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Mercury exposure in a large subantarctic avian community

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ABSTRACT

Mercury (Hg) contamination poses potential threats to ecosystems worldwide. In order to study Hg bioavailability in the poorly documented southern Indian Ocean, Hg exposure was investigated in the large avian community of Kerguelen Islands. Adults of 27 species (480 individuals) showed a wide range of feather Hg concentrations, from 0.4 ± 0.1 to 16.6 ± 3.8 μg g^{-1} dry weight in Wilson's storm petrels and wandering albatrosses, respectively. Hg concentrations increased roughly in the order crustacean- < fish- ≤ squid- ≤ carrion-consumers, confirming that diet, rather than taxonomy, is an important driver of avian Hg exposure. Adults presented higher Hg concentrations than chicks, due to a longer duration of exposure, with the only exception being the subantarctic skua, likely because of feeding habits' differences of the two age-classes in this species. High Hg concentrations were reported for three species of the poorly known gadfly petrels, which merit further investigation.

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1. Introduction

Mercury (Hg) is a pervasive non-essential metal affecting ecosystem health. Despite its natural origin, Hg has been mobilized by human activities such as mining and fossil-fuel combustion (UNEP, 2013), thus resulting in a significant increase in Hg available for cycling among land, air and the ocean since pre-industrial times (Selin, 2009). Hg emissions are transported through the atmosphere on a hemispheric-to-global scale, allowing for transport to remote locations such as sub-polar and polar regions (Fitzgerald et al., 1998). After atmospheric deposition and through biotic and abiotic mechanisms, Hg is readily transformed in methyl-Hg, the highly toxic form that bioaccumulates in the tissues of living organisms and biomagnifies up food webs, especially in aquatic environments (Fitzgerald et al., 2007). Top predators are thus exposed to significant quantities of Hg *via* their diet, providing information on Hg bioavailability within their food webs (Morel et al., 1998). Among consumers, birds have varied levels of ecological, spatial and temporal integration of contaminants depending on species, and they have been identified as effective indicators of Hg bioavailability in both terrestrial and marine environments (Burger and Gochfeld, 2004; Solonen and Lodenius, 1990).

The Kerguelen Islands are a remote subantarctic archipelago in the southern Indian Ocean, where the level of Hg bioavailability is poorly documented (Bocher et al., 2003; Bustamante et al., 2003; Cipro et al., 2014; Cossa et al., 2011). This archipelago hosts a large and highly diverse avian assemblage (35 different breeding species). The community includes a few terrestrial species and many seabirds, with Sphenisciformes (penguins) and Procellariiformes (albatrosses and petrels) dominating by mass and numbers, respectively (Guinet et al., 1996; Weimerskirch et al., 1989). Overall Kerguelen seabirds feed on a few key species of marine organisms, including some crustaceans (euphausiids, hyperiids), fish (myctophids, notothenioids) and cephalopods (oceanic squids) (Bocher et al., 2001; Cherel et al., 2010; Cherel and Hobson, 2005; Guinet et al., 1996), with some seabirds relying extensively on carrion. This biological richness can be related to the large and productive shelf surrounding the archipelago (Blain et al., 2001). Kerguelen seabirds show a wide range of contrasted feeding strategies, with species foraging in the benthic and pelagic environments and ranging from neritic to oceanic waters. Noticeably, the oceanic species forage over a large latitudinal gradient, from subtropical to Antarctic waters (Supplementary Table S1). Kerguelen seabirds therefore offer a unique opportunity to study Hg bioavailability over diverse water masses of the Southern Ocean.

