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# Spring distribution and density of minke whale *Balaenoptera acutorostrata* along an offshore bank in the central North Sea

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ABSTRACT: Minke whales were recorded in the central North Sea in an area characterised by frontal features and high productivity northeast of the Dogger Bank (4677 km$^2$). Survey efforts were carried out from 28 March to 2 July 2007, at a finer scale than in earlier studies in the region, using 2 vessels as platforms of opportunity and a dedicated line-transect survey vessel following distance sampling methods. The high density of whales indicated that this offshore bank slope is an important spring habitat for minke whales in the North Sea. In total, 77 sightings of minke whales comprising 130 individuals were recorded. The peak density of minke whales was estimated to be 0.029 whales km$^{-2}$ (minimum estimate, 95% CI: 0.012 to 0.070) in May. During peak abundance, the minke whales temporarily congregated in the area, suggesting that the whales were taking advantage of the local spring abundance of sandeels. The density found was higher than previous studies have suggested for the central North Sea. The results correspond to recent observations of minke whale redistribution within the North Sea, and these may be related to a decline in sandeel availability elsewhere in the North Sea. Offshore banks that aggregate prey may therefore become increasingly important feeding habitats for minke whales and other top predators in the North Sea. The observed habitat preference of minke whales along this offshore bank appeared to be similar to that observed in coastal areas, and this suggests some degree of generality regarding the preference for this type of habitat.

KEY WORDS: Minke whale · Distribution · Density · Relative abundance · Offshore bank · Platform of opportunity · Line-transect survey · Central North Sea



## INTRODUCTION

The northern minke whale *Balaenoptera acutorostrata* occurs widely in the northeast Atlantic and the North Sea, although this species is less common in the southern North Sea (Evans et al. 2003, Reid et al. 2003). In the northern North Sea, minke whales are mainly seen from April to October (Northridge et al. 1995, MacLeod et al. 2007, Robinson et al. 2007, Weir et al. 2007) although they can be seen year-round (Macleod et al. 2004). Most studies of North Atlantic minke whales have been carried out at either a large spatial scale (Hammond et al. 2002, Skaug et al. 2004) or at fine scale targeting coastal waters (Naud et al. 2003, Macleod et al. 2004, Robinson et al. 2007, 2009, Tetley et al. 2008). There appears to be a general pattern of minke whales moving into coastal areas in the late summer, but overall there is little knowledge regarding the seasonal distribution of minke whales (and cetaceans in general) in offshore habitats (MacLeod et al. 2007). One such offshore habitat is the Dogger Bank in the central North Sea, where Atlantic waters from the north meet and mix with waters from the English Channel (Pingree & Griffiths 1978, Van Haren & Joordens 1990). Most of the water column remains mixed throughout the year because of tidal mixing, while from May until September stratification occurs in deeper waters around this shallow sand bank (Pingree & Griffiths 1978). Relatively high primary production values have been reported in summer (Riegman & Colijn 1991), although this productivity on a small scale is patchy due to the complex hydrodynamics and the irregular occurrence of wind mixing.

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The present study was conducted between 29 March and 2 July along the northeastern slopes of the Dogger Bank and partially overlapped with recently announced/proposed special areas of conservation (SACs) according to the Habitats Directive of the European Union (Annex I: sandbank habitat; Lindeboom et al. 2005, Diesing et al. 2009). The bank offers a suitable sandeel habitat, and studies on fish, seabirds, and to a lesser degree cetaceans (e.g. Knijn et al. 1993, Stone et al. 1995, Evans et al. 2003) show that it has a high biodiversity. Minke whales have mainly been reported to the north and west of the Dogger Bank with only few sightings to the northeast. Other cetaceans, such as the harbour porpoise *Phocoena phocoena* and white-beaked dolphin *Lagenorhynchus albirostris*, are more common (Hammond et al. 2002, Evans et al. 2003, Reid et al. 2003, Van der Meij & Camphuysen 2006, SCANS-II 2008, Gilles et al. 2009). According to the EU Habitats and Species Directive, the minke whale is not an Annex-II-listed species and therefore the proposed Dogger Bank SAC may only include the harbour porpoise under this Annex.

The distribution and abundance of minke whales on feeding grounds will ultimately depend on the distribution of their prey and underlying primary production. Factors such as water depth, seabed sediment, fronts, and tides also influence the distribution and abundance of minke whales (Naud et al. 2003, Macleod et al. 2004, Johnston et al. 2005, Tetley et al. 2008, Robinson et al. 2009). The species also shows intra- and inter-annual variations in fine-scale distribution (Robinson et al. 2009), which highlights the need for long-term research effort in SACs.

The objective of the present study was to verify the distribution and density of minke whales and other cetaceans and to contribute to the understanding of the cetacean ecology along this offshore bank. Here we report on a complementary approach during a geophysical survey involving 2 research vessels used as platforms of opportunity (PO) and 1 dedicated line-transect (LT) survey vessel following distance sampling methods. The PO survey was conducted over a longer time span, and the results are used to (1) assess the cetacean community, (2) determine any observed temporal variability in occurrence, and (3) highlight the advantage of such surveys. The LT survey results are used to estimate the density of minke whales.

