Abundance of fin (*Balaenoptera physalus*) and sei whales (*B. borealis*) amid oil exploration and development off northwest Scotland

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ABSTRACT

A ship-based line transect survey was conducted during July-August 1998 to assess the distribution and abundance of cetaceans off northwest Scotland. Limited information from dedicated surveys exists for this area and the lack of baseline data is cause for concern given the expanding oil industry in these waters. Historical whaling records show that large numbers of baleen whales, particularly fin and sei whales, were captured in these waters during summer. The waters surveyed included former whaling grounds and currently licensed oil blocks to the west of the Outer Hebrides and the Faroe-Shetland Channel and both fin and sei whales were encountered. Neither species was recorded to the west of the Outer Hebrides whereas relatively high densities of both were recorded further north in the Faroe-Shetland Channel. The density of fin and sei whales was $0.021km^{-2}$ and $0.022km^{-2}$, respectively. Abundance was estimated as 933 (CV=0.38) fin whales, 1,011 (CV=0.35) sei whales and 1,923 (CV=0.33) 'large whales'. The high density of whales recorded in the Faroe-Shetland Channel supports the idea that it is an important summer feeding ground for both species and the potential for acoustic disturbance associated with increasing industrialisation of this area is a concern. Factors affecting the distribution and abundance of these whales are discussed.

KEYWORDS: FIN WHALE; SEI WHALE; ABUNDANCE ESTIMATE; ATLANTIC OCEAN; SURVEY-VESSEL; MOVEMENTS; DISTRIBUTION; WHALING-HISTORICAL

INTRODUCTION

The distribution of fin (*Balaenoptera physalus*) and sei whales (*B. borealis*) is cosmopolitan, they both occur almost worldwide, with populations in the Atlantic, Pacific and Southern Oceans (e.g. Rice, 1998). Both species may also be vagrant to the Indian Ocean (Rice, 1998). Most mysticetes are typically believed to undertake seasonal migrations between high latitude productive feeding grounds and low latitude breeding grounds. The predictable nature of some of these migrations has contributed to their exploitation. Commercial whaling began in the late 19th and 20th centuries and led to population declines of many of the great whales. Fin and sei whales were amongst those species that were heavily exploited and since the 1860s an estimated 79,000 fin whales and 16,000 sei whales have been taken globally (Sigurjónsson, 1995). The worldwide status of both species is currently listed as 'endangered' on the World Conservation Union (IUCN) Red List of Threatened Species (IUCN, 2004), primarily due to the decline in the Southern Hemisphere (Reeves *et al.*, 2003).

In the early 20th century, fin and sei whales were regularly caught in British waters. Between 1903-04, four whaling stations opened on the Shetland Islands and one in the Outer Hebrides. The Scottish whaling season extended from April to September and operations took part annually until whaling from these stations ended in 1929. The Hebridean whaling station completed a further two seasons in 1950 and 1951. Fin whales constituted the largest proportion of catches (Brown, 1976; Thompson, 1928) with 2,418 fin whales and 1,283 sei whales captured between 1908-14 and 2,164 fin and 439 sei whales captured between 1920-27 (Thompson, 1928). Whaling records suggest that these species were relatively abundant off northwest Scotland and it is considered likely that this area is still important for these species. Recent opportunistic sightings (e.g. Stone, 2003; Weir *et al.*, 2001), acoustic detections (Clark and Charif, 1998) and dedicated surveys (Buckland *et al.*, 1992; Macleod *et al.*, 2003; Sigurjónsson *et al.*, 1989) confirm that fin and sei whales still occur in these waters. Visual records of fin and sei whales off western Britain are largely restricted to the summer months (Macleod, 2001; Weir *et al.*, 2001), although fin whales have been recorded acoustically throughout the year in temperate North Atlantic waters (Clark and Charif, 1998).

During summer, the highest densities of large whales to the west of Great Britain occur further north in the Faroe-Shetland Channel (Pollock *et al.*, 2000). The productivity of the cold water Faroe-Shetland Channel is enhanced by eddies and meanders formed by strong currents and mixing of the relatively warm, saline continental slope current flowing northeast, and the deeper, cooler, less saline Nordic waters flowing south. The speed of the continental slope current also increases as it enters the Faroe-Shetland Channel (Hopkins, 1991), because of the restriction in flow and enhanced mixing over the Wyville-Thomson Ridge (Burrows *et al.*, 1999). Therefore, it is reasonable to assume that prey resources would be abundant during summer and provide a rich feeding area for fin and sei whales. Sei whale diet consists almost exclusively of copepods (Flinn *et al.*, 2002; Nemoto and Kawamura, 1977), especially *Calanus finmarchicus* in the North Atlantic (Ingebritsen, 1929), whereas fin whale diet includes euphausiids, copepods and fish (Nemoto, 1959; Sigurjónsson, 1995; Woodley and Gaskin, 1996).

