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Mercury in Bar-Tailed Godwit (*Limosa lapponica*) and Lesser Knot (*Calidris canutus*): Spatially Explicit Information from Non-Breeding Birds in New Zealand

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There is a wealth of information on the concentrations of mercury in birds from a wide range of environments and ecosystems, covering a broad spectrum of spatial and temporal scales. For example, Thompson and Dowding (1999) described mercury concentrations in blood of South Island pied oystercatchers (*Haematopus ostralegus finschi*), indicative of exposure over days to weeks, sampled from estuaries (spatial scale of tens of kilometers) in the Auckland region of New Zealand. In contrast, mercury concentrations reported in albatrosses (Stewart *et al.* 1999; Burger and Gochfeld 2000) represent spatial scales of hundreds to thousands of kilometers, and temporal scales of months to years, because these pelagic seabirds forage over extensive ranges (Jouventin and Weimerskirch 1990) and excrete mercury relatively slowly (Thompson and Furness 1989).

Migratory species potentially afford the opportunity to investigate exposure to mercury at two or more discrete locations without the need to sample tissues at each site, thus reducing logistic costs. In the case of mercury, this can be achieved by removal of a sample of feathers from individual birds, inducing new feathers to grow. Re-grown feathers are sampled at a later date from the same individuals, mercury burdens in the second sample indicative of the feeding area and time spent there since initial feather removal (Burger *et al.* 1992). Alternatively, some migratory species, including many shorebirds which often spend breeding and non-breeding seasons in discrete locations, undergo two molts; following breeding (post-breeding molt) and preceding the next breeding season (pre-breeding molt). Furthermore, breeding and non-breeding plumages in shorebirds are usually very different in appearance, allowing specific feather samples to be collected easily. Since mercury accumulated via the diet is stored in internal tissues during the inter-molt period, and excreted into growing feathers following feather molt (Furness *et al.* 1986), mercury concentrations in non-breeding plumage represent exposure to mercury at the breeding site while mercury levels in breeding plumage represent exposure to mercury at the non-breeding site.

Estuarine, harbor and coastal ecosystems in New Zealand support a diverse assemblage of both resident and migratory shorebirds. In particular, these sites are major non-breeding habitats for bar-tailed godwit (*Limosa lapponica*) and lesser knot (*Calidris canutus*) during the austral summer (Sagar *et al.* 1999). Adult

godwit and knot that spend the non-breeding season in New Zealand breed in Arctic Siberia and Alaska and migrate south as part of the East Asian-Australasian Flyway populations (Higgins and Davies 1996: Riegen 1999). Migrating birds arrive in New Zealand during September and October and depart northwards at the end of the non-breeding season during March and April (Heather and Robertson 1996; Riegen 1999). Importantly, both species undergo a complete post-breeding molt into non-breeding plumage, and towards the end of the non-breeding season both species molt again into breeding plumage (Higgins and Davies 1996). During both molts, body feathers are dropped and replaced towards the beginning of the molt cycle (Higgins and Davies 1996). Hence, body feathers sampled from non-breeding birds recently arrived in New Zealand, in non-breeding plumage, will contain mercury accumulated during the breeding season or on the southward migration. Similarly, body feathers sampled from birds that have molted back into breeding plumage immediately prior to departure northwards to Arctic breeding sites will contain mercury accumulated during the non-breeding season in New Zealand. Hence, two samples of body feathers from bar-tailed godwit and lesser knot should yield information about the birds' exposure to mercury at two discrete locations. In this paper I make use of this to test the specific hypothesis that there is no difference in exposure to mercury in bar-tailed godwit and lesser knot between their Arctic breeding sites and non-breeding sites in New Zealand, as determined through mercury concentrations in body feathers.

MATERIALS AND METHODS

Feather sampling was undertaken at the Firth of Thames (37°10'S 175°20'E) and at south Manukau Harbour (37°05'S 175°00'E) in the north of New Zealand. In all cases, roosting adult birds were captured at high tide using a canon net, and four to six body feathers were removed from the dorsal area between the wings of each individual. Feathers were stored in polythene bags prior to mercury analysis. Two collections of feather samples were made. An initial sample was obtained (in November 1999) after birds arrived in New Zealand following southward migration from their Arctic breeding sites. This first sample comprised feathers from birds in non-breeding plumage, and therefore representative of mercury exposure during the breeding season and southward migration (bar-tailed godwit: $n = 16$; lesser knot: $n = 23$). Since birds were sampled at non-breeding sites, it was not possible to recapture the same individuals. A second sample of feathers was taken after the birds had molted into their breeding plumage (in March 2000), immediately prior to departure northwards from New Zealand, and representative of mercury exposure whilst in New Zealand (bar-tailed godwit: $n = 23$; lesser knot: $n = 14$). Although these species undergo a complete post-breeding molt (into non-breeding plumage) and only a partial pre-breeding molt (into breeding plumage), body feathers are replaced towards the beginning of both molts (Higgins and Davies 1996). Therefore, the selection of body feathers from birds in non-breeding plumage (on arrival in New Zealand) and from birds in breeding plumage (prior to departure from New Zealand) ensures that mercury

concentrations in feathers from the same position in the molt process were being compared.

