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Pierrick Bocher, Pierrick Bocher, Florence Caurant, Pierre Miramand ...+2 more authors

Institutions: University of La Rochelle, Centre national de la recherche scientifique

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Influence of the diet on the bioaccumulation of heavy metals in small burrowing petrels from the Kerguelen Islands

Pierrick Bocher, Florence Caurant, Pierre Miramand, Yves Cherel, Paco Bustamante

#P. Bocher* §, F. Caurant*, P. Miramand*, Y. Cherel §, P. Bustamante*

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* Laboratoire de Biologie et Environnemnt Marins, EA 3168, Université de La Rochelle, Avenue Michel Crépeau, F-17042 La Rochelle cedex, France

§ Centre d'Etudes Biologiques de Chizé, UPR 4701 du Centre National de la Recherche Scientifique, F-79360 Villiers-en-Bois, France

Corresponding author : P. Bocher

e-mail : bocher@cebc.cnrs.fr

Abstract

Concentrations of cadmium, mercury, copper and zinc were measured in liver, muscle, kidney and stomach contents and the preys of five species of small burrowing petrels : South Georgian (*Pelecanoides georgicus*) and common (*P. urinatrix*) diving petrels, thin-billed (*Pachyptila belcheri*) and Antarctic (*P. desolata*) prions, and blue petrel (*Halobaena caerulea*). Inter-specific differences were significant for zinc concentrations in liver and kidney and for copper concentrations in the muscle. Blue petrel exhibited the highest mercury concentrations in the liver, but no significant difference were found for cadmium. Since they are very closely related species, concerning moult schedule, body size and life span (at least for four of them), their diet has been considered in order to evaluate its influence on heavy metal bioaccumulation. Both instantaneous exposure (with stomach content concentrations) and long term exposure –by the heavy metals analysis in the most frequent preys of their diet- have been evaluated. The most evident result is the influence of fish in the diet on the mercury levels. Diet does not seem to be discriminant for cadmium concentrations in the seabirds.

Introduction

The use of seabirds as monitors of the marine environment has largely been discussed (Furness & Camphuysen, 1997 ; Furness & Greenwood, 1993), and it has been shown that they are a suitable choice to play a role as bioindicators of food supplies (Cairns, 1987 ; Barrett & Krasnov, 1996 ; Cherel & Weimerskirch, 1995 ; Montevecchi, 1993 ; Montevecchi & Myers, 1997 ; Regehr & Montevecchi, 1997), but also of pollution, and especially oil pollution (Burger, 1993 ; Camphuysen & Van Franeker, 1992). The fact that seabirds are most often top predators and long-lived species means also that they are useful as biomonitors of pollutants such as organochlorines or heavy metals. Nevertheless, since they are entirely anthropogenic, the biological significance of organochlorines is best understood, compared to heavy metals which occur naturally in marine systems and so are always present in the tissues of marine vertebrates (Thompson, 1990). Among the heavy metals, cadmium and mercury have the ability to bioaccumulate in food webs and most of the long-lived predatory species exhibit high concentrations of these both toxic elements. This process is particularly exacerbated in high latitudes (Bustamante et al., 1998 ; Dietz et al., ; 1996 Dietz et al., 1998 ; Elliot & Scheuhammer, 1997 ; Wagemann et al., 1990) where the baseline concentrations are probably higher than in the temperate latitudes. This implies that it is difficult to assess the anthropogenic influence on the levels of trace elements found in the top predators of the polar and sublue petrelolar areas even if anthropogenic inputs for most of them - and especially cadmium and mercury - are considered more important than natural sources in their biogeochemical cycle (Walker et al., 1995). This is all the more difficult that a great number of factors -such as phylogeny, moult pattern, sex, life span, diet- are liable to influence trace elements bioaccumulation in seabird tissues, cadmium and mercury levels showing the largest variations among seabird species (Furness, 1993 ; Stewart et al., 1997 ; 1999 ; Stewart & Furness, 1998 ; Walsh, 1990). Among all these factors, it has been supposed that dietary was one of the more discriminant factor for the differences in mercury and cadmium concentrations. Thus cephalopods have been determined to be an important vector for the transfer of cadmium to top marine predators (Bustamante et al., 1998 ; Caurant & Amiard-Triquet, 1995 ; Honda et al., 1983 ; Muirhead & Furness, 1988), and Stewart et al. (1999) have shown that seabird species including appreciable amount of crustacea in their diet had lower cadmium and mercury concentrations than those which tended to rely predominantly on squid and fish alone. Nevertheless, trace element concentrations found in crustaceans from the Antarctic Ocean also exhibit considerable interspecific heterogeneity (Petri & Zauke, 1993), which implies that the interpretation of the concentrations in predators probably require a sharper knowledge of the diet.