The historical whaling grounds (and presumed feeding grounds) for fin and sei whales off northwest Scotland lie within licensed oil blocks and the area is undergoing rapid

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exploration and exploitation. Mysticetes produce loud, species-specific low frequency signals and are adapted for low-frequency hearing (Ketten, 1992). They are thought to be particularly susceptible to the powerful, predominantly low frequency seismic noise produced by airguns, typically with broadband source levels of 220-255dB re: 1μPa-m (Richardson *et al.*, 1995). Low frequency, underwater pulses from airguns are often audible many tens of kilometres away (Richardson *et al.*, 1995). Intense anthropogenic underwater sound may adversely affect the behaviour and hearing of marine mammals (Gordon *et al.*, 2003). It may also lead to their displacement from an area and mask communication and other sounds (Finneran *et al.*, 2000; Gordon *et al.*, 2003; Gordon and Moscrop, 1996; Richardson *et al.*, 1985; Richardson *et al.*, 1995). Short-term behavioural responses of cetaceans to anthropogenic noise include changes in dive-surfacing cycles (Richardson *et al.*, 1985), respiration rates (Richardson *et al.*, 1986) and swimming speeds and direction (Borggaard *et al.*, 1999). Short-term vocal responses have also been noted, such as changes in calling rates (Watkins *et al.*, 1985) or cessation of calls in response to unfamiliar or intense anthropogenic sounds (Finley *et al.*, 1990; Goold, 1996).

Summer abundance of fin and sei whales has been estimated within some areas of their eastern North Atlantic range (Fig. 1). Although survey strata have included waters to the west of the UK, survey effort was relatively low. Information on the abundance and seasonal distribution of cetaceans off northwest Scotland is limited but given the considerable interest in oil and gas exploration and development in the area, gaining baseline information is important. This paper presents an abundance estimate for fin and sei whales and a combined estimate of large whales off northwest Scotland. The data were collected during a dedicated survey conducted in summer 1998 (Macleod *et al.*, 2003). The distribution of both species was restricted to the Faroe-Shetland Channel, where relatively high densities were encountered. The importance of this information is discussed in the context of findings from previous surveys and implications for management of industrial activities off northwest Scotland.

METHODS

Survey methods

A line transect survey was conducted from 14 July-15 August 1998, in predominantly offshore waters (>200m) to the west of the Outer Hebrides (Stratum A) and in the Faroe-Shetland Channel (Stratum B) (Fig. 2). The survey strata were chosen to coincide with areas of historical whaling grounds and those currently licensed for oil exploration. The survey was conducted onboard the vessel M.V. *Neptun*, travelling at an average speed of 10 knots. The ship followed saw-tooth tracklines, designed from a random start point in an east-west direction to avoid paralleling depth contours. Surveying was conducted in Beaufort sea state 4 and below with good visibility. The survey was carried out in 'passing mode' meaning that the vessel did not approach sighted cetaceans.

Surveying was conducted using an Independent Observer (IO) method (Palka, 1995) involving two teams of observers on visually and acoustically separated platforms. The primary and secondary platforms were 5.7m and 8m above sea level, respectively. Three observers searched primarily with the naked eye on each platform, rotating around observation positions (port, centre, starboard and rest) every 30 minutes. Binoculars were used intermittently to search at distance and during sightings to aid species identification and school size estimation. Effort and environmental data were recorded every 30 minutes and when conditions changed. Radial distances (km) and angles to each sighting were measured using Fujinon 7×50 reticle binoculars and angle boards mounted on the ship's railings. Minimum, maximum and best estimates of school size were recorded. Automated recording of survey data was aided with the *Logger* software (IFAW 1994) run on a laptop connected to the ship's Global Positioning System (GPS) via an NMEA interface.

A two-day training period for observers to practise angle and distance estimation using the equipment and by eye was conducted before the survey. Estimates to surrounding vessels or headlands were taken and checked against the ships radar.

Abundance estimation

The conventional distance sampling estimator of animal abundance, $\hat{N}$, for line transects is (Buckland *et al.*, 2001):

$$\hat{N} = \frac{n_s \cdot \bar{s}}{2L\hat{\mu}} A = \frac{n \cdot \hat{f}(0) \cdot \bar{s}}{2L} A$$

with variance,

$$\hat{\text{var}}(\hat{N}) = \hat{N}^2 \left[\frac{\hat{\text{var}}(n_s)}{n_s^{\;2}} + \frac{\hat{\text{var}}(\hat{f}(0))}{\hat{f}(0)^2} + \frac{\hat{\text{var}}(\hat{\bar{s}})}{\hat{\bar{s}}^2} \right]$$

where, n_s = number of sightings (schools) after truncation; $\bar{s}$ = mean size of detected schools; L = length of transect surveyed (km); A = survey area (km²); $\hat{\mu} = 1/\hat{f}(0)$ (estimated effective strip half-width) where $\hat{f}(0)$ is the estimated probability density function of perpendicular distance evaluated at zero distance. This estimator assumes that all animals are detected on the survey trackline with certainty and there is no movement, random or responsive, to the survey vessel. The theory further assumes that measurements of sighting distances and angles in the field are accurate (Buckland *et al.*, 2001).

