

Bioacoustics Research Program
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Passive acoustic monitoring of whale distribution in the Faroe-Shetland Channel

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Passive acoustic monitoring of whale distribution in the Faroe-Shetland Channel

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Final report to the Atlantic Frontier Environmental Network

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2.0 Introduction

In recent years there has been increasing concern over the potential impacts of marine industrial noise on whales and dolphins, particularly where oil-related activities occur in areas containing high concentrations of cetaceans.

In response to this concern, BP Amoco, and subsequently the Atlantic Frontier Environmental Network (AFEN), funded a series of projects on the distribution of cetaceans in the Faroe Shetland Channel, focusing particularly around the Foinaven Schiehallion fields. This work was co-ordinated by the Joint Nature Conservation Committee, and carried out through a collaboration between the University of Aberdeen and the Cornell Laboratory of Ornithology.

Early phases of this work highlighted the importance of the Faroe Shetland Channel for large cetaceans such as fin whales (*Balaenoptera physalus*) and sperm whales (*Physeter macrocephalus*), and also discovered significant levels of industrial noise in this area. A key aim of these earlier studies was to develop techniques using arrays of "pop-ups" to track individual whales; thereby providing greater insight into their behaviour and residence times in this area. Detailed findings from these earlier studies can be found in Swift & Thompson (1999) and Swift et al. (2002).

This report outlines work carried out during the final phase of this study between April 2002 and June 2003, and summarises the key findings of the overall project. The principal aims of this part of the study were to estimate levels of received noise for individual fin whales in the Foinaven-Schiehallion region, and to assess the behavioural responses of these whales to different sources and levels of industrial noise. In addition, we aimed to extend our time-series of data on spatial and temporal variation in the wider-scale distribution of cetacean calls in the Faroe Shetland Channel.

The assessment of behavioural responses and received noise levels depended upon the successful deployment and recovery of an array of "pop-ups" during the autumn of 2002, thereby allowing us to track individual whales. Unfortunately, problems with logistic support, equipment failure, and the loss of devices has meant that reliable tracking of individual whales has proved impossible in this harsh and heavily fished environment. Nevertheless, whilst studies based upon "pop-up" arrays were not possible, recordings from single "pop-ups" in the summer of 2002 extended our earlier coverage of seasonal patterns of fin whale vocal activity, and highlighted that endangered blue whales (*Balaenoptera musculus*) are present within the Faroe Shetland Channel. Results from this work further highlighted the importance of the Faroe Shetland Channel for fin whales and, in combination with data from sighting surveys, suggest that this species is present in the area throughout the year. Pop-up data have also highlighted the presence of low frequency industrial noise from thrusters and seismic surveys within the study area, but it not possible to fully assess the precise impact of this noise upon the whales in this area. Unexpectedly, two of the "pop-ups" that had been lost after the autumn 2002 deployment were subsequently recovered during a Fisheries Research Service (FRS) cruise in the area in 2003, meaning that some further data are now also available for additional analysis.

Alongside these studies using remotely deployed “pop-ups”, ship-based acoustic studies were carried out in May and October 2002 in collaboration with FRS. These surveys allowed us to extend our time-series of data on the wide-scale distribution of fin whales, sperm whales and oceanic dolphins in the Faroe Shetland Channel. Data sets on oceanic dolphins were used to explore how distribution is influenced by various environmental factors such as water depth, and ongoing work at the Universities of Aberdeen and St Andrews is now extending this approach for sperm whales. Work carried out under this series of AFEN projects has therefore permitted the development of an important time-series of data, particularly for sperm whales. This now provides excellent opportunities for further collaborative studies with FRS that can monitor changes in distribution and relative abundance in relation to changes in ocean climate change and anthropogenic activities.

This report supplements the more detailed presentations in our earlier report (Swift et al. 2002) by providing summaries of results from each of the key areas of the project. Where analyses or publications have developed significantly since that report, more detailed treatment of these results in appendices. A further appendix provides information on all the key outputs from the series of contracts carried out for BP Amoco and AFEN.

3.0 Year round monitoring of blue and fin whale calls and their acoustic environment

Results of previous studies have suggested that the Faroe Shetland Channel is particularly important to fin whales and that the wider north-east Atlantic is important to both blue and fin whales (Thompson 1928; Weir et al. 2001). In this study we used pop-ups (autonomous bottom mounted recording systems) to extend our time-series sampling on the temporal occurrence of whales in the vicinity of the Foinaven Schiehallion development area.

Pop-ups were deployed in January 1999, October 2000, March 2001, October 2001, May 2002 and October 2002. These sampled at varying rates and for varying lengths of time (Fig. 3.1). Pop-ups were moored to the seafloor and retrieved using acoustic releases. Data were archived to HDD onshore and analysed for blue and fin whale vocalisations as described in Swift et al. (2002). In addition, we catalogued various sources of anthropogenic noise, including airgun sounds from seismic ships.

Coverage spans 79% (288 days) of the year (Figure 3.1), and includes continuous data from the longest single pop-up deployment between May and September 2002 (124 days). Fin whale calls were detected as early as August and as late as May (Fig. 3.2). Call rates varied throughout the year and were highest in October-November and lowest in the summer (May- August). Blue whale calls were detected as early as August and as late as November. Vocal rates varied throughout the year and were highest during the autumn. Low frequency seismic pulses (<100 Hz) were detected on 83 days during the summer. For the majority of this period seismic activity was continuous. Detections of seismic activity and whale activity could have been higher but for masking by other sources of anthropogenic noise, including noise from propellers and thrusters.

The deployment during the summer of 2002 confirmed that fin whale vocal activity is low during this season, even though sightings of this species peak over the summer. The extended time series confirms that the Faroe Shetland Channel is important in the autumn and winter, with the vocal activity over this period coinciding with the known breeding season of fin whales in the North Atlantic. Recordings from the summer 2002 deployment also confirmed the presence of blue whales in the Faroe Shetland Channel in late summer and early autumn, and highlighted the need to consider potential acoustic impacts from high-energy seismic surveys on this endangered species.

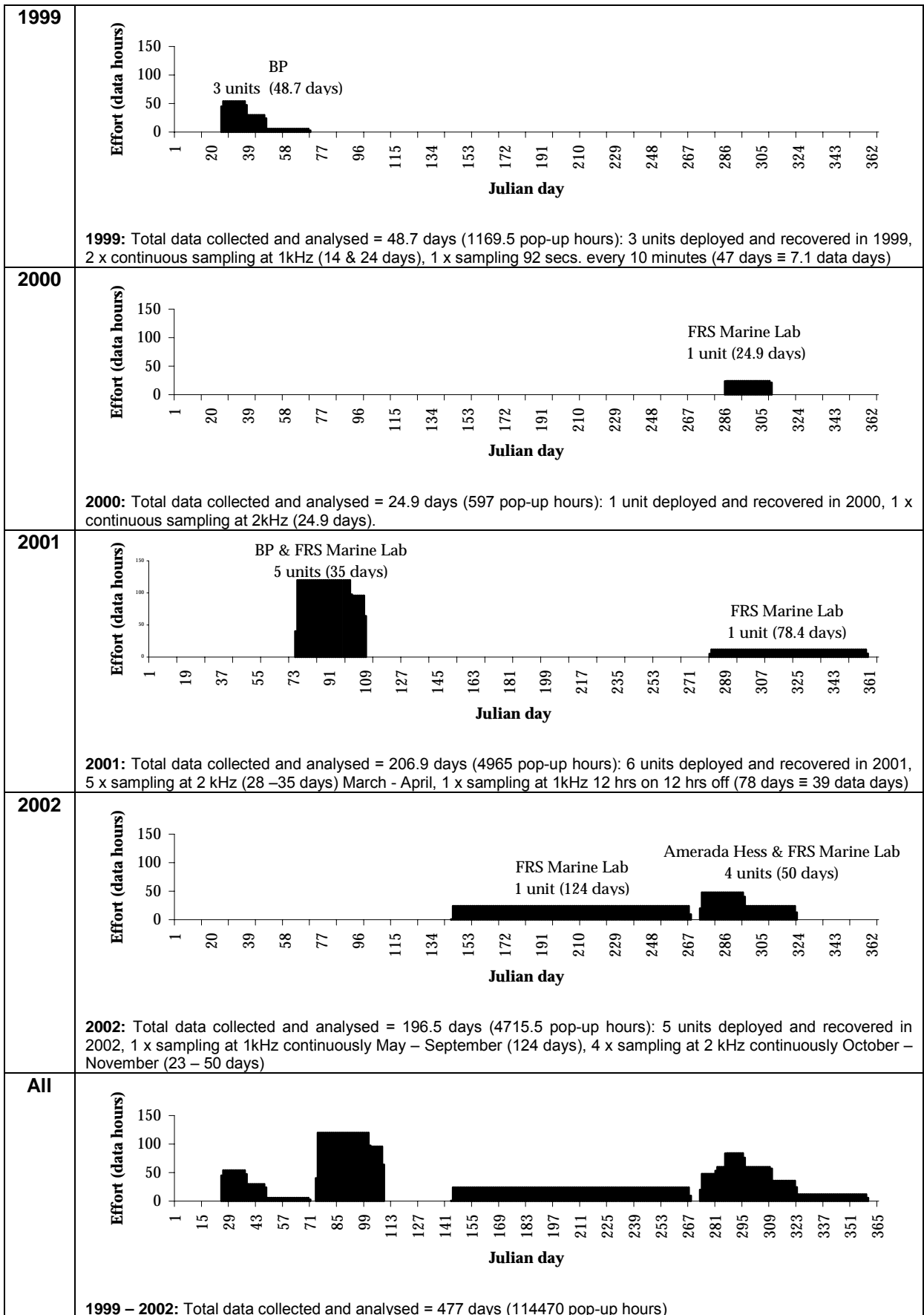


Figure 3.1. Pop-up deployment histories and daily coverage (hours of recorded data) between January 1999 and October 2002. Where logistic support has been provided for pop-up deployments or retrievals those companies or organisations involved have been credited.

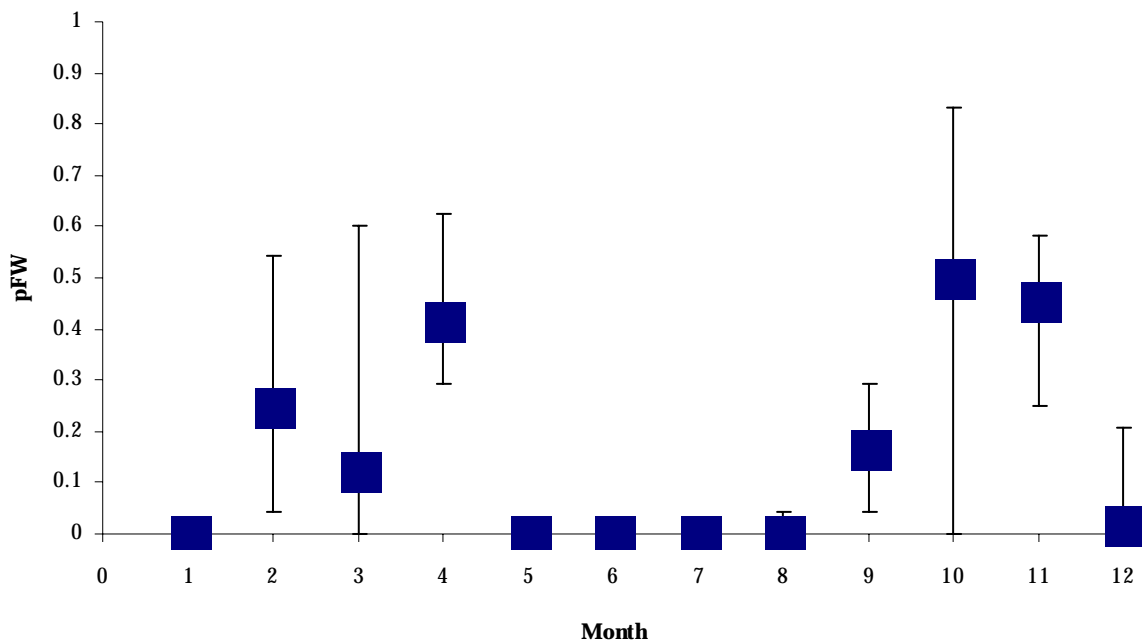


Figure 3.2. Probability of detecting fin whales over the year. Boxes represent the median value and error bars the 25% and 75% quartiles. PFW (the Bernoulli probability of detecting fin whales) was calculated as the number of frames (20 minute cuts) in which fin whale calls were detected divided by the total number of frames for a given period of time.

