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Inter-annual fluctuations in mercury contamination associated with environmental variability in two Procellariiformes species of Bass Strait, southeastern Australia

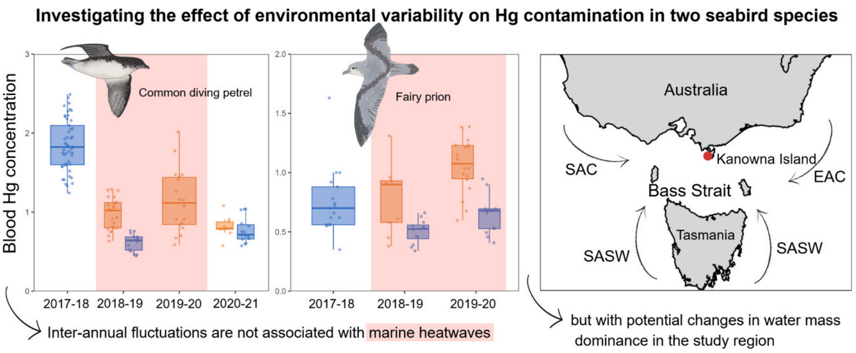
Margot Arabadjieva [a,*], Aymeric Fromant [b], John P.Y. Arnould [c], Paco Bustamante [a,d]

[a] *Littoral Environnement et Sociétés (LIENSs), UMR 7266 CNRS - La Rochelle Université, 17000, La Rochelle, France*
[b] *Biosis Pty Ltd, 38 Bertie Street, VIC, 3207, Australia*
[c] *School of Life and Environmental Sciences, Faculty of Science, Engineering and Built Environment, Deakin University, Burwood, Victoria, Australia*
[d] *Institut Universitaire de France (IUF), 1 rue Descartes, 75005, Paris, France*

HIGHLIGHTS

- Blood and feather Hg were measured in 2 seabird species of Bass Strait over 4 years.
- Influences of environmental variability and feeding ecology were investigated.
- There was inter-annual variation in blood Hg but not linked with marine heatwaves.
- Blood Hg concentrations were higher during incubation than during chick-rearing.
- Both species had higher Hg concentrations than conspecifics in the Southern Ocean.

GRAPHICAL ABSTRACT



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ABSTRACT

Mercury (Hg) is a toxic contaminant that biomagnifies along marine food chains, particularly exposing top predators such as seabirds through their diet. Bass Strait, in southeastern Australia, is one of the fastest warming oceanic regions on the planet and is influenced by several currents that create a highly variable physical and biological environment. Here, we studied the feather and blood Hg concentrations in two Procellariiformes species, the common diving petrel (*Pelecanoides urinatrix*) and the fairy prion (*Pachyptila turtur*) over four breeding seasons with different environmental conditions on site. We hypothesized that years marked by marine heatwaves would show different blood Hg contamination than colder years, due to differences in prey availability. Both species exhibited significantly higher blood Hg levels during incubation than during chick-rearing, suggesting a carry-over effect from pre-breeding period contamination. Inter-annual variation in blood Hg concentrations was observed in both species, and common diving petrels showed significant differences in Hg and isotopic values between the two colder years of the study. These results suggest that factors other than the increase of sea surface temperature associated with marine heatwaves caused inter-annual variation in Hg contamination. In particular, changes in the relative dominance of water masses may have altered the prey

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* Corresponding author.
E-mail address: margot.serrurierarabadjieva@univ-lr.fr (M. Arabadjieva).

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composition in Bass Strait, subsequently leading to fluctuations in Hg contamination. As the East Australian Current is expected to intensify, our results highlight that environmental variability associated with climate change could result in further variation in Hg contamination in seabirds in the future.

1. Introduction

Intensified anthropogenic activities have led to increasing emissions of non-essential metals such as mercury (Hg), which disperse globally through marine and atmospheric currents, exposing oceans worldwide to its contamination (Lamborg et al., 2014). Once in the ocean, Hg is methylated by microorganisms into its organic form (methyl-Hg), which bioaccumulates in organisms and biomagnifies through food webs (Fitzgerald et al., 2007). Therefore, the increase of Hg in marine ecosystems poses a major threat for wildlife due to its known neurological, physiological and behavioural toxicity in marine biota (Thain, 1984; Okpala et al., 2018; Kershaw and Hall, 2019; Chastel et al., 2022). Due to their position in the food web and being long-lived animals, marine predators are more likely to accumulate high Hg concentrations over time (Coelho et al., 2013; Teffer et al., 2014; Cherel et al., 2018). However, Hg methylation and its incorporation into marine food webs are modulated by factors such as sea temperature, primary production, or food web structure, which are all being affected by the current climate change (Blum et al., 2013; Eagles-Smith et al., 2018). Moreover, the biogeochemical cycle of Hg may be altered through biome shifts or ocean stratification in the context of global change (Wang et al., 2019; Sonke et al., 2023), thus raising new concerns on how environmental variability will affect Hg concentration levels in marine wildlife (Eagles-Smith et al., 2018).

Seabirds are widely used as bioindicators of Hg contamination in the environment, enabling a spatio-temporal monitoring of its bioavailability (Monteiro and Furness, 1995; Burger and Gochfeld, 2004; Carravieri et al., 2016). In seabirds, Hg uptake mainly occurs through dietary exposure (Becker et al., 2002; Bocher et al., 2003), and the analysis of various tissues reveals contamination over different timescales. Feathers reflect longer-term accumulation, as 70 to 90% of stored body Hg is eliminated during feather growth, integrating contamination since the last moult from months to years depending on the moulting pattern, generally once a year in most seabird species (Honda et al., 1986; Braune and Gaskin, 1987; Albert et al., 2019). In contrast, blood captures shorter-term contamination (weeks to months) due to the half-life of Hg in blood, estimated to be approximately 30–60 days (Bearhop et al., 2000; Monteiro and Furness, 2001), allowing the investigation of Hg contamination over shorter periods (e.g. a breeding season). Complementary ecological tracers such as stable isotopes of nitrogen (δ^{15}N) and carbon (δ^{13}C) further elucidates how feeding ecology influences Hg contamination: δ^{15}N gives insights into the effects of trophic position and prey type (Kojadinovic et al., 2007; Anderson et al., 2009), whereas δ^{13}C informs on the potential differences in Hg levels between feeding habitats or ocean compartments (benthic vs pelagic, coastal vs oceanic; e.g., Carravieri et al., 2014b; Cherel et al., 2018). As environmental variability can alter seabirds prey availability and foraging patterns (Garthe et al., 2011; Evans et al., 2020a; Quiring et al., 2021), this approach offers valuable insights into how changing environmental and oceanographical conditions can affect Hg exposure in seabirds over time (Fort et al., 2016; Tartu et al., 2022).

Bass Strait (southeastern Australia) is located in one of the fastest warming oceanic regions on the planet (Hobday and Pecl, 2014) with increasing marine heatwaves (MHW) frequency (Oliver et al., 2018; Holbrook et al., 2019). The region is considered to have low nutrient levels (Gibbs et al., 1986) and is under the influence of several water masses and currents: the East Australian Current (EAC) brings oligotrophic, warm water into the eastern Bass Strait (Ridgway and Ling, 2023); the South Australian Current (SAC), one of the main water masses contributing to Bass Strait (Sandery and Kämpf, 2007), brings nutrients from the Bonney Upwelling off the southeastern coast (Gibbs et al., 1986; Middleton and Bye, 2007). Additionally, a northward flow of the nutrient-rich Sub-Antarctic Surface Waters (SASW) mixes over the continental slope on both south edges of Bass Strait (Gibbs et al., 1986; Gibbs et al., 1991). Currents in the region, such as the EAC, are expected to intensify their flow with the ongoing climate change (Cai et al., 2005). Therefore, the area offers a unique field laboratory to study Hg contamination of seabirds in rapidly changing environmental conditions, as there is little information on how seabirds from southeastern Australia will be affected by climatic and oceanographical variability (Chambers et al., 2011).