Double platform surveys enable data to be collected to estimate the probability of detecting animals on the trackline. However, small numbers of fin and sei whale sightings during this survey precluded a double platform analysis and the data were analysed using conventional distance sampling methods (Buckland *et al.*, 2001). Sightings of each species from the two observation platforms were combined and one of the duplicate pair was removed to form data sets of unique sightings. Definite and probable sightings of both species and across all sea states (Beaufort 0-4) were included in the analysis.

Estimating *f(0)*, *μ* and group size

Reticle binocular measurements taken in the field were converted to radial distances using the equation given in Lerczak and Hobbs (1998). Radial distances (r) and sighting angles (θ) were converted to perpendicular distances, x, using basic trigonometry (i.e. $x=r \times sin\theta$). Histograms of perpendicular distances to the detected whale schools, under various groupings, were used to assess the need for truncation to remove outliers and to detect any obvious rounding of measured distances.

The detection probability, $f(x)$, was modelled by pooling the perpendicular distance data for both fin and sei whale sightings. Considering the similarity in the detection cues of

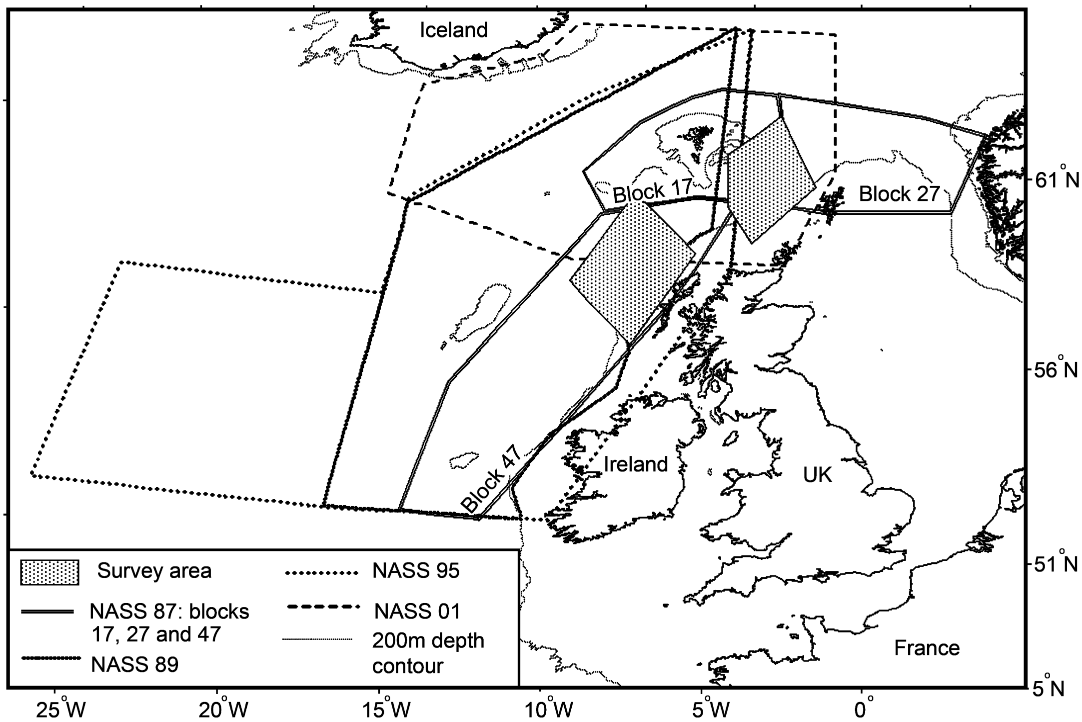

Fig. 1. Areas surveyed during the North Atlantic Sighting Surveys, 1987-2001 with coverage to the north and west of Scotland in relation to the position of the survey blocks for this study (survey area).