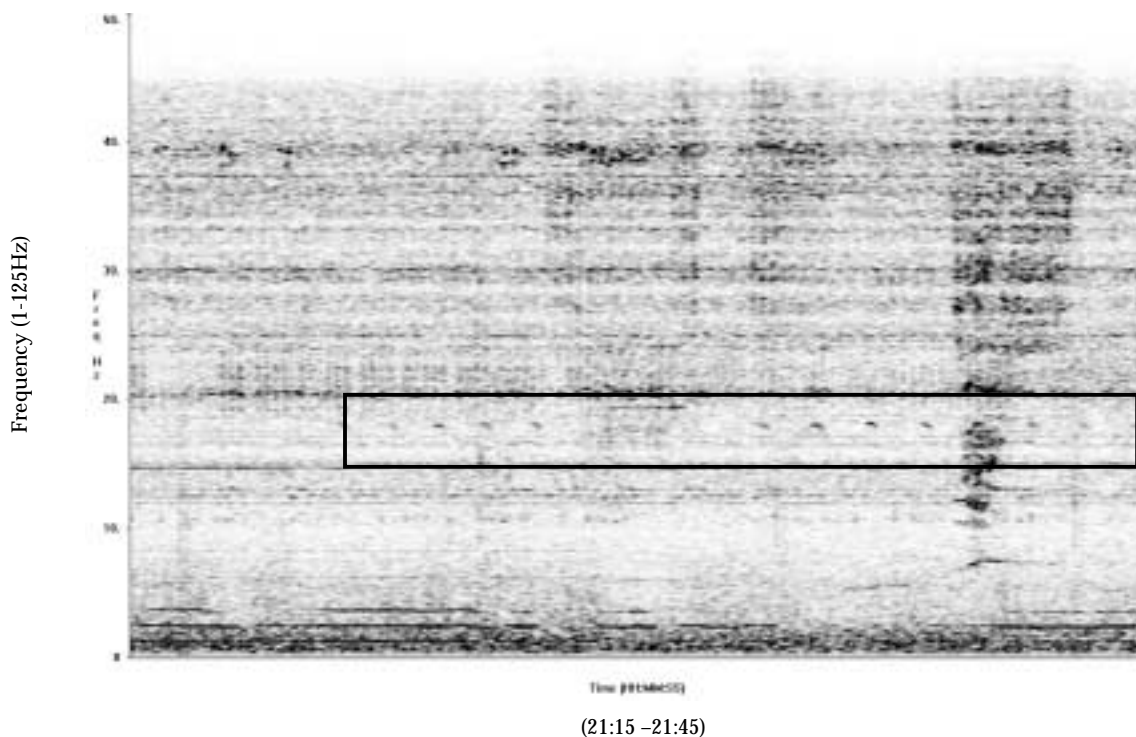


Figure 3.3 Spectrogram example of a vocalising blue whale recorded in the vicinity of the Foinaven and Schiehallion development area. All recordings were made using a 1Khz sample rate and later decimated to 200Hz. Spectrograms were produced in Syrinx v2.1H (© John Burt, 1999) using an FFT size of 1024 and Blackman Window function. The X-axis is time in minutes. The Y-axis is frequency (Hertz), the scale is 1 - 100Hz. Grey scale shading represents sound pressure level, where the darker the shading the more intense the sound.

4.0 The underwater acoustic environment of fin whales in the vicinity of an oil and gas development area

Hearing in the mysticete whales is poorly understood, and direct observations (electrophysiological or behavioural) of hearing sensitivity are not possible because of their size and their pelagic life histories. Nevertheless, evidence from cochlear mechanics suggests that baleen whales are well adapted for hearing in the low frequency range (Ketten 1991, 1992).

Traditionally assumptions about hearing sensitivity in those species for which no audiograms exist have been based on our knowledge of their vocalisations (frequency range and source level), i.e. an animal is likely to be most sensitive sounds made across the frequency range of its vocalisations and its hearing threshold must fall somewhere below the source level of these vocalisations. Although a good rule of thumb these assumptions are a subjective assessment of the hearing capabilities of a particular species, and as such make it difficult for managers to make recommendations about appropriate mitigation.

In this study we use a model mysticete audiogram as a step towards developing a more empirical approach to assessing the risk to fin whales from anthropogenic noise in oil and gas development area. Clark and Ellison (in press) describe a model mysticete audiogram that is based on our current knowledge of the relationship between hearing thresholds and ambient noise levels in terrestrial mammals and the bottlenose dolphin. Hearing thresholds in this model are given by:

$$\text{Threshold} = \text{LNANH} + \text{CR} \quad \text{Equation 1.}$$

Where LNANH is the lowest natural ambient noise in habitat and CR is the Critical Ratio. Critical Ratios are defined as the level of a pure tone signal in white noise when it is just perceptible; in terrestrial mammals critical ratios typically lie between 16dB and 24dB above the lowest natural ambient noise in habitat. We use these values of CR and ambient noise data from Urick (1983) to define our mysticete / fin whale audiogram (Figure 4.1):

$$\begin{aligned} \text{Lower limit for the threshold of hearing} \\ = \text{LNANH (Urick, 1983) + 16Db} \quad \text{Equation 2} \end{aligned}$$

$$\begin{aligned} \text{Upper limit for the threshold of hearing} \\ = \text{LNANH (Urick, 1983) + 24dB} \quad \text{Equation 3} \end{aligned}$$

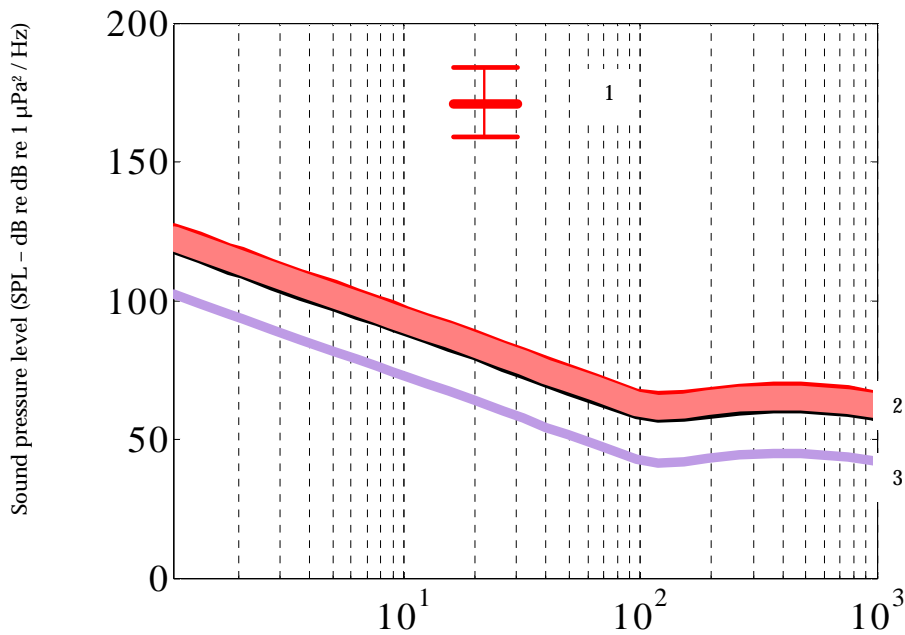


Figure 4.1: Model fin whale audiogram. X axis is frequency in hertz, Y axis is sound pressure level dB re dB re 1 $\mu\text{Pa}^2 / \text{Hz}$. Key: (1) SPL (Sound pressure level) of fin whale 20Hz pulse vocalisations (2) Fin whale auditory threshold (Upper limit = LNaNH + 24dB, Lower limit = LNaNH + 16dB), (3) LNaNH (Lowest Natural Ambient Noise in Habitat, Urick 1983).

Having developed this simple model we estimated received noise levels in 1/3rd octave bands every minute, across a 1Khz bandwidth, at each pop-up to determine how these related to our audiogram for the deployments in January 1999, October 2000 and March 2001. These data were then pooled and the following summary statistics calculated in each 1/3rd octave band: 50% percentile(median), 5 and 95% percentiles. Additional information about industrial activities and shipping movements within this area were used to identify sources of low frequency noise, and Arcview GIS 3.3 (ESRI Ltd) used to calculate a distance from the centre of the development area to each pop-up. Distance data was then used with 1/3rd octave band levels to determine received levels at 8 and 40 km.

All pop-up recordings were characterised by high levels of low frequency noise associated with the dynamic positioning systems used on the Floating Production Storage and Offloading facilities (FPSO's), supply vessels and tankers using the development area (Figure 4.2). In addition, summer recordings were dominated by seismic activity from geophysical surveys, where around the clock seismic activity was identified on 83 days in a 124 day deployment. Noise levels ranged from as high as 134 dB re 1 $\mu\text{Pa}^2 / \text{Hz}$ in the 1-3 Hz band, to as low as 51 dB re 1 $\mu\text{Pa}^2 / \text{Hz}$ in the 355-447 Hz frequency band. Noise levels in two fin whale bands (18-22Hz and 22-28Hz) ranged between 120 dB re 1 $\mu\text{Pa}^2 / \text{Hz}$ and 49 dB re 1 $\mu\text{Pa}^2 / \text{Hz}$ at distances of 8.5 and 40Km respectively. Predicted source spectrum levels ranged between a maximum of 209 dB re 1 $\mu\text{Pa}^2 / \text{Hz}$ and a minimum of 147 dB re 1 $\mu\text{Pa}^2 / \text{Hz}$; and were similar to those previously recorded from drillships and supertankers.

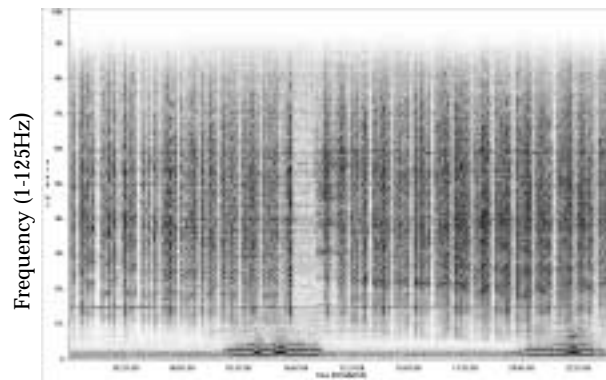


Figure 4.2a: High-energy seismic pulses.

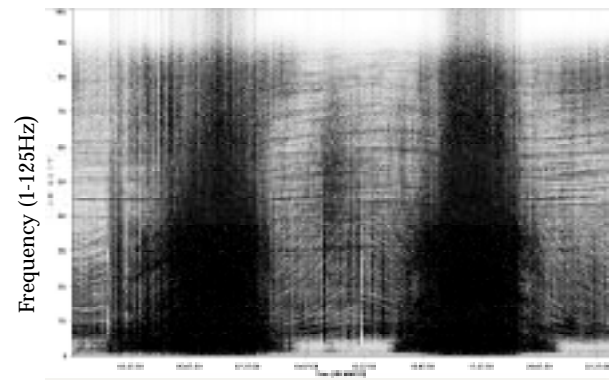


Figure 4.2b: High-energy seismic pulses and propeller / thruster activity.

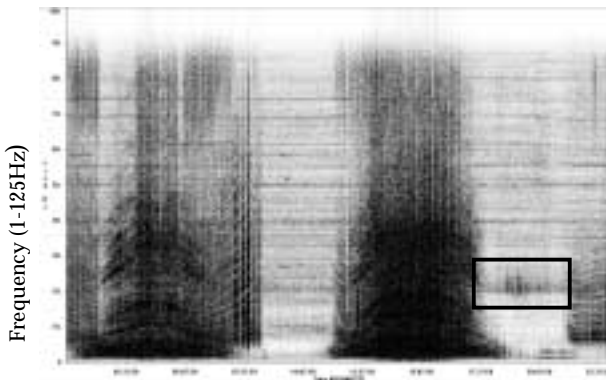


Figure 4.2c: High-energy seismic pulses, propeller / thruster activity and a vocalising fin whale (box).