The common diving petrel (*Pelecanoides urinatrix,* hereafter CDP) and the fairy prion (*Pachyptila turtur,* hereafter FP) are among the most abundant seabird species in Bass Strait (Schumann et al., 2014). They display similar feeding behaviour during their breeding period, with Australian coastal krill (*Nyctiphanes australis*) reported as their preferred prey in southeastern Australia (Schumann et al., 2008; Fromant et al., 2020a). Water temperature strongly affects the growth and reproduction of krill (Lagos et al., 2022), causing fluctuations in prey availability that alter predators' trophic niches and behaviour (Young et al., 1993), reduces reproductive success (Mills et al., 2008; Fromant et al., 2021) and decreases population abundance (McLeod et al., 2012). In the summers of 2017–18 and 2018–19, MHW driven by local air-sea fluxes and anthropogenic forcing (Perkins-Kirkpatrick et al., 2019; Kajtar et al., 2021, 2022) occurred in southeastern Australia, reducing prey availability and causing severe breeding failure for CDP in subsequent breeding seasons (Eizenberg et al., 2021). Both CDP and FP are currently classified at “Least Concern” on the IUCN Red List (BirdLife International, 2018a, 2018b). However, there is a substantial knowledge gap regarding the drivers of population changes in Australian seabirds and the relative effect of environmental variability and climate change (Chambers et al., 2011). Given that high Hg concentrations can have adverse effects on the health and demographics of seabirds (Goutte et al., 2014; Chastel et al., 2022), a close monitoring of their contamination in relation to environmental variability in Bass Strait appears essential for future conservation of their populations.

Reduced prey availability associated with environmental conditions may lead seabirds to adapt their foraging behaviour and diet (Fayet et al., 2021). In Bass Strait, environmental perturbations such as thermal stratification were previously associated with a switch of prey in little penguins (*Eudyptula minor*), causing low foraging and breeding success (Ropert-Coudert et al., 2009). In case of low abundance of their preferred prey (i.e., the Australian anchovy, *Eugraulis australis*), this species consequently feeds on alternative prey (Kowalczyk et al., 2014). In seabirds, diet shifts across trophic levels can alter their Hg exposure (Braune et al., 2014; Seco et al., 2021). The consumption of alternative prey by CDP due to reduced availability of *N. australis* following a MHW have been previously suggested (Fromant et al., 2022), such as echinoderm and bryozoan larvae, as well as tropical zooplankton species, which abundance are increasing in the region following the EAC intensification and MHW (Evans et al., 2020b). Yet, no evaluation of the potential variation of Hg in seabirds associated with MHW and prey composition alteration have been carried out in the region or elsewhere.

In this context, the objective of this study was to investigate the potential variation of Hg contamination in seabirds in response to environmental variability. The specific goals were to i) compare the blood Hg concentrations of CDP and FP across four successive breeding seasons with substantial variation in climatic and oceanographic conditions on site; ii) assess potential difference in blood Hg contamination between breeding statuses (i.e incubation and chick-rearing); iii) measure the annual Hg contamination through Hg analyses in feathers for both species, and iv) compare it with other populations in the Southern Ocean. We hypothesized that years with MHW events associated with shifts in prey types and composition will result in significantly different blood Hg concentrations in seabirds, in contrast with « normal conditions/colder » years where seabirds feed upon their preferred prey.

2. Materials & methods

2.1. Study site and sampling

Individuals in the present study were handled as part of a concurrent investigation on the breeding success (Eizenberg et al., 2021), at-sea movements and distribution of CDP and FP (Fromant et al., 2020b, 2022). For CDP, the breeding season in Bass Strait starts in mid-July and lasts until mid-December, whereas for FP it begins mid-October until early February (Fromant et al., 2020a). Sampling was conducted during the incubation (September–October and October–November for CDP and FP, respectively) and chick-rearing (November–December and December–January for CDP and FP, respectively; Fromant et al., 2020a) periods over four successive breeding seasons (2017–18 to 2020–21) of CDP and FP, at Kanowna Island (39°15′S 146°30′E, Fig. 1) in the northern Bass Strait, southeastern Australia. For both species, only birds during the chick-rearing period were sampled in 2017–18, whereas for CDP only birds in incubation period were sampled in 2019–20 due to their complete breeding failure that season (Fromant et al., 2021). Due to logistical constraints, no samples were collected for FP in 2020–21. Upon capture, a blood sample up to 0.2 mL was collected from the brachial vein, transferred in 1.5 mL polyethylene Eppendorf tubes, which were filled with 1 mL 70% ethanol. Additionally, body feathers were collected on the dorsal part and then stored in individual plastic zip-lock bags until further analyses.

2.2. Mercury and stable isotopes analyses

Blood samples were first placed under a fume hood for ethanol evaporation, then were freeze-dried for 48 h and finally grounded into a powder. Body feathers (4 per individual) were cleaned to remove any dirt and contaminants using a 2:1 chloroform:methanol solution in an ultrasonic bath for 3 min, then rinsed twice in methanol before being dried at 45 °C for 48 h. Dry feathers were homogenised into small pieces using stainless steel scissors. Total Hg was measured using an Advanced Mercury Analyzer spectrophotometer (Altec® AMA 254). For each sample, analyses were run 2 to 3 times to obtain a relative standard deviation <10%. At the beginning and the end of each series of analyses (~ every 10 samples), blanks and certified reference materials of TORT-3 (Lobster hepatopancreas, NRC, Canada; certified Hg concentration: 0.292 ± 0.022 μg g^{-1} dry weight (dw) and DOLT-5 (Dogfish liver, NRC, Canada; certified Hg concentration: 0.44 ± 0.18 μg g^{-1} dw) were analysed at the beginning and at the end of the analytical cycle, and every 10 samples to validate the method. Measured values for TORT-3 were 0.293 ± 0.006 μg g^{-1} dw ($n = 23$), with a recovery of 100.5 ± 2.1%. For DOLT-5, measured values were 0.399 ± 0.032 μg g^{-1} dw ($n = 15$). The limit of quantification of the AMA was 0.05 ng. The Hg concentrations were expressed in μg g^{-1} dw. The relative abundance of carbon and nitrogen isotopes in blood and feather samples was determined with a continuous-flow mass spectrometer (Thermo Scientific Delta V Advantage) coupled to an elemental analyzer (Thermo Scientific Flash EA 1112). The isotopic results are expressed using the notation:

$$\delta X = \left[\left(\frac{R_{sample}}{R_{standard}}\right) - 1\right]\Bigg) \times 1000$$

where X is ^{13}C or ^{15}N and R_{sample} is the isotopic ratio $^{13}C/^{12}C$ or $^{15}N/^{14}N$. $R_{standard}$ values are based on Vienna Pee Dee Belemnite for ^{13}C, and atmospheric nitrogen (N_2) for ^{15}N. For the complete methods regarding statistical analyses of isotopic values (inter-annual comparison and trophic niche investigation), see Fromant et al. (2021, 2022).

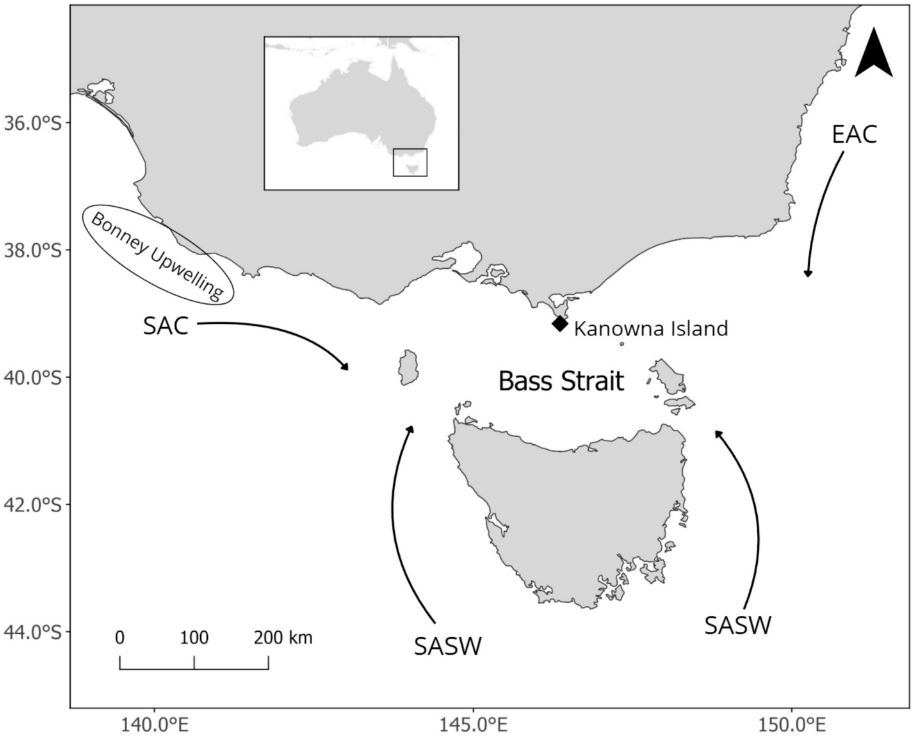

Fig. 1. Location of Kanowna Island (39°15′S 146°30′E) in northern Bass Strait, southeastern Australia. The arrows indicate the directions of the major water masses (South Australian Current, SAC; Sub-Antarctic Surface Waters, SASW; East Australian Current) prevailing in the region and potentially influencing the prey composition and trophic structure within Bass Strait. The local upwelling on the Bonney coast (Bonney Upwelling) is also shown in the ellipse box.

