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SHORT NOTE

Using isotopic analysis to identify incorporation of marine nutrients in terrestrial birds at Snares Islands

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Many islands around New Zealand support breeding colonies of petrels and shearwaters (Heather & Robertson 1996), and nutrient enrichment of colony soils is widely recognised (Warham 1996). Nutrients brought ashore by breeding seabirds can also be distributed to the terrestrial ecosystem away from the immediate vicinity of breeding colonies (Erskine et al. 1998; Harding *et al*. 2004). In addition to seabirds, pinnipeds inhabit the fringes of many islands, potentially contributing nutrients and disturbing vegetation.

Analysis of isotopic enrichment (especially carbon (C) and nitrogen (N) isotopes) complements traditional ecological methods. Among possible applications, relatively high values of δ^{13}C and δ^{15}N can be used to identify contributions of marine C and N to terrestrial ecosystems (Hobson 1986, 1990; Markwell & Daugherty 2003). However, other potential causes of isotopic enrichment need to be taken into account when assessing likely marine nutrient sources. For δ^{13}C, enrichment is higher at forest margins than under an enclosed canopy (Tieszen 1991), and increases when a plant is under water stress (Edwards *et al*. 2000). For δ^{15}N, enrichment increases in a stepwise fashion with trophic level (Minagawa & Wada 1984). Ecosystem enrichment in δ^{15}N also results from low rainfall (Vitousek 2004), and inputs from grazing animals (Hawke 2001).

In this study we analysed moulted terrestrial bird feathers from North East Island at Snares Islands (where large numbers of seabirds breed, and pinnipeds haul out) to test the hypothesis that C and N brought ashore by seabirds and pinnipeds (mostly Hooker's sea lions *Phocarctos hookeri* and New Zealand fur seals *Arctocephalus forsteri*) are transferred to terrestrial birds. Analysis of moulted feathers is entirely non-invasive and does not disturb the birds in any way. However, finding adequate sample sizes can be problematic due to the opportunistic nature of sampling. Another important caveat is that results only reflect nutrient assimilation during feather growth (Hobson 1999), probably a few weeks in late summer or autumn.

Isotopic analysis was carried out on individual feathers collected during other work in January – February 2002 and 2004. Species collected (one sample each, unless noted) were Snares Island snipe (*Coenocorypha aucklandica heugli*; sample collected after a dispute between two birds), silvereye (*Zosterops lateralis*; two samples), Snares Island tomtit (*Petroica macrocephala dannefaerdi*), and song thrush (*Turdus philomelos*). Three further feathers were from either Snares Island snipe or Snares Islands fernbird (*Bowdleria punctata caudata*).

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To establish whether any isotopic enrichment came from incorporation of marine nutrients, feathers from terrestrial birds occupying a range of trophic levels and environments away from seabird breeding and seal haulouts were analysed. Moulted Stewart Island brown kiwi (*Apteryx australis lawryi*), kereru (*Hemiphaga novaeseelandiae*), and silvereye feathers were collected opportunistically from Mason Bay on Rakiura/Stewart Island in April 2001 and January 2003. The kiwi feathers came from dunes adjacent to the beach, while the silvereye and kereru feathers came from low forest at Duck Creek, in the central sector of Mason Bay. In addition to foraging in forest, kiwi at Mason Bay forage for invertebrates consuming marine material on the beach. From the South Island's West Coast, which, like Snares Islands and Mason Bay, has a humid climate, came eight kereru feathers (collected from forest near Barrytown as part of a different study), and feathers from two road-killed weka (*Gallirallus australis*) (from farmland near Hokitika and Kumara). Finally, feathers were collected from a recently fledged, road-killed little owl (*Athene noctua*) near Geraldine in South Canterbury. Little owls are mostly insectivorous. However, small birds are often fed to nestlings (Rule 1977) so the little owl result represents a top predator living in a non-forested, agricultural environment with relatively low rainfall.

Feathers were stored dry in a cool, dark place until analysed. Isotopic analysis was carried out by the Institute of Geological and Nuclear Sciences Ltd (Lower Hutt, New Zealand). Duplicate analyses were carried out simultaneously on mg quantities of finely ground (<250 µm), cleaned (2:1 chloroform: methanol; Hobson 1999) feathers. Stable isotopic ratios are presented in standard δ notation with units of per mil (‰) calculated from the formula:

$$\delta X (‰) = 1000 \times (R_{sample} - R_{standard}) / R_{standard}$$

where X is ^{13}C or ^{15}N and R is the ratio of $^{13}C/^{12}C$ or $^{15}N/^{14}N$. Calibration for $\delta^{13}C$ used a secondary C standard calibrated against the international limestone standard PDB, and for $\delta^{15}N$ used atmospheric N. The median difference between duplicate sample analyses was 0.1‰ ($\delta^{13}C$) and 0.5‰ ($\delta^{15}N$). The song thrush, silvereyes from Snares Islands, and kiwi feathers were too small for a duplicate analysis.

Isotopic enrichment was significantly higher for both $\delta^{13}C$ (p = 0.0002, Mann-Whitney U = 0.000; 95% confidence interval of difference = 1.9-4.2‰) and $\delta^{15}N$ (p = 0.0002, Mann-Whitney U = 0.000; 95% confidence interval of difference = 4.9-13.7‰) in feathers from Snares Islands (Fig. 1), notwithstanding data from kiwi which probably consumed marine material. Values for $\delta^{13}C$ spanned a wider range at Snares Islands (3.2‰) than from the non-seabird breeding sites (1.9‰), even though the non-seabird sites encompassed both forest and farmland. Conversely, the range in $\delta^{15}N$ was higher at the non-seabird sites (13.9‰ compared with 8.1‰). The only species in common from seabird and non-seabird areas was the silvereye (an omnivore), for which The Snares samples were enriched by an average of 2.1‰ ($\delta^{13}C$) and 10.5‰ ($\delta^{15}N$).