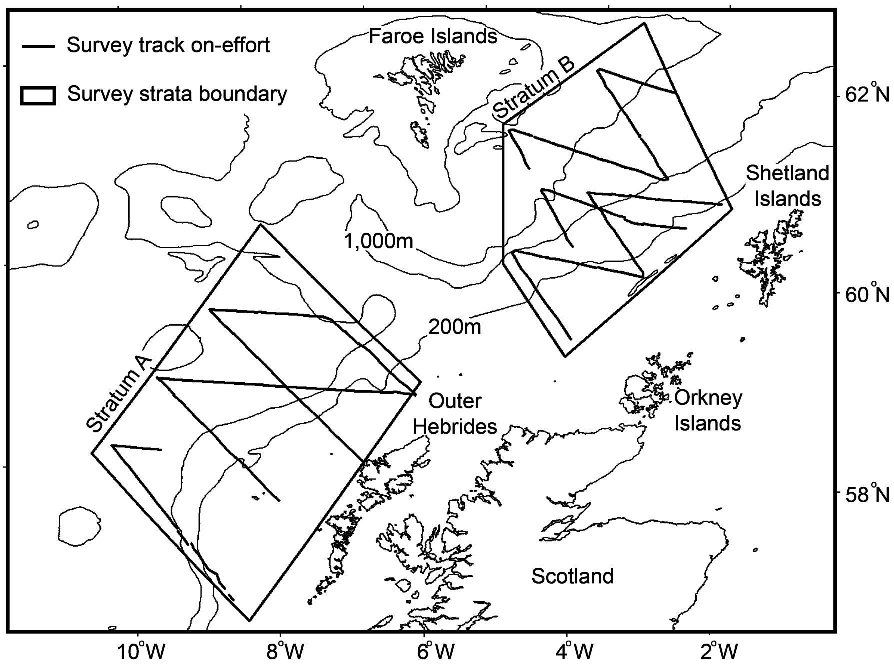

Fig. 2. Survey blocks and effort in Stratum A to the west of Outer Hebrides and Stratum B in the Faroe-Shetland Channel.

these species (e.g. blow height and shape) we considered it reasonable to assume that they would have similar detection functions. Perpendicular distances were modelled using the *Distance* 4.1 software (Thomas *et al.*, 2003). Several models were fitted to the data using combinations of key functions (half-normal and hazard rate) and series expansions (cosine, Hermite and simple polynomial) identified as model robust (Buckland *et al.*, 2001). The need for, and number of adjustment terms in the series expansion was determined using the Likelihood Ratio Test (Buckland, 1987; Buckland *et al.*, 2001). Selection of the best model was based on visual inspection of model fit (QQ-plot), goodness-of-fit statistics (Kolmogorov-Smirnov test) and the lowest value of the Akaike Information Criterion (AIC) (Buckland *et al.*, 2001).

School size was estimated for each species either from the regression of the log of school size against the fitted detection function if significant (α = 0.05) or as the observed mean school size. Best estimates of school size were used for the analysis. Density and abundance were estimated for each species using the estimated $f(0)$ from the pooled species perpendicular distance data and the estimated or observed mean school size. Abundance was also estimated for 'large whales' by pooling sightings of fin and sei whales and including further sightings recorded as fin or sei whale. Variance was estimated analytically, as described above, and 95% confidence intervals were calculated assuming that estimated density was log-normally distributed.

RESULTS

During the survey, 136 cetacean sightings of seven species were recorded (Macleod *et al.*, 2003). Fin and sei whales were only encountered in the Faroe-Shetland Channel (Stratum B) and none was identified to the west of the Outer Hebrides (Stratum A) despite over 1,000km of survey effort in Beaufort sea state 4 and below. In Stratum B, 1,057.6km of transect was surveyed in the 43,578km^2 area of the Faroe-Shetland Channel. This was only 54% of the planned survey effort; fog and consequently poor visibility was the primary cause of survey downtime. Most sightings occurred beyond the continental shelf (Fig. 3). The mean depth of fin whale sightings was 1,089.9m (SD=415.7) and 822m (SD=168.5) for sei whale sightings.

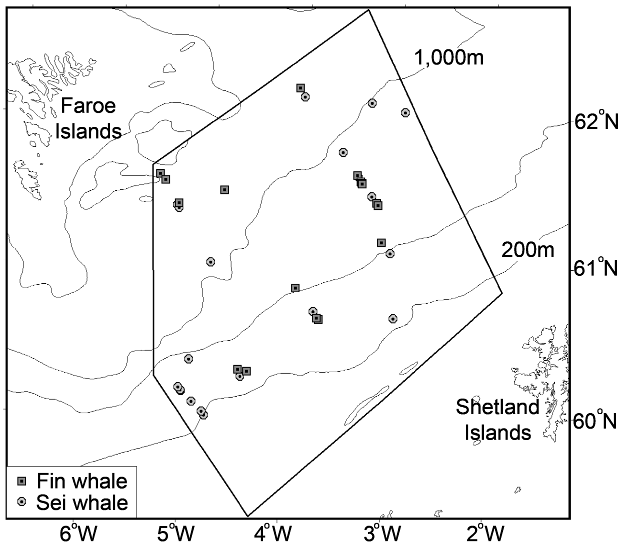

Fig. 3. Distribution of sightings of fin and sei whales in the Faroe-Shetland Channel.

