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Comparing the diet of cod (*Gadus morhua*) and grey seals (*Halichoerus grypus*): an investigation of secondary ingestion

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Otoliths from the stomachs of 138 by-caught grey seals (*Halichoerus grypus*) from the west coast of Ireland were compared with otoliths from the stomachs of 364 commercially caught cod (*Gadus morhua*) to determine if there were any overlaps in type, number and size of prey that might be attributable to secondary ingestion. A total of 19 species/groups were common to both cod and seal stomachs accounting for 99.6% and 95.8% of the otoliths from cod and seal stomachs respectively. There were significant differences between the otolith/fish lengths of all six species/groups compared but there were overlaps in the size distributions. Analysis of the diet composition of the cod stomachs suggested that larger cod consumed mainly fish and smaller cod consumed mainly crustaceans. Cod and seals were utilizing the same fish prey but the seals were generally consuming larger fish. Overlaps between the size distributions of prey species/groups suggest that secondary ingestion was possible and should be considered in future seal diet studies.

Traditionally, seal diet has been inferred from the recovery of fish otoliths from digestive tracts or scats. Numerous studies have investigated the associated biases with otolith recovery methods (e.g. Harvey, 1989; Pierce & Boyle; 1991). One of these biases is the theory of secondary ingestion (Pierce & Boyle, 1991). This is the possibility that otoliths recovered from seal stomachs may have come from the digestive tracts of fish prey, thus biasing the results. The aim of this study was to compare the fish prey of the cod, a predatory fish on which seals were known to feed, with that of the grey seal to determine any possible overlaps in prey species and size.

The stomachs of 364 cod were sampled between 1997 and 1999 from the Irish ports of Dunmore East, Porturlin, Howth and Killybegs. The stomachs of 138 by-caught grey seals were also collected during the same period from ports in County Mayo on the west coast of Ireland. Otoliths were measured to the nearest 0.01 mm using a micrometer and identified using a reference collection and otolith guide (Harkönen, 1986). Otoliths of related species, too similar to distinguish were grouped together. These were the genus *Trisopterus* from the cod family Gadidae, the sandeel family (Ammodytidae), the gurnard family (Triglidae) and the sole family (Soleidae). Although seal stomachs are more acidic than cod stomachs, no corrections were made to otolith measurements to account for digestion. Cod stomachs contained large numbers of whole sandeels and the comparison between cod and seal stomachs for sandeels was for fish length and not otolith length. Lengths of sandeels consumed from seal stomachs were determined from otoliths using regressions obtained from Harkönen (1986).

A total of 36 species/groups were identified from the two sample types. There were 19 species/groups that were common to both sample types. These were: brill (*Scophthalmus rhombus* L.), cod (*Gadus morhua* L.), dab (*Limanda limanda* L.), dragonet (*Callionymus lyra* L.), goby (*Gobiidae* sp.), gurnard (*Triglidae* sp.), haddock (*Melanogrammus aeglefinus* L.), herring (*Clupea harengus* L.), norwegian topknot (*Phrynorhombus norvegicus* Günther), plaice (*Pleuronectes platessa* L.), pollock (*Pollachius pollachius* L.), sandeel (*Ammodytidae* sp.), saithe (*Pollachius virens* L.), sole (*Soleidae* sp.), topknot (*Zeugopterus punctatus* Bloch), *Trisopterus* sp., turbot (*Scophthalmus maximus* L.), whiting (*Merlangius merlangus* L.) and witch (*Glyptocephalus cynoglossus* L.). These species/groups made up 99.6% (N=1666) and 95.8% (N=2813) of the otoliths from the cod and seal stomachs respectively. There was no significant difference in the ranks of these species/groups between the two sample types as determined by the number of otoliths (Wilcoxon signed rank test P=0.79) suggesting that the prey species/groups utilized by the seals and the cod were very similar in type and relative importance.

Sandeel otoliths were among the most numerous otoliths found in the seal stomachs. In this study, 83% (N=163) of the sandeel otoliths found within the seal stomach samples came from two samples. These samples did not contain any other otoliths but they did contain the bones of larger fish. One sample contained 107 sandeel otoliths and the bones of a lumpsucker (*Cyclopterus lumpus* L.) and the other sample contained 56 sandeel otoliths and the bones of a pollock. This may indicate secondary ingestion as both pollock and lumpsucker are known to prey on small fish (Wheeler, 1978). While processing the seal stomachs for this study it was common to find fish stomachs among the seal stomach contents even though the rest of the fish flesh had been digested. For obvious reasons, stomachs are resistant to digestion and may provide increased protection for their secondarily ingested contents.

