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Mercury exposure and short-term consequences on physiology and reproduction in Antarctic petrels☆

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ABSTRACT

Mercury (Hg) is a pervasive contaminant reaching Antarctic environments through atmospheric transport and deposition. Seabirds as meso to top predators can accumulate high quantities of Hg through diet. Reproduction is one of the most sensitive endpoints of Hg toxicity in marine birds. Yet, few studies have explored Hg exposure and effects in Antarctic seabirds, where increasing environmental perturbations challenge animal populations. This study focuses on the Antarctic petrel *Thalassoica antarctica* from Svarthamaren, Antarctica, where the world's largest breeding population is thought to be in decline. Hg and the stable isotopes of carbon ($\delta^{13}C$, proxy of feeding habitat) and nitrogen ($\delta^{15}N$, trophic position/diet) were measured in red blood cells from 266 individuals over two breeding years (2012–13, 2013–14). Our aims were to 1) quantify the influence of individual traits (size and sex) and feeding ecology (foraging location, $\delta^{13}C$ and $\delta^{15}N$ values) on Hg exposure, and 2) test the relationship between Hg concentrations with body condition and breeding output (hatching success and chick survival). Hg concentrations in Antarctic petrels (mean ± SD, 0.84 ± 0.25, min-max, 0.42–2.71 μg g^{-1} dw) were relatively low when compared to other Antarctic seabirds. Hg concentrations increased significantly with $\delta^{15}N$ values, indicating that individuals with a higher trophic level (i.e. feeding more on fish) had higher Hg exposure. By contrast, Hg exposure was not driven by feeding habitat (inferred from both foraging location and $\delta^{13}C$ values), suggesting that Hg transfer to predators in Antarctic waters is relatively homogeneous over a large geographical scale. Hg concentrations were not related to body condition, hatching date and short-term breeding output. At present, Hg exposure is likely not of concern for this population. Nevertheless, further studies on other fitness parameters and long-term breeding output are warranted because Hg can have long-term population-level effects without consequences on current breeding success.

1. Introduction

Increasing evidence shows that Antarctica is exposed to pervasive contaminants of natural and anthropogenic origins (Kallenborn et al., 2013; Mastromonaco et al., 2016). For instance, mercury (Hg), a non-essential metal, can travel long distances under its gaseous, elemental form (Fitzgerald et al., 2007) from its emission areas in industrialized countries through atmospheric transport, and reach Antarctica (Mastromonaco et al., 2016). There, Hg enters marine and terrestrial environments through wet and dry deposition processes, especially, but not exclusively, during springtime atmospheric Hg depletion events (Ebinghaus et al., 2002; Mastromonaco et al., 2016). Although Hg is partly re-emitted into the air, a fraction of waterborne Hg is assimilated by phyto- and zooplankton, in particular when Hg is under its methylated form (Morel et al., 1998). Once assimilated, methyl-Hg biomagnifies up the food web, with increasing Hg concentrations in tissues of organisms at higher trophic levels (Atwell et al., 1998; Bargagli et al., 1998). Upper predators such as seabirds can thus be exposed to large

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quantities of Hg via food intake (Bargagli et al., 1998). Consequently, seabirds are increasingly used as bioindicators of Hg distribution in the marine environment, including the polar regions (Carravieri et al., 2016; Fort et al., 2014; Polito et al., 2016), and are susceptible to Hg toxicity both at the individual and population levels (Goutte et al., 2014a,b; Tartu et al., 2013, 2016). In contrast to the Arctic, where spatio-temporal trends and negative effects of seabird exposure to Hg are relatively well-known (e.g., Bond et al., 2015; Braune et al., 2014a; Dietz et al., 2013; Fort et al., 2016, 2014; Goutte et al., 2015; Scheuhammer et al., 2015; Tartu et al., 2013), Hg occurrence and toxicity in Antarctic species are poorly studied. Hg exposure has mainly been assessed in penguins in a variety of tissues (Brasso et al., 2015; Carravieri et al., 2016) especially in West Antarctica (e.g., Ancora et al., 2002; Brasso et al., 2012; dos Santos et al., 2006; Jerez et al., 2011). By contrast, Antarctic flying seabirds have received much less attention (Tartu et al., 2014, 2015); most studies have reported Hg concentrations in eggs or tissues within a limited number of individuals, revealing similar levels to Arctic species, despite lower Hg concentrations in abiotic matrices (Bargagli et al., 1998; Calle et al., 2015; Cipro et al., 2017a; Nygård et al., 2001). Flying seabirds usually have larger foraging ranges than penguins during the breeding and/or wintering periods (BirdLife International, 2004), and thus visit a larger range of sites with potentially contrasting Hg bioavailability. As such, flying seabirds may be more at risk of exposure to high quantities of Hg.

