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ARTICLE

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Sex-specific mercury levels in skin samples of southern elephant seals (*Mirounga leonina*) at Isla 25 de Mayo (King George Island), Antarctic Peninsula

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Abstract

The southern elephant seal (SES; *Mirounga leonina*) has a circumpolar distribution, breeding mainly on sub-Antarctic islands and making long trips between breeding or molting and

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foraging areas. Most individuals from colonies in the South Shetland Islands (western Antarctic Peninsula; WAP) are distributed in Antarctic Specially Protected Areas (ASPA). Despite these protected habitats, pollutants can reach such remote areas far away from emission sources, affecting local fauna. To assess possible mercury (Hg) contamination in SES, we analyzed skin samples collected from free-ranging molting individuals using the remote biopsy PAXARMS system in Isla 25 de Mayo/King George Island (62°15′S, 58°39′W; ASPA 132). Hairless skin samples were analyzed to determine total-Hg (THg) concentrations, which ranged between 145 ng/g and 1,915 ng/g ($M = 730$, $SD = 388$ ng/g), showing significant differences between sexes, with adult-females having higher concentrations (range = 306–1,915, $M = 859$, $SD = 427$ ng/g dw) than subadult-males (range = 145–1,645, $M = 629$, $SD = 329$ ng/g dw). These differences may be explained mainly by feeding-niche partitioning between sexes. Females prefer mesopelagic prey or prey associated with sea-ice in the WAP, which are enriched in methylmercury. These results provide insight regarding Hg contamination in top Antarctic predators like SES, and the need to monitor for potential effects of Hg contamination in Antarctic marine mammals.

KEYWORDS
Antarctica, contamination, elephant seal, heavy metals, Hg, mercury, pinnipeds, South Shetland Islands

1 | INTRODUCTION

The southern elephant seal (*Mirounga leonina*), referred to herein as SES, is a top predator that has a circumpolar distribution, breeding mainly on sub-Antarctic islands. SES make long trips between molting and/or breeding haul out sites and their foraging areas (Hindell et al., 2016). During these long-distance migrations, SES are exposed to pollutants, such as mercury (Hg), through their diet. Of particular concern is the common organic Hg form, called methylmercury (MeHg), which has a high toxicity, biomagnifies along trophic webs including that of the Southern Ocean (e.g., Matias et al., 2022), and bioaccumulates in long-lived top predators. Therefore, the United Nations Environment Program through the goals of the Minamata Convention on Hg has proposed to implement a worldwide biomonitoring network (Bengston et al., 2021; Evers & Sunderland, 2019). This initiative has projected that given the large dispersion potential of Hg, it will continue to contaminate remote and pristine areas like the Arctic and Antarctica (Bargagli, 2016; Cossa et al., 2011; Fitzgerald et al., 1998; Soerensen et al., 2010).

In Antarctica, Hg has been reported in sediments, bottom water, column water, krill, and other local fauna and flora (e.g., Angel-Romero et al., 2018; Bargagli, 2016; Bengston et al., 2021; Carravieri et al., 2020; Cipro et al., 2017; Cossa et al., 2011; de Moreno et al., 1997; dos Santos et al., 2006; Kehrig et al., 2022; Matias et al., 2022; Seco et al., 2019, 2020a, 2020b; Sontag et al., 2019). Katabatic winds favor the transport of Hg from the mainland to coastal areas and sea-ice, where Hg is then released into sediments and deeper waters, and then spreads into the water column during upwelling events (Bargagli, 2016; Cossa et al., 2011; Liu et al., 2019). This inorganic Hg is biomethylated in deep waters by microorganisms (Bargagli, 2016; Cossa et al., 2011) such as sulphate-reducing and iron-reducing bacteria (e.g., Hsu-Kim et al., 2013), producing the bioaccumulative organic neurotoxin, MeHg. Thus, Antarctic fauna inhabiting both coastal and pelagic habits are exposed to MeHg through both sediments and water column sources (Liu et al., 2019).

