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Trophic ecology drives contaminant concentrations within a tropical seabird community☆

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A B S T R A C T

To support environmental management programs, there is an urgent need to know about the presence and understand the dynamics of major contaminants in seabird communities of key marine ecosystems. In this study, we investigated the concentrations and trophodynamics of trace elements in six seabird species and persistent organic pollutants (POPs) in three seabird species breeding on Grand Connétable Island (French Guiana), an area where the increase in human population and mining activities has raised concerns in recent years. Red blood cell Hg concentrations in adults were the highest in Magnificent frigatebirds *Fregata magnificens* (median: 5.6 μg g^{-1} dw; range: 3.8–7.8 μg g^{-1} dw) and lowest in Sooty terns *Onychoprion fuscatus* (median: 0.9 μg g^{-1} dw; range: 0.6–1.1 μg g^{-1} dw). Among POPs, dichlorodiphenyldichloroethylene (*p,p'*-DDE) was the most abundant compound in plasma of Cayenne terns *Thalasseus sandvicensis* (median: 1100 pg g^{-1} ww; range: 160 ± 5100 pg g^{-1} ww), while polychlorinated biphenyls (PCBs) were the most abundant compound class in plasma of Magnificent frigatebirds (median: 640 pg g^{-1} ww; range 330 ± 2700 pg g^{-1} ww). While low intensity of POP exposure does not appear to pose a health threat to this seabird community, Hg concentration in several adults Laughing gulls *Leucophaeus atricilla* and Royal terns *Thalasseus maximus*, and in all Magnificent frigatebirds was similar or higher than that of high contaminated seabird populations. Furthermore, nestling red blood cells also contained Hg concentrations of concern, and further studies should investigate its potential health impact in this seabird community. Differences in adult trophic ecology of the six species explained interspecific variation in exposure to trace element and POPs, while nestling trophic ecology provides indications about the diverse feeding strategies adopted by the six species, with the consequent variation in exposure to contaminants.

1. Introduction

Exposure to persistent toxicants may have detrimental effects on reproductive success, immunity, regulation of oxidative balance, endocrine system and survival perspectives of wildlife, even years after these toxicants have been banned (Burger and Gochfeld, 2001; Costantini et al., 2014; Erikstad et al., 2013; Goutte et al., 2015; Tartu et al., 2015a, 2015b). Persistent organic pollutants (POPs) are among the major contaminants currently detected in wildlife, of which polychlorinated biphenyls (PCBs) remain the most dominant chemical class despite that they have been banned more than 30 years ago (Tartu et al., 2015c). Among trace elements there has been growing interest in mercury (Hg), lead (Pb), and cadmium (Cd) because of their well-known detrimental effects on vertebrates

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(Beyer et al., 2011). For example, after Hg is deposited in aquatic ecosystems, it is rapidly transformed by microorganisms into methyl-Hg, its most toxic form that bioaccumulates in organisms and biomagnifies in food webs (Fitzgerald et al., 2007). Because seabirds are apex long-lived predators, they are particularly exposed to these major environmental contaminants (Rowe, 2008), and are therefore utilized as sentinel species for environmental monitoring (Furness and Camphuysen, 1997; Moreno et al., 2011).

While considerable attention has been paid to the occurrence and health effects of these contaminants in sub-polar and polar regions due to their potential to act as final sink (Blévin et al., 2016; Tartu et al., 2015b, 2016), comparatively less attention has been given to wildlife from other geographical regions (Bastos et al., 2015; Costantini et al., 2017; De Andres et al., 2016; Frery et al., 2001), especially in South America (De Andres et al., 2016; Guirlet et al., 2010; Sebastiano et al., 2016). This is surprising because local releases of contaminants (e.g. Hg) from major mining activities in the Amazon area may be considerable (Fujimura et al., 2012; Lodenius and Malm, 1998). Although to the best of our knowledge there are no sources of organic pollutants, the long-range transport of these contaminants and the bioaccumulation and biomagnification processes they undergo, might pose a threat to top predators. The Grand Connétable Island, a small rocky island located off the coast of French Guiana and close to the Brazilian border, with its strategic position for wildlife and the presence of six breeding seabird species, offers a unique opportunity to assess the presence and quantify the concentrations of both organic and inorganic pollutants in a tropical seabird community. Moreover, given the expected high variation in trophic ecology of the seabirds breeding on the Grand Connétable Island, this also enabled us to assess the importance of feeding ecology in driving inter- and intraspecific variation in exposure to contaminants.

To this end, we quantified the concentrations of POPs and trace elements in plasma and red blood cells, respectively, in the seabird community on Grand Connétable Island. We also measured the stable nitrogen and carbon isotope composition of red blood cells to test whether trophodynamics explain among and within species variation in contaminant burden. Of the trace elements, we focused particularly on Hg given the growing concern about the impact of this element on the health of South-American ecosystems.

