

Shortlist Masterplan Wind Aerial surveys of harbour porpoises on the Dutch Continental Shelf

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Cover photo: The two operational offshore wind farms on the Dutch Continental Shelf (Hans Verdaat)

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Samenvatting

In het kader van het Shortlist Masterplan Wind programma zijn in 2010-2011 vliegtuigtellingen uitgevoerd om het seizoensgebonden voorkomen en de verspreiding van bruinvissen *Phocoena phocoena* op het Nederlands Continentaal Plat (NCP) in kaart te brengen. Dergelijke informatie is essentieel om het effect van menselijke activiteiten, i.c. offshore windparken op bruinvissen te begrijpen, te kwantificeren en uiteindelijk te minimaliseren.

Drie series vliegtuigtellingen werden uitgevoerd in de zomer (juli 2010), in de late herfst (oktober/november 2010) en in het vroege voorjaar (maart 2011). De vliegtuigtellingen bedroegen 16013 km langs van te voren ontworpen transecten in het gehele NCP (Fig 3). Tijdens de tellingen werden in totaal 1085 waarnemingen (1236 individuen) van bruinvissen (Tb 2), 5 waarnemingen van witsnuitdolfijnen *Lagenorhynchus albirostris* (8 dieren) en 64 waarnemingen (66 dieren) van grijze *Halichoerus grypus* en gewone zeehonden *Phoca vitulina* gedaan (Fig 7). Moeder-kalfcombinaties werden met name in juli gezien, rond en ten westen van het windmolenonderzoeksgedebied W1 (Fig 6). Deze waarnemingen suggereren dat er voortplanting plaatsvindt in Nederlandse wateren. De gegevens werden geanalyseerd met de zogenoemde distance sampling methode. De resulterende schattingen van de dichtheid op het NCP waren 0.44 dieren/km² in juli, 0.51 in oktober/november en 1.44 in maart. Deze dichtheden komen overeen met totale aantallen bruinvissen van ca 26000 in juli (95%-betrouwbaarheidsinterval: 14,000-54000), ca 30000 in oktober/november (16000-59000) en ca 86000 in maart (49000-165000) in het gehele NCP (Tb 4). Deze aantallen vormen een substantieel aandeel van de populatie waar de Nederlandse dieren toe behoren, de zogenoemde management unit South-western North Sea and the Eastern Channel. Hoewel een goede schatting van de grootte van deze populatie ontbreekt, kan op grond van de resultaten van SCANS II in 2005 aangenomen worden dat deze kleiner is dan 180000 dieren. Het NCP herbergt minimaal minstens 14% (juli) en maximaal minstens 48% (maart) van deze populatie.

Kaarten van de ruimtelijke verspreiding van bruinvissen op het NCP zijn in eerste instantie gemaakt door de tellingen te corrigeren voor de waarnemingsinspanning. Dit levert een eerste beeld op van de verspreiding. Vervolgens is voor elk van de drie series vliegtuigtellingen een model opgesteld om de data tevens te corrigeren voor variaties in omgevingsvariabelen zoals locatie, bewolking, tijd van de dag en de zee staat. De uitkomsten van dit model zijn gebruikt om de verspreiding van bruinvissen over het NCP te voorspellen. De uitkomsten hiervan (fig. 13, 15 & 17) vormen de beste voorspelling van het verspreidingspatroon van bruinvissen (ten tijde van de observaties) die uit de verzamelde dataset is te distilleren. De kwaliteit van deze kaarten is echter sterk afhankelijk van de gekozen variabelen die geacht worden van invloed te zijn op de kans op het waarnemen van een bruinvis. Met een voortschrijdend inzicht in het gedrag en verspreiding van bruinvissen zullen deze modelvoorspellingen mogelijk veranderen. Deze verdeling van bruinvissen was niet uniform binnen het NCP en vertoont sterke seizoensgebonden variatie (Vergelijk Fig 13, 15 & 17). In maart 2011 werden in grote delen van het NCP hoge dichtheden gevonden, met uitzondering van Zeeland en in de nabije kustzone van Noord- en Zuid-Holland. Windmolenpark-onderzoeksgedebied W1 –en in mindere mate- W2 liggen in de gebieden met hogere dichtheden (Fig 17). In juli werden hoge dichtheden gevonden in de omgeving van de Bruine Bank, het gebied rond de Botney Cut-Doggersbank, en de Borkumse Stenen (Fig 13). In oktober is de ruimtelijke verdeling homogener. Moeder-kalfpaartjes werden met name waargenomen in juli, rond en ten westen van het windmolenpark-onderzoeksgedebied W1 (Fig 15). Voortzetting van vliegtuigtellingen is noodzakelijk om te bepalen of de vastgestelde patronen consistent zijn.

Summary

In 2010-2011, aerial surveys were conducted under the umbrella of the Shortlist Masterplan Wind programme. The aim of these aerial surveys was to assess the seasonal abundance and distribution of harbour porpoises *Phocoena phocoena* on the Dutch Continental Shelf (DCS), and how their distribution varies in space and by season. Such information is vital if we are to understand, quantify and eventually minimize the effect of human activities, i.c. offshore wind farms, on harbour porpoises.

