

Sperm whale distribution and seasonal density in the Faroe Shetland Channel

GORDON D. HASTIE*, RENÉ J. SWIFT*, JONATHAN C.D. GORDON†, GEORGE SLESSER‡ and WILLIAM R. TURRELL‡

Contact e-mail: hastie@zoology.ubc.ca

ABSTRACT

Results from previous surveys suggest that an area of the northeast Atlantic, the Faroe Shetland Channel, is important for cetaceans. This study utilised passive acoustic survey techniques to evaluate the density of sperm whales in the Channel. Two-week surveys were carried out during oceanographic cruises in May and October 2001, and May 2002. A two hydrophone array was towed behind the vessel throughout the majority of the survey routes and was monitored by a two-person team and by software designed to automatically detect and measure bearings to whales. Distances of individual sperm whales from the trackline were determined using target motion analysis. Standard line transect techniques were applied to calculate the density of whales during surveys. The effects of sea conditions and survey vessel on the ability to detect whales were tested; the encounter rate and effective stripwidth (*esw*) were estimated independently for each sea state and for each of the vessels. A total of 79 individual whales were detected, and their distances from the trackline were calculated. As a probable result of insufficient sample size and a small effects size, neither the *esw* nor the encounter rates varied significantly with sea state or between the two survey vessels. The density of sperm whales during each of the surveys was estimated to be 2.05, 0.52 and 1.75 whales per 1,000km² for the May 2001, October 2001 and May 2002 surveys respectively. Sperm whales were distributed across the majority of the Faroe Shetland Channel. This study has provided the basis for meaningful hypothesis generation in future studies and to gain a better understanding of the factors underlying the spatial and temporal distribution patterns of sperm whales in this area; data on oceanographic, biological and anthropogenic determinants should now be examined.

KEYWORDS: ATLANTIC OCEAN; INDEX OF ABUNDANCE; SURVEY-ACOUSTIC; SURVEY-VESSEL; ACOUSTICS; VOCALISATION; DISTRIBUTION

INTRODUCTION

There has been little dedicated research on sperm whales (*Physeter macrocephalus*) in the northeastern Atlantic but a number of data sources (Thompson, 1928; Brown, 1976; Gunnlaugsson and Sigurjónsson, 1990; Weir *et al.*, 2001) indicate that this may be an important area for this species.

Historical whaling records show that sperm whales were hunted in large numbers throughout the northeastern Atlantic (Brown, 1976; Jonsgård, 1977). More recently, dedicated sightings surveys have shown that sperm whales are distributed widely throughout oceanic waters in the northeastern Atlantic (Martin *et al.*, 1984; Sigurjónsson, 1985; Sigurjónsson *et al.*, 1989; Øien, 1990; Lens, 1991; Ciano and Huele, 2001). From boat based sighting surveys, Øien (1990) estimated a population size of 2,500 sperm whales in the Norwegian Sea and surrounding waters with densities ranging from 0.82 to 10.16 whales 1,000km⁻². Gunnlaugsson and Sigurjónsson (1990) estimated a population of 1,234 sperm whales to the east of Greenland and around Iceland. A population size of 308 sperm whales was estimated for waters around the UK and the Faroe Islands during the same study. However, the authors of these studies (Gunnlaugsson and Sigurjónsson, 1990; Øien, 1990) highlight that the numbers may be significant underestimates as no corrections were made for animals that may not have been seen because they were submerged.

Sperm whales are also frequently sighted to the northwest of the UK from opportunistic survey platforms (Evans, 1997; Weir *et al.*, 2001). Sightings typically peak during the summer and are rare between December and April.

However, this may be a result of unfavourable sighting conditions due to poor weather in these waters during winter (Evans, 1997). This possibility is supported by recent acoustic surveys in these areas which indicate that sperm whales may be present in significant numbers during winter months (Lewis *et al.*, 1998) and by the fact that strandings of sperm whales have been recorded from the coasts around the UK and Ireland throughout the year (Evans, 1997).

Recent opportunistic surveys to the northwest of the UK found significant numbers of sperm whales within the Faroe Shetland Channel (Lewis *et al.*, 1998; Weir *et al.*, 2001). This area provides one of the few deep water links between the northeastern Atlantic and polar waters, and is potentially an important corridor for migrating whales. However, to assess the biological and anthropogenic factors influencing the ecology of cetaceans in this region, more detailed survey work on their distribution, habitat use and behaviour is required.

The Faroe Shetland Channel encompasses part of the Scottish continental shelf and Faroese plateau, and is intersected by a deep channel approximately 1,400m deep that runs northeast through the area. At its northern entrance, the channel is connected to the Norwegian Sea and at its southern end, to the Atlantic Ocean (Turrell *et al.*, 1999). The hydrographic regime of the Faroe Shetland Channel is complex and it has long been recognised as one of the major conduits connecting the warm waters of the Atlantic with the cold waters of the Nordic seas (Sherwin *et al.*, 1999).

