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Polychlorinated biphenyl exposure and corticosterone levels in seven polar seabird species

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A B S T R A C T

The role of polychlorinated biphenyls (PCBs) on exposure-related endocrine effects has been poorly investigated in wild birds. This is the case for stress hormones including corticosterone (CORT). Some studies have suggested that environmental exposure to PCBs and altered CORT secretion might be associated. Here we investigated the relationships between blood PCB concentrations and circulating CORT levels in seven free-ranging polar seabird species occupying different trophic positions, and hence covering a wide range of PCB exposure. Blood $\sum_7$PCB concentrations (range: 61–115,632 ng/g lw) were positively associated to baseline or stress-induced CORT levels in three species and negatively associated to stress-induced CORT levels in one species. Global analysis suggests that in males, baseline CORT levels generally increase with increasing blood $\sum_7$PCB concentrations, whereas stress-induced CORT levels decrease when reaching high blood $\sum_7$PCB concentrations. This study suggests that the nature of the PCB-CORT relationships may depend on the level of PCB exposure.

1. Introduction

In Polar Regions, increasing attention has been directed towards environmental contaminants and their potentially hazardous effects on susceptible wildlife species (Bargagli, 2008; Bustnes et al., 2003, 2007; Gabrielsen, 2007; Verreault et al., 2010; Wania, 2003; Letcher et al., 2010). Among environmental contaminants, several persistent organic pollutants (POPs) may exhibit endocrine disruptive properties, and may alter functions of several hormones (e.g. Amaral Mendes, 2002). For example, a number of studies have reported significant relationships between concentrations of POPs and plasma levels of reproductive hormones such as steroids and some pituitary hormones in free-living birds and mammals (Giesy et al., 2003; Vos et al., 2000; Jenssen, 2006; Gabrielsen, 2007; Verreault et al., 2008, 2010).

Relationships reported to date in a limited number of studies on wild bird species between POP levels and stress hormones (glucocorticoids) have been largely inconclusive: in black-legged kittiwakes *Rissa tridactyla* baseline CORT levels were positively associated to $\sum_{11}$PCB concentrations (Nordstad et al., 2012). Also, in the most PCB-exposed Arctic seabird species, the glaucous gull *Larus hyperboreus*, a higher POP burden (including 58 PCB congeners, organochlorine pesticides, brominated flame retardants and their metabolically-derived products) was associated with higher baseline CORT levels in both sexes (Verboven et al., 2010). Moreover, in studies of pre-laying female kittiwakes and incubating

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snow petrels *Pagodroma nivea*, which bear low to moderate PCB contamination, stress-induced CORT levels increased with increasing $\sum_{10}$PCB concentrations and $\sum$POPs (including 7 PCBs congeners and organochlorine pesticides), respectively (Tartu et al., 2014, 2015). On the other hand, stress-induced CORT levels decreased with increasing POPs (58 PCB congeners, organochlorine pesticides, brominated flame retardants and their metabolically-derived products) in male glaucous gulls that accumulate the highest levels of these contaminants among Arctic species (Verboven et al., 2010). This suggests that the nature of the relationship between POPs, and CORT secretion may be related to the levels of contamination. The major POP detected in wildlife are still the PCBs despite their global ban more than 30 years ago. PCBs bioaccumulate in top predators such as polar seabirds (Letcher et al., 2010; Corsolini et al., 2011) and occasionally high levels of these compounds accumulate in lipid-rich tissues. Since PCB may be a good proxy for POPs in general, the link between PCB levels and stress hormones therefore deserves more attention especially because of the major role of stress hormones in allostasis (McEwen and Wingfield, 2003; Angelier and Wingfield, 2013). For example, in an experimental study conducted on captive American kestrels *Falco spaverinus* dosed with PCBs, decreased levels of baseline and stress-induced CORT were reported compared to levels measured in the control group (Love et al., 2003). CORT secretion is regulated through a number of physiological mechanisms. At the endocrine level, a stressful event will trigger the release of corticotropin-releasing hormone (CRH) from the hypothalamus; CRH will then stimulate the secretion of adrenocorticotropic hormone (ACTH) from the anterior pituitary, which in turn will activate the synthesis of glucocorticoids from the adrenal cortex (Sapolsky et al., 2000; Wingfield, 2013). In birds, up to 90% of glucocorticoids released into the bloodstream will bind to corticosteroid-binding globulin (CBG) and will be transported to target cells. Concurrently, glucocorticoids will provide negative feedback signals for ACTH and CRH release (Wingfield, 2013). This hormonal cascade may trigger an array of physiological and behavioural adjustments that shift energy investment away from reproduction, and redirect it towards survival (Wingfield and Sapolsky, 2003). Glucocorticoids are therefore considered as major mediators of reproductive decisions in birds (reviewed in Wingfield and Sapolsky, 2003) and have a strong connection with fitness in some seabird species (Angelier et al., 2010; Goutte et al., 2011; Schultner et al., 2014). It is thus crucial to determine how both baseline and stress-induced glucocorticoid secretion can be influenced by ubiquitous and abundant environmental contaminants including PCBs. Baseline and stress-induced CORT levels (i.e. CORT levels measured in response to a capture/handling stress), may depict different physiological status: baseline CORT mirrors energetic state (Landys et al., 2006), while stress-induced CORT can be used to infer on an individual's sensitivity to stress. The CORT release following a stress can be modulated (elevated or low release) in order to maximize either survival or reproduction (Lendvai et al., 2007; Bókony et al., 2009).

