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Verification of seabird contributions to Australasian harrier diet at Motunau Island, North Canterbury, using stable isotope analysis

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Abstract We analysed ^{13}C and ^{15}N isotopic enrichment in Australasian harrier (*Circus approximans*) eggshell and two discarded harrier feathers from Motunau Island, a regionally important seabird breeding island. Among the prey remains found at the nest was a prion (*Pachyptila* sp.) wing fragment and a predated blue penguin (*Eudyptula minor*). We combined isotope data from the prey remains, plus potential prey items obtained from the mainland, to reconstruct harrier diet and evaluate incorporation of seabird nutrients. During egg material formation, blue penguins made up a major part of the female harrier's diet. During autumn, when feathers were re-growing, the two feathers (which may or may not have been from different individuals) gave very different results. The feather with the more marine signature was growing when harrier diet included a significant proportion of blue penguin and/or fairy prion (*Pachyptila turtur*) material. Formation of the other feather may have occurred while harrier diet was primarily terrestrial. Our results are indicative of the usefulness of stable isotopic analysis in elucidating nutrient flows and contributions to animal diet.

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Keywords Australasian harrier; *Circus approximans*; New Zealand; diet; carbon-13; nitrogen-15; stable isotope

INTRODUCTION

In terms of nutrient flows, ecosystems are often conveniently seen as working more or less in isolation from each other. However, this view is increasingly challenged as being overly simplistic and as omitting key ecological processes (Polis *et al*. 2004). In particular, transfer of marine-derived nutrients to terrestrial ecosystems may at least partly balance the steady loss of nutrient elements from the land over time, which leaves terrestrial ecosystems increasingly depauperate (Richardson *et al*. 2004; Vitousek 2004). Marine nutrient subsidies of terrestrial ecosystems have been reported for systems as diverse as arid islands in the Gulf of California (Anderson & Polis 1999; Stapp & Polis 2003) and subantarctic Macquarie Island (Erskine *et al*. 1998). On seabird breeding islands in New Zealand, carbon (C) and nitrogen (N) brought ashore by seals and seabirds is incorporated into a wide range of terrestrial biota (Markwell & Daugherty 2002; Hawke & Newman 2005). For the pre-human New Zealand mainland, Worthy & Holdaway (2002) postulated a substantial marine nutrient subsidy from petrel breeding colonies which have now mostly gone. Recent studies support this contention for both aquatic (Harding *et al*. 2004) and terrestrial (Hawke & Holdaway in press) ecosystems.

The Australasian harrier (*Circus approximans*) became established in New Zealand after human settlement created enough areas of suitable habitat (Holdaway *et al*. 2001). Following further land clearance during the 19th century, the species is now a common feature of the New Zealand rural landscape. The introduction of small mammals (especially European rabbits (*Oryctolagus cuniculus*)), agricultural animals and birds also helped, by providing an abundance of suitable prey. Australasian harriers also occur on offshore islands around New Zealand (Heather & Robertson 2000), consuming petrels on islands where these seabirds breed (Oliver 1955).

Like many islands off the New Zealand coast, Motunau Island has dense seabird colonies (Cox *et al*. 1967). Australasian harriers are commonly seen foraging over Motunau Island and flying

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between the island and the mainland (Cox *et al.* 1967; CNC unpubl. data). Stead (1932) reported finding a harrier nest containing eggs on Motunau Island, but there are no recent reports of breeding. In this paper we report observations of seabird debris, some showing signs of harrier damage, in and near an Australasian harrier nest on the island. We obtained ^{13}C and ^{15}N isotope data from a selection of nest debris plus potential prey items from the adjacent mainland. The results allowed us to test the hypothesis that the presence of seabird debris reflected nutritional significance to harrier during defined times of the year.

STUDY AREA AND METHODS

Motunau Island (43° 08′S, 173° 10′E) is a 3.4 ha island lying 1 km off the North Canterbury coast. A detailed ecological survey of the island was undertaken in 1958-64 (Cox *et al.* 1967). However, vegetation has since changed considerably, and as of 2004 is dominated by extensive thickets of mallow (*Malva parviflora*). The island supports large breeding colonies of fairy prion (*Pachyptila turtur*), blue penguin (*Eudyptula minor albosignata*) and white-faced storm petrel (*Pelagodroma marina*). Smaller breeding colonies of red-billed gull (*Larus novaehollandiae*), black-backed gull (*L. dominicanus*), and sooty shearwater (*Puffinus griseus*) are also present.