Given that SES are top predators and feed in both coastal and pelagic habitats (Hindell, 2018; Lewis et al., 2006), they are relevant Hg bioindicators of ocean contamination in Antarctica. SES females and males forage mainly over the continental shelf (Bornemann et al., 2000; Hindell, 2018). However, in the South Shetland Islands (western Antarctic Peninsula), each sex exhibits different movements and feeding habits. Males from the Isla 25 de Mayo/King George Island tend to travel to the Weddell Sea and the Scotia Arc, which lies east of the Antarctic Peninsula and south of South Georgia Island, but feed mainly over the continental shelf in shallow waters and in areas with very high ice concentrations (McIntyre et al., 2014; Tosh et al., 2009). Conversely, females tend to move west of the Antarctic Peninsula, traveling in both pelagic waters and over the continental shelf of the Bellingshausen Sea in the south, and to the South Orkney Islands and South Georgia Island in the north (Figure 1), and prefer feeding in pelagic and mesopelagic waters or close to the pack ice zone (Bornemann et al., 2000; Hindell et al., 2003, 2016; Lewis et al., 2006). Feeding on mesopelagic organisms leads to enhanced exposure to MeHg as they bioaccumulate higher Hg concentrations than their epipelagic counterparts (Chouvelon et al., 2012; Choy et al., 2009). Similarly, organisms in closer proximity to sea-ice formation and melting reflect higher Hg concentrations in their tissues (Seco et al., 2019), so their predators bioaccumulate more Hg in comparison to individuals that feed in ice-free or solid-ice regions. Therefore, different SES sexes are exposed to varying degrees of Hg and can reveal the contamination status of their feeding habitats.

Despite the potential role of SES as Hg bioindicators in Antarctica, little is still known about their exposure. For instance, in the South Shetland Islands where breeding and molting colonies are established, only four studies have assessed current Hg accumulation in SES: two at Isla 25 de Mayo/King George Island (tissues: liver and muscle; Cipro et al., 2017; muscle, skin; de Moreno et al., 1997), one at Livingston Island (hair; Matias et al., 2022), and one in recently weaned pups from Elephant Island (lanugo; Kehrig et al., 2022).

Due to the lack of access to fresh carcasses and internal organs of SES, studies about pollutants in this species are scarce. For instance, the first two Hg assessments in SES in the Isla 25 de Mayo/King George Island only obtained results from a few samples collected opportunistically from one carcass each (Cipro et al., 2017; de Moreno et al., 1997). However, because of the decomposition state of the carcass, Hg concentrations could have been biased (Aubail et al., 2013), exhibiting potentially lower values due to the Hg vertical transport from the carcass to soil (Zvěřina et al., 2017). For this reason, tissue samples obtained by minimally invasive methods should be more effective for assessing Hg contamination of SES. Tissues like hair and blood have been successfully used for this assessment in the northern elephant seal (*Mirounga angustirostris*; e.g., Cossaboon et al., 2015; Peterson et al., 2015) and in the SES (e.g., Kehrig et al., 2022; Matias et al., 2022). Skin, obtained from minimally invasive remote biopsy sampling, has also been shown to provide accurate Hg concentrations from other free-ranging marine mammal species (e.g., Aubail et al., 2013; Cáceres-Saez et al., 2015; Fontaine et al., 2015).

Given the gap in information about Hg concentrations in the SES in Antarctica, the aim of this study was to obtain Hg concentrations from SES skin samples collected from Isla 25 de Mayo/King George Island. This work constitutes the first effort to determine sex-specific Hg concentrations in the skin (without attached hair) of SES, and the first study quantifying Hg in the SES colony located in the Antarctic Specially Protected Area (ASPA) 132. Furthermore, this study contributes to the aims of the recently established in the Southern Ocean Action Plan of the UN (Janssen et al., 2022).

