General and Comparative Endocrinology

Do foraging ecology and contaminants interactively predict parenting hormone levels in common eider?

--Manuscript Draft--

| **Abstract:** | Global climate change is causing abiotic shifts such as higher air and ocean temperatures and disappearing sea ice in Arctic ecosystems. These changes influence Arctic-breeding seabird foraging ecology by altering prey availability and selection, affecting individual body condition, reproductive success, and exposure to contaminants such as mercury (Hg). The cumulative effects of alterations to foraging ecology and Hg exposure may alter the secretion of key reproductive hormones such as prolactin (PRL), important for parental attachment to eggs and offspring and overall reproductive success. However, more research is needed to investigate the relationships between these potential links. Using data collected from 106 incubating female common eiders (Somateria mollissima) at six Arctic and sub-Arctic colonies, we examined whether the relationship between individual foraging ecology (assessed using δ13C, δ15N) and total Hg (THg) exposure predicted PRL levels. We found a significant, complex interaction between δ13C, δ15N and THg on PRL, suggesting that individuals cumulatively foraging at lower trophic levels, in phytoplankton-dominant environments, and with the highest THg levels had the most constant significant relationship PRL levels. Cumulatively, these three interactive variables resulted in lowered PRL. Overall, results demonstrate the potential downstream and cumulative implications of environmentally induced changes in foraging ecology, in combination with THg exposure, on hormones known to influence reproductive success in seabirds. These findings are notable in the context of continuing environmental and food web |
| | changes in Arctic systems, which may make seabird populations more susceptible to ongoing stressors. |

Highlights

- Blood samples from 106 common eiders from 6 colonies were analyzed (δ^{13}C, δ^{15}N, THg, prolactin)

- A significant interaction was found between δ^{13}C, δ^{15}N and Hg on prolactin

- In the 3-way interaction, δ^{15}N positively correlated with incubating prolactin

- Low δ^{13}C and high Hg had a consistent interactive impact in combination with δ^{15}N

- This complex interaction may have downstream implications for reproductive success
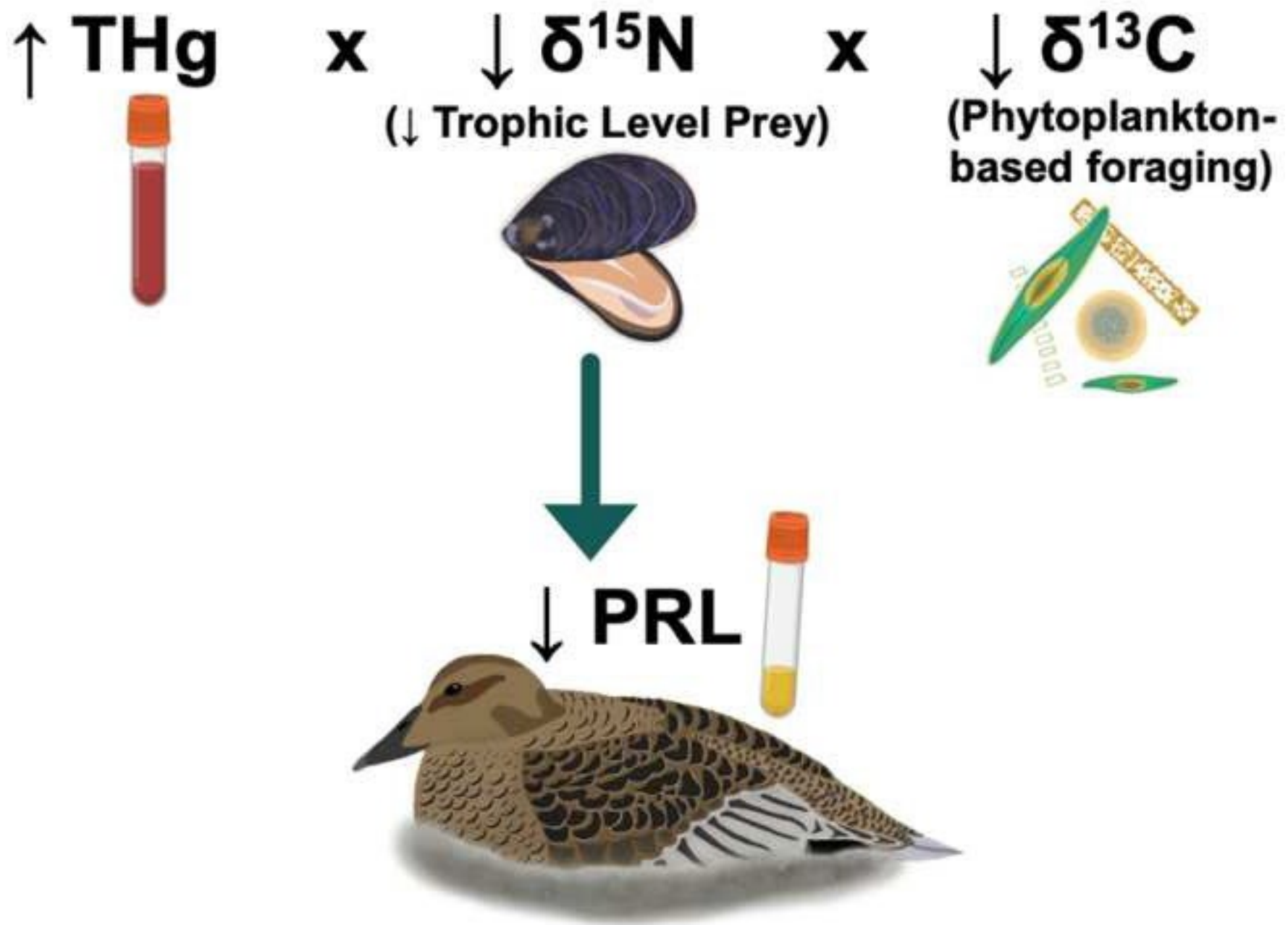
1   **Do foraging ecology and contaminants interactively predict parenting hormone levels in**

2   **common eider?**

3

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41

42   **Graphical Abstract**

↑ **THg** X ↓ **δ¹⁵N** X ↓ **δ¹³C**

(↓ Trophic Level Prey)   (Phytoplankton-based foraging)

↓ **PRL**
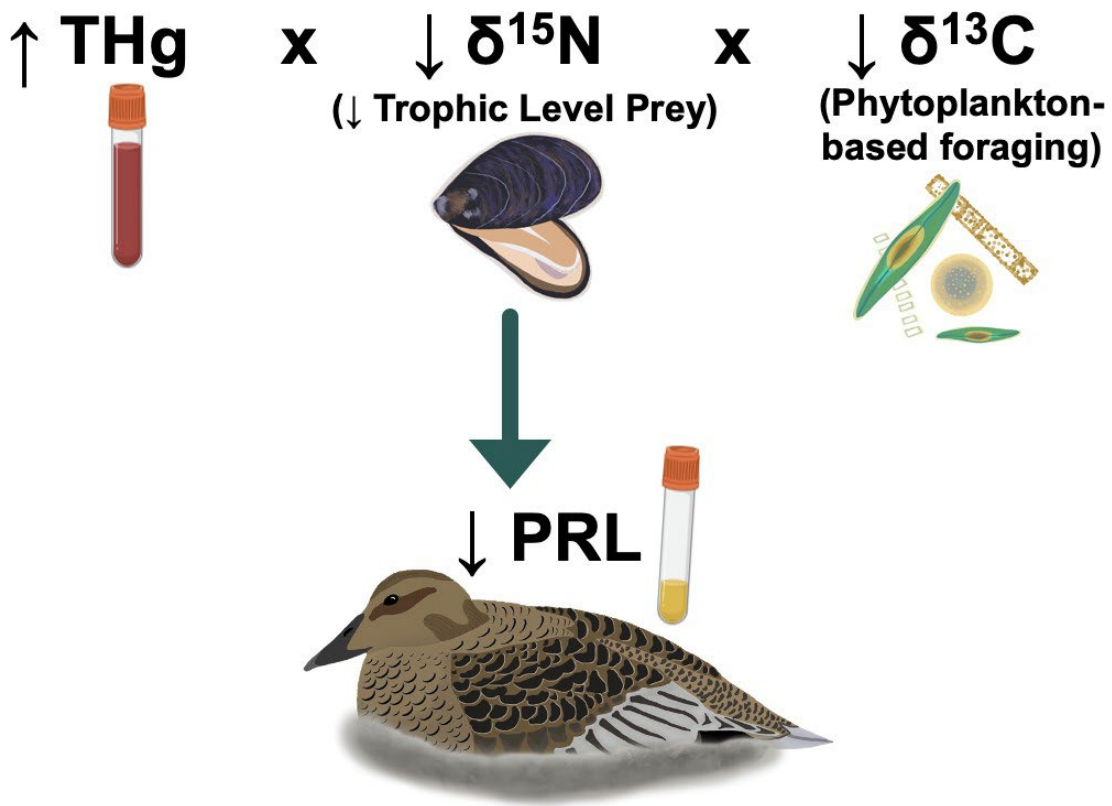
43

44 **Abstract**

45 Global climate change is causing abiotic shifts such as higher air and ocean temperatures and

46 disappearing sea ice in Arctic ecosystems. These changes influence Arctic-breeding seabird

47 foraging ecology by altering prey availability and selection, affecting individual body condition,

48 reproductive success, and exposure to contaminants such as mercury (Hg). The cumulative

49 effects of alterations to foraging ecology and Hg exposure may alter the secretion of key

50 reproductive hormones such as prolactin (PRL), important for parental attachment to eggs and

51 offspring and overall reproductive success. However, more research is needed to investigate the

52 relationships between these potential links. Using data collected from 106 incubating female

53 common eiders (*Somateria mollissima)* at six Arctic and sub-Arctic colonies, we examined

54 whether the relationship between individual foraging ecology (assessed using δ^{13}C, δ^{15}N) and

55 total Hg (THg) exposure predicted PRL levels. We found a significant, complex interaction

56 between δ^{13}C, δ^{15}N and THg on PRL, suggesting that individuals cumulatively foraging at lower

57 trophic levels, in phytoplankton-dominant environments, and with the highest THg levels had the

58 most constant significant relationship PRL levels. Cumulatively, these three interactive variables

59 resulted in lowered PRL. Overall, results demonstrate the potential downstream and cumulative

60 implications of environmentally induced changes in foraging ecology, in combination with THg

61 exposure, on hormones known to influence reproductive success in seabirds. These findings are

62 notable in the context of continuing environmental and food web changes in Arctic systems,

63 which may make seabird populations more susceptible to ongoing stressors.