JMC found an Australasian harrier nest on 14 November 2003 amongst active petrel and penguin burrows on the island's plateau. The nest was revisited by JMC and CNC on 9-12 December 2003, and material for analysis was collected from the nest and immediate vicinity on 26 January 2004. A blue penguin femur, a prion (most likely fairy prion) humerus and a rock pigeon (*Columba livia*) humerus were selected from this material for isotopic analysis, along with a harrier eggshell membrane, a harrier primary feather, a small tuft of wool (probably from a lamb's tail given the abundance of lambing rings in the nest), and a goldfinch (*Carduelis carduelis*) feather from the harrier nest. A harrier secondary feather found on the plateau at the other end of the island was also analysed. The nest site was visited again on 4 February 2005, and was found to have been unused in the 2004-2005 breeding season.

Material submitted for isotopic analysis from the nearby mainland was a rabbit forefoot claw and a yellowhammer (*Emberiza citronella*) primary feather, both from road kills. Potential harrier diet not analysed included brush-tailed possum (*Trichosurus vulpecula*) and European hedgehog (*Erinaceus europaeus occidentalis*). Given that the primary aim of our study was to evaluate incorporation of seabird prey, such a simplification is unimportant.

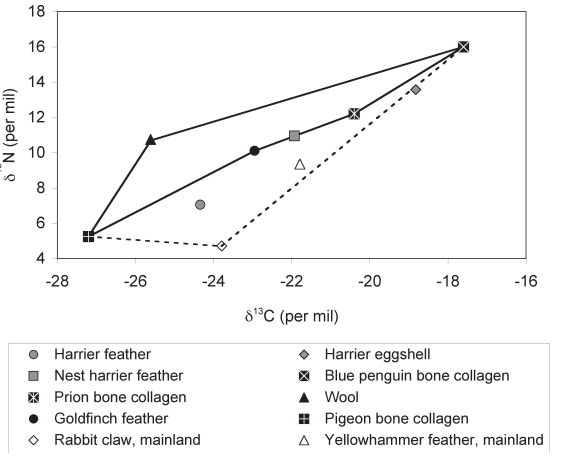

Figure 1 Diet polygons for Australaian harrier material from Motunau Island. The isotopic signatures of potential diet items are plotted as raw data except that the collagen $\delta^{13}C$ results were decreased by 2.0‰. The isotopic signatures of harrier items were adjusted for diet-tissue fractionation prior to plotting.

Isotopic analysis

Each item was analysed in duplicate, with sub-sampling to ensure representativeness. Prior to analysis, feathers and wool were washed in 2:1 chloroform: methanol to remove surface contamination. Eggshell membrane was sub-sampled by breaking off pieces with no visible adhering soil. Claw material was sub-sampled by paring with a scalpel. Bone samples were cleaned of adhering tissue, followed by grinding to a clean surface using an engraver's grinder. Bone collagen was extracted using the following procedure. Bone sub-samples were demineralised in 0.5M HCl until demineralization was complete, then washed with distilled water to remove the acid. After gelatinization at 70 °C at pH 3 for 24 hours, undissolved material was discarded and the solution freeze dried to yield collagen for analysis. Analysis for carbon-13 and nitrogen-15 was carried out by IsoTrace New Zealand Ltd, Dunedin, using isotope ratio mass spectrometry (IRMS). The notation ($\delta^{13}C$ and $\delta^{15}N$) refers to enrichment or depletion relative to a standard, with units of parts per thousand (per mil; ‰):

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

R_{sample} is the ratio of the heavy to the light isotope in the sample and $R_{standard}$ is the corresponding ratio for the standard (the international limestone standard VPDB for $\delta^{13}C$; atmospheric N_2 for $\delta^{15}N$). Thus, negative values indicate depletion relative to the standard and positive values indicate enrichment. Results were calibrated during the analytical run

by replicated analyses of NBS-22 and ANU sucrose ($\delta^{13}C$), and N-1 ($\delta^{15}N$) standards. The standard error of repeated analyses of standards was 0.1‰ ($\delta^{13}C$) and 0.2‰ ($\delta^{15}N$).

