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Occurrence of killer whales in Scottish inshore waters: temporal and spatial patterns relative to the distribution of declining harbour seal populations

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ABSTRACT

1. Sightings of killer whales around Shetland were recorded between 1991 and 2006 and for the whole of Scotland for 2007. The data were used to investigate temporal patterns in killer whale occurrence around Shetland and spatial patterns in occurrence around Scotland.
2. There was a strong seasonal peak in sightings around Shetland during June–July, coinciding with the harbour seal pupping season.
3. There was no clear trend in annual sightings around Shetland between 1991 and 2006.
4. Killer whales were sighted most frequently around Shetland and the Pentland Firth as well as around Mull and the Treshnish Isles.
5. These findings are discussed in terms of potential impacts upon local declining harbour seal populations and future research requirements.

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KEY WORDS: killer whale; *Orcinus orca*; Scotland; harbour seal; predation; top-down forcing

INTRODUCTION

The spatial and temporal occurrence of killer whales *Orcinus orca* in several geographic locations has been correlated with the presence of predictable and abundant prey resources (Nichol and Shackleton, 1996) and in particular with pinniped pupping seasons (Condy *et al*., 1978; Hoelzel, 1991; Baird and Dill, 1995; Keith *et al*., 2001). In the North-east Atlantic killer whale occurrence has so far only been correlated with the distribution of lipid-rich pelagic fish such as herring *Clupea harengus* and mackerel *Scomber scombrus* (Similä *et al*., 1996; Luque *et al*., 2006). However, there are reports of killer whales predating upon both grey seals *Halichoerus grypus* and harbour seals *Phoca vitulina* around Scotland (Fisher *et al*., 1999; Weir, 2002; Figure 1). Killer whale predation has been cited as a potential factor in the decline of several marine mammal populations (Guinet *et al*., 1992; Keith *et al*., 2001; Estes *et al*., 1998; Springer *et al*., 2003, 2008; but see DeMaster *et al*., 2006; Wade *et al*., 2007). Recent studies indicate that there have been significant declines of harbour seals around the UK over the last decade (Thompson *et al*., 2001; Lonergan *et al*., 2007). Work is now underway to investigate possible causes for these changes, and to identify appropriate conservation action. It is not currently known whether declines are the result of a single common factor, or multiple drivers. However, declines in the Northern Isles have been the most severe with an approximate decrease of 40% in Orkney and Shetland (Lonergan *et al*., 2007), suggesting that these exaggerated declines around the Northern Isles may result from an additional, localized cause (Lonergan *et al*., 2007).

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Figure 1. Predation of an estimated two-week old harbour seal pup by an adult male killer whale (ID number 014), South Nesting Bay, Shetland.

In this paper collated data on killer whale sightings in Scottish inshore waters from 2007 is presented to investigate the spatial occurrence of killer whales and data on sightings in Shetland waters collected from 1991–2006 to investigate seasonal occurrence in this area. Lastly these sightings are used to estimate the minimum and maximum potential number of Shetland harbour seal that sighted killer whales could consume annually.

METHODS

Spatial distribution

An existing sightings network set up by the Hebridean Whale and Dolphin Trust and the Shetland Biological Records Centre was built upon through a series of local seminars and was utilized to investigate the spatial distribution of killer whale sightings around Scotland during 2007. Sightings were plotted alongside the distribution of sightings contacts as an indicator of sightings effort using ArcView to see if killer whale sighting density correlated with areas of harbour seal decline (Figure 2).

Temporal distribution

The Shetland Biological Records Centre collected sightings of killer whales around Shetland from 1991–2006. If more than one sighting was reported for any day, then only one sighting was included to avoid duplication of sightings of the same group at different locations. To investigate any trend over time, the number of days killer whales were sighted was plotted for years 1990–2006. To investigate any correlation between killer whale presence and harbour seal decline, published Shetland harbour seal counts from Lonergan *et al.* (2007) were plotted on the same axis, as was the published total stock biomass of Shetland sandeels *Ammodytes marinus* from Frederiksen *et al.* (2007). Sandeels are an important component (51–60%) of Shetland harbour seal diet during pupping (Brown *et al.*, 2001).