Three complete aerial surveys of the DCS were conducted along predetermined track lines, in summer (July 2010), late autumn (October/November 2010) and early spring (March 2011). The surveys covered 16013 km on effort (in search modus for marine mammals, Figure 3). In total 1085 sightings (1236 animals) of harbour porpoises were recorded (Table 2), 5 sightings of white-beaked dolphins *Lagenorhynchus albirostris* (8 animals) and 64 sightings (66 animals) of grey *Halichoerus grypus* and harbour seals *Phoca vitulina* (Figure 7). Mother-calf pairs of porpoises were mostly sighted in July, around and west of the wind farm survey area W1 (Figure 6), suggesting that porpoises reproduce in Dutch waters. The data was analysed with standard distance sampling methodology. The resulting density estimates of harbour porpoises for the DCS were 0.44 animals/km² in July, 0.51 animals/km² in October/November and 1.44 animals/km² in March. This means total numbers for the entire DCS (Table 4) of ca. 26000 animals in July (95% Confidence Interval (C.I.): 14000-54000), ca. 30000 in October/November (C.I.: 16000-59000) and ca. 86000 in March (C.I.: 49000-165000). These numbers represent a substantial part of the population where the Dutch porpoises belong to, the so-called management unit South-western North Sea and the Eastern Channel. Based on the SCANS II data from 2005 the estimated number of porpoises in this management unit is less than ca. 180000 animals. Using these figures, the Dutch national waters in March thus comprise at least 48% of the population present in the central and southern North Sea. In July this proportion drops to at least 14%.

Maps of the spatial distribution of harbour porpoises on the DCS have initially been constructed by correcting the data for observation effort. Subsequently, for each of the three surveys, a model was constructed to correct the data for the additional effect of environmental factors (such as location, cloud cover, time of day and sea state) on the sighting rate. This model has been used to predict the distribution of porpoises over the DCS. The results of this prediction (Figs. 13, 15 & 17) give the best estimate of the 'true' distribution of porpoises (at the moment the surveys took place) that can be distilled from the data collected in this study. However, the quality of these model predictions depends strongly on the covariates included in the model. This model presented here is a first step towards understanding which covariates influence the sighting rate. In due time our understanding of the behaviour and distribution of harbour porpoises will probably improve, and as a consequence better distribution estimates may be obtained in the future. The modelled distribution of harbour porpoises was not uniform within the DCS and shows strong intra-annual variability (compare figures 13, 15 & 17). In March 2011, high densities were found in the whole DCS, except for Zeeland and in close proximity of the mainland coast. These higher density areas thus include the wind farm survey areas W1 and to a lesser extent W2 (Figure 17). In July, high densities were found near the Brown Ridge, Botney Cut-Dogger Bank and Borkumer Reef (Figure 13). In October, distribution seems more spatially homogeneous. Mother-calf pairs were mostly sighted in July, around and west of the wind farm survey area W1 (Figure 15). Repeated surveys are deemed necessary to ascertain if the established patterns are consistent.

1. Introduction

In the light of the further development of wind power on the Dutch Continental Shelf (DCS), the Dutch government intends to give out permissions for more offshore wind farms from mid-2011 onwards. In order to provide information for this, several knowledge gaps are covered in the Shortlist Masterplan Wind programme (SMW). The main aim of this study is to estimate the abundance of harbour porpoises on the Dutch Continental Shelf. Spatial and temporal patterns in distribution are assessed, for the whole DCS in general, with an emphasis on the wind farm survey areas. This report presents the results of three aerial surveys in July 2010, October/November 2010 and March 2011 aiming to determine the abundance and distribution of the harbour porpoise *Phocoena phocoena* on the DCS.

The harbour porpoise occurs mostly in coastal or shelf waters and it is the most numerous cetacean in the North Sea. The abundance of harbour porpoises can be an indicator for changes in the ecosystem, due to e.g. offshore wind farms. The effects of wind farms on harbour porpoises are poorly understood, but differ between the construction and the operational phase of wind farms (e.g. ICES, 2010; Tougaard *et al.*, 2006). Underwater noise can be considered as the most important factor associated with the construction phase. The construction phase often includes profiling, shipping, pile driving, trenching and dredging (Nedwell & Howell, 2004). In general, pile-driving during construction is considered the activity with the strongest negative effect on marine mammals (Koschinski *et al.*, 2003; Madsen *et al.*, 2006; Thomsen *et al.*, 2006). Depending on the frequency range and sound levels, noise can induce hearing impairment at close range, and can cause disturbance at ranges of many kilometres (e.g. Brandt *et al.*, 2009; Tougaard *et al.*, 2009). Modelled ranges indicate that pile driving sounds should be audible to marine mammals at ranges up to more than 100 km (Madsen *et al.*, 2006). Operating wind turbines commonly generate low sound levels, unlikely to impair hearing in harbour porpoises. In general the effect of operational wind farms on harbour porpoises is yet unclear (ICES, 2010). However, associated activities, such as shipping and maintenance have the potential to affect the animals. Furthermore, the physical presence of the turbines could act as a barrier and could cause animals to partly or completely avoid the area. Alternatively, the presence of the turbines can result in the creation of an artificial reef that provides a substrate on which animals and plants can grow, thereby attracting fish. Such changes to the fish fauna and productivity are likely to be neutral or even positive to opportunistic feeders like porpoises.

The conservation of harbour porpoise and monitoring the species' abundance is an obligation under several international conventions and agreements (Trouwborst & Dotinga, 2008). This species is protected under the *Convention on the Conservation of Migratory Species of wild animals* (commonly known as CMS or Bonn Convention) concluded in 1979. Under CMS the regional agreement ASCOBANS (*Agreement on the Conservation of Small Cetaceans of the Baltic and North Seas*) came into force in 1994. In 1992 the Convention for the protection of the marine environment in the north-east Atlantic (OSPAR) was concluded. All cetaceans in European waters are also protected by the *European Community Directive on the Conservation of Natural Habitats and of Wild Fauna and Flora* (commonly known as Habitats Directive). The Habitats Directive includes the obligations from the *Convention on the Conservation of Wildlife and Natural Habitats in Europe* (known as the Bern Convention). Furthermore, the European Marine Strategy Directive adopted in 2008 is relevant, since it strives to achieve a so-called Good Environmental Status described by a set of quality descriptors.