1. Introduction

Increasing anthropogenic activity has resulted in rapid and wide-ranging abiotic shifts in marine systems associated with climate change, including rising air and ocean temperatures (Screen and Simmonds 2010; Najafi et al. 2015), changes in ocean circulation and salinity (Timmermans et al. 2011; Zika et al. 2018), and dramatic changes in sea ice abundance and distribution within polar systems (Johannessen et al. 2004; Hoegh-Guldberg and Bruno 2010). Arctic regions disproportionately exhibit these simultaneous, cumulative effects (IPCC 2019; AMAP 2021), resulting in impacts on food web relationships (Vasseur and McCann 2005; Frederiksen et al. 2006; Parmesan 2006; Pecuchet et al. 2020). Alterations in the abundance and distribution of lower trophic level organisms (i.e., primary producers) have been evident, with organisms such as phytoplankton displaying advanced phenology and higher abundance relative to sea ice algae (Frederiksen et al. 2006; Renaut et al. 2018; Lewis et al. 2020). Additionally, changes in higher trophic level foraging ecology have been associated with climate change, as prey disruptions further disturb the relationships among food webs (Moline et al. 2008; Watt et al. 2016). Thus, bottom-up and top-down trophic level alterations can result in modifications to individual and species foraging ecology and, in some cases, sizeable population declines (Legagneux et al. 2012; Perkins et al. 2018; Durant et al. 2019). Seabirds are particularly susceptible to adverse outcomes resulting from changes in both directions of trophic alterations, which can influence body condition and, importantly, downstream reproductive success (Baird 1990; Hamer et al. 1993; Suryan et al. 2006; Perkins et al. 2018; Hovinen et al. 2019). Additionally, changing predator-prey dynamics and spatio-temporal prey abundance can alter, either positively or negatively, individual seabird exposure to environmental contaminants such as mercury (Hg)

86   through changes in prey selection and foraging locale (Bearhop et al. 2000; Braune et al. 2014;

87   Fort et al. 2016, Tartu et al. 2022).

88   Arctic marine systems are contaminated with Hg via northward transportation of Hg

89   through air and ocean circulation as well as through Arctic rivers (Macdonald et al. 2000; Sonke

90   et al. 2018; DiMento et al. 2019), and the melting of the cryosphere which releases stored Hg

91   from years of higher contaminant output back into the system (Rydberg et al. 2010; Schuster et

92   al. 2018; Hawkings et al. 2021). These factors have all cumulatively resulted in spatiotemporally

93   heterogeneous environmental Hg levels in Arctic regions that influence organism Hg levels by

94   factors including spatio-temporal location and foraging ecology (Braune et al. 2005; 2015; Leu et

95   al. 2011; de la Vega et al. 2019; Albert et al. 2021(b)). Individuals foraging at higher trophic

96   levels, usually determined using nitrogen stable isotope analysis (δ^{15}N, in relation to ^{15}N to ^{14}N

97   ratios), are often correlated with elevated Hg levels resulting from the methylmercury (MeHg)

98   biomagnification process, although individual variation outside of this correlation often exists

99   (Atwell et al. 1998; Bearhop et al. 2000; DiMento et al. 2019). Moreover, the influence of Arctic

100   marine primary producers on the diets of higher order predators, often determined using ratios of

101   carbon isotopes (^{12}C - phytoplankton enriched, ^{13}C - ice algae enriched; δ^{13}C), can offer insight

102   into potential Hg sources based on foraging location and sea ice abundance (Hobson and Welch

103   1992; Hobson et al. 1995; McMahon et al. 2006).

104   MeHg is a biologically converted form of Hg that affects endocrine functioning,

105   behaviour, and reproductive success in birds at even low, sub-lethal levels (Wiener et al. 2003;

106   Whitney and Cristol 2017; Evers 2018, Chastel et al. 2022). While the Hg levels in most seabirds

107   (95%) are considered lower risk, there have been recent calls to examine the potential impact of

108   Hg in a cumulative stressor framework to help address Article 22 of the Minimata Convention

109   (https://www.mercuryconvention.org/sites/default/files/documents/information_document/4_INF

110   12_MonitoringGuidance.English.pdf). Article 22 calls for an evaluation of the effectiveness of

111   the convention, in which Arctic seabirds serve as indicators for assessing environmental

112   contamination (Chastel et al. 2022). Avian reproduction can be affected by Hg exposure through

113   its endocrine-disrupting properties that can influence female breeding behaviour (Tan et al. 2009;

114   Ackerman et al. 2016; Whitney and Cristol 2017, Chastel et al. 2022). For example, in the

115   beginning stages of reproduction, sub-lethal Hg has been correlated with a decreased likelihood

116   to breed, attributed to the effect of Hg on luteinizing hormone (LH) and the subsequent release of

117   sex hormones (i.e., estrogen; Tartu et al. 2013; 2014). Importantly, exposure to Hg has been

118   linked to a decrease in prolactin (PRL), a pituitary hormone key for parental care behaviours (El

119   Halawani et al. 1984; Tartu et al. 2015; Angelier et al. 2016; Tartu et al. 2016). However, no link

120   between Hg and PRL has been observed in other studies, indicating a potentially complex

121   relationship and role of PRL in avian incubation (Gilmour et al. 2019; Blévin et al. 2020).

122   In birds, PRL secretion commences after the parent physically touches their eggs and

123   increases following the cessation of laying and the onset of incubation behaviour (Buntin 1996;

124   Sockman et al. 2000). In common eider (*Somateria mollissima*, hereafter eider), PRL increases at

125   the onset of incubation and remains at a consistent level during incubation, followed by a steep

126   increase immediately before hatching (Criscuolo et al. 2002). Additionally, the role of PRL in

127   clutch size determination has been previously proposed, with increased PRL signalling for a

128   decrease in LH that stops the laying period in anticipation of incubation (Sockman et al. 2000).

129   Disruption of PRL secretion during incubation has been proposed as a likely mechanistic link

130   that results in lowered quality of incubation behaviour via decreased incubation attentiveness

131   (Angelier and Chastel 2009; Angelier et al. 2009). Incubating females in worsened body

132 condition may have lower PRL levels, thus reducing incubation quality and increasing predation

133 risk (Criscuolo et al. 2002). Overall, the cumulative and interactive effects of prey consumption

134 and Hg accumulation on PRL can influence key reproductive traits such as incubation behaviour

135 and reproductive success. These linkages are important to examine, especially given the

136 accelerating rate of environmental shifts in Arctic marine systems.

137   A recent study from our group indicated that eider colonies highly varied in

138 multidimensional niche dynamics: migratory colonies had higher δ^{15}N and THg, but lower δ^{13}C

139 and sea-ice cover positively correlated with δ^{15}N, δ^{13}C and THg (Smith et al. 2021). The study

140 also found that individual eiders with lower δ^{13}C and higher trophic positions had higher THg

141 (Smith et al. 2021). In the current study, we built from these results to examine the interactive

142 effects of foraging ecology, inferred with stable isotope analysis (Kelly 2000), and Hg on PRL

143 levels of incubating female common eiders. Eiders are long-lived, colonial-nesting marine ducks

144 with dispersed breeding populations across the circumpolar and sub-Arctic. As such, they are

145 exposed to diverse environmental conditions, which influence variation in their foraging ecology

146 and Hg exposure (Albert et al. 2021(a); Smith et al. 2021). Eider prey includes a diversity of

147 benthic invertebrates (e.g., urchins and mussels) and pelagic macroinvertebrates (e.g.,

148 amphipods; Sénéchal et al. 2011). Eiders forage extensively in the pre-breeding period in various

149 ice conditions depending on the timing of spring melt to obtain an appropriate body condition

150 needed to breed (Jean-Gagnon et al. 2018). Importantly, female eiders undergo a 24-26 day

151 uniparental incubation fast, relying solely on their endogenous stores to fuel the incubation

152 period (Hanssen et al. 2002; Bottitta et al. 2003; Sénéchal et al. 2011). During this fasting period,

153 contaminants including Hg increase in the blood due to the mobilization of endogenous lipid and

154 protein stores (Wayland et al. 2005; Bustnes et al. 2010; McPartland et al. 2020). These levels

155   can go over the threshold known to be negatively correlated with PRL secretion in other seabird

156   species (Tartu et al. 2015; 2016). Consequently, in combination with reduced body condition,

157   elevated blood levels of Hg may interfere with hormones such as PRL, with the potential for

158   downstream influences on incubation behaviour and reproductive success (Tartu et al. 2016).

159   However, intricate relationships between these and other physiological aspects have been

160   demonstrated previously in the literature. In common eiders, complex and integrated

161   relationships have been shown between clutch size, body condition/mass, incubation duration,

162   PRL and the primary glucocorticoid in birds, corticosterone (CORT) (Erikstad et al. 1993;

163   Criscuolo et al. 2006). Clutch size and body condition are positively related, while body

164   condition can be negatively correlated with incubation duration but positively correlated with

165   incubation attentiveness (Erikstad et al. 1993; Erikstad and Tveraa 1995). Meanwhile, body mass

166   was positively linked to PRL levels, while baseline levels of CORT were negatively correlated

167   with plasma PRL, altogether leading to reductions in overall reproductive success (Criscuolo et

168   al. 2002; 2005; 2006). These relationships provide a background for examining the effects of

169   foraging ecology and Hg on PRL in female eiders.

170   Our overall hypothesis was that the combined effects of foraging ecology and Hg

171   contamination would affect PRL levels in incubating eiders. Specifically, we predicted that lower

172   levels of PRL would be correlated with lower δ^{15}N (lower trophic level foraging, lesser quality

173   prey), higher δ^{13}C (sea ice algae-based foraging, more restrictive foraging environment), and

174   elevated Hg levels. Examining these relationships will allow for a more extensive determination

175   of the indirect mechanisms by which climate change affects at-risk Arctic seabird populations.

176

177   **2. Methods**

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178 ***2.1. Sample collection and physiological analysis***

179 Seven Arctic and sub-Arctic breeding colonies were monitored in 2018 (Table 2, N=136).

180 Incubating eiders were captured on their nests using noose poles, bownets, or dogs (John's Island

181 location only; Milton et al. 2016). A 200-1,000 μL blood sample was collected from each

182 female's tarsal vein, jugular vein (Grindøya and Kongsfjorden), or brachial vein (Iceland) using

183 a 23G thin-wall, 1-inch needle attached to a heparinized 1 mL syringe (10 mL syringe -

184 Grindøya and Kongsfjorden). Samples were centrifuged within 8-12 h of collection at

185 approximately 10,000 rpm for 10 min to obtain red blood cells (RBC) for stable isotope (isotope-

186 ratio mass-spectrometer) and total Hg (THg; Advanced Mercury Analyser; see Smith et al. 2021

187 for further details on these methods and results). Plasma was collected from the centrifuged

188 whole blood, frozen for storage in the field, and later sent for PRL analysis to the Centre

189 d'Etudes Biologiques de Chizé (CEBC), France. Plasma samples were analyzed for PRL using

190 radioimmunoassay (RIA) following the procedure detailed in Cherel et al. (1994) and validated

191 in common eiders in previous studies (Criscuolo et al. 2002). The analysis consisted of

192 duplicates with colonies split into two runs: John's Island, Iceland and Tern Island in one run

193 (intra-assay variation = 12.01%), and Grindøya, Faroe Islands, Kongsfjorden, and Solovetskiy

194 Islands in a second run (intra-assay variation = 9.28%). Inter-assay variation between the two

195 runs was 14.75%, calculated from a sample run in both assays in 6 replicates. PRL was measured

196 in 10μL, and the lowest detectable limit was 0.45 ng/mL.

