Habitat characteristics of the shelf distribution of the harbour porpoise (*Phocoena phocoena*) in the waters around the Faroe Islands during summer

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ABSTRACT

Observations from a large number of seabird line-transect surveys conducted in Faroese waters are used to derive some general conclusions regarding the distribution of harbour porpoises (*Phocoena phocoena*) in the region using estimates of encounter rates (no./km^{-1}) in different meso-scale habitats around the Faroes during the breeding season (May-September). Based on a sub-set of the data collected during calm conditions (sea states below Beaufort 3) we analysed the distribution of harbour porpoises in relation to 5 potentially important physical parameters: water depth, distance to shore, slope of the ocean floor, distance to tidal front and Beaufort sea state. These parameters were determined from data collected during the surveys, the literature as well as from the new bathymetry established for the Faroese shelf. In order to link the differently scaled physical parameters with the encounter rates and sea states recorded during the surveys we used a suite of geo-statistical and raster-based GIS techniques based on a uniform grid resolution of 1 km in UTM zone 29 N projection. After removing parameters with insignificant effects a model of main effects was produced with sea state and distance to the tidal front having a significant negative effect on the rate of encountering harbour porpoises during both sets of cruises analysed (August 1997 and other surveys). During both sets of cruises the distance to the tidal front had a larger effect on the distribution of the animals than sea state. The strong relationship between harbour porpoise distribution and the average position of the tidal front around the Faroes strongly suggests that the species concentrates near the quasi-stationary circular shelf front separating mixed from stratified waters around the Faroes. However, the importance of shelf fronts for the distribution of harbour porpoises needs to be studied in detail in order to establish the proportion of the populations associated with these structures.

Skov, S., Durinck, J. and Bloch, D. 2003. Habitat characteristics of the shelf distribution of the harbour porpoise (*Phocoena phocoena*) in the waters around the Faroe Islands during summer. *NAMMCO Sci. Publ.* 5:31-40.

INTRODUCTION

The harbour porpoise (*Phocoena phocoena*) is found throughout the year in Faroese waters, and is thought to be most common in shelf waters within the 500 m depth contour, with lesser numbers occuring in deeper waters (Larsen 1995, Bloch *et al.* MS 2000). This general pattern of distribution does not deviate from the patterns documented from other parts of the Eastern Atlantic or from those described for the Western Atlantic (Watts and Gaskin 1985, Evans and Gilbert 1991, Hammond *et al.* 2002). As is the case in most waters the knowledge of the smaller scale distribution of the species within the shelf environment of the Faroese shelf is poorly known. Although no dedicated survey has yet been undertaken for harbour porpoises in these waters, it is possible to derive some general conclusions regarding the smaller scale spatial dynamics of the species by using observations from a large number of seabird surveys done in the region. We attempt to describe the shelf distribution of the species in relation to physical-oceanographical parameters like bottom depth, bottom slope, average position of tidal front and distance from shore.