This study records the cadmium, mercury, zinc and copper concentrations in individuals of five species of small burrowing petrels from Kerguelen Islands (South Indian Ocean) : South Georgian (*Pelecanoides georgicus*) and common (*P. urinatrix*) diving petrels, thin-billed (*Pachyptila belcheri*) and Antarctic (*P. desolata*) prions, and blue petrel (*Halobaena caerulea*), including their stomach contents. Their diet has been deeply investigated (Bocher, 2000, 2001) and consequently the same trace elements have been determined in their main prey species. This provided a unique opportunity to investigate the importance of the influence of the diet on trace element levels in closely related species, and the suitability of using these trace elements as tracers of the diet of species and /or populations.

Materials and methods

Sampling

Fieldwork was carried out at Kerguelen Islands, Southern Indian Ocean. Study colonies of birds were located in two adjacent islands of the "Golfe du Morbihan", a large gulf (about 700 km^2) located in the eastern part of the archipelago, where large populations of petrels breed (Weimerskirch et al. 1989). Blue petrels, thin-billed prions and common diving petrels were studied on Mayes Island (49°28'S, 69°57'E), and South Georgian diving petrels and Antarctic prions on Verte Island (49°31'S, 70°04'E).

Seabirds were collected during several breeding seasons mainly on Mayes and Verte Islands but also in others places on the archipelago. In order to not kill bird, we collected freshly dead birds as the result of predation by subantarctic skua or collisions of petrels at night with lights of buildings or ships. The number of birds so obtained varied greatly for each species and no birds were sampled unless they were largely intact and freshly dead. The birds collected could include both breeding adults and immature non-breeders which were generally not possible to discriminate.

Stomach samples were collected during the middle of the chick-rearing period in 1995 except for thin-billed prion which was sampling in summer 1999. Because breeding cycles are not synchronised between species (Weimerskirch et al. 1989), the time of food sampling varied according to the species and the whole study period occurring roughly from mid-January to mid-March. Breeding adult petrels and prions were caught at night by mist netting or in burrows fitted with trap doors at the entrance to retain the adult before the chick was fed. Food samples from blue petrel, thin-billed prion and antarctic prion were collected by spontaneous regurgitation, and those from common diving petrel and South Georgian diving petrel by stomach lavage following Gales (1987) and Bocher et al. (2000). No individual bird was sampled more than once.

Macrozooplankton and micronekton samples were collected on cruises of the R/V La Curieuse during austral summer. The amphipods (*Themisto gaudichaudii*) and the copepods

(Paraeuchaeta antarctica) were sampling inside the golfe du Morbihan in March 1997 with an ORI-net (2 m2, 1 mm mesh Antarctic prionerture). The amphipods (*Themisto gaudichaudii*), the euphausiids (*Euphausia vallentini* and *E. triacantha*) and myctophids were collected outside the gulf in eastern part of the peri-insular shelf in February 1998, using a IYGPT trawl (International Young Gadoid Pelagic Trawl; opening: 12 x 7 m) with 10-mm meshsize in the codend.

Birds, stomach samples, macrozooplankton and micronekton samples were weighed, immediately frozen and stored at –20°c on fieldwork before to be sent to the Laboratory of Biology and Environment in La Rochelle (France), for analysis. All birds were defrosted overnight, sexed and samples of liver, kidney and pectoral muscles removed. Each stomach sample was thawed and placed in a flat-bottomed tray for visual estimation of volume of main prey. For each main crustacean species from zooplanktonic samples, three sets of 5 to 40 individuals were constituted and the smallest and the tallest individual measured in order to establish the size range. The euphausiid *Thysanoessa* sp. was absent in zooplankton samplings and provided from stomach samples of South Georgian diving petrel which were constituted only from this species. Myctophids and squids were individually analysed.