197 As specific individual incubation stage was unable to be determined at many sites or

198 hens, we could not correct the potential effect of incubation fasting on THg or $\delta^{15}N$ levels

199 (Hobson et al. 1993; Wayland et al. 2005; Smith et al. 2021). However, using RBCs to determine

200 isotopic and THg values minimized this effect as $\delta^{15}N$ enrichment is lesser in blood cells than in

201   plasma (Cherel et al. 2005). Further, as PRL levels are consistent throughout incubation stages in

202   eiders prior to hatching (Criscuolo et al. 2002), we were able to conduct inter-colony and

203   individual comparisons of PRL without correction for individual or colony incubation stage.

204

205   *2.2. Statistical analysis*

206   To examine whether PRL levels varied between colonies, we first ran an ANOVA followed by a

207   posthoc Tukey's Honest Significant Difference (HSD) test using the R package car v.3.0-10 (Fox

208   and Weisberg 2019). We then used compact letter display, in combination with the R package

209   ggplot2 v.3.3.6, to visually determine significance at an alpha level of 0.05 between the seven

210   colonies using the R package multcompView v.0.1-8 (Graves et al. 2015; Wickham 2016).

211   Following this, we calculated AICc values for 12 potential models to determine the most

212   parsimonious model using the R package AICcmodavg v.2.3-1 (Mazerolle 2020). The model

213   with the lowest AICc also had a significantly lower log-likelihood value, thus, was a better fit

214   than the other models (Table 1). We then used a general linear mixed model (GLMM) with a

215   normal distribution to determine the interactive effect of $\delta^{15}N$, $\delta^{13}C$ and THg levels on PRL

216   secretion. The dependent variable was PRL, with $\delta^{15}N$, $\delta^{13}C$ and THg values included as fixed

217   independent variables in all single, two- and three-way interactions. Additionally, we included

218   female body mass (g) and clutch size as fixed independent variables in a two-way interaction. All

219   independent variables were standardized and centred for comparison to remove

220   misrepresentation of effects and increase the interpretability of coefficients (Schielzeth 2010).

221   We included breeding colony in the model as a random variable to control for inter-colony PRL

222   variation, with the objective being to examine individual variation. All statistical analyses were

223   conducted in RStudio version 2022.07.2 (RStudio Team). All model assumptions were met by

224   visually inspecting histograms to confirm a normal data distribution, quantile-quantile plots, and

225   residual plots from the model outputs. We also confirmed the absence of multicollinearity

226   between all variables using correlation coefficients and variance inflation factors (VIF), which

227   were below 0.36 and 3.90 (3-way interaction), respectively. In interpretations of three-way

228   interactions, the interaction among two factors (A * B) differs along with levels of a third factor

229   (C). To assist with the visualization of these complex relationships, significant interactions were

230   graphed using the R package Interactions v.1.1.3 (Long 2019). This package calculated Johnson-

231   Neyman intervals and simple slopes analysis to determine the significant slopes within the three-

232   way interaction.

233

234   **3. Results**

235   Median PRL levels were variable among eider colonies, ranging from 245.18 ng/mL (Tern

236   Island) to 348.99 ng/mL (Kongsfjorden), with the median PRL for all eiders at 287.60 ng/mL

237   (Table 2, Figure 2). At the individual eider level, the lowest (142.72 ng/mL) and highest (489.20

238   ng/mL) values were found at the Kongsfjorden colony. Mean colony PRL levels significantly

239   varied between colonies, with the Kongsfjorden colony having significantly higher mean PRL

240   levels than every colony except for Grindøya (Figure 2). Conversely, Tern Island had

241   significantly lower mean PRL levels than all colonies but Faroe Islands (Figure 2). Although we

242   report the PRL values for the John's Island colony, researchers at this location did not collect

243   body mass measurements. Therefore, this colony was omitted from the statistical model (n=18)

244   and any individuals that did not have body mass and/or clutch size data (n=12, total individuals

245   omitted = 30), with a remaining sample size of 106 individuals for the GLMM.

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246   The GLMM showed that δ^{15}N (t_{80}=2.289, p=0.025; Table 3) as well as the three-way

247   interaction between δ^{15}N, δ^{13}C and THg were significant (t_{95}=2.089, p=0.039; Table 3). Johnson-

248   Neyman intervals and simple slopes analysis determined that 6/9 of the slopes in the three-way

249   interaction were significantly different from zero. In particular, 3/3 slopes were significant at

250   THg +1 standard deviation (SD), 2/3 were significant at mean THg levels, and 1/3 were

251   significant THg -1 SD (Figure 3). At higher levels of THg (+1 SD), all levels of δ13C values (-1

252   SD, mean, and +1 SD) resulted in significant positive relationships between δ15N and PRL

253   (Figure 3). At mean THg levels, mean and low δ13C values (-1 SD) also resulted in significant

254   positive relationships between δ15N and PRL (Figure 3). At low THg levels (-1 SD), only low

255   δ^{13}C values (-1 SD) resulted in significant positive relationship between δ15N and PRL (Figure

256   3). However, there was no significant relationship between female body mass, clutch size, or a

257   two-way interaction of those variables with PRL (Table 3).

258

259   **4. Discussion**

260   We examined the interactive effects of individual foraging ecology and THg contamination on

261   PRL levels in incubating female common eiders across six colonies at a pan-Arctic scale. We

262   predicted an effect of the interaction between δ^{15}N, δ^{13}C and THg on PRL levels, given the

263   potential effect of these variables on female body condition and hormone regulation. Consistent

264   with our prediction, individuals at lower trophic levels (lower δ^{15}N) showed the lowest PRL

265   levels, most commonly in combination with individuals at higher THg levels and those foraging

266   in predominantly phytoplankton-based environments (lower δ^{13}C). Our findings suggest a

267   potential cumulative, interactive effect of foraging ecology and elevated THg exposure on PRL

268   levels in wild eider colonies.

269

4.1. Interactive relationship between foraging ecology and PRL levels

We found a significant positive relationship between δ^{15}N and PRL levels. Pre-breeding eiders

foraging at lower trophic levels may potentially have a relatively lower body condition going

into and then throughout incubation. PRL and incubating body condition have been linked in

previous studies, where lower-condition females showed reduced PRL levels (Criscuolo et al.

2002). Although body mass did not correlate with PRL, there is nonetheless potential for the

indirect linkages between trophic level (i.e., δ^{15}N) and body condition to influence PRL secretion

(see section 4.3). Changes in food web structure are apparent with continuing climate change and

are likely to vary spatio-temporally between colonies with differing prey availability (see section

1; Smith et al. 2021). These effects are important for a species such as eiders since a lower body

condition beginning in the pre-breeding stage could reduce the amount of PRL during

incubation, with potential implications on nest attentiveness and overall breeding success

(Erikstad et al. 1993; Criscuolo et al. 2002). Eiders forage primarily on amphipods and bivalves,

which have demonstrated sensitivity to warming ocean temperatures (Węsławski et al. 2011;

Dalpadado et al. 2016; Vinarski et al. 2021). Based on our current results, changes in eider

trophic niches due to ecosystem shifts (likely to vary widely and depend on spatio-temporal prey

availability) may have downstream impacts on body condition and PRL levels. For example,

individuals that consume a greater abundance of lower trophic level prey could have

comparatively lower body condition with expected negative impacts on PRL levels. This prey

may include bivalves, which have lower energy returns due to a low ratio of flesh content to shell

size compared to shell-less macroinvertebrates (Hamilton et al. 1999; Schummer et al. 2008). In

colonies where trophic niches shift to a greater abundance of higher trophic level prey, such as

292 arthropods, the reverse effect is possible where higher trophic level prey may improve

293 reproductive output, as seen in blue-footed boobies (González-Medina et al. 2018). Interestingly,

294 the colonies with the lowest median PRL levels (Faroe Islands, Tern Island) were also identified

295 previously as having the lowest median $\delta^{15}N$ out of the colonies studied (Smith et al. 2021),

296 indicating that their lower PRL values may be linked with their utilization of lower trophic level

297 prey such as bivalves. Despite these potential patterns, the eventual outcome of prey abundance

298 shifts on eider hormonal mechanisms at the heart of successful incubation outcomes remains to

299 be seen as climate change effects increase annually. However, our work provides a valuable

300 baseline to examine subsequent future changes.

301   We also detected a significant relationship between $\delta^{13}C$ and PRL levels in combination

302 with $\delta^{15}N$ and THg. Along with the food web changes described with $\delta^{15}N$ above, the most

303 consistently detected relationship was associated with phytoplankton-based foraging (low $\delta^{13}C$)

304 and PRL levels in our three-way interaction. Due to the increasing effects of climate change,

305 phytoplankton blooms are expected to become more intense and occur earlier in the year (Kahru

306 et al. 2011; Ardyna and Arrigo 2020). Phytoplankton blooms are also increasingly apparent

307 when sea ice is still present, even in the benthos, due to increased light transmission with

308 thinning ice (Arrigo et al. 2012; Horvat et al. 2017; Shiozaki et al. 2022). In eiders,

309 phytoplankton blooms in the Baltic Sea have been linked to a reduction in nesting eiders

310 (Larsson et al. 2014). In this study, the relationship was suggested to be connected to an impact

311 of the phytoplankton bloom on blue mussel (*Mytilus edulis*) availability (either through toxic or

312 non-toxic pathways), followed by a subsequent reduction in eider body condition that impacted

313 their breeding propensity (Larsson et al. 2014). Our results showing a consistently significant

314 effect of low $\delta^{13}C$ in our three-way model on PRL may be related to phytoplankton-based

315   environments resulting in less prey availability (such as blue mussels), either quality or quantity,

316   that affects eider body condition and subsequently PRL.

317   Conversely, we also detected a significant relationship between sea ice algae-based

318   foraging (high δ^{13}C) and PRL levels in our three-way interaction, only in high THg individuals.

319   The relationship between high δ^{13}C and PRL, along with elevated THg, may be due to

320   constraints in foraging areas with higher sea ice cover, as seen previously in eiders that rely on

321   access to open water to reach benthic and pelagic areas (Jean-Gagnon et al. 2018). As such,

322   constraints in prey availability, combined with a high proportion of ice cover, could result in

323   lower energetic stores (i.e., body condition) available to eiders during incubation, with possible

324   downstream impacts on PRL levels.

325   Overall, the relationships we have detected between foraging ecology (based on isotopic

326   niche) and PRL provide an initial look into how pre-breeding prey selection may indirectly

327   influence key reproductive hormones in eiders. Future studies may benefit from integrating

328   research into whether pre-breeding prey availability and quality may influence incubating PRL.