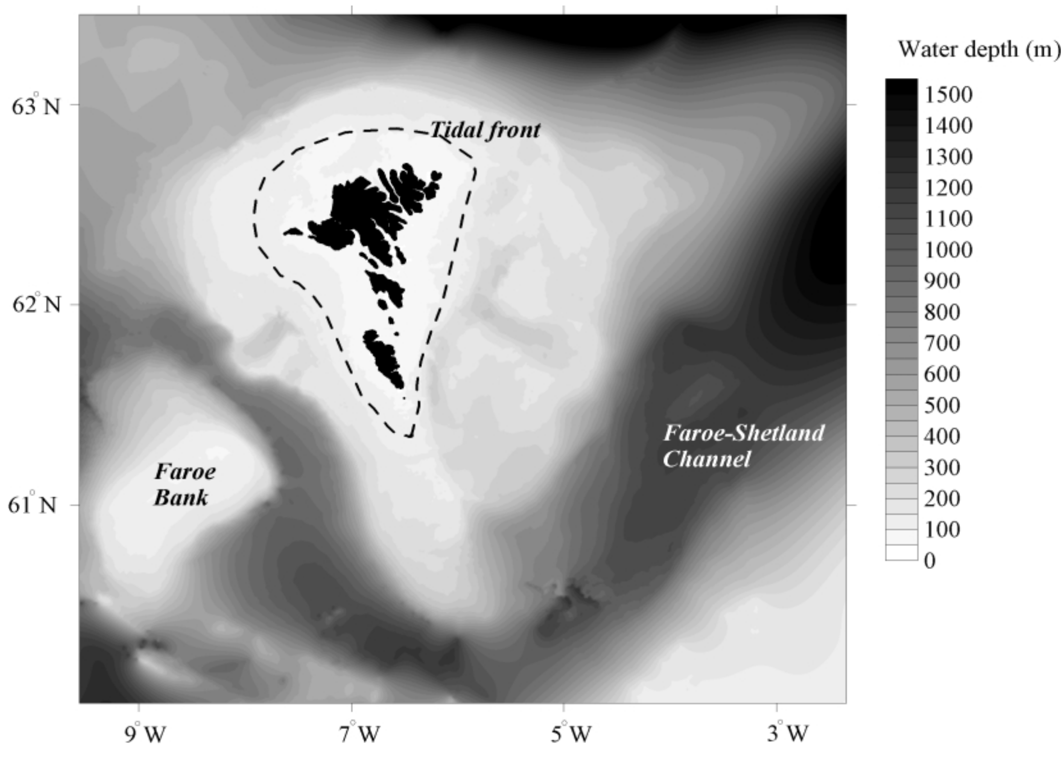
MATERIALS AND METHODS

Study area

The ecosystem of the Faroese shelf is characterised by a circular coastal ecosystem separated from the surrounding oceanic environment by a persistent tidal front (Hansen and Østerhus 2000, Gaard *et al.* 2002), both in terms of phytoplankton (Gaard *et al.* 1998), zooplankton (Gaard 1999) and fish (Gaard and Reinert MS 1996). In Fig. 1 the front is indicated by the 130 m depth contour, which marks the mid-frontal position (Hansen 2000). The ecosystem of the shelf water is basically a neritic phyto- and zooplankton habitat in contrast to the oceanic communities outside the tidal front. Furthermore, a large number of seabirds breeding on the Faroe Islands feed themselves and their chicks from the shelf water. As an example the main concentrations of puffins (*Fratercula arctica*), the most abundant fish-eating seabird species in the Faroes, are found exclusively inside the tidal front (Skov *et al.* 2001).

The bathymetry of the Faroese shelf has recently been updated by the production of a 300 m resolution grid based on detailed near-shore bottom depth soundings, 3D-seismic activity and

***Fig. 1**. The distribution of water depth on the Faroese shelf with names of locations mentioned frequently in the text. The map has been contoured from a 300 m resolution grid based on detailed near-shore bottom depth soundings, 3D-seismic activity and depths from echo soundings along the ship tracks of RV Magnus Heinarsson and RCGV Tjaldrid (from Simonsen et al. 2002).*



