



Research

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Physiology

To breed or not to breed: endocrine response to mercury contamination by an Arctic seabird

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Mercury, a ubiquitous toxic element, is known to alter expression of sex steroids and to impair reproduction across vertebrates but the mechanisms underlying these effects are not clearly identified. We examined whether contamination by mercury predicts the probability to skip reproduction in black-legged kittiwakes (*Rissa tridactyla*) from Svalbard. We also manipulated the endocrine system to investigate the mechanism underlying this relationship. During the pre-laying period, we injected exogenous GnRH (gonadotropin-releasing hormone) to test the ability of the pituitary to release luteinizing hormone (LH, a key hormone for the release of sex steroids and hence breeding) in relation to mercury burden. Birds that skipped reproduction had significantly higher mercury concentration in blood than breeders. Endocrine profiles of these birds also varied based on breeding status (breeders versus non-breeders), mercury contamination and sex. Specifically, in skippers (birds that did not breed), baseline LH decreased with increasing mercury concentration in males, whereas it increased in females. GnRH-induced LH levels increased with increasing mercury concentration in both sexes. These results suggest that mercury contamination may disrupt GnRH input to the pituitary. Thus, high mercury concentration could affect the ability of long-lived birds to modulate their reproductive effort (skipping or breeding) according to ongoing environmental changes in the Arctic, thereby impacting population dynamics.

1. Introduction

Mercury is a ubiquitous toxic element of both natural and anthropogenic sources. In its methylated form, mercury can impair reproduction and disrupt the expression of oestradiol and testosterone across vertebrates [1,2]. However, the mechanisms underlying these effects are not clearly identified [3]. In response to increased day length, gonadotropin-releasing hormone (GnRH) is secreted and triggers luteinizing hormone (LH) release from the pituitary gland. LH, in concert with follicle-stimulating hormone (FSH), promotes gonadal maturation, sex steroid secretion and in turn, the onset of reproduction. It is conceivable that mercury acts primarily on the ability of the pituitary to secrete gonadotropin hormones (LH and FSH), altering sex steroids release and ultimately impairing reproductive behaviour. Mercury may also suppress GnRH in the hypothalamus, thereby reducing LH production. Clearly, there is a need for studies investigating the mechanisms of LH suppression by mercury [3] and subsequent repercussions for breeding animals.

Recent investigations have highlighted a major role for LH on skipped breeding behaviour (non-breeding by individuals that previously bred), a common feature in long-lived birds [4,5]. In some seabirds, skipping individuals show either low levels of baseline LH (black-legged kittiwake, *Rissa tridactyla* [4]), or fail to maintain elevated LH levels after a GnRH injection (snow petrel, *Pagodroma nivea* [5]). LH secretion also appears to be sensitive to environmental stressors in kittiwakes [4]. This opens the yet unexplored possibility that some endocrine disruptors like mercury may play a role in skipping behaviour, by altering the release and secretion of LH.

Here, we test whether mercury concentrations (i) are linked to skipping behaviour, and (ii) affect patterns of LH release during the pre-breeding period in an Arctic population of black-legged kittiwakes. To evaluate LH release, we challenged the pituitary with an exogenous injection of GnRH. Kittiwakes provide an excellent model to address these questions, as they bear elevated mercury levels in Svalbard [6] and a significant proportion of adults skip breeding each year [4]. We predicted that high mercury concentration in blood would (i) be linked to a high probability to skip breeding, and (ii) impair baseline and/or GnRH-induced LH levels.