When looking at seasonal trends in killer whale occurrence there is a potential bias in sighting probability due to the number of daylight hours, which ranged from 22.1 in June to 5.5 in December. To account for seasonal variability in the number of daylight hours, a sighting index was created by dividing the number of sightings per month (1991–2006) by the mean number of daylight hours for that month at latitude 60°N (http://encarta.msn.com/media_701500905/hours_of_daylight_by_latitude.html).

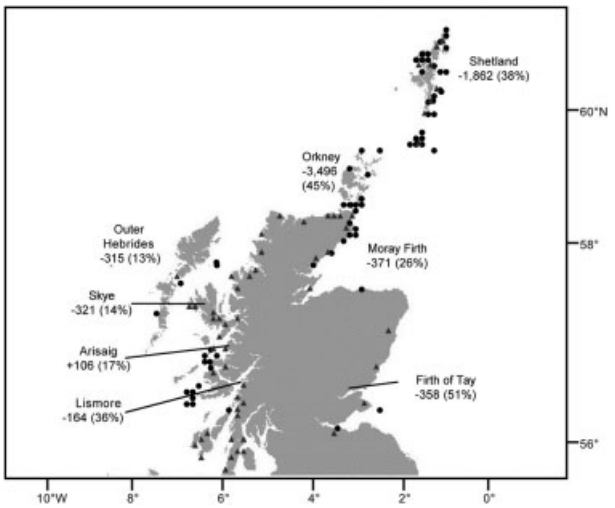

Figure 2. Distribution of killer whale sightings around Scotland in 2007 ($n = 74$; circles), sightings contacts are shown as triangles as a measure of effort distribution, changes in harbour seal counts from Lonergan *et al.* (2007) (– indicates a decline, + indicates an increase) between 2000 and 2006 for the Firth of Tay, 2002 and 2006 for the Moray Firth, 2001 and 2006 for Orkney and Shetland, 2000 and 2003 for the Outer Hebrides, and between 2000 and 2005 for Arisaig, Lismore and Skye.

Estimating potential killer whale predation levels on Shetland harbour seals

The number of harbour seals potentially consumed annually by killer whales will depend upon a number of factors, the most important being the composition of the diet of Shetland killer whales. As this is currently unknown, a value of 0 was assumed as the lower limit of number of harbour seals consumed based on a scenario where harbour seals do not form a part of the diet of Shetland killer whales. The scenario that would produce the maximum level of predation would be if the diet of killer whales sighted around Shetland comprised only harbour seal pups. Under this scenario the number of harbour seals consumed annually (n) could be estimated thus: Number of killer whale days (the sum of the group sizes for each sighting that year) multiplied by the published values of daily mass specific energy intake requirement ($55\,\mathrm{kcal\,kg^{-1}\,d^{-1}}$), average assimilation efficiency (85%) and body mass (2800 kg) of female/sub-adult male (Williams *et al.*, 2004). This gives the energy requirements of the killer whales that were sighted that year for the period they were sighted in Shetland waters. This is then divided by the calorific content ($2500\,\mathrm{kcal\,kg^{-1}}$; London, 2006) multiplied by the mean mass of seal pups (18.6 kg, based on unpublished data from a sample of 53 harbour seal pups that were weighed during a capture–release programme in the Moray Firth, Scotland between 1989 and 1995, see Thompson *et al.*, 1992 for protocol).

RESULTS

Spatial distribution

Killer whales were sighted around the entire coast of Scotland but most frequently around the north-east of Scotland and Shetland (Figure 2). Other areas with a high number of sightings contacts such as the north-west corner of Scotland reported relatively few sightings.

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Temporal distribution

Between 1991 and 2006 killer whale sightings were reported around Shetland on a total of 432 days. The sighting index (number of days killer whales sighted/daylight hours) showed a clear increase in killer whale presence in Shetland waters during the summer months (Figure 3). There was no significant trend in the number of days killer whales were seen per year between 1991 and 2006 ($r = 0.051$, $P = 0.852$; Figure 4) and no correlation with harbour seal counts ($r = 0.005$, $P = 0.497$; Figure 4), however, seal counts did correlate with the total Shetland sandeel biomass when considering data between 1993 and 2004 ($r = 0.998$, $P = 0.019$; Figure 4).

