Consumption of Shrews, *Sorex* spp., by Arctic Grayling, *Thymallus arcticus*

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In an investigation of the dietary habits of Arctic Grayling (*Thymallus arcticus*) we found that two individuals out of 93 sampled in southwestern Alaska (approximately 59°N, 159°W) contained a total of five shrews (*Sorex* spp.). These shrews contained enriched levels of nitrogen stable isotopes, suggesting utilization of nutrients derived from salmon. We hypothesize that normally terrestrial shrews accidentally enter streams while foraging along the productive riparian zones of creeks with high densities of salmon. Shrews are apparently susceptible to opportunistic predation by resident stream fishes, including Arctic Grayling, when they enter the streams.

Key Words: Arctic Grayling, *Thymallus arcticus*, diet, salmon-derived nutrients, shrews, *Sorex* spp., stable isotopes.

The Arctic Grayling (*Thymallus arcticus*) is a common nearctic freshwater fish in lakes and streams at high latitudes (Nelson 1994). Grayling typically feed on a variety of aquatic and terrestrial invertebrates in the water column or air-water interface (Armstrong 1986). In addition, Arctic Grayling occasionally supplement their diets with salmon eggs and small fish (Armstrong 1986). Despite existing knowledge of Arctic Grayling biology and its regional importance, the ecology and behavior of this species remain not well understood, including the extent to which Arctic Grayling exploit terrestrial sources of prey (Armstrong 1986).

As part of an extensive study of the aquatic and associated terrestrial ecosystem and its relationship to salmon in southwestern Alaska (Schindler et al. 2003), we had the opportunity to investigate dietary habits of Arctic Grayling. We discovered evidence of apparently rare consumption by Arctic Grayling of small terrestrial mammals of the Order Insectivora, shrews of the genus *Sorex*.

During summer 2001 we sampled resident fishes in five streams that flow into Lake Nerka in the Wood River-Tichick State Park, Dillingham County, southwestern Alaska (approximately 59°36'N, 159°05'W), by conventional and fly angling. The study streams support large runs of sockeye salmon (*Oncorhynchus nerka*). Captured fish were anesthetized, marked with subcutaneous tags, weighed, measured, and released. We obtained diet samples by back-flushing the stomach with a gastric lavage. Diet samples were preserved in ethanol and transported back to the University of Washington for analysis.

We sampled the stomach contents of 93 Arctic Grayling from five tributaries of Lake Nerka. Two of the 93 Arctic Grayling contained visible evidence of the body parts of shrews (Fig. 1, Table 1). One Arctic Grayling (length 394 mm, mass 591 g), captured on August 13 in the Little Togiak River contained the remains of three shrews. A second Arctic Grayling (length 391 mm, mass 522 g), captured on August 25 in Elva Creek contained the remains of two shrews.

Table 1. Characteristics of shrews removed from the stomachs of two Arctic Grayling.

Sorex spp.	$\delta^{15}N^1$	Location	Body dimensions[2]	Specimen number
S. cinereus[3]	4.73	Elva Creek	96-38-11 mm	UWBM 74151
S. monticolus[3]	5.21	Elva Creek	indeterminable	UWBM 74152
S. monticolus[4]	6.33	Little Togiak River	indeterminable	UWBM 74153
S. cinereus[3]	7.42	Little Togiak River	88-38-12 mm	UWBM 74154
S. cinereus[4]	5.70	Little Togiak River	indeterminable	UWBM 74155

[1]$\delta^{15}N$ is the stable isotope of nitrogen and can be used to trace salmon-derived nutrients.
[2]Dimensions are total length, tail length, and hind foot length, in mm.
[3]Identified both by dentition and cytochrome-*b* analyses.
[4]Identified by only cytochrome-*b* analyses because of missing/digested dentition.

Nothing else about the two observed Arctic Grayling was unusual other than their stomach contents. Although the fish were relatively large, they were not extreme, being longer than about 70% of the other Arctic Grayling. In addition to the shrews, the diets of these two fish contained aquatic and terrestrial insects typical of the diets of the other Arctic Graylings sampled at this same time and location.

The five alcohol-preserved shrews (*Sorex* spp.) from the diet samples of two Arctic Grayling were deposited in the Burke Museum mammal collection. Three shrews (UWBM 74151, 74152, 74154) were sufficiently intact that we could examine individual teeth in the skull, which is critical for species identification. We used the keys of Nagorsen (1996), based on body and skull measurements and dental characteristics, particularly the relative length of the third unicuspid. In two cases digestion had progressed too far to allow species determination by these characters. We subsequently referred tissue samples of all five specimens to Eric Waltari, Idaho State University, for molecular (cytochrome-*b*) identification, according to protocols used in his systematic investigation of *Sorex*, as developed by Demboski and Cook (2001). Molecular identification confirmed the three initial morphological identifications and provided definitive identification for the two previously unidentifiable individuals (UWBM 74153, 74155)

The two shrews from Elva Creek were identified as *Sorex monticolus* and *Sorex cinereus* (Fig. 1, upper). The *S. cinereus* specimen had a wet weight of 3.3g and was fairly intact except for digestion of the fur away from the skin. Due to more extensive digestion, the *S. monticolus* specimen could not be measured and weighed accurately, but its intact skull and dentition allowed a positive identification (Table 1).