329

330   *4.2. Importance of THg levels in relation to incubating PRL*

331   The interactive relationship between δ^{13}C and δ^{15}N with PRL, as described in section 4.1, was

332   most often significant in combination with high THg. The importance of THg in this relationship

333   could potentially relate to the endocrine-disrupting properties of THg (Zhu et al. 2000; Tan et al.

334   2009). In addition, negative relationships between THg and body condition, as seen in previous

335   studies (Provencher et al. 2016; but see Carravieri et al. 2022), may have also played a role in the

336   effect of THg on PRL in combination with δ^{13}C and δ^{15}N. Importantly, our findings support

337   concern over THg as an important component of cumulative stressors systems in the Arctic,

338   where the combination of stressors such as contaminants, climate change and food web dynamics

339   are expected to have cumulative impacts on birds (Chastel et al. 2022; Esparza et al. 2022; Smith

340   et al. 2022). Overall, we found that THg played an important interactive role along with foraging

341   ecology on PRL levels. However, whether this is related to the direct effects of THg on PRL, or

342   indirectly mediated by foraging ecology or other intermediate physiological parameters is

343   unclear and requires further study.

344

4.3. Other physiological and external factors with a potential influence on PRL

346   We were able to examine the relationship between body mass and PRL levels in this study.

347   However, while previous studies successfully used this metric to determine eider body condition

348   (Descamps et al. 2011), this measure of female condition may have been an incomplete look into

349   the relationship between body condition and PRL in incubating eiders. Body condition, often

350   measured as body mass divided by total head length (Jamieson et al. 2006) or scaled mass index

351   (Peig and Green 2009), may provide a more in-depth look into female quality at the time of

352   sampling, rather than only body mass which does not adjust for overall body size. Additionally,

353   individual body mass declines as eiders progressively use their endogenous resources during

354   their incubation fast (Criscuolo et al. 2002; Hanssen et al. 2002). We were unable to control the

355   incubation stage or body size in this study, but this would be ideal for future research on this

356   topic.

357   It is worth highlighting that the primary glucocorticoid hormone in birds, corticosterone

358   (CORT), is an important factor in eider pre-incubation body condition, where higher baseline

359   CORT corresponds to more intensive foraging in eiders (Hennin et al. 2015; 2018). Baseline

360   CORT may play an essential regulating role in the relationship we have detected between PRL

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361 and foraging ecology during pre-breeding periods. For example, during pre-breeding foraging,

362 females with higher baseline CORT may result in downstream elevated PRL levels during

363 incubation due to more intensive foraging, leading to higher body conditions at the start of

364 incubation (Criscuolo et al. 2002; Angelier et al. 2016). Additionally, elevated baseline CORT

365 has also been linked to a greater need for resources during incubation, as seen in incubating

366 macaroni penguins (*Eudyptes chrysolophus*; Crossin et al. 2012). Eiders, which fast during one

367 single incubation bout, have demonstrated a negative relationship between CORT and PRL

368 during incubation periods in previous studies that regulates incubation behaviour (Criscuolo et

369 al. 2005; 2006). The same pattern has been seen in birds that forage during incubation, with

370 stressed individuals leaving more often on foraging trips (Angelier and Chastel 2009; Angelier et

371 al. 2009). In addition, elevated CORT levels may negatively affect female immunity and mass

372 loss during incubation, as seen in previous common eider studies (Bourgeon and Raclot 2006;

373 Bourgeon et al. 2009). Higher energetic stress could have foraging ecology-mediated links to

374 PRL levels. While high CORT levels may be initially beneficial during the pre-breeding period,

375 these elevated may be detrimental to PRL during incubation, especially in fasting female eiders.

376 Further implications may also arise from the added effects of elevated stress-induced CORT,

377 especially as predator-prey relationships and climate conditions shift in Arctic systems.

378 Many eider colonies are facing increasing predation pressure from polar bears (*Ursus*

379 *maritimus)*, arctic foxes (*Vulpes lagopus*) and *Larus* sp. gulls (Smith et al. 2012; Hanssen et al.

380 2013; Prop et al. 2015; Jagielski et al. 2021). Eiders must also contend with elevated thermal

381 environments that can influence female incubation behaviour, especially when combined with

382 Hg exposure (Smith et al. 2022). Interestingly, studies on eiders in the Baltic Sea have

383 determined that those with elevated PRL and higher body condition may have higher nest

384   predation risk (Mohring et al. 2021). However, the correlation between PRL and elevated

385   predation risk was speculated to be attributed to an absence of low-quality individuals with

386   reduced PRL levels at nesting sites with higher predation risk (Mohring et al. 2021). In general,

387   lower PRL may result in a greater risk for egg predation due to lowered incubation consistency.

388   In comparison, higher PRL, thus greater incubation consistency, may lead to higher female

389   predation risk. However, further research is needed to establish these links. Ultimately, the

390   cumulative stressors eiders are now more often exposed to both pre-breeding and during

391   incubation have the potential to greatly decrease nesting success with a 'perfect storm' of

392   stressors influencing reproductive parameters via PRL secretion. In this study, we were unable to

393   examine the links between PRL levels and eider breeding behaviour, predation, or nest success.

394   However, examining these metrics, along with foraging ecology and contaminant loads, would

395   provide holistic context to the implications of these stressors on avian reproductive success.

396

397   **Conclusion**

398   The interactive effects of foraging ecology and THg exposure on PRL levels were examined in

399   incubating female common eiders. Our results show that individuals with high THg that were

400   interactively foraging at lower trophic levels (low δ^{15}N) and in areas with greater phytoplankton

401   abundance (low δ^{13}C) had the most significant relationships resulting in lowered PRL levels.

402   Overall, this complex interactive system, based on foraging ecology and Hg exposure, may have

403   downstream implications for reproductive success through hormone alteration and, therefore,

404   population demography. These effects may be strengthened within the context of continually

405   changing environmental conditions on a global scale. However, further studies are required to

406 fully understand these complex relationships and their reproductive and demographic

407 consequences in a changing Arctic.

408

Literature Cited

Ackerman, J.T., Eagles-Smith, C.A., Herzog, M.P., Hartman, C.A., Peterson, S.H., Evers, D.C., Jackson, A.K., Elliott, J.E., Vander Pol, S.S. and Bryan, C.E. 2016. Avian mercury exposure and toxicological risk across western North America: a synthesis. Science of the Total Environment, 568: 749-769.

Albert, C., Bråthen, V.S., Descamps, S., Anker-Nilssen, T., Cherenkov, A., Christensen-Dalsgaard, S., Danielsen, J., Erikstad, K.E., Gavrilo, M., Hanssen, S.A. and Helgason, H.H. 2021(a). Inter-annual variation in winter distribution affects individual seabird contamination with mercury. Marine Ecology Progress Series, 676: 243-254.

Albert, C., Helgason, H.H., Brault-Favrou, M., Robertson, G.J., Descamps, S., Amélineau, F., Danielsen, J., Dietz, R., Elliott, K., Erikstad, K.E. and Eulaers, I. 2021(b). Seasonal variation of mercury contamination in Arctic seabirds: a pan-arctic assessment. Science of the Total Environment, 750: 142201.

AMAP, 2021. Arctic Climate Change Update 2021: Key Trends and Impacts. Summary for Policy-makers. Arctic Monitoring and Assessment Programme (AMAP), Oslo, Norway.

Angelier, F., and Chastel, O. 2009. Stress, prolactin and parental investment in birds: a review. General and Comparative Endocrinology, 163: 142–148.

Angelier, F., Clément- Chastel, C., Welcker, J., Gabrielsen, G.W. and Chastel, O. 2009. How does corticosterone affect parental behaviour and reproductive success? A study of prolactin in black- legged kittiwakes. Functional Ecology, 23(4): 784-793.

Angelier, F., Wingfield, J.C., Tartu, S. and Chastel, O. 2016. Does prolactin mediate parental and life-history decisions in response to environmental conditions in birds? A review. Hormones and Behavior, 77: 18-29.

Ardyna, M. and Arrigo, K.R. 2020. Phytoplankton dynamics in a changing Arctic Ocean. Nature Climate Change, 10(10): 892-903.

Arrigo, K.R., Perovich, D.K., Pickart, R.S., Brown, Z.W., Van Dijken, G.L., Lowry, K.E., Mills, M.M., Palmer, M.A., Balch, W.M., Bahr, F. and Bates, N.R. 2012. Massive phytoplankton blooms under Arctic sea ice. Science, 336(6087): 1408-1408.

Atwell, L., Hobson, K.A. and Welch, H.E. 1998. Biomagnification and bioaccumulation of mercury in an arctic marine food web: insights from stable nitrogen isotope analysis. Canadian Journal of Fisheries and Aquatic Sciences, 55(5): 1114-1121.

452   Baird, P.H. 1990. Influence of abiotic factors and prey distribution on diet and reproductive

453   success of three seabird species in Alaska. Ornis Scandinavica, 21(3): 224-235.

454   Bearhop, S., Phillips, R.A., Thompson, D.R., Waldron, S. and Furness, R.W. 2000. Variability in

455   mercury concentrations of great skuas Catharacta skua: the influence of colony, diet and

456   trophic status inferred from stable isotope signatures. Marine Ecology Progress Series, 195:

457   261-268.

458   Blévin, P., Shaffer, S.A., Bustamante, P., Angelier, F., Picard, B., Herzke, D., Moe, B.,

459   Gabrielsen, G.W., Bustnes, J.O., and Chastel, O. 2020. Contaminants, prolactin and parental

460   care in an Arctic seabird: Contrasted associations of perfluoroalkyl substances and

461   organochlorine compounds with egg-turning behavior. General and Comparative

462   Endocrinology, 291: 113420.

463   Bottitta, G.E., Nol, E. and Gilchrist, H.G. 2003. Effects of experimental manipulation of

464   incubation length on behavior and body mass of common eiders in the Canadian Arctic.

465   Waterbirds, 26(1): 100-107.

466   Bourgeon, S. and Raclot, T. 2006. Corticosterone selectively decreases humoral immunity in

467   female eiders during incubation. Journal of Experimental Biology, 209(24): 4957-4965.

468   Bourgeon, S., Le Maho, Y. and Raclot, T. 2009. Proximate and ultimate mechanisms underlying

469   immunosuppression during the incubation fast in female eiders: roles of triiodothyronine and

470   corticosterone. General and Comparative Endocrinology, 163(1-2): 77-82.

471   Braune, B.M., Outridge, P.M., Fisk, A.T., Muir, D.C.G., Helm, P.A., Hobbs, K., Hoekstra, P.F.,

472   Kuzyk, Z.A., Kwan, M., Letcher, R.J. and Lockhart, W.L. 2005. Persistent organic pollutants

473   and mercury in marine biota of the Canadian Arctic: an overview of spatial and temporal

474   trends. Science of the Total Environment, 351: 4-56.