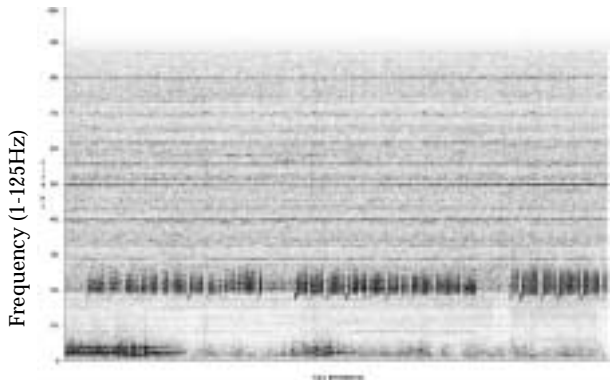


Figure 4.2d: Vocalising fin whale (*Balaenoptera physalus*) from figure 4.2c enlarged.

Figures 4.2 a, b, c & d: Spectrogram examples of anthropogenic and natural noise sources recorded in the Foinaven and Schiehallion development area. All recordings were made using a 1Khz sample rate and later decimated to 200Hz. Spectrograms were produced in Syrinx v2.1H (© John Burt, 1999) using an FFT size of 1024 and Blackman Window function. The X-axis in all cases is time (hours), the scale in figures 4.2 (a), (b) & (c) is 24 hours and in figure 2(d) 30 minutes. The Y-axis in all cases is frequency (Hertz), the scale is 1 - 100Hz. Grey scale shading represents sound pressure level, where the darker the shading the more intense the sound.

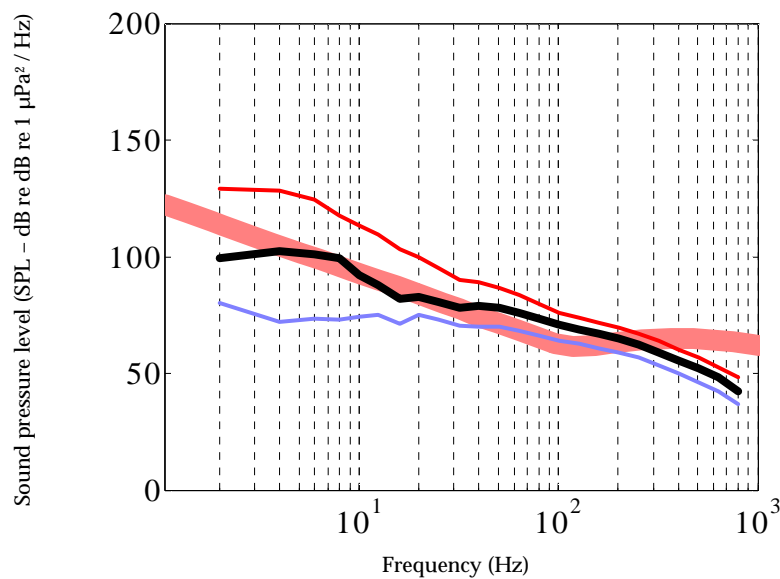


Figure 4.3. The relationship between received noise levels in the Foinaven Schiehallion development area and our model fin whale audiogram. The X-axis is frequency (1-1000 Hz), and the Y-axis is sound pressure level dB re $1 \mu\text{Pa}^2 / \text{Hz}$. The thick pink line is the model fin whale audiogram, the red line the 95th percentile of ambient noise levels, the black line the 50th percentile of ambient noise levels and the blue the 5th percentile of ambient noise levels, noise levels were measured in $1/3^{\text{rd}}$ octave bands.

A total of 5680 hours of pop-up data were analysed, and for 50% of the time (2840 hours) noise levels in 1/3rd octave bands exceeded our predicted lower limit for the threshold of mysticete hearing (Urick 1983 Ambient + 16dB), and for 25% (1420 hours) noise levels exceeded our predicted upper limit for the threshold of hearing (Urick 1983 Ambient + 24dB), figure 4.3. These results were equally valid when distance from noise sources was taken into account and similar results were obtained from pop-ups recording at 8.5 and 35km. It is important to point out that 1/3rd octave band analysis underestimates overall received noise levels, and in many cases received noise levels were sufficiently loud to mask fin whale vocalisations (Figure 2c). Charif and Clark (1999) reported that excessive levels of industrial noise prohibited determination of whether or not fin whales were vocalizing in 429 hours of data (47.9%). It is not possible to fully assess any long term impacts of this noise but, if the assumptions of this model are correct, then we estimate that noise from the Foinaven and Schiehallion development area would be audible to fin whales for 50% of the year at distances up to 40Km. These findings re-enforce previous recommendations to consider cumulative effects of anthropogenic low frequency on the efficiency with which these animals forage, navigate and communicate (Croll et al. 2001)

5.0 Distribution and seasonal density of sperm whales

Results from previous surveys suggest that an area of the north-east Atlantic, the Faroe Shetland Channel is important for cetaceans (Weir et al. 2001). This study utilised passive acoustic survey techniques to evaluate the density of sperm whales in the Faroe Shetland Channel.

Two-week surveys were carried out during oceanographic cruises in May and October 2001 and 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. To calculate the density of whales during surveys we applied standard line transect techniques. The effects of sea conditions and survey vessel on our ability to detect whales were tested; the encounter rate and effective strip-width (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. There appeared to be seasonal variation in the density of whales; the density was lower during the October surveys than during the May surveys (Table 5.1).

Sperm whales were distributed across most of the Faroe Shetland Channel. The majority of whales were detected in the deep water of the mid-channel. No whales were detected on the continental shelf of the Shetland side of the channel (Figure 5.1).

This study provides the basis for meaningful hypothesis generation for future studies. It has also yielded a better understanding of the factors underlying the spatial and seasonal distribution patterns of sperm whales in this area, and underscores the importance of integrating data on oceanographic, biological and anthropogenic determinants with survey data.

Table 5.1. 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.

	Effort (km)	esw (km)	n	\hat{D} (whales / 1000km ²)
May 2001	1676	5.53 (0.77)	38	2.05 (0.44)
October 2001	1536	7.6 (2.93)	12	0.51 (0.24)
May 2002	1364	5.41 (0.947)	26	1.75 (0.46)
October 2002	633	-	0	0 (0)
Combined	-	-	-	1.08 (0.83)

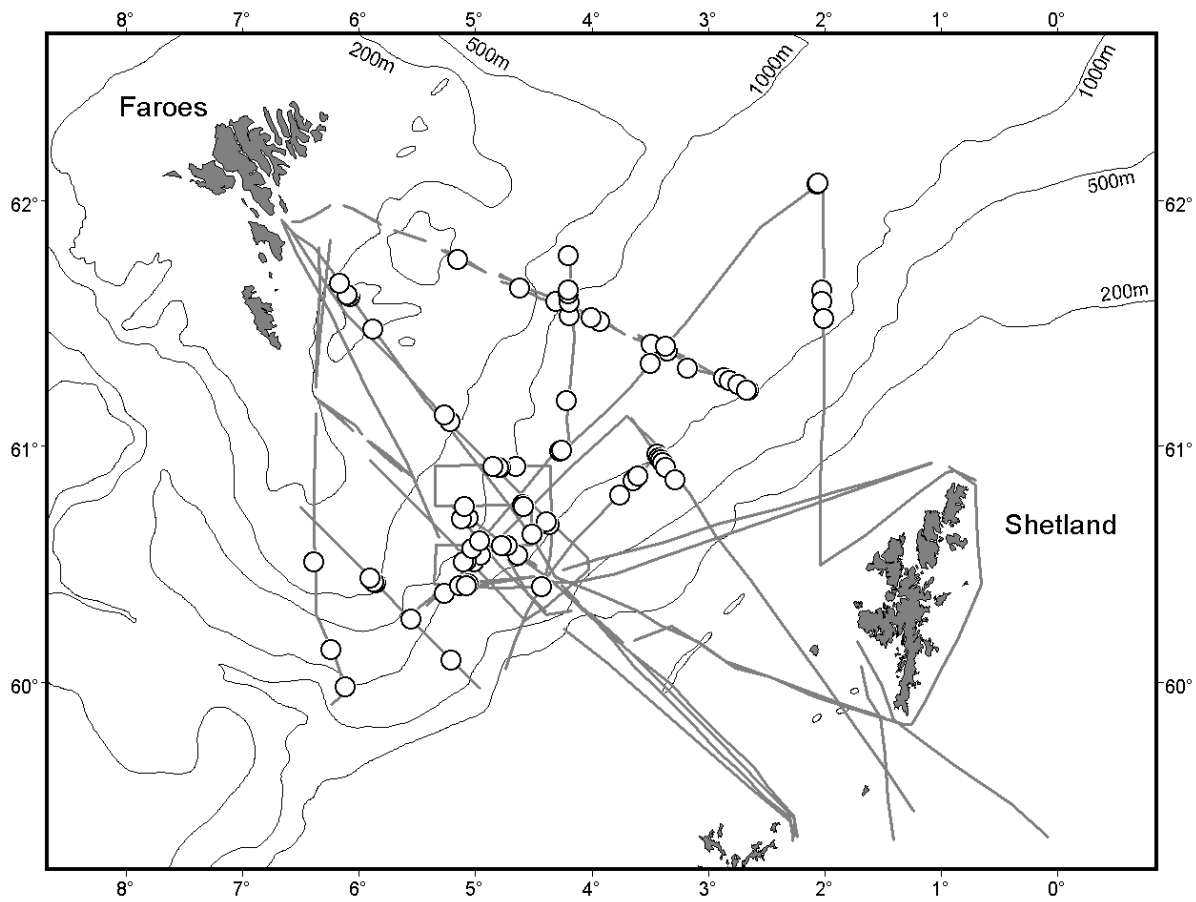


Figure 5.1. Acoustic survey track (grey lines) and the locations of individual sperm whales (open circles) in the Faroe Shetland Channel during surveys in May and October 2001 and 2002. The 200m, 500m and 1000m contour lines are shown.

6.0 Environmental models of oceanic dolphin distribution

The distribution of oceanic dolphins is clearly influenced by a range of environmental determinants. However, relationships between dolphin distribution and oceanography are dynamic and as such, results can prove to be extremely complex. The primary aim of this study was to evaluate the distribution of oceanic dolphins in the northeast Atlantic using passive acoustic survey techniques. We then relate the distributions of dolphins to key oceanographic variables and to the underwater topography of the area. Passive acoustic surveys for dolphins were carried out in the north-east Atlantic during two-week oceanographic cruises in May and October 2001 and May and October 2002.

The acoustic equipment to detect dolphins consisted of a towed stereo hydrophone streamer, 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). A two-person team worked in shifts to monitor the signals from the hydrophone twenty-four 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 were recorded to a database; vessel noise, sea noise, remote ship noise, strength of dolphin whistles and strength of dolphin clicks.

The relationship between dolphin occurrence and oceanographic variables was examined within a generalised additive modelling framework. Only data from the 2001 surveys were used to construct the environmental model. To test the predictive power of the resultant model, a cross validation approach was used to evaluate the accuracy of the model. A series of model predictions, based on the data collected during the 2002 surveys, were calculated at each step in the model building process. These predictions were then tested against the actual occurrence of dolphins from the 2002 data using generalised linear models. The model that provided the best predictor of the 2002 data was identified as the "best fit" model.

Dolphins were detected acoustically during each of the surveys throughout the study area (Figure. 6.1). The proportion of listening stations where dolphins were detected ranged from 0.02 during May 2001 to 0.34 during October 2001. Dolphins were heard across the majority of the channel. However, most detection were made within the deep water of the mid-channel.

The results of the modelling suggest that several environmental variables were significant influences on the probability of detecting dolphins. The "best-fit" model contained the variables month, water depth and time of day. Detection probability peaked during October and was at a minimum during May. In addition, the detection rate of dolphin calls varied throughout the day; the number of calls peaked between midnight and dawn and was at a minimum during the afternoon. Water depth was also found to have a significant effect with detection probabilities peaking in depths of around 1000m (Figure 6.2).

