Marine Protein Contributions to the Diet of Northern Saw-whet Owls on the Queen Charlotte Islands: A Stable-Isotope Approach

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Stable-isotope analysis has been used increasingly to determine the relative contributions of protein derived from marine and terrestrial ecosystems to the diets of a wide variety of species, including birds (reviewed by DeNiro 1987; Peterson and Fry 1987, Mizutani et al. 1990). Using stable-carbon isotope analysis of bone collagen, Hobson (1986) determined that Glaucous-winged Gulls (*Larus glaucescens*) depended on garbage dumps for food. Recently, Mizutani et al. (1990) analyzed feathers isotopically and delineated contributions of freshwater and marine protein to the diets of cormorants (see also Hobson 1990).

During studies of the Northern Saw-whet Owl (*Aegolius acadicus*) on the Queen Charlotte Islands (QCI), British Columbia, we examined the stomachs of several road-killed owls. The stomachs contained intertidal invertebrates, which implied that some dietary protein was derived from the marine environment. Before our investigation, almost nothing was known of the diet of saw-whet owls on these islands (but see Patch 1922). Subsequently we identified the prey taken by 12 saw-whet owls on the QCI, and we used stable-isotope analysis to ascertain marine and terrestrial protein contributions to the diets of this species. An advantage of this technique is that it provides relatively long-term dietary information, even from specimens with empty stomachs.

The stable isotopes of carbon, ^{13}C and ^{12}C, react at different rates in various biogeochemical reactions. As a result, the ratio $^{13}C/^{12}C$, which reflects the relative abundance of the heavier isotope, differs among various carbon reservoirs. This ratio is typically expressed in δ notation as parts per thousand (‰) deviation from the Pee Dee Belemnite limestone National Bureau of Standards isotope reference material (Craig 1953) as follows:

$$\delta^{13}C = [(R_{sample}/R_{standard}) - 1] \times 1000,$$

where R is the ratio $^{13}C/^{12}C$.

In terrestrial systems, atmospheric carbon dioxide enters the food chain with a $\delta^{13}C$ value close to -7‰. Plants fractionate or change this ratio according to three major photosynthetic pathways (C-3, C-4, and CAM). Higher trophic-level consumers show tissue $\delta^{13}C$ values that reflect the isotopic composition of their diet (DeNiro and Epstein 1978). Isotopic segregation of consumers according to their dependence on various plant-based proteins is thus possible. For example, estimates of the $\delta^{13}C$ values for bone collagen are -20 to -21.4‰ for C-3 consumers and -7‰ for C-4 consumers (van der Merwe 1982, Schoeninger and DeNiro 1984).

Carbon typically enters marine food chains as dissolved carbonates, with $\delta^{13}C$ values close to 0‰ (Craig 1953). Primary carbon fractionation occurs during photosynthesis in phytoplankton according to a C-3 pathway and the 7‰ difference between atmospheric and marine carbon reservoirs is maintained at this trophic level. Consumers of purely marine-based protein have tissue $\delta^{13}C$ values approximately 7‰ heavier than consumers that feed exclusively on terrestrial C-3 plant-based proteins (e.g. Chisholm et al. 1982). Consumers that take both terrestrial C-3 and marine-based proteins typically have $\delta^{13}C$ values intermediate between consumers that feed exclusively on either of these sources. In practice, relative C-3 terrestrial and marine protein contributions to bird diets can be approximated when the isotopic values of individuals known to have fed exclusively in each of these reservoirs has been established (e.g. Hobson 1986). In addition, the isotopic measurement of tissues with fast and slow turnover rates of carbon may yield both short- and long-term dietary information (Tieszen et al. 1983).

Between October and February, 1977–1986, 18 road-killed adult Northern Saw-whet Owls and one juvenile were recovered from QCI (all but one from Graham Island). All but two of the birds were found dead along 45 km of the coastal highway between Queen Charlotte City and Tlell. Here, the highway parallels the southwest coast of Graham Island and is often <100 m from the upper beach. One saw-whet owl (Univ. Manitoba Museum Zoology [UMZM] 1101) was killed on a road near Sandspit, along the shore of Skidegate Inlet. A second individual (Queen Charlotte Islands Museum [QCIM] 172) was salvaged near Pure Lake Park, <1 km from Masset Inlet. Two individuals (QCIM B-60, B-190) were presumably mainland birds (*acadicus* vs. *brooksii*; see frontispiece, Brooks and Swarth 1925).

