ASJ: *International Journal of Wildlife and Endangered Species Conservation (IJWESC)*
Vol. 04(01) 30 August, 2025, Pp. 150-176
www.academiascholarlyjournal.org/ijwesc/index_ijwesc.htm
Also Available@; Archive.org/Todd_and_Todd
Open access

Full Length Research

A Duck's Beak with Porpoise: Sightings of Cetaceans During and After a 3D Seismic Survey in the German North Sea

Ian B. Todd[1] and *Victoria L. G. Todd[1]

[1]Ocean Science Consulting, Spott Road, Dunbar, East Lothian, EH42 1RR, Scotland, UK.

*Correspondent E-mail: vt@osc.co.uk

Accepted August 03, 2025

Large-scale, inter-governmentally funded offshore marine mammal surveys are costly, leading to infrequent and often inadequate spatial data coverage, especially in Special Areas of Conservation (SACs). Conversely, offshore Oil & Gas Exploration and Production operators and renewables developers must perform extensive Environmental Impact Assessments to meet permit conditions, providing a potential source of valuable scientific data. In 2007, spring and summer line-transect surveys collected marine mammal observer data during (Survey 1 (S1)) and after (Survey 2 (S2)) the final seismic 3D survey in German waters (Entenschnabel 'Ducks' beak' Dogger Bank SAC). S1 reported 31 marine mammal sightings (110 individuals, four species); S2 resulted in ten sightings (22 individuals, three species). S1/S2 porpoise (*Phocoena phocoena*) sightings were similar, but S1 group size was smaller; spring density (*ca.* 6 porpoises/km²) was lower than summer (ca. 16 porpoises/km²). Conversely, minke whale (*Balaenoptera acutorostrata*) sightings were higher in spring (*ca.* 20 minke/km²) compared to summer (*ca.* one minke/km²). No evidence supported seismic survey effects on any species; differences in abundance were likely related to seasonal/prey movements. Results provide valuable sightings in this remote, yet highly developed, section of the North Sea, informing future EIAs for O&G E&P operators and renewable-infrastructure developers in the Dogger Bank SAC.

Keywords: Abundance, Density, Distance Sampling, Dogger Bank, Marine Mammals, North Sea, Seismic Survey

INTRODUCTION

Dedicated large-scale, offshore, inter-Governmental marine-mammal density and abundance estimation surveys are rare and often costly to perform, resulting in patchy and infrequent large-scale regional coverage (Kaschner et al., 2012). For example, Small Cetaceans in European Atlantic waters and the North Sea (SCANS) surveys, are conducted only once every eleven years throughout the European Atlantic and North Sea, covering an area of 1.2 million km^2 (Hammond et al., 2002; 2013; 2021). Consequently, while these broad-scale surveys facilitate region-wide estimates of marine mammal density, abundance, and distribution, additional fine-scale details are often required in specific regions of importance, such as Special Areas of Conservation (SACs), especially when considering targeted requirements for conservation and/or offshore exploration and development.

The North Sea is one of the most exploited shelf regions in the world, with a range of anthropogenic activities including, *inter alia,* offshore Oil and Gas (O&G) Exploration and Production (E&P), windfarm construction, shipping, fishing, and UneXploded-Ordnance (UXO) removal. These endeavours produce underwater noise, which can be detrimental to marine mammals which utilise different sound frequency bands for a number of activities, such as communication, navigation, foraging, and a range of activities within the wider social group (Southall et al., 2019, Southall et al., 2021). Noise impulses from offshore seismic surveys – spanning temporo-spatial scales broader than those considered typically in environmental assessments – may have acute, cumulative, and chronic effects on marine mammals, including habitat displacement, disruption of biologically important behaviours (e.g. masking of communication signals), stress, and potential auditory damage (Nowacek et al., 2015). Consequently, as part of O&G seismic-exploration permit applications, mitigation in the form of Marine Mammal Observer (MMO) and/or Passive Acoustic Monitoring, PAM (Todd et al., 2015), is often stipulated, particularly in SACs.

While industry MMO observations are constrained mostly to periods of a few hours to days, covering the industrial noise period of concern (e.g. a seismic survey), over time, they can develop into substantial datasets within themselves (Todd et al., 2016). Moreover, while resultant raw data are usually submitted to regulators, they often remain confined to confidential reports, thus representing a valuable, often overlooked resource on marine megafauna species. When proprietary surveys cover temporo-spatially data deficient regions, the value of such observations increases. The current downsizing of seismic vessel fleets, and exit of many seismic operators, is due to a combination of factors. Firstly, the global energy-supply market has seen a marked diversification in the last decade, shifting away from O&G E&P to renewables. Secondly, numerous countries have issued individual standards for offshore-noise monitoring before, during, and after any industrial activity, limiting survey capacity. For example, threshold values were issued by the German Federal Environment Agency (UmweltBundesAmt, UBA) which are legally binding in German waters (and have been adopted elsewhere). These are described by de Jong et al. (2011), as a threshold consisting of dual criteria of 160 dB re 1 μPa²s Sound Exposure Level (SEL) and 190 dB re 1 μPa Peak-to-Peak (p-p) Sound Pressure Level (SPL), that should not be exceeded at a distance of 750 m around a noise-emitting site. This threshold was based on a Temporary Threshold Shift (TTS) found in a single harbour porpoise (*Phocoena phocoena*) at 164 dB re 1 μPa²s SEL and 199 dB re 1 μPa p-p SPL; thus, the chosen values include some safety adjustment (de Jong et al., 2011). As a consequence of this 2011 legislation, seismic activity in German waters effectively ceased overnight, and to the best of our knowledge, the last large-scale seismic survey to enter German waters was the 2007 *Angelina* survey (Arfai et al., 2014), which is presented in this study. Historical datasets from these types of surveys, especially in German waters, have therefore become suddenly valuable, both for seismic operators looking to develop new fields, and marine consultants/academic scientists dependent on previous data sets of marine mammal distribution and abundance, to inform future offshore renewable developments.

In 2007, four years prior to the enforced UBA noise thresholds, a German O&G operator, Wintershall, performed the 3-Dimensional (3D) commercial '*Angelina*' seismic survey in the central North Sea, including the German sector's Entenschnabel (duck's beak). Spring and summer line-transect surveys collected marine mammal observer data during (Survey 1 (S1)) and after (Survey 2 (S2)) the seismic 3D survey. The area contains 29 exploratory O&G wells, and one commercial gas field (Arfai and Lutz 2018). Part of the Entenschnabel is located within (and borders) the Dogger Bank (DB), which is an offshore 18,000 km^2 sandbank formed from submerged glacial moraine. The DB straddles thermally-stratified northern and isothermal southern waters (Pingree and Griffiths, 1978), and is a productive ecosystem within itself (Diesing et al., 2009; Sell and Kröncke, 2013).

In line with the 'sandbank habitat' classification under Annex I of the European Union (EU) Habitats Directive (92/43/EEC 1992), the entire site is designated as an SAC, and supports a rich ecosystem, regularly inhabited by several species of marine mammal (Todd et al., 2009; de Boer, 2010; Cucknell et al., 2016; Todd et al., 2016; Todd et al., 2022). Consequently, as part of the EIA, MMOs were stationed on the seismic source and guard vessels and dedicated marine mammal Line Transect (LT) surveys were also performed in the German sector.

Part of these data surveys – predominantly in relation to minke whale (*Balaenoptera acutorostrata*) sightings – were presented by de Boer (2010).

Rationale

The prime aim of this study was to estimate density and abundance of marine mammals, during and after the last seismic survey in German waters to (1) address a dearth of historical data from this region, and (2) to inform future EIAs conducted by offshore O&G E&P operators and developers of renewable infrastructure in the Dogger Bank SAC. This was achieved through distance-sampling analysis of commercial MMO data from two dedicated line transect surveys conducted in spring and summer of 2007. A further objective was to compare findings of this study to those presented in de Boer (2010). Finally, results of this study were compared qualitatively with historical SCANS MMO survey data from the region.

MATERIALS AND METHODS

This work is an extension of a 2007 collaborative initiative between Wintershall A.G. (primary operator), Ocean Science Consulting Ltd. (industry scientists performing data collection, analysis, and reporting), de Boer (2010), one of the commercial MMOs aboard one of the line-transect vessels, and Petroleum Geo-Services (PGS), the seismic operator pgerforming the 3D *Angelina* seismic-survey.