The three shrews from the Little Togiak River (Fig. 1, lower) included a highly intact *S. cinereus* with considerable fur still attached to its skin (Fig. 1, lower, center). The other two shrews were extensively digested and could only be identified by molecular analysis, as *S. cinereus* (left) and *S. monticolus* (right). In summary, the two Arctic Graylings from two different streams both had fed on shrews of two species (Table 1).

The presence of the shrews *Sorex monticolus* and *Sorex cinereus* in this region of southwest Alaska lying to the north of Bristol Bay and east of the Kilbuck Mountains is consistent with the known geographic ranges of shrews (Hall 1981) and a more recent distributional analysis (S. O. MacDonald and J. A. Cook, *personal communication*). Shrew abundance and diversity are high in this area, and three other species are also present: *S. hoyi*, *S. tundrensis*, and *S. yukonicus*.

Although some species of the genus *Sorex* live and feed primarily in water (Beneski and Stinson 1987), none of the five *Sorex* species in the study area is primarily aquatic. Howevr, all five occur to some extent in riparian habitat, where their success is enhanced by the aquatic component of the food chain. As a result of this habitat association, the shrews are potentially accessible to predatory fishes in these waters. The tendency for shrews of the genus *Sorex* to enter water, whether for foraging or dispersal, has been reviewed by Hanski (1986). In addition to intentional entry into the water, it is also possible that these shrews occasionally enter the water accidentally, resulting from their normal activities near the water's edge.

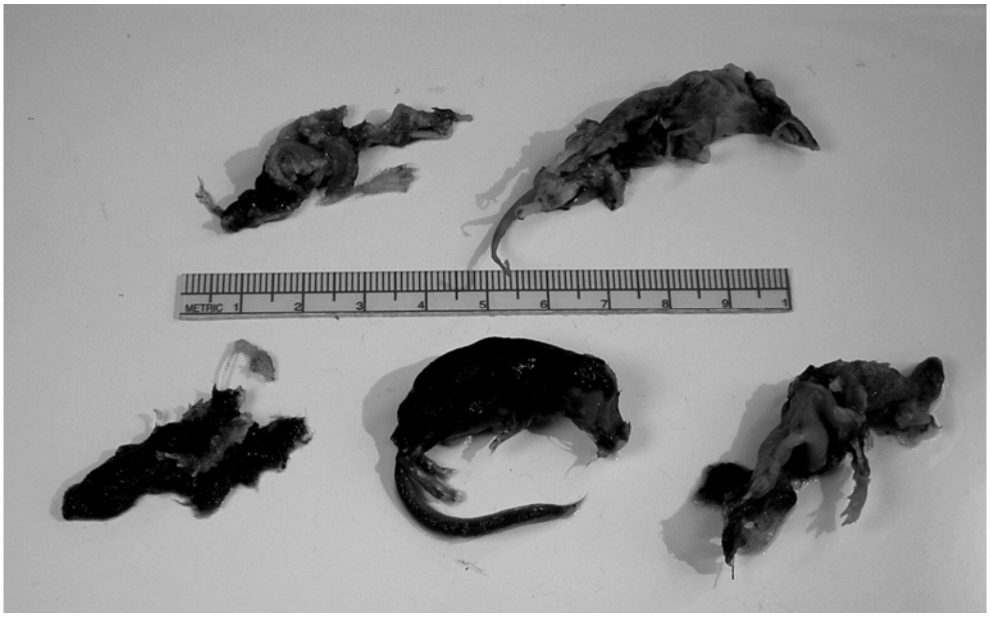

Fig. 1. Shrews removed from the stomachs of two Arctic Grayling, in various stages of digestion. Upper: Shrews from a 522 g Arctic Grayling sampled at Elva Creek (59°34'N, 159°05'W)—*S. monticolus* (UWBM 74152) left and *Sorex cinereus* (UWBM 74151) right. Lower: Shrews from a 591 g Arctic Grayling at Little Togiak River (59°36'N, 159°04'W)—*Sorex cinereus* (UWBM 74155) left, *S. cinereus* (UWBM 74154) center, and *Sorex monticolus* (UWBM 74153) right.