Heavy metal analysis

Stomach contents, samples of preys and samples of bird tissues were analysed in the same way. For cadmium (Cd), copper (Cu) and zinc (Zn) determination, two aliquots of aprox. 200 or 300 mg of each homogenised dried samples were digested in 5 ml of supra-pure 65% nitric acid at 80°C on a hot plate until the solution was clear. After evaporation, the residues were dissolved in 10ml of 0.3N supra-pure nitric acid. Cd, Cu and Zn were determined by Flame Atomic Absorption Spectrophotometry (AAS) with a Varian spectrophotometer Spectra 250 Plus with a deuterium background correction.

Mercury analysis were carried out with an Automatic Mercury Analyser spectrophotometer, ALTEC AMA 254, which does not require an acid-digestion of the samples. Aliquots ranging from 10 to 50 mg of dried samples were directly analysed after they have been inserted in the oven of the apparatus. After drying, the samples is heated under oxygen atmosphere for 3 minutes and subsequently amalgamated on Au-net. Then the net was heated after a 45 sec. waiting time to liberate the collected Hg, which was then measured by absorption spectrophotometry.

Accuracy and reproducibility of the methods were tested by using dogfish liver (DOLT-2) and muscle (DORM-2) (National Research Council, Canada) reference standards. Standard and blanks were analysed along with each set of samples. Measurements were also validated by the IAEA Intercalibration Exercise (Coquery et al., 2001).

Concentrations are expressed in $\mu g.g^{-1}$ wet weight (w.w.), in order to interpret our results in the context of the transfer of metals between the preys and their predators. Nevertheless, the percentage of humidity is included in the tables in order to facilitate the comparison with other studies.

Results

Diet of the different species

The diet of these species have been studied in details elsewhere on a greater number of individuals (Bocher et al., 2000 ; Bocher, 2001), but the composition by estimated volume of the stomach contents of the birds analysed for trace elements is shown in Fig.1. Crustaceans dominated in the stomach contents of all the species except the blue petrels. One species predominated in common diving petrel, South Georgian diving petrel and antarctic prion, whereas crustaceans were more diversified in thin-billed prion. The amphipod *Themisto gaudichaudii* was the main prey in common diving petrel, whereas it was the euphausiid *Thysanoessa* sp. in South Georgia diving petrels, and the euphausiids *Euphausia vallentini* in

Antarctic prion, which also exhibited a few percentage of *T. gaudichaudii*. *E. vallentini* and *Thysanoessa sp* were the two main preys in thin-billed prion, but *T. gaudichaudii* and the copepod *Paraeuchaeta antarctica* were also present. Fish was the main prey and represented more than 50% of the estimated volume of the stomach contents of blue petrel. Fish were also present and accounted for more than 25% and for a few percentage (by volume) of the stomach contents of thin-billed prion and Antarctic prion respectively (Fig.1).

Heavy metal in bird tissues

Comparison between tissues

Cadmium, copper, zinc and mercury concentrations in liver, muscle and kidney tissues of the five species are presented in Table 1.

In all species, cadmium concentrations were higher in kidney than in liver and muscle tissues, and mercury concentrations were higher in liver than in kidney and muscle tissues.

For the essential metals, zinc and copper, the highest levels varied between tissues according to the species. Nevertheless, copper concentrations were always lower in kidney tissue, and zinc concentrations were always lower in muscle tissue.

The variability of coefficients of variation reflected the individual variations typical of each element in one species : a low coefficient reflects limited individual variations as a consequence of homeostasis processes, which is usually the case for the essential elements as copper and zinc. If we only consider blue petrels and common diving petrels, the species with larger sample sizes, there is no such a big difference of coefficients of variation between essential and non essential elements in some tissues and they did not follow the same pattern between both species. Thus blue petrels exhibited relatively high coefficients of variation for copper in the liver (as much as cadmium) compared to common diving petrels, and common diving petrels exhibited particularly low coefficients of variation for mercury in the three tissues.