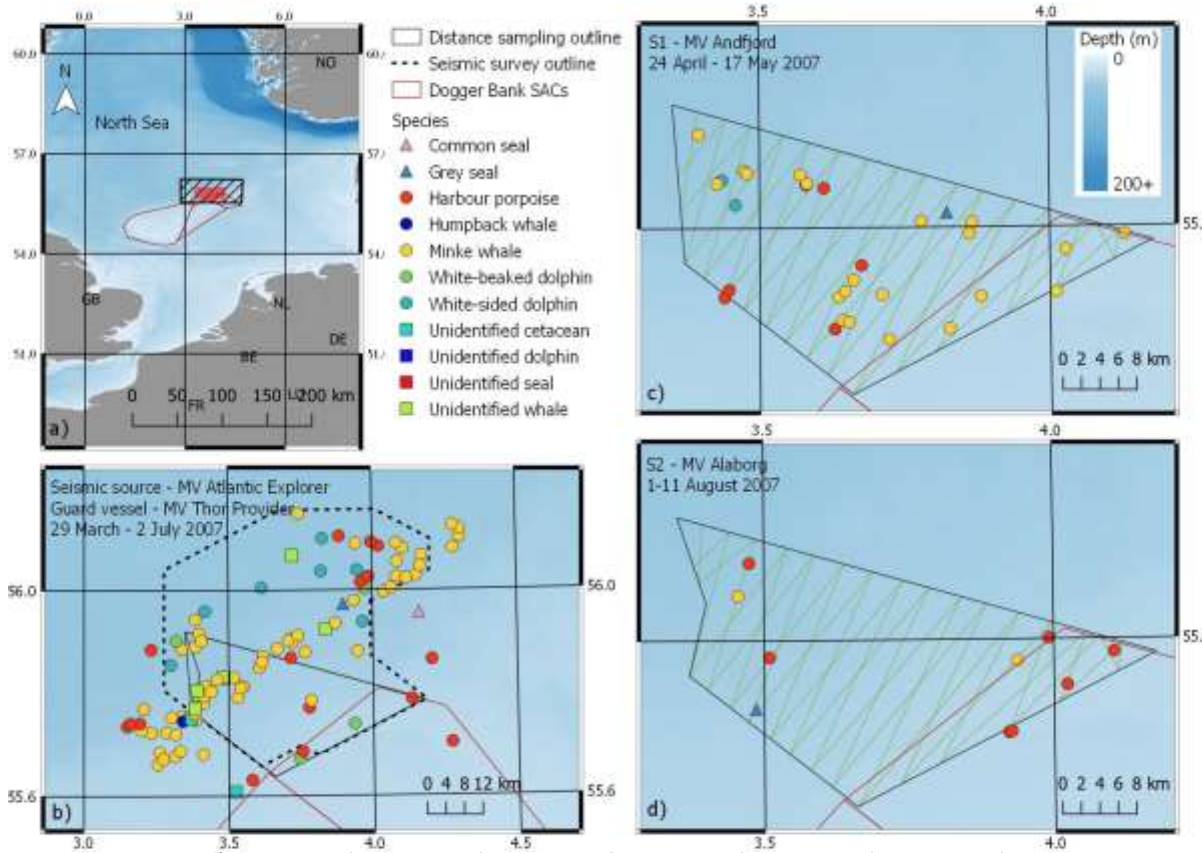
In the de Boer (2010) study, throughout the entire seismic survey, commercial MMO data were analysed from the 91 m Length Over All (LOA) seismic source, Motor Vessel (MV), *Atlantic Explorer*, its supporting 46 m LOA guard vessel MV *Thor Provider*, and from a dedicated Line Transect (LT) survey aboard the 38 m LOA MV *Andfjord.* Part of these data were partitioned between two papers: 1. de Boer (2010) analysed sightings of minke whale (MW) from all vessels during the seismic survey, and 2., this study, which presented line transect (LT) data collected from MV *Andfjord*, and also from data collected after the *Angelina* seismic survey had finished from the 31 m LOA MV *Alaborg*, focusing predominantly on harbour porpoise (HP). Consequently, to remain consistent with de Boer (2010), similar terminology was adopted here.

Timing and location

Figure 1 shows sources of MMO data collected from the four different survey vessels during de Boer (2010) study, and this work, along with survey dates, vessel names, and locations. Between 29/03/2007–02/07/2007, the 3D *Angelina* seismic survey was performed with the MV *Atlantic Explorer*. The seismic source comprised two airgun arrays, each with operating volume of 50 L (3,090 in^3). The seismic survey took place in the central portion of the southern North Sea within the Exclusive Economic Zones (EEZs) of Germany (DE), Denmark (DK), the United Kingdom (UK) and the Netherlands (NL) – see Arfai et al. (2014) for details. Seismic-survey coordinates ranged from 55° 12' to 56° 58' N to 002° 54' to 4° 33'E, encompassing an area of *ca.* 4677 km^2. This included part of the Dogger Bank SAC, in water depths ranging from 23 m (SE) to 70 m (NW). During the seismic survey, between 31/03/2007–13/06/2007, MV *Thor Provider* travelled at unknown distances ahead of, and to the side of, the MV *Atlantic Explorer* seismic-source vessel.

In the German 'Entenschnabel' portion of this study area, two dedicated marine mammal line-transect (LT) distance-sampling surveys were conducted. The first survey (S1), between 23/04/2007–17/05/2007, was performed during seismic exploration activities, aboard the MV *Andfjord*, which was positioned always at least 20 km away from the MV *Atlantic Explorer* seismic-source vessel. The second dedicated LT survey (S2) took place 76 days later, between 1–11/08/2007, aboard the MV *Alaborg* vessel, after the seismic survey had finished, and all vessels had departed the area.

Marine Mammal Observers (MMOs) were present on all vessels. Some commercial MMO data from the MV *Atlantic Explorer* seismic-source vessel, MV *Thor Provider* guard vessel, and MV *Andfjord* were analysed and presented by de Boer (2010); however, the de Boer (2010) study included both off-effort and incidental sightings data, which were excluded here. Only on-effort MMO data from both dedicated LT surveys (MV *Andfjord*, Survey S1, and *MV Alaborg*, Survey S2) were analysed and presented here. For clarity and in summary, the de Boer (2010) study presented data from MVs *Atlantic Explorer, Thor Provider,* and the *Andfjord,* focussing on MW. This study used only on-effort MMO data both during the 3D *Angelina* seismic survey (MV *Andfjord*), and after it (MV *Alaborg*) focussing predominantly on HP, but



Mar-07	Apr-07	May-07	Jun-07	Jul-07	Aug-07
UK	UK	DE	DE	DK	DE
Atlantic Explorer - seismic source					
Thor Provider - guard vessel					
	Andfjord				*Alaborg*

Figure 1: Map of study area showing region in North Sea including Dogger Bank SAC (a); seismic survey area and sightings from both seismic source vessel MV Atlantic Explorer and guard vessel MV Thor Provider (b); and, distance sampling survey transects and sighting locations from S1 – MV Andfjord (c) and S2 – MV Alaborg (d). For reference, survey areas for S1 and S2 are shown along with seismic survey area in (b); (e) vessel survey timeline. Map coordinates in World Geodetic System (WGS)'84 decimal degrees.

also re-analysing MW data, correcting for effort and excluding incidental sightings.

Data collection

Parallel survey-track design for S1 was designed jointly by the authors of this study and de Boer (2010). To maintain data comparability, the same trackline was followed in the post-seismic S2 from *MV Alaborg*. Two dedicated Joint Nature Conservation Committee (JNCC, 2004) trained, qualified, and experienced MMOs worked back-to-back during daylight hours only. Marine Mammal Observers searched from the bridge, or the most suitable vantage point in the vessel, with a minimum eye height of *ca.*7 m above sea level. Data collection was limited to Beaufort-Sea States ≤5 during S1 and S2, because of survey vessel operational limits, as opposed to optimal sighting conditions. Observers scanned an area of 180°, centred systematically on the vessel's transect, with the naked eye using 7x50 or 8x42 magnification Opticron Marine II reticle binoculars, while the vessel moved along predetermined zig-zag line transects. A total of 31 transect lines were conducted, covering an area of 797.3 km-[2] (Figure 1 c and d). Upon sighting an individual, or group of marine mammals, the MMO recorded species, sighting distance (using binocular reticles or range sticks in S1, and binocular reticles only in S2; considering eye height above water, later converted to metres), bearing to animal (°; estimated using angle board), animal(s') direction of travel (° in relation to vessel's direction), group size (maximum, minimum, or best estimate), number of juveniles, and general behaviour description including association with/ avoidance of vessel or other traffic/operations/installations. The vessel did not deviate from transects when a sighting was made and travelled at a constant speed of 10.8 km h^{-1}. In addition to sightings data, observers recorded time, vessel heading (°) and speed (ms^{-1}), Beaufort-Sea state, glare, swell (m), visibility (km), and water depth (m, recorded from the depth sounder or chart). Recordings were made at the start and end of each transect line, every 30 minutes (if no changes occurred), when there was a change in observer, and when there was an obvious change in one or more of the environmental variables. Standard Joint Nature Conservation Committee recording forms were used (JNCC 2004).