Despite the obligation to monitor harbour porpoises, systematically collected data on the species' abundance and distribution in Dutch waters are scarce. Most data are a by-product of surveys aimed at seabirds, like the land-based sea watching scheme and the ship-based and aerial surveys on the DCS. The results of the ship-based and aerial surveys were published in two atlases (Baptist & Wolf, 1993;

Camphuysen & Leopold, 1994). After publication of these atlases the aerial monitoring program continued to the present day (MWTL programme e.g. Arts, 2010). Albeit this data gives an indication of offshore distribution in space and time, it cannot provide abundance estimates due to the method used.

Two broad scale dedicated surveys SCANS and SCANS II, aimed at estimating the abundance of harbour porpoises in European waters, were conducted in summer 1994 and 2005 (Hammond *et al.*, 2002; SCANS, 2008). Unfortunately during both SCANS surveys the actual survey coverage in Dutch national waters was relatively low, and the survey blocks of those surveys did not correspond with the national waters. Furthermore, Camphuysen (2004) showed that the most distinct peak of porpoise density along the Dutch coast is in the winter months, although porpoises are now sighted year-round with a regular occurrence in spring and autumn. These seasonal changes in porpoise distribution and density were confirmed by aerial surveys conducted by IMARES since May 2008, commissioned by the Dutch government (e.g. Scheidat & Verdaat, 2009). These surveys were concentrated in a sub-area in the Dutch EEZ, from the coast to about 120 km offshore from the Belgian border to Texel. However, a DCS-wide survey using the same methods was still lacking.

Over the last decade, the occurrence of harbour porpoises in Dutch waters has increased significantly probably as a result of a southerly shift in distribution (SCANS, 2008). The reasons for this are not clear, but a shift in prey species is a likely cause (Camphuysen, 2004). With this increase, the intensity of potential conflict with human activities also increases. Possible effects on harbour porpoises during offshore constructions and operations can range from short-term behavioural reactions to long-term changes in distribution patterns, increased stress, lowered fitness and poor health. To evaluate the effect of offshore wind farms through environmental impact assessments- by a lack of data on densities and distribution-, it has been assumed that harbour porpoises are distributed homogenously throughout Dutch waters. It is important to obtain baseline data on porpoise distribution, density and abundance on the DCS. Additionally, information on the presence of mother-calf pairs is important to evaluate the potential existence of areas with high sensitivity to disturbance.

"He would stand still for hours: but never sat or leaned; his wan but wondrous eyes did plainly say – We two watchmen never rest"

Herman Melville: Moby Dick

2. Assignment

This report presents the aerial survey results using line transect distance sampling as described in the original assignment, with one exception. A secondary goal of the aerial surveys was to collect data to calculate a correction factor for animals missed along the surveyed track lines, the so-called $g(0)$. This value is needed for calculating absolute densities and abundance in line transect distance sampling. This factor is equal to 1, if all the animals on the track line are seen. In practice this is never the case, either because animals are visible but missed by the observer (observer bias), or because they are present but not visible, since they are sub-merged (availability bias). To obtain an appropriate calculation of density it is necessary to estimate the proportion of animals actually seen on the track line i.e. the true value of $g(0)$. For aerial surveys, the so called "racetrack" method (Hiby & Lovell, 1998) is used to obtain a value for $g(0)$. See 3.3 for details on this method. Between 50 and 100 racetracks are needed to calculate $g(0)$.

During the evaluation in December 2010, however, it became clear that determining a specific $g(0)$ for the SMW surveys was not feasible. Performing enough race tracks proved to be impossible due to safety reasons and too high densities of porpoises. After a comparison of values for $g(0)$ in different studies the decision was made to use the $g(0)$ with the associated effective strip width (ESW) from a German study (Geelhoed, 2011). These $g(0)$ values were assumed to be the most suited for the SMW surveys, since on the one hand the methodology and survey plane were the same as in the present study and on the other hand the observer teams in Germany and the Netherlands partly consisted of the same observers, who have fine-tuned the used methodology in practice. Additionally the conditions in the study areas are similar, covering turbid coastal waters also. As will be explained in chapter 3 the $g(0)$ calculation done with the racetrack method is directly linked to a specific ESW, that is used to calculate densities. To check if the ESW from the German surveys is comparable to the Dutch surveys, the ESW was calculated for the Dutch porpoise sightings (see appendix I).

The resources reserved for calculating $g(0)$ by performing race tracks in the original assignment was subsequently re-allocated and used to survey extra extended track lines around the Borkumer Reef in March 2011. The summer 2010 survey yielded a relatively high number of observations on the eastern most track line along the Dutch part of the Borkumer Reef. The extra track lines were designed to determine if this high density extends into the adjacent German waters.

3. Materials and Methods

3.1 Study area, survey design and data acquisition

The study area included the entire Dutch section of the continental shelf (Figure 2). The study area was divided into the sub-areas: A ("Dogger Bank", 9615 km²), B ("Offshore", 16892 km²), C ("Frisian Front", 12023 km²) and D ("Brown Ridge", 20797 km²) (Figure 3). The design of the track line set-up was chosen to be parallel in areas C and D and zig zag in area A and B to ensure a representative coverage of the sub-areas (Figure 3). Additional track lines were surveyed in the two smaller wind farm survey areas within the sub-areas D (W1) and C (W2) (Figure 3). The direction of transects followed depth gradients in order to get a better sample by minimising variance in encounter rate (Buckland et al., 2001).