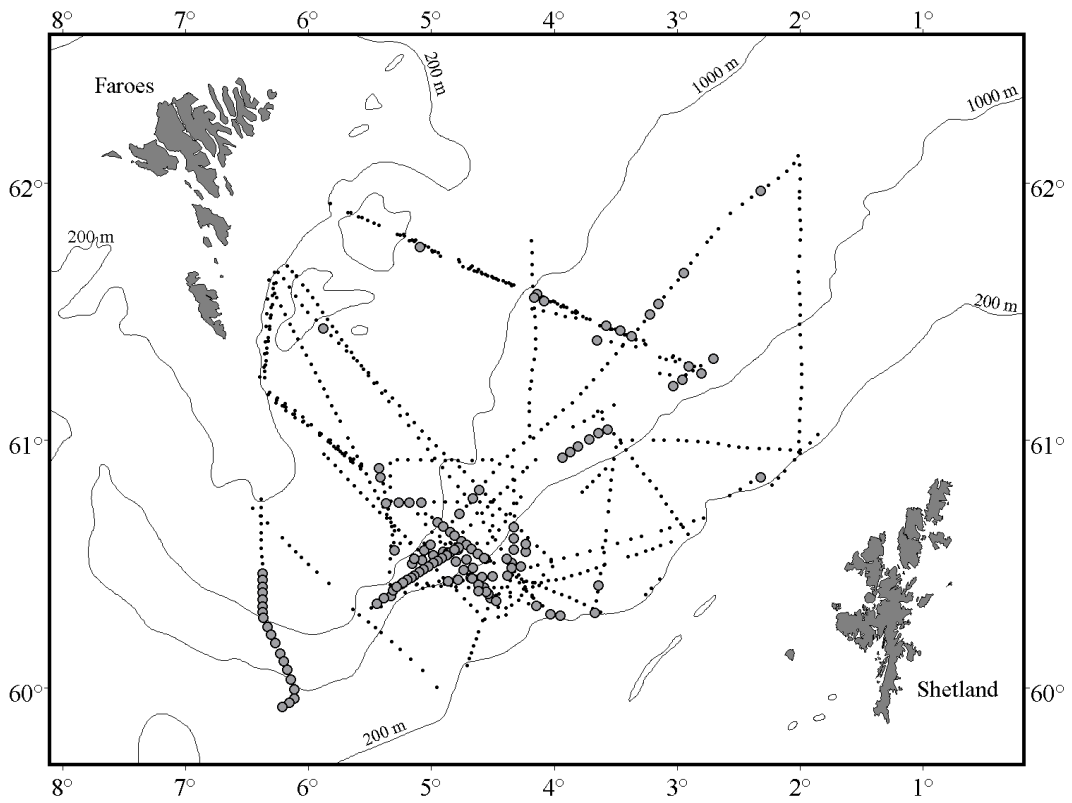


Figure 6.1. Map of the study area in the north-east Atlantic showing the UK, Faroes islands and Shetland islands. The locations of the acoustic listening stations are shown by the black dots and the locations where dolphins were heard are shown by the large grey dots. The contour lines show water depths of 200m and 1000m.

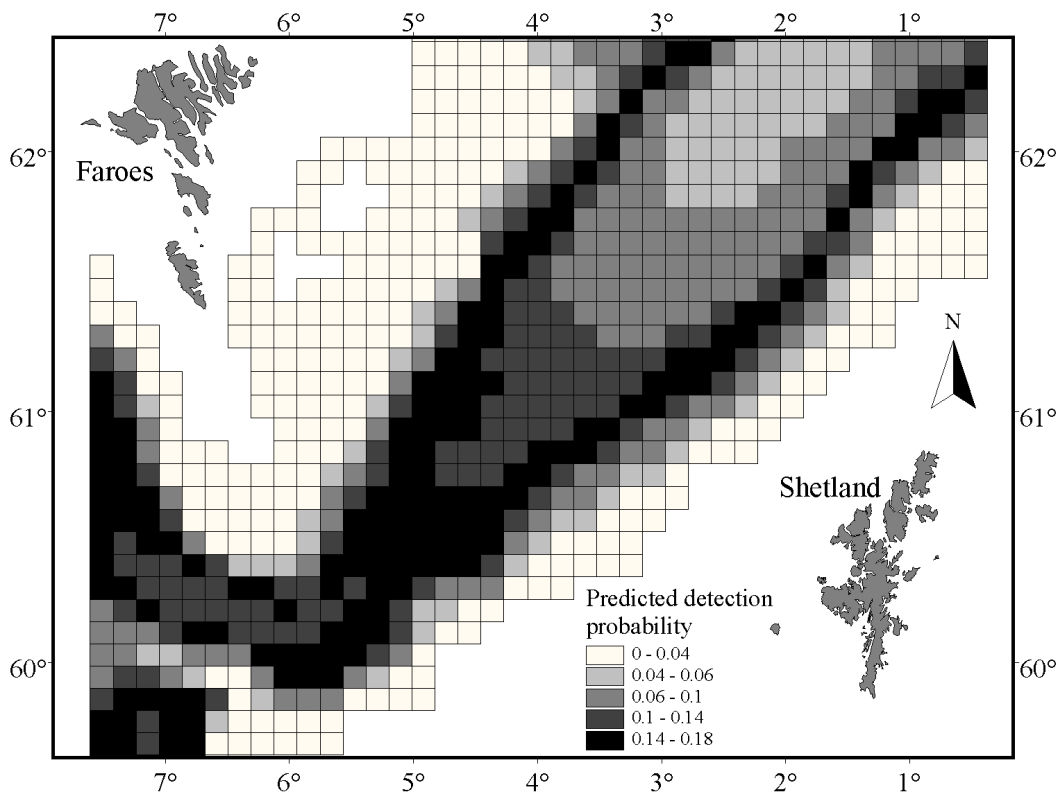


Figure 6.2. Predicted distribution of dolphins in the Faroe Shetland Channel, based on the "best fit" environmental model. The values for month and time were set to standard values of October and 0700 respectively. The model was created using data from 2001 and was tested for its predictive power against data from 2002.

This study provides the first quantitative data on the influence of environmental determinants on the offshore distributions of dolphins in the northeast Atlantic. The results support previous studies showing that dolphins are widespread throughout the offshore regions of the northeast Atlantic. We have now demonstrated that patterns of distribution are closely linked to the environmental regime within the area.

The predictive power of the final model appeared to be relatively robust; with the data collected during 2001 providing a good predictor of the distribution of dolphins in 2002. This reinforces the significance of the model and provides a solid framework for future predictions of dolphin distributions based on environmental data across the northeast Atlantic. Consequently, these types of model offer managers a valuable tool for predicting the occurrence of dolphins within different regions and provide a basis for more informed management decisions to be made in this area of the northeast Atlantic.

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8.0 Acknowledgements

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Appendix 1. Sperm whale distribution and seasonal density in the Faroe Shetland Channel

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ABSTRACT

Results from previous surveys suggest that an area of the north-east 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 Faroe Shetland 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. To calculate the density of whales during surveys we applied standard line transect techniques. The effects of sea conditions and survey vessel on our ability to detect whales were tested; the encounter rate and effective strip-width (*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 1000km² 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 north-east Atlantic but a number of data sources (e.g. Brown, 1976; Gunnlaugsson and Sigurjónsson, 1990; Thompson, 1928; 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 northeast Atlantic (Brown, 1976; Jonsgard, 1977). More recently, dedicated sighting surveys showed that sperm whales are distributed widely throughout oceanic waters in the north-east Atlantic (Ciano and Huele, 2001; Lens, 1991; Martin, et al., 1984; Øien, 1990; Sigurjónsson, 1985; Sigurjónsson and Gunnlaugsson, 1989). 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 per 1000km². 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 in these two previous 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 north-west 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 conditions in these waters during winter (Evans, 1997). This possibility is supported by recent acoustic surveys in these areas that indicate 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 north-west 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 north-east 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 1400 metres 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; 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 that they are 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 been shown to be a highly effective survey method for this species (Barlow and Taylor, 1998; Gillespie and Leaper, 1996; Leaper, *et al.*, 1992).

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 between 7th May 2001 and 21st May 2001, 4th Oct 2001 and 18th Oct 2001 from the *FRV Scotia*, a 68 metre oceanographic research vessel and between 15th and 28th May 2002 from the *FRV Cirolana*, a 73 metre oceanographic research vessel.

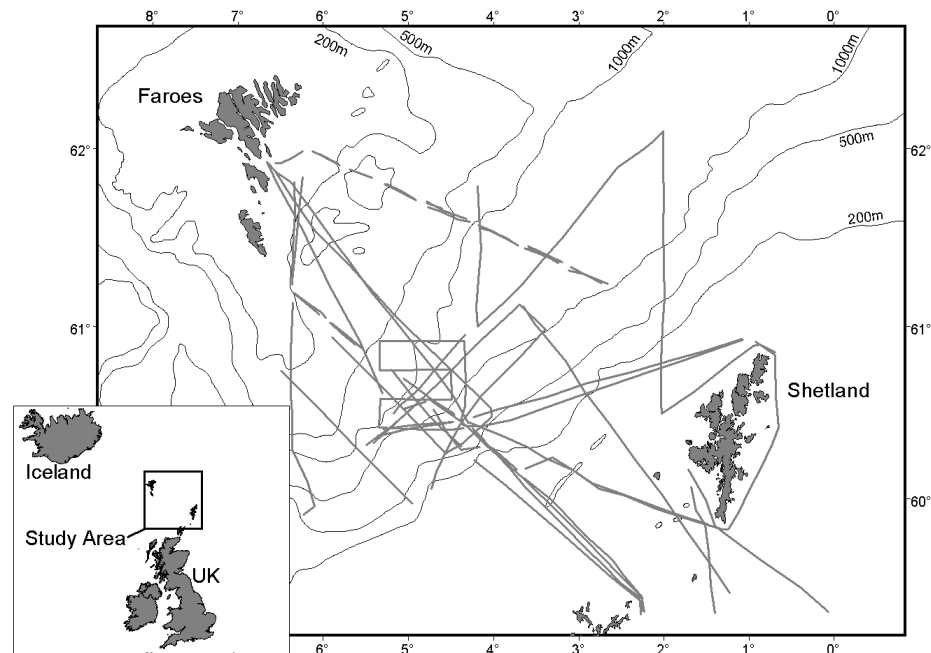


Fig. 1. The location of the study area in the Faroe Shetland Channel (inset), showing the track of the acoustic surveys for sperm whales during May and October 2001 and October 2002. The 200m, 500m and 1000m contour lines are shown.

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 15 kHz 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 400 metre strengthened cable. At speeds of 10 knots, this design of array with a 400 metre cable has been found to tow at around 5-6 metres 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 sixty-metre 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 400 Hz or 1600 Hz 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 *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 twenty-four 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 were recorded to a database using the *Logger 2000* 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 *Logger 2000* made thirty-second 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, we set the programs software filters to a band pass between 2 and 6 kHz to reduce false triggers from low frequency vessel noise and from the survey vessel's 18 kHz 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.* (2001). 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.* (2001) 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

To calculate the density of whales during surveys we applied standard line transect techniques. 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 don't 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 (Gillespie, 1997; Leaper, *et al.*, 1992).

To assess the potential effects of sea conditions and survey vessel on our ability to detect whales, the encounter rate (number of whales per 100 km) 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 1676 km were surveyed in May 2001, 1536 km in October 2001 and 1365 km 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 vessel's cruising speeds 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 378 metres to 14.1 kilometres 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.

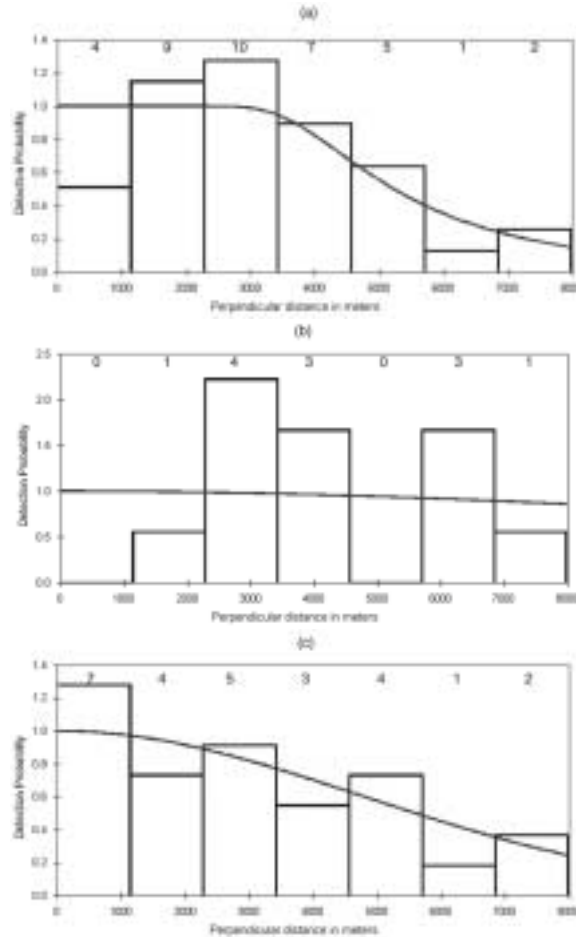


Fig. 2 (a-c). Detection functions for sperm whales. Data is from the (a) May 2001, (b) October 2001 and (c) May 2002 surveys. The numbers in parentheses above the bars represent the number of whales detected.