Over the last 100 years, the FRS Marine Laboratory in Aberdeen has conducted oceanographic research in the Faroe Shetland Channel (Heath and Jónasdóttir, 1999;

* University of Aberdeen, School of Biological Sciences, Department of Zoology, Lighthouse Field Station, George Street, Cromarty, Ross-shire, IV11 8YJ, Scotland.

† Sea Mammal Research Unit, Gatty Marine Laboratory, University of St Andrews, Fife, KY16 8LB, Scotland.

‡ FRS Marine Laboratory Aberdeen, PO Box 101, Victoria Road, Aberdeen, AB11 9DB, Scotland.

Turrell *et al.*, 1999). Throughout the year, systematic surveys are carried out to assess both the hydrographic and biological characteristics of this area. These surveys provide an ideal platform to study the density of sperm whales within this unique area.

Conventionally, cetacean surveys have used visual techniques to search for animals at the water surface. However, sighting efficiency can be severely affected by weather conditions; it rapidly decreases in rough seas, and is curtailed by factors such as fog. Sperm whales can be particularly difficult subjects because they make long deep dives which may last for over an hour. However, sperm whales are highly vocal animals, producing loud clicks (Backus and Schevill, 1966), for most of the time spent underwater. They can be detected at ranges of several miles using simple hydrophone systems, and acoustic monitoring (whether used alone or in conjunction with visual methods) has proven to be a highly effective survey method for this species (Leaper *et al.*, 1992; Gillespie and Leaper, 1996; Barlow and Taylor, 1998).

The primary aim of this study was to estimate the density and distribution of sperm whales in the Faroe Shetland Channel using passive acoustic survey techniques from oceanographic survey vessels.

METHODS

Passive acoustic surveys for sperm whales were carried out in the Faroe Shetland Channel (Fig. 1) during oceanographic cruises from 7-21 May 2001 and 4-18 October 2001 from the

FRV Scotia, a 68m oceanographic research vessel, and from 15-28 May 2002 from the *FRV Cirolana*, a 73m oceanographic research vessel.

Equipment

The acoustic equipment consisted of a towed stereo hydrophone streamer, an amplification and filtering unit and a computer for making recordings. The hydrophone was specially designed and built for this project but was based on systems developed in previous studies (Leaper *et al.*, 1992). The streamer consisted of two AQ4 elements (*Benthos*, Falmouth, USA) with individual preamplifiers (*Magrec*, Devon, UK) mounted 3m apart in a 10m, oil-filled, 1" diameter polyurethane tube. The preamplifiers had a low-cut filter designed to provide -3dB gain at 100Hz to limit low frequency tow and water noise. The system was otherwise flat to 15kHz and had good sensitivity to well above the 22kHz upper limit of the computer sound card. The streamer was towed behind the vessel on a 400m strengthened cable. At speeds of 10 knots, this design of array with a 400m cable has been found to tow at around 5-6m below the surface (Gillespie, 1997). For retrieval and storage, the cable and streamer were coiled onto the main net drum winch situated centrally above the aft deck of the vessels. A 60m extension cable was connected to the tow cable once it was deployed linking the array to recording equipment located within the vessel's laboratories.

Signals from the hydrophones were filtered using high pass filters set at 400Hz or 1,600Hz depending on background noise conditions, and amplified by 20dB or 30dB using a custom built differential amplifier/filter unit (*Magrec*, Devon, UK). The data logging software package

