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Concentrations of 17 elements, including mercury, and their relationship to fitness measures in arctic shorebirds and their eggs

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ABSTRACT

Exposure to contaminants is one hypothesis proposed to explain the global decline in shorebirds, and this is of particular concern in the arctic. However, little information exists on contaminant levels in arctic-breeding shorebirds, especially in Canada. We studied potential contaminants in three biparental shorebird species nesting in Nunavut, Canada: ruddy turnstones (*Arenaria interpres*), black-bellied plovers (*Pluvialis squatarola*) and semipalmated plovers (*Charadrius semipalmatus*). Blood, feathers and eggs were analyzed for As, Be, Cd, Co, Cr, Cu, Fe, Hg, Mn, Mo, Ni, Pb, Sb, Se, Tl, V, and Zn. We assessed whether element concentrations a) differed among species and sexes, b) were correlated among pairs and their eggs, and c) were related to fitness endpoints, namely body condition, blood-parasite load, nest survival days, and hatching success.

Non-essential elements were found at lower concentrations than essential elements, with the exception of Hg. Maximum Hg levels in blood approached those associated with toxicological effects in other bird species, but other elements were well below known toxicological thresholds. Reproductive success was negatively correlated with paternal Hg and maternal Pb, although these effects were generally weak and varied among tissues. Element levels were positively correlated within pairs for blood-Hg (turnstones) and feather-Ni and Cr (semipalmated plovers); concentrations in eggs and maternal blood were never correlated. Concentrations of many elements differed among species, but there was no evidence that any species had higher overall exposure to non-essential metals. In conclusion, whereas we found little evidence that exposure to the majority of these elements is leading to declines of the species studied here, Hg levels were of potential concern and both Hg and Pb warrant further monitoring.

1. Introduction

Many shorebird species are in decline around the world (IWSG, 2003), including two thirds of those found in Canada (Donaldson et al., 2000). Several global causes for these declines have been suggested, including habitat loss and fragmentation, reduced prey availability, and increased exposure to environmental pollutants (Morrison et al., 1994). Shorebirds may be at particular risk of contaminant exposure as their primary feeding areas include coastal and estuary sediments and agricultural fields, where many contaminants accumulate disproportionately (White et al., 1983; Evans et al., 1987). Environmental contaminants can cause avian mortality directly, but more commonly exact their toll through sub-lethal effects such as altered behaviour and reduced reproductive success, immune function, and body condition (Koller, 1980; Scheuhammer, 1987; Wolfe et al., 1998; de Luca-Abbott et al., 2001; Clotfelter et al., 2004).

Shorebirds that nest in the arctic are apparently especially vulnerable to decline, likely due to the risks associated with their lengthy migration (Zöckler et al., 2003), habitat disturbance due to climate change (Drent et al., 2006; Johnson et al., 2007), and/or contaminant exposure. The latter is of increasing concern for arctic wildlife, as pollution from industrialised areas is deposited disproportionately in the arctic via long-range air and water transport (MacDonald et al., 2000; AMAP, 2002). 'Legacy' organochlorines (e.g., DDTs) have decreased in arctic biota over the past decades (Braune et al. 2005). However some non-essential (i.e. toxic) elements such as mercury (Hg) have increased, particularly in Canada (Braune et al., 2005). Despite growing concern about shorebird declines and the effects of pollution on arctic wildlife (Braune et al., 2005; Fisk et al., 2005), there is a paucity of information about the contaminant loads of shorebirds nesting on Canada's arctic shores (Braune and Noble, 2009).

Whereas toxicology studies historically required lethal collection to evaluate contaminants in internal organs, sampling tissues that can be collected non-lethally has become increasingly common, with obvious advantages for threatened species. Blood samples provide the

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most direct, non-lethal assessment of dietary exposure, reflecting recent exposure primarily, and recently metabolised contaminants to a lesser extent (Moriarty, 1975; Pain, 1996; Evers et al., 2005). Egg contaminants reflect those in maternal blood and organs during egg formation. As arctic shorebirds provision eggs using primarily arctic-based resources (Klaassen et al., 2001; Morrison, 2006), egg elements should reflect those in the arctic environment. Feather contaminants accumulate via depuration of internal loads during feather growth, and/or exogenous absorption from the environment, to varying degrees depending on the contaminant. For example, feathers are an important depuration route for internal Hg and feather-Hg remains stable for the life of the feather (Burger et al., 1993), reliably indicating blood-Hg during growth (Goede and de Bruin, 1984; Thompson et al., 1991; Tavares et al., 2008). As arctic-nesting shorebirds grow most flight feathers on wintering grounds (Prater et al., 1977), feather levels of such endogenously accumulated elements provide otherwise hard to obtain information on contaminant exposure at the opposite end of the bird's range. Feather levels of elements that can be absorbed exogenously, such as cadmium (Cd), iron (Fe), lead (Pb), selenium (Se), manganese (Mn) and chromium (Cr) (Goede et al., 1989; Burger et al., 1993; Burger et al., 2008b), provide a measure of overall environmental exposure but are less reliable as indicators of internal levels (Goede and de Bruin, 1984; Goede and de Voogt, 1985; Scheuhammer, 1987; Pilastro et al., 1993; Pain et al., 2005).