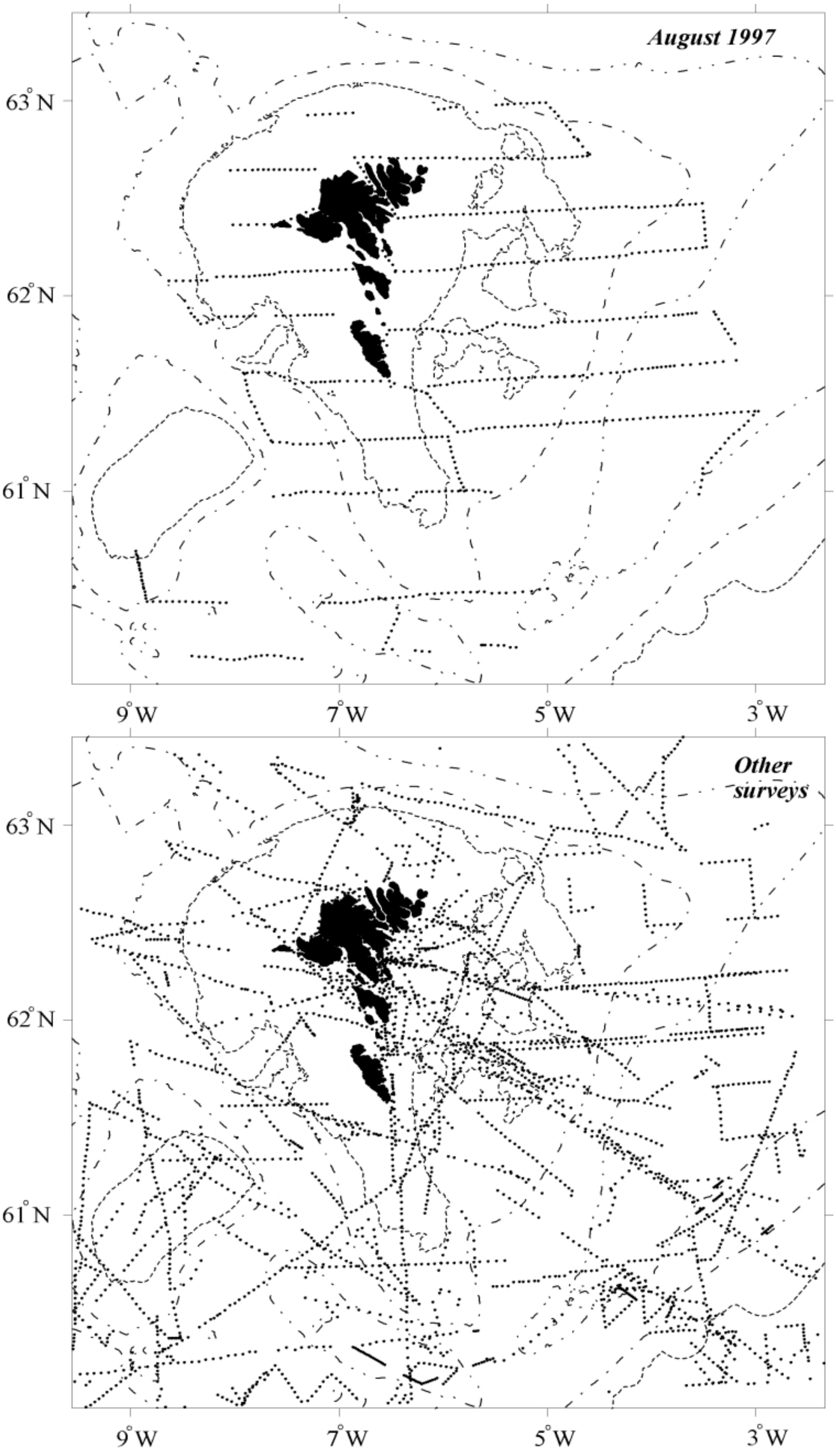


Fig. 2. *The distribution of samples (line transect segments) of the abundance of harbour porpoise in sea states 0-2 during the survey in August 1997 and during the remaining surveys done between May and September 1987-1999. The 100 m, 300 m and 1000 m depth contours are indicated.*

depths from echo soundings along the ship tracks of RV Magnus Heinarsson and RCGV Tjaldrid (Simonsen *et al.* 2002). The high-resolution bathymetry grid was available for this analysis of harbour porpoise habitat variables in the Faroes. In Fig. 1 such bathymetric features as the Faroese shelf, the offshore banks outside the shelf such as the Faroe Bank, and the deep water areas such as the Faroe-Shetland channel can be seen.

Surveys

A number of ship-based seabird line-transect surveys have been carried out around the Faroes during the period between August 1987 and December 1999 (reviews in Danielsen *et al.* 1990, Skov *et al.* 1995, 2001). During these surveys recording methods for harbour porpoises varied. Some of the work was carried out as part of the North Atlantic Sightings Surveys (NASS) in 1987, 1989 and 1995 (Sigurjónsson *et al.* 1989, 1990). Relatively few harbour porpoises were recorded during the NASS and by 'platforms' of opportunity, as only a minority of sighting effort during these types of surveys was made in calm weather. Moreover, the NASS had larger cetacean species as highest priority, and it has not been feasible to optimise the surveys for all sizes of animals on the same survey. Most records of the species for this study stem from a chartered seabird survey in August 1997, which was carried out primarily during calm conditions (Fig. 2).

