ScienceDirect

Science of The Total Environment

Volume 919, 1 April 2024, 170923

Short Communication

Distribution of rare earth elements (REEs) in the feathers of gentoo penguins (*Pygoscelis papua*) from different geographical locations of the Antarctic peninsula area

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https://doi.org/10.1016/j.scitotenv.2024.170923

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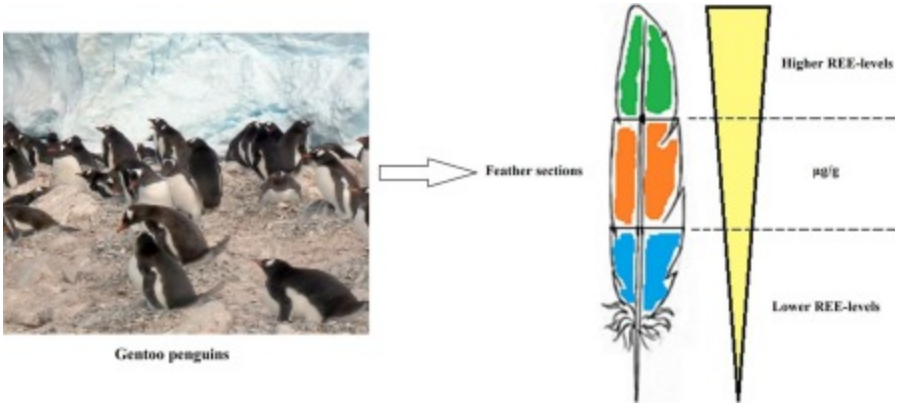
Highlights

- Rare earth elements levels were assessed within the feather of gentoo penguins.
- Some enrichment was detected for rare earth elements along the feathers.
- Higher REE-levels at feather's tip might have some biological effects in penguins.
- Toxicological studies are needed to better understand the effects in penguins.

Abstract

Antarctica is the most remote and coldest regions of the planet, but the presence of REEs there has received little attention. This study assessed REE-contents in the feathers of adult gentoo penguins from Ardley Island, Kopaitic Island and Base O'Higgins. Field work was accomplished during 2011 (austral summer), and determination of elements was performed with ICP-MS. In general, REE-levels showed descending relations as follows: Ce>La>Y>Nd>Sc>Pr>Gd>Sm>Dy >Er>Yb>Eu>Ho>Tb>Tm>Lu. The data showed an increase of the levels of REEs from the lower part of the feather to the tip. This finding seems to be spatially dependent, but geochemical, anthropogenic conditions, feeding habits, sex, or even health status of birds should also be considered. It is a subject that requires deeper attention in future studies.

Graphical abstract



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Introduction

Even though Antarctica is a remote region with low human presence, its fragile ecosystems are now challenged by global environmental changes and anthropic activities (Siegert et al., 2019; Cordero et al., 2022). For these reasons, it is crucial to preserve this last unique region of the Southern hemisphere. Some evidence has shown signs of chemical contamination at various trophic levels of the marine food web in this region (Celis et al., 2015; Chiang et al., 2021; Espejo et al., 2020; Padilha et al., 2021; Celis et al., 2022b).

At present, producers require rare earth elements (REEs) such as Ce, Eu, La and Y, which are used in cell phones, electric vehicles, lasers, radars, guided missiles, flat panel displays, magnets, ceramics, hearing aids, and fiber optics, among others (Pagano et al., 2015; Pagano, 2017; Celis et al., 2020). They have been released into the environment, and some of them have already been found in marine animals of Antarctica (Celis et al., 2022a; Espejo et al., 2023; Celis et al., 2023a; Celis et al., 2023b). The possible effect of REEs have become of increased global concern, as now there is evidence that indicates that these elements have the capacity to affect a great variety of organisms, including humans (Pagano et al., 2015; Abdelnour et al., 2019).

The study of birds as monitors of environmental pollution has been well recognized as these animals are particularly sensitive to the anthropogenic impacts on the environment (Denneman and Douben, 1993; Dauwe et al., 2003). Birds are more sensitive to environmental contaminants than other vertebrates, and certain chemicals in these organisms present lower variations than in other animals, thus a low number of bird samples is equivalent to a higher number in other groups of animals (Pérez-López et al., 2005; Zhang and Ma, 2011). The presence of metals can be assessed through feathers because they are accumulated and then eliminated during molting (Padilha et al., 2021). In this sense, seabird feathers constitute a non-lethal matrix that can be used to evaluate acceptably the toxicological condition of any marine ecosystem (Celis et al., 2018; Bahamonde et al., 2023). Penguin feathers are useful for assessing avian exposure to metals, including REEs (Espejo et al., 2023). Besides, gentoo penguins are good bioindicators for monitoring the contamination of Antarctica, because they represent an important part of the biota in this region (Metcheva et al., 2006).