Hg is a potent neurotoxin and an endocrine disruptor (Tan et al., 2009; Wolfe et al., 1998), and it has also been associated with decreased body condition and immune responses (Scheuhammer et al., 2007; Wayland et al., 2002). In aquatic and marine birds, reproduction is one of the most sensitive endpoints of toxicity (Evers et al., 2008; Wolfe et al., 1998). Specifically, Hg can reduce egg hatchability and embryo survival (Scheuhammer et al., 2007), but it can also impact parents' breeding decisions, behaviour and investment (Evers et al., 2008; Goutte et al., 2015; Tartu et al., 2013, 2015), with negative fitness consequences such as decreased breeding success over the short- and long-term (Evers et al., 2008; Goutte et al., 2014a,b). Antarctic species may be particularly sensitive to the toxic effects of contaminants as they have to cope with multiple additional environmental stressors in this rapidly changing, extreme environment (Barbraud and Weimerskirch, 2001; Descamps et al., 2015; Goutte et al., 2014a). Therefore, more studies are required to determine Hg concentrations and effects in Antarctic flying bird species and thereby fully grasp exposure, toxic effects and ultimately population-level consequences of Hg in this region.

In this context, the present study focuses on the Antarctic petrel *Thalassoica antarctica*, from Svarthamaren, Dronning Maud Land, Antarctica. The Antarctic petrel is a long-lived, middle-sized seabird and one of the least-studied Antarctic species. Svarthamaren hosts the largest known colony of this seabird, totalling 200 000 breeding pairs historically (Mehlum et al., 1988; van Franeker et al., 1999). However, lower numbers have been reported recently (<100 000 breeding pairs, Descamps et al., 2016a and unpublished data), and the population is thought to be in overall decline. Evaluating exposure and potential negative effects of Hg in this population is thus a pressing priority. The present study has two main aims: first, to quantify Hg exposure and disentangle the influence of individual traits (body size and sex) and feeding ecology on Hg concentrations, and second, to relate individual Hg exposure to fitness components. To this end, Hg burdens were quantified in blood in a large number of individuals across two consecutive breeding years. Blood is considered to be an excellent tool to evaluate Hg exposure in seabirds: circulating quantities are representative of recent dietary intake and are in equilibrium with internal tissue burdens (Bearhop et al., 2000; Fort et al., 2015; Fromant et al., 2016). Feeding ecology was evaluated by measuring blood values of the stables isotopes of carbon ($\delta^{13}C$) and nitrogen ($\delta^{15}N$), which are chemical proxies of feeding habitat and trophic position, respectively (Newsome et al., 2007), and by equipping birds with Global Positioning System (GPS) loggers. During the breeding period, Antarctic petrels forage in high Antarctic waters over a large spatial scale, travelling up to 2000 km from the colony (Descamps et al., 2016b). Latitude-dependent Hg exposure has been previously shown in subantarctic (Carravieri et al., 2014a) and Antarctic (Tartu et al., 2014) seabirds. We thus predicted a geographical variation in exposure in individuals feeding at distant oceanic sites. Antarctic petrels are mainly krill-eaters, but their diet at Svarthamaren also includes a variable proportion of fish and squid (Descamps et al., 2016b). Given the biomagnifying properties of Hg, we predicted individuals with higher $\delta^{15}N$ values (i.e. feeding at higher trophic positions) to bear higher Hg concentrations. Considering previous evidence of Hg effects on polar seabirds, we predicted individuals with high Hg concentrations to have a low body condition index and decreased breeding output (later hatching date, lower hatching success and chick survival) (Tartu et al., 2014, 2015).

2. Material and methods

2.1. Study site and sampling procedure

Fieldwork was carried out at the Svarthamaren Antarctic petrel colony (71°53′S, 5°10′E) where Antarctic petrels lay a single egg at the end of November/early December. Chicks hatch around mid-January and fledge early March. Both parents contribute to incubation and chick rearing, with the chick being continuously guarded for the first 7–15 days following hatching (Lorentsen and Røv, 1995). A total of 266 breeding individuals were captured during incubation or chick brooding over two breeding years (2012–13 and 2013–14). After taking morphometric measures (see section 2.2.), a small amount of blood (<2 ml) was sampled from the brachial vein, and temporarily preserved unfrozen in heparinized microtubes until being centrifuged. Red blood cells and plasma were then kept frozen in separate microtubes until subsequent analyses (see section 2.3). Some individuals (N = 91) were equipped with GPS loggers, which were attached to tail feathers using Tesa® tape (Descamps et al., 2016b; Tarroux et al., 2016; see also section 2.4.). Birds were immediately released onto their nests after handling, which typically lasted 10–20 min. Upon retrieval, GPS birds were sampled for blood again and weighed following the same procedures. In addition, all nests were monitored every other day on average from incubation to chick-rearing as presented in Descamps et al. (2015), to estimate hatching date, hatching success and chick survival. For logistical reasons, nests could not be monitored until fledging and chick survival was therefore estimated 15 days after hatching.

2.2. Morphological measurements and body condition index

Birds were weighed with a 1000-g Pesola balance (precision ± 5 g), their bill height and culmen measured with a calliper (±0.1 mm), and their wing length measured with a ruler (±1.0 mm). In order to define body condition, the “scaled mass index” (Peig and Green, 2010, 2009), hereafter SMI, was calculated following Meillère et al. (2015). This body condition index adjusts the mass of all individuals to that expected if they had the same body size (Peig and Green, 2009).

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