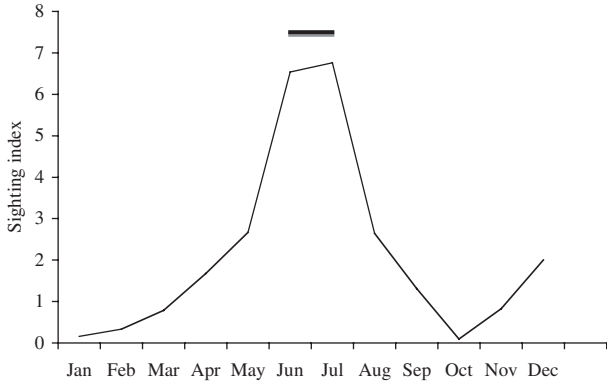

Figure 3. Monthly sighting index (number of days killer whales sighted around Shetland divided by the number of daylight hours) of killer whales for years 1991–2006 ($n = 409$). The harbour seal pupping season (Thompson, 1988) is indicated by the thick solid line.

Estimating potential killer whale predation levels on Shetland harbour seals

Our range of estimates for harbour seal consumption ranged from 0 (for all years) to a maximum annual estimate of 828 harbour seal pups for the year (2000) with the most killer whale sightings (57 days killer whales were sighted, 294 killer whale days) assuming that killer whale diet comprised 100% of harbour seal pups.

DISCUSSION

Killer whales were sighted at locations all around Scotland and as far south as the Firth of Forth during 2007. Sightings were concentrated around Mull and the Treshnish Islands on the west coast and the Northern Isles and north-east coast. Some of the variation in sighting density may have been an artefact of effort, for example there were lower numbers of sightings around Orkney than Shetland or Caithness, however, we had