Comparison between species

Since the number of individuals were low in species, statistical comparisons have been carried out by using the Kruskal-Wallis non parametric test. Significant differences have been found for zinc concentrations in the liver ($T = 11.8$; $p = 0.019$), and zinc concentrations in the kidney ($T = 12.7$; $p = 0.013$). Blue petrels exhibited the highest zinc concentrations in the liver (62 $\mu g.g^{-1}$), followed by thin-billed prions (51 $\mu g.g^{-1}$), common diving petrel (42 $\mu g.g^{-1}$), South-Georgia diving petrel (34 $\mu g.g^{-1}$) and Antarctic prions (31 $\mu g.g^{-1}$) (Table 1). For the same element, in the kidney the order was modified, since common diving petrel exhibited the highest value (44 $\mu g.g^{-1}$), and the blue petrel one of the lowest value (33 $\mu g.g^{-1}$) with the Antarctic prions (30 $\mu g.g^{-1}$) (Table 1). Copper concentrations in the muscle were also significantly different between species, the blue petrels exhibiting the lowest levels (3.71 $\mu g.g^{-1}$), compared to the other species which all exhibited concentrations between 5 and 6 $\mu g.g^{-1}$ (Table 1). Concerning cadmium and mercury no significant differences were found between the five species. Nevertheless Hg concentrations were much higher in the tissues of the blue petrels (Table 1), and the low values exhibited by one individual (see the concentrations minimum of 0.10, 0.01 and 0.05 in liver, muscle and kidney respectively) was responsible for the non significance of the difference.

Relationships between cadmium concentrations in kidney tissue and mercury concentrations in liver tissue - the organ where they are long term stored respectively - showed the bioaccumulation of these both non essential elements and the differences between species (Fig.2). The higher mercury concentrations in the liver of blue petrels compared to the other species were thus evident. This was also the case in muscle and kidney (Table 1).

Trace elements in stomach contents and in preys

The exposure to trace elements for the different species have been estimated from the analysis of stomach contents, and from the analysis of preys collected on cruises. Mean concentrations of trace elements in stomach contents and in preys are shown in Table 2 and Table 3 respectively. Concerning the stomach contents, the Kruskal-Wallis test showed significant differences between species for Cu ($T = 24.6$, $p < 0.001$), for Zn ($T = 10.1$, $p = 0.039$) and for Hg ($T = 26{,}4$, $p < 0.001$). Zinc and copper concentrations were lower in stomach contents of the common diving petrel with 3.76 and 1.23 $\mu g.g^{-1}$, respectively (Table 2). Copper concentrations were higher in stomach contents of the thin-billed prions (11.4 $\mu g.g^{-1}$), and mercury concentrations were particularly high in stomach contents of the blue petrel (0.026 $\mu g.g^{-1}$), and not negligible (0.016 $\mu g.g^{-1}$) in the stomach contents of the South Georgia diving petrels compared to the other species (Table 2).

Although the number of preys analysed was low, the main differences between species Antarctic prionpeared for Cd concentrations which were higher in the amphipod *Themisto gaudichaudii* (the difference between outside and inside the "Golfe du Morbihan" being linked to the size of the individuals which were larger outside the gulf), and in the squids (Table 3). Only squids exhibited higher Cu concentrations, which seemed to be equivalent in the other species. The copepod *Paraeuchaeta antarctica* exhibited the highest Zn concentrations which were at least two times higher than in the other species. Mercury concentrations were higher in myctophids (0.039 $\mu g.g^{-1}$) and to a lesser extent in squids (0.022 $\mu g.g^{-1}$) compared to the other species. Among crustaceans, the amphipods exhibited the lowest Hg concentrations, compared to the other species.

Discussion

Cadmium and mercury

There are several papers that deal with the concentrations of selected trace elements in Southern Hemisphere seabirds (Hindell et al., 1999 ; Kim et al., 1998 ; Muirhead & Furness, 1988 ; Stewart et al., 1999 ; Szefer et al., 1993a ; Szefer et al., 1993b), but most of them concern albatrosses, storm petrels or other species of petrels different from small burrowing species. The 5 species of small burrowing petrels investigated in this study are closely related, and very similar in their body size and moult schedule. The life span is also very similar for 4 of them, since thin-billed prion, Antarctic prion, South Georgian diving petrel, common diving petrel can live about 10 years, blue petrel life span being significantly longer, with about 20 years. This makes the study of bioaccumulation of trace elements quite interesting since the main differences between these 5 species is the diet which has been supposed to be a very discriminant factor for trace element bioaccumulation (Monteiro et al, 1998 ; Stewart et al., 1997 ; Stewart et al., 1999 ; Thompson et al., 1998). Thus the exposure of these seabirds has been evaluated by the trace element analysis in the stomach contents and also directly in the preys.