## MATERIALS AND METHODS

**Study site.** The study site (4677 km$^2$) ranged from 2° 54′ to 4° 33′ E and from 55° 30′ to 56° 18′ N in an area northeast of the Dogger Bank stretching out over British, Dutch, Danish, and German waters (Fig. 1). The waters ranged in depth from 23 m (SE) to 70 m (NW) and ran from tidally mixed to temperature-stratified. A survey stratum of 848.6 km$^2$ was covered by both dedicated and opportunistic survey effort in German waters (Fig. 1).

**Data collection.** Observations were conducted during a geophysical seismic survey (28 March to 2 July 2007) involving 2 PO vessels: the 91 m RV 'Atlantic Explorer' (PO1) carrying out a geophysical survey and the 46 m support motor vessel (MV) 'Thor Provider' (PO2, 31 March to 13 June). In addition, the 38 m MV 'Andfjord' carried out a dedicated LT survey (23 April to 17 May). PO1 was sailing predetermined parallel survey transects and was accompanied by PO2, which sailed parallel and ahead of PO1. The PO vessels were in frequent communication regarding sightings and are regarded as one ('tandem') platform. The LT vessel was surveying at distances of ≥20 km away from the PO vessels and followed predetermined line transects placed randomly in a zigzag pattern in the central (German) part of the survey area. The vessels travelled at 4.5 knots (PO) and 6 knots (LT).

Experienced observers searched for cetaceans from the bridge deck (heights: PO2/LT: 6.25 to 7.0 m and PO1: 10.5 to 13.5 m). Dedicated watches were conducted during daylight with one observer on watch. After mid-June one observer remained onboard PO1, reducing the amount of effort due to planned breaks. Observers scanned with the naked eye and used binoculars (7 × 50 and 8 × 42) for identification and group-size estimations. Standard recording forms were used (JNCC 2004). When a sighting was made, the vessel continued on the track-line. The radial sighting distance was determined using reticule binoculars or person-specific range sticks. The bearing to animal(s) and heading were determined by ship's compass or using an angle-board (LT vessel). Other sightings data included water depth (depth sounder or electronic sea chart), species identification (definite, probable, or possible), calf/juvenile presence, group-size (maximum, minimum, or best), composition, and behaviour.

**Data analysis.** Data collected in slight Beaufort Sea States (BSS) 0 to 4, good visibility (>1 km) and low swells (<4 m) were used for density calculations. Duplicate sightings made from the PO vessels were verified (using time, position, composition, heading, and PO-communication data) and excluded. Both definite identification and probable identification of species were used.

**Relative abundance.** The relative abundance was measured as the number of sightings 100 km$^{-1}$. A grid with a resolution of 10 × 10 nm was created, and cells with a survey effort <10 km were excluded. The latitude and longitude were assigned to the centre of each grid cell when determining the mean water depth.

**Density and responsive movement.** Minke whale density (whales km$^{-2}$) was estimated from LT data fol-

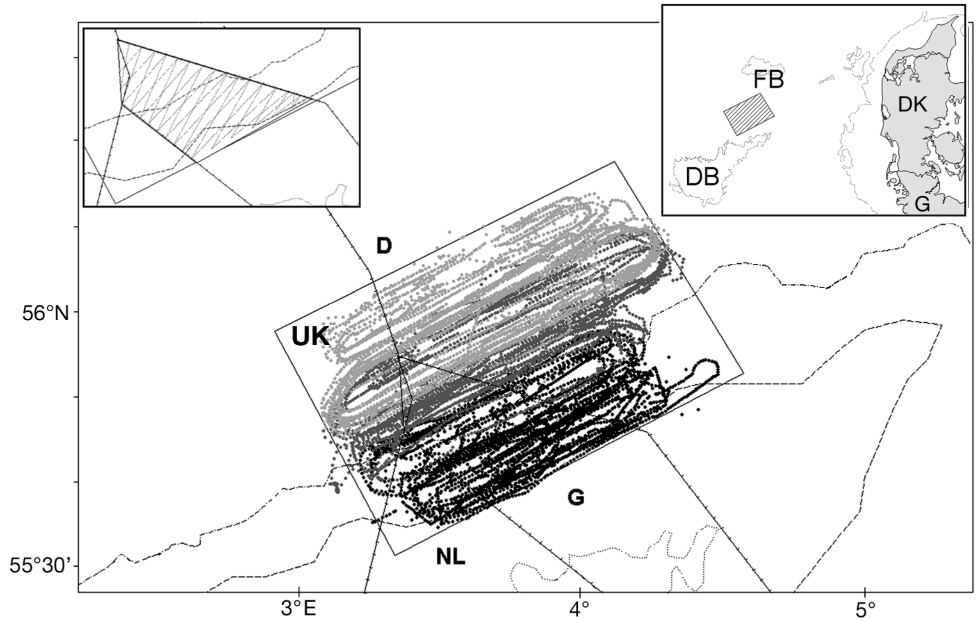


Fig. 1. The central North Sea study area (rectangle) was surveyed by platforms of opportunity (PO) vessels with effort in April (in black), May (in dark grey) and June (in light grey). Line transects are displayed in the left inset image (dotted zigzag lines), where one set was covered 3 times and the other 2 times. The Dogger Bank (DB) and Fisher Bank (FB) are shown in the right inset image. International exclusive economic zone (EEZ) waters (Denmark [D], United Kingdom [UK], The Netherlands [NL], and Germany [G]) and depth contours are shown: 50 m (dash-dot line), 40 m (dashed line) and 30 m (dotted line)