The esw was largest in sea states 1 & 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 & 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 5.53 km, 7.6 km & 5.41 km for the data from the May 2001, October 2001 & 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 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, thirteen whales were detected in waters shallower than 500 m 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).

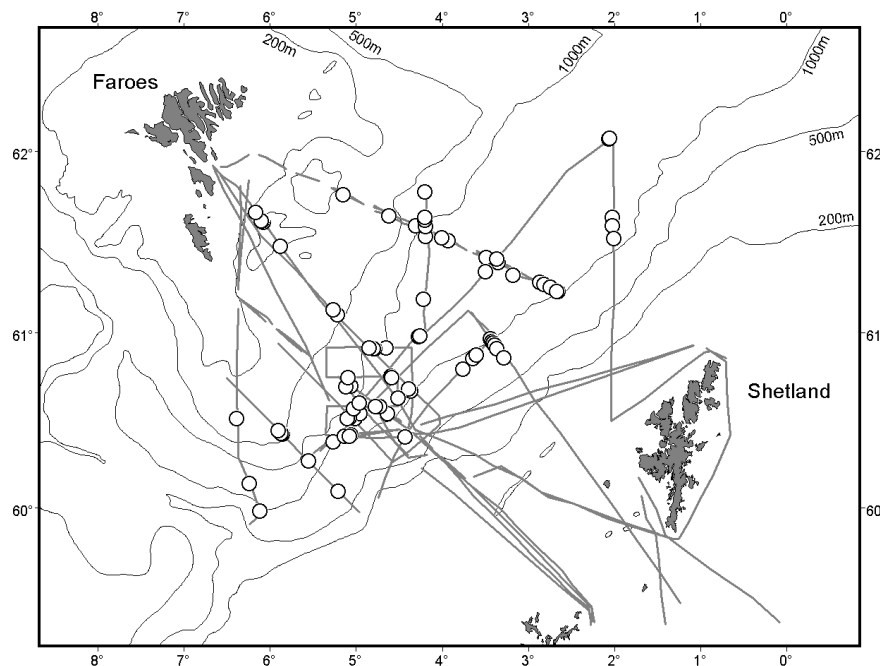


Fig. 3. Acoustic survey track (grey lines) and the locations of individual sperm whales (open circles) in the Faroe Shetland Channel during surveys in May and October 2001 and May 2002. The 200m, 500m and 1000m contour lines are shown..

DISCUSSION

This study presents current data on density of sperm whales within the Faroe Shetland Channel which compliments 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 north-east 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 5 km and 7 km in this study. This is lower than the *esw* calculated in a previous study using similar equipment (Leaper, *et al.*, 2001); 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.* (2001) study was around 2 knots slower than the vessels used in this current study. Therefore, increased vessel noise could potentially be a factor that reduced the detection range of the array in this present 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.*, 2001), 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 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 when 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 6 km, 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 1000km². 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, 2002). They are within the lower range of previous estimates of density in the north-east Atlantic which varied from 0.82 to 10.16 whales per 1000km² (Øien, 1990). They are also similar to estimates made within the eastern tropical Pacific, where densities of between 0.26 and 1.16 whales per 1000km² 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.*, 2001) where estimates were lower (between 0 to 0.13 whales per 1000km²) 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 north-east 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. Gordon, *et al.*, 1999; Griffin, 1997; 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, we will also be able to collect better information on the effects of background noise and propagation conditions on detection range. In addition, we can explore how oceanographic, topographical, biological and anthropogenic factors affect seasonal distributions and abundance.

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Appendix 2.

Environmental models for predicting oceanic dolphin habitat in the northeast Atlantic

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Dolphins are clearly influenced by their environment and their distributions have been shown to be related to a range of oceanographic determinants. The complex topography and hydrography of the Faroe Shetland Channel appear to have a significant influence on the distribution and abundance of many species. However, there are no details on how oceanography affects the distributions of dolphins in this region. The aim of this study was to relate the distributions of dolphins in the Faroe Shetland Channel to key oceanographic variables using a general additive modelling framework (GAM). Models were created using data from 2001 and a cross-validation approach was used to test their predictive power. Predictions were calculated at each step in the model building process and were tested against data collected during 2002. The results of the GAM suggest that water depth, month, time of day, latitude and sea state were significant influences on the probability of detecting dolphins during 2001. Furthermore, the model was a significant predictor of the distribution of dolphins in 2002. The model with the greatest predictive power included the terms water depth and month; detection probability was highest during May, in depths of 1000m. Furthermore, dolphins showed a distinctive diurnal pattern in vocal behaviour, with a peak in activity between 05:00 and 08:00 GMT. These results provide valuable new information in understanding the determinants of oceanic dolphin distributions and help managers to address concerns about potential impacts from anthropogenic activities in the region.

Keywords: Passive acoustic, cetacean, general additive model, surface temperature, month, water depth, surface salinity, surface fluorescence, diurnal, *Lagenorhynchus acutus*.

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Introduction

Distributions of dolphins are clearly influenced by their oceanographic environment. Although such relationships are inherently dynamic, these distributions have been shown to be related to a range of environmental determinants including sea surface temperature (e.g., Baumgartner et al., 2001; Forney, 2000; Hamazaki, 2002; Selzer and Payne, 1988), salinity (e.g., Forney, 2000; Selzer and Payne, 1988), water depth (e.g., Baumgartner, 1997; Davis et al., 1998; Gowans and Whitehead, 1995; Ross et al., 1987) and seabed gradient (Baumgartner, 1997; Davis et al., 1998; Gowans and Whitehead, 1995; Selzer and Payne, 1988). However, the importance of these determinants appears to vary between regions and species; a feature that highlights the need to focus studies on the role of oceanography in dolphin habitat selection on a regional basis.

Recent and historical data suggest that parts of the northeast Atlantic may provide an important habitat for a number of dolphin species (Brown, 1976; Evans, 1980; Gunnlaugsson and Sigurjónsson, 1990; Thompson, 1928; Weir et al., 2001). Sighting surveys have recorded significant numbers of white-sided dolphins (*Lagenorhynchus acutus*) throughout the area (Skov et al., 1995; Weir et al., 2001) and it is thought to be the most abundant species of dolphin in this region (Harwood and Wilson, 2001). Recently, an estimate of over 20,000 white-sided dolphins was made within a small region of the northeast Atlantic; the Faroe Shetland Channel (Hughes et al., 1998). This species was recorded during all months of the year and was most abundant in deep water along the shelf edge (Weir et al., 2001).

The Faroe Shetland Channel encompasses part of the UK continental shelf and Faroese plateau and is intersected by a channel approximately 1500 metres deep that runs northeast through the area. At its northern entrance, the channel is connected to the Norwegian Sea and at its southern end, the Wyville-Thompson ridge runs perpendicular to the channel and there is a connection over the ridge with the northeast Atlantic Ocean (Turrell et al., 1999). The hydrographic regime of the Faroe Shetland Channel is extremely complex, and it has long been recognised as an important conduit connecting the warm waters of the Atlantic with the cold waters of the Nordic seas (Sherwin et al., 1999). The complex topography and the dynamic hydrography of this area appear to have a significant influence on the distribution and abundance of many species (Bett, 2001). However, there are currently no details on how environmental factors affect the distributions of dolphins in the Faroe Shetland Channel. Therefore, to understand the role of oceanography in the ecology of dolphins in this area, robust data on the distribution of dolphins must be collected in parallel with detailed oceanographic information.

Such data should provide the basis for environmental models with the flexibility suitable for examining relationships between dynamic oceanographic variables and complex, and often patchy, distributions of animals. These models should aim to have both within-year explanatory value, and inter-annual predictive power, to ensure that the pertinent variables are correctly identified and that distribution-environment relationships are consistent between years. This information is important, both in understanding the determinants of oceanic dolphin distributions and in helping to address concerns about potential impacts from increasing numbers of anthropogenic activities in the region (Harwood and Wilson, 2001).

The initial aim of this study is to evaluate the distribution of oceanic dolphins in the Faroe Shetland Channel. We then seek to relate the distribution patterns of dolphins to key environmental variables and to the underwater topography of the area, and build environmental models that describe dolphin distribution in this region. This is followed by a series of formal tests to determine whether the resultant models are robust at predicting dolphin distribution inter-annually.

Materials and methods

Passive acoustic surveys for dolphins were carried out in the Faroe Shetland Channel during two-week oceanographic cruises in May and October 2001 and October 2002 from the FRV "Scotia", a 68 metre oceanographic research vessel, and during May 2002 from the FRV "Cirolana", a 73 metre oceanographic research vessel.

Dolphin data collection

The acoustic equipment to detect dolphins 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 Benthos AQ4 elements 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 at 100Hz to limit low frequency tow and water noise. The system was otherwise flat to 15 kHz and had good sensitivity to well above the 22kHz upper limit of the computer sound card. The streamer was towed on a 400 metre strengthened cable behind the vessel. At speeds of 10 knots, this design of array generally tows at around 5-6 metres 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 sixty-metre extension cable was connected to the tow cable once it was deployed to connect the array to recording equipment located within the vessel's laboratories.

Signals from the hydrophones were filtered using high pass filters set at 400 Hz or 1600 Hz depending on background noise conditions and amplified by 20dB or 30dB using a custom built differential amplifier/filter unit. The data logging software package *Logger2000* (Gillespie, 1997) ran in real time throughout the surveys and maintained a database of monitoring effort, recordings and acoustic detections.

A two-person team worked in shifts to monitor the signals from the hydrophone twenty-four 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 were recorded to a database using the *Logger 2000* software; vessel noise, sea noise, remote ship noise, strength of dolphin whistles and strength of dolphin clicks. The location of each listening station was recorded in the database using a GPS (Garmin GPS 75, Garmin Ltd.), In addition, an automated recording module within *Logger 2000* made thirty-second recordings direct to the computer's hard disk every 2 minutes.

Visual watches for cetaceans were maintained on an opportunistic basis to identify species that were detected acoustically. The distribution of acoustic detections of dolphins made during the surveys was mapped using a GIS software package (Arcview version 3.2, ESRI Inc.).

Environmental data collection

Surface water temperature and salinity were recorded continuously throughout the surveys using an OceanData model TSG 103 thermosalinograph connected to the vessels non-toxic sea water supply. Surface water fluorescence was also recorded throughout the surveys giving an indirect measure of phytoplankton concentration measured in $\mu\text{g l}^{-1}$. Simultaneous navigation data were recorded from a GPS navigation system. Depth and seabed gradient were estimated for each listening station using a digital elevation model, interpolated from satellite derived altimetry (available from http://topex.ucsd.edu/marine_topo/mar_topo.html) (Smith and Sandwell, 1997). The digital elevation model was created in a GIS package (Arcview, version 3.2, ESRI Inc.) using an Inverse Distance Weighted algorithm. The derived depths were tested against water depth recorded by the survey vessel's

echosounder (Simrad EK-500) and were not significantly different to the echosounder depths ($t = -1.01$, d.f. = 0.481, $p = 0.311$).

Data Analyses

The relationship between dolphin occurrence and oceanographic variables was examined within a generalised additive modelling framework (Hastie and Tibshirani, 1990). Such models fit non-parametric functions to estimate the relationships between response and predictor variables, without imposing limitations on the form of the underlying relationships.

The occurrence of dolphins at each of the 15 minute listening stations were considered independent. This was based on the fact that at the vessels lowest cruising speeds of around 10 knots, each station would have acoustic overlap at a radius of 4.6km. This is likely to be further than dolphins could be detected using the equipment in this study (Gordon et al., 1998). The presence or absence of dolphin calls at each listening station was based on the acoustic information that was recorded in the field. Only data from the 2001 surveys were used to construct the environmental model.

Presence or absence of dolphins was analysed by specifying a binomial distribution of errors with a logit link function. Models were selected and evaluated by first, fitting each variable to the null model. The term that resulted in the greatest improvement in the model fit was selected for inclusion at the next step. At each successive step, all remaining variables were again tested individually for possible inclusion. The significance of each variable or interaction term was evaluated with an analysis of deviance. A level of smoothing corresponding to 3 degrees of freedom was chosen for all variables because it permits non-linear effects yet it restricts unrealistic detail in the shape of the curve. This allows for the detection of major effects but reduces spurious patterns or potential sampling artefacts (Forney, 2000). Cubic smoothing splines were used to estimate the functions (Hastie and Tibshirani, 1990).