2 | METHODS

2.1 | Study area

The Argentine Antarctic Base Carlini (62°14′18″S, 58°40′00″W; Figure 1) is situated at Isla 25 de Mayo/King George Island, which is located northwest of the Antarctic Peninsula. SES samples were collected at Potter Peninsula, within

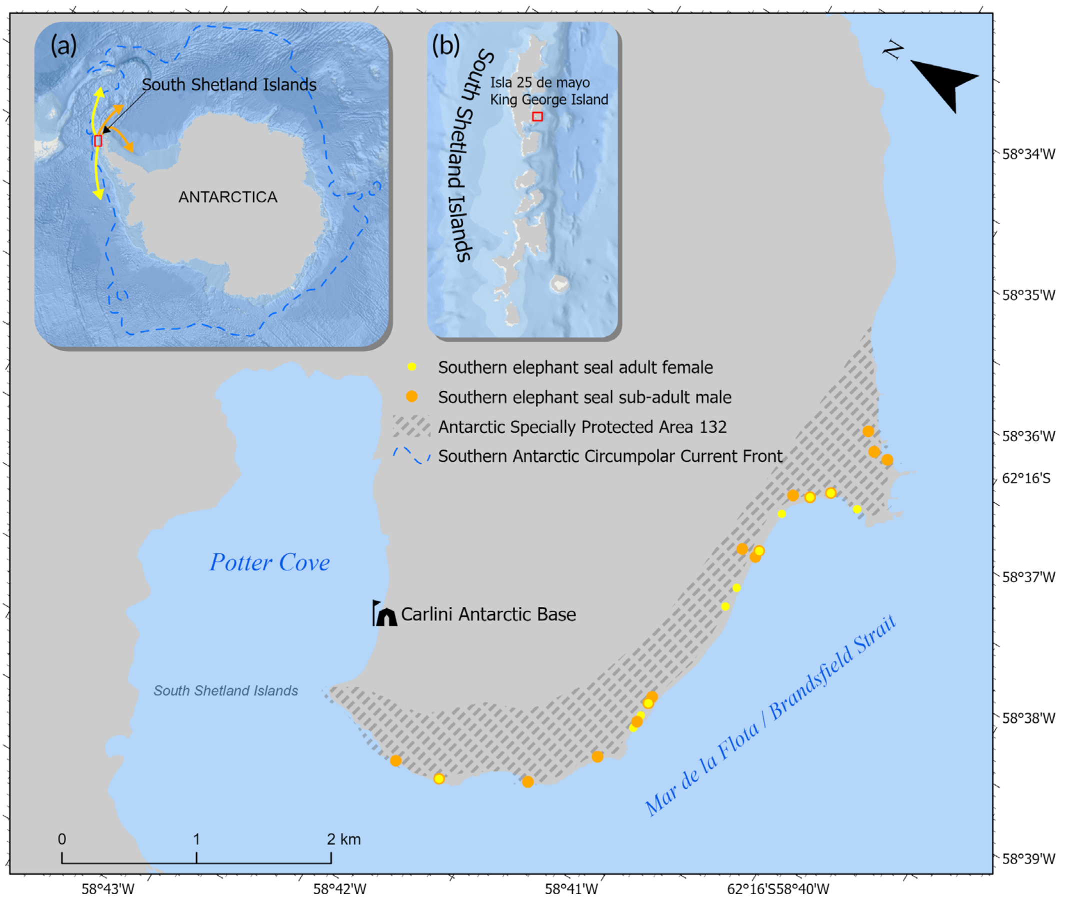

FIGURE 1 Sampling sites for southern elephant seals (*Mirounga leonina*) along the Potter Peninsula in the Antarctic Specially Protected Area (ASPA) 132, located in the vicinity of the Argentine Antarctic Carlini Base on Isla 25 de Mayo/King George Island, South Shetland Islands, western Antarctic Peninsula. (a) Representation of migratory patterns of females (yellow arrows) and males (orange arrows) based on previous satellite tracking data (Bornemann et al., 2009; Hindell et al. 2009; Tosh et al., 2009). The Southern Antarctic Circumpolar Front is represented as a blue dotted line. (b) Location of sampling site in the Isla 25 de Mayo/King George Island, South Shetland Islands.

the ASPA 132 "Peninsula Potter" (62°15′S, 58°39′W; Figure 1). In this ASPA, a SES breeding and molting colony is located; however, SES samples were collected only during molting season. The area is comprised of a coastal portion around 7 km in length consisting of small bays between rocky headlands, where some sandy and fine gravel beaches are located (Negrete, 2011).