The aircraft used was a high-wing two-engine Partenavia 68, equipped with bubble windows (Figure 1), flying at an altitude of 183 m (600 feet) with a speed of ca. 186 km/hr (ca. 100 knots). Every four seconds the aircraft's position and time (to the nearest second) was recorded automatically onto a laptop computer connected to a GPS. Surveys were conducted by a team of three people. Sighting information and details on environmental conditions were entered by one person (the navigator) at the beginning of each transect and whenever conditions changed. Observations were made by two dedicated observers located at the bubble windows on the left and right sides of the aircraft. For each observation the observers acquired sighting data including species (all cetaceans and seals), declination angle measured with an inclinometer from the aircraft abeam to the group, group size, presence of calves, behaviour (Table 1), swimming direction, cue, and reaction to the survey plane. The perpendicular distances from the transect to the sighting were later calculated from aircraft altitude and declination angle. Environmental data included sea state (Beaufort scale), turbidity (4 classes, assessed by visibility of objects below the sea surface), cloud cover (in octaves), glare and subjective sighting conditions (Table 2). These sighting conditions represent each observer's subjective view of the likelihood that the observer would see a harbour porpoise within the primary search area should one be present, and could differ between left and right.

Table 1. Behavioural codes and description for marine mammals.

Behaviour	Description
Swim	directional swimming
Slsim	slow directional swimming
Fasw	fast directional swimming or porpoising
Mill	milling, non-directional swimming
Rest	resting/logging: not moving at the surface
Feed	Feeding
Headup	spy hop of seals vertically in the water column
Other	other behaviour, noted down in comments

Table 2. Description of sighting conditions.

Sighting condition	Description
Good (G):	Observer's assessment that the likelihood of seeing a porpoise, should one occur within the search strip, is good. Normally, good subjective conditions will require a sea state of two or less and a turbidity of less than two.
Moderate (M):	Observer's assessment that the likelihood of seeing a porpoise, should one occur within the searching area, is moderate.
Poor (P):	Observer's assessment that it is unlikely to see a porpoise, should one occur within the search strip.
Exceptional (X):	Observer off effort due to adverse circumstances

Surveys were conducted in weather conditions safe for flying operations (no fog or rain, no chance of freezing rain, visibility >3km) and suitable for porpoise surveys (Beaufort sea state equal or less than 3). Surveys were co-ordinated with other aerial surveys conducted by the department Management Unit of the North Sea Mathematical Models (MUMM) in Belgian waters, and by the Forschungs- und Technologiezentrum Westküste of the University of Kiel (FTZ) in German waters.



Figure 1. The survey aircraft used, a Partenavia 68.