Variables tested in the analyses were surface temperature, surface salinity, surface fluorescence, latitude, month, water depth, and seabed gradient. In addition, there was the possibility that sea conditions and the time of day (e.g., Goold, 2000) would affect the probability of hearing dolphins at listening stations. Therefore, the variables, "Sea state", measured on the Beaufort scale, and the time of day, were tested as a predictor variables in the modelling procedure. All analyses were carried out using the software package SPLUS 2000 (Mathsoft Inc.).

To test the predictive power of the resultant model, a cross-validation approach was used. A series of model response predictions, based on the data collected during the 2001 surveys, were calculated at each successive step in the model building process. These predictions were then tested against the occurrence of dolphins from the 2002 data using generalised linear models with a logit link function. The model that provided the best predictor of the 2002 data was identified as the "best fit" model.

Results

Survey data

Survey coverage in the Faroe Shetland Channel was extensive, with a total of 3482 km covered and 779 listening stations made during all 4 cruises. Survey tracks were

generally longer during the May cruises than the October cruises with more listening stations being made in May.

The oceanographic environment differed between cruises; mean surface temperature was generally higher during the May cruises than the October cruises ($F = 652.4$, d.f. = 3, $p < 0.0001$), mean surface salinity was highest during the May 2002 cruise and was at a minimum during the October 2002 cruise ($F = 779.9$, d.f. = 3, $p < 0.0001$) and mean surface fluorescence peaked during the October 2002 cruise and was at a minimum during the October 2001 cruise ($F = 86.07$, d.f. = 3, $p < 0.0001$). Furthermore, the sea state varied significantly between cruises ($F = 349.75$, d.f. = 3, $p < 0.0001$), with sea states generally being higher during the October cruises and lower during the May cruises. The range of water depths and seabed gradients surveyed during each of the cruises also varied significantly (Water depth, $F = 29.34$, d.f. = 3, $p < 0.0001$; Seabed gradient, $F = 5.92$, d.f. = 3, $p = 0.001$).

Dolphins were acoustically detected during each of the surveys throughout the study area. The proportion of listening stations where dolphins were detected, varied from 0.02 during May 2001 to 0.34 during October 2001 (Table 1). Three schools of dolphins were sighted during opportunistic watches from the vessels bridge; two of the schools were Atlantic white-sided dolphins and one school remained unidentified as it was too far from the vessel to identify the species.

Environmental model

The results of the general additive modelling suggest that several environmental variables were significant influences on the probability of detecting dolphins during 2001. Specifically (in order of selection), the model included water depth, month, time of day, latitude and sea state.

The model was a significant predictor of the distribution of dolphins in 2002 at several of the steps in the model selection procedure. However, the model with the greatest predictive power included the terms water depth, month and time of day (Table 2). The functions were non-linear for both water depth and time of day; detection probability was highest in depths of around 1000m (Fig. 1a), between 05:00 and 08:00 GMT and lowest in depths of 200m, between 15:00 and 18:00 GMT (Fig. 1c). In addition, detection probability was higher during October than May (Fig 1b). The predicted spatial distribution of dolphins from the “best fit” model is shown in Figures 2(a) and 2 (b) and the actual distribution of dolphin detections during 2002 is shown in Figure 3.

Discussion

This study provides the first quantitative data on the oceanic distribution of dolphins in the Faroe Shetland Channel. Furthermore, we have shown that there are clear and predictable influences of environmental determinants on the distributions of dolphins in this region.

The use of passive acoustics to study the distribution or abundance of vocal animals such as dolphins is now recognised as a highly efficient monitoring technique (Leaper et al., 2001; Van Parijs et al., 2002). Such techniques offered several advantages over traditional sighting surveys; acoustic range is generally greater than visual range and acoustic detection probability is likely to be less affected by environmental conditions at the surface. In addition, when at the surface, dolphins can be visually elusive and are often difficult to sight. In the context of a

project aiming to achieve year round coverage in the northeast Atlantic, an area where rough seas are common and winter days are short, these advantages were telling. One of the drawbacks with only using acoustic data to map dolphin distribution is that oceanic dolphin species are difficult to identify to species level, and it remains likely that some acoustic detections were of schools of different species or mixed species. However, previous studies suggest that the most common dolphin species in this region are white-sided dolphins, with other species such as white beaked dolphins (*Lagenorhynchus albirostris*) generally occurring in water depths less than 200m (Weir et al., 2001) and common dolphins (*Delphinus delphis*) generally occurring further south than the Faroe Shetland Channel (Evans, 1980). The visual sightings made in this current study support this, and it seems likely that most of the acoustic detections were of white-sided dolphins. In future, more detailed analyses of whistle features may allow discrimination between many species (Rendell et al., 1999).

The results support previous studies showing that dolphins are widespread throughout the offshore regions of the northeast Atlantic (Evans, 1992; Weir et al., 2001). We have demonstrated that patterns of distribution are closely linked to the oceanographic and topographic regime within the area. The use of general additive models provided a flexible framework that allowed the development of environmental models without the constraints of assumptions about the underlying relationships. The results suggest that many of the relationships between oceanographic determinants and dolphin distributions are non-linear and as such, it is possible that they would not have been detected or would have been misinterpreted using other methods of analysis that rely on assumptions about the underlying relationships.

The model created using the data collected during 2001 suggests that the variables (in order of significance), water depth, month, time of day, latitude and sea state are all significant predictors of dolphins distribution. However, as a result of the flexibility of GAM's, there is a possibility of over-fitting the data (Forney, 2000) resulting in misinterpretations about distribution-environment relationships from a single year's data.

The model does appear to have a reasonable degree of predictive power, with several of the steps in the model building process being significant predictors of the 2002 data. However, many of the variables that explained within-year patterns of dolphin distribution within 2001 turned out to be poor predictors of distribution between years. This is likely to be caused by spurious within-year patterns that do not represent true ecological relationships. The "best fit" model, or the one that proved to be the best predictor of the 2002 data, contained the variables water depth, month and time of day. Therefore, it seems reasonable to assume that the two environmental variables in this model, water depth and month have the greatest influence on the distribution of dolphins in this region.

Previous studies have shown that water depth is a major factor determining the distribution of air breathing marine species (e.g., Baumgartner, 1997; Raum-Suryan and Harvey, 1998; Schneider, 1997; Selzer and Payne, 1988). Although varying in their detail, all hypotheses relate water depth to the availability of prey. With limited information on the distribution of fish species within the study area, it is difficult to make concise links between the predator and prey distributions. However, a study of the stomach contents of white-sided dolphins west of Ireland found that the most common fresh prey item in stomachs were mackerel (*Scomber scombrus*). This is a

species that makes a southerly spawning migration along the fringes of shelf edge between October and March (Reid et al., 1997). Although survey effort in the current study was limited to May and October, it is interesting to note that we found that dolphin occurrence increased in this region during October. This is similar to previous studies that suggest that dolphins are most commonly sighted during the late summer months through to November in this region (Weir et al., 2001). However, as our surveys were limited to water depths greater than 200m, decreases in detection probability during May could represent inshore movements by dolphins during the summer months (Northridge et al., 1997), making direct comparisons with other studies difficult.

In addition to water depth and month, time of day was a significant influence on the probability of detecting dolphins. Due to geographical extent of the survey effort, this pattern is unlikely to be a result of variations in distribution throughout the day. It is more likely that the result is a consequence of diurnal variations in vocal activity of dolphins. Such behaviour has been recorded previously in common dolphins in the Irish Sea (Goold, 2000). Furthermore, the diurnal patterns of activity in this previous study (Goold, 2000) are almost identical to the variations in detection probability with time of day in the current study; activity peaked during the early morning and late evening. Goold (2000) suggested that this behaviour may reflect an increase in vocal communication due to the lack of visual cues at night or diurnal patterns in feeding activity. Alternatively, variations in dive depth (Mate et al., 1995) or temperature characteristics of the vertical water column throughout the day may also account for the observed patterns of detection probability.

It is interesting to note that the hydrographic regime of the study area was a relatively poor predictor of distribution both within, and between years. This is in contrast to previous studies that suggest that surface water temperature and salinity are good predictors of dolphin occurrence (e.g., Baumgartner et al., 2001; Forney, 2000; Hamazaki, 2002; Selzer and Payne, 1988). However, the hydrography of the Faroe Shetland Channel is highly complex, with up to five water masses occupying the channel and mesoscale eddies travelling north through the area (Sherwin et al., 1999). The areas described in many previous studies (Forney, 2000; Hamazaki, 2002) may be more stable both temporally and spatially, allowing relationships with hydrography to develop.

Alternatively, complications in the relationships between dolphin detection and surface temperature or surface salinity in this current study are introduced due to the inherent effects of water temperature and salinity on the speed of sound in sea water (Urick, 1967). This may have the result that potential ecological links between dolphins and temperatures or salinities were masked or distorted due to variations in detection probability with these variables.

In conclusion, this study utilised passive acoustic techniques from oceanographic research vessels to map the distribution of dolphins in the Faroe Shetland Channel and related them to key environmental variables. The results of the modelling procedures show that dolphins are distributed widely in this area and that water depth and month are robust predictors of their distribution between years. Furthermore, dolphins showed a distinctive diurnal pattern in vocal behaviour. These models provide important new information in understanding the determinants of oceanic dolphin habitat in the northeast Atlantic and provide a valuable tool in helping managers to address concerns about potential impacts from anthropogenic activities

in the region. Further studies should now be focused on refining these habitat predictions and examining relationships between dolphin distributions and environmental correlates over periods of several years. This will provide valuable insights into the long term role of oceanography on top predators and could potentially be used to monitor biological aspects of the changing oceanographic regime in this important area.

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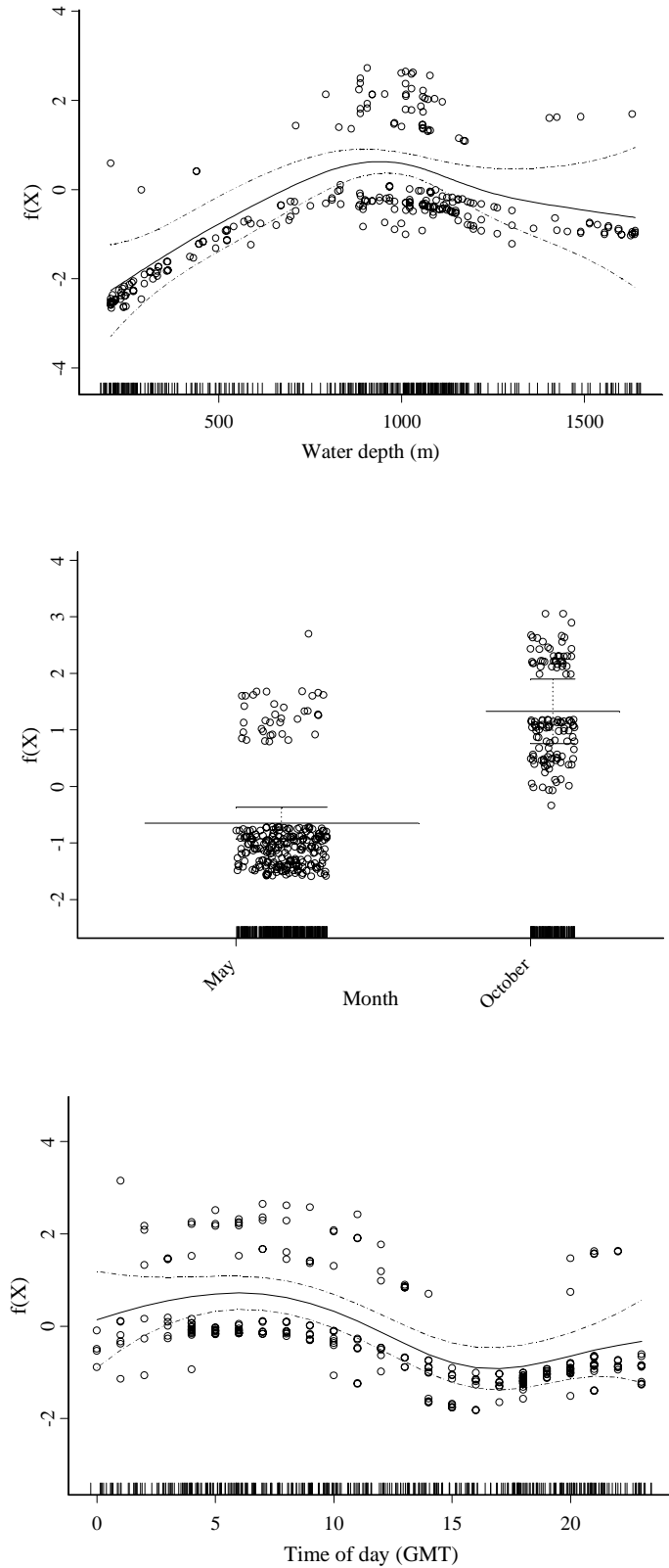


Figure 1 (a-c). Generalised additive model functions of dolphin encounter rates in relation to environmental variables. Functions are scaled to the model mean. The dashed lines represent two standard error bands.