Data analysis

Quality checks performed on raw JNCC MMOs forms revealed that, for the S1 *Andfjord* survey, some entries were missing sighting effort (*e.g.* failed to report start and end of breaks). This meant that these data had to be processed differently to the S2 *Alaborg* data, which logged effort accurately. Consequently, in periods where effort clearly exceeded feasible MMO shifts (these are typically no longer than 1-2 hours), substantiated by a clear absence of marine mammal encounter data recorded during that same span, entry duration was corrected to match the minimum duration which could be trusted to be defined as 'on-effort'. An R code was developed using *R software* version 4.2.1. (R Core Team 2022) to estimate each entry session that could be trusted, depending on the survey's planned break and shift times, and on reported encounter times. This credible watch duration was used instead of the 'absolute time duration' between each entry, when computing any statistics on the S1 MV *Andfjord* data. Harbour Porpoise (HP) and Minke Whale (MW) abundance was estimated using conventional distance-sampling analyses (Buckland et al., 1993; Buckland et al., 2001; Buckland et al., 2004). The following analysis was conducted using *R software* version 4.2.1. (R Core Team 2022).

Briefly, a detection function, $g(y)$, which models probability of detecting an object given its perpendicular distance, y, from the transect, is fitted to the distances of observed objects. From this function, number of missed objects can be estimated, and density (number of objects per unit area; D; Equation 1) calculated using Horvitz–Thompson-like estimators (Buckland et al., 1993). Density was then converted to abundance (number of total animals in the area; N) by multiplying by the size of the survey region, as per Buckland et al., (1993).

$$\boldsymbol{D} = \frac{\boldsymbol{n * E(s) * f(0)}}{\boldsymbol{2L}} \qquad --------\text{(Equation 1)}$$

where n is number of detections, $E(s)$ is mean group size, L is transect length (km), and $f(0)$ which is the detection function $g(0)$ rescaled to the unity (Buckland et al., 2001).

As the vessel traversed each transect, MMO effort alternated between being 'on-effort' and 'off-effort'. To account for this in analysis, each 'on-effort' interval was included as its own individual record. Prior to analysis, datasets were explored thoroughly by plotting multiple histograms of recorded distances. This allowed detection of any potential issues that could bias results, or lead to violation of distance sampling assumptions, and determination of whether grouping of distances might be needed and (if required) the number of groups (Figure S1 and S2).

In addition, cluster size was plotted against distance for each observation of HP and MW in S1 and S2 (Figure S3). For both species, it was concluded to be reasonable to analyse these data with the assumption that there was no size bias.

Two important steps in distance-sampling studies include (1) choosing an appropriate truncation distance (the maximum distance from the transect line or point at which observations are included in the analysis), and, (2) deciding if data should be treated as grouped by distance or ungrouped (Buckland et al., 1993). Consequently, three different filters for both grouping and truncation were considered:

1. *Grouping filters*: ungrouped, four equal groups, and three equal groups; and,
2. *Truncation*: untruncated, truncated at 95% maximum distance, and truncated at 1000 m and 300m for MW and HP, respectively, which is realistic

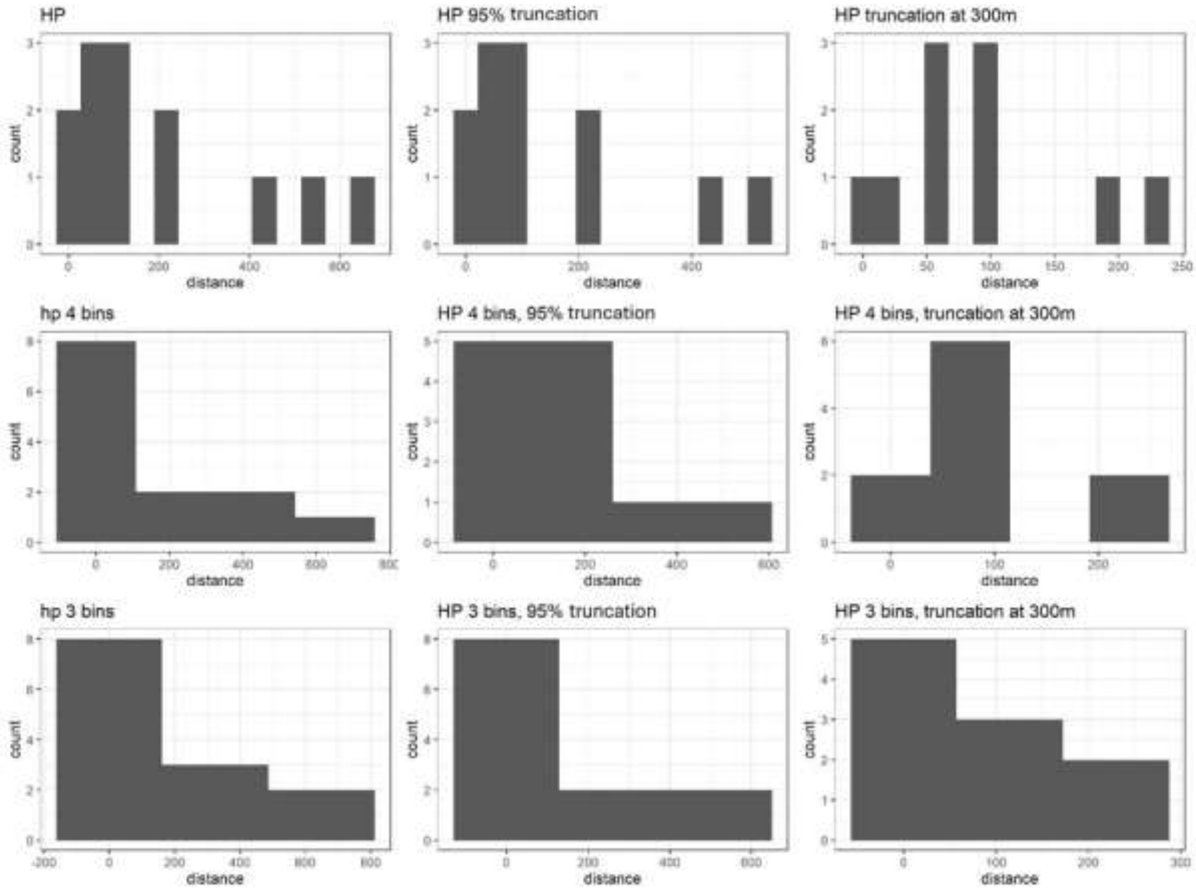


Figure S2: histograms of harbour porpoise distance data for S1 and S2 surveys with different data filters. Left column: observed distances. Middle column: observed distances truncated at 0.95 quantile. Right column: observed distances truncated at 1000 m. Top row: no grouping. Middle row: four groups. Bottom row: three groups.

for these species. Number of groups were selected by plotting multiple histograms with different cutting points (Figures S1 and S2) and selecting the one that closely followed all distance modelling assumptions. Grouping of data can be used to improve robustness in the estimator of density, in cases of violation of assumptions such as heaping, errors in measurement, or evasive movement prior to detection (Buckland et al., 1993).

Based on data visualisations, a decision was made to analyse HP observations as three-equal groups without truncation, and MW observations as four-equal groups without truncation. Given the chosen data filters, a selection of candidate detection functions was estimated using the mrds R Package (Miller et al., 2019; Laake et al., 2022), and the best model for each species was selected by inspecting model fit and evaluating Akaike's Information Criterion, AIC (Akaike 1973). A summary of AIC for each candidate detection function is presented in Table S1. For both HP and MW, a simple half-normal detection function without adjustment terms was fitted.