Dietary modelling

The contributions to harrier diet were determined qualitatively by constructing a diet polygon from the isotope results. To allow direct comparison between harrier material and potential diet items, fractionation factors must be included. This is because the isotopic signature of an animal will show an offset (or fractionation) relative to its diet. In addition, the tissue available for isotopic analysis (in our study, feather, bone collagen, wool, or claw material) within a given diet species may be isotopically different from the tissue consumed by (in our case) a harrier.

Dealing with the fractionation between harrier feathers and diet first, we used the $\delta^{13}C$ fractionation of +2.1‰ obtained by Hobson & Clark (1992) for peregrine falcons (*Falco peregrinus*) consuming Japanese quail (*Coturnix japonica*). A $\delta^{15}N$ fractionation of +3.09‰ was based on the meta-analysis of Vanderklift & Ponsard (2003). This value is close to the +2.7‰ for falcons consuming quail determined by Hobson & Clark (1992). For harrier eggshell membrane, we used ostrich (*Struthio camelus*) eggshell fractionation results of +1.5‰ ($\delta^{13}C$) and +3.0‰ ($\delta^{15}N$) determined by Johnson *et al.* (1998).

We now consider the differences between the tissue contributing to harrier nutrition (likely to be mostly muscle) and the tissue available for isotopic analysis. Hobson & Clark (1992) found an insignificant difference between feathers and muscle of American crows (*Corvus brachyrhynchus*) fed on fish for both $\delta^{13}C$ and $\delta^{15}N$. For bone collagen, $\delta^{15}N$ was not significantly different from muscle, but $\delta^{13}C$ was 2.0‰ enriched relative to muscle. Consistent with these experimental results, our fairy prion collagen result for $\delta^{13}C$ (-18.4‰) was 2.3‰ higher than the mean ± SE of -20.7 ± 0.4‰ for breast muscle of fledgling and adult fairy prions on Stephens Island reported by Cree *et al.* (1999). We consequently chose to apply the experimental result obtained by Hobson & Clark (1992).

We could find no data relating to wool or mammalian claw material. However, Bearhop *et al.* (2003) found no significant difference between avian claw material and feathers from the same individual. Macko *et al.* (1999) successfully reconstructed ancient diet using stable isotope analysis of human and animal hair. Therefore, we assumed that the isotopic signatures of feathers, wool, and claw material gave reliable estimates of muscle isotopic enrichment.

The diet polygon was constructed by plotting the raw isotope data for the diet items represented by feather, wool, or claw material. The isotopic results for collagen material were corrected by subtracting 2.0‰ from the measured $\delta^{13}C$, with no change to the measured $\delta^{15}N$. The harrier data were then plotted, after subtracting the diet tissue fractionation factors listed above.

Isotopic signatures of tissue such as feathers and eggshell membrane reflect diet at the time of tissue formation (Hobson 1999). Australasian harriers probably undergo a post-breeding moult, so that feathers would have regrown in autumn. Given that most lambing in Canterbury occurs during late winter and spring, lamb's tails were probably not a significant dietary component at the time of feather regrowth. Lamb's tails were, therefore, excluded from the model for harrier feathers.

RESULTS

The Australasian harrier nest was within an area dominated by mallow, *c.*10 m west of an area with remnant indigenous shrub land. Dry mallow stems, leaves and branches formed the majority of the nest construction material, with cabbage tree (*Cordyline australis*) leaves and introduced grasses making up the remainder. On the initial visit, a prion wing lay nearby, with a lamb's tail and rubber ring in the nest itself. The nest held one live chick, one moribund chick, one dead chick and an egg. When the nest was revisited on 9-12 December, only one chick and the egg remained. On 26 January 2004, JMC found numerous prion pectoral, sternum, clavicle and caracoid bones. Many, especially the sternum bones, bore puncture holes consistent with harrier damage. A juvenile blue penguin skeleton and skin was also found *c.*5 m east of the nest, hanging in a mallow bush. The skin had been turned inside out; the broken ribs and damage to other bones suggested that it too had been gathered by a harrier.