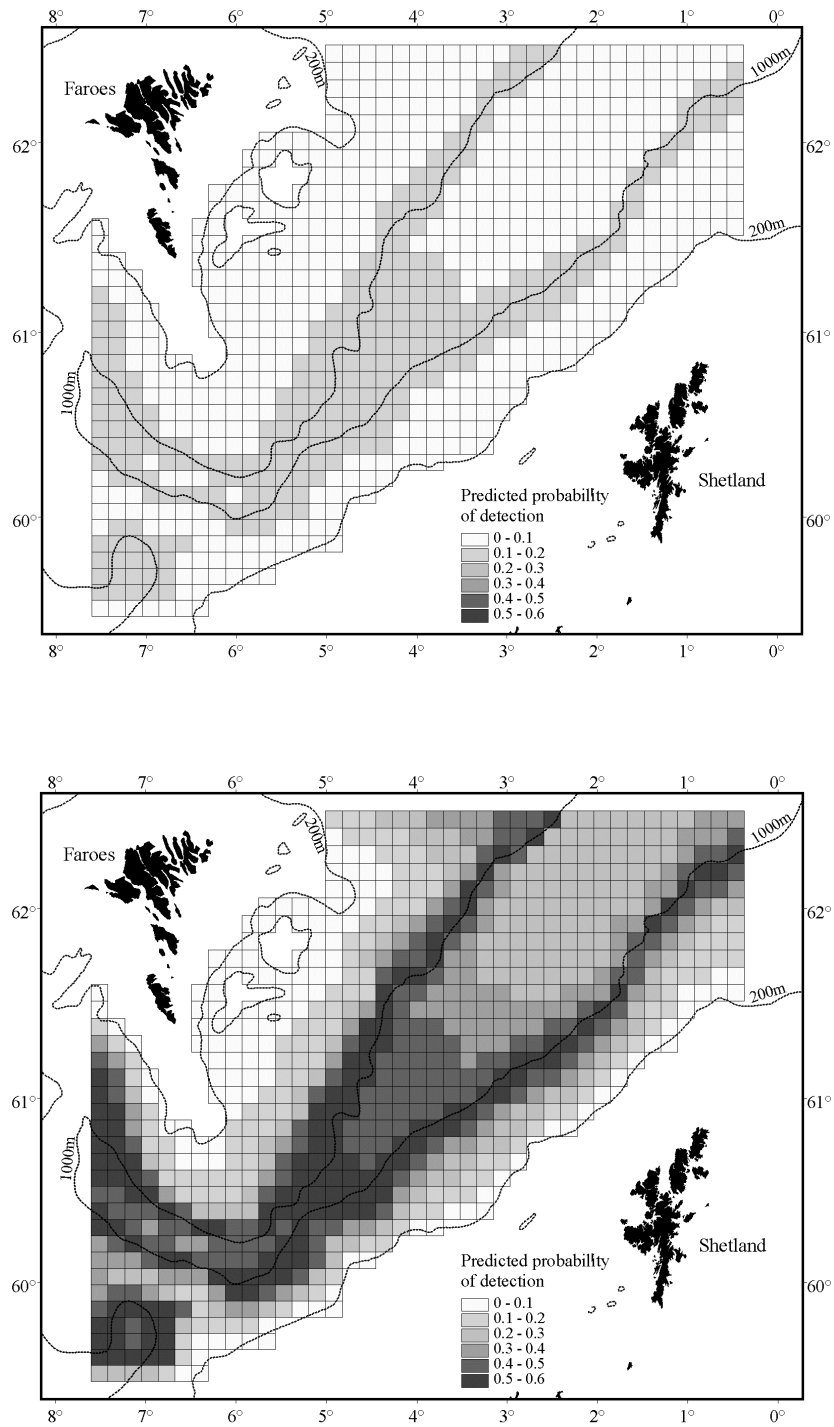


Figure 2 (a-b). Predicted spatial distributions of dolphins in the Faroe Shetland Channel, based on the “best fit” model during (a) May and (b) October. The model was based on data from fourteen day surveys that were carried out in May and October 2001. The value for time of day was set to a standard value 12:00 GMT for both predictions. The dashed contour lines represent water depths of 200m and 1000m

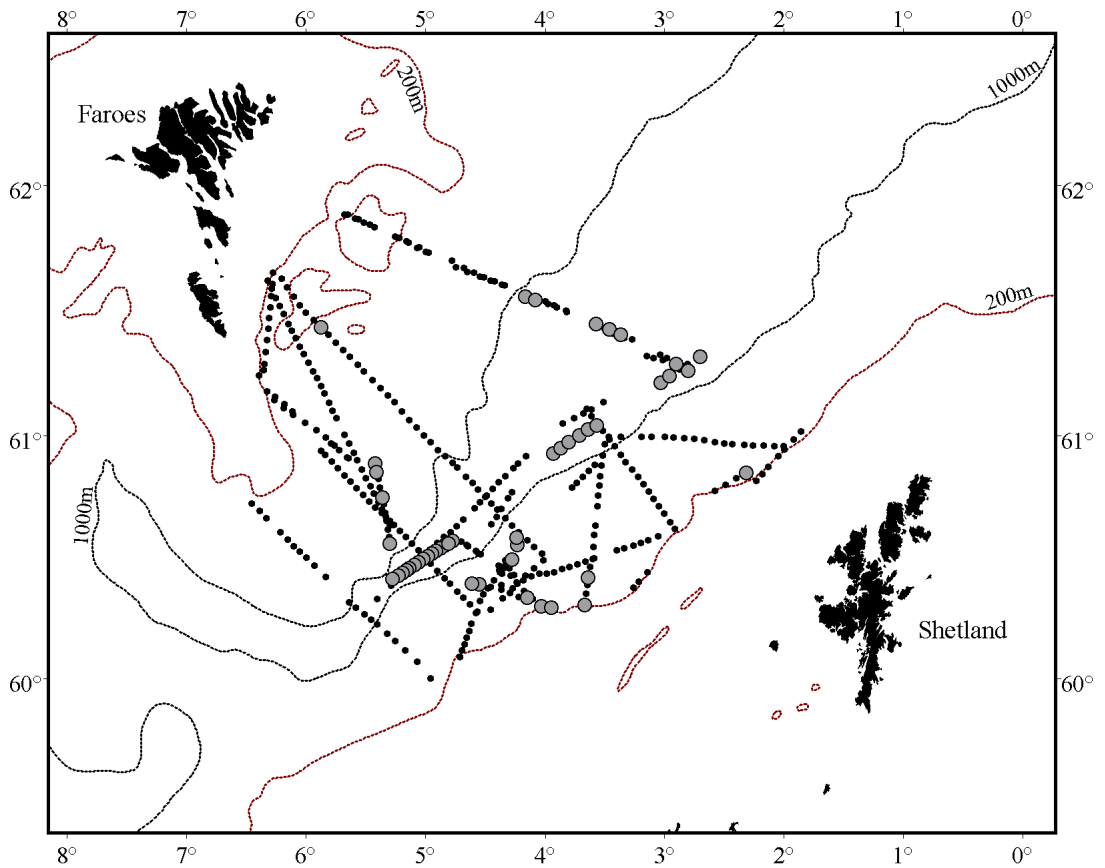


Figure 3. Map of the study area in the north-east Atlantic showing the Faroes and Shetland Islands. Fourteen day surveys were carried out in May and October 2002 to test the model predictions from the 2001 data. The locations of the acoustic listening stations are shown by the black dots and the locations where dolphins were heard are shown by the large grey dots. The dashed contour lines represent water depths of 200m and 1000m.

Table 1. Summary of survey effort and environmental variables during the 2001 and 2002 surveys. Details include the distance surveyed, the number of 15-minute listening stations monitored, the number of stations where dolphins were heard, and the range and mean values for surface temperature, surface salinity, surface fluorescence, water depth and seabed gradient.

	2001		2002	
	May	October	May	October
SURVEY EFFORT				
Distance surveyed (km)	1193	599	1057	633
No. of listening stations	256	125	247	151
No. of stations with dolphins	36 (14%)	42 (34%)	4 (2%)	43 (29%)
ENVIRONMENT				
Surface temperature (°C)				
Range	7.9 – 12.3	9.7 – 12.3	8.1 – 10.9	10.9 – 13.1
Mean (s.d.)	9.5 (0.5)	10.9 (0.7)	9.8 (0.7)	12.0 (0.4)
Surface salinity (ppm)				
Range	35.01 – 35.24	34.97 – 35.29	35.12 – 35.56	34.83 – 35.19
Mean (s.d.)	35.27 (0.05)	35.18 (0.07)	35.35 (0.07)	35.02 (0.07)
Surface fluorescence ($\mu\text{g.l}^{-1}$)				
Range	141 – 6882	639 – 1418	294 – 3494	1961 – 2818
Mean (s.d.)	1430 (1232)	889 (184)	1303 (647)	2422 (144)
Water depth (m)				
Range	204 – 1639	204 – 1302	200 – 1302	202 – 1333
Mean (s.d.)	929 (379)	711 (383)	642 (334)	742 (336)
Seabed gradient (degrees)				
Range	0.17 – 3.14	0.18 – 2.86	0.17 – 5.46	0.00 – 3.25
Mean (s.d.)	0.86 (0.60)	0.85 (0.68)	1.03 (0.72)	0.73 (0.74)

Table 2: Summary of the General additive model for predicting the occurrence of dolphin calls at listening stations during 2001. The terms were fitted on a stepwise basis to construct progressively more complex models. The predictive power of the models at each successive step was tested against data from 2002. The “best fit” model is shown by a * next to the significance value.

Term added to model	Deviance	d.f.	p (χ^2)	Predictive power of model		
				Deviance	d.f.	p (χ^2)
Water depth	29.57	1.9	< 0.0001	25.75	1	< 0.0001
Month	52.5	1.0	< 0.0001	97.31	1	< 0.0001
Time of day	14.9	1.9	0.0005	107.75	1	< 0.0001*
Latitude	15.03	2.0	0.0005	44.48	1	< 0.0001
Sea state	11.25	2.0	0.0036	27.14	1	< 0.0001
Surface temperature	4.09	2.0	0.129	22.3	1	< 0.0001
Seabed gradient	2.63	2.0	0.268	5.94	1	0.015
Surface fluorescence	2.18	1.9	0.46	6.94	1	0.008
Surface salinity	0.79	2.0	0.791	7.19	1	0.007

Appendix 3. Project outputs

3.1. Reports

Charif, R.A. & Clark, C.W. (1999) Passive acoustic monitoring of whales in the Foinaven – Schiehallion region. Unpublished Report to BP. Cornell Laboratory of Ornithology

Swift, R.J. & Thompson, P.M. (2000) Identifying potential sources of industrial noise in the Foinaven and Schiehallion region. Unpublished Report to BP. University of Aberdeen.

Swift, R.J., Hastie, G.D., Barton, T.R., Clark, C.W., Tasker, M.L. & Thompson, P.M. (2002). Studying the distribution and behaviour of cetaceans in the northeast Atlantic using passive acoustic techniques. Unpublished Report to AFEN. University of Aberdeen.

Swift, R.J., Hastie, G.D., Barton, T.R., Clark, C.W., Tasker, M.L. & Thompson, P.M. (2004) Passive acoustic monitoring of whale distribution in the Faroe-Shetland Channel. Unpublished Final Report to AFEN. University of Aberdeen.

3.2. Peer-reviewed papers

Hastie, G.D., Swift, R.J., Gordon, J.C.D., Slesser, G. & Turrell, W. (In Press) Sperm whale distribution and seasonal density in the Faroe Shetland Channel. *Journal of Cetacean Research & Management*.

Hastie, G.D., Swift, R.J., Slesser, G., Thompson, P.M. & Turrell, W.R. (Submitted). Environmental models for predicting oceanic dolphin habitat in the northeast Atlantic. *ICES Journal of Marine Science*

3.3. Conference presentations.

Swift, R.J., Clark, C.W., Gordon, J.C.D., Hastie, G.D., Heath, M., Tasker, M.L., Thompson, P.M. & Turrell, W. (2001) The distribution of large whales at different spatial and temporal scales in the Faroe - Shetland Channel, north-east Atlantic.