Due to the small number of samples, detection function was estimated using the entire dataset (S1 and S2 combined), while density, cluster size and encounter rate were estimated for each survey individually. Unlike de Boer (2010), who analysed data from all four vessels, this study did not implement Multiple Covariate Distance Sampling (MCDS) approaches (Buckland et al., 2001; Marques and Buckland, 2003) to include sighting covariates in detection functions. While in theory, MCDS is better placed to deal with cases where there are fewer

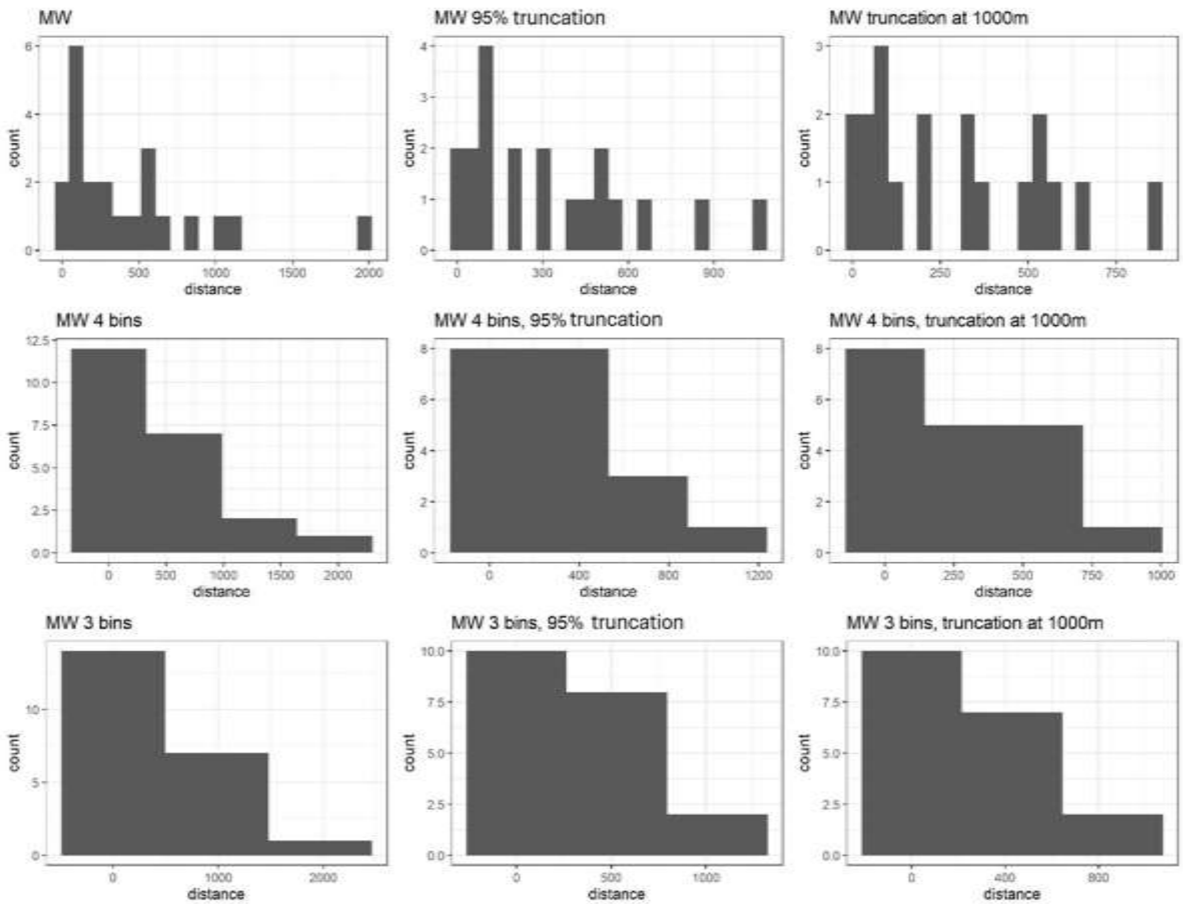


Figure S3: histograms of minke whale distance data for S1 and S2 surveys with different data filters. Left column: observed distances. Middle column: observed distances truncated at 0.95 quantile. Right column: observed distances truncated at 1000m. Top row: no grouping. Middle row: four groups. Bottom row: three groups.

observations of each species and by pooling data from species with similar detectability, the method reduces the amount of per species samples required, in reality for commercially derived MMO data, it may not be reliable. This is because extensive experience analysing commercial JNCC MMO data over the last 20 years, has revealed poor reliability of reporting covariates (e.g., habitat type, observer experience, weather conditions), a requirement of MCDS. If such data are not available or are incomplete, implementing MCDS can be challenging.

Comparison with SCANS

Density estimates obtained in this study were compared to values from each of the three SCANS surveys (summers of 1994, 2005 and 2016) for the study area, which covered the border between sections F and G in SCANS I, U and V in SCANS II, and N and Q in SCANS III (Table 1).

RESULTS

Effort and sightings

The n = 16-day S1 (MV *Andfjord*) and the n = 11-day S2 (MV *Alaborg*) line-transect distance-sampling surveys were performed in April/May and August 2007 respectively; hours/survey effort in this study were compared with de Boer (2010) (Table 2; Figure 1). While S1 was five days longer than S2, effort in terms of observation was only six hours 1.28 km longer, than S2.

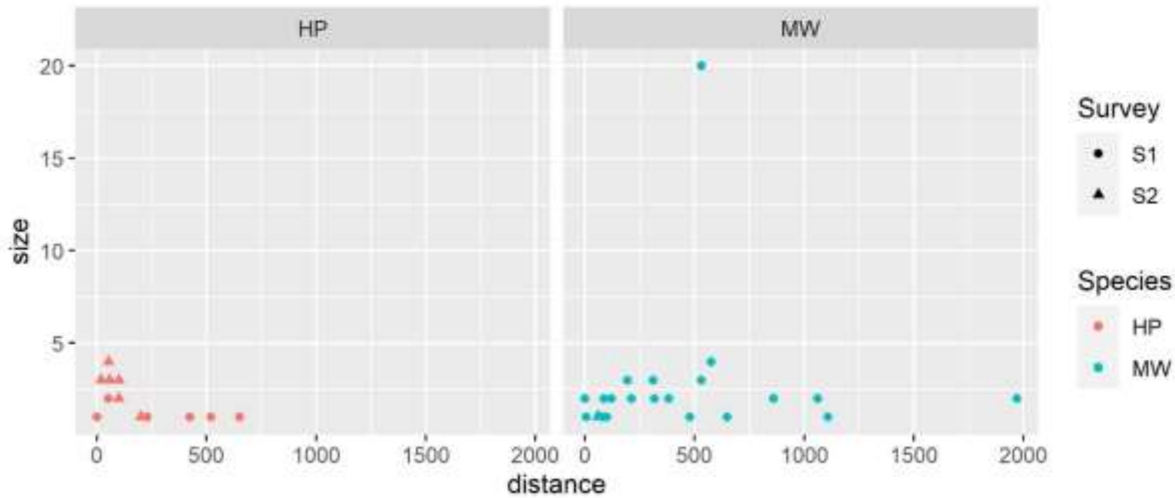


Figure S4: Observed distance and cluster size for harbour porpoise (HP) and minke whale (MW). Shape of plotted points indicated whether the sighting occurred in S1 or S2.

Table S1: Akaike information criteria (AIC) for candidate detection functions fitted to minke whale (MW) and harbour porpoise (HP) observations from S1 and S2. AIC for best models (with the lowest values) in bold, and a missing value indicates that the model either did not converge or returned a non-monotonic detection function.

	MW	**HP**
Half-normal	**46.71**	**25.61**
Hazard-rate	47.25	-
Half-normal + (cosine adjustment)	-	-
Hazard-rate + (cosine adjustment)	-	-
Half-normal + (polynomial adjustment)	-	27.16
Hazard-rate + (polynomial adjustment)	49.25	-

Table 3 details the number of sightings of each species in each survey period. The number of HP sightings between S1 and S2 were comparable (*n* = 6 and *n* = 7, respectively) – the same reported in de Boer (2010), with group size generally larger during S2 (mean = 2.71 ± SD 0.95) compared to S1 (mean = 1.17 ± SD 0.41).

During S1, 57 individual MW were observed across 21 sightings (with the same group size as HP for S2, purely coincidentally), whereas, during S2, only two MW were detected (Table 3). de Boer (2010) reported 60 individual MWs in 22 sightings for S1, but one individual/one sighting was made off-effort in that study (and therefore, should not have been included in any density and abundance estimates), and is therefore not included here. There were no sightings of white sided/white-beaked dolphins during S2, and a grey seal was sighted in both surveys.

Density and abundance

Observations of HP were grouped into three equally sized bins and the best detection function fitted was a half-normal with no adjustments (Table S1). The first four rows of Table 4 present density and abundance estimates for surveys S1 and S2. A larger number of HP were estimated for S2 (*ca.* 16 HP per km^2) than for S1 (*ca.* 6 HP per km^2); however, coefficients of variation were similar for both estimates, and this is likely due to there being a

Table 1: Relative density in animals/km2 (and respective Coefficient of Variation in brackets) estimated for each detected species from SCANS I, II and III surveys for regions covering study area. Harbour porpoise = HP, minke whale = MW.