During all surveys, including NASS, harbour porpoises were recorded within a 90° angle to one side of the ship by a team of 1 to 3 observers located on the roof of the ship. As distances to sighted pods were not always recorded during the seabird surveys, only the encounter rate has been used as a basis for measuring correlations with habitat variables. Harbour porpoises were counted continuously along the transect, and the data were split into ten-minute segments, thus allowing for a spatial resolution of approximately 3 km. As harbour porpoises become difficult to detect in Beaufort sea states greater than 2 (Palka 1996), only data collected in sea states 0 to 2 between May and September were retained for analysis (in total 3,596 segments). Even when abundance data on porpoises are collected under calm conditions it is likely that animals remain undetected on the track-line. However, this should not have introduced a systematic bias in relation to the analysis of habitat use of the animals. In addition, use of binoculars to scan the transect for animals may to some degree have reduced this bias.

Statistical analysis

The following potential habitat variables were selected: bottom depth, bottom slope, average position of tidal front and distance from shore. Distance from shore and bottom depth were selected as possibly important habitat variables because of the common notion that harbour porpoises are more frequently observed in coastal, shallow waters, although this has not necessarily been supported by surveys in various regions. Quite often, surveys have indicated the presence of onshore/offshore seasonal movements. In coastal British waters, peak abundance of harbour porpoises varied from area to area but mainly occurred between July and October (Evans *et al.* MS 1986). Coastal sighting surveys around the Shetland Islands also showed a peak in numbers between July and October, with very low numbers in winter and early spring (Evans MS 1990). A similar seasonal onshore/offshore migration pattern has also been found in the populations of harbour porpoise in the Western Atlantic and the Pacific (Taylor and Dawson 1984, Gaskin and Watson 1985). However, in the Netherlands observations from the coast and at sea have shown that harbour porpoises are mainly present in coastal waters there during winter (Camphuysen and Leopold 1993). Besides, cross-shelf descriptions of the distribution of harbour porpoises often have a negative bias in offshore areas because of the higher frequency of rough seas offshore. Thus, the description and analysis of the distribution of the species around the Faroes was based only on observations collected during calm conditions and the determination of the importance of physical-oceanographical parameters was designed to first take the effect of wave height into account. Bottom slope and distance to tidal front were also selected as potentially important habitat variables on the basis of knowledge from fine-scale monitoring activities in the eastern North Sea. Here, it has been documented that harbour porpoise distribution is correlated with topographic irregularities like banks and