lowing both conventional (CDS) and multiple covariate distance sampling (MCDS) approaches (Buckland et al. 2001, Marques & Buckland 2003) using Distance 4.1 (Research Unit for Wildlife Population Assessment). Essentially, the program fits a detection function to the distribution of perpendicular distances and this function is used to estimate the effective strip half-width (ESW). The density (whales km$^{-2}$) is given as:

$$D = \frac{n \cdot E(S)}{2L \cdot ESW \cdot g(0)} \quad (1)$$

Where n is the number of detections, $L$ is the length of transect (km), $E(S)$ is the mean group size, and $g(0)$ is the detection probability on the track-line. MCDS allows for the inclusion of environmental covariates in the estimation of detection probability. It is expected that the detection probability is positively correlated with group size but negatively correlated with the sea state (e.g. Buckland et al. 2001). The estimates of density generated here are based on a number of assumptions, including that the probability of detecting minke whales on the track-line, $g(0) = 1$, i.e. every animal on the track-line is detected. Another assumption of the line-transect methodology is that animals do not respond to the approaching survey vessel before detection. This was investigated by using a vector component of the whale's velocity away from the vessels (i.e. the cosine of the difference between bearing and heading; de Boer et al. 2008).

## RESULTS

### Survey effort and summary of sightings

A total of 9902 km PO effort was completed during 96 d (Table 1). The southern, middle, and northern sectors of the study site were surveyed in April, May, and June, respectively (Fig. 1). 103 sightings were made, totalling 281 animals involving 6 species (Table 2). Some PO sightings remained unidentified (12.5%; Table 2). The LT survey covered 1452 km planned effort (Table 1) from 23 April to 17 May; 31 cetacean sightings were made, totalling 112 animals (Table 2).

### Minke whale density

To reduce bias in mean group size estimates due to the potential of a positive relationship between group size and perpendicular distance ($x$), exploratory analysis (regression of group size versus detection probability) was carried out. The detections were independent of group size and therefore mean group size was used. Because of small sample size (n = 22), models with single covariates were considered. Akaike's information criterion (AIC) was used, and the best fitting model was the half-normal key function with cosine series expansion (Fig. 2). The sea state was selected as a covariate in the analysis model. The density estimate was 0.029 whales km$^{-2}$ (95% CI: 0.012 to 0.070, 0.51 CV). The vector component of the whale's velocity was explored, and this suggested no responsive movement of the whales prior to detection.

Table 1. Extent of visual effort for platforms of opportunity (PO) and line-transect (LT) vessels, including the percentage of survey effort in Beaufort sea state ≤4 (% BSS)

| Research vessel | Survey period | Hours of effort | Survey effort (km) | % BSS |
|---|---|---|---|---|
| PO vessels | 28 March–2 July 2008 | 951 | 9901.7 | 81 |
| LT vessel | 23 April–17 May 2008 | 318 | 1452 | 99 |
| All vessels | 28 March–2 July 2008 | 1269 | 11353.7 | 83 |

Table 2. Information on sightings and individuals (in parentheses). The relative abundance (N/L, the number of sightings 100 km$^{-1}$) for different species observed from PO and LT vessels are shown for all weeks (Weeks 1 to 14) and for 24 April to 21 May (Weeks 5 to 8)

| Species | PO | LT | N/L-PO (Weeks 1 to 14) | N/L-PO (Weeks 5 to 8) | N/L-LT (Weeks 5 to 8) |
|---|---|---|---|---|---|
| Minke whale | 55 (70) | 22 (60) | 0.56 | 1.77 | 1.52 |
| Humpback whale | 1 (1) | 0 | 0.01 | 0.04 | 0 |
| Atlantic white-sided dolphin | 8 (78) | 2 (25) | 0.08 | 0.14 | 0.14 |
| White-beaked dolphin | 5 (37) | 0 | 0.05 | 0.07 | 0 |
| Atlantic white-sided/ white-beaked dolphin | 1 (4) | 1 (20) | 0.01 | 0.04 | 0.07 |
| Bottlenose dolphin | 1 (1) | 0 | 0.01 | 0 | 0 |
| Harbour porpoise | 15 (28) | 6 (7) | 0.15 | 0.25 | 0.41 |
| | | | 0.45[a] | 0.45[a] | 1.27[a] |
| Unidentified dolphin | 9 (50) | 0 | 0.09 | 0.07 | 0 |
| Unidentified whale | 6 (8) | 0 | 0.06 | 0.18 | 0 |
| Unidentified cetacean | 2 (4) | 0 | 0.02 | 0.04 | 0 |
| **Totals** | 103 (281) | 31 (112) | 1.04 | 2.58 | 2.13 |

