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Diet of minke whales *Balaenoptera acutorostrata* in Scottish (UK) waters with notes on strandings of this species in Scotland 1992–2002

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During 1992–2002 approximately 110 strandings of minke whales *Balaenoptera acutorostrata* were recorded in Scotland (UK). Most strandings were recorded between April and November, with a peak of strandings of males in July and August. There were two length modes at 4–6 m and 7–10 m. Stomach contents samples were obtained from ten animals. The diet comprised mainly sandeels (Ammodytidae, around two-thirds of the diet by number or weight) and clupeids (herring *Clupea harengus* and sprat *Sprattus sprattus*). Results on diet are consistent with results from whaling catches in the North Sea. The possibility that minke whales compete with fisheries is discussed.

INTRODUCTION

Minke whales *Balaenoptera acutorostrata*, the smallest and most abundant of the rorquals are widely distributed in the North Atlantic (Stewart & Leatherwood, 1985). Surveys off the north and west of Scotland indicate that this species is found almost exclusively on the continental shelf (Northridge et al., 1995; Weir et al., 2001; Hammond et al., 2002). In the UK and Ireland, minke whale is the most commonly recorded mysticete amongst stranded cetaceans (Berrow & Rogan, 1997). The regular presence of minke whales off the west coast of Scotland supports a local whale-watching industry.

Although the diet in the southern hemisphere is apparently composed entirely of euphausiids (krill), in the northern hemisphere minke whales eat both small shoaling fish and krill (Larsen & Kapel, 1983; Bushuev, 1986; Tamura & Fujise, 2002).

Minke whales are hunted commercially off Norway, while Iceland carried out some 'scientific' whaling in 2003 with the stated aim of investigating fish consumption by minke whales. This new focus on possible interactions between minke whales and fisheries makes it increasingly important that recent data on minke whale diets are brought into the public domain. There are no previous studies of minke whale diet in Scottish waters although some data exist for the North Sea, Norwegian Sea and Barents Sea (e.g. Olsen & Holst, 2001; Haug et al., 2002).

In the present study, stomach contents of minke whales stranded in Scotland (UK) during 1992–2002 were analysed to determine whether minke whales prey on commercially important fish species. In addition, the relatively large number of strandings of this species affords the opportunity to use strandings data to make inferences about distribution patterns.

MATERIALS AND METHODS

During 1992–2002, 78 confirmed minke whale strandings were recorded in Scotland. There were also 32 probable minke whale strandings, where the species identity was not positively confirmed. Given the extreme rarity of confirmed strandings of any other rorqual in Scotland (one humpback whale *Megaptera novaengliae* in 2001, one unconfirmed stranding of fin whale *Balaenoptera physalus* in the Western Isles in 1999 and four records of unidentified mysticetes since 1992), these animals may also reasonably be assumed to be minke whales. The majority of the animals were decomposed when found, although several fresh (e.g. entangled) animals and live strandings were also recorded. A brief description and analysis of the pattern of strandings (year, month, location) and of the physical characteristics of the animals (length distribution, sex ratio) is provided here. Strandings locations were mapped using ArcView®, to reveal any geographical pattern in month of stranding, body length or sex.

Necropsies were carried out on 23 animals and samples of stomach contents were obtained from ten of these—the majority of which were mortalities related to entanglement (Table 1). In most cases these samples were not the complete stomach contents.

All prey remains recovered were from fish. The otoliths and bones were identified using reference material and published guides (Härkönen, 1986; Watt et al., 1997). Fish were enumerated by counting otoliths and other paired bones, notably jaw bones, using the bone (or otoliths) that yielded the higher number. When large numbers of otoliths were present, a random sub-sample of at least 30 was measured (length or width). Length distributions of the main prey were calculated.

Prey weights were initially estimated by applying standard regressions (based on various sources as summarized by Brown & Pierce, 1998). Since fish were also identified using bones, which sometimes indicated higher numbers of fish than did otoliths, estimated total weights for each taxon in each stomach were adjusted using raising factors, equal to the number of individual fish of a given taxon present in the sample divided by the number detected from otoliths.

