



## Demographic, endocrine and behavioral responses to mirex in the South polar skua

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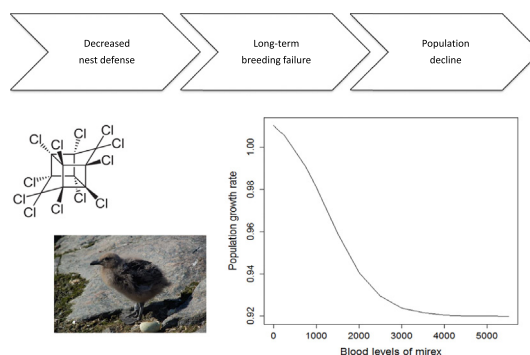
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### HIGHLIGHTS

- Blood levels of POPs did not affect survival rate nor long-term breeding probability.
- Long-term breeding success decreased with increasing mirex and stress levels.
- Stress and parental care hormones were not affected by POP burden.
- Nest defense behavior was weakened in breeders bearing high mirex levels.
- Demographic responses to POP burden were projected using matrix population models.

### GRAPHICAL ABSTRACT



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### ABSTRACT

Population consequences of chronic exposure to multiple pollutants at low environmental doses remain speculative, because of the lack of appropriate long-term monitoring surveys. This study integrates proximate and ultimate aspects of persistent organic pollutants (POP) burden in free-living vertebrates, by coupling hormonal and behavioral endpoints, life-history traits, and population dynamics. Blood samples ( $N = 70$ ) were collected in South polar skuas during two breeding periods, in 2003 and 2005, and individuals were annually monitored until 2011. Multi-state mark recapture models were used to test the effects of POP levels on demographic traits. Survival rate and long-term breeding probability were not related to individual POP levels, whereas long-term breeding success significantly decreased with increasing blood levels of mirex, an organochlorine insecticide. At the proximate level, corticosterone (stress hormone) and prolactin (parental care hormone) levels were not linked to individual POP burden. Nest defense in 2005 was significantly less intensive in chick-rearing skuas bearing higher mirex levels, suggesting reproductive behavioral impairment. Matrix population models were then built to project the rate of population decline according to increasing mirex burden. Although mirex levels were 2.8 times higher in 2003 than in 2005, the population-level effect of mirex was only detected in 2005, the year of higher corticosterone levels. The combination of endocrine traits with demographic analysis thereby enables to provide new support of synergistic interactions between pollutants and stress levels on long-term breeding outputs and population dynamics.

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## 1. Introduction

Environmental chemicals may contribute to wildlife population vulnerabilities, by altering biochemical, genetic, immune, neurological, hormonal and behavioral functions (e.g. Vos et al., 2000). First reports of wildlife population collapses following acute chemical pollution were documented in the late 19th century, after large and intensive spraying of organochlorine pesticides, such as DDT (dichlorodiphenylthichloroethane, Wurster et al., 1965). Poisoning disasters still resonate today, with for instance, the high mortality and population collapses of three *Gyps* vultures' species in South Asia, due to scavenging of domestic livestock carcasses that had been treated with diclofenac (Oaks et al., 2004). Besides these spectacular cases of acute intoxication, wild animals are chronically exposed to complex mixtures of chemical substances at sublethal levels. A large scale experimental manipulation (Kidd et al., 2007) has demonstrated that low doses of a synthetic estrogen, 17 $\alpha$ -ethynylestradiol, may decimate free-living fathead minnow populations *Pimephales promelas*. Long-term effects of such chronic pollution in natural conditions are less readily measurable and remain mainly speculative, because of the dearth of large and longitudinal monitoring data.

Capture-mark-recapture models have shed new light on potential relationships between individuals' pollutant burdens and fitness-related traits. Specifically, recent studies on seabirds have pointed out a decrease in long-term reproductive performances with increasing persistent organic pollutants (POPs) and trace metal elements, such as mercury (Hg) levels in the Brown skua *Catharacta lonnbergi* from the Kerguelen Islands and the South polar skua *C. maccormicki* from Adélie Land, Antarctica (Goutte et al., 2014a) and in the Wandering albatross *Diomedea exulans* in the Crozet Archipelago (Goutte et al., 2014b). A decrease in adult survival rate has been linked to high levels of oxychlorane in the Glaucous gull *Larus hyperboreus* (Erikstad et al., 2013), and to high levels of HCB (hexachlorobenzene) and the chlordan mixture in the Black-legged kittiwakes *Rissa tridactyla* (Goutte et al., 2015). Matrix population models have been built to project demographic responses to pollutant levels in fish species (Miller and Ankley, 2004), amphibians (Willson et al., 2012), reptiles (Salice et al., 2011) and birds (Nakamaru et al., 2003; Goutte et al., 2014a, 2014b). These works support the assumption that pollutant exposure even at low environmental levels may lead to wildlife population decline, by compromising fitness-related traits. Complex issues have also been raised, including species-differences, interrelationships between POP and individual parameters (e.g. sex, previous reproductive state, age, breeding experience and body condition) or environmental factors (e.g. parasite load, food availability, habitat loss; Bustnes et al., 2006a, 2015; Salice et al., 2011).