2. Material and methods

The study was conducted at Kongsfjorden, Svalbard (78°54' N, 12°13' E) from 20 May to 6 June 2008 (52 birds) and from 21 May to 7 June in 2011 (104 birds) during the pre-breeding period. Birds were caught on the nests and a blood sample was collected immediately after capture. In 2008, we performed a GnRH challenge immediately after the first blood sampling, kittiwakes were injected with 0.1 ml of a solution of GnRH (see the electronic supplementary material, figure S1). Blood samples were collected from the alar veins 10 and 30 min after the GnRH injection to measure baseline and GnRH-induced levels of LH (both sexes) and testosterone (males only) as detailed in the electronic supplementary material. Total mercury from all 2008 and 2011 samples was measured at LIENSs from lyophilized red blood cells, by atomic absorption spectrophotometry on 5–10 mg aliquots [7]. Mercury concentrations are expressed in $\mu\text{g g}^{-1}$ dry weight. In both years, focal birds were measured as described in Goutte *et al.* [4] to calculate a scaled mass index and observed daily. The nest content was checked every two days, to monitor whether birds had engaged in breeding (at least one egg laid) or whether they had skipped (no egg laid). We also monitored fitness, including date of first egg-laying, clutch size and the number of chicks that reached 12 days post-hatch (hereafter breeding success). To test the effects of mercury and scaled mass index on these reproductive parameters, we pooled data from 2008 and 2011 (no birds were sampled twice). Then, for 2008, we tested the effects of mercury concentration and interaction with sex, on baseline and GnRH-induced hormone levels in skipping and breeding birds. Data are available from the Dryad Digital Repository: doi.org/10.5061/dryad.4ff07. All statistical analyses were performed using R v. 2.13.1 and we used generalized linear models (GLM) with a normal/binomial error distribution and an identity/logit link function to test our biological assumptions. Model selection was performed by a step-down approach starting from the global model including all the independent variables.

3. Results

Sex and year did not explain reproductive decisions (skippers versus breeders; GLM, all p -values > 0.10). Mercury predicted

the likelihood of breeding, as skippers had significantly elevated mercury levels compared with breeders ($\chi^2 = 14.06$, $p = 0.001$, figure 1*a,b*). This was true in both sexes (females: $\chi^2 = 4.41$, $p = 0.036$; males: $\chi^2 = 4.61$, $p = 0.032$). There was no interaction between mercury and either sex, year or scaled mass index (GLM, all p -values > 0.87). Among birds that bred, pre-breeding mercury concentration did not predict first egg-laying date, clutch size or breeding success (all p -values > 0.18).

In birds that bred, baseline LH levels were higher in females than in males ($F_{1,34} = 5.9$, $p = 0.02$), but were unrelated to mercury levels ($F_{1,33} = 0.08$, $p = 0.783$; mercury \times sex: $F_{1,32} = 1.5$, $p = 0.23$, figure 1*c,d*). GnRH-induced LH levels were not linked to either sex ($F_{1,17} = 3.23$, $p = 0.09$) or mercury levels ($F_{1,17} = 0.88$, $p = 0.361$; mercury \times sex: $F_{1,17} = 2.72$, $p = 0.118$) in breeders.

In skipping birds, baseline LH levels were not affected by sex ($F_{1,12} = 0.43$, $p = 0.523$) but significantly and negatively correlated to mercury levels in males, and positively in females (mercury \times sex: $F_{1,12} = 19$, $p < 0.001$; figure 1*e,f*). GnRH-induced LH levels significantly increased with increasing mercury concentration in skipping males and females (mercury: $F_{1,10} = 21.6$, $p < 0.001$; mercury \times sex: $F_{1,8} = 0.07$, $p = 0.805$, figure 1*e,f*). Baseline testosterone levels tended to decrease in skipping males ($F_{1,7} = 5.92$, $p = 0.051$) but not in breeding males ($F_{1,19} < 0.01$, $p = 0.97$). GnRH-induced testosterone levels were not related to mercury levels neither in skipping ($F_{1,5} = 0.1$, $p = 0.761$) nor in breeding males ($F_{1,9} = 0.6$, $p = 0.458$).

4. Discussion

Long-lived seabirds often skip reproduction in certain years, and our previous investigations in kittiwakes demonstrate that LH levels are lower in the birds which choose to skip breeding (skippers, [4]). Could environmental toxicants influence LH and/or GnRH levels, and therefore reproductive decisions? We evaluated a possible role for mercury contamination in non-breeding black-legged kittiwakes, and investigated the endocrine mechanisms that underlie this decision.