Table 1. *Minke whales from which stomach samples were obtained.*

Code	Date	Place	Latitude (°N)	Longitude (°E)	Sex	Length (cm)	Weight (kg)	Cause of death
M2239/92	27/09/92	Culbin Sands	57.64	−3.75	Female	450	—	Entanglement
M2895/92	23/12/92	Kerrera	56.39	−5.52	Female	443	—	Entanglement
M1333/95	18/07/95	Peterhead	57.52	−1.79	Male	585	—	Not established
M1723/95	31/08/95	Whiteness Point	57.60	−3.99	Male	363	—	Entanglement
M1606/97	15/07/97	Leven Wick, Shetland	59.98	−1.26	Female	460	—	Live stranding
M2193/97	20/09/97	Fearnmore Loch	57.58	−5.80	Female	753	—	Entanglement
M0053/00	20/03/00	Scarfskerry	58.65	−3.26	Female	770	5000	Entanglement
M0070/00	30/04/00	Scarfskerry	58.65	−3.26	Female	—	—	Entanglement
M0005/02	09/01/02	Sannox Bay, Isle of Arran	55.69	−5.17	Female	505	—	Entanglement
M0086/02	19/06/02	Off Dunbar	56.01	−2.51	Female	755	4320	Entanglement

Dietary importance of each prey taxon was expressed as frequency (F, the number of stomachs in which it occurred), number of individuals summed across all stomachs (N), estimated weight of all individuals from otolith measurements summed across all stomachs (W) and corrected weight (WC, accounting for individuals represented by bones). These indices were also expressed as percentages, %F expressing the percentage of stomachs in which a prey taxon occurs while %N, %W and %WC are based on sums of prey importance across all taxa. Lastly, since prey remains in several stomachs represented only part of the contents, the contribution of each stomach to the dietary importance figures was standardized by expressing the importance (by number or weight) of each taxon as a proportion of the total for all taxa in that stomach. This allows derivation of the new values $\%N_s$, $\%W_s$ and $\%WC_s$, where the subscript s denotes that data were standardized.

Although sample size was small, and statistical power hence very limited, standardized data for numerical importance were examined for evidence of dietary variation in relation to sex, season ('summer' [April–September] versus 'winter' [October–March]) and body length, using Kruskal–Wallis tests and Spearman's correlations.

RESULTS

Fewest strandings were recorded in months between December and March and the highest number was recorded in July. Strandings of animals positively identified as female minke whales were fairly evenly distributed through the year whereas almost all confirmed males stranded between July and November (Figure 1). Note that sex was confirmed (as male) for only two of the 32 strandings suspected to be minke whales. Strandings occurred all around the Scottish coast (Figure 2), with no obvious geographical pattern in relation to sex, size-class or season.

The two smallest animals were stillborn calves and there were two length modes at 4–6 m and 7–10 m. There was no obvious sex-related difference in size, both sexes being represented in both size modes. Weights were available for only four animals: two animals (one female, one of unknown sex) of around 1.8 tn, and two females weighing approximately 4 tn and 5 tn respectively. The two stillborn calves were recorded in November (250 cm in length) and January (approximately 280 cm). Otherwise, there was no obvious monthly pattern in the size distribution.

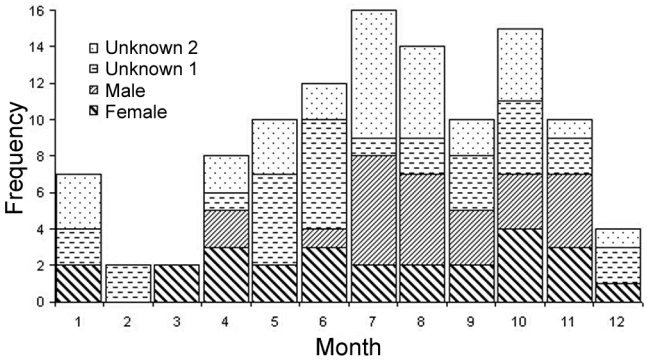

Figure 1. Seasonal distribution of minke whale strandings 1992–2002. Data are plotted separately for females (N=26), males (N=24), unknown sex ('unknown 1', N=30) and animals of unknown sex for which species identification was not positively confirmed ('unknown 2', N=29).