2.2 | Sampling

Skin samples were collected from molting SES during the austral summer of 2015–2016, between February and March 2016. Free-ranging subadult males and adult females were sampled using the PAXARMS remote biopsy system from a distance of around 10 m (Krützen et al., 2002). This technique does not cause major short- or long-term negative effects on individuals or populations (Clapham & Mattila, 1993; Tezanos-Pinto &

FIGURE 2 Sampling collection of southern elephant seals (*Mirounga leonina*) using the PAXARMS remote biopsy system in the Antarctic Specially Protected Area (ASPA) 132, Isla 25 de Mayo/King George Island, South Shetland Islands (western Antarctic Peninsula). (a) The red dart is located within the yellow circle next to an individual after sampling collection. (b) Skin and blubber sample collected with the dart. (c) Detailed photograph of the sample collected, in which skin with some hairs attached is observed; however, only skin without attached hair was used to conduct mercury analysis. Photos: (a) Dalia C. Barragán-Barrera, (b, c) Diego F. Mojica-Moncada.

Baker, 2012). Sixty skin samples from 30 adult females and 30 subadult males were collected, preserved in 70% ethanol, and stored at −20°C until laboratory analysis (Figure 2). Following the age classification parameters of the Laboratory of Marine Mammals from Argentine Antarctic Institute, sex and age class were determined by visual inspection of external characteristics and body size was estimated for each individual sampled.