The present study aims to assess Hg bioavailability in the southern Indian Ocean by using birds from the Kerguelen Islands as bioindicators. Hg exposure was evaluated by using body feathers,

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because feathers are the main route of Hg excretion in birds (Braune and Gaskin, 1987). Importantly, this work complements a recent investigation on Hg in chicks (Blévin et al., 2013) by focussing on breeding adults and by including more species. While Hg concentrations in chick feathers are representative of a well-defined, relatively short period of exposure (the chick-rearing period), adult feathers provide a wider perspective on Hg exposure of the species over their whole life cycles (Evers et al., 2005). Thus adult feather Hg concentrations were determined in 27 representative species, including the only two terrestrial birds of the assemblage, in order to: (i) describe Hg exposure in a large number of sympatric bird species from the poorly documented southern Indian Ocean; (ii) compare the exposure pattern to that of avian communities from other subantarctic and oceanic remote locations worldwide; (iii) test the effect of age-class on feather Hg concentrations by using the recently published Hg data on chicks (Blévin et al., 2013), and (iv) investigate the influence of various factors (taxonomy, diet, feeding habitats, moulting patterns) on Hg exposure. Taxonomy, which was not tested in Blévin et al. (2013), was expected to play a minor role in explaining feather Hg concentrations when compared to feeding strategies, since diet is considered to be the main factor driving Hg variation in birds (Becker et al., 2002; Blévin et al., 2013; Bocher et al., 2003; Monteiro et al., 1998; Stewart et al., 1999). In addition, adult birds were expected to show higher feather Hg concentrations than chicks, as they are exposed over a longer period to Hg *via* their diet (Catry et al., 2008; Stewart et al., 1997).

2. Materials and methods

Fieldwork was carried out from 2003 to 2011 on the Kerguelen Islands (49°21′ S, 70°18′ E, Fig. 1), which are located in the southern part of the Polar Frontal Zone, in the immediate vicinity of the Polar Front (Orsi et al., 1995; Park and Gamberoni, 1997). Breeding adults from 27 bird species belonging to 5 orders and 10 families were sampled ($n = 5$ to 33 individuals per species, Supplementary Table S2). Sampling was conducted at different locations of the archipelago, depending on the species breeding sites. Resident neritic seabird species (Kerguelen shag and gentoo penguin) were sampled at colonies close to the open sea, while terrestrial species (lesser sheathbill and Kerguelen pintail) were sampled on islands of the large Morbihan Bay (closed sea). Birds were non-destructively captured by mist net or by hand, depending on species, and released immediately after sampling. A few whole body feathers (6–10) were pulled out from the lower back of the birds and then stored dry in sealed plastic bags until analysis at the University of La Rochelle, France.

Depending on bird and hence feather size, 1 to 5 whole feathers per individual were cleaned, oven-dried to a constant mass and homogenised as described in Blévin et al. (2013). An Advanced Mercury Analyzer spectrophotometer (Alted AMA 254) was used to measure total Hg, which approximates the amount of methyl-Hg in feathers (Bond and Diamond, 2009; Thompson and Furness, 1989a). For each individual, analyses were run in duplicate-triplicate by taking sub-samples of the homogenised feathers (relative standard deviation <10% for each individual). Accuracy was checked using certified reference material (Tort-2 Lobster Hepatopancreas, NRC, Canada; certified Hg concentration: 0.27 ± 0.06 μg g^{-1} dry weight). Our measured values were 0.24 ± 0.01 μg g^{-1} dry weight, $n = 22$. Blanks were analysed at the beginning of each set of samples and the detection limit of the method was 0.005 μg g^{-1} dry weight. Hg concentrations are presented μg g^{-1} dry weight (dw).