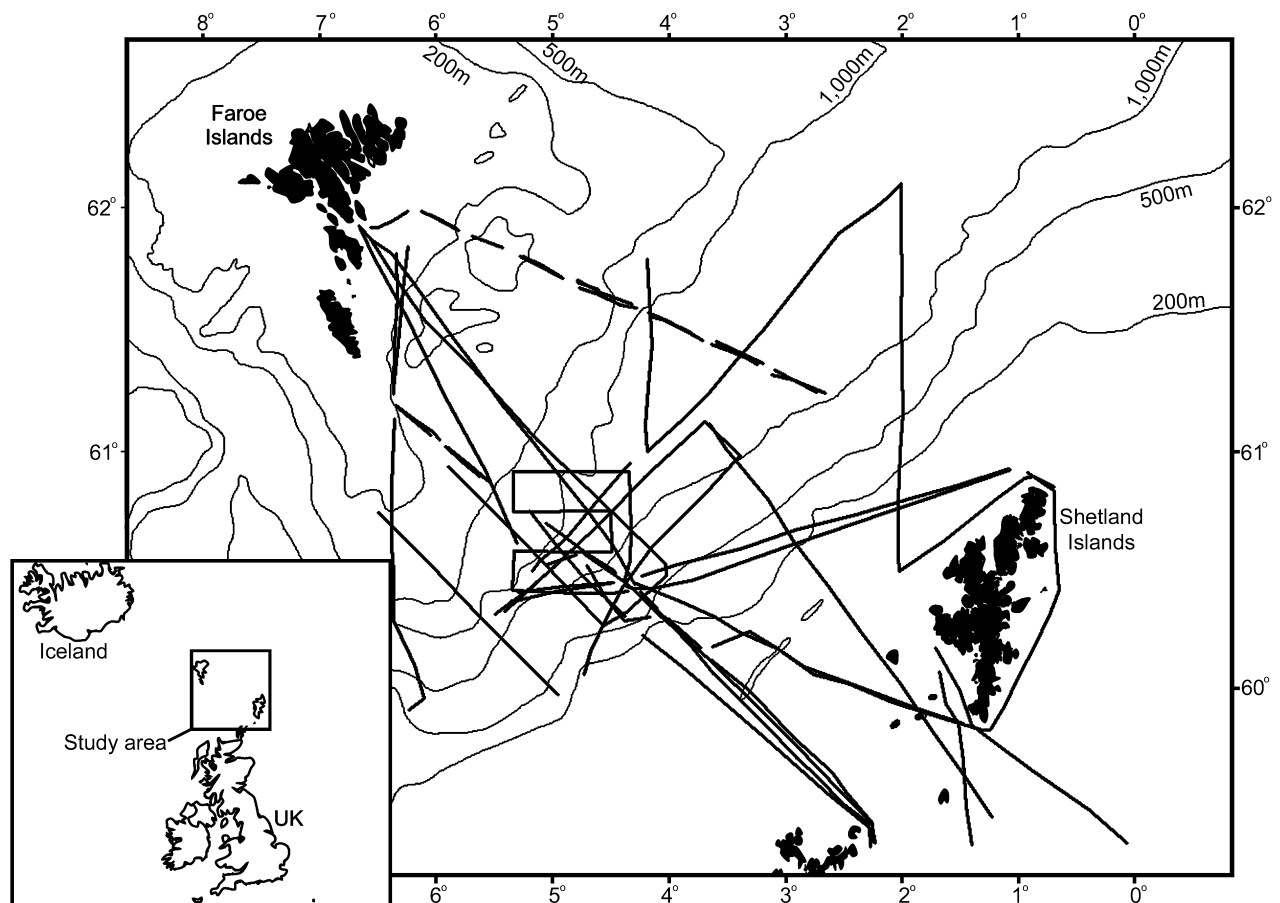


Fig. 1 The location of the study area in the Faroe Shetland Channel (inset), showing the track of the acoustic surveys for sperm whales during May and October 2001 and October 2002. The 200m, 500m and 1,000m contour lines are shown.

Logger2000 (Gillespie, 1997) ran in real time throughout the surveys and maintained a database of monitoring effort, recordings and acoustic detections.

Field protocol

A two-person team worked in shifts to monitor the signals from the hydrophone 24 hours a day. Hydrophones were monitored carefully for one minute every 15 minutes and a qualitative assessment of the strength, from 0 (absent) to 5 (high), of the following acoustic information was recorded to a database using the *Logger2000* software: vessel noise; sea noise; remote ship noise; number of sperm whales; and strength of sperm whale clicks. In addition, an automated recording module within *Logger2000* made 32 recordings direct to the computer's hard disk every 2 minutes.

Throughout the surveys, an automatic click detection and classification program, *Rainbow Click* (Gillespie, 1997) ran continuously. *Rainbow Click* identifies putative sperm whale clicks, calculates their bearings and attempts to distinguish sperm whale clicks from other transients based on their duration and spectral content. To optimise detection of sperm whale clicks, the program's software filters were set to a band pass between 2 and 6kHz to reduce false triggers from low frequency vessel noise and from the survey vessel's 18kHz echo sounder. In addition, the 'forward veto' facility in the software was used to reject any detections within a 20° cone ahead of the array, further eliminating false triggers due to vessel noise.

Rainbow Click calculates bearings to each click from the relative time of arrival of the click at the two hydrophones in the array. Distances of sperm whales from the trackline were determined using target motion analysis as described by Gillespie (1997) and Leaper *et al.* (2000). As the survey vessel travels past individual whales, bearings change, tending to move astern. A series of bearing lines to a vocalising whale plotted from different points on the trackline will cross at the whale's estimated location, and distance from the trackline can be measured from plots. The accuracy of the bearing estimations were assessed by Leaper *et al.* (2000) during a study which utilised similar equipment. Errors were small but increased with wind speed, due to increased movement of the array, from $\pm 1.3^\circ$ in 14 knots of wind to $\pm 2.3^\circ$ in 28 knots of wind.

Sperm whale density

Standard line transect techniques were applied to calculate the density of whales during surveys. Effective strip widths (*esw*) were estimated from acoustically derived perpendicular distances from the trackline using the software *DISTANCE* Version 4.0 Beta 6 (Thomas *et al.*, 2001). Two models (hazard rate and half-normal) were fitted to the data and the most parsimonious model was selected based on minimising Akaike's Information Criterion (Buckland *et al.*, 1993). Distance data were truncated to exclude the largest 5% of distances.

For the purposes of this study, it was assumed that $g(0) = 1$; i.e. that all whales on the survey track would be detected. Diving sperm whales typically do not vocalise when they are at the surface but surfacing intervals are generally less than 15 minutes (Gordon and Steiner, 1992). Furthermore, during previous studies of sperm whales using similar equipment, whales were never sighted before being detected acoustically (Leaper *et al.*, 1992; Gillespie, 1997).