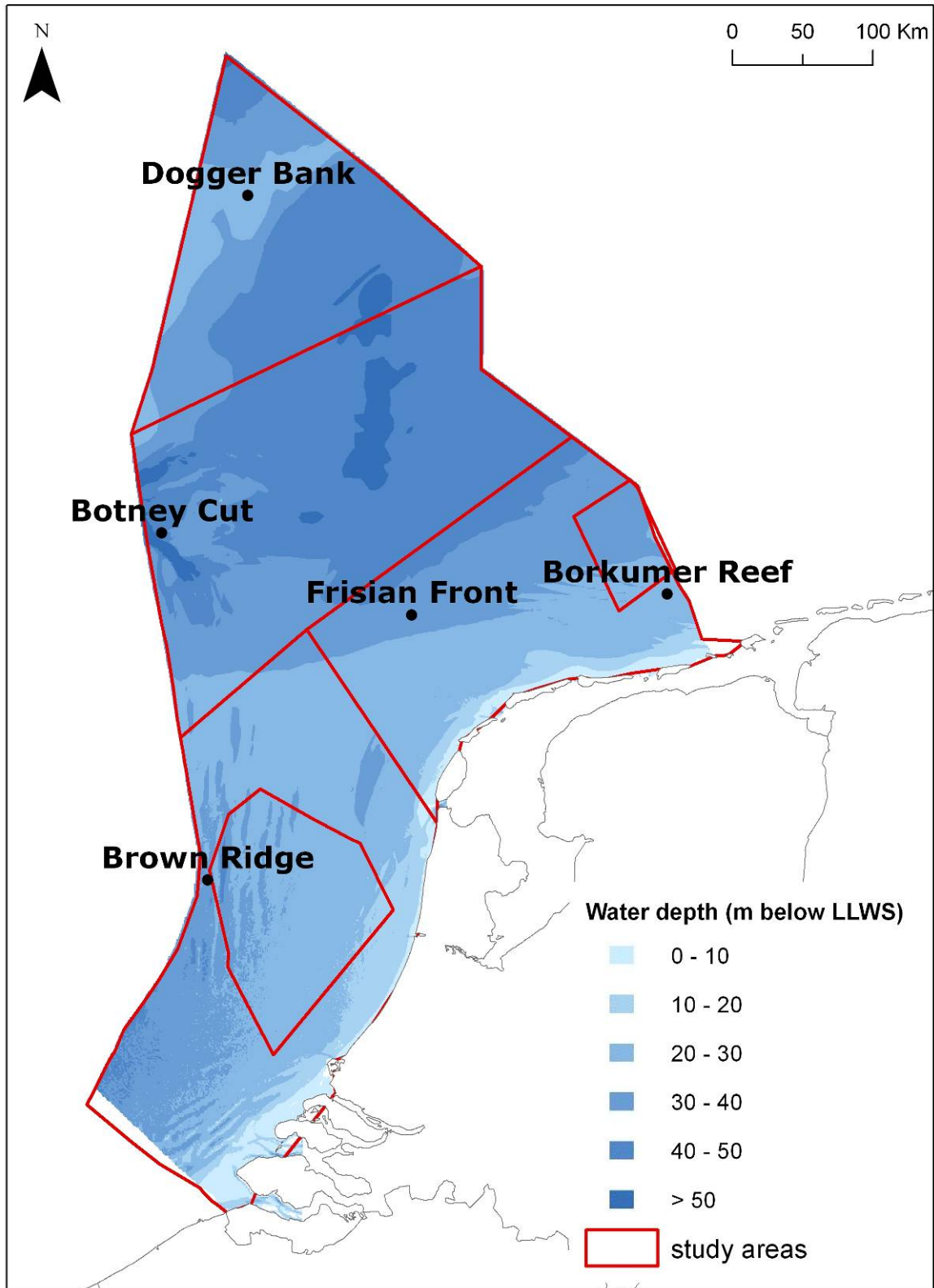


Figure 2. Map of the Dutch Continental Shelf with the boundaries of the study areas.

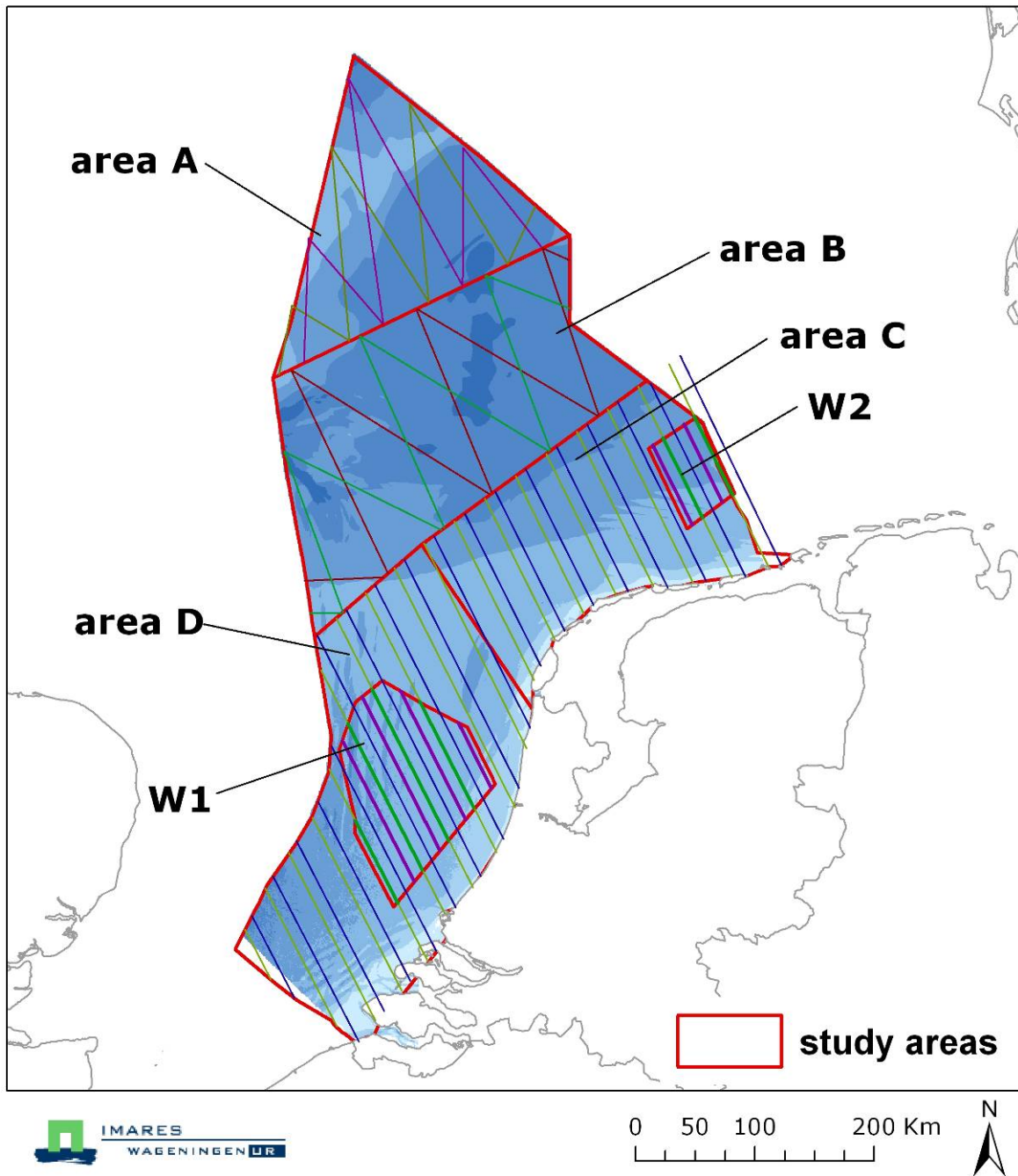


Figure 3. Map of the Dutch Continental Shelf with study areas A ("Dogger Bank"), B ("Offshore"), C ("Frisian Front") & D ("Brown Ridge") as well as the wind farm survey areas W1 and W2 and planned track lines. Track lines from the same survey set are shown in the same colour.

3.2 Data analysis

The survey data were collected using distance sampling techniques. The collected sightings are used to calculate densities and abundance estimates, and to produce distribution maps. For the latter sightings are presented in three different ways: 1) un-corrected sightings; 2) sightings corrected for survey effort per grid cell and 3) sightings corrected for effort and sighting conditions by means of a model. Only data from transect lines flown in good or moderate conditions were considered in the analyses. The extra track lines in German waters were not used in the model.