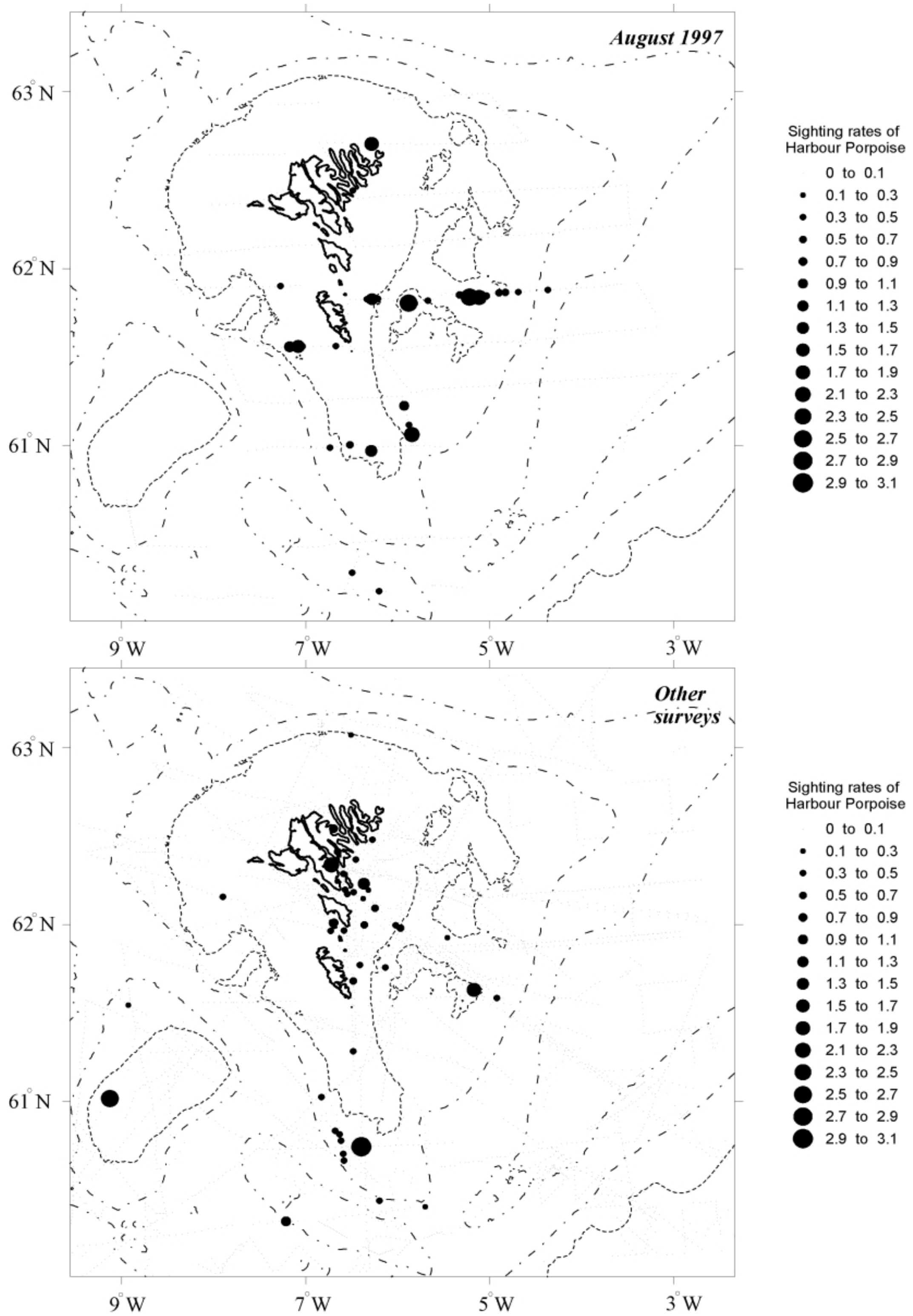


Fig. 3. *The distribution of sightings (encounter rates – no./km^{-1}) of harbour porpoises in sea states 0-2 during the survey in August 1997 and during the remaining surveys made between May and September 1987-1999. The 100 m, 300 m and 1000 m depth contours are indicated.*

reefs and the position of a persistent shelf front (Skov *et al.* MS 2000a). The distribution of the animals in the eastern North Sea is characterised by high numbers in the mixed water of the coastal current with the large concentrations at the front separating the coastal current from North Sea water masses (Skov *et al.* MS 2000a). Increased abundance of harbour porpoises at a shelf front has also been reported from a study in the Irish Sea, where most of the animals were observed at the tidal front or in the mixed water mass adjacent to the front (Weir and O'Brien MS 2000).

The statistical analysis of the relationship between encounter rates of harbour porpoise and the habitat variables was based on a raster GIS design in Idrisi Ver. 32, which made it possible to construct a common spatial framework for linking harbour porpoise survey data with the physical-oceanographical parameters at a scale of 1 km. In order to facilitate geostatistical analysis and the measurement of distances to habitat features all data were transformed from geographical co-ordinates to UTM zone 29 N. The geostatistical analysis (kriging) of encounter rates of harbour porpoises produced surfaces of continuous (interpolated) values. By using the kriged data as input to statistical tests, auto-correlation effects could be minimised. However, statistical tests based on links between raster GIS surfaces such as interpolated grids typically produce invalid correlation coefficients and unrealistically high P-values. To account for this we constructed a sub-sample of the GIS coverages by filtering the 1 x 1 km grid cells which overlapped the survey lines, and retain the filtered data for analysis. In order to show the persistence of the habitat affinities of the porpoises, separate statistical tests were performed on the August 1997 data and the rest of the data. The number of filtered grid cells were 534 for the August 1997 survey and 3,137 for the remaining cruises 1987-1999.

Analysis of the spatial continuity in the distribution of harbour porpoises as reflected by the data obtained during the August 1997 cruise and during the remaining cruises was made on the basis of variogram models fitted to experimental variograms. Encounter rates of harbour porpoises were log-transformed (log (n +1)) before analysis. Several models including nugget effect were tested visually, including nesting of variograms before deciding on the selection of the spherical model with a nugget effect. Anisotropy ratios and angles were determined by the Autofit module in Surfer 7.0. Interpolation was made by using ordinary kriging on the selected variograms at a resolution of 1 km. As the variograms of the encounter rates of harbour porpoises were non-linear and all showed a clear range structure, the range parameter was used to constrain extrapolation from sample locations.