As expected, total blood mercury measured after arrival significantly predicted the likelihood of breeding. Although our study was correlational and would require experimental manipulation of contaminants [1,8], there is support for causal effects because experimental mercury administration can alter pairing in white ibises (*Eudocimus albus*) and suppress spawning in fathead minnows (*Pimephales promelas*) [1,8]. In our study, the most contaminated males and females were less likely to breed although there was a large overlap in mercury levels between skipping and breeding birds. Some of the skipping birds may have been young or low-quality individuals [5], and therefore be intrinsically more sensitive to mercury. In birds that did breed, mercury had no effect on egg-laying dates, clutch size and breeding success. In breeders, total blood mercury averaged $1.8 \mu\text{g g}^{-1}$ (range: 0.91 – $3.08 \mu\text{g g}^{-1}$), which could be below a threshold level beyond which breeding success is significantly impaired as shown in other bird species [9]. However, mercury–breeding success relationships appear complex in birds since administration of a low mercury dose could even enhance breeding in mallards *Anas platyrhynchos* [10].

Mercury concentration predicted LH levels in skippers, but patterns were different among males and females, and varied between baseline and GnRH-induced LH. Baseline LH and testosterone decreased with increasing blood

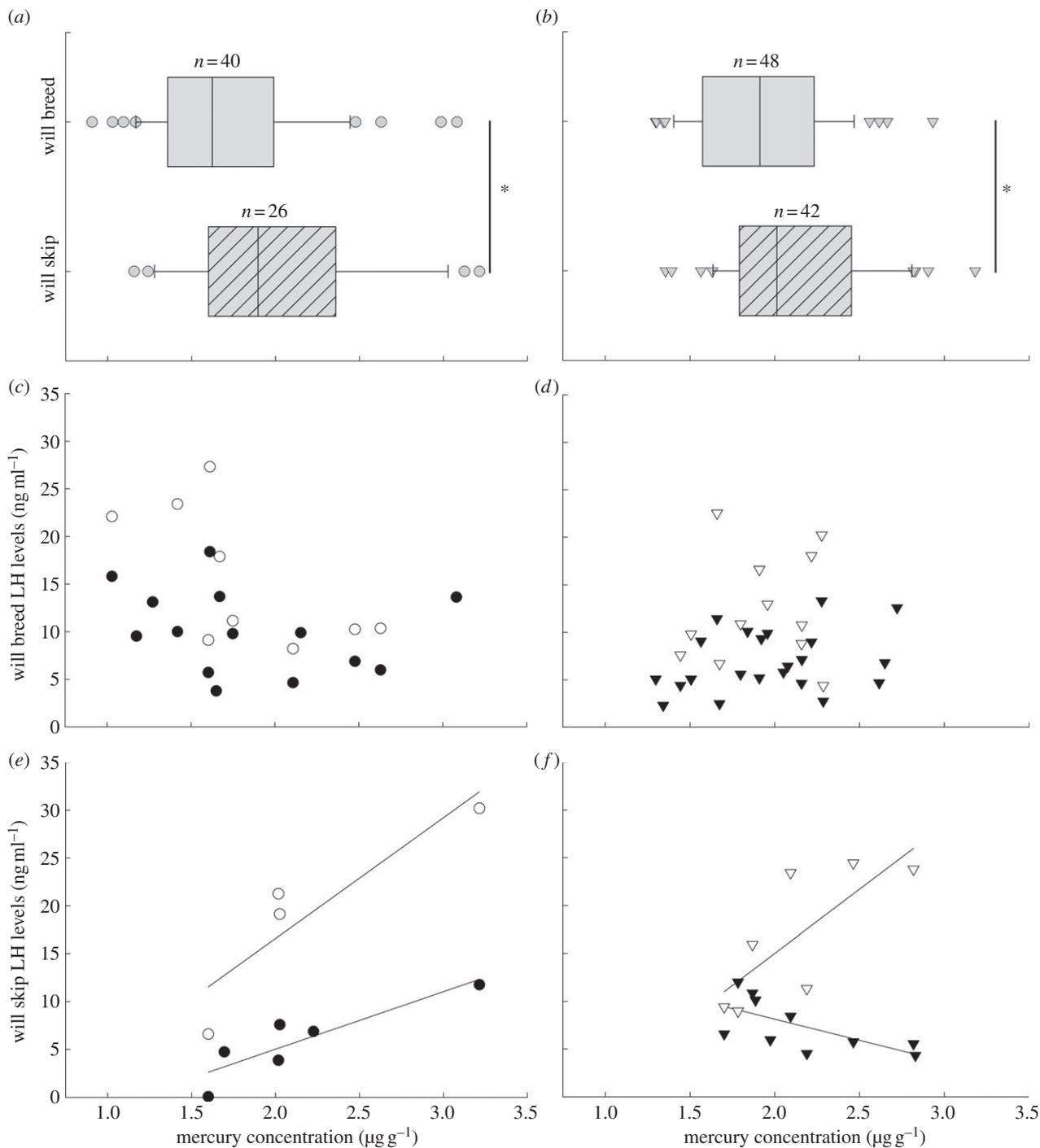


Figure 1. Pre-breeding mercury ($\mu\text{g g}^{-1}$ dwt) and LH levels (ng ml^{-1}) in breeding and skipping black-legged kittiwakes. Breeding birds (empty boxes) had lower mercury levels in blood than birds that would skip breeding (striped boxes), both in (a) females and (b) males. Boxes represent median, 25th and 75th percentiles and outliers. (c–d) In breeders, baseline and GnRH-induced LH levels were not affected by mercury. (e) In skipping females (circles), baseline LH increased with increasing mercury, whereas in (f) skipping males (triangles), baseline LH decreased with increasing mercury. GnRH-induced LH levels, in both skipping males and females, increased with increasing mercury levels (e–f). Filled circles and triangles denote baseline, and open circles and triangles denote GnRH-induced.