475   Braune, B.M., Gaston, A.J., Hobson, K.A., Gilchrist, H.G. and Mallory, M.L. 2014. Changes in

476   food web structure alter trends of mercury uptake at two seabird colonies in the Canadian

477   Arctic. Environmental Science & Technology, 48(22): 13246-13252.

478   Braune, B., Chételat, J., Amyot, M., Brown, T., Clayden, M., Evans, M., Fisk, A., Gaden, A.,

479   Girard, C., Hare, A. and Kirk, J. 2015. Mercury in the marine environment of the Canadian

480   Arctic: review of recent findings. Science of the Total Environment, 509: 67-90.

481   Buntin, J.D. 1996. Neural and hormonal control of parental behavior in birds. Advances in the

482   Study of Behavior, 25:161-213.

483   Bustnes, J.O., Moe, B., Herzke, D., Hanssen, S.A., Nordstad, T., Sagerup, K., Gabrielsen, G.W.

484   and Borgå, K. 2010. Strongly increasing blood concentrations of lipid-soluble

485   organochlorines in high arctic common eiders during incubation fast. Chemosphere, 79(3):

486   320-325.

487   Carravieri, A., Vincze, O., Bustamante, P., Ackerman, J.T., Adams, E.M., Angelier, F., Chastel,

488   O., Cherel, Y., Gilg, O., Golubova, E. and Kitaysky, A. 2022. Quantitative meta- analysis

489   reveals no association between mercury contamination and body condition in birds.

490   Biological Reviews.

491   Chastel, O., Lacroix, A., Weimerskirch, H. and Gabrielsen, G.W. 2005. Modulation of prolactin

492   but not corticosterone responses to stress in relation to parental effort in a long-lived

493   bird. Hormones and Behavior, 47(4): 459-466.

494   Chastel, O., Fort, J., Ackerman, J.T., Albert, C., Angelier, F., Basu, N., Blévin, P., Brault-

495   Favrou, M., Bustnes, J.O., Bustamante, P., Danielsen, J., Descamps, S., Dietz, R., Erikstad,

496   K.E., Eulaers, I., Ezhov, A., Fleishman, A.B., Gabrielsen, G.W., Gavrilo, M., Gilchrist, G.,

497   Gilg, O., Gislason, S., Golubova, E., Goutte, A., Grémillet, D., Hallgrimsson, G.T., Hansen,

498   E.S., Hanssen, S.A., Hatch, S., Huffeldt, N.P., Jakubas, D., Jónsson, J.E., Kitaysky, A.S.,

499   Kolbeinsson, Y., Krasnov, Y., Letcher, R.J., Linnebjerg, J.F., Mallory, M., Merkel, F.R.,

500   Moe, B., Montevecchi, W.J., Mosbech, A., Olsen, B., Orben, R.A., Provencher, J.F.,

501   Ragnarsdottir, S.B., Reiertsen, T.K., Rojek, N., Romano, M., Søndergaard, J., Strøm, H.,

502   Takahashi, A., Tartu, S., Thórarinsson, T.L., Thiebot, J.B., Will, A.P., Wilson, S.,

503   Wojczulanis-Jakubas, K., and Yannic, G. 2022. Mercury contamination and potential health

504   risks to Arctic seabirds and shorebirds. Science of The Total Environment, 844 (2022):

505   156944.

506   Cherel, Y., Mauget, R., Lacroix, A. and Gilles, J. 1994. Seasonal and fasting-related changes in

507   circulating gonadal steroids and prolactin in king penguins, *Aptenodytes*

508   *patagonicus*. Physiological Zoology, 67(5): 1154-1173.

509   Cherel, Y., Hobson, K.A., Bailleul, F. and Groscolas, R. 2005. Nutrition, physiology, and stable

510   isotopes: new information from fasting and molting penguins. Ecology, 86(11): 2881-2888.

511   Criscuolo, F., Chastel, O., Gabrielsen, G.W., Lacroix, A. and Le Maho, Y. 2002. Factors

512   affecting plasma concentrations of prolactin in the common eider *Somateria*

513   *mollissima*. General and Comparative Endocrinology, 125(3): 399-409.

AAM version of Smith, Reyd A. ...et al.
Do foraging ecology and contaminants interactively predict parenting hormone levels in common eider?. General and Comparative Endocrinology 2023 ;Volum 337. s. -
10.1016/j.ygcen.2023.114261 CC BY

514   Criscuolo, F., Chastel, O., Bertile, F., Gabrielsen, G.W., Maho, Y.L. and Raclot, T. 2005.
515   Corticosterone alone does not trigger a short term behavioural shift in incubating female
516   common eiders *Somateria mollissima*, but does modify long term reproductive success.
517   Journal of Avian Biology, 36(4): 306-312.

518   Criscuolo, F., Bertile, F., Durant, J.M., Raclot, T., Gabrielsen, G.W., Massemin, S. and Chastel,
519   O. 2006. Body mass and clutch size may modulate prolactin and corticosterone levels in
520   eiders. Physiological and Biochemical Zoology, 79(3): 514-521.

521   Crossin, G.T., Trathan, P.N., Phillips, R.A., Gorman, K.B., Dawson, A., Sakamoto, K.Q. and
522   Williams, T.D. 2012. Corticosterone predicts foraging behavior and parental care in macaroni
523   penguins. The American Naturalist, 180(1): E31-E41.

524   Dalpadado, P., Hop, H., Rønning, J., Pavlov, V., Sperfeld, E., Buchholz, F., Rey, A. and Wold,
525   A. 2016. Distribution and abundance of euphausiids and pelagic amphipods in Kongsfjorden,
526   Isfjorden and Rijpfjorden (Svalbard) and changes in their relative importance as key prey in a
527   warming marine ecosystem. Polar Biology, 39(10): 1765-1784.

528   De La Vega, C., Jeffreys, R.M., Tuerena, R., Ganeshram, R. and Mahaffey, C. 2019. Temporal
529   and spatial trends in marine carbon isotopes in the Arctic Ocean and implications for food
530   web studies. Global Change Biology, 25(12): 4116-4130.

531   Descamps, S., Bêty, J., Love, O.P. and Gilchrist, H.G. 2011. Individual optimization of
532   reproduction in a long- lived migratory bird: a test of the condition- dependent model of
533   laying date and clutch size. Functional Ecology, 25(3): 671-681.

534   DiMento, B.P., Mason, R.P., Brooks, S. and Moore, C. 2019. The impact of sea ice on the air-sea
535   exchange of mercury in the Arctic Ocean. Deep Sea Research Part I: Oceanographic Research
536   Papers, 144: 28-38.

537   Durant, J.M., Molinero, J.C., Ottersen, G., Reygondeau, G., Stige, L.C. and Langangen, Ø. 2019.
538   Contrasting effects of rising temperatures on trophic interactions in marine
539   ecosystems. Scientific Reports, 9(1): 1-9.

540   El Halawani, M.E., Burke, W.H., Millam, J.R., Fehrer, S.C. and Hargis, B.M. 1984. Regulation
541   of prolactin and its role in gallinaceous bird reproduction. Journal of Experimental
542   Zoology, 232(3): 521-529.

543   Erikstad, K.E., Bustnes, J.O. and Moum, T. 1993. Clutch-size determination in precocial birds: a
544   study of the common eider. The Auk, 110(3): 623-628.

AAM version of Smith, Reyd A. ...et al.
Do foraging ecology and contaminants interactively predict parenting hormone levels in common eider?. General and Comparative Endocrinology 2023 ;Volum 337. s. -
10.1016/j.ygcen.2023.114261 CC BY

545   Erikstad, K.E. and Tveraa, T. 1995. Does the cost of incubation set limits to clutch size in
546   common eiders *Somateria mollissima*? Oecologia, 103(3): 270-274.

547   Esparza, I., Elliott, K.H., Choy, E.S., Braune, B.M., Letcher, R.J., Patterson, A. and Fernie, K.J.
548   2022. Mercury, legacy and emerging POPs, and endocrine-behavioural linkages: Implications
549   of Arctic change in a diving seabird. Environmental Research, 212: 113190.

550   Evers, D. 2018. The effects of methylmercury on wildlife: a comprehensive review and approach
551   for interpretation. The Encyclopedia of the Anthropocene, 5: 181-194.

552   Frederiksen, M., Edwards, M., Richardson, A.J., Halliday, N.C. and Wanless, S. 2006. From
553   plankton to top predators: bottom- up control of a marine food web across four trophic levels.
554   Journal of Animal Ecology, 75(6): 1259-1268.

555   Fort, J., Grémillet, D., Traisnel, G., Amélineau, F. and Bustamante, P. 2016. Does temporal
556   variation of mercury levels in Arctic seabirds reflect changes in global environmental
557   contamination, or a modification of Arctic marine food web functioning? Environmental
558   Pollution, 211: 382-388.

559   Fox, J. and Weisberg, S. 2019. An R Companion to Applied Regression, Third edition. Sage,
560   Thousand Oaks CA.

561   Gilmour, M.E., Lavers, J.L., Lamborg, C., Chastel, O., Kania, S.A. and Shaffer, S.A. 2019.
562   Mercury as an indicator of foraging ecology but not the breeding hormone prolactin in
563   seabirds. Ecological Indicators, 103: 248-259.

564   González-Medina, E., Castillo-Guerrero, J.A., Herzka, S.Z. and Fernández, G. 2018. High
565   quality diet improves lipid metabolic profile and breeding performance in the blue-footed
566   booby, a long-lived seabird. PloS one, 13(2): p.e0193136.

567   Graves, S., Piepho, H.P. and Selzer, M.L. 2015. Package 'multcompView'. Visualizations of
568   paired comparisons.

569   Hamer, K.C., Monaghan, P., Uttley, J.D., Walton, P. and Burns, M.D. 1993. The influence of
570   food supply on the breeding ecology of kittiwakes *Rissa tridactyla* in Shetland. Ibis, 135(3):
571   255-263.

572   Hamilton, D.J., Nudds, T.D. and Neate, J. 1999. Size-selective predation of blue mussels
573   (*Mytilus edulis*) by common eiders (*Somateria mollissima*) under controlled field conditions.
574   The Auk, 116(2): 403-416.

AAM version of Smith, Reyd A. ...et al.
Do foraging ecology and contaminants interactively predict parenting hormone levels in common eider?. General and Comparative Endocrinology 2023 ;Volum 337. s. -
10.1016/j.ygcen.2023.114261 CC BY

575　Hanssen, S., Engebretsen, H. and Erikstad, K. 2002. Incubation start and egg size in relation to
576　　　body reserves in the common eider. Behavioral Ecology and Sociobiology, 52(4): 282-288.