To assess the potential effects of sea conditions and survey vessel on the ability to detect whales, the encounter rate (number of whales 100km^{-1}) and *esw* were estimated

independently for each Beaufort sea state and for each of the vessels. Standard errors were calculated for each estimate and *z*-tests were used to assess whether there were significant differences in encounter rate and *esw* during different sea states and for each vessel. The density of whales was estimated for each of the cruises independently. A combined estimate was then evaluated as a mean of the estimates for each cruise, weighted by the total effort during each cruise. Density (\hat{D}) was estimated by:

$$\hat{D} = n/L \cdot (2 \cdot esw)$$

where:

n = the number of whales detected within the *esw*;

L = distance surveyed;

esw = the effective strip width.

RESULTS

The array was deployed successfully across the majority of the survey routes on each cruise (Fig. 1). A total of 1,676km were surveyed in May 2001, 1,536km in October 2001 and 1,365km in May 2002. A total of 356, 339 and 366 one-minute monitoring periods were made during May 2001, October 2001 and May 2002 respectively. It proved practical to deploy the array and collect useful data during an oceanographic cruise without any significant negative impacts on the survey's primary work. The hydrophone towed steadily behind the vessels and noise levels were reasonable at the vessels' cruising speed of 12 knots. However, at speeds of 14 knots, only occasionally achieved on *FRV Scotia* when travelling down large waves, the hydrophone came to the surface and could not be monitored.

Sperm whale density

Sperm whales were heard in a total of 185 (17.4%) of the monitoring periods. The majority of these sperm whales were also detected by the *Rainbow Click* detection program. From visual inspections of the bearing lines to clicks, it was determined that a total of 79 individual whales were detected. These ranged in distance from 378m to 14.1km from the survey track. Single whales were detected aurally but were not detected by the software on four occasions. These were usually faint clicks that were presumed to be from distant whales.

The *esw* was largest in sea states 1 and 4, was at a minimum during sea state 3 and was higher for the survey vessel *FRV Scotia* than for the *FRV Cirolana*. The encounter rates decreased with increasing sea state and were higher for the *FRV Cirolana* than for the *FRV Scotia* (Tables 1 and 2). However, as a probable result of insufficient sample size and a small effects size, neither the *esw* nor the encounter rates varied significantly with sea state or between the two survey vessels. The data were therefore pooled for all subsequent analyses of whale density.

The perpendicular distance data from both the May 2001 and May 2002 were best fitted by a half-normal model with cosine adjustment terms. Data from October 2001 were best fitted to a Hazard rate model with cosine adjustments (Fig. 2). These resulted in *esw* of 5.53km, 7.6km and 5.41km for the data from the May 2001, October 2001 and May 2002 cruises (Table 3).

Sperm whales were heard in 105 (29.5%), 29 (8.6%) and 50 (13.7%) of the monitoring periods during May 2001, October 2001 and May 2002 respectively. The estimated density of sperm whales during each of the surveys is shown

Table 1

Number of whales (after truncation), *esw* and encounter rate stratified by sea state. Standard errors in parentheses.

Beaufort sea state	Number of whales (<i>n</i>)	<i>esw</i> (km)	Encounter rate (<i>n</i> /100km)
1	14	7.29 (1.99)	2.43 (0.33)
2	24	5.59 (0.76)	2.25 (0.23)
3	25	5.46 (1.27)	2.27 (0.59)
≥4	13	7.92 (2.71)	0.69 (1.04)

Table 2

Number of sightings (after truncation), *esw* and encounter rate stratified by survey vessel. Standard errors in parentheses.

Vessel	Number of whales (<i>n</i>)	<i>esw</i> (km)	Encounter rate (<i>n</i> /100km)
<i>FRV Cirolana</i>	26	5.41 (0.95)	1.89 (0.37)
<i>FRV Scotia</i>	50	5.97 (0.76)	1.54 (0.75)

Table 3

Estimates of sperm whale density for each survey, where *esw* is the effective strip width, *n* is the number of whales used in the estimate (after truncation) and \hat{D} is the estimate of the density of whales. Standard errors in parentheses. The combined estimate of density is expressed as a mean density, weighted by survey effort during each survey.

Date	Effort (km)	<i>esw</i> (km)	<i>n</i>	\hat{D} (whales/1,000km ²)
May 2001	1676	5.53 (0.77)	38	2.05 (0.44)
Oct. 2001	1536	7.6 (2.93)	12	0.51 (0.24)
May 2002	1364	5.41 (0.947)	26	1.75 (0.46)
Combined	–	–	–	1.44 (0.83)

in Table 3. The highest estimated density was during the May 2001 and the lowest was during the October 2001 cruise.

Sperm whales were distributed across the majority of the Faroe Shetland Channel. Although the majority of whales were detected within the deeper water of the mid-channel, 13 whales were detected in waters shallower than 500m on the Faroese side of the channel. In contrast, no whales were detected over the shallow water on the Shetland side of the channel (Fig. 3).

DISCUSSION

This study presents current data on density of sperm whales within the Faroe Shetland Channel which complements the results of earlier surveys in the North Atlantic (e.g. Gunnlaugsson and Sigurjónsson, 1990; Øien, 1990).