2.3. Oceanographic conditions

The preferred prey of CDP and FP, the coastal krill, is known to have an optimal temperature range of 12–18 °C (Sheard, 1953). Thus, the monthly means of SST (a proxy for food availability) from December 2015 to December 2020 were downloaded from the Copernicus marine data store to evaluate if the inter-annual differences in SST could be associated with variations in Hg, with a focus on the austral summers and austral falls (hereafter summer and fall) preceding each breeding season. Additionally, as chlorophyll-a has previously been identified as a predictor of Hg variation in seabirds (Tartu et al., 2022), monthly means of chlorophyll-a were obtained for the same study period. Data were retained for the whole Bass Strait region (38.5–41.0°S, 144.0–148.0°E) following Fromant et al. (2021). SST data were obtained at a spatial resolution of 0.05° (~31.4 km^2 per pixel), while chlorophyll-a concentrations were available at a resolution of 4 km (~16 km^2 per pixel).

2.4. Statistical analyses

All statistical analyses were performed using the software R, version 4.4.3. Data exploration and assumptions checking was conducted following Zuur et al., 2010, using the functions “plot” and “qqnorm” in R. Intra-specific differences in Hg in blood and feathers between years were tested using ANOVA or the non-parametric test Kruskal-Wallis with subsequent post-hoc tests. To assess potential variations in SST and chlorophyll-a across years, the same tests were used. To evaluate inter-specific differences in blood and feather Hg contamination, Student *t*-test and ANOVA test were performed or their non-parametric equivalent (Wilcoxon t-test and Kruskal-Wallis, respectively) with subsequent post-hoc tests as well.

To investigate the influence of trophic ecology, as well as the breeding status and the sex on Hg contamination across the four years, Linear Mixing Models (LMM) with year as the random effect were used. Models were built using the R package “nlme” (Pinheiro et al., 2022), with an identity link-function and a gaussian distribution. The continuous variables $\delta^{13}C$ and $\delta^{15}N$ were checked for collinearity using variance inflation factors (VIF) and centered to reduce collinearity when VIF > 5. Residuals in the CDP model were log-transformed for assumptions validation, and sex was not included as a fixed term as only a few individuals were sexed in 2020–21. The initial models for each species were built as follow:

$$(CDP)\ Hg \sim \delta13C + \delta15N + Breeding\ status + \delta13C{*}Breeding\ Status + \delta15N{*}Breeding\ status + 1 \mid Year$$

and

$$(FP)\ Hg \sim \delta13C + \delta15N + Sex + Breeding\ status + \delta13C{*}Breeding\ Status + \delta15N{*}Breeding\ status + 1 \mid Year$$

where “1 | Year” corresponds to the random term in the model.

For model selection, we used the Akaike Information Criterion corrected for small sample size (AIC_c), where the model with the smallest AIC_c is considered the best fit to the data (Burnham and Anderson, 2004). When the difference in AIC_c between two models is <2, they are considered statistically equivalent. Models with all possible combinations of variables were extracted and ranked by AICc using the function “dredge” from the *MuMIn* package in R (Bartoń, 2022). Model performance was determined by Akaike weights (w_i) (Johnson and Omland, 2004), and the marginal R-squared (R2m, variance explained only by the fixed terms) and the conditional R-squared (R2c, variance explained by both fixed and random terms) were calculated using the *r.squaredGLMM*() function (Bartoń, 2022). The relationship between $\delta^{13}C$ and $\delta^{15}N$ and Hg concentrations in feathers was not considered due to the temporal mismatch between Hg and stable isotope integration in feathers (Bond, 2010).

3. Results

A total of 130 CDP blood samples were collected and analysed for Hg and stable isotopes across four years (2017–18 to 2020–21, Table 1), and 68 FP blood samples across three years (2017–18, 2018–19, 2019–20, Table 1). For feathers, 79 and 33 samples were collected and analysed for CDP and FP, respectively, across three years (no samples in 2018–19, Table 1).

3.1. Intra-specific variations in Hg concentrations

For CDP, Hg blood concentrations were higher for the 2017–18 season than for the three other years (Kruskal-Wallis, chi-squared = 67.961, df = 3, $P < 0.001$), regardless of the breeding status: the mean Hg concentration that year reached 1.85 ± 0.33 $\mu g\ g^{-1}$ dw, whereas all other years had mean concentrations below 1.15 $\mu g\ g^{-1}$ dw (Table 1, Fig. 2). For FP, blood concentrations were significantly lower during the chick-rearing period in 2018–19 than in 2017–18 (Tukey post-hoc test, $P = 0.003$), but there was no significant difference between 2018–19 and 2019–20 (i.e years with MHW events). Blood Hg concentrations were the highest overall for this species during the incubation of 2019–20 (Table 1, Fig. 2), with a mean of 1.06 $\mu g\ g^{-1}$ dw. Mean blood Hg concentration was also significantly higher during the 2019–20 incubation stage than in 2018–19 (Student *t*-test, $t = -2.69$, df = 25, $P = 0.01$). Regarding feathers, CDP did not a have significant difference in mean Hg between years (ANOVA, F = 0.541, df = 2, $P = 0.6$). In FP, mean feather Hg concentration was significantly higher in 2019–20 than in 2017–18 (Student t-test, $t = -3.3676$, df = 31, $P < 0.01$), with respective means of 1.60 $\mu g\ g^{-1}$ and 0.99 $\mu g\ g^{-1}$ dw. The results regarding stable isotopic values and isotopic niches across our four years of study can be found in Fromant et al. (2020b, 2021, 2022), and in Table 1 and Fig. 3 adapted from Fromant et al. (2020b, 2021, 2022).

3.2. Inter-specific variations in Hg concentrations

Significant inter-specific differences in blood Hg concentrations were recorded in years where data from the same breeding status were available. CDP had significantly higher blood Hg concentrations during the chick-rearing period in 2017–18 and in 2018–19 than FP (Wilcoxon t-test, W = 514, $P < 0.001$; Student t-test, $t = 2.81$, df = 26, $P < 0.001$, respectively). CDP also had significantly higher Hg concentrations during the incubation period in 2018–19 (Student t-test, $t = 2.18$, df = 30, $P < 0.05$). No significant differences were observed between the two species blood Hg concentrations during the incubation period in 2019–20. Regarding feathers, no significant difference in Hg concentrations was found between the two species in 2017–18 (Student t-test, $t = 0.9624$, df = 68, $P > 0.05$, Fig. 4). However, in 2019–20, FP had significantly higher Hg concentrations than CDP (Student t-test, $t = -2.3577$, df = 31 $P = 0.03$, Fig. 4).

3.3. Effect of ecological and biological variables over Hg blood concentrations

For CDP, the mixed model with $\delta^{15}N$, breeding status and the interaction $\delta^{15}N$ * breeding status as explaining variables of blood Hg variation resulted in the most parsimonious fit to the data (Table 2). However, the model including only the breeding status as the explaining variable had an AICc <2, thus of comparable statistical significance (Table 2). In the lowest AICc model, the significant interaction between $\delta^{15}N$ and breeding status indicate that the effect of $\delta^{15}N$ on Hg is different during the chick-rearing period compared to the incubation (Supplementary materials Table S1). Indeed, there is a significant decrease of blood Hg concentrations with increasing $\delta^{15}N$ values during the incubation period, and a slight increase of blood Hg concentrations with increasing $\delta^{15}N$ values during the chick-rearing period (β ± SE: 0.13 ± 0.04, Fig. 5, Table S1). In all models, the fixed terms explained

Table 1

Mercury concentrations (μg g^{-1} dw) and stable isotopes values (‰) in the blood and body feathers of common diving petrels and fairy prions from Kanowna Island, Bass Strait. Values are means ± standard deviation (with range given in brackets). Stable isotopes values are extracted from (Fromant et al., 2020a, 2021, 2022). Years in bold indicate the occurrence of a marine heatwave in Bass Strait the austral summer preceding the seabirds' breeding season.