577　Hanssen, S.A., B. Moe, B-J. Bårdsen, F. Hanssen, G.W. Gabrielsen (2013) A natural anti-
578　　　predation experiment: Predator control and reduced sea ice increases colony size in a long-
579　　　lived duck. Ecology and Evolution 3: 3554-3564, doi: 10.1002/ece3.735

580　Hawkings, J.R., Linhoff, B.S., Wadham, J.L., Stibal, M., Lamborg, C.H., Carling, G.T.,
581　　　Lamarche-Gagnon, G., Kohler, T.J., Ward, R., Hendry, K.R. and Falteisek, L. 2021. Large
582　　　subglacial source of mercury from the southwestern margin of the Greenland Ice Sheet.
583　　　Nature Geoscience, 14(7): 496-502.

584　Hennin, H.L., Legagneux, P., Bêty, J., Williams, T.D., Gilchrist, H.G., Baker, T.M. and Love,
585　　　O.P. 2015. Pre-breeding energetic management in a mixed-strategy
586　　　breeder. Oecologia, 177(1): 235-243.

587　Hennin, H.L., Dey, C.J., Bêty, J., Gilchrist, H.G., Legagneux, P., Williams, T.D. and Love, O.P.
588　　　2018. Higher rates of prebreeding condition gain positively impacts clutch size: A
589　　　mechanistic test of the condition- dependent individual optimization model. Functional
590　　　Ecology, 32(8): 2019-2028.

591　Hobson, K.A. and Welch, H.E. 1992. Determination of trophic relationships within a high Arctic
592　　　marine food web using δ^{13}C and δ^{15}N analysis. Marine Ecology Progress Series, 84(1): 9-18.

593　Hobson, K.A., Alisauskas, R.T. and Clark, R.G. 1993. Stable-nitrogen isotope enrichment in
594　　　avian tissues due to fasting and nutritional stress: implications for isotopic analyses of
595　　　diet. The Condor, 95(2): 388-394.

596　Hobson, K.A., Ambrose Jr, W.G. and Renaud, P.E. 1995. Sources of primary production,
597　　　benthic-pelagic coupling, and trophic relationships within the Northeast Water Polynya:
598　　　insights from δ^{13}C and δ^{15}N analysis. Marine Ecology Progress Series, 128: 1-10.

599　Hoegh-Guldberg, O. and Bruno, J.F. 2010. The impact of climate change on the world's marine
600　　　ecosystems. Science, 328(5985): 1523-1528.

601　Horvat, C., Jones, D.R., Iams, S., Schroeder, D., Flocco, D. and Feltham, D. 2017. The
602　　　frequency and extent of sub-ice phytoplankton blooms in the Arctic Ocean. Science
603　　　Advances, 3(3): e1601191.

AAM version of Smith, Reyd A. ...et al.
Do foraging ecology and contaminants interactively predict parenting hormone levels in common eider?. General and Comparative Endocrinology 2023 ;Volum 337. s. -
10.1016/j.ygcen.2023.114261 CC BY

604   Hovinen, J.E., Tarroux, A., Ramírez, F., Forero, M. and Descamps, S. 2019. Relationships

605   between isotopic ratios, body condition and breeding success in a High Arctic seabird

606   community. Marine Ecology Progress Series, 613: 183-195.

607   IPCC 2019: Climate Change and Land: an IPCC special report on climate change,

608   desertification, land degradation, sustainable land management, food security, and greenhouse

609   gas fluxes in terrestrial ecosystems [P.R. Shukla, J. Skea, E. Calvo Buendia, V. Masson-

610   Delmotte, H.-O. Pörtner, D. C. Roberts, P. Zhai, R. Slade, S. Connors, R. van Diemen, M.

611   Ferrat, E. Haughey, S. Luz, S. Neogi, M. Pathak, J. Petzold, J. Portugal Pereira, P. Vyas, E.

612   Huntley, K. Kissick, M. Belkacemi, J. Malley, (eds.)].

613   Jagielski, P.M., Dey, C.J., Gilchrist, H.G., Richardson, E.S., Love, O.P. and Semeniuk, C.A.

614   2021. Polar bears are inefficient predators of seabird eggs. Royal Society Open Science, 8(4):

615   210391.

616   Jamieson, S.E., Gilchrist, H.G., Merkel, F.R., Falk, K. and Diamond, A.W. 2006. An evaluation

617   of methods used to estimate carcass composition of common eiders *Somateria mollissima*.

618   Wildlife Biology, 12(2): 219-226.

619   Jean-Gagnon, F., Legagneux, P., Gilchrist, G., Bélanger, S., Love, O.P. and Bêty, J. 2018. The

620   impact of sea ice conditions on breeding decisions is modulated by body condition in an arctic

621   partial capital breeder. Oecologia, 186(1): 1-10.

622   Johannessen, O.M., Bengtsson, L., Miles, M.W., Kuzmina, S.I., Semenov, V.A., Alekseev, G.V.,

623   Nagurnyi, A.P., Zakharov, V.F., Bobylev, L.P., Pettersson, L.H. and Hasselmann, K. 2004.

624   Arctic climate change: observed and modelled temperature and sea-ice variability. Tellus A:

625   Dynamic Meteorology and Oceanography, 56(4): 28-341.

626   Kahru, M., Brotas, V., Manzano- Sarabia, M. and Mitchell, B.G. 2011. Are phytoplankton

627   blooms occurring earlier in the Arctic? Global Change Biology, 17(4): 1733-1739.

628   Kelly, J.F. 2000. Stable isotopes of carbon and nitrogen in the study of avian and mammalian

629   trophic ecology. Canadian Journal of Zoology, 78(1): 1-27.

630   Larsson, K., Hajdu, S., Kilpi, M., Larsson, R., Leito, A. and Lyngs, P. 2014. Effects of an

631   extensive Prymnesium polylepis bloom on breeding eiders in the Baltic Sea. Journal of Sea

632   Research, 88: 21-28.

633   Legagneux, P., Gauthier, G., Berteaux, D., Bêty, J., Cadieux, M.C., Bilodeau, F., Bolduc, E.,

634   McKinnon, L., Tarroux, A., Therrien, J.F. and Morissette, L. 2012. Disentangling trophic

635   relationships in a High Arctic tundra ecosystem through food web modeling. Ecology, 93(7):
636   1707-1716.

637   Leu, E., Søreide, J.E., Hessen, D.O., Falk-Petersen, S. and Berge, J. 2011. Consequences of
638   changing sea-ice cover for primary and secondary producers in the European Arctic shelf
639   seas: timing, quantity, and quality. Progress in Oceanography, 90(1-4): 18-32.

640   Lewis, K.M., van Dijken, G.L. and Arrigo, K.R. 2020. Changes in phytoplankton concentration
641   now drive increased Arctic Ocean primary production. Science, 369(6500): 198-202.

642   Long, J.A. 2019. Interactions: Comprehensive, User-Friendly Toolkit for Probing Interactions. R
643   package version 1.1.0, https://cran.r-project.org/package=interactions.

644   Macdonald, R.W., Barrie, L.A., Bidleman, T.F., Diamond, M.L., Gregor, D.J., Semkin, R.G.,
645   Strachan, W.M.J., Li, Y.F., Wania, F., Alaee, M. and Alexeeva, L.B. 2000. Contaminants in
646   the Canadian Arctic: 5 years of progress in understanding sources, occurrence and pathways.
647   Science of the Total Environment, 254(2-3): 93-234.

648   Mazerolle, M.J. 2020. Model Selection and Multimodel Inference Based on (Q)AIC(c). R
649   package version 2.3-1, https://cran.r-project.org/web/packages/AICcmodavg/index.html

650   McMahon, K.W., Ambrose Jr, W.G., Johnson, B.J., Sun, M.Y., Lopez, G.R., Clough, L.M. and
651   Carroll, M.L. 2006. Benthic community response to ice algae and phytoplankton in Ny-
652   Ålesund, Svalbard. Marine Ecology Progress Series, 310: 1-14.

653   McPartland, M., Garbus, S.E., Lierhagen, S., Sonne, C. and Krøkje, Å. 2020. Lead isotopic
654   signatures in blood from incubating common eiders (*Somateria mollissima*) in the central
655   Baltic Sea. Environment International, 142: 105874.

656   Milton, G.R., Iverson, S.A., Smith, P.A., Tomlik, M.D., Parsons, G.J. and Mallory, M.L. 2016.
657   Sex-Specific Survival of Adult Common Eiders in Nova Scotia, Canada. The Journal of
658   Wildlife Management, 80(8): 1427-1436.

659   Mohring, B., Angelier, F., Jaatinen, K., Parenteau, C. and Öst, M. 2021. Parental Investment
660   Under Predation Threat in Incubating Common Eiders (*Somateria mollissima*): A Hormonal
661   Perspective. Frontiers in Ecology and Evolution, 474(9): 637561

662   Moline, M.A., Karnovsky, N.J., Brown, Z., Divoky, G.J., Frazer, T.K., Jacoby, C.A., Torres, J.J.
663   and Fraser, W.R. 2008. High latitude changes in ice dynamics and their impact on polar
664   marine ecosystems. Annals of the New York Academy of Sciences, 1134: 267-319.

665 Najafi, M.R., Zwiers, F.W. and Gillett, N.P. 2015. Attribution of Arctic temperature change to
666   greenhouse-gas and aerosol influences. Nature Climate Change, 5(3): 246-249.

667 Parmesan, C. 2006. Ecological and evolutionary responses to recent climate change. Annual
668   Review of Ecology, Evolution, and Systematics, 37: 637-669.

669 Pecuchet, L., Blanchet, M.A., Frainer, A., Husson, B., Jørgensen, L.L., Kortsch, S. and
670   Primicerio, R. 2020. Novel feeding interactions amplify the impact of species redistribution
671   on an Arctic food web. Global Change Biology, 26(9): 4894-4906.

672 Peig, J. and Green, A.J. 2009. New perspectives for estimating body condition from mass/length
673   data: the scaled mass index as an alternative method. Oikos, 118(12): 1883-1891.

674 Perkins, A., Ratcliffe, N., Suddaby, D., Ribbands, B., Smith, C., Ellis, P., Meek, E. and Bolton,
675   M. 2018. Combined bottom- up and top- down pressures drive catastrophic population
676   declines of Arctic skuas in Scotland. Journal of Animal Ecology, 87(6): 1573-1586.

677 Prop, J., Aars, J., Bårdsen, B.J., Hanssen, S.A., Bech, C., Bourgeon, S., de Fouw, J., Gabrielsen,
678   G.W., Lang, J., Noreen, E. and Oudman, T. 2015. Climate change and the increasing impact
679   of polar bears on bird populations. Frontiers in Ecology and Evolution, 3(33): 1-12.

680 Provencher, J.F., Forbes, M.R., Hennin, H.L., Love, O.P., Braune, B.M., Mallory, M.L. and
681   Gilchrist, H.G. 2016. Implications of mercury and lead concentrations on breeding physiology
682   and phenology in an Arctic bird. Environmental Pollution, 218: 1014-1022.