Species	SCANS I (CV)		SCANS II (CV)		SCANS III (CV)	
	F	G	U	V	N	Q
HP	0.776 (0.25)	0.340 (0.34)	0.598 (0.028)	0.293 (0.36)	0.837 (0.26)	0.333 (0.35)
MW	0.011 (0.36)	0.009 (0.70)	0.023 (0.69)	0.028 (0.51)	0.020 (0.50)	0.007 (0.76)
Dates	27th June–26th July 1994		27th June–4th August 2005		27th June–31st July 2016	

Table 1: Line-transect extent of visual effort for this study compared to de Boer (2010).

.

Survey	Vessel	Survey period	Hrs of effort (this study)	Hrs of effort (De Boer 2010)	Survey effort (km) this study	Survey effort (km) de Boer (2010)	Area (km^2)
S1	MV *Andfjord*	23/04/2007 – 17/05/2007	131.29	318	1,420.48	1452	818
S2	MV *Alaborg*	01 – 11/08/2007	125.15	N/A	1,393.60	N/A	797

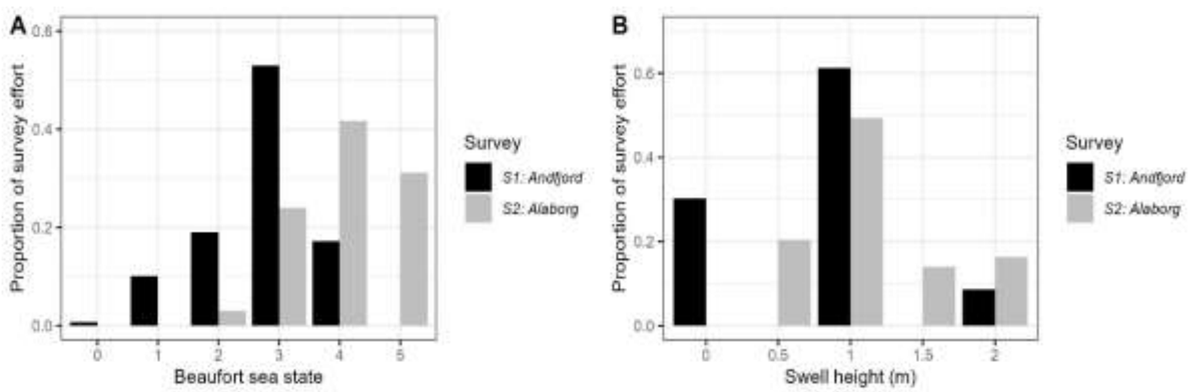


Figure 2: Beaufort-sea state and swell height throughout total survey effort for S1 (MV Andfjord), and S2 (MV Alaborg). Bar graphs showing the relative proportion of survey effort (MMO on-shift time as a proportion of the whole) against Beaufort Sea state (A) and swell height (B)

Table 3: Number of sightings (and individuals) for each species for S1 (MV Andfjord) and S2 (MV Alaborg). HP = harbour porpoise, WS/WB =, Atlantic white-sided/white-beaked dolphin, MW = minke whale, and GS = grey seal.

Species	Number	
	S1	S2
HP	6 (7)	7 (19)
MW	21 (57)	2 (2)
WS/WB	3 (45)	0
GS	1 (1)	1 (1)
All marine mammals	31 (110)	10 (22)

similar number of sightings for HP across both survey periods. The increase in the density estimate for HP in S2 is most likely attributed to the difference in observed cluster sizes between each survey (Figure S3 and Table 3). Observations of MW were grouped into four equally sized bins and the best detection function fitted was a half-normal with no adjustments (Table S1). The last four rows of Table 4 detail density and abundance estimate for surveys S1 and S2. Values differed considerably between S1 and S2. In contrast with HP, a larger density of MW was observed for S1 (*ca.* 20 MW per km^2) than S2, with

Table S1: Akaike information criteria (AIC) for candidate detection functions fitted to minke whale (MW) and harbour porpoise (HP) observations from S1 and S2. AIC for best models (with the lowest values) in bold, and a missing value indicates that the model either did not converge or returned a non-monotonic detection function.

	MW	HP
Half-normal	**46.71**	**25.61**
Hazard-rate	47.25	-
Half-normal + (cosine adjustment)	-	-
Hazard-rate + (cosine adjustment)	-	-
Half-normal + (polynomial adjustment)	-	27.16
Hazard-rate + (polynomial adjustment)	49.25	-

Table 4: Relative density (D, animals km^2) and abundance (N, animals in area) for individual harbour porpoise (HP) and minke whales (MW) for S1 (MV Andfjord) and S2 (MV Alaborg), with respective standard error (s.e.), coefficient of variation (%CV), degrees of freedom (df), and 95% confidence intervals (CI).

			Estimate	s.e	%CV	df	95% CI
HP	**S1** ***Andfjord***	**D**	0.0073	0.0036	48.63	75.88	(0.0029;0.018)
		N	5.82	2.83	48.63	75.88	(2.32;14.57)
	S2 ***Alaborg***	**D**	0.0201	0.0098	48.60	34.72	(0.0080;0.051)
		N	16.10	7.83	48.60	34.72	(6.32;41.0201)
MW	**S1** ***Andfjord***	**D**	0.025	0.010	42.22	77.026	(0.011;0.055)
		N	19.57	8.26	42.22	77.026	(8.74;43.84)
	S2 ***Alaborg***	**D**	0.00088	0.00067	76.63	27.76	(0.00022;0.0035)
		N	0.70	0.54	76.63	27.76	(0.17;2.82)

only close to a single MW per km^2 estimated for S2. This is reasonable when considering differences in sightings between the two surveys (see Table 3), and this discrepancy was also reflected in the reported coefficients of variation (%CV), where estimates for S2 presented a much higher %CV.

No density/abundance estimates were calculated for Atlantic white-sided (*Lagenorhynchus acutus*) and white-beaked (*L. albirostris*) dolphins (WS/WB) and grey seal (*Halichoerus grypus*), due to the low number of sightings (Table 3).

Weather

Weather covariates were considered in preliminary models; however, there was limited evidence that incorporating this information improved quality of estimates, more than likely because of inadequate MMO reporting, and small sample sizes. Nonetheless, Beaufort Sea state and swell data are presented in Figure 2. While S1 covered a 15-day longer period than S2 (MV *Alaborg*), *ca.* ten days during S1 were lost due to poor weather conditions, rendering the surveys more comparable in duration. Environmental conditions were mixed throughout both surveys. Beaufort-Sea state ranged from 0–5 in S1, and from 2–5 in S2. Most visual effort occurred in Beaufort-Sea states of 3 and 5 for surveys S1 and S2, respectively, and swell heights of 1-2 m (Figure 2). There was some conflict with data presented by (de Boer 2010), in that the paper stated that HP were sighted only in a Beaufort ≤2, but sightings in that study appear to have also been made in a Beaufort 3.

Comparison with SCANS

Estimated densities of HP were lower than those reported in the SCANS surveys, with densities of 0.25 and 0.00088 animals km^{-2} estimated in this study, and densities ranging from 0.293 to 0.837 animals km^{-2} estimated during the SCANS surveys. For MW, density estimates for S1 (0.0073 animals km^{-2}) and S2 (0.0201 animals km^{-2}) both fell within the range of densities estimated during SCANS surveys (0.007 to 0.028 animals km^{-2}).

DISCUSSION

In 2007, two dedicated line-transect surveys collected marine mammal observer data during (S1 MV *Andfjord*), and after (S2 MV *Alaborg*), the last O&G seismic 3D survey ever conducted in German waters. Data were compared to de Boer (2010), to original JNCC MMO data from the *Andfjord* survey (corrected for effort, and excluding any opportunistic/off-effort – non-line-transect – sightings), and to previous SCANS surveys from the region. The study demonstrated that HP, MW, and grey seal were present in the duck's beak (Entenschnabel) part of the Dogger Bank (central North Sea) in both spring and summer, during and after the seismic survey.

Effort and sightings

Exclusion of incidental and correction of off-effort MMO data during S1 *Andfjord* (April/May), produced comparable visual/trackline survey effort numbers to S2 *Alaborg* (August) surveys, as expected. Numbers reported by de Boer (2010) for S1 *Andfjord* differed substantially from raw reanalysed data here. While all discrepancies in values cannot be explained with any form of certainty, poor reporting of 'off effort' durations, is one of the most common industry MMO reporting mistakes (Todd et al., 2015), rendering a large proportion of commercial MMO data unreliable in this regard. Forgetting to log when going 'off effort' dilutes sightings data, resulting underestimation of animals detected along a survey track. Despite this (and interestingly), numbers of animal sightings reported in de Boer (2010) were still similar to those in this study for both HP and MW. This provides an indication that, notwithstanding effort discrepancy, MMO detections were likely to be representative of actual numbers of animals in the region given the range of seas states encountered during both surveys (which were far from ideal); consequently, numbers presented by de Boer (2010) are likely to be fairly accurate, and comparable to data presented here.