An Idrisi coverage of water depth was created by re-sampling the 300 m resolution bathymetry grid (Simonsen *et al.* 2002) to a 1 km resolution. An Idrisi coverage of distances to the coasts of the Faroes was calculated from the 0 m grid cells of the depth coverage. An Idrisi coverage of distances to the tidal front was calculated from the 130 m depth contour of the bathymetry coverage, which approximately marks the mid-frontal position of the front (Hansen 2000). Based on the depth coverage a coverage with the slope (in %) of the sea floor of the Faroe shelf was estimated by using the surface module in Idrisi 32 (Monmonier 1982). The surface module determines the slope of each depth grid cell based on the cell resolution

Table 1. Test of significance of linear relationship (general linear model) between the log-density of harbour porpoises and Beaufort sea state and distance to tidal front. Significance level is: * $P < 0.0001$

	Beaufort Sea State *F*-value	Distance to tidal front *F*-value
August 1997	19.67*	35.51*
All other data 1987 - 2000	18.40*	215.59*

and the values of the immediate neighbouring cells to the top, bottom, left and right of the cell in question using the following formula:

$$\text{Tangent} = \sqrt{\left(((right - left)/(res\sum 2))^2 + ((top - buttom)(res\sum 2))^2\right)}$$

which measures the tangent of the angle that has the maximum downhill slope; *left, right, top, bottom* are the attributes of the neighbouring cells and *res* is the cell resolution. The coverage of Beaufort sea state was created by linear interpolation of sampled sea states obtained during the surveys.

Tests of the effect of habitat variables on the distribution of harbour porpoises during the August 1997 cruise and the remaining cruises were made using general linear modelling (GLM) in SAS. Encounter rates of harbour porpoises were log-transformed before analysis. The GLM analysis was carried out using sequential selection of habitat variables as main effects while taking account of the effect of Beaufort sea state. First, all variables were considered, after which a sequence of models was analysed in which variables with insignificant effects were removed until a model of main effects was produced.

RESULTS AND DISCUSSION

A total of 31 sightings of 90 harbour porpoises were sighted during the August 1997 cruise and 46 sightings of 94 animals during the remainder of the cruises. The plots of both sets of sightings show that most of the animals were found on the shelf in waters shallower than 500 m (Fig. 3). The species was found commonly both in coastal, upper shelf (below 100 m depth), lower shelf (100 to 300 m depth) and shelf break (300 to 500 m depth) environments. No obvious trends in the encounter rates was seen in the plots. The first sequence of linear tests corroborated that the effect of distance to the coasts of the Faroes on the distribution of the animals was negligible, as was the water depth. Removing both of these variables from the models clarified that the effect of slope of the ocean floor was moderate during the August 1997 cruise ($F = 12.0$, $P = 0.0006$, df=533) and non-significant during the remainder of the cruises ($F = 2.35$ $P = 0.1256$, df=3,136). Thus, Beaufort sea state and distance to the tidal front were selected for the final model of main effects. Strong effects of Beaufort sea state and distance to the tidal front were shown for both sets of cruises (Table 1). During both sets of cruises the distance to the tidal front had a larger effect on the distribution of the animals than sea state ($F = 35.51$, $P < 0.0001$, df= 533 and $F = 215.59$ $P < 0.0001$, df= 3,136).

Our findings suggest that harbour porpoises occur throughout shelf, bank and oceanic environments around the Faroes, and that patches of high abundance are confined to shelf and bank environments shallower than 500 m. The tidal front encircling the islands may be a more important habitat feature than the topographic features, including the slope of the ocean floor. This indicates that hydrographic conditions play a major role in shaping the habitat of harbour porpoises. Fronts between residual currents and the more oceanic environments may be a major habitat feature affecting harbour porpoise distribution as indicated by detailed studies in the southeastern North Sea and the Irish Sea (Skov *et al.* MS 2000a, Weir and O'Brien MS 2000). Although the species has a broad overall distribution in European waters, these structures may support the largest aggregations of the species (Skov *et al.* MS 2000b). From our averaged data sets and due to the use of the average frontal position it is, however, not possible to reveal the finer-scale cross-frontal distribution of the species. Both Skov *et al.* (2000a) and Weir and O'Brien (MS 2000) showed that the bulk of the animals were located on the mixed side of the front, and the stratified side of the front was generally characterised by lower abundance.