3.3 Line-transect distance sampling

The survey planes followed pre-designed track lines in the four designated survey areas and the wind farm survey areas (Figure 3). Line-transect distance sampling allows for obtaining absolute densities, i.e. the number of animals/km² with the associated 95% confidence interval (C.I.) and coefficient of variation (C.V.; Buckland et al. 2001.). To do this the so called effective strip width (ESW), the strip along the track line in which all animals are counted, is calculated. To obtain the first component the perpendicular distance of a sighting (a single animal or the centre of a group of animals) to the track line is measured. To calculate the distance of the sighting to the track line from air, the plane flies at a constant height (600 feet = 183m) and the vertical or 'declination' angle to the animal is measured when it comes (or is estimated to come) abeam. By modelling a detection curve to all these distances the effective strip width is obtained.

One of the assumptions of line-transect distance sampling is that all animals are detected on the track line, which would mean that the chance to see all animals at a distance of 0 m from the track line is 1 (100%). For most animals, but in particular for cetaceans, this assumption is not true and a correction factor, called $g(0)$, needs to be obtained to correct for the proportion of animals missed on the track line.

In practice there are two reasons why animals are not recorded: 1. the animals are not "available" to be seen, (e.g. because they are sub-merged) or 2. they are missed by the observers ("observer bias"). To obtain a reliable estimate of absolute abundance (the number of animals in a given area e.g. the DCS) it is therefore needed to estimate the proportion of animals actually seen on the track line: the true value of $g(0)$, and use this value to correct the ESW. For the aerial surveys, the so-called racetrack method (Hiby & Lovell, 1998) has been developed. With this method a part of a track line during which a harbour porpoise has been seen is covered a second time by the plane some minutes later, by circling back to the track line prior to the location where the sighting was made. The basic concept is to estimate what proportion of animals known to be present is actually resighted. Further details of the racetrack method and the analyses are described in Hiby & Lovell (1998) and Hiby (1999).

As explained in chapter 2 it was not feasible to fly enough racetracks to calculate a new $g(0)$. During previous surveys conducted in German waters the same racetrack method was used (Scheidat *et al.*, 2008). Since the observer team, methodology and the survey plane were consistent with the ones used in the German study the $g(0)$ values and thus the ESW values obtained from the latter were applied in the present study. These $g(0)$ values are 0.37 for good conditions and 0.14 for moderate conditions. The calculated ESW's for the Dutch survey team (data from 2008 onwards) and the German ESW's are almost identical (see appendix I). Therefore we assumed that the $g(0)$ values will be identical as well and can be used until an updated $g(0)$ value for the Dutch aerial survey team will be obtained. The consequence of using inaccurate $g(0)$ is that the absolute density of animals is offset by the same factor as the error in $g(0)$ (e.g. if $g(0)$ is assumed to be 1 but is in truth 0.2, then the results will be an underestimation of abundance by a factor 5). In line transect distance sampling methodology, it is assumed that the parameter is constant for the entire survey (or per survey condition, in this case good and moderate). An error in $g(0)$ hence affects the absolute densities and population size estimates, but not the observed spatial patterns, because any bias would be constant over space.

Animal abundance in each stratum v (i.c. area) was estimated using a Horvitz-Thompson-like estimator as:

$$\hat{N}_v = \frac{A_v}{L_v} \left(\frac{n_{gsv}}{\hat{\mu}_g} + \frac{n_{msv}}{\hat{\mu}_m} \right) \bar{s}_v \quad (1)$$

where A_v is the area of the stratum, L_v is the length of transect line covered on-effort in good or moderate conditions, n_{gsv} is the number of sightings that occurred in good conditions in the stratum, n_{msv} is the number of sightings that occurred in moderate conditions in the stratum, $\hat{\mu}_g$ is the estimated total effective strip width in good conditions, $\hat{\mu}_m$ is the estimated total effective strip width in moderate conditions and \bar{s}_v is the mean observed school size in the stratum.

Group abundance by stratum was estimated by $\hat{N}_{v(\text{group})} = \hat{N}_v / \bar{s}_v$. Total animal and group abundances were estimated by

$$\hat{N} = \sum_v \hat{N}_v \quad \text{and} \quad \hat{N}_{(\text{group})} = \sum_v \hat{N}_{v(\text{group})} \quad (2)$$

respectively. Densities were estimated by dividing the abundance estimates by the area of the associated stratum. Mean group size across strata was estimated by $\hat{E}[s] = \hat{N} / \hat{N}_{(\text{group})}$.

Coefficients of variation (C.V.) and 95% confidence intervals (C.I.) were estimated by a non-parametric bootstrap (999 replicates) within strata, using transects as the sampling units. The variance due to estimation of ESW was incorporated using a parametric bootstrap procedure which assumes the ESW estimates to be normally distributed random variables. More details on this method can be found in Scheidat *et al.* (2008).

3.4 Distribution maps

Distribution maps were created using ESRI ArcMap 9.3 software. Densities were represented spatially in the 1/9 ICES grid. This grid has latitudinal rows at intervals of 30', and longitudinal columns at intervals of 1°. To allow for more detail, these blocks are divided into nine sub-rectangles, which have latitudinal intervals of 10' and longitudinal intervals of 20'. ICES 1/9 rectangles intersecting with the DCS measure approximately 20x20km, resulting in areas ranging from 388 to 409 km².