The upper team of observers recorded 13 fin whales and 15 sei whales. The lower team recorded 12 fin whales and 8 sei whales. The combined dataset (FS) from both platforms of unique fin and sei whale encounters (definite and probable) resulted in a sample size of 40 (20 fin and 20 sei whales) and they were the most frequently recorded baleen whales in the area. A further 7 schools of large whales were classified as fin or sei whales and were used to estimate a combined 'large whale' (LW) abundance. Additionally, 43 unidentified whales were recorded in the Faroe-Shetland Channel but these were not used in the analysis. These observations were mainly of blows and may have been fin and sei whales but could also have been blue (*B. musculus*), sperm (*Physeter macrocephalus*) or humpback whales (*Megaptera novaeangliae*). The combination of species in the 'unidentified whale' category would weaken the assumption that pooling sightings to estimate the detection function was valid. Identifying species from blows alone, which was the most common sighting cue of large whales, can be extremely difficult, particularly in windy weather conditions or moderate visibility. Conducting the survey in closing mode would have helped species identification.

Density and abundance of whales could not be estimated for Stratum A and estimates are presented for Stratum B only. For both the FS and LW datasets, histograms of the distribution of perpendicular distances to sightings (Figs 4 and 5) showed that detections within 100m of the trackline were low. This suggests that some whales ahead of the ship may have moved away from the survey trackline prior to detection. Alternatively, the low number of detections close to the trackline may have been due to rounding problems or sampling errors. Outliers were removed by truncating both datasets at 1.5km.

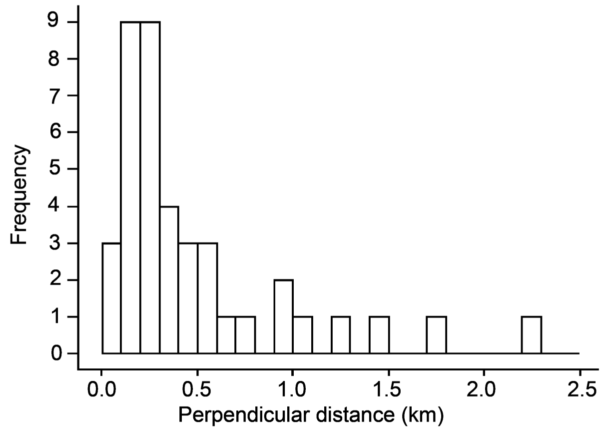

Fig. 4. Frequency histogram of the perpendicular distance data for pooled fin and sei whale sightings (FS data).

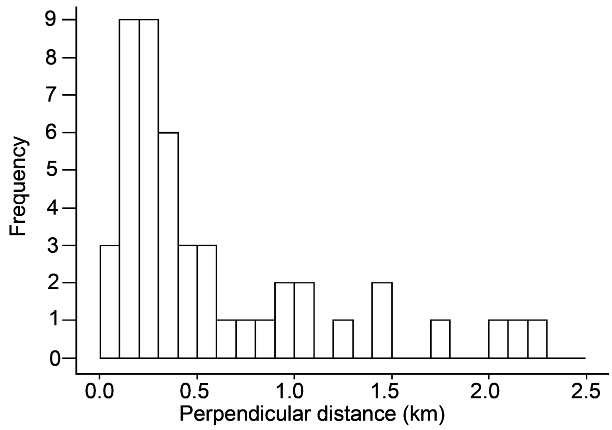

Fig. 5. Frequency histogram of the perpendicular distance data for all large whale sightings (LW data).

The resulting sample size for analysis of the FS data was 38 observations ($n_{s\ \mathrm{fin}}$=19 and $n_{s\ \mathrm{sei}}$=19). The probability density function of the perpendicular distances was modelled with a hazard rate key function without adjustment terms (Fig. 6) and was a good fit to the data (Kolmogorov-Smirnov, p=0.466). The point estimate of $f(0)$ was 1.82 (CV=0.21) and the estimated effective strip half-width was 550m (SE=116) (Table 1). The size-bias regression estimates of school size for FS data were not significant (P_{fin}=0.755, P_{sei}=0.417) and the mean school size for each species was used. Mean school size was slightly smaller for fin whales than sei whales (Table 1) but school sizes ranged from 1-3 individuals for both species. Animal density was estimated to be 0.021 fin whales km^{-2} and 0.022 sei whales km^{-2}. Fin whale abundance was estimated as 933 (CV=0.38, 95% CI=435-2,003) individuals and sei whale abundance was slightly higher at 1,011 (CV=0.35, 95% CI=497-2,058) individuals (Table 1).

Forty-three observations from the LW dataset were used to estimate abundance after truncation. A hazard rate function without adjustment terms (Fig. 7) was used to fit the probability density function (Kolmogorov-Smirnov, p=0.519) (Table 1). Abundance of large whales was estimated as 1,923 animals (CV=0.33, 95% CI=994-3,721) (Table 1).