Density and abundance

One of the objectives of this study was to assess any impact of the 3D seismic survey. Assessing 'impact' of anthropogenic activities on marine life requires high-level, unambiguous, and unbiased research, before any conclusions and subsequent recommendations to marine stakeholders are derived. Firstly, it is important to stress that density and abundance estimates reported here (Table 3) were calculated using data with reasonably small sample sizes in relatively inclement sea states and should therefore be interpreted as such. Additional sightings data in calmer conditions would most likely have improved quality and reliability of estimates. Secondly, there were no baseline line-transect data collected before the seismic survey, or at a control location, despite strong recommendations to the client. Controls provide a baseline to compare against potentially impacted locations to distinguish effects of anthropogenic activities from natural variations, such as changes in prey distribution, breeding requirements, or population movements. Finally, it is critically important to consider the known ecology for species in this study, before any inference on potential effects of the *Angelina* 3D seismic survey on marine mammal behaviour can be interpreted. There were higher levels of HP estimated for the summer S2 *Alaborg* survey (*ca.* 16 HP per km^2) than during the spring S1 *Andfjord* survey (*ca.* 6 HP per km^2). This difference in abundance between S1 and S2 is probably unconnected with occurrence of the seismic survey during S1. More likely, this is related to HP seasonal movement. Firstly, HP are found year-round in the Dogger Bank (Todd et al., 2009; Gilles et al., 2012; Todd et al., 2016; Todd et al., 2022), and their abundance peaks between the months of July and November (Gilles et al., 2011; Geelhoed and Scheidat, 2018), in line with this study. There is also some evidence for movements north in summer and south in winter (Culik 2004), supported with findings of Henriksen et al. (2004) and Tougaard et al. (2006), who recorded higher HP echolocation activity off the Danish coast in summer and lower activity in winter. Similarly, in north-eastern Scottish waters off Aberdeen, sightings peak in August and September (Weir et al., 2007) and Diederichs et al. (2003) found a clear decrease in HP activity from August until December 2002 off the German west coast island of Sylt and, confirmed by concurrent aerial HP sightings, in line with results of this study. It's not entirely clear, however, that movements follow these patterns in recent years, since HP are also observed in higher numbers in German coastal waters in summer (Siebert et al., 2006), and there has been a distribution shift within the North Sea towards the south (Hammond et al., 2013), with some evidence that animals are resident in the southern North Sea, (Peschko et al., 2016). Moreover, in other areas of the North Sea, HP are present year-round (Sonntag et al., 1999; Thomsen et al., 2006). Consequently, it is not possible to deduce with any certainty (especially without baseline or control data), any form of HP displacement because of the seismic survey. Finally, in terms of accuracy of reported numbers and density estimates, since HP are normally seen in calm and clear weather conditions in Beaufort Sea state ≤2 (Hammond et al. 2002). Sightings conditions for both surveys in this study were suboptimal for this small and unobtrusive species and it is highly likely, that individuals remained undetected on the track line. There was a considerably higher abundance estimate for MW in the spring *Andfjord* S1, compared to the summer, *Alaborg,* S2. This is entirely in-line with known ecology of this species in the North Sea. While MW are found year-round in the North Sea, most sightings occur between April and October (Reid et al., 2003; Risch et al., 2019); concurrent with de Boer (2010), who reported MW sightings peaking in early to mid-May 2007 and decreasing after 22nd May, this study also found highest densities occurring within the DB during spring. Minke presence has been reported to be related to seasonal migrations throughout the North Sea from April–October (Northridge et al., 1995; Weir et al., 2007; Risch et al., 2019), and seasonal water column productivity (such as spring phytoplankton blooms and subsequent summer stratification and formation of thermoclines), thermal frontal systems (Doniol-Valcroze et al., 2007), and subsequent prey distribution (MacLeod et al., 2004). For example, a study on MW off the west coast of Scotland revealed that in June, animals were distributed predominately over sandeel (*Ammodytidae* spp.) habitat, but in July they dispersed to the predicted pre-spawning herring (*Clupea harengus*) habitat, clustering in that area by August (MacLeod et al., 2004). The latter study further suggested shifts in prey distribution and abundance occurring in this region between March and November are most likely the factors governing distribution and abundance of MW. There is strong evidence to suggest that MW migrate to higher latitudes during summer to forage, and to lower latitudes or offshore in the winter to breed (Northridge et al., 1995; Weir et al., 2007; Risch et al., 2019). This pattern could, in part, account for the relatively large number of MW, recorded during S1 in spring, and the near absence of animals during S2 in summer, as animals may have already moved on to more northerly latitudes. It is possible, therefore, that S1 correlated with northwards migrations of MWs through the area, while S2 occurred after they had passed through, resulting in far lower detections. Indeed, Weir et al. (2007) found presence of MW in the north east of Scotland (north west of the study area) to be strictly seasonal, with peak occurrences during August. MW detections along the east coast of Scotland peak during July/August (Tetley et al., 2008; Robinson et al., 2009), suggesting many are further north than the study area during this period. Additionally, Weir et al. (2007) also found presence of MW in the north east of Scotland (north west of the study area) to be strictly seasonal, with peak occurrences during August. The fine-scale distribution of this species varied within the study area, with an apparent preference for sections of coast adjacent to deeper water. Similarly, Reid et al. (2003) reported MW sightings in water depths of 150–500 m during August and September. Assuming that MW generally have a preference for deeper waters during August, this could also account for their apparent departure from the survey area, typically shallow with a minimum depth of only approximately 16 m (Reiss et al., 2007). Indeed, previous research on MW sampled at Jan Mayen, Svalbard, Vestfjorden/Lofoten, the North Sea and the Barents Sea, suggested populations are quite mobile and may feed in multiple areas within the eastern North Atlantic (Hobbs et al., 2003). Despite this, MW were still detected during S2, potentially indicating a degree of residence in the area during summer. Consequently, any future EIAs for this species for future offshore infrastructure developments, especially offshore wind, should consider incorporating mitigation impacts for underwater noise for MW, especially with regards to estimates of both Temporary, and Permanent Threshold Shift calculations (Southall et al., 2007; NMFS 2018; NMFS 2024).

Only three pods of white-sided/white-beaked dolphin were detected during S1, with no detections during S2. White beaked dolphin inhabits temperate and sub-polar continental shelf waters up to around 200 m depth and are found commonly in the North Sea, associated with continental shelf habitats (Galatius and Kinze 2016). As residents to the Dogger Bank, they occur year-round (van der Meij and Camphuysen 2006). There were not enough data to conclude why there were no detections in August, and there is still relatively little information on the biology and life history of these species (reviewed in Evans 2018).

One grey seal was sighted in both S1 and S2, suggesting that while the species may be an infrequent visitor to this offshore region, its presence far offshore is of note, and should be accounted for in EIAs. This offshore presence is well known for this species, which travels long distances (and can remain in the area for protracted periods) during foraging trips (Matthiopoulos et al., 2004); travelling even greater distances during the breeding season (Vincent et al., 2017).

Comparison with SCANS

While for MW, density estimations obtained in this study were comparable to SCANS surveys, this was not the case for HP. While this was expected for S1, given the occurrence of a seismic survey during this period and that survey was conducted in May while SCANS surveys were always conducted in summer, it was anticipated that HP abundance between S2 and SCANS surveys would be similar. One potential explanation for observed discrepancies in abundance could be the fact that this study survey area is located on the border of two blocks during each of the three SCANS surveys, thus having limited survey effort. It is possible that densities obtained during the SCANS survey may not have been representative of densities occurring in this area; however, it is worth noting that density in SCANS was corrected for availability bias, which could not be achieved during this survey; therefore, it was expected that relative densities reported here would be lower.

CONCLUSION

Results provided the reasonable estimates of marine mammal density and abundance in this difficult-to-reach section of the central North Sea, an area with limited effort on the border of two blocks during each of the three SCANS surveys. This area was found to consistently host HP throughout spring and summer, with more individuals detected in summer. While most MW whale transit through this area during spring (and likely again in autumn), some were still present in August, which should be accounted for in future EIAs. Other marine mammals including dolphins and seals were transient visitors to the area. Overall, it was not possible to quantify any effects of the PGS *Angelina* 3D seismic survey on marine mammals in the German Entenschnabel sector of the Dogger Bank, but this does not necessarily preclude the possibility that there might have been subtle impacts undetected because of inclement weather, small sample sizes, or short survey durations. While other studies have found limited effects of seismic surveys on marine mammal distribution, with detection of only short-term behaviour alterations (Harris et al., 2001; Stone and Tasker 2006; Potter et al., 2007; Thompson et al., 2013; Pirotta et al., 2014; Dunlop et al., 2020; Sarnocińska et al., 2020), mysticetes can sometimes remain in the area, although orienting away and increasing distance from the source (Stone and Tasker 2006).