The aim of the present study was to investigate the relationships between $\sum_7$PCB concentrations, plasma baseline CORT levels and stress-induced CORT levels in seven polar seabird species. We selected seabird species occupying different trophic positions that encompassed a wide range of plasma PCB levels (Letcher et al., 2010). These include the glaucous gull, the black-legged kittiwake, the common eider *Somateria mollissima*, these three species were sampled in the Norwegian Arctic (Bear Island and Kongsfjorden, 74° 22′N, 19° 05′E and 78°54′N, 12°13′E, respectively) the snow petrel, the cape petrel *Daption capense*, the south polar skua *Catharacta maccormicki*, the three species were sampled in Antarctica (Adélie land, 66°40′S, 140°01′E) and the wandering albatross *Diomedea exulans* which was sampled at Crozet Island (46° 24′ S, 51° 45′E) a subantarctic French territory. All species were sampled within a short period of time during the breeding period, that is, from late incubation to early chick-rearing (corresponding to the month of June for Arctic species, and early to late December for Antarctic and subantarctic species). Based on the previous reports on PCB/CORT relationships (Verboven et al., 2010; Nordstad et al., 2012; Tartu et al., 2014), we predicted that the relationships between PCB and CORT levels would differ between species according to their blood PCB levels: 1) baseline CORT concentrations would increase with increasing PCB levels, whereas 2) stress-induced CORT levels would increase in moderately contaminated species and decline in highly contaminated bird species.

2. Material and methods

2.1. Ethics statement

Animals were handled in accordance with the national guidelines for ethical treatment of experimental animals from the Governor of Svalbard, the Norwegian Animal Research Authority (NARA), and the ethic committee of the Institut Polaire Français Paul Emile Victor (IPEV): Governor of Svalbard (2004/00481-12 to G.W. Gabrielsen and J. Verreault, (2007/00165) to S.A. Hanssen and B Moe; NARA 2006/16056 to G.W. Gabrielsen and J. Verreault, (2007/6072) to S.A. Hanssen and B. Moe, FOTS id 2086, 3319 to O. Chastel and IPEV programs no. 109 to H. Weimerskirch and no. 330 to O. Chastel.

2.2. Sampling year, study site and species

Two hundred eighty-six blood samples were available from three high Arctic seabird species: the black-legged kittiwake (hereafter 'kittiwakes', $N = 25$, 2011), the common eider ($N = 55$ females, 2007) and the glaucous gulls ($N = 38$, 2006) and four Antarctic species, the wandering albatross ($N = 75$, 2008), the snow petrel ($N = 35$, 2010), the cape petrel ($N = 27$, 2011), and the south polar skua ($N = 31$, 2003). Main diet and average body mass during late incubation to early chick-rearing are reported for all species in Table 1. Wandering albatrosses were not weighed but the average body mass of wandering albatrosses during incubation is around 8403 ± 642 g for females and 10,720 ± 966 g for males (Weimerskirch, 1995). Study sites, bird capture, and sampling protocols have been described in previous studies (Verboven et al., 2010; Bustnes et al., 2012; Angelier et al., 2013; Goutte et al., 2013; Tartu et al., 2014, 2015; Goutte et al., 2014). Because in seabirds blood CORT and PCB levels may vary between breeding phases (Nordstad et al., 2012), we selected blood samples of birds collected during late incubation and early chick-rearing periods. Briefly, a first blood sample (*ca.* 0.3 mL) for baseline CORT analysis was collected immediately after capture from the alar vein using a heparinized syringe and a gauge needle (Romero and Reed, 2005). Birds were then kept in opaque cloth bags during 30 min after which blood samples were collected immediately following previously described methods for stress-induced CORT analysis (e.g. Tartu et al., 2014). Stress-induced CORT levels were calculated by subtracting the baseline CORT concentrations from the CORT concentration following 30 min handling protocol: stress-induced CORT levels = ($CORT_{t=30\ min} - CORT_{t=0\ min}$). Wandering albatrosses and south polar skuas were not subjected to a capture/handling stress protocol and only baseline CORT levels are available.

2.3. Molecular sexing and hormone assay

Whole blood samples were centrifuged and plasma was stored