Proximate mechanisms may help understand and better predict the impact of chronic pollution on wildlife population dynamics. Hormone levels play a major role in regulating reproductive phenology and behavior, acquisition and allocation of resources and life-history trade-offs (Kitaysky et al., 2007; Angelier and Chastel, 2009). Hg and POPs can interfere with hormones that trigger the onset of breeding (e.g. luteinizing hormone, sex steroids), the hormone that regulate parental care (prolactin, hereafter referred as PRL; Verreault et al., 2008; Angelier et al., 2016), and with stress hormones (glucocorticoids, such as corticosterone or cortisol, hereafter referred as CORT) (Tyler et al., 1998; Tartu et al., 2015a, 2015b, 2015c, 2016). Such endocrine disruption may result in behavioral impairments during the breeding period. For instance, nest temperature decreased with increasing blood POP levels in incubating Glaucous gulls (Verboven et al., 2009). In female South polar skuas with high blood POP levels, egg hatching was delayed and chicks were in poor body condition (Bustnes et al., 2007).

This study investigates the endocrine, behavioral and demographic consequences of POP burden in a South polar skua population breeding in Antarctica. We are revisiting a long-term data set that was previously used to assess the effect of Hg on vital rates and population dynamics in

this skuas population (Goutte et al., 2014a). In addition, proximate end-points were explored by considering hormone levels and nest defense behavior. The South polar skua is an ideal model for several reasons: (1) polar apex predators are predicted to be highly contaminated, because Arctic and to a lesser extent Antarctic environments are considered as 'sinks' for POPs and because biomagnification of POPs occurs across trophic levels (Bustnes et al., 2006b; Bargagli, 2008), (2) life-history traits could be acquired annually and at the individual level in this long-lived species with high nest fidelity, (3) nest defense behavior is particularly pronounced. The first aim of this study was to investigate whether demographic traits (adult survival rate, breeding probability, probability of raising one or two chicks the following years) are linked with individual POP levels. To do so, we used a 10 year longitudinal monitoring survey and multi-state mark recapture models (MSMR; Lebreton and Pradel, 2002). Because breeding success of long-lived animals has a low elasticity (i.e. has a low importance for population growth rate), we hypothesized that skua with high POP levels will fail to raise their fledglings the following years, as validated for Hg levels in the same skua population (Goutte et al., 2014a). The second goal was to explore whether endocrine and behavioral traits (CORT, PRL and nest defense intensity) the same year were negatively affected by high individual POP levels. The third objective was to project population-level consequences to increasing POP levels, through matrix population modeling (Caswell, 2001).

## 2. Materials and methods

### 2.1. Site and species

South polar skuas were studied in Antarctica, Adélie Land, on the Pointe Géologie Archipelago (66°40' S, 148°01' E), where ~50 pairs of breeders have been checked every year since 1964/1965. This long-lived species reproduces in loose colonies in Antarctica and is highly territorial during breeding with strong site tenacity and mate fidelity (Young, 1963; Jouventin and Guillotin, 1979; Pietz and Parmelee, 1993). Pair formation starts in October, and usually 2 eggs are laid in intervals of 2–4 days in mid-November, hatching of the eggs occurs in late-December and chicks fledge 50 days after (Young, 1963). Parents feed their chicks until they leave the nesting territory between late March and mid-April (Le Morvan et al., 1967). First reproduction can occur at 3-year old at the earliest, but most females start breeding between 5 and 7 years, and a little later for males (Ainley et al., 1990). After the breeding season, adults from Pointe Géologie migrate directly and winter off at the East of Japan (Weimerskirch et al., 2015). Once arrived on the breeding grounds in October, South polar skuas feed regularly on dead Emperor penguin (*Aptenodytes forsteri*) chicks that are available at the surface of sea-ice occupied by the penguin colony (Pryor, 1968). At Pointe Géologie, South polar skuas have been observed feeding on dead chicks of Emperor penguins daily, from their arrival in October until sea-ice breaks up in January or February (C. Barbraud, personal observation). From mid-November until the end of the breeding season South polar skuas feed mainly on eggs and chicks of Adélie penguins (*Pygoscelis adeliae*, Jouventin and Guillotin, 1979; Weimerskirch et al., 2015). All studied skuas were ringed with a stainless steel ring, as well as a plastic ring engraved with a unique alphanumeric code for identification without recapture. Every year, from early November to early February, each individual was identified on its nest or territory during the pre-laying period, incubation, and the chick-rearing period. In addition, groups of non-breeders were observed and ringed birds were identified. Nests and surroundings were monitored for the presence of one or two eggs or chicks.

Skull (head and bill) length was measured using a caliper (nearest 0.5 mm) and weight was measured using a spring balance (nearest 2 g). As female skuas are significantly larger than males, we calculated body condition (BC) from a least squares linear regression of weight against skull length for males and females separately.

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