Numbers of prey recorded in the stomach samples ranged from 1 to almost 19 000. Six taxa of fish were identified: sandeels (Ammodytidae), herring (*Clupea harengus*), sprat

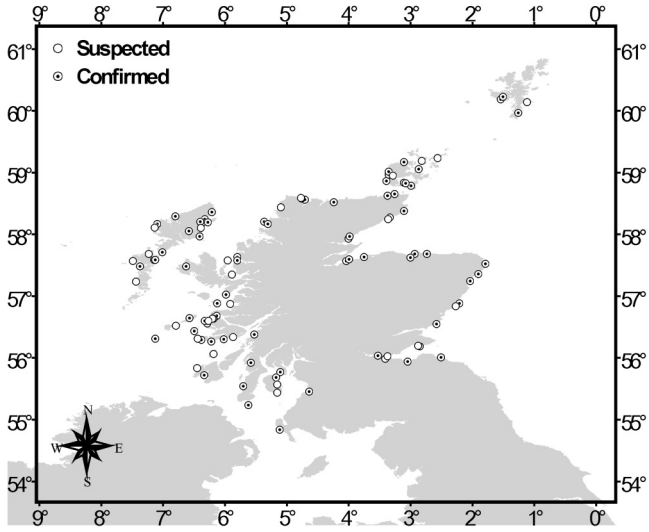

Figure 2. Locations of probable and confirmed minke whale strandings (and entanglements) 1992–2002.

Table 2. *Summary of diet composition. Indices of importance for each prey taxon are as follows: F=frequency of occurrence, N=minimum number of individual prey recovered from the set of stomachs, W=reconstructed weight based on otoliths only. The indices are also expressed as percentages. Since the samples from several of the stomachs were incomplete it may be more appropriate to standardize the contribution of each stomach, which is achieved by initially expressing prey weights and numbers in each stomach as proportions of the all-taxon totals for the stomach. Overall standardized % values (indicated by the subscript s) are then based on the summed proportions (across all stomachs). Finally, weight calculations were revised to estimate the weight of fish identified and enumerated from bones and thereby derive corrected weights (WC).*

Prey taxon	F	%F	N	%N	$\%N_s$	W (g)	%W	$\%W_s$	WC (g)	%WC	$\%WC_s$
Sandeel	7	70	23 985	93.8	65.51	39 893.2	78.29	79.51	39 899.7	75.67	61.71
Clupeid*	2	20	25	0.10	20.00	0.0	0.00	0.00	186.9	0.35	20.00
Herring	2	20	4	0.02	0.04	266.5	0.52	1.66	603.5	1.14	1.34
Sprat	5	50	1512	5.91	13.04	10 432.7	20.47	13.57	11 306.1	21.44	11.02
Mackerel	1	10	44	0.17	1.32	350.1	0.69	5.08	716.5	1.36	5.83
Trisopterus	1	10	3	0.01	0.09	12.4	0.02	0.18	12.4	0.02	0.10
Gobiidae	1	10	1	0.00	0.00	0.1	0.00	0.00	0.1	0.00	0.00
SUM	—	—	25 574	100	100	50 955.0	100	100	52 725.3	100	100

*, This category comprises clupeid remains that could not be identified to species level. These fish are most likely to be herring or sprat. It was not possible to directly estimate the contribution by weight of this category. Since sprat were much more numerous than herring in stomachs, calculations of corrected weight assumed that these clupeids were sprat of the average weight found in minke whale stomachs in this study.

(*Sprattus sprattus*), mackerel (*Scomber scombrus*), Norway pout and/or poor cod (*Trisopterus* spp.) and gobies (Gobiidae).

Sandeels were the most important prey. Using the best available indices ($\%N_s$ and $\%WC_s$), sandeels are seen to have comprised around 66% of the diet by number and 62% by weight. Clupeids (herring and sprat) form the next most important category, accounting for 33% by number and 32% by weight of the diet. The estimated size of sandeels eaten ranged from 6 cm to 15 cm, and the majority of sprats were 10–13 cm in length. These are minimum estimates since digestive size reduction of otoliths was not taken into account.