Species	Blood								Feathers	
	Incubation				Chick-rearing					
	n	Hg	$\delta^{13}C$	$\delta^{15}N$	n	Hg	$\delta^{13}C$	$\delta^{15}N$	n	Hg
Common diving petrel (*Pelecanoides urinatrix*)										
2017/2018	–	–	–	–	49	1.85 ± 0.33 (1.24–2.49)	−21.5 ± 0.4 (−22.2 ● -20.5)	14 ± 0.2 (13.5–14.6)	52	1.14 ± 0.55 (0.43–2.67)
2018/2019	23	0.98 ± 0.20 (0.63–1.27)	−19.5 ± 0.5 (−20.7 ● -18.5)	13.6 ± 0.6 (12.5–13.8)	16	0.61 ± 0.11 (0.44–0.77)	−21 ± 0.3 (−21.6 ● -20.7)	13.2 ± 0.4 (12.5–13.8)	–	–
2019/2020	18	1.14 ± 0.40 (0.59–2.01)	−19.7 ± 0.7 (−22.1 ● -18.6)	14.1 ± 1 (11.6–14.9)	–	–	–	–	18	1.15 ± 0.51 (0.54–2.10)
2020/2021	9	0.82 ± 0.14 (0.57–1.08)	−20.1 ± 0.5 (−20.9 ● -19.6)	15 ± 0.2 (14.7–15.4)	15	0.77 ± 0.16 (0.57–1.04)	−20.4 ± 0.2 (−21 ● -20.2)	14.5 ± 0.3 (14–14.9)	10	1.25 ± 0.35 (0.73–1.84)
Fairy prion (*Pachyptila turtur*)										
2017/2018	–	–	–	–	17	0.75 ± 0.28 (0.35–1.63)	−20.9 ± 0.3 (−21.5 ● -20.2)	13.5 ± 0.5 (12.3–14.1)	18	0.99 ± 0.47 (0.41–2.45)
2018/2019	9	0.78 ± 0.30 (0.38–1.31)	−19.7 ± 0.1 (−20 ● -19.6)	11.9 ± 0.7 (10.8–13.2)	12	0.50 ± 0.10 (0.34–0.66)	−20.6 ± 0.4 (−20.9 ● -19.6)	11 ± 0.7 (10.1–12.1)	–	–
2019/2020	18	1.06 ± 0.23 (0.60–1.39)	−18.9 ± 0.8 (−19.8 ● -17.7)	12.6 ± 1.1 (11–14.4)	9	0.64 ± 0.16 (0.41–0.95)	−19.3 ± 0.5 (−20.2 ● -18.6)	12.9 ± 1 (10.9–14.1)	15	1.60 ± 0.74 (0.84–3.68)

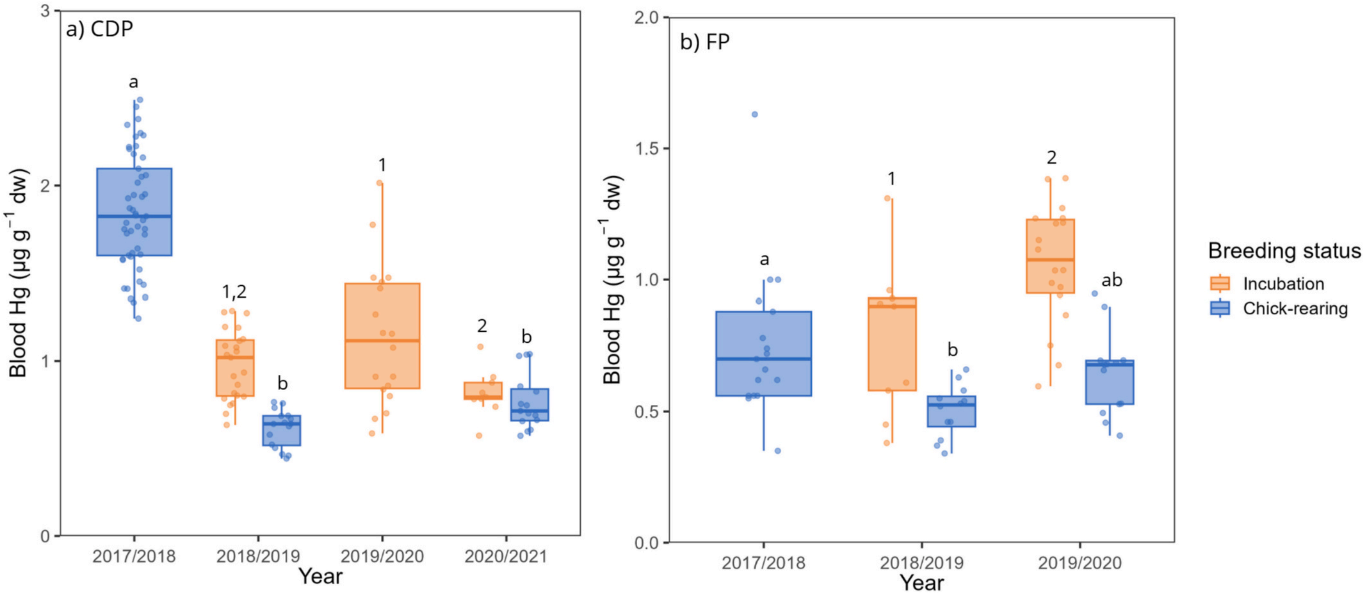

Fig. 2. Inter-annual variations of Hg blood concentrations (μg g^{-1} dw) across years and breeding status in common diving petrels (a). and fairy prions (b). For each species, different numbers indicate significant inter-annual differences in Hg concentrations during incubation, and different letters for chick-rearing. For both species, birds during the chick-rearing period were significantly less contaminated than during the incubation period (Table S1).

less than 13% of the variance (Marginal R-squared, Table 2), but the combined fixed and random terms explain >80% of the variance (Conditional R-squared, Table 2), suggesting a strong effect of the factor "Year" in CDP.

For FP, the model with only the breeding status as an explaining variable for the variation in blood Hg concentration resulted with the best fit for the data (Table 2), explaining 29.85% of the variance alone, whereas the random term and fixed term combined explained 49.77% (Table 2). For both species, birds had lower contamination levels during the chick-rearing period than during incubation (β ± SE: −0.33 ± 0.06 for CDP, β ± SE = − 0.36 ± 0.06 for FP, Table S1).

3.4. *Oceanographic conditions*

For chlorophyll-a, the monthly mean between 2016 and 2020 ranged from 0.25 mg/m^3 (recorded in December 2017, hence during the summer preceding the 2018–19 breeding season) to 0.95 mg/m^3 (April 2016, during the fall preceding the 2016–17 breeding season which was not investigated in the present study). The concentration was significantly higher during the austral fall of 2016 in comparison with all the subsequent falls (from 2017 to 2020, ANOVA; F-value = 9.257, P = 0.002; Tukey' post-hoc all $P \leq 0.01$, between the other years all $P > 0.05$), with a mean of 0.78 mg/m^3 in 2016 and means all <0.52 mg/m^3 the other years. For spring, summer and winter, there were no significant differences between years (ANOVAs, all $P > 0.05$). Regarding SST, there were significant inter-annual seasonal differences: the summers of