We assessed the levels of 16 metals and Se in blood, feathers and eggs of three biparental shorebird species at a breeding site in Nunavut, Canada. Of these elements, As, beryllium (Be), Cd, Hg, nickel (Ni), Pb, antimony (Sb) and thallium (Tl) are toxic with no known biological use, whereas the others [cobalt (Co), copper (Cu), Cr, iron (Fe), Mn, molybdenum (Mo), Se, vanadium (V) and zinc (Zn)] are essential in small concentrations but toxic at higher levels. We compared element concentrations to measures of adult fitness, reproductive success, and established avian toxic effects thresholds to assess whether pollutants may pose a threat to East Bay shorebird populations. All three study species have experienced recent population declines in Canada (Donaldson et al., 2000), and local Inuit have noted overall declines in shorebird populations in the study area (Aiviq Hunters and Trappers Association, Coral Harbour, personal communication). To assess whether paired birds experienced similar contaminant exposure in the arctic and elsewhere, we tested for positive element correlations in blood and feathers. These data provide the first baseline element levels for non-lethally collected tissues of shorebirds nesting in Canada's arctic, and help fill a recognized knowledge gap regarding metals other than Hg and Cd in arctic wildlife (NCP, 2003).

We made four predictions: 1) blood levels would be positively correlated between paired birds, as pairs tend to feed close to their nest, but no correlation would exist for feathers, as pairs do not necessarily winter or migrate together; 2) levels would be positively correlated between females (blood) and their eggs, as shorebirds typically acquire the energy used for egg production in the arctic; 3) hatching success would be negatively correlated with toxic element levels in eggs and/or adults, as egg contaminants can influence embryo health directly and those in adults can decrease anti-predator behaviour (Clotfelter et al., 2004); and 4) adult toxic element levels would be correlated positively with blood-parasite loads and negatively with body condition.

2. Methods

2.1. Study site and species

Field work was conducted within the East Bay Migratory Bird Sanctuary on Southampton Island, Nunavut, (63°59′N, 81°40′W) during June and July 2008. We assessed contaminant loads of three shorebird species: ruddy turnstones (*Arenaria interpres*, hereafter turnstones), black-bellied plovers (*Pluvialis squatarola*) and semipalmated plovers (*Charadrius semipalmatus*). Black-bellied plovers and turnstones were the focal species of this study, whereas blood and feathers were collected opportunistically from semipalmated plovers trapped for a separate study (DB Edwards, unpublished data). Tissue types vary slightly as a result (see below); samples sizes are presented in Table 1.

2.2. Adult condition and reproductive success

A long-term 3 × 4 km study plot was searched for nests of all shorebird species (ca. 450 person h), which were then monitored until they either failed or hatched (see Smith et al., 2007). We calculated two measures of reproductive success: a binary response for nests of known fate (hatched or failed; hereafter hatching success), and nest duration for all nests. Nest duration is the days of incubation completed, and was calculated as the Mayfield end date (Mayfield, 1975) minus the date of clutch completion, where the latter was either known or estimated by floating eggs (Liebezeit et al., 2007). Nests found later during incubation are more likely to be successful than those found at earlier stages (Mayfield, 1975); we accounted for this bias by including the estimated days of incubation completed when each nest was found as a covariate in models of reproductive success.

We trapped adult birds on the nest using Potter, bow-net or small Fundy pull traps (Gratto-Trevor, 2004). Birds were banded, weighed, and their exposed culmen measured. Since body condition can influence contaminant concentration (Wienburg and Shore, 2004; Jaspers et al., 2007), we quantified condition as mass/culmen (mass controlled for skeletal size; O'Hara et al., 2007). This was included as a covariate in analyses of reproductive success to control for parental body condition.

2.3. Blood

Blood samples (0.4 to 2 µL, always <1% of body weight) were collected from the brachial vein of trapped birds using a pre-heparinized syringe with a 25 gauge needle. Blood smears were made the same day, and once dry were fixed and stained with Diff–Quik. The entire area of each smear was later examined under a compound microscope (1000×) for blood parasites, particularly *Leucocytozoon* sp., *Hemoproteus* sp., and microfilarial species.

Entire blood samples from turnstones and black-bellied plovers were analyzed, whereas plasma from semipalmated plover blood was removed for a separate study, leaving only red blood cells (RBC) for contaminant analysis. To facilitate multi-species comparisons, we analyzed RBC and plasma separately for seven black-bellied plovers and six turnstones. This enabled us to compare RBC concentrations across all three species, and to calculate the proportion of each

Table 1
Sample sizes available for the study. Non-viable eggs were those found ejected from the nest or that failed to hatch in otherwise successful nests. For toxicological sampling, each egg was collected from a separate clutch. A complete family means that both adults of a pair and one of their eggs were sampled.

Species	Reproductive success			Toxicological sampling			
	Nests found	Nests hatched	Non-viable eggs	Eggs	Females	Males	Complete families
Black-bellied plover	15	4	1	13	7	5	5
Ruddy turnstone	29	20	4	27	21	15	10
Semipalmated plover	8	6	1	6	6[a]	6	6

[a] One female semipalmated plover blood sample discarded; $n = 5$ for blood, $n = 6$ for feathers.