Poster presented at the 14th Biennial Conference on the Biology of Marine Mammals. Vancouver, Canada. (Nov. 28 - Dec. 3, 2001), and the Atlantic Frontier Environmental Network Conference - *Managing the resources of the Atlantic Margin*. Edinburgh, Scotland, (Dec 4 –5 2001).

Swift, R.J., Hastie, G.D., Clark, C.W. & Thompson, P.M.(2003) The underwater acoustic environment of fin whales in the vicinity of an oil and gas development area

Oral presentation at the 17th European Cetacean Society Annual Conference, Las Palmas, Gran Canaria (9-12th March 2003).

Hastie, G.D., Swift, R.J., Gordon, J.C.D., Slesser, G. & Turrell, W. (2003) Sperm Whale Distribution And Seasonal Density In The Faroe Shetland Channel

Poster presentation at the 17th European Cetacean Society Annual Conference, Las Palmas, Gran Canaria (9-12th March 2003).

Swift, R.J., Calupca, T., Clark, C.W., Fowler, T., Hastie, G.D. & Thompson, P.M. (2003) Pop-up ears in the ocean - passive acoustic monitoring of whale behaviour, distributions and their underwater acoustic environment.

Presentation to 6th Underwater Science Symposium, Society of Underwater Technology, Aberdeen, Scotland (3-6th April 2003)

Appendix 4. Summary of Project history

Initial one-year BP funded project (Oct 1998- Oct 1999)

“Foinaven and Schiehallion passive underwater acoustic monitoring system for detecting whales”

January 1999 **1st pop-up deployment:**

BRP personnel: Thom Calupca, Adam Frankel & Tom Fowler
BP and Cornell BRP deploy 5 pop-ups in the Foinaven Schiehallion development using the BP West of Shetland support vessel *Far Server* and support from Fugro Ltd..

March 1999 **1st pop-up retrieval:**

BRP personnel: Thom Calupca, Adam Frankel & Tom Fowler
BP and Cornell BRP retrieve 3 pop-ups using *Far Server* and Ferugo support. Two units are damaged:

October 1999 **1st report:**

Charif, R. A. and C. W. Clark. (2000). *Passive acoustic monitoring for whales in the Foinaven-Schiehallion region*: Report prepared for BP Amoco UK. Ithaca, Bioacoustics Research Program (Cornell University): 1-100.

October 1999 René Swift employed by AU to determine environmental factors affecting fin whale distribution west of Shetland, focusing on the identity of sources of low frequency noise in Foinaven Schiehallion development area. AU begin analysis of pop-up data and activity records to identify sources of low frequency noise.

December 1999 **Presentation to BP and AFEN:**

Swift, R. J. (1999). *The distribution of whales in the Faroe Shetland Channel*. Presentation to BP, Dyce, 01/12/99.

January 2000 **Presentation to AFEF:**

Swift, R. J. (1999). *The distribution of whales in the Faroe Shetland Channel*. Presentation to AFEF, Aberdeen, 20/01/00.

January 2000 **Project group meeting**, University of Aberdeen

Present: G. Bishop (AFEN) R. A. Charif (BRP), C. W. Clark (BRP), René Swift (AU), M. Tasker (JNCC), P. M. Thompson (AU).

**Project extension through a one-year contract from AFEN to AU, BRP & JNCC.
March 2000-March 2001.**

“Passive acoustic monitoring of whale distribution in the Faroe Shetland Channel.” Contract AMJIG/00/15.

May 2000 **1st broad scale acoustic survey**

Cruise leader: Dr. W. R. Turrell; *AU personnel:* René Swift
First collaborative hydrographic cruise with FRS Marine Lab. Trials of sonobuoys and SEICHE towed hydrophone array. Areas covered include Faroe Shetland Channel and Rockall:

October 2000 Tom Fowler, BRP, flies to the UK to instruct René Swift in pop-up construction, set up and deployments.

October 2000 **2nd broad scale acoustic survey**

Cruise leader: G. Slesser; *AU personnel:* R. Swift
Second collaborative hydrographic cruise with FRS Marine Lab. with Sonobuoys (donated by RAF) deployed in the Faroe Shetland Channel.

2nd pop-up deployment:

AU deploy single pop-up unit as part of FRS Marine Lab. hydrographic mooring.

October 2000 **2nd report:**

Swift, R. J. and P. M. Thompson. (2000). *Identifying potential sources of industrial noise in the Foinaven and Schiehallion region.*, University of Aberdeen Lighthouse Field Station: 1-42.

October 2000 René Swift is re-employed for 6 months, under AFEN funding, to manage pop-up deployments and data analysis.

December 2000 **3rd broad scale acoustic survey**

Cruise leader: Dr. M. Heath; *AU personnel:* R. Swift & G. Hastie
Third collaborative hydrographic cruise with FRS Marine Lab. Sonobuoy deployments in the Faroe Shetland Channel and North East Atlantic. Towed hydrophone array surveys funded by Shell.

January 2001 Tom Fowler, BRP, flies to the UK to continue instructing René Swift in pop-up construction, set up and deployments.

March 2001 **3rd pop-up deployment:**

AU deploy 5 pop-ups in the vicinity of the Foinaven Schiehallion using BP West of Shetland support vessel Northern Gambler.

Project extension through a second one-year contract from AFEN to AU, BRP & JNCC. April 2001- March 2002

AMJIG/00/15. "*Passive acoustic monitoring of whale distribution in the Faroe Shetland Channel*".

April 2001. Gordon Hastie employed by AU on the project.

April 2001. FV Mizpah accidentally trawls up one pop-up from the 3rd (March 2001) deployment West of Shetland.

May 2001 **4th broad scale acoustic survey**

Cruise leader. Dr. W. R. Turrell; *AU personnel:* R. Swift & G. Hastie
Fourth collaborative hydrographic cruise with FRS Marine Lab aboard the FRV *Scotia*. Sonobuoy deployments in the Faroe Shetland Channel and North East Atlantic, and towed hydrophone array surveys.

2nd and 3rd pop-up retrievals:

AU retrieve three pop-ups from the March 2001 deployment, and one pop-up from the October 2000 deployment using the FRV *Scotia*.

June 2001. René Swift and Gordon Hastie visit Cornell Lab of Ornithology, for Project Group meeting and instruction on pop-up data handling and

July 2001. Project group meeting, University of Aberdeen

Present: G. Hastie (AU), R. Swift (AU), M. Tasker (JNCC), P. Thompson (AU).

August 2001. MV Aberdonian opportunistically finds 5th and final pop-up from March 2001 deployment floating in the Tartan Field, North Sea.

August 2001 **Project group meeting**, University of Aberdeen

Present: C. W. Clark (BRP), Gordon Hastie (AU), René Swift (AU), M. Tasker (JNCC), P. M. Thompson (AU).

October 2001 **Presentation to AFEN:**

Rene. J. Swift & Gordon D. Hastie (2001). *Acoustic monitoring of large whales in the Faroe Shetland Channel*.

October 2001 **5th broad scale acoustic survey**

Cruise leader. G. Slesser; *AU personnel:* René Swift & Gordon Hastie
Fifth collaborative hydrographic cruise with FRS Marine Lab aboard the FRV *Scotia*. Sonobuoy deployments in the Faroe Shetland Channel and North East Atlantic, and towed hydrophone array surveys.

October 2001 **4th pop-up deployment:**

AU deploy 3 pop-ups in the vicinity of the Foinaven Schiehallion oilfields with the aim of tracking the fine scale movements of individual whales. Pop-ups are deployed from FRV *Scotia*.

November 2001. René Swift and Gordon Hastie spend 2 days at BRP, Cornell Lab of Ornithology, for project group meetings and training

December 2001 **Poster presentations at:**

14th Biennial Conference on the Biology of Marine Mammals, Vancouver, BC,

Atlantic Frontier Environmental Network Conference – Managing the resources of the Atlantic Margin. Edinburgh, Scotland,

Project extension through a third one-year contract from AFEN to AU, BRP & JNCC. April 2002- March 2003

Contract AMJIG 02/15 extension to contract AMJIG/00/15. “*Measuring the responses of fin whales to industrial noise in the Faroe- Shetland Channel*”.

April 2002 **Project group meeting**, University of Aberdeen

Present: Zoe Crutchfield (JNCC), Gordon Hastie (AU), René Swift (AU), M. Tasker (JNCC), P. M. Thompson (AU), Anne Walls (AFEN / BP).

May 2002 **6th broad scale acoustic survey**

Cruise leader: Dr. W. R. Turrell; *AU personnel:* R. Swift & G. Hastie
Sixth collaborative hydrographic cruise with FRS Marine Lab aboard the RV *Cirolana*. Sonobuoy deployments in the Faroe Shetland Channel and North East Atlantic, and towed hydrophone array surveys.

4th pop-up retrieval:

AU retrieve one of the three pop-ups deployed in October 2001 using the RV *Cirolana* on hire to FRS Marine Lab. Two units are lost to fishing activity.

5th pop-up deployment:

AU deploy 1 long term pop-up in the vicinity of the Foinaven Schiehallion oilfields with the aim of monitoring baleen whale vocal activity over the summer. Pop-ups are deployed from the RV *Cirolana* on hire to FRS Marine Lab.

August 2002

Presentation to AFEN:

René J. Swift and Gordon D. Hastie (2002). *Studying the distribution and behaviour of cetaceans in the northeast Atlantic using passive acoustic techniques.*

August 2002

3rd report:

René J. Swift, Gordon D. Hastie, Tim R. Barton, Christopher W. Clark, Mark L. Tasker, Paul M. Thompson. (2002). *Studying the distribution and behaviour of cetaceans in the northeast Atlantic using passive acoustic techniques*

September 2002

Project group meeting, Video conference

Present: C. W. Clark (BRP), Gordon Hastie (AU), René Swift (AU)

October 2002

7th broad scale acoustic survey

Cruise leader. G. Slesser; *AU personnel:* René Swift & Gordon Hastie
Seventh collaborative hydrographic cruise with FRS Marine Lab aboard the FRV *Scotia*. Sonobuoy deployments in the Faroe Shetland Channel and North East Atlantic, and towed hydrophone array surveys.

October 2002

5th pop-up retrieval & 6th pop-up deployment:

AU deploy 4 pop-ups in the vicinity of the Foinaven Schiehallion oilfields using FRV *Scotia* with the aim of tracking the fine scale movements of fin whale and understanding the impacts of industrial noise. Single popup from May 2002 deployment recovered from FRS long-term mooring.

November 2002

6th pop-up retrieval (partial):

Retrieval of two pop-ups using the West Navion support vessel Far Strider. Two units fail to respond to release commands, assumed lost.

March 2002

Presentations at:

17th European Cetacean Society Conference, Las Palmas de Gran Canaria.

Project extension to wrap up project through a 3-month contract from AFEN to AU, BRP & JNCC. April 2003- June 2003

Passive acoustic monitoring of whale distribution in the Faroe Shetland Channel. Extension to contract AMJIG 02/15.

April 2003 **Presentation at**

Society for Underwater Technology Conference Aberdeen.

April 2003 **8th broad scale acoustic survey**

Cruise leader. Dr. W. R. Turrell; *AU: personnel:* René Swift & Sonia Mendes
Eighth collaborative hydrographic cruise with FRS Marine Lab aboard the FRV *Scotia*. Sonobuoy deployments in the Faroe Shetland Channel and North East Atlantic, and towed hydrophone array surveys carried out as part of Sonia Mendes's PhD Project (funded by Portuguese Research Council).

6th pop-up retrieval (partial):

AU retrieve 2 missing pop-up units from the 6th (September 2002) deployment using the FRV *Scotia*.

Appendix 5. Inventory of major (> £1K) equipment items

Item	Year Purchased	Cost	Current Location
Panrix Computer Workstation	1999	£8K	AU Lighthouse Field Station
5 no. Oceano AR661 Acoustic Releases	2000	£32K	3 lost at sea, 4 remaining units stored at AU OceanLab
2 no. Oceano AR861 Acoustic releases	2002	£13K	
Acoustic Release Telecommand unit	2000	£7.5K	AU OceanLab
4 no. Acoustic Release buoyancy collars	2002	£6.5K	AU OceanLab
4 no. Popup buoyancy collars	2002	£8.5K	BRP, Cornell