Quasi-stationary shelf fronts separating mixed from stratified waters are generally known to host aggregations of marine life from plankton to fish and seabirds. However, the importance of these fronts for the distribution of harbour porpoises needs to be studied in detail in order to establish the proportion of the populations associated with these structures. Thus, more concurrent measurements of hydrographic parameters and the frequency/density of harbour porpoises are recommended in the North Atlantic. In addition, studies are needed to uncover the ecological link between the tidal front and harbour porpoises.

The primary prey of harbour porpoises in the Faroes has not been examined in detail but is believed by fishermen to be composed of herring (*Clupea harengus*) and sandeel (*Ammodytes sp*.) (Larsen 1995). Unfortunately, the distribution of these fish species in relation to the tidal front has not been studied in detail. There is clearly a need to carry out more integrated studies of the harbour porpoise and the oceanography. Due to the uniformity and the limited size of the primary area of occurrence, there is a good potential for carrying out ecological studies of the variability of the occurrence of harbour porpoises and controlling for oceanographic parameters in this part of the North Atlantic.

ACKNOWLEDGEMENTS

Knud Simonsen from the Faculty of Science and Technology at the University of the Faroes is thanked for providing access to the new bathymetry for the Faroese shelf (Simonsen *et al.* 2002). The field data presented in this paper are a result of the efforts of a large number of observers. Unfortunately, the number of observers who participated is too large to be listed here. Special thanks go to the leaders of the Faroese part of the NASS cruises: Geneviève Desportes, Gerald Joyce and Jim Cotton as well as to the crew members of the survey ships, including the Faroese marine research vessel 'Magnus Heinason', the chartered trawlers 'Hvítiklettur' and 'Havkyst', the fishery inspection ship 'Beskytteren' and the coast-guard vessel 'Tjaldrið, Icelandic. Credit is given to GEM, the Faroes Fisheries Laboratory and the Joint Nature Conservancy Council for allowing use of the data.

REFERENCES

Bloch, D., Mikkelsen, B. and Ofstad, L.H. (MS) 2000. *Marine Mammals in Faroese waters with special attention to the south-south-eastern sector of the region*. GEM Report to Environmental Impact Assessment Programme: 1-20.

Camphuysen, C.J. and Leopold, M.F. 1993. The Harbour Porpoise *Phocoena phocoena* in the Southern North Sea, in particular in the Dutch sector. *Lutra* 36:1-24.

Danielsen, F., Skov, H., Durinck, J. and Bloch, D. 1990. Marine distribution of seabirds in the Northeast Atlantic between Iceland and Scotland, June-September 1987 and 1988. *Dansk Orn. Foren.Tidsskr.* 84:45-63.

Evans, P.G.H., Harding, S., Tyler, G. and Hall, S. (MS) 1986. *Analysis of cetacean sightings in the British Isles 1958-1985*. Report from the Cetacean Group, UK Mammal Society to the Nature Conservancy Council. 65 pp.

Evans, P.G.H. (MS) 1990. Harbour porpoises (*Phocoena phocoena*) in British and Irish waters. International Whaling Commission SC/42/SM49.

Evans, P.G.H. and Gilbert, L. 1991. The distributional ecology of harbour porpoises in the Shetland Islands, North Scotland. In: Evans, P.G.H. (ed.) *European Research on Cetaceans* 5, European Cetacean Society, pp. 47-52.

Gaard, E. 1999. The zooplankton community structure in relation to its biological and physical environment on the Faroese shelf, 1989-1997. *J. Plankton Res*. 21:1133-1152.

Gaard, E. and Reinert, J. 1996. (MS) Pelagic cod and haddock on the Faroe Plateau: Distribution, diets and feeding habitats. ICES CM 1996/L:16.

Gaard, E., Hansen, B. and Heinesen, S.P. 1998. Phytoplankton variability on the Faroe shelf. *ICES J. Mar. Sci.* 55:688-696.

Gaard, E., Hansen, B., Olsen, B. and Reinert, J. 2002. Ecological features and recent trends in the physical environment, plankton, fish stocks and seabirds in the Faroe shelf ecosystem. In: Sherman, K. and Skjoldal, H-R. (eds) *Large Marine Ecosystems of the North Atlantic.* Elsevier Science, 464 pp.