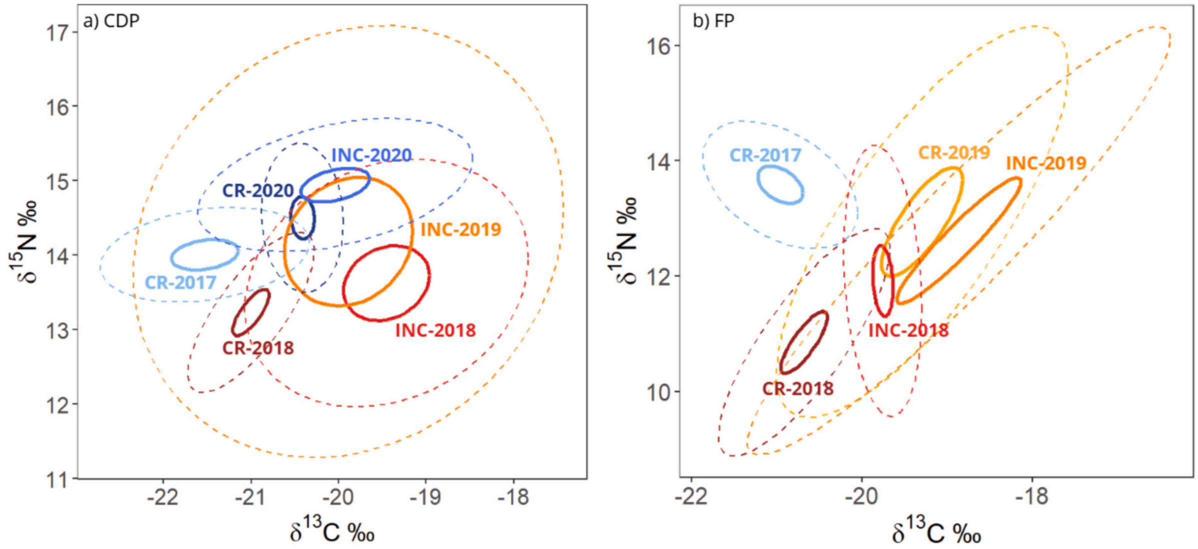

Fig. 3. Whole blood δ^{15}N and δ^{13}C values (‰) of common diving petrels (a) and fairy prions (b), during incubation (INC) and chick-rearing (CR) stages, adapted from Fromant et al., 2021 and Fromant et al., 2022. Full lines ellipses incorporate 40% of the data points and dashed lines incorporate all data points. The blue colours represent the colder years, whereas the red/orange colours indicate years with MHW events.

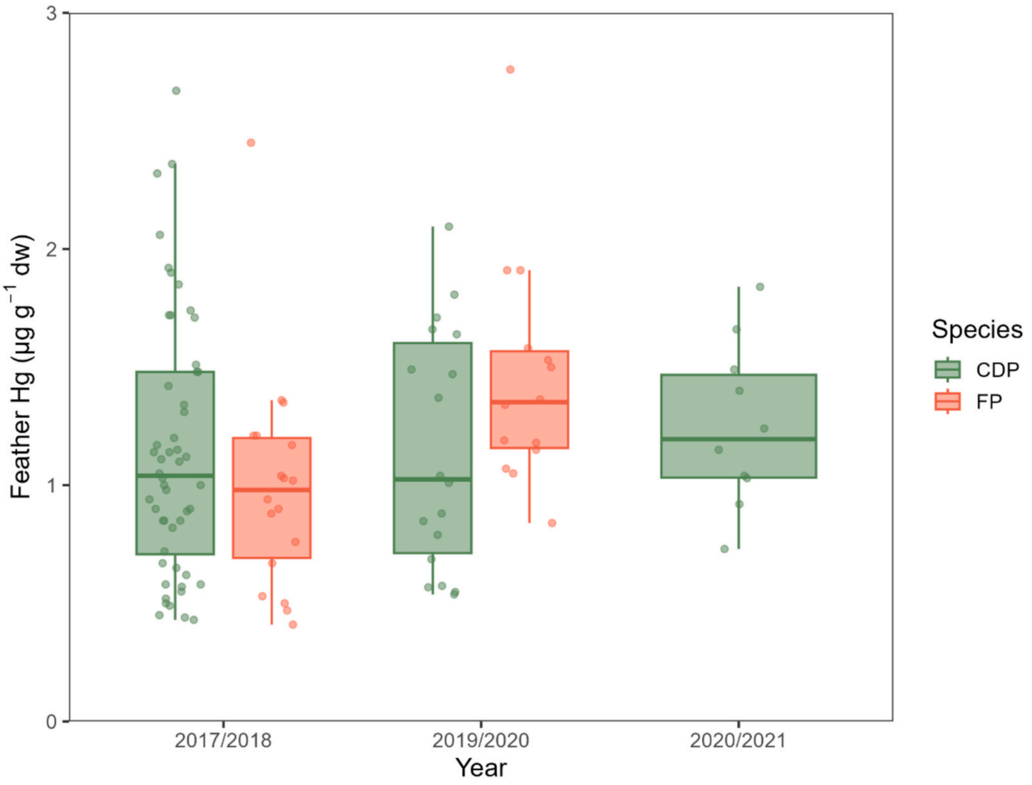

Fig. 4. Variations of Hg concentrations (μg g^{-1} dw) in feathers across years and between common diving petrels (green) and fairy prions (red). No significant difference between species was found in 2017/2018, but there was a significant difference in 2019/2020, fairy prions having a higher mean Hg concentration.

2016–17 and 2019–20 (summers prior the 2017–18 and 2020–21 breeding seasons) were significantly colder than the summers of 2017–18 and 2018–19 (summers prior the 2018–19 and 2019–20 breeding seasons; Kruskal-Wallis chi-squared 135.21, df = 3, $P < 0.001$), with means of 17.11 °C (2016–17) and 16.54 °C (2019–20) for the two colder seasons, and 18.65 °C (2017–18) and 18.27 °C (2018–19) for the two summers with MHW events. The falls prior each breeding season were also marked by significant differences, 2020 being significantly colder (ANOVA, F-value = 17.3, $P < 0.001$) with a mean of 16.27 °C, whereas other years all had means above 17 °C. The fall of 2017 had the warmest temperature recorded and a mean of 17.59 °C, as well as 35 days with temperatures above 18 °C.

4. Discussion

The present study reports the variations in blood and feather Hg concentrations in two Procellariiformes species in Bass Strait, south-eastern Australia, across several successive breeding seasons marked by

Table 2

AICc linear mixing models with Year as a random effect ranking for Hg blood concentration in common diving petrels and fairy prions from Kanowna Island, Bass Strait. k = number of parameters. AICc = Akaike's Information Criteria corrected for small sample sizes. w_i = Akaike's weights. R2m = marginal R-squared, R2c = Conditional R-squared.

Models	k	AICc	ΔAICc	w_i	R2m	R2c
Common diving petrel ($n = 130$)						
δ^{15}N + Breeding status + δ^{15}N * Breeding status	**7**	**6.1**	**0**	**0.385**	**11.0**	**88.3**
Breeding status	**5**	**6.6**	**0.47**	**0.305**	**8.6**	**88.0**
δ^{15}N + Breeding status	6	8.3	2.21	0.128	11.2	89.0
δ^{15}N + δ^{13}C + Breeding status + δ^{15}N * Breeding	8	9.1	2.98	0.087	11.0	87.3
δ^{15}N + δ^{13}C + Breeding status + δ^{15}N * Breeding + δ^{13}C * Breeding status	9	10.0	3.84	0.056	12.1	86.1
δ^{15}N + δ^{13}C + Breeding status	7	14.6	8.52	0.005	10.9	88.7
NULL	4	25.7	19.56	0	0	71.5
Fairy prions ($n = 68$)						
Breeding status	**4**	**12.6**	**0**	**0.742**	**29.9**	**49.8**
Sex + Breeding status	5	16.5	3.98	0.102	31.1	50.1
δ^{15}N + Breeding status	5	17.4	4.81	0.067	34.1	41.9
δ^{13}C + Breeding status	5	18.4	5.85	0.040	34.9	47.8
Sex * Breeding status	6	19.0	6.45	0.029	33.1	52.2
δ^{15}N + δ^{13}C + Sex + Breeding status + δ^{15}N*Sex + δ^{13}C*Sex + δ^{15}N*Breeding status + δ^{13}C*Breeding status	12	51.9	39.30	0	31.2	49.2
NULL	3	32.5	19.93	0	0	15.8

Note: Models in bold are with the best fit to the data, and or equal statistical significance. Only the first six models are shown (n_{total} CDP = 13, FP = 26).