DECLARATIONS

Funding

Both authors declare that no funds, grants, or other support were received during preparation of this manuscript; all work was performed in the authors' own time.

Conflict of interest

Authors declare that there are no conflicts of interest associated with this manuscript.

Ethics approval

This study did not involve any human participants, animal subjects, or sensitive data requiring ethical approval.

Data/code availability

All relevant data are included within the manuscript and supplementary materials. Additional data, if required, can be made available upon request.

Author contribution

IBT conceived and designed the study and VLGT supervised. IBT collected the MV *Alaborg* field data and, as part of a PhD by papers, participated in processing and analysing data sets. Both authors drafted the manuscript.

SUPPLEMENTARY MATERIALS

Additional supplementary material is available online (**place Aquatic Mammals Reference page location here**.) Supplementary Figure 1 provides histograms of harbour porpoise distance data with different data filters. Supplementary Figure 2 provides histograms of minke whale distance data with different data filters. Supplementary Figure 3 indicates observed distance and cluster size for harbour porpoise and minke whales. Supplementary Table 1 provides Akaike information criteria (AIC) for candidate detection function fitted to minke whales and harbour porpoise.

ACKNOWLEDGEMENTS

Firstly, thanks to all MMOs and personnel aboard MV *Thor Provider* and MV *Alaborg*. Thanks also to Wintershall, PGS, and their partners and to Hanneke Van den Berge (formerly Wintershall, now Orange Nassau B.V.) who supported publication of these data. IBT acknowledges assistance of several former research assistants at Ocean Science Consulting Ltd. over the years, and three anonymous reviewers. Firstly, thanks to Dr. Kathyrn Turnbull for re-verifying all values in the raw data, and assistance with analysis, and to Dr. Ana Couto for the same, with previous data sets, and permutations of statistical approaches. Thanks to Drs Katie Rapson & Matt Sharpe for assisting with sea-state graphs. Thanks to our RA, Laura Park (OSC) for formatting for journal submission, and to Helen McLachlan for editorial assistance. Finally, to the authors' daughter, Petra Todd, whose timely birth in 2007, allowed a less-than-timely completion of this manuscript.

REFERENCES

92/43/EEC (1992). Council Directive 92/43/EEC of 21 May 1992 on the conservation of natural habitats and of wild fauna and flora Official Journal of the European Communities; 35: 8-51.

Akaike H. (1973). Information theory and an extension of the maximum likelihood principle. In: Petran BN, Csaaki F (eds.), International Symposium on Information Theory, 2nd edn. Budapest, Hungary: Akadeemiai Kiadi, 267-281

Arfai J. and Lutz R. (2018). 3D basin and petroleum system modelling of the NW German North Sea (Entenschnabel). Geological Society, London, Petroleum Geology Conference series; 8: 67-86. https://doi.org/10.1144/pgc8.35

Arfai J., Jähne F. and Lutz R. (2014). Late Palaeozoic to Early Cenozoic geological evolution of the Northwestern German North Sea (Entenschnabel): New results and insights. Netherlands Journal of Geosciences - Geologie en Mijnbouw; 93: 147-174. https://doi.org/10.1017/njg.2014.22

Buckland S., Anderson D. and Burnham K. (1993). Distance sampling: estimating abundance of biological populations. Chapaman and Hall.

Buckland S.T., Anderson D.R. and Burnham K.P. (2001). Introduction to distance sampling: estimating abundance of biological populations. Oxford, UK: Oxford University Press.

Buckland S.T., Anderson D.R. and Burnham K.P. (2004). Advanced distance sampling: estimating abundance of biological populations. In, Oxford, UK: Oxford University Press, 416.

Cucknell A.C., Boisseau O. and Leaper R. (2016). Harbour porpoise (*Phocoena phocoena*) presence, abundance and distribution over the Dogger Bank, North Sea, in winter. J. Mar. Biol. Assoc. UK, 1-11.

Culik B.M. (2004). *Phocoena phocoena* harbour porpoise. In: Review of small cetaceans Distribution, behaviour, migration and threats, Bonn, Germany: United Nations Environment Programme, Conservation of Migratory Species (Regional Seas Reports and Studies), 219-230.

de Boer M.N. (2010). Spring distribution and density of minke whale Balaenoptera acutorostrata along an offshore bank in the central North Sea. Mar. Ecol. Prog. Ser.; 408: 265-274. https://doi.org/10.3354/meps08598

de Jong C.A.F., Ainslie M.A. and Blacquière G. (2011). Standard for measurement and monitoring of underwater noise, Part II: procedures for measuring underwater noise in connection with offshore wind farm licensing. In: Nederlandse Organisatie voor Toegepast Natuurwetenschappelijk Onderzoek, 56.

Diederichs A., Gruenkorn T. and Nehls G (2003). Do porpoise detectors detect porpoises? In: Poster at European Cetacean Society Conference, Las Palmas, Gran Canaria, Spain, Las Palmas, Gran Canaria, Spain.

Diesing M., Ware S., and Foster-Smith B. (2009). Understanding the marine environment - seabed habitat investigations of the Dogger Bank offshore draft SAC. In, Peterborough, UK: Joint Nature Conservation Committee (JNCC), 89

Doniol-Valcroze T., Berteaux D. and Larouche P. (2007). Influence of thermal fronts on habitat selection by four rorqual whale species in the Gulf of St. Lawrence. Mar. Ecol. Prog. Ser.; 335: 207-216.

Dunlop R.A., McCauley R.D. and Noad M.J. (2020). Ships and air guns reduce social interactions in humpback whales at greater ranges than other behavioral impacts. Mar. Pollut. Bull.; 154: 111072. https://doi.org/10.1016/j.marpolbul.2020.111072

Evans P.G. (2018). North Sea cetacean research since the 1960s: advances and gaps.

Galatius A. and Kinze C.C. (2016). *Lagenorhynchus albirostris* (Cetacea: Delphinidae). Mamm. Spec., 48: 35-47.

Geelhoed S.C. and Scheidat M (2018). Abundance of harbour porpoises (*Phocoena phocoena*) on the Dutch Continental Shelf, aerial surveys 2012-2017. Lutra; 61: 127-136.

Gilles A., Adler S. and Kaschner K. (2011). Modelling harbour porpoise seasonal density as a function of the German Bight environment: implications for management. Endang. Spec. Res., 14: 157-169. https://doi.org/10.3354/esr00344

Gilles A., Peschko V. and Scheidat M. (2012). Survey for small cetaceans over the Dogger Bank and adjacent areas in summer 2011. In, Galway, Ireland: ASCOBANS, pp1-15.

Hammond P., Berggren P., and Benke H. (2002). Abundance of harbour porpoise and other cetaceans in the North Sea and adjacent waters. Journal of Applied Ecology; 39: 361-376.

Hammond P., Lacey C., and Gilles A. (2021). Estimates of cetacean abundance in European Atlantic waters in summer 2016 from the SCANS-III aerial and shipboard surveys, p.42

Hammond P.S., Macleod K., and Berggren P. (2013). Cetacean abundance and distribution in European Atlantic shelf waters to inform conservation and management. Biol. Conserv., 164: 107-122.

Harris R.E., Miller G.W., and Richardson W.J. (2001). Seal responses to airgun sounds during summer seismic surveys in the Alaskan Beaufort Sea. Mar. Mamm. Sci.; 17: 795-812.

Henriksen O.D., Carstensen J., and Tougaard J. (2004). Effects of the Nysted offshore wind farm construction on harbour porpoises: Annual status report for the acoustic T-POD monitoring programme during 2003. In: Ministry for the Environment, p31.

Hobbs K.E., Muir D.C.G., and Born E.W. (2003). Levels and patterns of persistent organochlorines in minke whale (*Balaenoptera acutorostrata*) stocks from the North Atlantic and European Arctic. Environ. Pollut., 121: 239-252.

JNCC (2004). Guidelines for minimising acoustic disturbance to marine mammals from seismic surveys. In, Aberdeen: Joint Nature Conservation Committee.

Kaschner K., Quick N.J., and Jewell R. (2012). Global coverage of cetacean line-transect surveys: status quo, data gaps and future challenges. PLoS ONE; 7. https://doi.org/10.1371/journal.pone.0044075

Laake J., Borchers D., and Thomas L. (2022). mrds: Mark-Recapture Distance Sampling.