Plotted as diet polygons (Fig. 1), the potential diet items encompassed the harrier data so long as items collected from the adjacent mainland (but not found at the nest) were included. The harrier feather found away from the nest, the harrier feather from the nest, and the harrier eggshell, were progressively more enriched in both isotopes, implying increasing marine influence. The location of the eggshell data near the blue penguin datum point and beyond the other potential diet items implies that blue penguins made a major contribution to nutrition of the parent female harrier when egg material was forming. The location of the eggshell datum point outside the portion of the polygon enclosed by the wool datum point implies that lamb's tails may not have been a significant food source during egg development. Superficially, the location of the eggshell datum point outside the polygon made up

only of items collected from the nest implies that additional prey species from the adjacent mainland were also significant. However, it would only take a small inaccuracy in the blue penguin and fairy prion isotopic signatures, or the eggshell fractionation factors, for the eggshell datum point to lie between the blue penguin and fairy prion data. Thus, it is not possible to exclude the possibility that nutrition during egg formation was entirely from seabirds.

For the more enriched of the two harrier feathers, seabird prey (either blue penguin or fairy prion) was important during feather formation, but isotopic enrichment of the second harrier feather was sufficiently small for neither seabird species to be necessarily significant. Estimation of the significance of fairy prions is not possible for any of the harrier material, because polygons would still contain the harrier data if the prion datum point was deleted. The same is true for most of the other potential diet items.

DISCUSSION

Our observations verified consumption and assimilation of seabirds, especially blue penguins, during spring by Australasian harriers breeding on Motunau Island. Notwithstanding the apparent abundance of prion remains, consumption of fairy prion during egg or feather formation may not have been significant, given that a zero contribution to nutrition was a feasible solution to the diet model.

Our modelling provided evidence relating to harrier consumption of marine material that would have required many hours of fieldwork using traditional observation techniques. Furthermore, small prey items such as passerines may easily have been missed by such techniques. Our results are consistent with other stable isotope studies showing the consumption of seabird material by a range of terrestrial animals (tuatara *Sphenodon punctatus*, Cree *et al.* 1999; Keen's mice (*Peromyscus keeni*), Drever *et al*. 2000; northern saw-whet owls (*Aegolius acadicus*), Hobson & Sealy 1991). Transfer of marine nutrients to terrestrial birds other than birds of prey has been demonstrated at The Snares (Hawke & Newman 2005) and at a Westland petrel (*Procellaria westlandica*) colony on the South Island West Coast (Hawke & Holdaway 2005).

Important limitations to the stable isotope modelling as applied in our study include the inability to distinguish between consumption of live prey and of carrion; potential incompleteness of the model (in other words, the accidental omission of significant prey items); the accuracy of the isotopic signatures of the potential diet items; and the assumption that each diet item contributes proportionately to C (or N) assimilation. Because we analysed discarded harrier feathers and eggshell, it is also impossible to say whether or not we were determining the diet of the same individual harrier. Traditional observational techniques play an important role in ensuring the completeness of the model, and provide the only way of determining the relative importance of live prey as opposed to carrion. For predators such as harriers, assumptions relating to prey-dependent contributions to C (or N) assimilation are probably valid since harriers will be primarily consuming flesh regardless of the prey species. It is with omnivorous species such as (in a New Zealand context) weka (*Gallirallus australis*) that such assumptions are probably invalid (Koch & Phillips 2002; Phillips & Koch 2002; Hawke & Holdaway 2005).

The stable isotope method that we used has the advantage that it is entirely non-invasive, in that only discarded items are removed. However, sample size is often limited. Questions relating to the accuracy of the isotopic signatures of potential diet items essentially come down to the validity of small sample sizes and tissue choice. Although no measurements of variance for prey items were obtained, literature results indicate that both seabirds and terrestrial animals show a variability within biomes that is small in relation to the spread of data in our study (eg, Cree *et al.* 1999; Hobson 1999; Hawke & Holdaway 2005).

In conclusion, the application of stable isotope methods verified the significance of seabird prey, particularly blue penguins, to harriers breeding on Motunau Island. Terrestrial birds of prey living in the vicinity of seabird breeding colonies can, therefore, assimilate and then disperse marine nutrients to the wider terrestrial environment.

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