Table 1

Summary of the estimates for fin, sei whale and large whale abundance estimation, where $\hat{\mu}$ = effective strip half-width, s = average school size, n_s = number of schools, n_sL^{-1} = encounter rate ($n_s$km^{-1}), $\hat{D}_s$ = density of schools, $\hat{D}$ = density of whales and $\hat{N}$ = abundance of whales.

	Estimates (CV)		
	Fin whale	Sei whale	Large whales
$\hat{\mu}$	0.550 (0.21)	0.550 (0.21)	0.612 (0.22)
s	1.26 (0.10)	1.37 (0.10)	1.28 (0.06)
n_sL^{-1}	0.018 (0.30)	0.018 (0.27)	0.041 (0.24)
$\hat{D}_s$	0.016 (0.36)	0.016 (0.34)	0.033 (0.32)
$\hat{D}$	0.021 (0.38)	0.022 (0.35)	0.042 (0.33)
$\hat{N}$	933 (0.38)	1011 (0.35)	1923 (0.33)

DISCUSSION

The effects of sea state on whale detection were not considered in this analysis. Sample sizes were too small for stratification by sea state or for selecting effort and sightings recorded only in low sea states (0-2, for example). Borchers and Burt (1997) found that $\hat{\mu}$ for sei and fin whales detected in Beaufort sea states 4-6 was half that in sea states 0-3, although they were not significantly different. About 97% of the survey effort in Stratum B in this study was in sea state 3 or below and so the effects of sea state on whale detection would be expected to be small.

There are potential sources of bias in the abundance estimates presented. Animals can go undetected because observers miss them (perception bias) or because they are diving and underwater (availability bias). Missing whales on the survey trackline causes negative bias. However, the large size and tall blows of fin and sei whales are very visible and easy to detect. Fin and sei whales can be detected far from the ship and mean dives times are also relatively short (Croll *et al.*, 2001). It is reasonable to assume, therefore, that the probability of detection on the trackline is close to one and that any bias in abundance estimates is small.

Responsive movement of animals away from the survey vessel before they are detected will also cause negative bias. A suggestion of this was found in these data (Figs 4 and 5). Avoidance of ships has been documented for fin whales and in general it is particularly strong when ships head directly towards the whale or vessel noise is changing rapidly because of changes in speed (Richardson *et al.*, 1995). If animal orientation data are collected, methods are available to correct for responsive movement during analysis (Palka and Hammond, 2001). These data should be collected in future surveys.

Abundance estimates and previous surveys

The only dedicated cetacean surveys of offshore waters to the north and west of Scotland are the international North Atlantic Sighting Surveys (NASS). NASS have been conducted during the summers of 1987, 1989, 1995 and 2001 (Fig. 1), primarily to assess abundance of minke whales (*B. acutorostrata*), pilot whales (*Globicephala macrorhynchus*), fin and sei whales (Pike *et al.*, 2003), although all species sighted were recorded. The results of the early NASS surveys suggested that the numbers of fin and sei whales to the northwest of Britain were relatively low compared to East Greenland/Iceland stocks (Borchers and Burt, 1997; Buckland *et al.*, 1992). In previous surveys with survey effort off northwest Scotland (Fig. 1), no sightings (NASS-87) and a single sighting (NASS-89) of sei whales were made (Joyce *et al.*, 1990). Sei whale abundance has only previously been estimated from NASS-95 survey data to the west of the UK and Ireland (Borchers and Burt, 1997). An abundance of about 9,250 sei whales was estimated for the entire NASS-95 survey region, including waters around Iceland in the central North Atlantic. The highest densities occurred to the southwest of Iceland (mean density over three strata = 0.034 whales km^{-2}, CV=0.79) and are comparable to estimated density in the Faroe-Shetland Channel from this study (0.022 whales km^{-2}, CV=0.35) (Table 1). NASS surveys (1987-1995) show that the highest densities of fin whales have consistently occurred in the Irminger Sea off southwest Iceland. However, in 2001, the highest density was recorded off northwest Iceland (0.34 km^{-2}). The estimates of fin whale density in the northeast Atlantic suggest an increasing trend and the increases in abundance between Iceland and Greenland account for nearly all the increase in abundance over the entire NASS area (Pike *et al.*, 2003). However, full

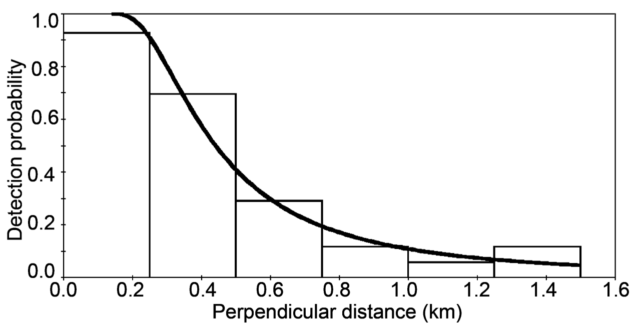

Fig. 6. Detection probability of pooled fin and sei whale sightings against perpendicular distances. The data are fitted with a hazard-rate key function and the fitted curve indicates the estimated probability density function.