[a]Because porpoises are notoriously difficult to observe in higher sea states, the relative abundance for porpoises was also measured for Beaufort sea states 0 to 2 only

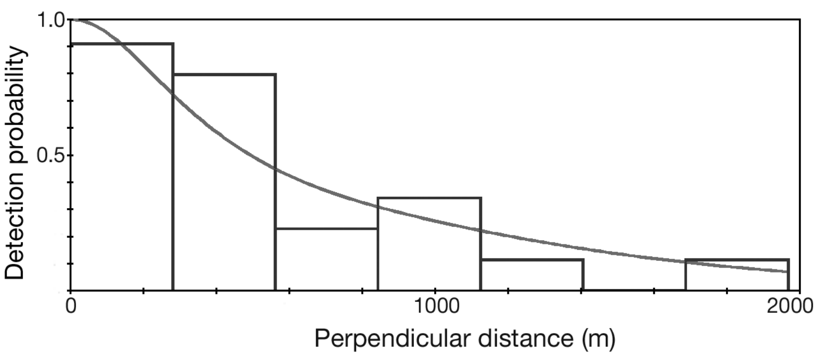


Fig. 2. *Balaenoptera acutorostrata.* Perpendicular sighting distances, detection probability, and fitted detection function for minke whales in German waters of the study area, central North Sea

**PO versus LT survey**

The first minke whale sightings were made on 26 April (LT) and 30 April (PO). The whales were relatively abundant for 4 wk (Weeks 5 to 8 of the survey: 24 April to 21 May; Fig. 3). One juvenile was sighted. The LT effort was restricted by inclement weather conditions and finished on 17 May. During Week 8, the whales were observed in deeper waters. The PO surveys offered enough temporal coverage to show that whale numbers were nearing zero from Week 9 (Fig. 3). The mean water depth of minke sightings (PO) was <50 m (Weeks 5 to 6) and >55 m (Weeks 7 to 8), whilst this measured <50 m throughout the LT survey. The mean group sizes measured for minke whales were 1.26 (PO [±0.7 SD]; n = 50, Weeks 5 to 8) and 2.7 (LT [±3.9 SD]; n = 22). The latter was affected by a large group (20 whales); however, without this sighting the mean group size remained high (1.9). The average sighting distance (LT) was short (752 m) and explains why all animals were identified to species. The relative abundance peaked during Week 6 (PO) and Week 7 (LT). Overall (Weeks 5 to 8) the PO survey measured the highest relative abundance (1.77 whales 100 km$^{-1}$; Table 2).

**Movement and foraging behaviour**

Three types of foraging behaviour were observed (PO + LT): (1) whales making quick directional changes, (2) association with seabirds, and (3) lunge feeding. During Week 5, the whales were observed in the southwestern sector (Fig. 4A). In Week 6, the majority of whales had spread northeast and were congregating along the 50 m depth contour. In Week 7, the whales had moved further northeast, and by Week 8 the distribution was more spread out (Fig. 4C). A high relative abundance (2.04 whales 100 km$^{-1}$) was measured in water depths ranging between 50 and 59 m (Fig. 4F), and this was slightly lower (1.75) in depths ranging between 40 and 47 m (Fig. 4F). A high relative abundance (>6) was measured (at depth 69 m), but this was based on only one sighting. The