This study has demonstrated that by using passive acoustic monitoring equipment, small field teams can collect high quality data on the density and distribution of sperm whales (and possibly other cetaceans) utilising oceanographic research vessels as platforms of opportunity. The primary research activities of the survey vessels were not affected and the simple acoustic monitoring and detection system used here, tended by a team of two, proved perfectly adequate for this purpose.

No significant effects on *esw* or encounter rates due to sea state or survey vessel were detected. This highlights advantages of using passive acoustics to survey for sperm whales in regions such as the northeast Atlantic, where sighting conditions are often poor due to rough seas. However, it should be noted that other factors that could affect the detection rate of whales were not examined in this study; these are likely to include underwater propagation conditions and background noise levels.

Esw were estimated to be between 5km and 7km in this study. This is lower than the *esw* calculated in a previous study using similar equipment (Leaper *et al.*, 2000); a factor which could result from differences in the acoustic properties of the water or from variations in noise levels. The cruising speed of the vessel used by Leaper *et al.* (2000) was around 2 knots slower than the vessels used in this study. Therefore, increased vessel noise could potentially be a factor that reduced the detection range of the array in this study. In addition, the hydrophones are likely to tow closer to the water surface at higher speeds, potentially also reducing the range of the array due to noise interference from breaking waves.

As in previous acoustic studies (Barlow and Taylor, 1998; Leaper *et al.*, 2000), it was assumed in this study that *g*(0) was equal to one, that is to say that all whales on the survey track were detected. Sperm whales are not generally vocal

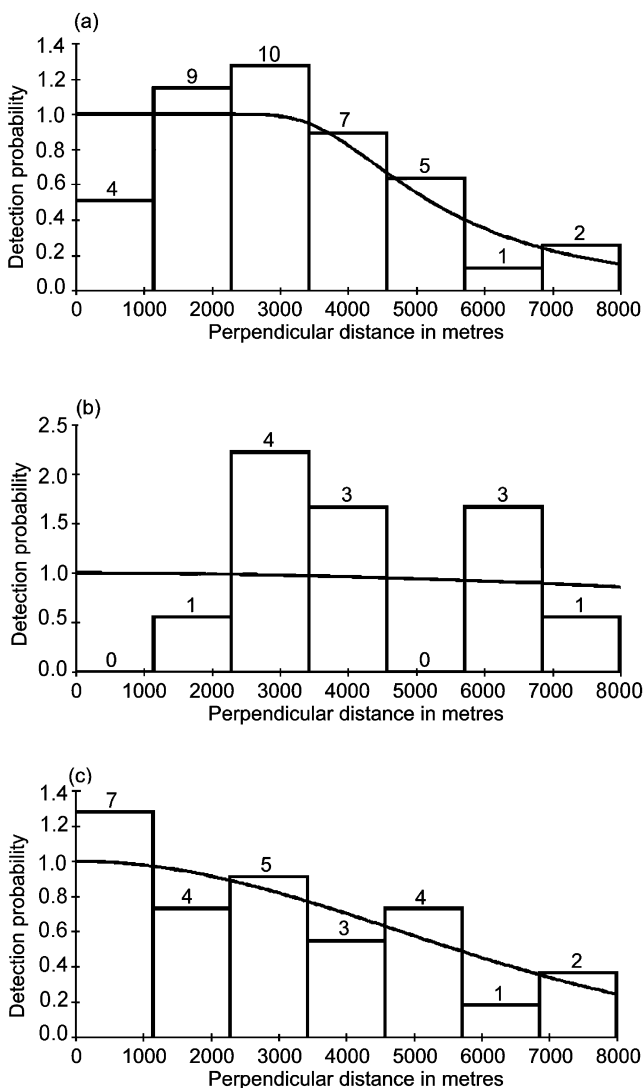


Fig. 2(a-c). Detection functions for sperm whales. Data is from the (a) May 2001; (b) October 2001; and (c) May 2002 surveys. The numbers above the bars represent the number of whales detected.