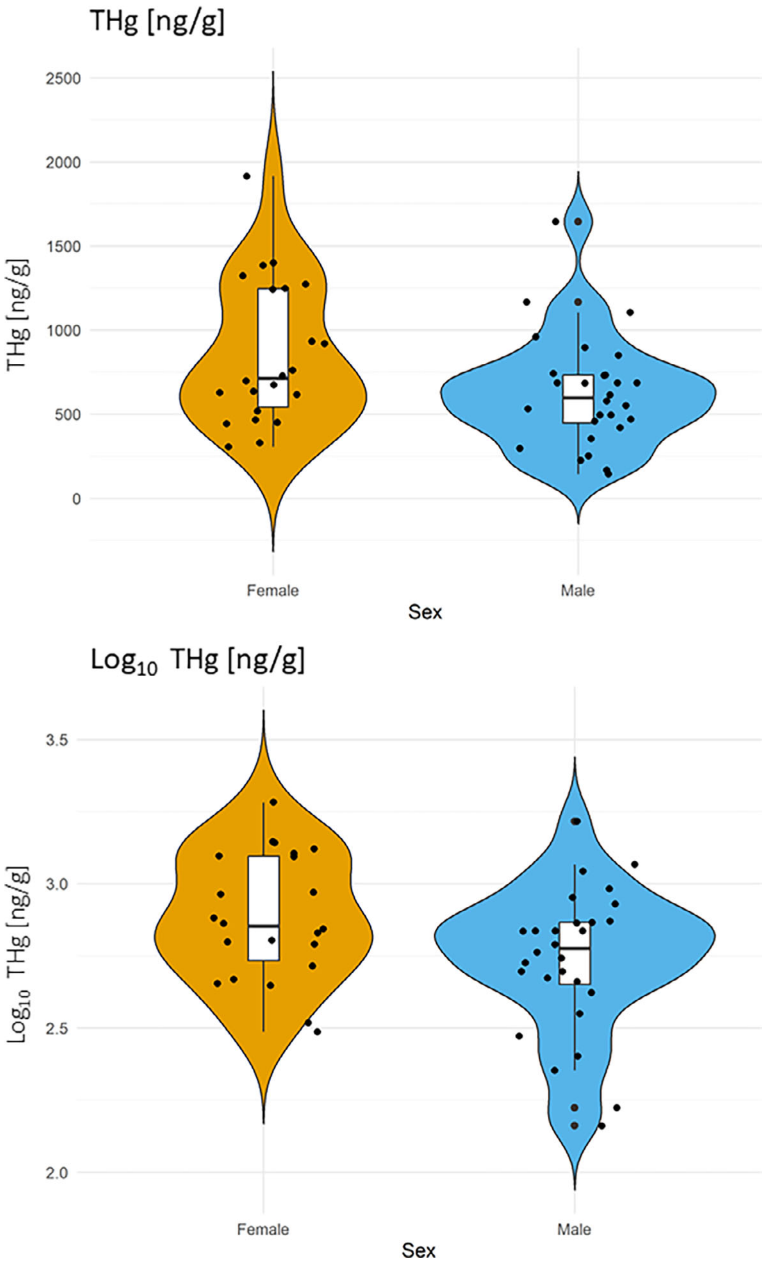

FIGURE 3 Total mercury (THg) concentrations (ng/g dw) in molted skin samples (without attached hair) of southern elephant seals (*Mirounga leonina*) females (22 adults) and males (28 subadults) collected from molting individuals at Isla 25 de Mayo/King George Island (South Shetland Islands, western Antarctic Peninsula). The upper plot represents nontransformed THg data, and the lower one shows the Log-transformed THg data. The vertical lines of the boxes capture a 95% confidence interval and the bold line represents the mean. Significant differences in mean THg concentrations were detected between sexes ($n = 50$, $p < .05$).

2.3 | Total mercury assessment

In the lab and following Vélez et al. (2021), skin samples were left to alcohol evaporate and then were homogenized and freeze-dried for later analysis. Total-mercury (THg) concentrations of skin were measured using a solid sample

TABLE 1 Total mercury (THg in ng/g dw) concentration in molted skin samples (without attached hair) of southern elephant seals (*Mirounga leonina*) in the Antarctic Specially Protected Area (ASPA) 132, Isla 25 de Mayo/King George Island, South Shetland Islands (western Antarctic Peninsula).

Adult female		Subadult male	
Number	THg	Number	THg
1	628	1	354
2	450	2	615
3	616	3	578
4	306	4	496
5	330	5	1,645
6	1,915	6	896
7	636	7	167
8	675	8	225
9	1,242	9	296
10	697	10	459
11	466	11	552
12	1,248	12	959
13	919	13	145
14	519	14	729
15	1,273	15	419
16	760	16	685
17	1,399	17	496
18	444	18	252
19	728	19	742
20	933	20	687
21	1,385	21	684
22	1,322	22	1,167
		23	471
		24	850
		25	686
		26	532
		27	1,104
		28	733
Mean	859		629
SD	427		329

atomic absorption spectrometer AMA-254 (Advanced Altec Mercury Analyzer) as described in Barragán-Barrera et al. (2019). At least two replicates of 1–2 g dry weight (dw) were analyzed for each homogenized and lyophilized sample. The reproducibility for duplicate samples was approved when the relative standard deviation (RSD) was below 10%, so the mean value for the two measurements was used for subsequent statistical analyses. However, when RSD was above 10%, a third replicate was analyzed (Barragán-Barrera et al., 2019; Seco et al., 2019; Vélez et al., 2021). To ensure analytical quality of THg measurements, blanks were run at the beginning of each analytical session and certified reference material (CRM) DOLT-3 (Dogfish Liver Certified Reference Material, National

Research Council of Canada) was run after blanks and every seven analyses. Eight CRM's were used of which the measured mean concentration was 324, *SD* = 0.01 ng/g, showing a good precision of the assigned concentration since percent of recovery was 96% with a relative standard deviation of 0.72%. The THg concentrations are reported in ng/g on a dw basis, and the detection limit of the AMA was 0.05 ng.

2.4 | Statistical analyses

Shapiro–Wilk and Levene tests were performed to evaluate the assumptions of parametric tests (normality and homogeneity of variance, respectively). Transformations were performed so that the data fulfilled these assumptions (logarithmic transformation for THg). A *t*-test to compare geometric means (Nelson et al., 2019) was used to evaluate significant differences in THg concentrations between sexes. These analyses were conducted in R. v. 3.4.3 with a *p*-value of <.05 for significant differences.

3 | RESULTS

Ten of the samples showed analytical differences above 10%. Because each sample mass was too small to conduct more than two analyses, they could not be considered (Barragán-Barrera et al., 2019; Seco et al., 2019; Vélez et al., 2021). We suspect this was due to the samples not being well homogenized. For this reason, a total of 50 samples were successfully analyzed in this study (22 females and 28 males). Overall, THg concentrations ranged between 145 and 1,915 ng/g dw, with *M* = 730, *SD* = 388 ng/g dw (Figure 3). Despite the high variation among individuals, significant differences were detected between sexes (Figure 3). Females showed higher THg concentrations ranging from 306 to 1,915 ng/g dw (*M* = 859, *SD* = 427 ng/g dw), while males had THg concentrations between 145 and 1,645 ng/g dw (*M* = 629, *SD* = 329 ng/g dw; Table 1).

