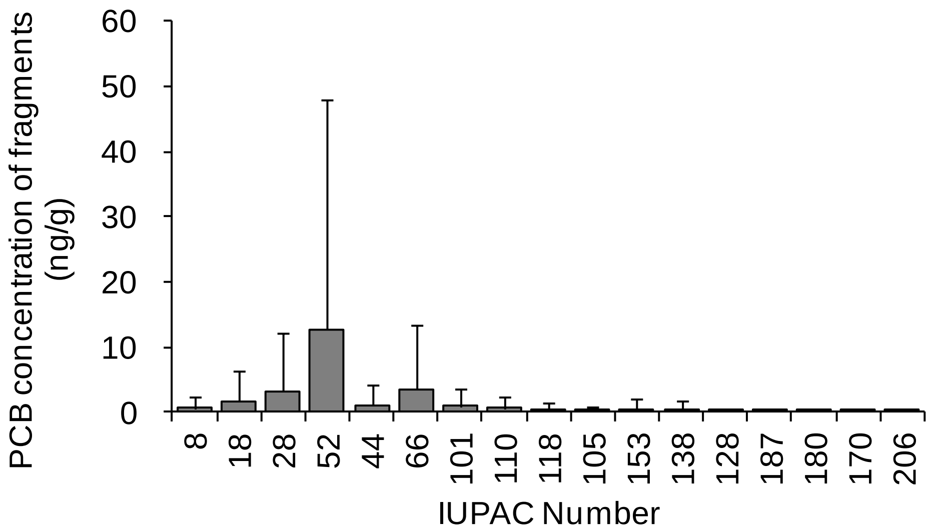

Figure 5

PCB congener compositions of plastic fragments from Central Pacific Gyre (data from Hirai et al. 2011).

Table 1 Number (pieces) and mass (g) by the product type of plastics found in short-tailed shearwater, 2003 and 2005.

			Product type					
Year			Resin pellet	Fragments	Fiber	Foam	Sheet	Total
2003 (n=87)								
	Number	%	20.7	60.4	7	0.8	11.2	
		Average	2.8	8.1	0.9	0.1	1.5	13.4
		sd	3.0	6.5	1.6	0.6	2.7	9.6
	Mass	%	30.5	59.8	5.3	0.6	3.9	
		Average	0.066	0.130	0.012	0.0013	0.008	0.218
		sd	0.085	0.114	0.074	0.008	0.019	0.187
2005 (n=12)								
	Number	%	8.3	56.3	6.2	0	29.2	
		average	2.3	15.3	1.7	0.0	7.9	27.1
		sd	1.9	8.4	2.3	0.0	19.4	25.6
	Mass	%	16.1	75	0.7	0	8.2	
		average	0.046	0.217	0.002	0.000	0.024	0.289
		sd	0.050	0.115	0.004	0.000	0.048	0.163
Total of 2003 and 2005 (n=99)								
	Number	%	18.0	59.5	6.8	0.6	15.1	
		average	2.7	8.9	1.0	0.1	2.3	15.1
		sd	2.9	7.1	1.7	0.6	7.3	13.2
	Mass	%	28.2	62.1	4.6	0.5	4.6	
		average	0.064	0.141	0.010	0.001	0.010	0.226
		sd	0.082	0.117	0.070	0.008	0.025	0.185

Table 2 Number (pieces) and mass (g) by the polymer type of plastics found in short-tailed shearwater, 2005.

		Polymer type					
		Float[a]		Sink[b]			
		PE	PP	PC/ABS	PS	NI	Total
Number	%	50.5	22.8	3.4	0.6	22.8	
	average	13.7	6.2	0.9	0.2	6.17	27.1
	sd	10.0	7.5	1.2	0.4	8.30	25.6
Mass	%	67.9	21.8	2.2	1.8	6.3	
	average	0.196	0.063	0.006	0.005	0.018	0.289
	sd	0.136	0.053	0.008	0.015	0.015	0.163

[a] Polymer gravity <1.0

[b] Polymer gravity >1.0