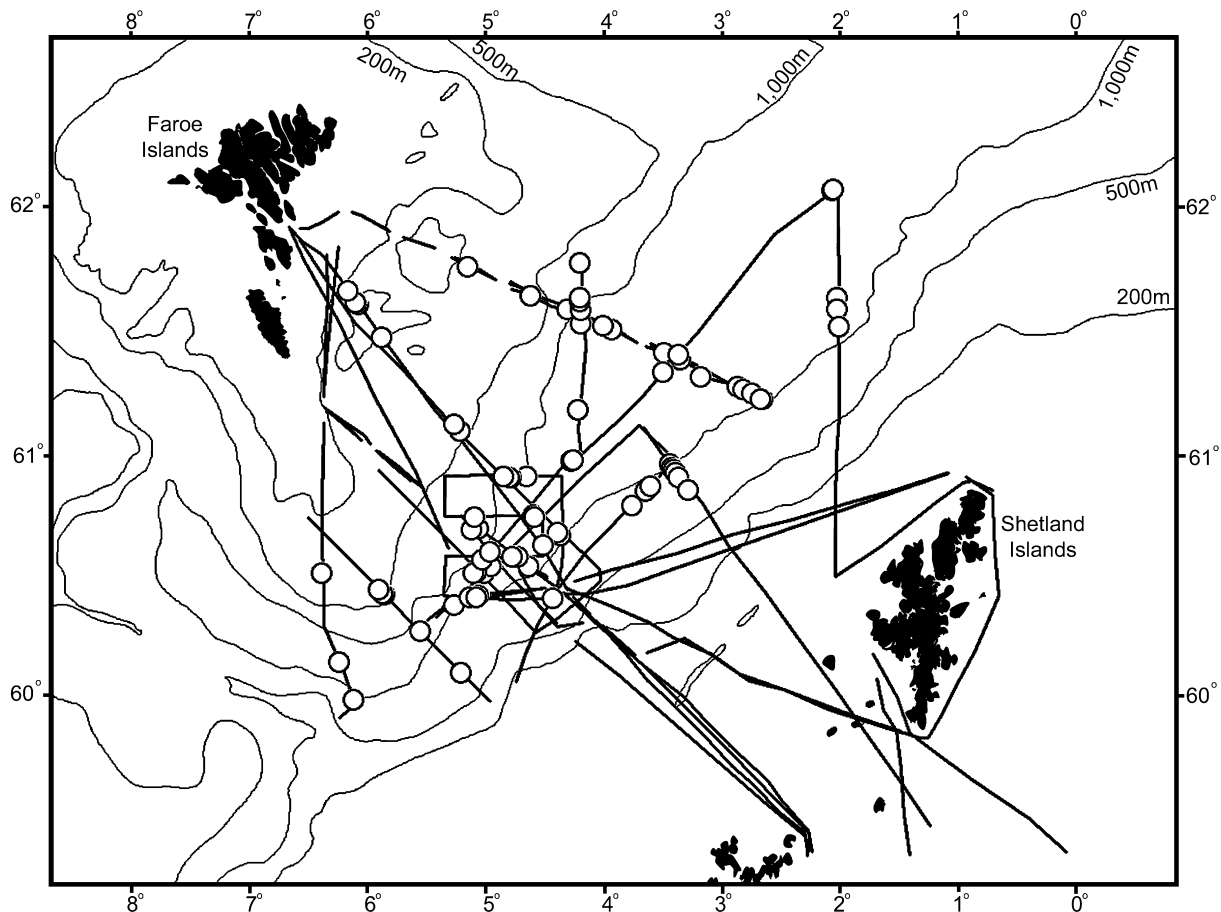


Fig. 3. Acoustic survey track (grey lines) and the locations of individual sperm whales (open circles) in the Faroe Shetland Channel during surveys in May and October 2001 and May 2002. The 200m, 500m and 1,000m contour lines are shown.

when at the water surface and therefore, there was the potential to miss whales on such occasions. Male sperm whales off the coast of Canada typically spend around 8 minutes near the water surface between dives, during which time they are generally silent (Whitehead *et al.*, 1992). At the survey speed of 12 knots in this study and with an effective detection range of 6km, a whale on the trackline would have to be silent for around 32 minutes to remain undetected. It is therefore unlikely that a significant proportion of diving whales were missed during this study, and the assumption that $g(0) = 1$ appears to be valid. However, female sperm whales and their young, living in temperate waters, have been observed to spend several hours a day in a resting or socialising mode during which they rarely produce the sort of regular clicks detected during acoustic surveys. This makes such animals undetectable during acoustic surveys for periods of several hours (Hiby and Lovell, 1989). Although it is not known whether the mature males found in the current study area also have significant non-vocal resting periods, males off Nova Scotia and New Zealand rarely stayed near the surface for prolonged periods (Gordon *et al.*, 1992; Whitehead *et al.*, 1992). To better assess the need for a correction factor to account for silent animals, it would be useful to collect data on patterns of vocal output in this study area and/or to directly measure detection probability using dual-mode independent platform survey techniques.

The estimates of whale density in this study ranged from 0.51 to 2.05 with a combined mean of 1.44 whales per 1,000km². The mean estimate in this study is almost exactly the same as a recent mean density estimate for the 25% of the worlds oceans that have been visually surveyed (Whitehead and Planck, 2002). The estimates are within the lower range

of previous estimates of density in the northeast Atlantic which varied from 0.82 to 10.16 whales per 1,000km² (Øien, 1990). They are also similar to estimates made within the eastern tropical Pacific, where densities of between 0.26 and 1.16 per whales 1,000km² have been recorded (Hammond and Laake, 1981; Laake and Hammond, 1984). However, it is important to note that because the survey tracks in this current study are not a representative sample of the entire region, it is not possible to compute abundance estimates and comparisons with other areas are difficult. Furthermore, it is unlikely that the results are directly comparable to previous estimates from sightings data where it was not possible to correct the estimates for submerged animals. Perhaps more comparable are the results from a similar passive acoustic survey in the Southern Ocean (Leaper *et al.*, 2000) where estimates were lower (between 0 to 0.13 whales per 1,000km²) than those made during this current study.