4 | DISCUSSION

This study provides the first description of sex-specific THg concentrations in hairless skin of SES from molting individuals on Isla 25 de Mayo/King George Island. Mean THg concentrations are similar to those reported previously for SES hair from the South Shetland Islands (*M* = 1,654, *SD* = 1,390 ng/g dw, *n* = 15; Matias et al., 2022), and below to those reported for lanugo from pups that reflected THg transferred from their mothers (*M* = 5,600, *SD* = 300 ng/g dw, *n* = 35; Kehrig et al., 2022), and adult liver samples (*M* = 25,680 ng/g dw, *n* = 2; Cipro et al., 2017). They were, however, higher than fat (*M* = 180 ng/g ww, *n* = 2; de Moreno et al., 1997), muscle (613 ng/g dw, *n* = 1; *M* = 180 ng/g ww, *n* = 2; Cipro et al., 2017; de Moreno et al., 1997), and skin (*M* = 120 ng/g ww, *n* = 2; de Moreno et al., 1997). Concentration differences are explained by toxicokinetics of THg in each tissue, with hair acting as a route of Hg excretion and liver acting as a Hg storage location (Gray et al., 2008; Wagemann & Muir, 1984). Although the toxicokinetics of THg in elephant seal skin is not known, our results provide a preliminary assessment of sex-specific THg levels for this species in the western Antarctic Peninsula.

4.1 | Sex-specific mercury differences based on age class or feeding habits?

In marine mammals, Hg bioaccumulates throughout life, increasing its concentration with age (Reijnders et al., 2018). Consequently, differences between sexes found here may be due to the fact that females were adults while males were subadults. However, unfortunately we do not have information about the age of each sampled individual, so this hypothesis cannot be evaluated. SES females are considered as adults from 3–4 years old onward, while for males, although individuals are not considered adults until 7 years of age when they reach the physical maturity required to face agonistic encounters (Carrick et al., 1962), 4–6 year old individuals are physiologically adults because have reached sexual maturity (Carrick et al., 1962; Negrete, 2011) and have adult migratory patterns (J.N., personal observation). Therefore, in many cases, it is possible that some subadults sampled may be of the same age as young adult females sampled. Nevertheless, SES colony located in the ASPA 132 are composed of older philopatric females up to 15 years old (J.N., personal observation), which also would suggest older females were sampled. Consequently, with no information about age of sampled individuals, the THg differences will be discussed based on sex, considering the different foraging habits and distribution patterns between SES females and males.

SES spend more than 80% of their life cycle at sea, making long trips of up to thousands of kilometers to feed intensively before fasting during their breeding and molting haul-outs (Hindell, 2018). Both sexes of the Isla 25 de Mayo/King George Island colony make particularly long journeys, but males tend to use shallower waters in the eastern Antarctic Peninsula and forage in the benthic environment, while females prefer to feed in deeper pelagic waters in the western Antarctic Peninsula and areas close to the pack ice (Bornemann et al., 2000; McIntyre et al., 2014; Tosh et al., 2009). Additionally, although some males from Isla 25 de Mayo/King George Island use the area for breeding and molting haul-outs, they probably were born on South Georgia Island (McIntyre et al., 2014). Therefore, SES males' movements include the shelf region of this island (Hindell et al., 2016), so they may feed there (McIntyre et al., 2014), where the Antarctic krill (*Euphausia superba*) that is the trophic base in the Antarctic food web has shown lower THg levels (Seco et al., 2019). Conversely, females tend to be philopatric to Isla 25 de Mayo/King George Island, but some individuals make long trips to South Orkney Islands (Bornemann et al., 2000), where higher THg levels have been reported for Antarctic krill (Seco et al., 2019). These migratory preferences are likely a strategy to avoid niche overlapping between sexes, as well as reach their specific energetic requirements (Banks et al., 2014). This may also partially explain the THg concentration differences between sexes, and has resulted in clear dietary partitioning between females and males as has been described previously for SES from ASPA 132 based on isotopic ^{13}C and ^{15}N data (Pedraza et al., 2018). Thus, these findings support the role of foraging behavior on Hg concentrations, previously reported for northern elephant seals (Peterson et al., 2015).