Feathers were washed with distilled water to remove gross surface contamination then dried in an oven at 40°C for 24 hours. Prior to weighing for mercury analysis, feather samples were allowed to equilibrate at ambient laboratory temperature (ca. 20°C) for 2 hours since dried feathers increased rapidly in mass when removed from the oven due to re-absorption of water from the atmosphere. Hence, although feathers were dried, mercury concentrations should be considered on a fresh mass basis. Body feathers taken from each individual were pooled into a single sample for mercury analysis.

Mercury concentrations were determined using inductively-coupled plasma mass spectrometry (ICP-MS) preceded by digestion with concentrated nitric and hydrochloric acids at 100°C for 1 hour. All mercury analyses were carried out by R.J. Hill Laboratories Ltd., Hamilton, New Zealand, and are presented as μg of mercury per g of feather (parts per million, ppm). Feather samples were regularly interspersed with two in-house reference hair samples for routine quality control (hair sample 'A', certified mean mercury concentration = 0.57 μg/g, based on hundreds of analyses: mean of 4 quality control samples analyzed during feather analysis = 0.57 μg/g ± 0.02 SD. Hair sample 'B', certified mean mercury concentration = 0.30 μg/g: mean of 4 quality control samples = 0.30 μg/g ± 0.02 SD). Replicate mercury analyses of NIES CRM No 13 human hair reference sample (n = 6, mean = 4.37 μg/g, SD = 0.05) were also extremely close to the certified value (4.40 μg/g). Limit of detection was 0.01 μg/g.

Mercury concentration data were tested for deviation from normality using Shapiro-Wilk W tests (Shapiro and Wilk 1965). Mean mercury concentrations in feathers from the two samples, for both species, were compared using t-tests, as were inter-species comparisons. The word 'significant' has been used in the statistical context only, indicating a probability of chance occurrence of less than 0.05. All statistical procedures were carried out using NCSS 2000 (Kaysville, Utah) software.

RESULTS AND DISCUSSION

The distribution of mercury concentrations in all samples did not deviate significantly from normal (Shapiro-Wilk W tests, $p > 0.05$ in all cases). Mercury concentrations in body feather samples taken from bar-tailed godwit and lesser knot recently arrived in New Zealand from breeding sites in the Arctic, and from birds immediately prior to departure north from New Zealand at the end of the austral summer are presented in Table 1. There was no significant difference in mean mercury concentration between bar-tailed godwit sampled in non-breeding plumage on arrival in New Zealand (mean = 2.13 μg/g, Table 1) and in breeding plumage prior to departure from New Zealand (mean = 2.53 μg/g, Table 1: t-test, $t = 1.26$, $df = 37$, $p = 0.21$). Similarly, there was no significant difference in mean mercury concentration in feathers from lesser knot at the same sampling occasions

('arrival' mean = 2.00 μg/g, 'departure' mean = 1.85 μg/g, Table 1: t-test, t = 0.64, df = 35, p = 0.53).

Table 1. Mercury concentrations (μg/g fresh mass) in body feather samples taken from bar-tailed godwit and lesser knot recently arrived in New Zealand from northern breeding sites, and from birds shortly prior to departure north from New Zealand at the end of the austral summer.

	Arrival in New Zealand		Departure from New Zealand	
Species	n	Mean ± 1 SE (Range)	n	Mean ± 1 SE (Range)
Bar-tailed godwit	16	2.13 ± 0.18 (0.95 – 3.93)	23	2.53 ± 0.23 (0.35 – 4.80)
Lesser knot	23	2.00 ± 0.12 (0.93 – 3.03)	14	1.85 ± 0.24 (0.91 – 3.40)