Pectoral muscle tissue was removed for $\delta^{13}C$ analysis ($n = 14$). Coracoids from nine island and both mainland type specimens were removed for isotopic analysis of bone collagen. To estimate an isotopic endpoint value for owls that feed exclusively in a C-3 terrestrial biome, we measured $\delta^{13}C$ values for pectoral muscle tissues of six Northern Saw-whet Owls and four Boreal Owls (*A. funereus*) salvaged from mainland British Columbia (Bulkley Valley, Terrace, Mount Lehman, and Vanderhoof) and a single saw-

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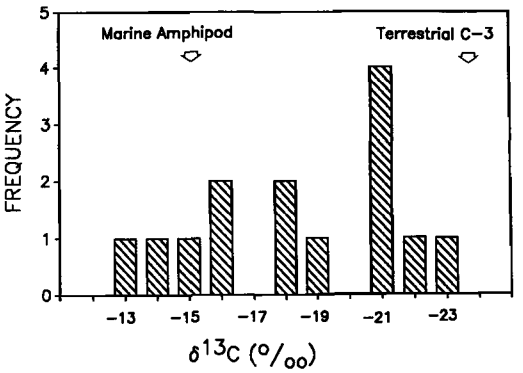

Fig. 1. Stable-carbon isotope values for muscle tissue of Northern Saw-whet Owls from the Queen Charlotte Islands.

whet owl from near Oakland, Manitoba. Muscle from three shrews (*Sorex obscurus*) and four deer mice (*Peromyscus maniculatus*) from Graham Island were measured isotopically to confirm a terrestrial C-3 plant-based food chain in the study area. One shrew was removed from the stomach of an island owl, the remainder were salvaged by the QCIM near Queen Charlotte City. We trapped deer mice along the upper beach at 3 locations south of Tlell during October 1986. The marine end-point that represents owls that feed exclusively on amphipods was calculated from measurements of $\delta^{13}C$ values of amphipods removed from the stomachs of two saw-whets and from two amphipod samples collected near Tlell during October 1986.

Muscle tissue was freeze-dried and powdered, and lipids were removed with chloroform as a solvent in a soxhlet apparatus. To extract bone collagen as a gelatin, we used the method of Longin (1971) as modified by Chisholm et al. (1983). The collagen was freeze-dried, and lipids removed before isotopic analysis. We treated amphipod samples with 0.1N HCl to remove carbonates, then rinsed briefly in distilled water, dried them, and removed lipids. All samples were loaded into Vycor tubes with 1 g of wire form CuO, evacuated, sealed, and heated to 850°C for 4 h, and then cooled slowly. The resultant CO_2 was analyzed in a dual inlet mass spectrometer (VG Micromass 903) at the University of Waterloo. Overall measurement precision was estimated as ±0.2‰ (SD).

Diet.—One adult female had ingested 156 individuals of the beach amphipod *Orchestia traskiana* Stimpson (Crustacea: Talitridae) and a single seaweed fly, *Coelopa* sp. (Diptera: Coelopidae). Stomachs of seven additional specimens contained quantities or fragments of *Orchestia* or *Orchestoidea californiana* (Brandt). One specimen had ingested 14 individuals of *Coelopa* sp. and several of the high intertidal isopod *Ligia pallisii* (Brandt). One juvenile spider, either *Anyphaena aptera* (Banks) or *A. pacifica* (Banks), was removed from the stomach of another bird. One owl had eaten a dusky shrew and the stomach of another, a mainland type, contained a few hairs. Seven birds (including one mainland type) had empty stomachs.

Isotopic analyses.—Stable-carbon isotope values for amphipods (n = 4 samples) averaged (±SD) −15.7 ± 0.8‰, and those of shrews (n = 3) and deer mice (n = 4) averaged −23.8 ± 1.0‰ (Table 1). Applying an assumed +1‰ fractionation value between consumer muscle tissue and dietary protein (DeNiro and Epstein 1978, Tieszen et al. 1983) to these values, the marine and terrestrial end-point values for owl muscle tissue are −14.7 ± 0.8‰ and −22.8 ± 1.0‰, respectively. Muscle $\delta^{13}C$ values for Northern Saw-whet and Boreal owls from mainland locations averaged −22.8 ± 1.4‰, which confirms the calculated terrestrial C-3 end-point value. Assuming a diet-to-collagen fractionation factor of + 4.5‰, marine and terrestrial end points for owl collagen are −11.2 and −19.3‰, respectively.

Saw-whets from Graham Island had a much broader range of $\delta^{13}C$ values than those obtained from the mainland (Fig. 1). The muscle $\delta^{13}C$ values of a few individuals were more positive than the assumed marine end point. Isotopic end points used in our dietary model are only approximations, and it is important to realize that they are based on *average* isotopic values for potential prey and *assumed* fractionation factors. It is possible that the diet-to-tissue fractionation factor of +1‰ is too small for owls that feed on marine-based protein. Alternatively, prey other than amphipods with higher $\delta^{13}C$ values may have been present in the diets of some individuals.