Particularly in the Isla 25 de Mayo/King George Island colony, both SES sexes feed mainly on Antarctic glacial squid (*Psychroteuthis glacialis*), but females also consume fish such as the myctophid Nichol's lanternfish (*Gymnoscopelus nicholsi*) at a higher frequency than males (Daneri et al., 2015). These fish were shown to have higher THg muscle concentrations ($M = 150$, $SD = 20$ ng/g dw, $n = 5$; Seco et al., 2020a) than the Antarctic glacial squid ($M = 83$, $SD = 18$ ng/g dw; Seco et al., 2020b). Consequently, it is possible that females are acquiring more THg through additional fish consumption (McArthur et al., 2003; Seco et al., 2020a). Additionally, a recent study on eight cephalopod species in the Southern Ocean suggest a decreasing trend in Hg levels from 2006 to 2016. Specifically, the Antarctic glacial squid showed the lowest THg values in the digestive gland and the second lowest values in gills and muscle in relation to the other cephalopod species (Seco et al., 2020b). These findings may imply a potential alleviation of the Hg burden on SES. However, females may still be exposed to higher Hg due to their fish dietary preferences and sea-ice or mesopelagic feeding locations.

Female northern elephant seals that feed on deep pelagic waters of the Pacific Ocean have higher THg concentrations than individuals feeding in shallower pelagic waters, as well as those that feed close to the continental shelf (Peterson et al., 2015). In the Southern Ocean, this tendency appears to be the same. SES females tend to move northwards with the advance of sea-ice (Hindell et al., 2016). Specifically, females from the South Shetland Islands tend to remain close to the sea-ice (Bornemann et al., 2000), but will also forage in pelagic waters through all regions of the Southern Ocean, although waters from the western Antarctic Peninsula are preferred (Hindell et al., 2016). Particularly in the Southern Ocean, THg and MeHg profiles revealed lower concentrations in surface waters in comparison to deep waters, which showed higher concentrations mainly in pelagic waters (Cossa et al., 2011). Additionally, the highest MeHg concentrations have been reported in pelagic waters south of the Southern Antarctic Circumpolar Current Front (Southern Polar Front; Cossa et al., 2011). Consequently, marine prey distributed in pelagic waters are exposed to higher MeHg concentrations (Chouvelon et al., 2012; Choy et al., 2009; Monteiro et al., 1996). Maps of tracked adult females from the South Shetland Islands show long migrations mostly along Southern Atlantic and Antarctic Peninsula waters including the Southern Polar Front in comparison to subadult males, which tend to have restricted movements to South Georgia and Elephant Islands (see Figure 1 and Hindell et al., 2016). As a result of these pelagic habits, females may acquire higher THg levels through their diet.

4.2 | Mercury differences may be influenced by climate change

In the Antarctic spring, higher atmospheric Hg precipitation rates occur mostly on the sea-ice, where Hg is oxidized by halogens radicals and deposited. Thus, areas where ice is melting reflect higher Hg levels (Bargagli et al., 2016; Dommergue et al., 2010; Ebinghaus et al., 2002). In Antarctica, the western Antarctic Peninsula has been affected mostly by climate change, reporting the highest temperatures in the Southern Hemisphere (Kejna et al., 2013; Mojica-Moncada et al., 2021; Turner et al., 2005; Vaughan et al., 2003, 2013). Consequently, glaciers in this area, specifically in the South Shetland Islands, have shown higher melting rates (e.g., Rosa et al., 2015; Mojica-Moncada et al., 2021; Simões et al., 1999) in comparison to the eastern Antarctic Peninsula (Depoorter et al., 2013; Vaughan et al., 2013). Additionally, western winds over Antarctic coastal areas have increased since late 1970s (Turner et al., 2013), which may increase the Hg transport toward sea-ice. Altogether, climate change effects on the western Antarctic Peninsula may increase THg concentrations in this area.