Densities per 1/9 ICES grid cell were calculated by dividing the total number of animals observed during good and moderate conditions by the total surveyed area. The surveyed area is the distance travelled multiplied by the total effective strip width (ESW). The effective strip half-width (ESW corrected for $g(0)$ values of 0.37 and 0.14 for good and moderate sighting conditions respectively) was defined as 76.5 m for good sighting conditions and 27 m for moderate sighting conditions on each side of the track line (Gilles *et al.*, 2009; Scheidat *et al.*, 2008). Densities in grid cells extending outside the borders of the surveyed area (e.g. the Wadden Sea) could be less reliable due to lower effort. Grid cells with an effort less than 1 km² were omitted from the density calculations.

3.5 Model-based estimation of porpoise distribution

The observed distribution of harbour porpoises is not only influenced by a multitude of spatial and temporal processes, but also by factors related to sighting conditions. For example, sea state influences the probability of observing porpoises (Teilmann, 2003). This means that if there are more sightings in one region, this does not necessary mean porpoises are more abundant. Instead, the spatial heterogeneity may be caused by surveying that region under more favourable conditions. Some of the

observation bias due to different sighting conditions, should be accounted for by the estimates of effective strip width (corrected for by $g(0)$). However, because time-consuming racetrack observations are needed to estimate the ESW, the statistical power was only sufficient to differentiate between the subjective conditions; good and moderate (see Gilles *et al.*, 2009; Scheidat *et al.*, 2008). In practice, the sighting rate may be influenced by a more complex suite of environmental conditions (e.g. sea state, glare, cloud cover). In an attempt to capture the 'real' distribution of harbour porpoises as good as possible, it is necessary to correct for the aforementioned confounding factors related to sighting conditions. The objective of the modelling is to try to differentiate between true spatial heterogeneity in the actual distribution of porpoises and heterogeneity in the observations caused by sighting conditions, that cannot be explained by differences in ESW for good and moderate. One indirect (and given the availability of data, the only) way to correct for this, is to investigate how the distribution of porpoise sightings in space and time can be explained by several variables, e.g. sea state, turbidity, etc. To capture the multivariate effect of several of these potential factors on the distribution of porpoise sightings, empirical Generalized Additive Models (GAMs, Wood, 2006) were fitted to the data. These type of models can deal with non-normally distributed data, e.g. counts and non-linear effects of covariates on the sighting rate. For example, the effect of sea state does not necessarily have a linear effect on the sighting rate. The resulting model can be used to make predictions of what the harbour porpoise spatial distributions would look like if the entire survey area had been observed under constant conditions.

Although the raw environmental data (e.g. sea state, glare, cloud cover, etc.) was collected at 4s interval, for computational reasons, the response variable was defined as the number of sightings in each 1 minute interval, corresponding to on average 3.0 km (SD =0.54) of transect line. The log of the effective strip half-width (76.5 m for good and 27 m for moderate sighting conditions) multiplied by the segment length, was included as the offset.

Covariates – The covariates included in the model were smooth functions of time of day and the sighting conditions; turbidity, cloud cover ($x/8$) and sea state, and a 2-dimensional smooth of spatial coordinates. The covariate time of day may capture potential daily variability in behaviour (e.g. logging) or differences in light intensity. The sighting conditions turbidity, cloud cover and sea state were also included to parameterize any remaining effects not captured by the effective strip width (see offset term). Although cloud cover is unlikely to influence porpoise sightings directly, it may act as a proxy for light conditions and the strength of the silvery shine. Admittedly it would be better to measure these conditions directly, which is currently implemented in the new aerial survey program. Any spatial heterogeneity was captured by a 2-dimensional smooth function of the x and y coordinates (projection: UTM 31N, datum: WGS84). If this spatial component significantly improves the explained deviance after accounting for temporal variability and sighting conditions, there is evidence for a non-uniform distribution in space.

The full model is specified as:

$$Y = NB(\lambda, \phi)$$

$$\lambda = \log(a) + \beta_0 + s(\text{Turbidity}) + s(\text{Seastate}) + s(\text{Cloud cover}) + s(\text{Hour}) + te(x, y)$$

Here Y are the numbers of porpoise sighted, which are assumed to be distributed according to a negative binomial distribution (NB, Venables & Ripley, 2002), λ is the expected count, ϕ is the dispersion parameter to allow for over- or under-dispersion, a is the effective survey area of each segment, β_0 is the intercept and te represents a tensor product smooth (Wood, 2006).

Model selection – Using forward model selection based on the Akaike's Information Criterion (AIC - Burnham & Anderson, 2002), the (smooth functions of) covariates were added one by one, until the full model (specified above) was reached. The variable explaining the heterogeneity in sightings best is

retained first, and so forth. If adding a variable leads to a lower AIC, it means that the inclusion of that variable significantly describes the variability in porpoise sightings.

Model prediction - The final model (lowest AIC) was used to estimate the distribution in space. The model describes the sighting rate as a function of covariates (see model equation above). Hence, to make predictions, one needs to set the values of all model covariates (e.g. sea state, cloud cover, hour of day, and x- and y-coordinates). Predictions were made for a regular 1km grid.

A common problem with spatial predictions from empirical models (like GAMMs) is that they are only reliable in regions for which there is sufficient data. If this is not the case (e.g. at the edges of the study area), the model may yield extreme high predicted porpoise densities. Insight into the uncertainty of the predictions over space can prevent such model artefacts from affecting the conclusions. To deal with this issue, two steps have been taken. First, uncertainty in the model predictions were shown by spatially presenting the standard errors of the prediction (see Figs). Second, to prevent extreme predictions in regions with little data, we used empirical Bayesian prediction (Wood 2006). The basic principle behind this idea is that the observed sighting rate is used as prior information. For example, if the model predicts a very high porpoise density and if these predictions are highly uncertain (large standard errors), our sighting rate observed in the field informs us that these predictions are probably overestimated. In more detail, the approach works as follows: For each point in space the model is used to predict the mean porpoise density. Next, based on the standard errors of the prediction, random noise is added to the mean prediction. This is repeated 5000 times. Finally, using the statistical distribution of the sighting rate observed in the field (i.e. the prior distribution), a weighted average of these predictions is estimated. As a consequence, predictions similar to the observed sighting rates in the field, will receive a higher weight.