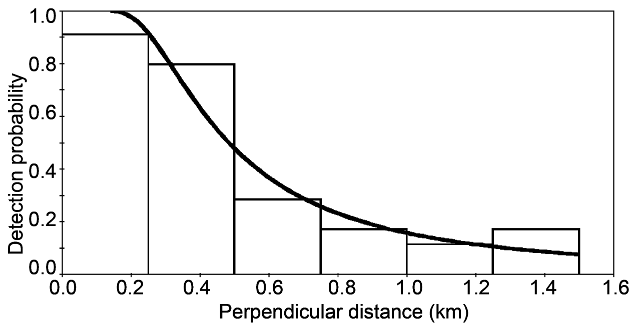

Fig. 7. Detection probability of all large whale sightings against perpendicular distances. The data are fitted with a hazard-rate key function and fitted curve indicates the estimated probability density function.

interpretation of the NASS estimates is complicated by the fact that stratification and coverage have changed in every survey, as have analytical methods (Pike *et al.*, 2003). There are insufficient data to interpret trends in sei whale abundance. Migrations of sei whales have been described as 'erratic' (e.g. Ingebritsen, 1929) and high densities in an area in one year would not necessarily hold for subsequent years.

The density of fin whales (0.021 km^{-2}) and sei whales (0.022 km^{-2}) in the Faroe-Shetland Channel estimated in this study are the highest recorded off western and northern Britain and Ireland since dedicated surveying began in 1987. The high densities of fin and sei whales in the Faroe-Shetland Channel in July 1998 indicate that this area is an important feeding ground and/or migration route to feeding grounds further north.

The high density of large whales in the Faroe-Shetland Channel contrasts with the complete absence of fin and sei whale sightings further south to the west of the Outer Hebrides. Both species were once caught in considerable numbers off the Hebridean shelf. The Scottish whaling season extended from April to September with peak catches of fin and sei whales occurring in June and July. However, by the end of July, the 'sei-season' closed for Hebridean whalers, but continued off the Shetland Islands until September (Brown, 1976; Thompson, 1928). Fin whale catches peaked in July at all stations. The absence of sightings off the Outer Hebrides may be a true reflection of the very low density of animals in these waters compared to numbers present historically or it may have been caused by some other factors. Changes in the timing of fin and sei whale migrations off the Scottish continental shelf may have occurred since whaling ceased, perhaps resulting in most whales now passing through Hebridean waters earlier to concentrate at the Faroe-Shetland Channel in July. Stone (1998) noted movements of fin whales throughout the area and found that, in June, most fin whales were near the Wyville-Thomson Ridge at the mouth of the Faroe-Shetland Channel. In July, most sightings occurred to the north and west of Shetland and this continued until October.

Changes in prey distribution and availability off the Outer Hebrides may also have contributed to the apparent lack of fin and sei whales in Hebridean waters compared to the Faroe-Shetland Channel. The calanoid copepods, *C. finmarchicus* and *C. helgolandicus* constitute one of the major components of the northeast Atlantic Ocean zooplankton (Planque, 1996). Since the 1960s, there has been a dramatic decline in abundance of *C. finmarchicus* in the northeast Atlantic Ocean and North Sea. Significant declines have occurred off the northwest of the UK and one of the areas where the decline is most evident is on the Malin Shelf, southwest Hebrides (OSPAR QSR, 2000). For almost four decades, the decline in *C. finmarchicus* was linked to the warmer seawater temperatures of the mainly positive North Atlantic Oscillation Index (NAOI) over this period. However, in 1996, there was a pronounced drop in the NAOI and it was predicted that there would be a corresponding increase in *C. finmarchicus* abundance. However, this did not occur and abundance continues to decline. The preference of *C. finmarchicus* for cooler water temperatures limits its distribution ever further north with increasing sea temperatures. A corresponding shift in marine predators feeding on this species might also be predicted.