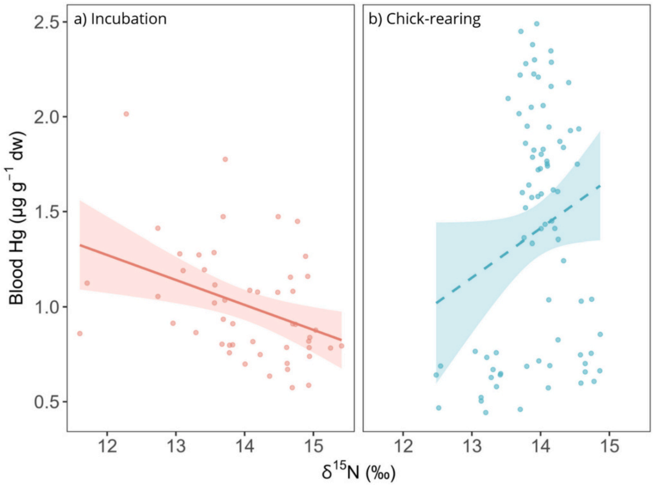

Fig. 5. Effect of the interaction between δ^{15}N (‰) and breeding status over Hg blood concentrations (µg g^{-1} dw) in common diving petrels ($n = 50$ in incubation, $n = 80$ in chick-rearing). Blood Hg decreases with increasing δ^{15}N values during the incubation period and increases with increasing δ^{15}N values during the chick-rearing period (β ± SE: 0.13 ± 0.04, LMM with year as random term, Table S1). The full line indicates a significant relationship between blood Hg and δ^{15}N and the dashed line a non-significant relationship.

contrasted climatic and oceanographic conditions. Although our data was limited to four years, significant inter-annual differences in blood Hg and isotopic values were observed, suggesting an effect of environmental variability on Hg contamination in those two seabird species. Contrary to our hypothesis, the two breeding seasons with colder SST and no MHW events, presumedly providing optimal conditions for the CDP and the FP preferred prey, had significantly different blood Hg values, suggesting that environmental variables other than temperature influences Hg contamination in those two seabirds species.

4.1. Mercury concentrations in blood and feathers: Comparison with other populations

To the best of our knowledge, very few studies have focused on Hg in FP: only one specimen from New Zealand was assayed for feather Hg (Lock et al., 1992, Table 3) thus limiting comparisons with populations from other regions. However, two closely related species to FP, the Broad-billed prion *Pachyptyla vittata* and the Antarctic prion *P. desolata* that range from the subtropic to the Polar Front (Menkhorst et al., 2017) and which are also zooplanktivorous (Klages and Cooper, 1992; Cherel et al., 2002), were more largely investigated for feather Hg (see Table 3). FP in Bass Strait had higher blood Hg concentrations than broad-billed prions in New-Zealand and Antarctic prions in South Georgia, but similar concentrations compared to Antarctic prions in the Kerguelen Archipelago (Table 3). Regarding CDP, blood Hg concentrations in Bass Strait were in the same range to those recorded in the population of Chatham Islands in New Zealand (Table 3; Thébault et al., 2021), where *N. australis* is also abundant (Young et al., 1993). They also displayed similar concentrations with the closely related species the Whenua Hou diving petrel (*P. georgicus whenuahouensis*) in New-Zealand (Okado et al., 2026; Table 3). However, conspecifics from South Georgia in Antarctica (Anderson et al., 2009) had two to six times lower concentrations than those from Bass Strait considering our lowest and highest concentrations found during the chick-rearing periods of 2018–19 and of 2017–18 (Tables 1 and 3). Thus, the Bass Strait CDP and FP populations appears to be much more contaminated with Hg in comparison with the Southern Ocean populations. Such differences may be due to potential variation in Hg bioavailability in the environment (Carravieri et al., 2017), or to differences in the diet between populations (Bocher et al., 2003; Quillfeldt et al., 2023). It is also consistent with the existence of a latitudinal gradient in Hg concentration in seabirds of the Southern Indian Ocean, with populations in Antarctic and sub-Antarctic areas being less contaminated than those in the subtropics (Carravieri et al., 2014a, 2016, 2017).

For CDP, Hg feather concentrations (Fig. 4, Table 1) are comparable with levels recorded in sub-Antarctic populations at Kerguelen Archipelago, as well as in New-Zealand (Table 3, Carravieri et al., 2014b; Thébault et al., 2021). However, CDP in South Georgia had higher Hg concentrations, whereas populations at Gough Island exhibited lower concentrations (Table 3, Anderson et al., 2009; Becker et al., 2016). As CDP from Kanowna Island spend their non-breeding period near the Polar Front in the Southern Indian Ocean (Fromant et al., 2020b), these similar concentrations between birds from the Kerguelen Archipelago and those from Bass Strait are consistent with the latitudinal gradient of Hg contamination in seabirds and the similarities in diet (Fromant et al., 2020b). Conversely, the higher Hg concentrations recorded in South Georgia and lower at Gough Island compared to those from Bass Strait could reflect the spatial variability of Hg across the Southern Ocean, as well as differences in their dietary behaviour and consequently in their exposure to Hg (Bocher et al., 2003; Cusset et al., 2023). As Hg

Table 3

Synthesis of blood and feathers Hg concentrations (μg g^{-1} dry weight) recorded in common diving petrels and fairy prions at Bass Strait and other breeding sites. The Broad-billed prion and the Antarctic prion were added for comparison, due to the lack of information in the literature regarding Hg contamination in fairy prions. Values are means ± standard deviations. The number of individuals analysed is given in brackets.

Species	Site	Year	Blood Hg	Feather Hg	Reference
Common diving petrel (*Pelecanoides urinatrix*)	Bass Strait, Australia	2017	1.85 ± 0.33 (49)	1.14 ± 0.55 (52)	This study(b)
	Stewart Island, New Zealand	2017	0.94 ± 0.22 (18)	–	Okado et al., 2026(a)
	Chatham Islands, New Zealand	2015	0.94 ± 0.16 (10)	0.98 ± 0.55 (10)	Thébault et al., 2021(b)
	Northern New Zealand	2011–2013	–	3.36 ± 2.02 (30)	Lyver et al., 2017
	Kerguelen Archipelago, Southern Indian Ocean	2003	–	1.06 ± 0.54 (29)	Carravieri et al., 2014b
	South Georgia, Southern Ocean	2001–2002	0.31 ± 0.15 (15)	2.90 ± 1.63 (15)	Anderson et al., 2009 (b)
	South Georgia, Southern Ocean	1998	–	0.59 ± 0.15 (2)	Becker et al., 2002
	Gough Island, South Atlantic	2009	–	0.58 ± 0.19 (10)	Becker et al., 2016
Whenua Hou diving petrel (*Pelecanoides georgicus whenuahouensis*)	Stewart Island, New Zealand	2017	1.95 ± 0.43 (27)	–	Okado et al., 2026(a)
South Georgia diving petrel (*Pelecanoides georgicus*)	South Georgia, Southern Ocean	2001–2002	0.41 ± 0.14 (15)	5.07 ± 1.30 (14)	Anderson et al., 2009 (b)
	South Georgia, Southern Ocean	1998	–	1.6 (1)	Becker et al., 2002
Fairy prion (*Pachyptila turtur*)	Bass Strait, Australia	2017	0.75 ± 0.28 (17)	0.99 ± 0.47 (18)	This study(b)
	New Zealand	1991–1992	–	0.5 (1)	Lock et al., 1992
Broad-billed prion (*Pachyptila vittata*)	Chatham Islands, New Zealand	2015	0.40 ± 0.09 (9)	1.00 ± 0.39 (10)	Thébault et al., 2021(b)
	Gough Island, South Antarctic	2009	–	0.75 ± 0.62 (10)	Becker et al., 2016
Antarctic prion (*Pachyptila desolata*)	Kerguelen Archipelago, Southern Indian Ocean	2008	–	1.73 ± 0.50 (10)	Carravieri et al., 2014b
	Kerguelen Archipelago, Southern Indian Ocean	2012	0.67 ± 0.11 (10)	2.8 ± 1.2 (10)	Fromant et al., 2016*
	Kerguelen Archipelago, Southern Indian Ocean	2012–2013	0.71 ± 0.18 (10)	2.39 ± 0.58 (10)	Quillfeldt et al., 2022(a)
	South Georgia, Southern Ocean	2001	0.53 ± 0.21 (16)	4.51 ± 1.26 (15)	Anderson et al., 2009 (b)
	South Georgia, Southern Ocean	2010–2011	0.39 ± 0.13 (15)	1.69 ± 0.75 (20)	Quillfeldt et al., 2022(a)
	South Georgia, Southern Ocean	2011–2012	–	1.49 ± 0.44 (6)	Quillfeldt et al., 2022

Note: Reference studies annotated with (a) means that blood concentrations are indicative of birds sampled during the incubation, (b) during chick-rearing period and * unknown breeding status. For detailed Hg concentrations during chick-rearing and incubation of CDP and FP in Bass Strait between 2017 and 2020, see Table 1.

concentrations in feathers are representative of the contamination between two moults, i.e. one year for both species (Fromant et al., 2020b, 2022), they represent the integration in both breeding (in Bass Strait) and non-breeding periods. Both species head south-west of Bass Strait, with CDP migrating further to the Polar Front and FP staying closer to the sub-tropical front. Therefore, the inter-annual variation in the context of environmental variability in Bass Strait was not investigated. The Hg contamination levels in both CDP and FP revealed some intra-individual variation (Fig. 4), reflecting that individuals use different non-breeding grounds (Fromant et al., 2020b), which can result in variation of Hg exposure.