mercury concentration in males, as found in mercury-fed laboratory rats [11]. Conversely, in skipping females, LH and mercury were positively related (although levels are still significantly lower than in breeding females [4]). These data suggest that mercury–LH relationships are complex and LH disruption could also be the result of differential negative feedback from mercury given its oestrogen-like effect [2].

To test the functionality of the pituitary, we performed GnRH challenges in breeders and skippers. Based on previous work [4], we assume that the dose of GnRH we used was sufficient to elicit a significant increase of LH 10 min after injection, and interpretation of our results is based on

this assumption. If mercury is suppressing LH secretion directly at the pituitary, we would expect LH response to GnRH to be suppressed in skippers. Contrary to our predictions, skippers were clearly able to release LH, and increased LH three- to fivefold above baseline (breeders did show a slight LH increase). Although based on correlations, it suggests that mercury may act at the hypothalamic level, disrupting GnRH synthesis or secretion. Evidence from other vertebrates demonstrates that mercury can accumulate in the hypothalamus and alter GnRH content and signalling [3,12]. In response to GnRH decline, the pituitary may have upregulated GnRH receptors, explaining the large increase

in LH with GnRH injection. Thus in kittiwakes, mercury contamination could lead to a decline in GnRH release, the subsequent increase of pituitary GnRH receptors explaining why the disrupted pituitary over-releases LH when experimentally challenged by GnRH. Although we originally hypothesized that mercury was targeting the pituitary, the induced LH response also points to a problem at the hypothalamus. It is additionally possible that mercury could bind to LH [13] making LH less able to activate gonadal receptors. Further experiments evaluating LH and GnRH expression in the brain would be necessary to meter out these possibilities.

Long-lived birds often skip breeding when foraging conditions are poor, modulating their reproductive effort

according to environmental conditions [14]. The present situation in the Arctic is of concern: mercury levels in seabirds are increasing [15] and if combined with rapid climate change, we are facing a worst-case scenario [16]. Ultimately, the likelihood to skip breeding may become too high to maintain current population levels.

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