Whilst variation in environmental mercury contamination has been investigated through sampling feathers from the same species at a number of different sites (for example, Evers *et al.* 1998), or through sampling feathers from different species at the same site (for example, Gochfeld *et al.* 1999), the use of specific feathers sampled from birds at a single site to elucidate mercury burdens at discrete locations has received relatively little attention. However, Burger *et al.* (1992) removed feathers from marked common terns (*Sterna hirundo*) and roseate terns (*S. dougallii*) trapped at their breeding grounds, and compared mercury concentrations in initial feather samples with those in feathers regrown by the same individual birds. They concluded that these species were generally exposed to higher levels of mercury at breeding sites, as revealed from regrown feathers, in North America compared to South American wintering (non-breeding) sites, as revealed through feathers sampled initially (Burger *et al.* 1992). Removal of feathers as a means to induce feather growth has obvious benefits for the study of mercury contamination in birds, specifically where it is possible to recapture the same individuals. Theoretically any species, which can be sampled twice with reliability, would lend itself to this approach, and exposure to mercury at two or more locations and at different times can be investigated. However, one possible drawback with induction of new feather growth could be that the feathers induced to grow are promoted to the start of an artificial molt and feather growth process. Mercury ingested in the diet accumulates in internal tissues during inter-molt periods (Bearhop *et al.* 2000) and is excreted at higher concentrations in feathers molted and replaced early in a molt cycle (Furness *et al.* 1986). Therefore, if a feather that would normally be replaced relatively late in a 'natural' molt cycle is induced to grow at the start of an 'artificial' molt cycle, when the body pool of accumulated mercury is likely to be relatively large, it follows that such feathers

could exhibit correspondingly high mercury levels as a result, at least in part, of their promotion to the start of an 'artificial' molt.

Mercury concentrations in feathers are also a function of the length of the inter-molt period over which mercury is ingested and accumulated. Bar-tailed godwit and lesser knot spend approximately equal amounts of time on their Arctic breeding grounds and in New Zealand during the non-breeding season (Higgins and Davies 1996). Mercury concentrations presented here (Table 1), corresponding to exposure to mercury during the breeding season and during the non-breeding season, are therefore relatively accurate indices of exposure to mercury during these two phases of the annual cycle of godwit and knot. The fact that no significant differences were detected between the two seasons (see above), in either species, could reflect similar exposure to mercury in both the Arctic breeding environments and in non-breeding environments in New Zealand. However, this is relatively unlikely since diet in both species during the breeding season includes varying proportions of terrestrial invertebrates and plant material (Cramp and Simmons 1983). By contrast, during migration and during the non-breeding season, the diet consists mainly of inter-tidal mollusks and worms (Cramp and Simmons 1983; Piersma 1991; Cummings *et al.* 1997). Mercury concentrations tend to be relatively low in terrestrial systems compared to inter-tidal estuarine or marine systems, so the similarity in mercury concentrations in godwit and knot between the two sampling periods may reflect mercury ingestion during the southward migration between the Arctic and New Zealand. In a recent review of migration patterns in these species, Riegen (1999) identified a number of estuarine and coastal sites that godwit and knot use or are very likely to use as they move south. It could be that mercury ingested during the journey south is similar to that acquired whilst in New Zealand, although this remains to be investigated.

There was no significant difference between mercury concentrations in feathers from bar-tailed godwit and from lesser knot (Table 1), either in non-breeding plumage on arrival in New Zealand (t-test, $t = 0.59$, $df = 37$, $p = 0.57$), nor in breeding plumage prior to departure from New Zealand (t-test, $t = 1.93$, $df = 35$, $p = 0.06$). There are few published mercury data for bar-tailed godwit and lesser knot with which to compare results in the present study. Goede (1985) reported mercury levels in feather shafts of bar-tailed godwit and lesser knot sampled from the Dutch Wadden Sea that were higher than those in the present study: mean levels ranged between 2-5 μg/g in godwit and between 3-6 μg/g in knot (Goede 1985). It is very unlikely that the mercury concentrations reported here represent any threat to these species, and it seems reasonable to conclude that these mercury levels are generally low. The mercury concentrations noted here are certainly lower than in other studies where mercury pollution has been implicated or where mercury levels are likely to have detrimental effects on bird reproduction or survival (for example, Beyer *et al.* 1997; Cahill *et al.* 1998; Evers *et al.* 1998).

Nevertheless, that mercury levels in the present study were generally low and exhibited no significant variation either between sampling periods, nor between

species, should not detract from the usefulness of targeting specific feathers for mercury analysis in order to reveal spatially and temporally discrete information about exposure of birds to mercury. The sampling approach adopted here is relatively straight forward in logistic terms, causes relatively little disturbance to birds since they are not breeding and further develops the use of birds, and particularly feathers, as robust and informative monitors of environmental mercury contamination.

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