4.2. Inter-annual variation in blood mercury concentrations

In CDP, significantly higher blood Hg concentrations were recorded during the chick-rearing period in 2017–18 (Fig. 2, Table 1), suggesting that available prey was more contaminated that year. The summer prior the 2017–18 breeding season was significantly colder than the two subsequent seasons, marked by MHW events (Kajtar et al., 2021). However, the summer prior the 2020–21 breeding season also had significantly colder SST than the two previous years, and yet significantly lower Hg blood concentrations were recorded in CDP in comparison to 2017–18 (Fig. 2, Table 1). The CDP isotopic niches in 2017–18 and 2020–21 showed no overlap (Fig. 3), which can be indicative of different prey sources (Layman et al., 2007). Thus, despite being colder seasons and providing optimal temperature range for the coastal krill *N. australis* (12–18 °C, Sheard, 1953), it appears that CDP consumed different food sources between those colder years. CDP and FP are pelagic feeders, foraging predominantly in central and western Bass Strait during the breeding season (Fromant et al., 2021, 2022). GPS tracking conducted on both species during our four years of study reported in Fromant et al. (2021, 2022), evidenced differences in foraging areas between 2017-18 and 2020–21, despite similar oceanographical conditions. Although we have no Hg nor isotopic data available for FP in 2020–21, blood Hg during chick-rearing was significantly higher during the colder year 2017–18 than 2018–19 in this species as well (Table 1, Fig. 2), whereas the two years with MHWs events had similar concentrations. The absence of isotopic niche overlap between 2017-18 and the two years with MHWs (Fig. 3) also suggests different prey sources which could have resulted in contrasted Hg contamination.

A prey switch due to different currents and water masses prevailing in Bass Strait between the years of study could result in such Hg and isotopic differences. Bass Strait is replenished by water masses with distinct oceanographic properties, with the SAC flowing eastwards and SASW from the northern edges of Tasmania (Fig. 1, Gibbs et al., 1986; Middleton and Bye, 2007), as well as southward seasonal influx of the EAC (Ridgway and Ling, 2023). Water within the strait can take more than 6 months to be replaced by external waters (Sandery and Kämpf, 2005, 2007), suggesting that prey with high Hg concentrations brought by a specific current into the strait in 2016 or early 2017 could have caused high Hg contamination in seabirds for the 2017–18 breeding season through a lagged effect. Indeed, in other locations such as the Arctic, climate variables like surface air temperature over Hg concentrations in murres and fulmars' eggs had a lagged effect of two to ten years (Foster et al., 2019). Hence, the significantly higher chlorophyll-a concentration recorded during the fall of 2016 (Fig. 6) could be the indicator of a distinct water mass entering the strait, associated with an upwelling event (Kämpf, 2015) and affecting Hg contamination in CDP and FP during the 2017–18 breeding season. The Bonney Upwelling, occurring seasonally on the southeast Australian coast on the western edge of Bass Strait (Fig. 1), is one of the major inputs of nutrient and water flow into the strait (Middleton and Bye, 2007). However, the carbon isotopic values of both CDP and FP in 2017–18 (−22.16 ‰ to −20.48 ‰ and − 21.55 ‰ to −20.24 ‰, respectively) are closer to temperate/subantarctic water mass associated values found in seabirds of this region (Cherel et al., 2006; Fromant et al., 2020b). It suggests that a water mass bringing dense, nutrient-rich waters of subantarctic origin into the strait could have caused distinct isotopic signatures and Hg contamination in the two procellariform species, feeding on alternative prey. Further studies investigating the Hg contamination of prey associated with each of these water masses, as well as their isotopic values, are necessary to better understand the influence of the oceanographical dynamics over Hg contamination in seabirds of this region.

In 2018–19 and 2019–20, the MHW events are likely to have caused lower availability of *N. australis*, due to high SST impacting the growth of this key krill species (Lagos et al., 2022), as well as its distribution and abundance in the region (Young et al., 1993). Thus, the two species may have fed on a wider variety of prey, as evidenced by wider isotopic niches the two years with MHWs in comparison with the colder seasons (Fig. 3). They also had lower $\delta^{15}N$ values, suggesting predation over lower trophic level species. In contrast, Seco et al. (2021) recorded high Hg concentrations in seabirds (albatrosses, petrels, skuas and prions) from South Georgia in the Southern Ocean, during years with low availability of the herbivorous Antarctic krill, *Euphausia superba*. The authors suggested that it could be due to the seabirds' switching their predation over higher trophic levels species (squids and fish) or the lengthening of the food chain, the Antarctic krill being substituted by several other species such as myctophid fish and squid, as well as other predatory zooplankton species. However, in the present study, the two seasons marked by MHW events were associated with significantly lower Hg concentrations than the 2017–18 colder season, as well as drastic breeding failure in CDP (Fromant et al., 2021). Thus, the years with assumed lower krill availability, seabirds in our study seemed to have limited access to higher trophic level prey to compensate the potential lack of their preferred prey item, which resulted in larger isotopic niches and lower Hg concentrations (Fig. 3). CDP and FP also appear to be specialists when it comes to their dietary preferences, predominantly feeding on *N. australis* and occasionally on other temperate zooplankton species such as hyperiid amphipods (*Themisto australis*) and crab megalopa (Schumann et al., 2008; Fromant et al., 2020a). Thus, switching to prey such as fish or squid may not be a viable option for them when temperate krill species are less abundant.

Throughout those two years marked by MHW events, high SST could have caused an increase of tropical zooplankton species. Shifts in zooplankton communities with warm water species becoming more abundant for the past decades have been recorded in the region (Johnson et al., 2011). For example, following the 2015–16 Tasman Sea MHW caused by the intensification of the EAC (Oliver et al., 2017), a significant increase of EAC zooplankton associated species was recorded off the south-east coast of Tasmania (Evans et al., 2020b). Temperate species such as *N. australis* were less abundant, whereas bryozoan and echinoderm larvae, tropical zooplankton species and gelatinous plankton (e.g salps) increased in abundance (Evans et al., 2020b). Therefore, it is possible that a zooplankton shift occurred in the foraging area of CDP and FP following a MHW event, leading the two seabird populations to feed on different types of prey. Oligotrophic waters such as those associated with the EAC have been found to have higher Hg contaminated food webs than highly productive water masses (Chouvelon et al., 2018). In productive systems, the large biomass of phytoplankton and zooplankton at the base of the trophic chain causes a “bio-dilution” effect (Pickhardt et al., 2002), which reduces biomagnification toward the upper trophic levels. However, the lower $\delta^{15}N$ values during the two warmer years suggest that the prey available were of a lower trophic level, hence less contaminated due to the biomagnification process of Hg (Atwell et al., 1998). In Bass Strait, the little penguin was found to feed opportunistically on salps and gelatinous plankton (Cavallo et al., 2018), suggesting that seabirds in the region may be feeding on those lower trophic level prey when their preferred food items are scarce. Gelatinous zooplankton can become dramatically more abundant in ecosystems after a MHW event, subsequently altering the structure of food webs (Brodeur et al., 2019), and potentially causing variation in Hg contamination of predators.