There appeared to be differences in the density of whales between May and October with fewer whales detected during October than May. This contrasts with results from previous opportunistic surveys that suggested that sightings of sperm whales in the northeast Atlantic peak during the second half of the year (Evans, 1997). However, sample sizes were small and sighting conditions were likely to have played a significant role in the results from this previous study (Evans, 1997). Alternatively, as different routes were surveyed during each of the cruises in this present study, the variation in density may represent relatively fine-scale spatial patterns of whale distribution.

The distribution of whales in the Faroe Shetland Channel is consistent with previous studies showing that sperm whales primarily occur adjacent to, or over the continental

shelf break (e.g. Griffin, 1997; Gordon *et al.*, 1999; Waring *et al.*, 2001; Weir *et al.*, 2001); the majority of whales were detected within the deeper water around the middle of the channel with a smaller number detected over the Faroes Plateau. As with most predators, this pattern is likely to reflect spatial variations in the distribution of prey (Hairston *et al.*, 1960). However, a lack of reliable information about the distribution of prey species in the channel makes it extremely difficult to explore links between the predator and prey distributions.

More survey effort is now required to quantify changes in seasonal and spatial patterns of distribution. With increased effort, it will be possible to collect better information on the effects of background noise and propagation conditions on detection range. In addition, it will be useful to explore how oceanographic, topographical, biological and anthropogenic factors affect seasonal distributions and abundance.

ACKNOWLEDGEMENTS

This work was supported by the Atlantic Frontier Environmental Network. A preliminary feasibility study was supported by Shell UK and the International Fund for Animal Welfare. It was only made possible with the collaboration of the scientists at the FRS Marine Laboratory, Aberdeen who allowed us space onboard *FRV Scotia* and *FRV Cirolana* and accommodated acoustic monitoring within their existing survey programme. We thank Talisman Energy (UK) for the original purchase of the acoustic equipment. We are particularly grateful to the Captain, scientists and crew of the *FRV Scotia* and *FRV Cirolana*, for their invaluable assistance on the cruises. We thank Dave Borchers for his advice on line-transect sampling and Paul Thompson whose comments improved earlier drafts. We also thank Hal Whitehead and an anonymous referee for their suggestions that led to an improved final draft of this paper.