Taking into account the increasing demand for REEs, it is crucial to obtain information about REEs-associated biological effects (Malhotra et al., 2020). There is evidence showing that Ce,

La, Nd and Y may obstruct the metabolism of Ca at various levels in animals (Redling, 2006). The interference of Y with Ca may obstruct the calcification of the developing embryos' skeleton (Chien et al., 2009; Kaweewong et al., 2013). Pagano (2017) reported that Pr can induce haematological, reproduction and fertility adverse effects in rats and mice. In another study, Y, La, Ce, Nd, Sm, Eu and Gd caused growth defects, cytogenetic anomalies, decreased fertilization success and offspring damage in two sea urchin species, *Sphaerechinus granularis* and *Arbacia lixula* (Trifuoggi et al., 2017). Some recent studies have shown that Y, La, Ce, Nd and Gd can produce oxidative stresses and toxicity to human cells, primary affecting liver, lungs and blood, as well as renal toxicity (Rim, 2016; Adeel et al., 2019; Malhotra et al., 2020). These findings are highlighting the need to biomonitor REEs before they become a serious health problem, since they can be transferred to human body through the trophic chain (Brouziotis et al., 2022).

The ecotoxicological effects of REEs on the aquatic and terrestrial Antarctic environments are poorly understood, thus data are quite necessary to design adequate environmental risk assessments. Feathers (as well as excreta) can be one of the main sources of chemical contaminants to Antarctic terrestrial ecosystems, posing a potential menace for the biota there, as some studies have evidenced with migratory species transporting metals (Padilha et al., 2023) and with penguins acting as biovectors of metals and REES (Espejo et al., 2017; Espejo et al., 2023).

It is necessary to determine REE-baseline levels in remote and pristine areas to be taken as global reference values. So far, the available data on the levels of REEs in feathers of Antarctic penguins are scarce. Some evidence has shown that some metals can accumulate differently in the feathers of birds (Dauwe et al., 2003; Adout et al., 2007; Calle et al., 2015; Yamac et al., 2018; Celis et al., 2023b). However, to our knowledge no studies are done regarding the bioaccumulation of REEs along the length of gentoo penguin's feathers. Consequently, the aim of the present research was to reveal for the first-time certain accumulation behavior of REE-concentrations in the feathers of gentoo penguins from different geographical locations of the Antarctica.

Section snippets

Methods

Sampling was achieved during the austral summer and seabird breeding seasons of 2011, after permission given by the Instituto Antártico Chileno (INACH). As shown in Fig. 1, feathers of adult gentoo penguins were collected at Kopaitic Island (63°19′S, 57°55′W), Base O'Higgins (63°19′S, 57°53′W), and Ardley Island (62°12′S, 58°55′W). The individuals were captured using a long-handled net during molting and before foraging, and feathers collected were immediately placed in Ziploc bags.

In the…

Results and discussion

As shown in Fig. 2 (see also Table S1 in the Supplementary material), the concentrations of REEs in the feathers of gentoo penguins appear to increase from the lower part of the feather to the tip.

In fact, the values of Nd, Eu, Dy, Er, Tm and Yb were higher in the tips of the feathers than the contents in the middle of the feathers and the lower part of the feathers sampled at Ardley Island (Kruskal Wallis ANOVA, $p<0.05$). The increase of the REE-concentrations along the feather from the lower …

Conclusions

This preliminary study was the first to show how REE-concentrations vary along the feathers of gentoo penguins. Some REEs (Nd, Eu, Dy, Er, Tm and Yb) bioaccumulate mostly in tips than lower part of the feather, probably expressing external deposition. Differences between REE-concentrations in the feathers appears to be spatially dependent, although weathering conditions, geochemical background, anthropogenic activities, as well as diet, trophic ecology, sex, or even health status of birds…

CRediT authorship contribution statement

José E. Celis: Conceptualization, Visualization, Writing – original draft, Writing – review & editing. **Stefania Squadrone:** Methodology, Validation, Writing – review & editing. **Giovanna Berti:** Formal analysis. **Maria Cesarina Abete:** Visualization. **Marco Sandoval:**

Writing – review & editing. **Winfred Espejo:** Investigation, Methodology, Project administration, Writing – review & editing.…

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.…

Acknowledgments

This study was financially supported by ANID (Chile) through project postdoc FONDECYT 3200302 (W. Espejo), and partially funded by the Italian Health Ministry through research project IZS PLV 12/22RC (S. Squadrone). The authors also thank Dr. Daniel González-Acuña, who participated in the sample collection (Muñoz-Leal et al., 2021). Also, many thanks are due to Claudia Villanueva for her work on preparing the fresh samples. Finally, we thanks to Diane Haughney for the English of the manuscript.…

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