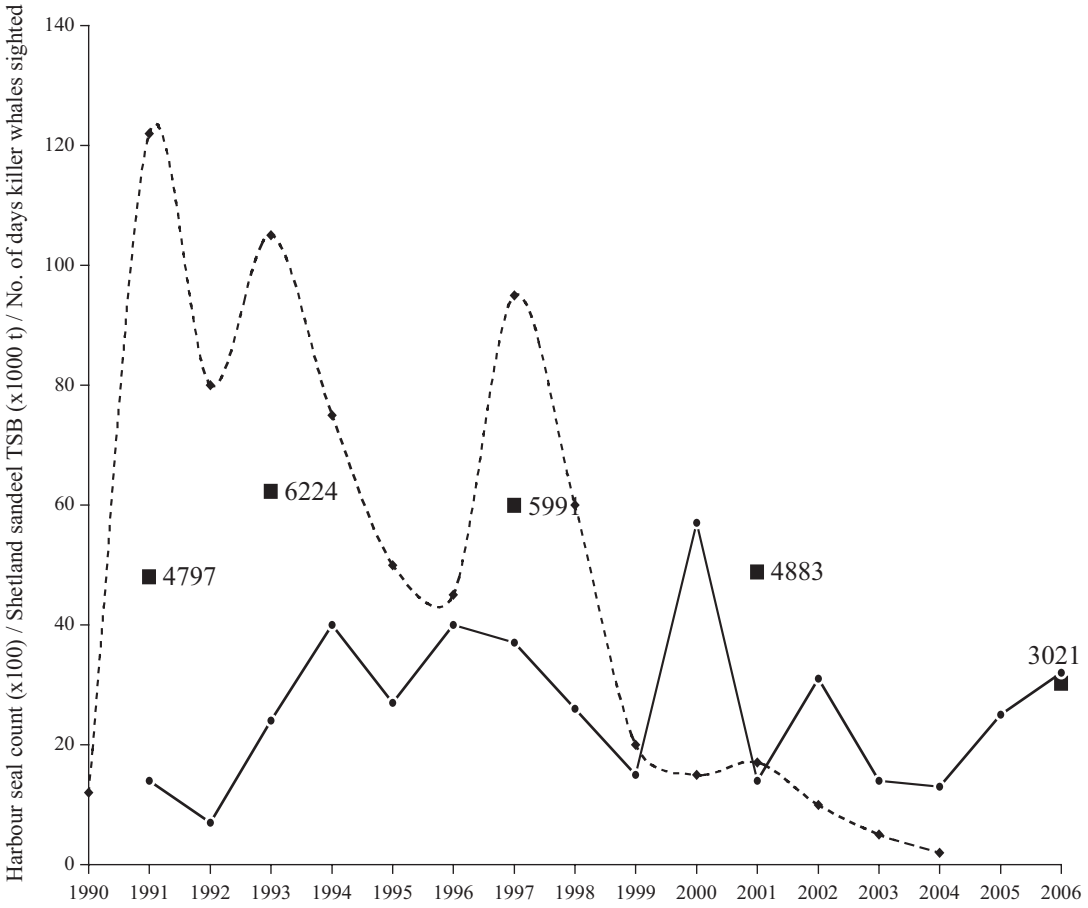

Figure 4. Time series of the number of days killer whale sighted around Shetland ●, Shetland sandeel total stock biomass ♦, (Frederiksen *et al.*, 2007) and harbour seal counts ■, (Lonergan *et al.*, 2007).

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no sightings contacts on Orkney (Figure 2). Several sightings of bottlenose dolphins *Tursiops truncatus* were received from sightings contacts from southern Caithness and Aberdeenshire (Ingram, unpublished data). The lack of reported killer whale sightings on the east coast south of Caithness therefore appears to reflect their relative absence from this area and is not simply due to unresponsive sightings contacts. Taking into account the variation in distribution of sightings contacts, there does appear to be overlap in the regions of greatest sighting frequency and the most drastic declines in harbour seal counts (Lonergan *et al*., 2007).

Sightings of killer whales around Shetland showed a strong peak and temporal overlap with harbour seal pupping season (Figure 3). Although corrected for the number of daylight hours, seasonal variation in sighting probability could also include sea state or visitor influx. There could therefore be a bias towards higher sighting probability during the summer months. However, the monthly peak in sightings is very short (June–July) and is more consistent with a correlation with harbour seal pupping than a seasonal bias in sightings conditions due to sea state. A seasonal peak in sightings of killer whales during the pupping season of pinnipeds has been noted at other locations (Condy *et al*., 1978; Hoelzel, 1991; Baird and Dill, 1995; Keith *et al*., 2001). There was also a small increase in sightings in December, which would coincide with the grey seal pupping season.

There was no increase in annual sightings over time during the period that sightings were collected, however, a previous study had found an increase in sightings during the late 1980s and early 1990s (Fisher *et al*., 1999). The lack of correlation between the temporal pattern of annual killer whale sightings and decline in harbour seal count numbers is not consistent with a causative recent increase in top-down forcing through increased predation by killer whales. Shetland harbour seal count numbers appeared to be better correlated with Shetland sandeel total stock biomass suggesting bottom up effects may potentially be a factor in Shetland harbour seal declines, however, this requires further indepth analyses. Declines in sandeels could increase predation rates by increasing foraging bouts (Frid *et al*., 2006).

Theoretical estimates of harbour seal consumption indicate that the relatively low numbers of killer whales in waters around Shetland have the potential to consume a large number of seals annually. This is dependent upon the composition of the whale's diet, which is currently unknown. Even if predation is not the principal driver of the recent harbour seal decline it could have an impact on the rate of any population recovery. To fully understand this impact a number of uncertainties and data gaps must be filled by dedicated research on killer whales around Shetland. Most important of these gaps is the diet composition of these killer whales; although predation on harbour seals around Shetland has been observed, grey seals, eider ducks *Somateria mollisima*, sea birds and mackerel are also occasionally taken in nearshore waters during the summer months (Fisher *et al*., 1999; Weir, 2002; Smith, 2006). Boat-based fieldwork around Shetland is currently underway and research methods include group follows with a towed hydrophone to detect predation events (Deecke *et al*., 2005), visual and molecular identification of prey species and age class of harbour seals, stable isotope and fatty acid analyses of tissue to better understand the diet (Herman *et al*., 2005), and photo-identification (Bigg, 1982) to identify which and how many individuals are targeting harbour seals. This information will be used to generate more robust estimates of harbour seal predation by killer whales and population viability projections of Shetland harbour seals incorporating killer whale predation as a factor.

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