REFERENCES

- Backus, R.H. and Schevill, W.E. 1966. *Physeter* clicks. pp. 510-28. In: K.S. Norris (ed.) *Whales, Dolphins and Porpoises*. Univ. Calif. Press, Berkeley. 789pp.
- Barlow, J. and Taylor, B.L. 1998. Preliminary abundance of sperm whales in the northeastern temperate Pacific estimated from a combined visual and acoustic survey. Paper SC/50/CAWS20 presented to the IWC Scientific Committee, April 1998 (unpublished). 3pp. [Paper available from the Office of this Journal].
- Brown, S.G. 1976. Modern whaling in Britain and the north-east Atlantic Ocean. *Mammal Rev.* 6(1):25-36.
- Buckland, S.T., Anderson, D.R., Burnham, K.P. and Laake, J.L. 1993. *Distance Sampling: Estimating Abundance of Biological Populations*. Chapman and Hall, New York and London. xii+446pp.
- Ciano, J.N. and Huelo, R. 2001. Photo-identification of sperm whales at Bleik Canyon, Norway. *Mar. Mammal Sci.* 17(1):175-80.
- Evans, P.G.H. 1997. Ecology of sperm whales (*Physeter macrocephalus*) in the eastern North Atlantic, with special reference to sightings and strandings records from the British Isles. *Biol. Unserer Zeit* 67-Suppl.:37-46.
- Gillespie, D. 1997. An acoustic survey for sperm whales in the Southern Ocean Sanctuary conducted from the *RSV Aurora Australis*. *Rep. int. Whal. Commn* 47:897-907.
- Gillespie, D. and Leaper, R. 1996. Detection of sperm whale (*Physeter macrocephalus*) clicks and discrimination of individual vocalisations. *Eur. Res. Cetaceans* [Abstracts] 10:87-91.
- Gordon, J. and Steiner, L. 1992. Ventilation and dive patterns in sperm whales, *Physeter macrocephalus*, in the Azores. *Rep. int. Whal. Commn* 42:561-5.
- Gordon, J., Leaper, R., Hartley, F.G. and Chappell, O. (eds.). 1992. *Effects of Whale-Watching Vessels on the Surface and Underwater Acoustic Behaviour of Sperm Whales off Kaikoura, New Zealand*. Department of Conservation, Wellington. 63pp.
- Gordon, J., Matthews, J.N. and Steiner, L. 1999. Distribution and relative abundance of sperm whales and dolphins in the Azores archipelago. Paper SC/51/CAWS25 presented to the IWC Scientific Committee, May 1999, Grenada, WI (unpublished). 11pp. [Paper available from the Office of this Journal].
- Griffin, R.B. 1997. Relationships between odontocete distributions and zooplankton community structure along the southern edge of Georges Bank. *J. Northwest Atl. Fish. Sci.* 22:27-36.
- Gunnlaugsson, T. and Sigurjónsson, J. 1990. NASS-87: Estimation of whale abundance based on observations made onboard Icelandic and Faroese survey vessels. *Rep. int. Whal. Commn* 40:571-80.
- Hairston, N.G., Smith, F.E. and Slobodkin, L.B. 1960. Community structure, population control and competition. *Am. Nat.* 94:421-25.
- Hammond, P.S. and Laake, J.L. 1981. Sperm whale density in the eastern tropical Pacific. *Rep. int. Whal. Commn* 31:761-4.
- Heath, M.R. and Jónasdóttir, S.H. 1999. Distribution and abundance of overwintering *Calanus finmarchicus* in the Faroe-Shetland channel. *Fish. Oceanogr.* 8(Suppl. 1):40-60.
- Hiby, A. and Lovell, P. 1989. Acoustic survey techniques for sperm whales. Paper SC/41/Sp3 presented to the IWC Scientific Committee, May 1989 (unpublished). 60pp. [Paper available from the Office of this Journal].
- Jonsgård, Å. 1977. Tables showing the catch of small whales (including minke whales) caught by Norwegians in the period 1938-75, and large whales caught in different North Atlantic waters in the period 1868-1975. *Rep. int. Whal. Commn* 27:413-26.
- Laake, J.L. and Hammond, P.S. 1984. Estimates of sperm whale density in the eastern Tropical Pacific, 1974-1982. *Rep. int. Whal. Commn* 34:255-8.
- Leaper, R., Chappell, O. and Gordon, J. 1992. The development of practical techniques for surveying sperm whale populations acoustically. *Rep. int. Whal. Commn* 42:549-60.
- Leaper, R., Gillespie, D. and Papastavrou, V. 2000. Results of passive acoustic surveys for odontocetes in the Southern Ocean. *J. Cetacean Res. Manage.* 2(3):187-96.
- Lens, S. 1991. North Atlantic Sightings Survey 1989: Report of the Spanish Cruise. *Rep. int. Whal. Commn* 41:539-43.
- Lewis, T.P., Swift, R., Gonzalbes, P., Butler, J. and Gordon, J. 1998. *Passive Acoustic Monitoring of Cetacean Distribution North-West of the Hebrides*. Hebridean Whale and Dolphin Trust, Mull. 75pp.
- Martin, A.R., Hembree, D., Waters, T.D. and Sigurjónsson, J. 1984. IDCR cruise/aerial survey in the north eastern Atlantic 1982: cruise report. *Rep. int. Whal. Commn* 34:645-53.
- Øien, N. 1990. Sightings surveys in the northeast Atlantic in July 1988: distribution and abundance of cetaceans. *Rep. int. Whal. Commn* 40:499-511.
- Sherwin, T.J., Turrell, W.R., Jeans, D.R.G. and Dye, S. 1999. Eddies and a mesoscale deflection of the slope current in the Faroe-Shetland channel. *Deep-Sea Res.* 46:415-38.
- Sigurjónsson, J. 1985. Sightings survey in the Irminger Sea and off Iceland in 1983. *Rep. int. Whal. Commn* 35:499-503.
- Sigurjónsson, J., Gunnlaugsson, T. and Payne, M. 1989. NASS-87: Shipboard sightings surveys in Icelandic and adjacent waters June-July 1987. *Rep. int. Whal. Commn* 39:395-409.
- Thomas, L., Strindberg, S., Marques, F.F.C., Borchers, D.L., Buckland, S.T., Anderson, D.R., Burnham, K.P., Hedley, S.L. and Pollard, J.H. 2001. Distance 4.0. Beta 4. Research Unit for Wildlife Population Assessment, University of St Andrews, UK. [At: <http://www.ruwpa.st-and.ac.uk/distance/>].
- Thompson, D.W. 1928. On whales landed at the Scottish whaling stations during the years 1908-1914 and 1920-1927. *Fish. Board Scotl. Sci. Invest.* 3:3-39.
- Turrell, W.R., Slesser, G., Adams, R.D., Payne, R. and Gillibrand, P.A. 1999. Decadal variability in the composition of Faroe Shetland Channel bottom water. *Deep-Sea Res.* 46:1-25.
- Waring, G.T., Hamazaki, T., Sheenan, D., Wood, G. and Baker, S. 2001. Characterization of beaked whale (Ziphiidae) and sperm whale (*Physeter macrocephalus*) summer habitat in shelf-edge and deeper waters off the northeast US. *Mar. Mammal Sci.* 17(4):703-17.
- Weir, C.R., Pollock, C.M., Cronin, C. and Taylor, S. 2001. Cetaceans of the Atlantic Frontier, north and west of Scotland. *Cont. Shelf Res.* 21:1047-71.
- Whitehead, H. and Planck, M. 2002. Estimates of the current global population size and historical trajectory for sperm whales. *Mar. Ecol. Prog. Ser.* 242:295-304.
- Whitehead, H., Brennan, S. and Grover, D. 1992. Distribution and behaviour of male sperm whales on the Scotian Shelf, Canada. *Can. J. Zool.* 70(5):912-8.

Date received: 19 September 2002.

Date accepted: 10 January 2003.