Each data subset showed clear trophic level effects for $\delta^{15}N$. At Snares Islands, the single verified snipe showed the highest enrichment ($\delta^{15}N$ = +21.7‰) consistent with its diet of invertebrates (Heather & Robertson 1996) while one of the silvereye samples had the lowest ($\delta^{15}N$ = +13.7‰). From non-seabird areas, the kereru sample from Mason Bay had the lowest enrichment ($\delta^{15}N$ = -1.5‰) while the little owl had the highest ($\delta^{15}N$ = +12.4‰).

Although made up of different plant species, North East Island and Mason Bay coastal forests have similar growth habits, with both closed canopy and open areas. Water stress (which causes enrichment in plants in both ^{13}C and ^{15}N) should be higher at Mason Bay due to the well-drained sandy soil. Both sites are exposed to strong, salt-laden westerly winds. Because rainfall at the control sites is similar to (or lower than) that at Snares Islands, climatic differences are unlikely to underlie the observed enrichments. Even though the little owl was subject to all factors known to lead to isotopic enrichment (agricultural input, water stress, a non-forested environment, and a high trophic level), its $\delta^{13}C$ and $\delta^{15}N$ were both lower than any of the results from Snares Islands. There is no evidence that the data from Snares Islands were affected by plant uptake of guano ammonia with a highly depleted $\delta^{15}N$ (c.f. Erskine *et al.* 1998).

Literature data for Steller sea lion (*Eumetopias jubatus)* (Hobson *et al.* 1997, in the absence of data for pinnipeds found at Snares Islands), and sooty shearwater (*Puffinis griseus)* (lipid-free liver $\delta^{13}C$, Thompson *et al.* 2000; muscle $\delta^{15}N$, Hobson *et al.* 1994) provided indicative values for likely marine C and N sources (Fig. 1). These data broadly encompass the feather data collected from Snares Islands, supporting the hypothesis that the marine C and N came ashore via marine animals. Marine C and N could find their way into terrestrial birds at Snares Islands by two routes. The most direct is consumption of invertebrates which had been feeding directly on seabird or seal guano and carcases, and unhatched seabird eggs. Snares fernbird and Snares tomtit associate directly with pinnipeds (Heather & Robertson 1996; J. N., pers. obs.). Alternatively, marine nutrients could contribute to plant growth. This C and N could then be passed to nectar and herbivorous invertebrates, to be consumed by terrestrial birds.

Both direct and indirect mechanisms may be important, perhaps depending on the territory and habits of each individual bird. In particular,

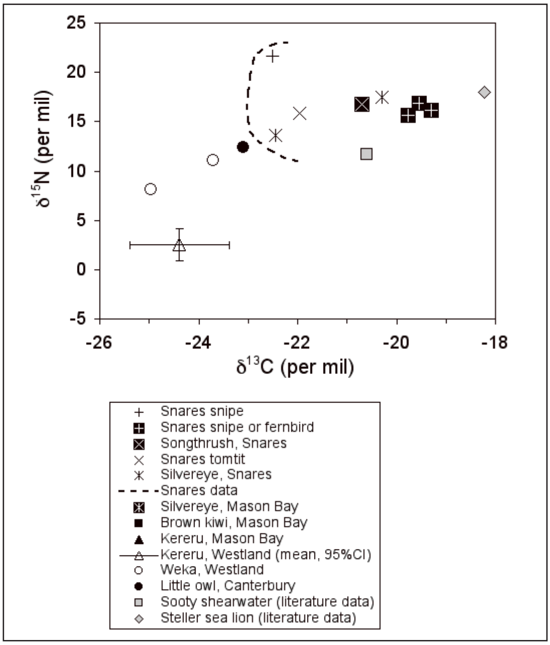

Figure 1 Isotopic enrichment of feathers from terrestrial birds on North East Island, Snares Islands (to the right of the dashed line), compared with feathers from non-seabird breeding areas on Rakiura/Stewart Island and South Island, New Zealand. Literature values (sources in text) for sooty shearwater and Steller sea lion are also shown as indicative estimates of marine inputs.

the single positively-identified Snares Island snipe sample showed a much-enriched δ^{15}N but a depleted δ^{13}C in relation to the 3 snipe/fernbird samples. Because both Snares Island snipe and Snares Islands fernbird are ground-dwelling insectivores (Heather & Robertson 1996), a trophic level effect on isotopic enrichment is unlikely (Minagawa & Wada 1984). We suggest that the positively-identified Snares Island snipe consumed invertebrates which were feeding on terrestrial vegetation, whose C was not primarily derived from marine material. Such vegetation would have a δ^{13}C less affected by marine inputs but an elevated δ^{15}N reflecting uptake of soil N affected by volatilisation of ammonia (see Hawke 2001). Conversely, the three snipe/fernbird individuals could have consumed invertebrates directly associated with seabirds or pinnipeds. The two silvereye samples from Snares Islands also gave widely separated results, with the sample having the lower δ^{13}C being only 1‰ more enriched than the Mason Bay sample.

Our results are consistent with other studies showing marine nutrient subsidies of island communities (Erskine *et al.* 1998; Anderson & Polis 1999). A more systematic study could more clearly elucidate routes for transferring marine nutrients to terrestrial birds. Notwithstanding limitations due to limited sampling effort, our results support the hypothesis that there is a significant transfer of marine C and N to terrestrial birds from pinnipeds and/or breeding seabirds. An important implication of this hypothesis is that seabirds and pinnipeds have a fundamental role of in maintaining the terrestrial ecosystem of Snares Islands, and conceivably other seabird breeding islands around New Zealand as well.

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