The differences in THg concentrations between the western and eastern Antarctic Peninsula appear to be reflected in the SES sex-specific THg levels. Migratory patterns of males from Isla 25 de Mayo/King George Island show that they also use the shelf margin of the Weddell Sea in the eastern Antarctic Peninsula (Tosh et al., 2009). Males' movements through this region were associated with high sea-ice concentrations (Tosh et al., 2009). However, because this area is less susceptible to climate change effects, males are likely acquiring less THg levels through their diet in comparison to females, whose feeding migrations in the Antarctic Peninsula are based mainly in the western sea-ice, where they tend to be philopatric (Bornemann et al., 2000).

4.3 | Implications of mercury exposure on southern elephant seals

Mean THg skin concentrations reported here were lower than concentrations found in northern elephant seal molt samples in Año Nuevo, in northern California ($M = 3{,}600$, $SD = 800$ ng/g dw, $n = 3$; Cossaboon et al., 2015), higher than in skin of harbor seal (*Phoca vitulina*) found dead along the west coast of northern Germany ($M = 400$, $SD = 430$ ng/g ww, $n = 47$; Wenzel et al., 1993), and in the same order of magnitude as in Alaskan harbor seal skin (not detected–2,760 ng/g dw, $n = 3$) and Alaskan Steller sea lion (*Eumetopias jubatus*) skin (120–6,240 ng/g dw, $n = 7$; Ferdinando, 2019). Therefore, our results show that, although Antarctica is a remote place away from potential sources of pollution, Hg is still accumulating in Antarctic wildlife. Accumulation of Hg could potentially have negative effects, such as immunotoxic effects related to suppression of lymphocyte proliferation or suppression of phagocytosis in pinniped and other marine species, as suggested by Desforges et al. (2016). Specifically for SES females, exposure to the toxic Hg form may imply a potential toxicological risk (related to deleterious effects on health), as well as their pups during their gestational period, since while pregnant females are feeding and acquiring Hg through their diet during foraging migrations, MeHg is transferred mainly by the placenta rather than by lactation (Habran et al., 2011).

However, more studies are needed to elucidate the potential detrimental health effects of Hg exposure on SES. Furthermore, correlations between Hg concentrations in skin and intern organs in SES should be assessed, as it has been demonstrated in Commerson's dolphins (*Cephalorhynchus commersonii*) of sub-Antarctic waters (Cáceres-Saez et al., 2015) and small cetaceans of the northeast Atlantic Ocean coast (Aubail et al., 2013). This study has allowed a first assessment of ecological differences between SES sexes, as well as the relevance of this species as bioindicator of Hg contamination in Antarctica due their wide migratory patterns in the Southern Ocean.

The THg concentrations reported here for SES indicate that Antarctic pelagic waters may be an important Hg source for marine top predators. Thus, SES may also act as a natural vector of MeHg from the open ocean to Antarctic coastal areas through molting, since pinniped hair has an important role in Hg excretion (Gray et al., 2008). For this reason, monitoring Hg concentrations in different tissues of SES and in both sexes, and the role of SES as potential MeHg source to nearshore areas around molting and breeding colonies should be considered in future research to assess potential top-down contamination at Antarctic marine areas where SES colonies are established.

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AUTHOR CONTRIBUTIONS

Dalia C. Barragán-Barrera: Conceptualization; data curation; formal analysis; funding acquisition; investigation; methodology; software; validation; writing – original draft. **Federico German Riet Sapriza:** Conceptualization; funding acquisition; methodology; writing – review and editing. **Diego Fernando Mojica-Moncada:** Conceptualization; methodology; writing – review and editing. **Javier Negrete:** Methodology; resources; writing – review and editing. **Antonio Curtosi:** Resources. **Paco Bustamante:** Methodology; writing – review and editing. **Susana Caballero:** Resources; writing – review and editing. **Andrea Luna-Acosta:** Conceptualization; formal analysis; software; validation; writing – review and editing.

DECLARATION OF COMPETING INTEREST

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

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