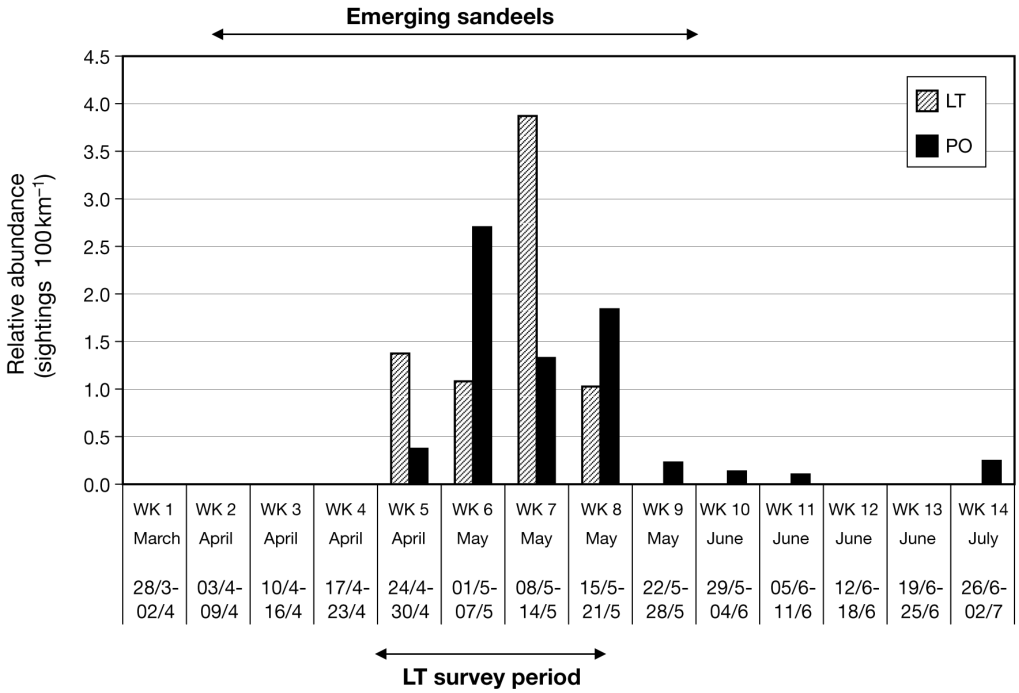


Fig. 3. *Balaenoptera acutorostrata*. Relative weekly (WK) abundance of minke whales (whales 100 km$^{-1}$) from platform of opportunity (PO) and line-transect (LT) surveys

latitudes of the sighting positions were plotted and confirmed a northerly movement of the whales ($p < 0.05$, $r^2 = 0.422$, linear regression). The PO coverage varied over a long time; it is unknown whether the whales remained present in the southern sector, but given the northerly movement this seems unlikely.

## DISCUSSION

### Minke whales

The estimated minke whale density in April–May was 0.029 whales km$^{-2}$ (95% CI: 0.012 to 0.070, 0.51 CV), which is higher than the SCANS densities reported in July (Block G [SCANS-I 1994]: south-central North Sea 0.0088 whales km$^{-2}$, 0.70 CV; Block U [SCANS-II, 2005]: south-central North Sea 0.022 whales km$^{-2}$, CV 0.69) and corresponds to the density in Block V in July 2005 (Block V [SCANS-II]: north-central North Sea 0.028 whales km$^{-2}$, CV 0.45; Hammond et al. 2002, SCANS-II 2008). Other studies report on comparable densities between 0.002 and 0.078 whales km$^{-2}$ in the northeast Atlantic (Skaug et al. 2004), whereas densities off Alaska (0.002 to 0.017 whales km$^{-2}$; Zerbini et al. 2006) and California (0.00072 whales km$^{-2}$; Barlow & Forney 2007) were lower.

The group size of minke whales (2.7: LT) was high compared to SCANS (Block G: 1.33; Block U: 1.0; Block V: 1.05; Hammond et al. 2002, SCANS-II 2008). The SCANS relative abundances for minke whales (Block G: 0.33 whales 100 km$^{-1}$; Block U: 0.58; Hammond et al. 1995; and Block V: 0.69; SCANS-II 2008) are lower than the LT survey (1.52 whales 100 km$^{-1}$, 0.21 CV) whereas the PO survey revealed a corresponding abundance (0.56 whales 100 km$^{-1}$) compared to Block U, although during the 'peak' period this was much higher (Weeks 5 to 8: 1.77 whales 100 km$^{-1}$). The PO coverage of the study area varied over time, and whale movements may have impacted the observed relative abundances. High local relative abundances for minke whales have been reported off Mull, Scotland (2.1 whales 100 km$^{-1}$ in spring; Macleod et al. 2004) and off the Moray Firth (0.7 to 3.9 whales 100 km$^{-1}$ in summer; Robinson et al. 2007), suggesting that minke whales may temporarily congregate on favoured feeding grounds.

### Potential sources of bias

The lack of a correction factor for $g(0)$ probably causes substantial bias in minke whale densities (e.g. Schweder et al. 1999, Skaug et al. 2004). Skaug & Schweder (1999) estimated that 56 to 68% of minke whales were missed during surveys in the north Atlantic. SCANS implemented methods that allow for the estimation of a correction factor (SCANS-I: $g(0) = 0.82$ to 1.0; Hammond et al. 1995). The whale density esti-