McConnell et al. (1984) estimated that the weight of fish estimated from otoliths in seal scats was roughly equal to the energy content of the scats suggesting that secondary ingestion was not taking place. These calculations did not take into account contributions from other prey groups such as cephalopods or the fact that errors caused by the otoliths of secondarily ingested fish might be masked by larger prey from which otoliths were not ingested. Undigested fish in the stomachs of gadids would also contribute to the energy requirements of the seal (Pierce & Boyle, 1991).

The otolith/fish lengths of the top six species/groups common to both stomach types differed from the normal distribution were compared using non-parametric Mann–Whitney U-tests. The

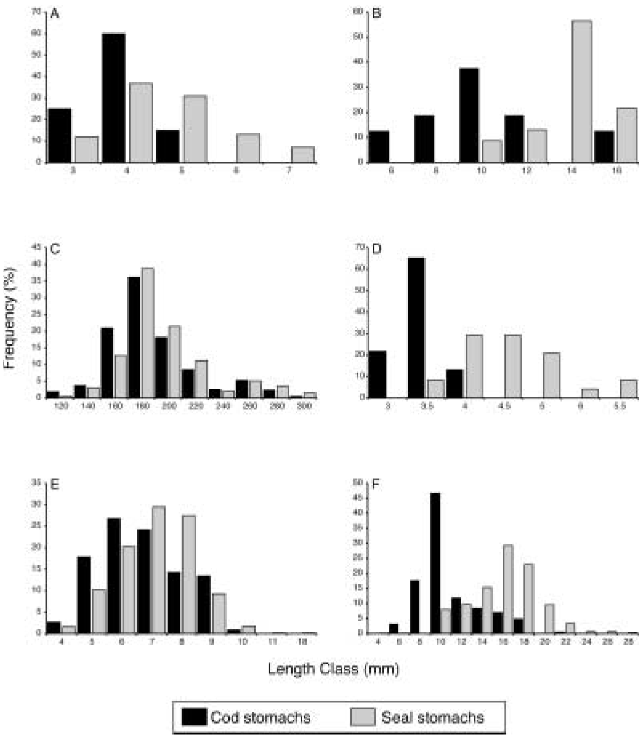

Figure 1. The length–frequencies of (A) brill otoliths; (B) pollock otoliths; (C) whole sandeels; (D) sole otoliths; (E) *Trisopterus* sp. otoliths; and (F) whiting otoliths as a percentage of the total, recovered from the stomachs of grey seals and cod.

results suggest that there were significant differences between the otolith/fish lengths of all species/groups compared (brill $Z=-3.02$, $P=0.003$; pollock $Z=-3.66$, $P=0.0003$; sandeels $Z=-2.93$, $P=0.003$; sole $Z=-5.13$, $P<0.0001$; *Trisopterus* sp. $Z=-2.82$, $P=0.005$; whiting $Z=-17.26$, $P\leqslant0.0001$). The length–frequency distributions show that there are overlaps in all of the six species/groups (Figure 1). With the exception of sandeels, the modal lengths of prey from seal stomachs were larger. Seals are capable of eating larger fish than cod and any overlap due to secondary ingestion would take place at the lower end of the seal otolith size distribution. Quantification of overlap would be very difficult because it would never be clear which particular otoliths were secondarily ingested. While processing the cod stomachs it was noted that a great deal of cod prey was intact and could easily be secondarily ingested in an intact state.

The levels of crustaceans in cod diet are related to fish size. Cod from Killybegs were the smallest with a mean length of 35 cm (N=57; SD 2.29 cm) and 75% of these samples contained crustaceans. The cod from Porturlin were the largest with a mean length of 80 cm (N=44; SD 7.26 cm) and only 9% of these samples contained crustaceans. Using cod otoliths recovered from the seal stomachs (Harkönen, 1986), the mean length of cod ingested by seals was 26.2 cm (SD 5.99 cm). If high levels of secondary ingestion of cod of this size were taking place, appropriate amounts of crustacean material should be found in seal stomachs. Although actual numbers of seal stomachs containing crustacean remains were not recorded in this study, the occurrences were infrequent. It is possible that the seals were feeding on larger cod but discarding the heads and otoliths as has been reported for harbour seals feeding on salmon (Olesiuk, 1990). It is also worth noting that gadid diets vary seasonally and crustaceans may not always be present (Pierce & Boyle, 1991).

Seals and cod are utilizing the same prey species but those ingested by the cod tend to be smaller. There are size overlaps between the two sample types but if secondary ingestion is taking place, it is difficult to prove. There is however sufficient evidence to suggest that secondary ingestion should be considered as a factor when investigating seal diet.

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