The most interesting tissues to consider for inter-specific comparisons of cadmium and mercury are liver and kidney which are the main sites for long-term storage in high vertebrates. Only two studies included very similar species in their analysis : recently, 2 individuals of fairy prion (*Pachyptila turtur*) were included in a study on seabirds from New Zealand (Stewart et al., 1999). They exhibited mean Cd concentrations of 24 ± 1.4 and 76 ± 9.2 µg.g^{-1} dry weight respectively in liver and kidney, which is very similar to our results in prions after conversion to dry weight (32 and 24 ± 7.6 in liver of antarctic prion and thin-billed prion respectively ; 102 and 100 ± 46 in kidney of Antarctic prion and thin-billed prion respectively). Mean mercury concentrations were slightly lower in the liver of Antarctic prion and thin-billed prion (Table 1) compared to the concentrations found by Stewart et al (1999) in *Pachyptila turtur*. Moreover mean mercury concentrations were similar in liver and kidney of fairy prions (2.6 ± 0.8 and 2.5 ± 0.8 $\mu g.g^{-1}$ d.w., respectively) (Stewart et al., 1999), whereas they were 2 to four times lower in the kidney compared to the liver in our samples (Table 1). This different pattern of Hg distribution between both organs could reflect a difference in mercury detoxification between the species. Thus, the demethylation of mercury from its more toxic methyl form to the less toxic inorganic one is often associated with the displacement of mercury from kidney to the liver a less vulnerable organ (Lourdes et al., 1991). The levels and the physico-chemical form of mercury and selenium in the preys could influence this detoxification (Caurant et al., 1996). However in both studies, sample sizes were small, and since the individual variation is high in toxic element concentrations, these mean values should be considered with caution. Muirhead & Furness (1988) analysed cadmium in liver and kidney and mercury in liver of 17 common diving petrels and 31 broad-billed prions (*Pachyptila vittata*). Mean Cd concentrations reported in their study (32 ± 12 and 7 ± 2.9 $\mu g.g^{-1}$ w.w. , in kidney and liver of common diving petrels respectively ; 33 ± 10 and 16 ± 5.2 $\mu g.g^{-1}$ w.w. in kidney and liver of broad-billed prions respectively), as well as mean mercury concentrations (0.54 ± 0.34 and 0.38 ±0.21 $\mu g.g^{-1}$ w.w. in common diving petrels and broad-billed respectively) were similar to our own results (Table 1).

Stewart et al. (1999) have classified different seabird species according to their pattern of accumulation of mercury in the liver and cadmium in the kidney. They found that 3 broad categories existed : 1° extremely high mercury and high cadmium levels (with range of means varying from 350 to 450 $\mu g.g^{-1}$ d.w. for mercury and from 125 to 132 $\mu g.g^{-1}$ d.w for cadmium) which included wandering and royal albatross, 2° moderately high mercury (from 79 to 143 $\mu g.g^{-1}$ d.w.) and high cadmium levels (from 86 to 190 $\mu g.g^{-1}$ d.w.), which included black-browed albatross, white-chinned petrel, black petrel and grey petrel, and 3°low or very low mercury (from 2.5 to 35 µg.g^{-1} d.w.) but high cadmium levels (from 74 to151 µg.g^{-1} d.w.), this last category including Buller's albatross, shy albatross, sooty shearwater, grey-faced petrel, and cape petrel and fairy prion. The 5 species of small burrowing petrels we analysed, which included 2 prions belonged to this third categories (Table1). However, inside this third category, it does exist some differences, which are shown in Fig. 2, blue petrel exhibiting higher mean mercury concentrations in the liver, compared to the other species.