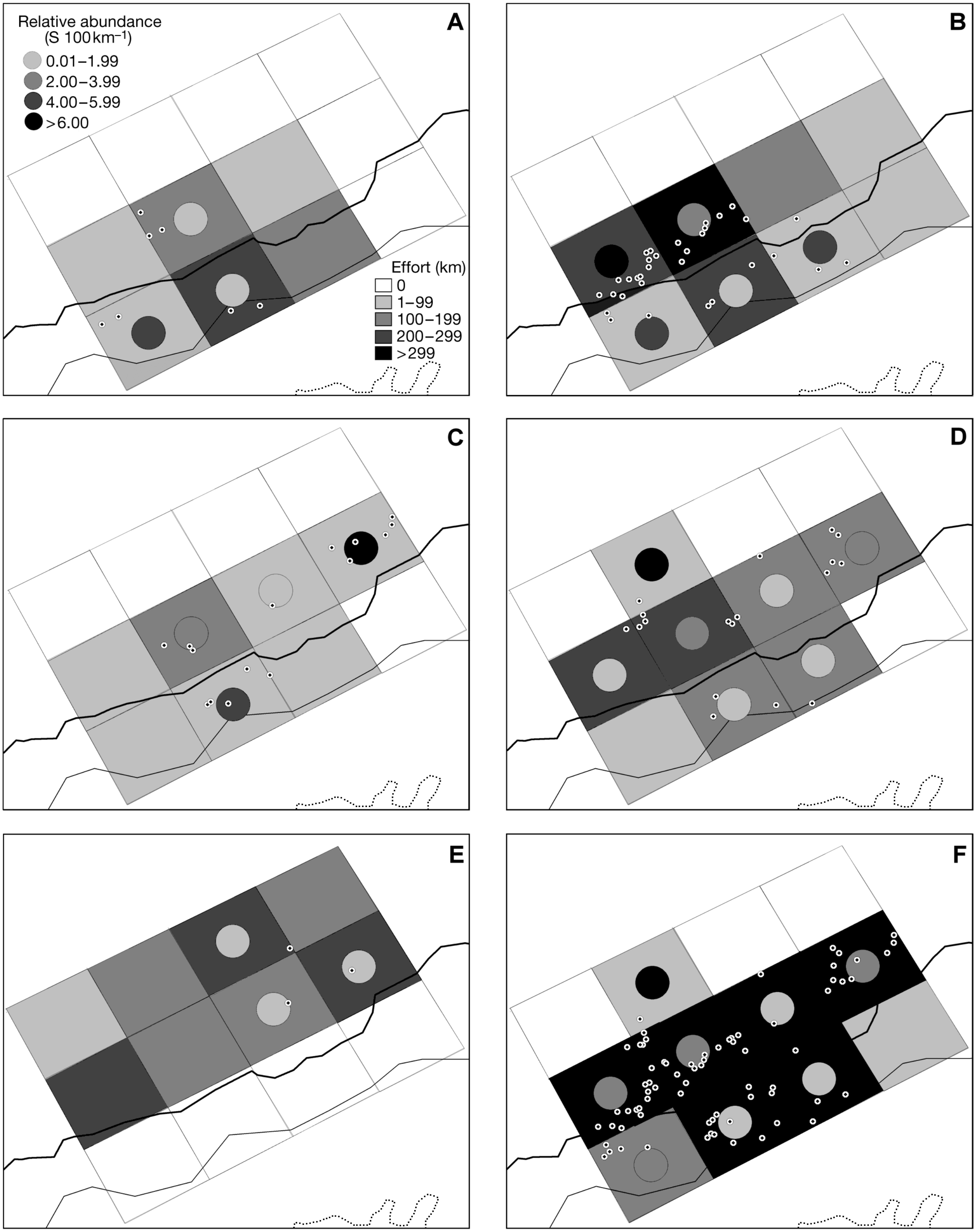


Fig. 4. *Balaenoptera acutorostrata.* Distribution of effort (km) and spatial distribution of relative abundance (sightings 100 $km^{-1}$) from all vessels during (A) Week 5, (B) Week 6, (C) Week 7, (D) Week 8, (E) Weeks 9 & 10 (PO only), and (F) Weeks 5 to 8 (PO + LT). Effort is indicated by shaded blocks; relative abundance is indicated by shaded circles; and sightings are plotted as open dots. Depth contours: 50 m (thick line), 40 m (thin line) and 30 m (dotted line)

mated here must be regarded as a minimum because correction factors could not be calculated. Furthermore, LT surveys generally have 2 observers on watch whilst this survey used 1. The effect of excluding the covariate for sea state resulted in a negative bias of 17.8 % in the density estimate, and similar patterns have been shown in other studies (Schweder et al.1999, Skaug et al. 2004, Palka 2005). It was not possible to assess the effect of relatively slow survey speed or the problems of replicating transect lines. However, this may have caused a positive bias in the density estimate. The differences in whale density may be a result of timing (summer versus spring). Minke whale surfacing rates in western Scotland have been shown to vary as a result of different foraging strategies for different prey, with slightly higher rates measured in May compared to those in June and July (Stockin et al. 2001). It is likely that foraging minke whales have short surfacing intervals, which may cause a positive bias (Stockin et al. 2001).

**Offshore bank**

The present study area lies along the slopes of the Dogger Bank and includes a delicate transition zone between tidally mixed and stratified waters characterised by relatively high primary production values during summer (Riegman & Colijn 1991) and in May (Van Haren & Joordens 1990). The latter is the result of a front that causes a subtidal current predominantly directed along the isobath and enhanced vertical mixing (Van Haren & Joordens 1990). Other frontal zones in the region are the Spurn and Flamborough Head fronts (Pingree & Griffiths 1978), which lie to the west. Frontal systems can be regarded as biological 'hot spots' where within short distances significant changes can be observed in the pelagic food web regarding productivity, structure, and diversity (Nielsen Gissel & Munk 1998).