Statistical analyses were performed using R 2.15.1 (R Core Team, 2012). Data exploration was performed mainly following Zuur et al. (2010). The influence of taxa (species, genus, family and order) on adult feather Hg concentrations was tested by using generalized linear models (GLM) with a gamma distribution and an inverse link function. Model selection was based on Akaïke's Information Criteria adjusted for small sample sizes (AICc) (Burnham and Anderson, 2002). The sampling year was not included in the models because most species were sampled in only one year (Supplementary Table S2) and thus the year effect would be confounded by the species effect. Nonetheless, no inter-annual differences in feather Hg concentrations were found on the six species that were sampled in two different years (light-mantled sooty albatross, soft-plumaged and Kerguelen petrels, black-bellied storm petrel, South Georgia diving petrel and lesser sheathbill, data not shown). As biometric measurements were not performed on individual birds during the sampling procedure, the effect of size and mass on feather Hg concentrations could not be incorporated in the models. However, mean values of size and mass were obtained for each species from the literature (Supplementary Table S1) and their correlations with mean feather Hg concentrations were tested. Finally, the effect of age-class on feather Hg concentrations was investigated on 21 out of the 27 species by comparing adult data from the present study with chick data from the same Kerguelen locations (Blévin et al., 2013). A significance level of $\alpha < 0.05$ was used for all statistical tests. Results are means ± SD.

General information on the feeding ecology of Kerguelen birds was based on published and unpublished data obtained using various methods (stomach content and stable isotope analyses and tracking devices), and is summarized in Supplementary Table S1. Importantly, dietary information was restricted to the chick food, collected during the chick-rearing period, because parent birds carry significant amounts of food in their stomach at that time only. By contrast, adult diet is poorly known both during and outside the breeding period. The relationship between Hg exposure and trophic ecology was not studied here using stable isotopes, because of the uncoupled temporal integration of Hg and stable isotopes in feathers of adult birds (Bond, 2010; Thompson et al., 1998).

3. Results

Feather Hg concentrations were measured in a total of 480 adult birds from the Kerguelen Islands (details in Supplementary Table S2). Feather Hg concentrations varied widely within the avian community, with means ranging from 0.42 ± 0.13 to 16.6 ± 3.8 μg g^{-1} dw in Wilson's storm petrels and wandering albatrosses, respectively (Fig. 2). The lowest feather Hg concentration occurred in a South-Georgian diving petrel and the highest in a northern giant petrel (0.10 and 32.1 μg g^{-1}, respectively). Model selection showed that species was the most important factor explaining feather Hg concentrations when compared to other taxonomic levels (Table 1). Coefficients of variations (CV) also varied considerably between species, ranging from 13 to 109% (Supplementary Table S2). Mean feather Hg concentration was significantly related to species size (Pearson correlation, $r = 0.50$, $p = 0.008$, $n = 27$), but not to species mass ($r = 0.23$, $p = 0.256$, $n = 27$).

By combining feather Hg data of adults from this study with those of chicks from Blévin et al. (2013), a total of 654 individuals from 21 seabird species were analysed. The model including

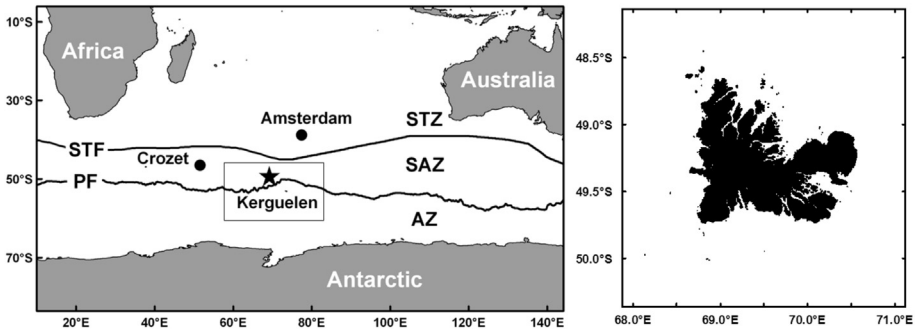

Fig. 1. Map and location of the Kerguelen Islands and of the main oceanic fronts and zones within the southern Indian Ocean. Abbreviations: STF, Subtropical Front; PF, Polar Front; STZ, Subtropical Zone; SAZ, Subantarctic Zone; AZ, Antarctic Zone.

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