683 Renaut, S., Devred, E. and Babin, M. 2018. Northward expansion and intensification of
684   phytoplankton growth during the early ice- free season in Arctic. Geophysical Research
685   Letters, 45(19): 10590-10598.

686 RStudio Team (2022). RStudio: Integrated Development Environment for R. RStudio, PBC,
687   Boston, MA URL http://www.rstudio.com/.

688 Rydberg, J., Klaminder, J., Rosén, P. and Bindler, R. 2010. Climate driven release of carbon and
689   mercury from permafrost mires increases mercury loading to sub-arctic lakes. Science of the
690   Total Environment, 408(20): 4778-4783.

691 Schielzeth, H. 2010. Simple means to improve the interpretability of regression
692   coefficients. Methods in Ecology and Evolution, 1(2): 103-113.

693 Shiozaki, T., Fujiwara, A., Sugie, K., Nishino, S., Makabe, A. and Harada, N. 2022. Bottom-
694   associated phytoplankton bloom and its expansion in the Arctic Ocean. Global Change
695   Biology.

696   Schummer, M.L., Petrie, S.A. and Bailey, R.C. 2008. Dietary overlap of sympatric diving ducks

697   during winter on northeastern Lake Ontario. The Auk, 125(2): 425-433.

698   Schuster, P.F., Schaefer, K.M., Aiken, G.R., Antweiler, R.C., Dewild, J.F., Gryziec, J.D.,

699   Gusmeroli, A., Hugelius, G., Jafarov, E., Krabbenhoft, D.P. and Liu, L. 2018. Permafrost

700   stores a globally significant amount of mercury. Geophysical Research Letters, 45(3): 1463-

701   1471.

702   Screen, J.A. and Simmonds, I. 2010. Increasing fall- winter energy loss from the Arctic Ocean

703   and its role in Arctic temperature amplification. Geophysical Research Letters, 37(16):

704   L16707.

705   Sénéchal, É., Bêty, J., Gilchrist, H.G., Hobson, K.A. and Jamieson, S.E. 2011. Do purely capital

706   layers exist among flying birds? Evidence of exogenous contribution to arctic-nesting

707   common eider eggs. Oecologia, 165(3): 593-604.

708   Sockman, K.W., Schwabl, H. and Sharp, P.J. 2000. The role of prolactin in the regulation of

709   clutch size and onset of incubation behavior in the American kestrel. Hormones and Behavior,

710   38(3): 168-176.

711   Sonke, J.E., Teisserenc, R., Heimbürger-Boavida, L.E., Petrova, M.V., Marusczak, N., Le

712   Dantec, T., Chupakov, A.V., Li, C., Thackray, C.P., Sunderland, E.M. and Tananaev, N.

713   2018. Eurasian river spring flood observations support net Arctic Ocean mercury export to the

714   atmosphere and Atlantic Ocean. Proceedings of the National Academy of Sciences, 115(50):

715   E11586-E11594.

716   Smith, P.A., Tulp, I., Schekkerman, H., Gilchrist, H.G. and Forbes, M.R. 2012. Shorebird

717   incubation behaviour and its influence on the risk of nest predation. Animal Behaviour, 84(4):

718   835-842.

719   Smith, R.A., Yurkowski, D.J., Parkinson, K.J., Fort, J., Hennin, H.L., Gilchrist, H.G., Hobson,

720   K.A., Mallory, M.L., Bustamante, P., Danielsen, J., Garbus, S.E., Hanssen, S.A., Jónsson,

721   J.E., Latty, C.J., Magnúsdóttir, E., Moe, B., Parsons, G.J., Sonne, C., Tertitski, G. and Love.,

722   O.P. 2021. Environmental and life-history factors influence inter-colony multidimensional

723   niche metrics of a breeding Arctic marine bird. Science of the Total Environment, 796:

724   148935.

725   Smith, R.A., Albonaimi, S.S., Hennin, H.L., Gilchrist, H.G., Fort, J., Parkinson, K.J.,

726   Provencher, J.F., and Love, O.P. 2022. Exposure to cumulative stressors affects the laying

AAM version of Smith, Reyd A. ...et al.
Do foraging ecology and contaminants interactively predict parenting hormone levels in common eider?. General and Comparative Endocrinology 2023 ;Volum 337. s. -
10.1016/j.ygcen.2023.114261 CC BY

727   phenology and incubation behaviour of an Arctic-breeding marine bird. Science of the Total

728   Environment, 807: 150882.

729   Suryan, R.M., Irons, D.B., Brown, E.D., Jodice, P.G. and Roby, D.D. 2006. Site-specific effects

730   on productivity of an upper trophic-level marine predator: bottom-up, top-down, and

731   mismatch effects on reproduction in a colonial seabird. Progress in Oceanography, 68(2-4):

732   303-328.

733   Tan, S.W., Meiller, J.C. and Mahaffey, K.R. 2009. The endocrine effects of mercury in humans

734   and wildlife. Critical Reviews in Toxicology, 39(3): 228-269.

735   Tartu, S., Goutte, A., Bustamante, P., Angelier, F., Moe, B., Clément-Chastel, C., Bech, C.,

736   Gabrielsen, G.W., Bustnes, J.O. and Chastel, O. 2013. To breed or not to breed: endocrine

737   response to mercury contamination by an Arctic seabird. Biology Letters, 9(4): 20130317.

738   Tartu, S., Bustamante, P., Goutte, A., Cherel, Y., Weimerskirch, H., Bustnes, J.O. and Chastel,

739   O. 2014. Age-related mercury contamination and relationship with luteinizing hormone in a

740   long-lived Antarctic bird. PLoS One, 9(7): e103642.

741   Tartu, S., Angelier, F., Wingfield, J.C., Bustamante, P., Labadie, P., Budzinski, H.,

742   Weimerskirch, H., Bustnes, J.O. and Chastel, O. 2015. Corticosterone, prolactin and egg

743   neglect behavior in relation to mercury and legacy POPs in a long-lived Antarctic

744   bird. Science of the Total Environment, 505: 180-188.

745   Tartu, S., Bustamante, P., Angelier, F., Lendvai, A.Z., Moe, B., Blévin, P., Bech, C., Gabrielsen,

746   G.W., Bustnes, J.O. and Chastel, O. 2016. Mercury exposure, stress and prolactin secretion in

747   an Arctic seabird: an experimental study. Functional Ecology, 30(4): 596-604.

748   Tartu, S., Blévin, P., Bustamante, P., Angelier, F., Bech, C., Bustnes, J.O., Chierici, M.,

749   Fransson, A., Gabrielsen, G.W., Goutte, A., Moe, B., Sauser, C., Sire, J., Barbraud, C., and

750   Chastel, O. 2022. A U-Turn for Mercury Concentrations over 20 Years: How Do

751   Environmental Conditions Affect Exposure in Arctic Seabirds? Environmental Science and

752   Technology, 56: 2443–2454.

753   Tan, S.W., Meiller, J.C. and Mahaffey, K.R. 2009. The endocrine effects of mercury in humans

754   and wildlife. Critical Reviews in Toxicology, 39(3): 228-269.

755   Timmermans, M.L., Proshutinsky, A., Krishfield, R.A., Perovich, D.K., Richter- Menge, J.A.,

756   Stanton, T.P. and Toole, J.M. 2011. Surface freshening in the Arctic Ocean's Eurasian Basin:

AAM version of Smith, Reyd A. ...et al.
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10.1016/j.ygcen.2023.114261 CC BY

757   An apparent consequence of recent change in the wind- driven circulation. Journal of
758   Geophysical Research: Oceans, 116(C8): C00D03.

759   Vasseur, D.A. and McCann, K.S. 2005. A mechanistic approach for modeling temperature-
760   dependent consumer-resource dynamics. The American Naturalist, 166(2): 184-198.

761   Vinarski, M.V., Bolotov, I.N., Aksenova, O.V., Babushkin, E.S., Bespalaya, Y.V., Makhrov,
762   A.A., Nekhaev, I.O. and Vikhrev, I.V. 2021. Freshwater Mollusca of the Circumpolar Arctic:
763   a review on their taxonomy, diversity and biogeography. Hydrobiologia, 848(12): 2891-2918.

764   Watt, C.A., Orr, J. and Ferguson, S.H. 2016. A shift in foraging behaviour of beluga whales
765   Delphinapterus leucas from the threatened Cumberland Sound population may reflect a
766   changing Arctic food web. Endangered Species Research, 31: 259-270.

767   Wayland, M., Gilchrist, H.G. and Neugebauer, E. 2005. Concentrations of cadmium, mercury
768   and selenium in common eider ducks in the eastern Canadian arctic: influence of reproductive
769   stage. Science of the Total Environment, 351: 323-332.

770   Węsławski, J.M., Kendall, M.A., Włodarska-Kowalczuk, M., Iken, K., Kędra, M., Legezynska,
771   J. and Sejr, M.K. 2011. Climate change effects on Arctic fjord and coastal macrobenthic
772   diversity—observations and predictions. Marine Biodiversity, 41(1): 71-85.

773   Whitney, M.C. and Cristol, D.A. 2017. Impacts of sublethal mercury exposure on birds: a
774   detailed review. Reviews of Environmental Contamination and Toxicology, 244: 113-163.

775   Wickham, H. 2016. ggplot2: Elegant Graphics for Data Analysis. Springer-Verlag New York.
776   ISBN 978-3-319-24277-4, https://ggplot2.tidyverse.org.

777   Wiener, J.G., Krabbenhoft, D.P., Heinz, G.H. and Scheuhammer, A.M. 2003. Ecotoxicology of
778   mercury. Handbook of Ecotoxicology, 2: 409-463.

779   Zhu, X., Kusaka, Y., Sato, K. and Zhang, Q. 2000. The endocrine disruptive effects of mercury.
780   Environmental Health and Preventive Medicine, 4(4): 174-183.

781   Zika, J.D., Skliris, N., Blaker, A.T., Marsh, R., Nurser, A.G. and Josey, S.A. 2018. Improved
782   estimates of water cycle change from ocean salinity: the key role of ocean
783   warming. Environmental Research Letters, 13(7): 074036x.

Tables and Figures

785 **Table 1.** Results of model selection on plasma PRL levels of 106 female common eiders from 6

786 breeding colonies. The number of parameters (k), corrected Akaike information criterion (AICc),

787 change in AICc (ΔAICc), AICc weight, and log-likelihood are provided for each competing

788 model. Colony was included as a random variable in all models, however, when clutch size was

789 included as a random variable it is denoted with [R].