In May, high numbers of sandeels *Ammodytes* sp. were reported in the study area by Danish fishermen and PO1 crew. Stomach contents studies (Folkow et al. 2000, Olsen & Holst 2001, Pierce et al. 2004) have shown that the lesser sandeel *A. marinus* is a preferred prey for North Sea minke whales. Sandeels are a schooling fish that emerge from the sandy substrata during April–May in which they over-winter. They emerge during daylight to forage on calanoid copepods (Macer 1966, Winslade 1974). Highest monthly landings of sandeels were reported in the area in May–June 2001 to 2008 (Boulcott et al. 2006, ICES 2008a). The study area also boarders onto the Fischer Bank, where the concentration of sandeel larvae peaked near a front in May (Nielsen Gissel & Munk 1998). A seasonal distribution of minke whales over sandeel habitat was reported off Scotland during June (Macleod et al. 2004). Similar observations of pelagic daytime feeding behaviour on sandeels were found in the northern North Sea (Olsen & Holst 2001) and along offshore banks in Greenland (Laidre et al. 2009).

The minke whales were associated with the 50 m depth contour (Fig. 4). It is hypothesised that the slopes of this offshore bank were acting as a temporary congregation area when considerable primary production over suitable sandy sediments resulted in an increased availability of sandeels to foraging minke whales. From late May the feeding conditions for minke whales were no longer optimal for unknown reasons, although it is likely that this temporary congregation site probably extended beyond the study area. The habitat preferences of minke whales along this offshore bank appeared to be similar to those previously observed in coastal areas, in particular the association with the 50 m isobath, gravel/sand sediments and steep slopes (Macleod et al. 2004, Robinson et al. 2009). This suggests some degree of generality regarding the habitat preferences of minke whales in the north Atlantic.

Early spring plankton at the Dogger Bank is patchily distributed, and sandeels only emerge from the seabed when feeding conditions are optimal (Van der Kooij et al. 2008). Because sandeels depend on such a specific habitat and form clusters of schools, it makes them vulnerable to local depletion (Mackinson 2007).

**Cetacean diversity**

The species diversity recorded along this offshore bank was high: 6 cetacean (Table 2, Fig. 5) and 2 seal species. The PO data are potentially influenced by unknown reactions of each species to sound produced during the PO1 operations. The porpoise relative abundance from the PO survey was lower than the LT survey (PO: 0.45 and LT: 1.27 porpoises 100 $km^{-1}$, April–May), although this was based on low sample size. This was also much lower than measured in the central North Sea in July (Block G: 3.53, Block U: 4.85 porpoises 100 $km^{-1}$; Hammond et al. 2002, SCANS-II 2008) and in May (13.00 porpoises 100 $km^{-1}$, Gilles et al. 2009). The harbour porpoise is common in the North Sea and occurs year-round in the southern North Sea (Camphuysen 2004). The porpoise has also been reported at the Dogger Bank in winter (Todd et al. 2009). Although porpoises are notoriously difficult to observe, we expected to see more porpoises, particularly since sandeels may be important prey (Santos et al. 2004).

White-beaked dolphins are common in the central North Sea (Evans et al. 2003, Reid et al. 2003), but Atlantic white-sided dolphins *Lagenorhynchus acutus* dominated north of the 50 m depth contour. Other sightings included a (probable) bottlenose dolphin

*Tursiops truncatus* and humpback whale *Megaptera novaeangliae* (3 May). Interestingly, 1 wk later a humpback whale was reported off the Dutch coast (10 to 13 May 2007; Camphuysen 2007).

## Redistribution of minke whales

In the North Sea the timing of various plankton groups do not seem to respond to ocean warming synchronously, resulting in predator-prey mismatches that resonate to higher trophic levels, such as fish, seabirds, and marine mammals (Edwards & Richardson 2004). SCANS-I showed that minke whales were more abundant in the northwest North Sea (north of 55° N and west of 4° E; Hammond et al. 2002), and the SCANS-II density surface models predicted highest concentrations of animals in the central North Sea (west of the study area), off Norway, northeastern Scotland, southwestern England, and southern Ireland (SCANS-II 2008). Minke whales were also concentrating further south in summer than previously recorded in the northwest North Sea (54 to 58° 30′ N, 2° E; Camphuysen et al. 2006). The results presented here corroborate the other observations of minke whale redistribution within the North Sea. The observed southward change in minke whale distribution is yet unexplained, but may be related to environmental factors such as a decline in prey availability, most likely that of sandeels, elsewhere in the North Sea (ICES 2008b).