MacLeod K., Fairbairns R., and Gill A. (2004). Seasonal distribution of minke whales Balaenoptera acutorostrata in relation to physiography and prey off the Isle of Mull, Scotland. Mar. Ecol. Prog. Ser., 277: 263-274.

Marques F.F., and Buckland S.T. (2003). Incorporating covariates into standard line transect analyses. Biometrics; 59: 924-935.

Matthiopoulos J., McConnell B., and Duck C. (2004). Using satellite telemetry and aerial counts to estimate space use by grey seals around the British Isles. Journal of Applied Ecology; 41: 476-491.

Miller D.L., Rexstad E., and Thomas L. (2019). Distance sampling in R. Journal of Statistical Software; 89: 1-28. https://doi.org/10.18637/jss.v089.i01

NMFS (2018). 2018 Revisions to: Technical guidance for assessing the effects of anthropogenic sound on marine mammal hearing (Version 2.0): underwater thresholds for onset of permanent and temporary threshold shifts. In, Silver Springs, Maryland: National Marine Fisheries Service, U.S. Department of Commerce, and National Oceanic and Atmospheric Administration, p.167.

NMFS (2024). Technical Guidance for assessing the effects of anthropogenic sound on marine mammal hearing (Version 2.0). NOAA Technical Memorandum; NMFS-OPR-59.

Northridge S.P., Tasker ML., and Webb A. (1995). Distribution and relative abundance of harbor porpoises (*Phocoena phocoena* L), white-beaked dolphins (*Lagenorhynchus albirostris* Gray), and minke whales (*Balaenoptera acutorostrata Lacepede*) around the British-Isles. ICES J. Mar. Sci., 52: 55-66.

Nowacek D.P., Clark CW., and Mann D. (2015). Marine seismic surveys and ocean noise: time for coordinated and prudent planning. Front. Ecol. Environ., 13: 378-386. https://doi.org/https://doi.org/10.1890/130286

Peschko V., Ronnenberg K., and Siebert U. (2016). Trends of harbour porpoise (*Phocoena phocoena*) density in the southern North Sea. Ecol. Indic., 60: 174-183.

Pingree R., and Griffiths D. (1978). Tidal fronts on the shelf seas around the British Isles. J. Geophys. Res., 83: 4615-4622.

Pirotta E., Brookes K.L., and Graham I.M. (2014). Variation in harbour porpoise activity in response to seismic survey noise. Biol. Lett., 10. https://doi.org/10.1098/rsbl.2013.1090

Potter J.R., Thillet M., and Douglas C. (2007). Visual and Passive Acoustic Marine Mammal Observations and High-Frequency Seismic Source Characteristics Recorded During a Seismic Survey. IEEE J. Ocean. Eng., 32: 469-483. https://doi.org/10.1109/JOE.2006.880427

R Core Team (2022). R: A language and environment for statistical computing. In, 4.2.1 edn. Vienna, Austria.

Reid J.B., Evans P.G.H., and Northridge S.P. (2003). Atlas of cetacean distribution and north-west European waters. Peterborough, UK: Joint Nature Conservation Committee.

Reiss H., Wieking G., and Kroncke I. (2007). Microphytobenthos of the Dogger Bank: a comparison between shallow and deep areas using phytopigment composition of the sediment. Mar. Biol., 150: 1061-1071.

Risch D., Wilson S.C., and Hoogerwerf M. (2019). Seasonal and diel acoustic presence of North Atlantic minke whales in the North Sea. Sci. Rep., 9: 3571. https://doi.org/10.1038/s41598-019-39752-8

Robinson K.P., Tetley M.J., and Mitchelson-Jacob E.G. (2009). The distribution and habitat preference of coastally occurring minke whales (Balaenoptera acutorostrata) in north-east Scotland. J Coast Conserv., 13: 39-48. https://doi.org/MM-Cetacea: 2009-09, DOI: 10.1007/s11852-009-0050-2

Sarnocińska J., Teilmann J., and Balle J.D. (2020). Harbor porpoise (Phocoena phocoena) reaction to a 3D seismic airgun survey in the North Sea. Frontiers in Marine Science; 6. https://doi.org/10.3389/fmars.2019.00824

Sell A.F., and Kröncke I. (2013). Correlations between benthic habitats and demersal fish assemblages — A case study on the Dogger Bank (North Sea). Journal of Sea Research; 80:12-24. https://doi.org/http://dx.doi.org/10.1016/j.seares.2013.01.007

Siebert U., Gilles A., and Lucke K. (2006). A decade of harbour porpoise occurrence in German waters - analyses of aerial surveys, incidental sightings and strandings. Journal of Sea Research; 56:65-80. https://doi.org/DOI: 10.1016/j.seares.2006.01.003

Sonntag R.P., Benke H., and Hiby A.R. (1999). Identification of the first harbour porpoise (*Phocoena phocoena*) calving ground in the North Sea. Journal of Sea Research; 41: 225-232.

Southall B.L., Bowles A.E., and Ellison W.T. (2007). Marine mammal noise exposure criteria, initial scientific recommendations. Aquat. Mamm., 33: 411-414.

Southall B.L., Finneran J.J., and Reichmuth C. (2019). Marine mammal noise exposure criteria: Updated scientific recommendations for residual hearing effects. Aquat. Mamm., 45: 125-232.

Southall B.L., Nowacek D.P., and Bowles A.E. (2021). Marine mammal noise exposure criteria: assessing the severity of marine mammal behavioral responses to human noise. Aquat. Mamm., 47: 421-464. https://doi.org/https://doi.org/10.1578/AM.47.5.2021.421

Stone C.J., and Tasker M.L. (2006). The effects of seismic airguns on cetaceans in UK waters. Journal of Cetacean Research and Management, 8: 255-263.

Tetley M.J., Mitchelson-Jacob E.G., and Robinson K.P. (2008). The summer distribution of coastal minke whales (*Balaenoptera acutorostrata*) in thesouthern outer Moray Firth, NE Scotland, in relation to co-occurring mesoscaleoceanographic features. Remote Sensing of Environment; 112: 3449-3454. https://doi.org/10.1016/j.rse.2007.10.015

Thompson P.M., Brookes K.L., and Graham I.M. (2013). Short-term disturbance by a commercial two-dimensional seismic survey does not lead to long-term displacement of harbour porpoises P Roy Soc B: Biol. Sci., 280: 1-8.

Thomsen F., Laczny E.M., and Piper W.A. (2006) recovery of harbour porpoises (Phocoena phocoena) in the southern North Sea? A case study off eastern Frisia, Germany. Helgoland Mar. Res., 60: 189-195. https://doi.org/https://doi.org/10.1007/s10152-006-0021-z

Todd V.L.G., Pearse W.D., and Tregenza N.C. (2009). Diel echolocation activity of harbour porpoises (*Phocoena phocoena*) around North Sea offshore gas installations. ICES J. Mar Sci.; 66: 734-745. https://doi.org/10.1093/icesjms/fsp035

Todd V.L.G., Todd I.B., and Gardiner J.C. (2015). Marine mammal observer and passive acoustic monitoring handbook. Exeter, UK: Pelagic Publishing Ltd.

Todd V.L.G., Warley J.C., and Todd I.B. (2016). Meals on wheels? A decade of megafaunal visual and real-time Passive Acoustic Monitoring detections from on-tow and stationary offshore oil and gas rigs and platforms in the North and Irish Seas. PLoS ONE; 11: 25. https://doi.org/10.1371/journal.pone.0153320

Todd V.L.G., Williamson L.D., and Couto A. (2022). Effect of a new offshore gas platform on harbor porpoise in the Dogger Bank. Mar. Mamm. Sci., 38: 1609-1622. https://doi.org/https://doi.org/10.1111/mms.12949

Tougaard J., Rosager P., and Amundin M. (2006). Detection function of T-PODs and estimation of porpoise densities. In: Leeney RH, Tregenza NJC (eds.), 20th Annual Meeting of the European Cetacean Society, 2nd-7th April, Workshop: Static acoustic monitoring of cetaceans, Gydnia, Poland, 7-14

van der Meij S., and Camphuysen K. (2006). The distribution and diversity of whales and dolphins (Cetacea) in the southern North Sea: 1970-2005. Lutra; 49: 3-28.

Vincent C., Huon M., and Caurant F. (2017). Grey and harbour seals in France: Distribution at sea, connectivity and trends in abundance at haulout sites. Deep Sea Res PT II; 141: 294-305.

Weir C.R., Stockin K.A., and Pierce G.J. (2007). Spatial and temporal trends in the distribution of harbour porpoises, white-beaked dolphins and minke whales off Aberdeenshire (UK), north-western North Sea. J. Mar. Biol. Assoc. UK; 87: 327-338.