Most QCI individuals had some marine proteins in their diets ($\bar{x}$ ± SD: 47 ± 37%, range: <0% to >100%).

TABLE 1. Stable-carbon isotope values for muscle tissue of owls and prey species.

Sample	Location[a]	n[b]	Mean $\delta^{13}C$ (‰)	Range (‰)
Northern Saw-whet Owls	QCI	14	−18.9 ± 3.3	−13.6 to −23.7
Northern Saw-whet and Boreal owls	Mainland	10	−22.8 ± 1.4	−21.3 to −24.7
Amphipods	QCI	4	−15.7 ± 0.8	−14.6 to −16.4
Shrews and deermice	QCI	7	−23.8 ± 1.0	−22.2 to −24.9

[a] QCI = Queen Charlotte Islands, British Columbia; Mainland = mainland British Columbia and Manitoba (see text).
[b] Each amphipod sample consisted of 7–10 individuals.

The two mainland type individuals showed muscle $\delta^{13}C$ values of -22.7 and $-21.9‰$, which indicates little marine protein in their diets. One juvenile, found on 25 October 1980, had a muscle $\delta^{13}C$ value of $-18.2‰$, which implies a marine protein contribution in the diet of approximately 50%. Single adult females collected on 12 October and 10 November, 1983, had muscle $\delta^{13}C$ values more positive than the assumed marine end point, and so they were classed as having diets that comprised marine protein exclusively. Stable carbon isotope values for both collagen from these individuals averaged $-18.2 \pm 0.2‰$. This indicates a long-term marine dietary contribution of ca. 13%. Collagen $\delta^{13}C$ values for the remaining island sample averaged $-19.3 \pm 1.5‰$ ($n = 7$). This represents little, if any, long-term marine contribution to their diets. The two mainland type individuals had collagen $\delta^{13}C$ values that averaged $-20.8 \pm 0.7‰$, which confirms an exclusively terrestrial diet.

Marine invertebrates contributed substantially to the diet of nonbreeding Northern Saw-whet Owls from the Queen Charlotte Islands. Elsewhere in the species' range invertebrates were taken only in trace amounts, and small mammals comprised approximately 97% of the total prey items (review in Mueller 1986). The dietary plasticity of this population has probably contributed to its success in this archipelago, and the species is the only resident owl on the QCI (Godfry 1986).

Capturing prey on beaches exposed intertidally is not surprising, as other terrestrial birds in the Pacific northwest also forage there (e.g. Guiguet 1949, Sealy 1974, Egger 1979). The "sand-hoppers" (*Orchestia* and *Orchestoidea*) are numerous and widely distributed amphipods on beaches of the Pacific northwest (Kozloff 1974). Active at night, they feed on vegetation at or near the high-tide line on exposed sandy beaches. *Ligia pallasii* normally lives in the splash zone and tends also to become active at night (P. Lambert in litt., 9 January 1980). The seaweed flies occur on decaying seaweed on beaches (R. A. Cannings in litt., 23 January 1980). The shrew and deer mouse inhabit the upper beaches, but they also occur inland (Foster 1965).

Stable-carbon isotope analysis of tissues allowed us to extend the information on diet gained from the few stomachs examined, whether or not they contained prey when the birds were killed. Isotopic measurement of muscle tissue presumably provided dietary information based on periods of at least several weeks before death (Tieszen et al. 1983), but precise turnover rates for birds are lacking. Tieszen et al. (1983) determined that the half-life for carbon in gerbil muscle tissue is 27.6 days. Isotopic turnover rates are related to metabolic activity (Tieszen et al. 1983), and the half-life of carbon in pectoral muscle tissues of flying birds may be substantially less than that for gerbil tissue. A reasonable estimate is that our muscle $\delta^{13}C$ values provided time-integrated estimates of the diet based on periods of several weeks before death.

Due to the slow turnover rate of carbon in bone collagen, isotope values yield information that may approach the lifetime of the individual (Stenhouse and Baxter 1979). Alternatively, Mizutani et al. (1986) suggested that collagen isotope values may primarily reflect diet during the chick and juvenile stages, when bones grow rapidly. If collagen values represent lifetime dietary averages, then our measurements indicated that although individuals may forage almost exclusively on beach amphipods for several days or weeks, this protein source probably contributes a maximum of 10–15% of the yearly dietary intake. Presumably individuals move away from the coasts during the breeding season and forage on terrestrial protein. This conclusion is supported by the almost total absence of owls salvaged between March and September. The owls that forage intertidally on amphipods were either opportunistic or perhaps even depended upon this food source at times during the nonbreeding season.

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