Model	k	AICc	ΔAICc	AICc Weight	Log-likelihood
THg*δ^{15}N*δ^{13}C+Mass*Clutch	**13**	**1106.61**	**0.00**	**0.80**	**-538.33**
THg*δ^{15}N*δ^{13}C+Mass+Clutch	12	1109.70	3.09	0.17	-541.17
THg*δ^{15}N+THg*δ^{13}C+ δ^{15}N*δ^{13}C +Mass*Clutch	12	1113.91	7.30	0.02	-543.28
THg*δ^{15}N*δ^{13}C+Mass+Clutch[R]	12	1115.73	9.12	0.01	-544.19
THg*δ^{13}C+δ^{15}N+Mass+Clutch	9	1123.24	16.63	0.00	-551.68
δ^{13}C*δ^{15}N+Mass+Clutch	8	1126.41	19.80	0.00	-554.46
THg+δ^{15}N+δ^{13}C+Mass+Clutch	8	1126.57	19.96	0.00	-554.54
δ^{15}N+Mass+Clutch	6	1136.47	29.86	0.00	-561.81
δ^{13}C+Mass+Clutch	6	1139.02	32.40	0.00	-563.08
THg+Mass+Clutch	6	1139.53	32.91	0.00	-563.34
THg*δ^{15}N*δ^{13}C+Mass	11	1173.26	66.64	0.00	-574.30
THg*δ^{15}N*δ^{13}C+Clutch	11	1191.18	84.57	0.00	-583.28
THg*δ^{15}N*δ^{13}C	10	1457.05	350.44	0.00	-717.64

790

791 **Table 2.** Locations of common eider colonies used in this study, sample size, month samples

792 were obtained, colony coordinates as well as median and range of PRL levels.

Location	n	Sampling month	Latitude	Longitude	Female mass (g)	Median PRL (ng/mL)
Breiðafjörður, Iceland	21	June	65.078	-22.736	1780 ± 111.6	310.21 ± 57.02
Grindøya, Norway	17	June	69.633	18.844	2050 ± 168.3	336.50 ± 48.13
John's Island, Canada	18	July	43.645	-66.041	N/A	277.68 ± 49.58
Kirkjubøhólmur, Faroe Islands	16	July	61.950	-6.799	1400 ± 223.9	264.75 ± 41.13
Kongsfjorden, Norway	16	June	78.918	11.910	1525 ± 210.7	348.99 ± 82.29
Solovetskiy Islands, Russia	24	June	65.048	35.774	1800 ± 105.4	280.04 ± 49.38
Tern Island, Canada	24	June	69.547	-80.812	1660 ± 213.7	245.18 ± 44.65

793

794 **Table 3.** Results of a general linear mixed effects model examining the interactive effects of

795 THg (μg/g dry weight), δ^{15}N and δ^{13}C (‰) as well as an interaction between body mass (g) and

796 clutch size on prolactin (PRL) levels (ng/mL). The breeding colony (n=6) of the 106 female

797 arctic-breeding common eiders throughout Canada and Eurasia was a random variable in the

798 model, with the John's Island eiders and 12 additional individuals from other colonies removed

799 from the model due to the absence of morphometrics (significant p-values are bolded).

	Estimate	Standard Error	df	t-value	p-value
Intercept	306.746	19.540	4.526	15.599	**<0.001**
Body Mass	-9.472	7.375	93.941	-1.284	0.202
Clutch Size	4.628	6.389	94.890	0.724	0.471
Mass*Clutch	-0.36	6.872	92.220	-0.053	0.958
THg	-7.108	9.509	93.910	-0.747	0.457
δ^{13}C	-17.543	11.313	77.172	-1.551	0.125
δ^{15}N	25.427	11.107	80.279	2.289	**0.025**
THg*δ^{13}C	7.484	8.609	94.777	0.869	0.387
THg*δ^{15}N	6.437	5.918	94.889	1.088	0.280
δ^{15}N*δ^{13}C	-13.376	10.882	92.772	-1.229	0.222
THg*δ^{15}N*δ^{13}C	14.138	6.767	94.561	2.089	**0.039**

800

801

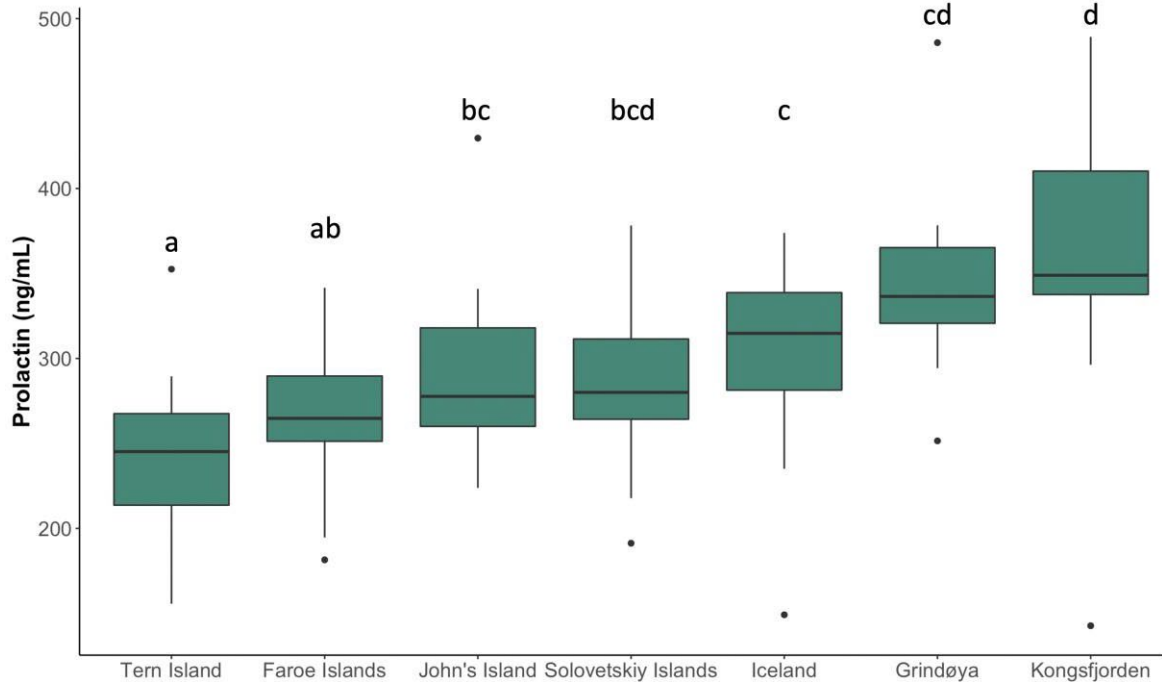802 **Figure 1.** Locations of the seven pan-Arctic and subarctic common eider colonies used in this

803 study (stars). Colonies are numbered by descending median colony PRL levels (1=highest,

804 7=lowest). Map provided by naturalearthdata.com.

805

806

Figure 2. Boxplot depicting whether the mean PRL levels at each common eider colony vary

significantly. Significance was determined using a one-way ANOVA at an alpha of 0.05 and a

posthoc Tukey test using the R package car v.3.0-10. Letters above each colony show whether a

colony significantly differs from the others, where the absence of shared letters indicates

significant difference in mean PRL levels between locations.

812
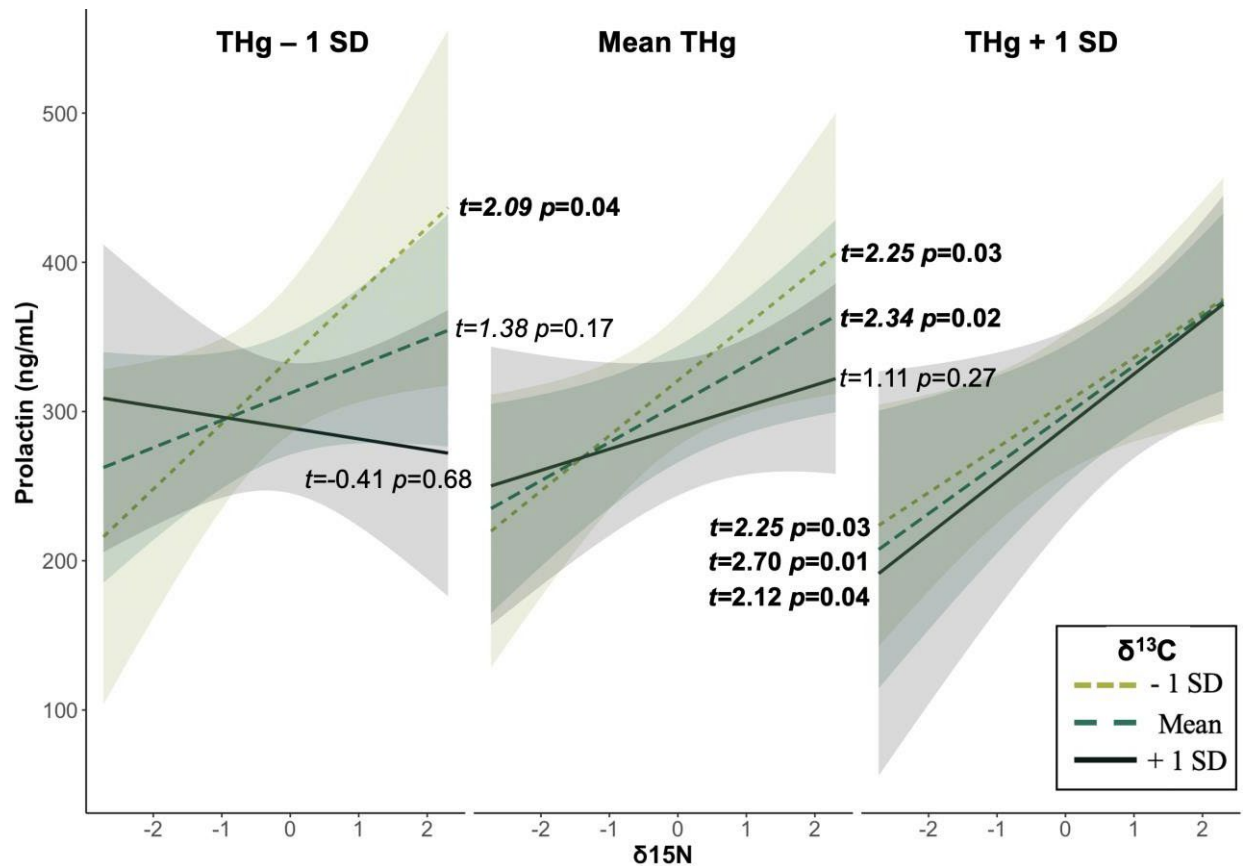
Figure 3. Interactive effect of δ^{15}N, δ^{13}C and THg (visualized using standard deviation from the

mean; SD) on PRL levels in 106 incubating common eiders combined from six pan Arctic

breeding colonies. The model used for this analysis included eider colony as a random variable.

Values for δ^{15}N, δ^{13}C and THg are without units as they are derived from standardized model

output for simplicity using the R package Interactions version 1.1.3. Shaded areas represent a

95% confidence interval for each slope. Slopes that are significantly different from zero, as

determined by Johnson-Neyman simple slopes analysis, are bolded.

Do foraging ecology and contaminants interactively predict parenting hormone levels in common eider?

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