Mean mercury concentrations were significantly higher in the blue petrel stomach contents (Table 2), which is in accordance with the fact that they contained a high percentage of fish (Fig.1), which also exhibited the highest mercury concentrations (Table 3). Considering the long-term exposure, the global study of the diet carried out on all the sampled stomach contents showed that fish was the main prey and represented 57% of the reconstituted mass (including myctophids : 14%) in the diet of blue petrel (Bocher, 2001). Blue petrel fed also on cephalopods, which represented 2% of the reconstituted mass in their diet, and participated in the mercury exposure (Table 3). The high mercury levels in this species was also expected due to the longer exposure time available to long-lived species. The few reported results on age-related variation of mercury levels in soft tissues are contradictory (Monteiro & Furness, 1995), but it would not be surprising that in the older individuals of this species, the elimination to the plumage during the annual moult was insufficient to balance the dietary intake.

Although the amphipod, *Themiso gaudichaudii* exhibited the highest cadmium concentrations (either inside or outside the gulf) compared to the other crustaceans (Table 3), Cd concentrations in stomach contents were not significantly different between species (Table 2, Fig.1). However, the results shown in Fig.1 were in accordance with the global study of the diet carried out on this seabird species (Bocher, 2001) and the theoretical exposure to cadmium would be higher for common diving petrel, which fed almost exclusively on this amphipod which predominated by number (61%) and by mass (91%) in their diet. The exposure to cadmium was under-estimated by the analysis of stomach contents of Antarctic prions and thin-billed prions. The theoretical exposure was probably higher for these species, since considering the global study on the diet (Bocher, 2001), the amphipod *Themisto gaudichaudii* (and not the euphausiid, *Euphausia vallentini* and *Thysanoessa sp*. as shown in Fig.1) predominated by number (70% and 76%), respectively in antarctic prion and thin-billed prion and by mass (57%) in both species (Bocher, 2001). According to the estimated exposure of the species, significantly lower levels of cadmium would have been expected in blue petrel and South Georgian diving petrel liver and kidney. This was not the case and this implies that either cadmium in the amphipods would not be bioavailable for the birds or that elimination processes balance the cadmium dietary intake. The relatively low coefficients of variation of cadmium concentrations in kidney seabirds (Table 1) would support this hypothesis. It must also be noticed that diet has been studied during the breeding season, but it is not during the inter-breeding season. Bocher et al. (2000) have shown for example that the stable isotopic composition ($\delta^{13}C$ and $\delta^{15}N$) of South Georgian and common diving petrels adult feathers were identical in both species, indicating no trophic segregation during the moulting period when birds feed in offshore waters. This could imply that the exposure to Cd would be very similar during most of the time.

Copper and zinc

For the essential elements copper and zinc, concentrations are supposed to be regulated in the body of vertebrates (Underwood, 1977 ; Walsh, 1990), and this is normally shown by low coefficients of variation. In our study copper concentrations in liver and kidney were not significantly different between seabirds with mean concentrations ranging from 4.8 to 8.7 $\mu g.g^{-1}$ wet weight (Table 1). Moreover diet can't be a discriminant factor for the accumulation of this element in the predators since only the cephalopods exhibited higher concentrations, compared to the other preys. According to the global study of the diet, blue petrel, thin-billed prion and Antarctic prion exhibited cephalopods in their diet, but they represented only 2%, 6% and 3% of the reconstituted mass respectively.