However, anthropogenic factors, such as seismic surveys, may also influence the distribution and abundance of these species. During summer 1998 (June-August inclusive), the number of seismic surveys reported to the UK Joint Nature Conservation Committee (JNCC) was four times as many to the west of the Outer Hebrides than in the Faroe-Shetland Channel (Barton, pers. comm.). In each month, seismic activity was consistently greater to the west of the Outer Hebrides than further north. However, since reporting to the JNCC is not mandatory this can only be used as rough indicator of seismic activity in the area. Fin and sei whales may have avoided the area or passed through it because of the noise from seismic surveys. The impact of low-frequency noise from seismic surveys on the distribution of these species is unknown because of the lack of studies. The impact has been studied in other Balaenopterids such as the bowhead (*Balaena mysticetus*) and gray whale (*Eschrichtius robustus*). Evidence of avoidance behaviour in response to seismic activity, even at several kilometres away from the source, is well documented for bowhead whales in the Bering, Chuckchi and Beaufort Seas (Richardson *et al.*, 1995). Gray whales off Sakhalin Island, Okhotsk Sea shifted their distribution away from an area of seismic activity within their feeding ground (Weller *et al.*, 2002). Similarly, indirect effects on prey distribution and abundance may also be an important consideration.

Conservation concerns in the Faroe-Shetland Channel

The Faroe-Shetland Channel is an important habitat for large baleen whales. The Faroe-Shetland Channel and west coast of Scotland is undergoing industrialisation and the numbers of animals potentially at risk in these waters becomes an important factor for assessing both short- and long-term impacts to populations. In total, 24 species of cetacean have been recorded off western Scotland (Parsons *et al.*, 1999) and the list includes other large baleen whales, such as blue and humpback whales. A major concern is the effect of acoustic disturbance on cetaceans from seismic exploration and the associated noise from development and production. Mysticetes are thought to be particularly susceptible to the predominantly low frequency noise associated with oil and gas development because it is likely to be within the range of their hearing sensitivity. Two Floating Production Storage and Offloading facilities (FPSOs) are currently in production in the Faroe-Shetland Channel anchored at 4-600m. Swift *et al.* (2003) studied ambient noise levels and tracked fin whales in the vicinity of these FPSOs with autonomous bottom mounted recording systems. Low frequency noise associated with the dynamic positioning system of the FPSOs and from supply vessels and tankers characterised recordings. Seismic activity dominated summer recordings. In two fin whale frequency vocalisation bands (18-22Hz and 22-28Hz), noise levels ranged from 120dB re: $1mPa^2Hz^{-1}$ to 49dB re: $1mPa^2Hz^{-1}$ at distances of 8.5 and 40km, respectively. In 50% and 25% of the data, noise levels exceeded the predicted lower and upper limits, respectively, of mysticete hearing (Swift *et al.*, 2003).

Seismic exploration off northwest Scotland is likely to increase over the coming years with the success of the fields in the Faroe-Shetland Channel and the continual advancement of technology, which enables these deep waters to be exploited. Peak seismic activity coincides with peak densities of fin and sei whales in this region. The seismic zone of influence on these whales should be considered in the context of the amount and availability of suitable feeding habitat for them. If seismic surveys and industrial development were to reach such a level as to acoustically swamp feeding grounds off northwest Scotland, then fin and sei whales may be displaced. The theoretical zone of audibility for seismic pulses can be large, reaching distances of over 50km (Richardson *et al.*, 1995; Richardson and Würsig, 1997) although the maximum radius of influence is normally expected to be much less than the maximum radius of audibility (Richardson *et al.*, 1995). An immediate means of mitigating the effects of seismic activity on cetaceans is by avoiding areas with high cetacean densities (Harwood and Wilson, 2001). As densities are lower in September and October (Stone, 1998; Weir *et al.*, 2001) any seismic operators wishing to survey offshore waters off northwest Scotland could survey at this time with a reasonable expectation of having a lesser impact on these species. In addition, exploitation licences could be limited to reflect the sensitivities of the wildlife of the region and guidelines for minimising acoustic disturbance (e.g. JNCC, 1998) strictly adhered to as a minimum protective measure. Other management measures, which may include time-area closures (Macleod, 2001), should be considered to ensure disturbance to cetaceans off northwest Scotland is minimised.

The populations of fin and sei whales are still thought to be recovering from overexploitation. Baseline abundance estimates are crucial for monitoring populations and assessing the impacts of potentially harmful activities. However, it is important that surveys try to capture the entire range of populations, as 'regional' estimates are difficult to interpret at the population level. Future surveys to assess the summer abundance of northeast Atlantic fin and sei whales should ensure that areas off northwest Scotland are included.

ACKNOWLEDGEMENTS

The survey was made possible by funding from the Greenpeace Environmental Trust and the Whale and Dolphin Conservation Society. We would especially like to thank the survey team, H. Arnold, M. De Boer, R. Irish, C. Mackins, K. Norris, J. Pert and M. Stanley. Thanks also to the captains and crew of the MV *Neptun* and Carolyn Barton, Joint Nature Conservation Committee, for information on reports of seismic surveys. These data were partly collected using the software, *Logger*, developed by the International Fund for Animal Welfare (IFAW) to promote benign and non-invasive research.

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Date received: July 2006
Date accepted: September 2006