The utility of statistical analysis was limited by small sample sizes and no differences in numerical importance of different prey were apparent between sexes or between winter and summer, nor was the importance of any prey taxon correlated with whale length. The median size of sandeels eaten was not correlated with minke whale length (N=6); none of the other prey taxa occurred sufficiently frequently to allow such a comparison to be made.

DISCUSSION

Strandings data suggest some seasonality in minke whale occurrence in Scotland, especially of males, with peak numbers of strandings recorded in summer and autumn. The very limited evidence available from (two) stillborn calves suggests that birth takes place around the end of the year.

It is notable that entanglement was the main diagnosed cause of death for those animals sampled for stomach contents. Usually no rope was seen when examining the animals but it is possible that creel lines or mooring ropes were involved. One animal had part of a net caught at the back of the mouth and had been unable to feed. Two animals that were not necropsied are known to have been struck by boats.

There are no previous published results on minke whale diet in Scottish waters but data from adjacent waters are in close agreement with those of the present study. Olsen & Holst (2001) examined stomach contents of 22 minke whales caught in the North Sea in 1999. Sandeels were seen in 19 of these stomachs and were estimated to have made up almost 87% of the diet by weight. Mackerel, whiting (*Merlangius merlangus*), herring, Norway pout (*Trisopterus esmarkii*) and haddock (*Melanogrammus aeglefinus*) were the other species recorded.

Haug et al. (1993) recorded krill, herring, capelin (*Mallotus villosus*) and sandeels as being the main prey of minke whales the Norwegian Sea in 1992. However, capelin dominated the diet at Spitzbergen and Bear Island, herring was most important off Finnmark and sandeels were important off Kola and Vesterålen. Haug et al. (1994) demonstrated seasonal variation in the diet, with krill common in the diet in northern areas in summer, while cod (*Gadus morhua*) were the most numerous component of the diet off Finnmark in autumn. Minke whales caught in 2000 in the Norwegian Sea had eaten herring (Olsen & Holst, 2001), a species that is also prominent in minke whale diet in the Barents Sea, at least in years of good herring recruitment (Haug et al., 2002; Lindstrøm et al., 2002). Haug et al. (2002) also point out minke whales had switched from feeding mostly on capelin to a diet of krill (*Thysanoessa* sp. and *Meganyctiphanes norvegica*) since the collapse of the Barents Sea capelin stock in 1993. Recent stable isotope data for the North Atlantic showed that minke whales fed at lower trophic levels than previously thought (Born et al., 2003).

Since minke whales are both large and relatively abundant, it is reasonable to conclude that they consume large amounts of fish. Sigurjónsson & Vikingsson (1998) estimated that minke whales consumed over one million tons of fish annually in Icelandic and adjacent waters. Although minke whales take mainly small fish, many of these species (e.g. capelin and herring in the Barents Sea, sandeels in the North Sea) are also targets of fisheries. There is, for example, the potential for competition between minke whales and the industrial fishery for sandeels in the North Sea, which targets the lesser sandeel

Ammodytes marinus. Tamura & Fujise (2002) argued that the presence of Pacific saury in minke whale diet [in the Pacific] demonstrated competition with the saury fishery.

However, an overlap between diet of a marine mammal and fishery catches does not mean that competition exists. The dynamics of a system need to be explored to establish whether there actually is any competition. Whether competition occurs depends on the nature and strength of both direct and indirect trophic links. Modelling studies on such systems reveal the possibility of opposite consequences if a single indirect link is changed (Punt & Butterworth, 1995). A recent simulation study using ECOSIM (Mackinson et al., 2003) pointed towards fishing having an adverse effect on minke whale populations, indeed more so than direct harvesting, although the models are sensitive to assumptions about the functional response.

In the North Sea, the industrial fishery for sandeels is the largest single species fishery in the world and competition with marine mammals and seabirds seems intuitively likely. However, Furness (2002) points out that, as fishery landings of sandeels increased, most seabirds and grey seals increased in number. In fact, these trends may be explained by depletion of larger predatory fish: Furness concluded that the 'overwhelming influence of predation on food-fish by predatory fish may be a feature of many marine food webs worldwide'.

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