There was a fair degree of variation in zinc levels in the seabirds analysed in this study, but if the lowest levels were in Antarctic prions in the liver as well as in the kidney, the order of the species changed between the hepatic and renal levels (Table 1). The presence of the copepod *Paraeuchaeta antarctica* in the diet could influence Zn levels in the predators since they exhibited higher concentrations (55 ± 32 µg.g-1 wet weight), compared to the other prey species (Table 2). The analysis of thin-billed prion and South Georgian diving petrel stomach contents, which included the copepod in a significant amount (Fig.1), were in accordance with this, since Zn levels were higher with 6.94 ± 1.82 and 7.13 ± 3.42 $\mu g.g^{-1}$ wet weight respectively (Table 3). However, the global study of the diet have shown that *Paraeuchaeta antarctica* was only represented in the diet of common diving petrel and only accounted for 21% of the total number of prey and 9% of the food by estimated reconstituted mass. This was in accordance with the higher Zn concentrations in common diving petrel kidney, but blue petrel exhibited the highest zinc concentrations in the liver (Table 1). It is not surprising that zinc and copper concentrations did not reflect exactly dietary intake, since an homeostatic control exists as a consequence of a regulation of their absorption in vertebrates, which depends on the nutritional requirements of the individual (Underwood, 1977). However, inter specific variations have often been shown in zinc and copper levels in seabirds (Elliot et al., 1992 ; Kim et al., 1998 ; Muirhead & Furness, 1988 ; Stewart et al., 1999 ; Szefer et al., 1993) as well as correlations between zinc, copper and cadmium in liver or in kidney (Elliot et al., 1992 ; Stewart et al. 1999 ; Wenzel et al., 1996). Zinc and copper were correlated with cadmium in blue petrel kidney and copper was correlated with cadmium in common diving petrel (unpubl. data). Metallothioneins have been shown in seabirds (Elliot et al., 1992 ; Elliot & Scheuhammer, 1997 ; Stewart et al., 1996) and molecular interactions between the essential elements Cu and Zn and the toxic metals Cd and Hg may be envisaged as a consequence of their affinities for metallothioneins, as it has been shown in mammals (Webb, 1987). Another hypothesis would explain that Cu and Zn levels in seabirds would not be reflected by dietary intake. The antagonism between Cd, Zn and Cu implies that the levels of one of them in the diet compared to the others, would modify the absorption, the retention, and the distribution in the organism of the less abundant element in the diet (Underwood, 1977).

Conclusions

The small burrowing petrels analysed in this study had low or very low mercury levels compared to many seabirds, but cadmium levels were comparable to numerous seabird species from the Antarctic. Mercury levels in the seabirds reflected well the different dietary intake, and especially the presence of fish in the diet. But despite a different Cd dietary intake -at least during the breeding period- between these very closely related species no significant different Cd concentrations were found. Even if high levels of Cd are reached in Antarctic seabirds, the interactions of this element with Cu and Zn and the similar behaviour of the three metals through the binding to the metallothioneins could be responsible for a kind of “regulation” of Cd. It is well established that squid contribute to high levels of Cd, but it will probably more difficult to evaluate the influence of other preys on Cd accumulation in seabirds.

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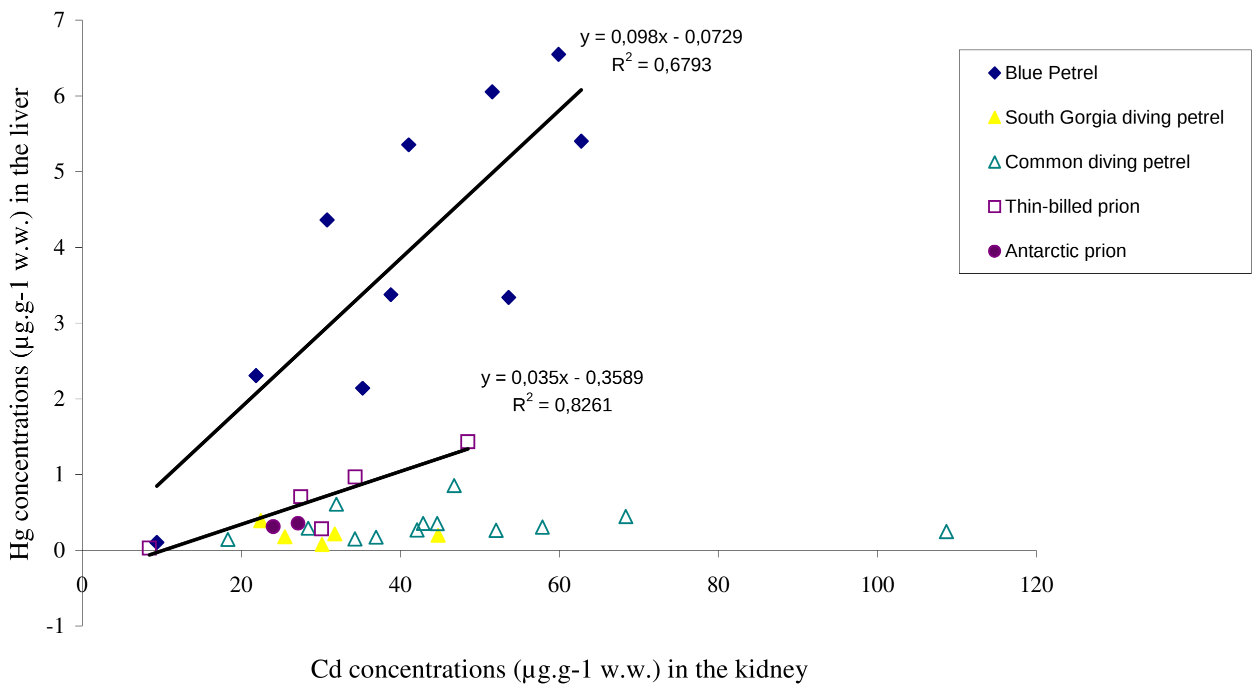
Table 2. Mean mass (in g) and mean concentrations of trace elements (in µg.g^{-1} wet weight) ± SD of the stomach contents of five species of burrowing petrels collected in Kerguelen Island, Southern Indian Ocean.