2. Materials and methods

2.1. Sample collection

In 2013 we performed sample collection on the Grand Connétable Nature Reserve, a small island located 18 km off Cayenne (French Guiana, 4°49′30 N; 51°56′00 W). The seabird community of Grand Connétable Island typically includes six species: the Laughing gull *(Leucophaeus atricilla)*, the Brown noddy *(Anous stolidus)*, the Royal tern *(Thalasseus maximus)*, the Cayenne tern *(Thalasseus sandvicensis)*, the Magnificent frigatebird *(Fregata magnificens;* hereafter Frigatebird*)*, and the Sooty tern *(Onychoprion fuscatus)* (Dujardin and Tostain, 1990). These six seabird species differ in both feeding style (pelagic versus benthic) and foraging area (inshore versus offshore). For instance, Frigatebirds feed on both pelagic and benthic fish by surface dipping, kleptoparasitism and opportunistic feeding (mostly on shrimp trawler discards), and although most foraging occurs in coastal waters, some foraging trips can exceed 200 km away from the breeding colony (Weimerskirch et al., 2003). Finally, they are also seen to follow tuna school formations because tuna and other marine predators push other small fish toward the surface, making them accessible to frigatebirds. The Laughing gull feeds on coastal pelagic fish, marine invertebrates and fishery discards, while the Brown noddy feeds on fish and squid in offshore waters by dipping the surface, and may show kleptoparasitism. Terns diet consists predominantly of small fish, squids and crustaceous, obtained by dipping the surface and occasionally diving (del Hoyo et al., 1996; Dujardin and Tostain, 1990).

Adult seabirds were sampled during the incubation or early chick rearing (27th to 30th of May) while nestlings were sampled within a few weeks after adult sampling (24th to 26th of June). A total of 101 adults and 102 nestlings were captured. Since all nestlings were captured by hand on their nests while adults were captured by mist nets (or, in case of frigatebirds, were captured with a noose attached to a fishing rod), adults and nestlings are likely unrelated to each other. For the Laughing gull, Royal tern, Cayenne tern, Sooty tern and Brown noddy, the egg laying period usually begins around mid-April and ends around the end of April (Dujardin and Tostain, 1990), and the incubation period lasts 25–30 days (except for the Brown noddy that can take a few more days; Dujardin and Tostain, 1990). Therefore, nestlings of these species had approximately the same age. Frigatebird, instead, were a few weeks older than the nestlings of the other species, with an approximate age of three to four months (the age of nestling frigatebirds was incorrectly reported in Sebastiano et al., 2016). Blood samples (around 2 mL) were collected from the brachial vein using a heparinized syringe (25 G needle) within a few minutes after capture, and samples were immediately put on ice. Blood was then centrifuged within one hour to separate plasma and red blood cells. Both fractions were kept at −20 °C until laboratory analyses.

2.2. Stable isotope analysis

The analysis of the carbon and nitrogen stable isotopes is considered an important tool for the interpretation of both the foraging area and the trophic level of the species. In marine ecosystems, higher nitrogen values are associated with higher trophic level prey, e.g. bigger prey (Overman and Parrish, 2001), while the carbon stable isotopes can decrease with decreasing latitudes (Kelly, 2000) and seem to decrease from the coast to the open sea in the Southern Indian Ocean (Cherel and Hobson, 2007), even if proofs of such stratification in the Southern Atlantic Ocean are not available. In this study, the stable carbon and nitrogen values were measured in red blood cells, therefore providing trophic information integrated over a few weeks prior to sampling (Hobson and Clark, 1993; Newsome et al., 2007). The composition of the carbon and nitrogen isotopes of the species, which provides information on the isotopic niches of the birds, was used as a proxy of their ecological niche (Jackson et al., 2011). Analyses were carried out following a previous protocol (Sebastiano et al., 2016), and results are expressed as δ (‰) for δ^{13}C and δ^{15}N, respectively, calibrated against the international isotopic references (atmospheric nitrogen for δ^{15}N and Pee Dee Belemnite for δ^{13}C). The experimental imprecision, based on secondary isotopic reference material, did not exceed ± 0.15 and ± 0.20‰ for δ^{13}C and δ^{15}N, respectively.

2.3. Contaminant analysis

Trace element concentration analyses (Ag, As, Cd, Co, Cr, Cu, Fe, Hg, Mn, Ni, Pb, Se, V, and Zn) were performed by the Littoral Environnement et Sociétés (LIENSs) laboratory on lyophilized red blood cells as previously described (Sebastiano et al., 2016). In brief, an Altec Advanced Mercury Analyzer AMA 254 spectrophotometer was used for the quantification of total Hg, while the other trace elements were quantified using a Varian Vista-Pro ICP-OES or a Series II Thermo Fisher Scientific ICP-MS (aliquots mass: 3–8 mg for AMA and 50–200 mg dw for ICP). Analyses on blanks and Certified Reference Materials (CRM) from NRCC (dogfish liver DOLT-4 and