Dietary shifts linked to environmental variability may drive changes in Hg concentrations in seabirds: in the Arctic, long-term monitoring revealed that higher Hg concentrations in black-legged kittiwakes *Rissa tridactyla* coincided with periods of elevated chlorophyll-a, reflecting a switch from more to less contaminated prey (Tartu et al., 2022). In the same region, long-term Hg variation in eggs of murres and fulmars was associated with the North Atlantic Oscillation and surface air temperature, however the link with potential MHW events was not investigated (Foster et al., 2019). Regarding the Southern hemisphere, the effect of sea surface temperature and MHWs over Hg concentrations in seabirds has not been studied. However, in Bass Strait, inter-annual variation in trace elements linked with environmental conditions have been reported in lactating Australian fur seals *Arctocephalus pusillus doriferus*, associated with the oceanographical conditions of the Bonney Upwelling (Mathews et al., 2024). Additionally, variations of the isotopic niche space of three seabird species were recorded at Montague Island in New South Wales associated with the EAC intensification (Niella et al., 2025), confirming the influence of this current over seabirds' diet in the region. In the present study, it remains uncertain which oceanographical process could have caused an alteration of the trophic structure, resulting in inter-annual variation in blood Hg of both species. This substantial variation could ultimately be reflecting a change in water mass

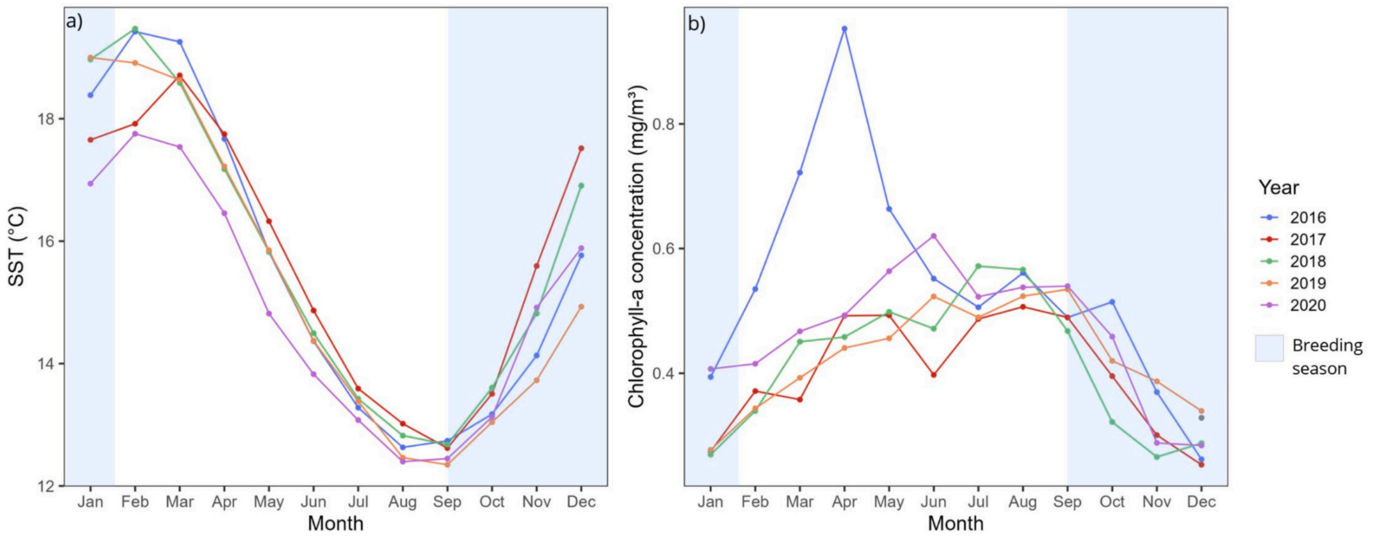

Fig. 6. a) Monthly average SST (sea surface temperature, in °C), b) monthly average chlorophyll-a concentration (mg/m^3) in the Bass Strait (38.5–41.0°S, 144.0–148.0°E) for the years 2016 to 2020. The breeding season of CDP and FP is indicated in light blue. Marine heatwaves occurring during the austral summer preceding the breeding season may alter the prey composition, abundance and availability in Bass Strait, consequently affecting CDP and FP's feeding ecology.

dominance in Bass Strait affecting the prey composition, distribution and abundance, but further studies investigating how environmental variables affect Hg contamination in seabirds over longer periods are necessary to clarify such variations.

4.3. Variation in blood mercury concentrations with breeding status

In both species, the breeding status had a significant effect on blood Hg concentrations (Table 2). For years when blood Hg concentrations for both reproductive statuses were available, higher values were consistently recorded during the incubation period compared to the chick-rearing period (Fig. 2, Table 1). This difference is probably due to a carry-over effect from Hg contamination during the non-breeding period, with birds being less exposed in the breeding area (Lavoie et al., 2014; Quillfeldt et al., 2022). Indeed, blood concentrations represent a dynamic balance between absorbed Hg and Hg stored in internal tissues, with the turnover of the metal in blood cells requiring several months to reach stabilisation (Bearhop et al., 2000). Higher blood Hg concentrations during the incubation period highlights that CDP and FP are more exposed to Hg when in their non-breeding grounds, feeding on alternative prey of higher trophic level or with higher Hg contamination at the base of the food chain, in comparison to Bass Strait. In CDP, the significant increase of δ^{15}N values as Hg decreases during incubation supports this first hypothesis (Fig. 5), reflecting a diet switch between non-breeding and breeding grounds. In contrast during the chick-rearing period, this negative relationship between blood δ^{15}N and Hg was not observed (Fig. 5). This contrasted pattern between the two-breeding status did not occur in FP (Fig. S1), potentially due to their different non-breeding areas compared to CDP (Fromant et al., 2020b, 2022). The decrease of blood Hg concentrations between incubation and chick-rearing could also result from differential foraging strategies, both species exhibiting different foraging patterns between the two reproductive periods (Fromant et al., 2021, 2022).

4.4. Comparison of mercury concentrations between the two species

Despite a similar diet with the coastal krill *N. australis* being their main food item (Fromant et al., 2020a), the two species had significant differences in Hg blood concentrations some years (2017–18 chick-rearing and 2018–19 both breeding status). Moreover, CDP were more largely influenced by the year parameter in the variation of their blood Hg concentrations than FP (Table 2), as well as by δ^{15}N values (Fig. 5, Table S1). Their distinct non-breeding grounds could explain such differences during incubation, as well as separate foraging areas during chick-rearing (Fromant et al., 2021, 2022). For example, CDP forage within central Bass Strait during incubation, whereas FP may go outside of Bass Strait westward (Fromant et al., 2021, 2022). Moreover, FP would have a greater ability to adapt to changes in environmental conditions, due to higher flying distance capabilities and stomach oil production (Manno et al., 2014; Eizenberg et al., 2021). These flying abilities allow FP to access more distant foraging grounds (Navarro et al., 2013), while the stomach oil increases the energy intake of chicks, enabling adults to make longer and more distant foraging trips (Roby et al., 1997). Thus, FP could have adapted more easily their foraging strategies when exposed to strong environmental variability and switch in prey availability in Bass Strait, resulting in lower variation in Hg contamination over the years of study in comparison to CDP.

5. Conclusion

Significant inter-annual differences were observed in blood Hg concentrations of CDP and FP during the span of only four years: however, it remains challenging to precisely determine which are the factors explaining such variation. Our results suggest a modification of the trophic structure linked with changes in water mass dominance in Bass Strait, such as SASW or EAC water masses. As an intensification of the EAC is expected due to climate change, as well as an increase of MHW events (Cai et al., 2005; Oliver et al., 2018), it suggests that such alterations of the food web associated with environmental variability could cause further variation in Hg contamination in seabirds. Additional studies conducted over a longer time span, marked by climatic events such as MHWs or El Niño Southern Oscillation (ENSO), as well as investigations over the Hg contamination of prey from the different water masses entering the strait, are necessary to have a better understanding of the drivers of Hg contamination and variations in seabirds of Bass Strait.

CRediT authorship contribution statement

Margot Arabadjieva: Writing – review & editing, Writing – original draft, Visualization, Methodology, Investigation, Formal analysis. **Aymeric Fromant:** Writing – review & editing, Methodology, Investigation, Formal analysis. **John P.Y. Arnould:** Writing – review & editing, Supervision, Resources, Investigation. **Paco Bustamante:** Writing – review & editing, Supervision, Resources, Project administration, Funding acquisition, Conceptualization, Investigation.

Ethics

All animal handling and sampling was approved by the Deakin Animal Ethics (Approval B16-2017) and DELWP Wildlife Research (Permit no. 100084552).

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.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.scitotenv.2026.181786.

Data availability

Data will be made available on request.

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