Species	n	Moisture (%)	Mean mass (g)	Cd	Cu	Zn	Hg
Blue Petrel *Halobaena Coerulea*	10	72 ± 12	33.9 ± 14.6	0.80 ± 0.92	7.10 ± 4.31	5.04 ± 1.33	0.026 ± 0.030
Thin-Billed prion *Pachyptila belcheri*	7	68 ± 5	17.2 ± 9.6	1.05 ± 0.81	11.4 ± 4.47	6.94 ± 1.82	0.006 ± 0.004
Antarctic prion *Pachyptila desolata*	9	81 ± 5	18.2 ± 7.2	1.60 ± 1.55	7.85 ± 6.30	5.34 ± 3.03	0.004 ± 0.001
South Georgia diving petrel *Pelecanoides georgicus*	8	76 ± 5	6.6 ± 3.1	0.90 ± 0.54	7.75 ± 3.27	7.13 ± 3.42	0.016 ± 0.009
Common Diving petrel *Pelecanoides urinatrix*	9	84 ± 2	9.8 ± 4.8	1.04 ± 0.7	1.23 ± 0.3	3.76 ± 1.54	0.003 ± 0.002

Table 3. Mean concentrations of trace elements (in µg.g^{-1} wet weight) ± SD in macrozooplankton, micronekton, fish and cephalopods collected on cruises of the R/V La Curieuse during the austral summer in Kerguelen Island, Southern Indian Ocean.

Species	n	Moisture (%)	Cd	Cu	Zn	Hg
Fishes						
Myctophidae	45	66 ± 3	0.011 ± 0.007	1.0 ± 0.3	9 ± 2	0.039 ± 0.028
Crustaceans						
Euphausiacea						
Euphausia vallentini	3	61 ± 3	0.19 ± 0.09	7.0 ± 0.8	23 ± 4	0.016 ± 0.001
Euphausia triacantha	3	70 ± 3	0.09 ± 0.01	4.4 ± 2.1	16 ± 1	0.010 ± 0.003
Thysanoessa sp.	6	76 ± 5	0.80 ± 0.40	7.5 ± 2.6	7 ± 2	0.015 ± 0.007
Copepoda						
Paraeuchaeta antarctica	3	67 ± 3	0.48 ± 0.24	2.3 ± 0.7	55 ± 32	0.017 ± 0.008
Amphipoda						
Themisto gaudichaudii (HG)	3	71 ± 1	21.4 ± 2.1	4.7 ± 2.1	24 ± 1	0.007 ± 0.001
Themisto gaudichaudii (Golfe)	3	71 ± 1	8.4 ± 2.0	3.5 ± 0.3	15 ± 1	0.008 ± 0.002
Cephalopods						
Squids	20	78 ± 3	13.0 ± 9.3	14.0 ± 8.1	20 ± 7	0.022 ± 0.013

Fig. 2. Relationship between mercury concentrations in the liver and cadmium concentrations in the kidney (µg.g^{-1} wet weight) of 5 species of burrowing petrels from the Kerguelen Island, South Indian Ocean



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