Shrews may be attracted to the riparian zones of these creeks because of the potential foraging opportunities offered by abundant salmon carcasses. Cederholm et al. (1989) list shrews, including *Sorex cinereus*, as known scavengers of salmon carcasses. Evidence from stable isotopes (^{15}N) from our study (Table 1) and Ben-David et al. (1998) show that shrews (*Sorex* spp.) living near streams containing anadromous salmon runs bear the enriched isotopic signature of feeding directly or indirectly on salmon, for example, on insects that feed on salmon carcasses. We analyzed the stable isotope signature of muscle tissue from each shrew. Because anadromous salmon have a relatively high isotopic signature ($\delta^{15}N$ = 11-13) compared to most other potential food sources, isotopes have been used to trace salmon nutrients through both aquatic and terrestrial food webs (Kline et al. 1990; Ben-David et al. 1998). The abundance of ^{15}N in shrew muscle tissue was measured by combusting several mg of ground muscle tissue from each shrew in a mass spectrometer by the Stable Isotope Lab at the University of California, Davis. Stable isotopes were expressed as a delta (δ) value--the deviation from an isotope standard (atmospheric nitrogen). In other words,

$$\delta^{15}N=[(^{15}N_{sample}/^{14}N_{sample})/(^{15}N_{atmosphere}/^{14}N_{atmosphere}) - 1] \times 1000.$$

We used a two-sample t-test to compare $\delta^{15}N$ of shrews in diets of Arctic Grayling to published values of isotopes from six shrews that were collected more than 500 m from streams with salmon in southeastern Alaska by Ben-David et al. (1998). The five shrews we collected from Arctic Grayling diets were relatively enriched, averaging 5.88 $\pm$ 0.47 $\delta^{15}N$ (mean $\pm$ standard error; Table 1), higher than shrews collected from sites over 500 m from Alaskan salmon-bearing streams, that averaged 4.5 $\pm$ 0.3 $\delta^{15}N$ ($t_{2,9}$ = 2.24, P < 0.10) (Ben-David et al. 1998). This relative enrichment suggests that the shrews we found in the Arctic Grayling diets may have been feeding directly on salmon carcasses or indirectly, for example, by feeding on insects that had been feeding on salmon carcasses. The high productivity of these riparian zones, especially along streams with high densities of salmon, probably contributes positively to the success and survival of shrews, the tiniest of mammals, in this extreme northern environment.

The skewed distribution of the number of shrews contained per Arctic Grayling is evidence that consumption of shrews is not a random event. We assessed whether Arctic Grayling consumption of shrews was random by comparing the observed frequency distribution of the number of shrews in Arctic Grayling stomachs to the expected distribution, assuming predation to be random. We calculated expected frequency distributions using the Poisson function in Matlab 5.313, assuming an average number of shrews per Arctic Grayling of 0.054 (5 shrews in 93 Arctic Grayling). We encountered fish with either two or three shrews in their stomachs, but no fish with only one shrew. Based on a random expectation for Arctic Grayling consumption, there was a 0.12 probability of sampling an Arctic Grayling with two shrews and only a 0.003 probability for three shrews. Thus we conclude that Arctic Grayling consumption is not random, and we speculate that this is due to individual differences in either the effectiveness or motivation of individual Arctic Grayling as shrew predators or scavengers. It may also be due to differences in the probability of shrews entering the feeding sites of specific Arctic Grayling.

Although Arctic Grayling are typically considered to be specialists on aquatic and terrestrial insects (Armstrong 1986), our observation indicates that some Arctic Grayling are opportunistic feeders, capable of consuming small mammals. Shrews, typically 4 - 8 g (Nagorsen 1996), represent a meal for Arctic Graylings that provides a large amount of energy compared to that of typical individual invertebrate food items. Consumption by Arctic Grayling of small mammals, including shrews, has been reported by several previous authors. Alt (1978*) reported an unspecified small number of shrews in diets of Arctic Grayling in the Fox River of western Alaska. De Bruyn and McCart (1974*) found that seven out of 136 Arctic Grayling contained a single shrew in the Firth River, Yukon, Canada. A European study of the grayling *Thymallus thymallus* indicated a 10% incidence of small mammals in the diet, particularly the shrew *Sorex araneus*, and the capture of these fish at night by bait angling suggested their ability as nocturnal hunters of semiaquatic prey such as shrews (Teplov 1943). Miller (1946) reported that one out of 102 Arctic Grayling at Great Bear Lake, Canada, contained juvenile lemmings (rodent) of an unspecified species in the diet. Reed (1964*) also found juvenile lemmings in two Arctic Grayling out of 1,300 individuals sampled in the Tanana River drainage, Alaska.

Terrestrial food sources often subsidize the diets of freshwater fish, and these food sources can include small mammals (for example, Brown Trout, Cochran and Cochran 1999; and Largemouth Bass, Hodgson and Kinsella 1995). Although Arctic Grayling are traditionally considered insectivores, our report demonstrates that they also opportunistically consume shrews that venture into freshwaters.

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