## PO versus LT survey

PO vessels provide a low-cost tool for cetacean research and provide opportunities to survey otherwise inaccessible offshore habitats. The combination of different methodologies to solve problems associated with the choice of a single method has proven to be effective, e.g. aerial and boat-based surveys, acoustic and visual surveys, and aerial and PO surveys (Hammond et al. 2002, Certain et al. 2008, SCANS-II 2008). Unique for this study was the combination of both PO and LT vessels, which provided data suitable for density estimation. The longer time-span increased the probability of detecting all cetacean species and can be contrasted to large-scale surveys in which an area the size of the present study area is covered far less extensively, both in time and space. The timing of the LT survey unexpectedly supplied a 'peak' density for minke whales, whilst the PO datasets showed the temporal variability of the whales. The longer temporal coverage highlighted the problem of timing a dedicated survey properly and showed that PO vessels can successfully be used to identify areas and periods of high density to improve designs for future line-transect surveys.

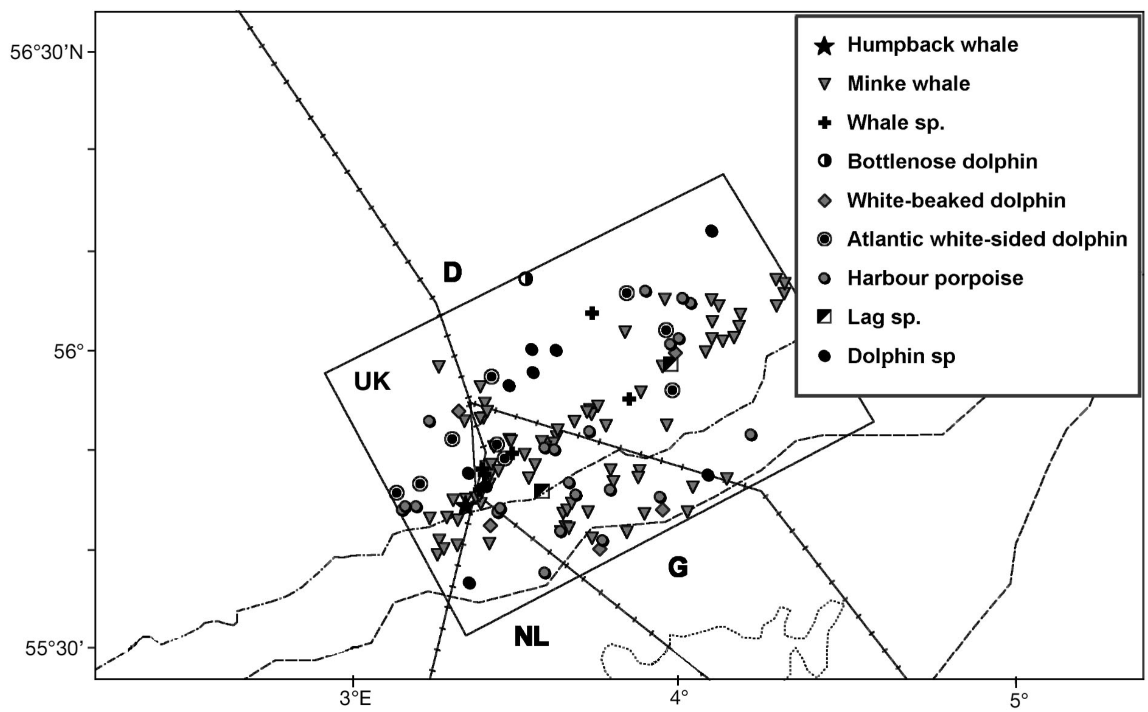


Fig. 5. The distribution of cetacean species in the study area from all vessels plotted by species. International EEZ waters (Denmark [D], United Kingdom [UK], The Netherlands [NL], and Germany [G]) and depth contours are shown: 50 m (dash-dot line), 40 m (dashed line) and 30 m (dotted line)

## CONCLUSIONS

Finding temporary congregation sites in offshore waters and identifying concentrations of animals requires a prolonged presence of observers, which is not easily achieved during standard surveys. To overcome the difficulties in detecting trends (e.g. expensive LT surveys) it will be important for future monitoring to apply a consistent methodology using suitable PO vessels. The present study showed the advantages of surveys at a finer spatial scale with longer temporal coverage and, as such, provided ecological information regarding foraging minke whales along an offshore bank in May.

At present there are some threats to minke whales in these waters, and an increased understanding of this species ecology is needed. Parts of the Dogger Bank have been proposed as SACs (sandbank habitat; Diesing et al. 2009). Our observations suggest that the slopes of the Dogger Bank support a high species diversity and offer a predictable foraging site for minke whales and other predators, particularly during spring when they exploit local sandeel aggregations. The habitat preferences of minke whales along this offshore bank appeared to be similar to those previously observed in coastal areas, and this suggests some degree of generality regarding the habitat preferences of minke whales in the north Atlantic. This offshore bank is currently the last extensive sandeel fishing ground in the North Sea, and concern has been raised regarding the effects of local sandeel depletion at the bank on their predators and the North Sea ecosystem as a whole (Mackinson 2007). Especially when prey becomes less abundant elsewhere, these offshore banks may become increasingly important to marine predators within the North Sea. It is necessary to further study the environmental variables in the area in order to predict the importance of these offshore banks as spring feeding habitats for minke whales and other top predators.

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