Gaskin, D.E. and Watson, A.P. 1985. The Harbor porpoise, *Phocoena phocoena*, in Fish Harbour, New Brunswick, Canada: Occupancy, distribution, and movements. *Fishery Bulletin* 83:427-442.

Hammond, P.S., Berggren, P., Benke, H., Borchers, D.L., Collet, A., Heide-Jørgensen, M.P., Heimlich, S., Hiby, A.R., Leopold, M.F. and Øien, N. 2002. Abundance of harbour porpoise and other cetaceans in the North Sea and adjacent waters. *Journ. Appl.* Ecol. 39:361-376.

Hansen, B. 2000. Havið. Føroya Skúlabókagrunnur. 232 pp.

Hansen, B. and Østerhus, S. 2000. North Atlantic – Nordic Seas exchanges. *Progress in Oceanography* 45:109-208.

Larsen, B.H. 1995. A note on catches and exploitation of harbour porpoise (*Phocoena phocoena*) around the Faroese Islands. In: Bjørge, A. and Donovan, G.P. (eds) Biology of the Phocoenids. *Rep. int. Whal. Commn* (Special issue 16):155-158.

Monmonier, M. 1982. Computer-Assisted Cartography: *Principles and Prospects.* Prentice-Hall, Inc., Englewood Cliffs, N.J. 80 pp.

Palka, D. 1996. Effects of Beaufort Sea State on the sightability of harbour porpoises in the Gulf of Maine. *Rep. int. Whal. Commn* 46:575-582.

Sigurjónsson, J., Gunnlaugsson, T.and Payne, M. 1989. NASS-87: Shipboard sightings surveys in Icelandic and adjacent waters June-July 1987. *Rep. int. Whal. Commn* 39:395-411.

Sigurjónsson, J., Gunnlaugsson, T., Ensor, P., Newcomer, M. and Vikingsson, G. 1991. North Atlantic Sighting Survey (NASS-89): Shipboard surveys in Icelandic and adjacent waters July-August 1989. *Rep. int. Whal. Commn* 41:559572.

Simonsen, K., Larsen, K.M.H., Mortensen, L. and Norbye, A.M. 2002. *New Bathymetry for the Faroe Shelf.* NVD Ritt 2002:7. Faculty of Science and Technology. University of the Faroe Islands.

Skov, H. Durinck, J., Danielsen, F. and Bloch, D. 1995. Co-occurrence of cetaceans and seabirds in the Northeast Atlantic. *J. Biogeography* 22:71-88.

Skov, H., Tougaard, S and Kinze, C.C. (MS) 2000a. Environmental Impact Assessment. Investigation of marine mammals in relation to the establishment of a marine wind farm on Horns Reef. Fisheries and Maritime Museum, Esbjerg, Ornis Consult A/S and Zoological Museum, University of Copenhagen.

Skov, H, Bloch, D, and J.. Durinck, (MS) 2000b. Meso scale variability in the distribution of the harbou porpoise *Phocoena phocoena* – comparisons between estuarine and oceanic environments. In: Evans, P.G.H., Pitt-Aiken, R. and Rogan, E. (eds) *European Research on Cetaceans* 5, European Cetacean Society, p. 345.

Skov, H., Upton, A.J., Reid, J.B., Webb, A.W., Taylor, S.J. and Durinck, J. 2001. *Dispersion and vulnerability of marine birds and cetaceans in Faroese waters.* Joint Nature Conservation Committee 2001. Peterborough. 180 pp.

Taylor, B.L. and Dawson, P.K. 1984. Seasonal changes in density and behavior of harbour porpoise (*Phocoena phocoena*) affecting census methodology in Glacier Bay National Park, Alaska. *Rep. int. Whal. Commn* 34:479-483.

Watts, P. and Gaskin, D.E. 1985. Habitat index analysis of the Harbour porpoise (*Phocoena phocoena*) in the southern coastal Bay of Fundy, Canada. *J. Mamm.* 66:733-744.

Weir, C.R. and O'Brien, S. (MS) 2000. Association of the harbour porpoise with the western Irish Sea front. In: Evans, P.G.H., Pitt-Aiken, R. and Rogan, E. (eds) *European Research on Cetaceans* 5, European Cetacean Society, pp. 61-65.