The model was used to predict the density of harbour porpoise. The integral of this over the DCS theoretically represents an absolute abundance (Hammond *et al.* 2002, Gilles *et al.* 2011). The model was not used for calculating this abundance, because there are some complicating issues. An important complication is that also after accounting for the differences in the effective strip width between good and moderate sighting conditions, the covariate sea state is retained in the model. Most likely the effect of sea state relates to the sighting probability. So which sea state should be chosen to estimate absolute abundance? One possible solution could be to predict the porpoise density using the mean sea state of the German race-track data collected under good conditions (i.e. the basis of the $g(0)$ and ESW estimate for good conditions), and to use the corresponding ESW estimate. This issue should receive more attention in future aerial survey work.

4. Results

4.1 Effort and sightings of harbour porpoises

Table 3 and Figure 6 give an overview of the survey effort and sightings of harbour porpoises. The July 2010 and March 2011 survey had the best coverage with around 6000 km on effort. In July and March two sets of track lines in areas A-D and the extra track lines in the wind farm survey areas could be surveyed. In July severe glare resulted in a high proportion of unsuitable sighting conditions along parts of the surveyed track lines. Survey conditions were more adverse in October and November (shorter days, unstable weather) leading to lower survey effort, but one set of track lines could be completed in areas A-D and in the wind farm survey areas. Thus, even in October/November the Dutch Continental Shelf has been entirely surveyed. Overall, 2.3% of the track lines were flown in sighting conditions that were unsuitable on both sides of the plane. In total, over a thousand harbour porpoise groups were sighted during all surveys combined. Calves were sighted during the July survey (7.9%) and the March survey (0.3%). During the October survey one calf was recorded by the navigator.

Table 3. Total survey days, effort, sighting conditions (G – good, M – moderate, P – poor, X – not possible to observe) and harbour porpoise sightings during the three aerial surveys. Calves are included in the number of animals. * a navigator sighting of one calf is not included.

Survey	Effort (km)	Sighting conditions (%)			Porpoise sightings (n)		
		G	M	P / X	Sightings	animals	calves
July 2010 (5,6; 8-11; 18-20 July)	6040	35	35	30	263	330	26
Oct/Nov 2010 (12-14 Oct; 19, 21, 24 Nov)	4028	12	76	11	137	163	0*
March 2011 (18,19; 21 – 27 March)	5945	29	62	9	684	743	2
Total	16013				1085	1236	28

For most harbour porpoise sightings the animal's behaviour at the (short) time of the sighting was recorded (Figure 4). The main behaviour of harbour porpoises was normal directional swimming (49%), followed by slow swimming or resting behaviour (32%). Fast swimming was observed in 8% and milling (un-directional swimming) and feeding in 5% of the sightings. No clear spatial patterns in behaviour were visible.

Average group size of harbour porpoise sightings for all surveys combined was 1.14 animals. Average group size was 1.09 animals in March, 1.19 in October/November and 1.25 in July. The largest group size observed was a pod of 8 animals in July. Figure 5 shows the distribution of group sizes for the three surveys. In all seasons over 80% of the sightings consisted of single animals. In summer and in autumn more sightings were of two or more animals than in early spring.

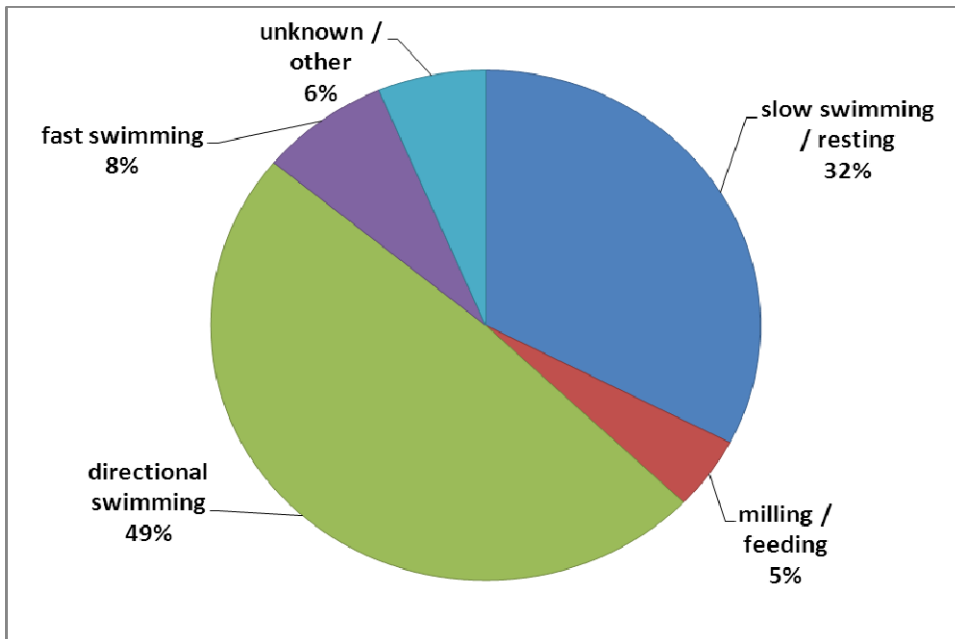


Figure 4. Overview of different behaviour categories for all porpoise sightings.

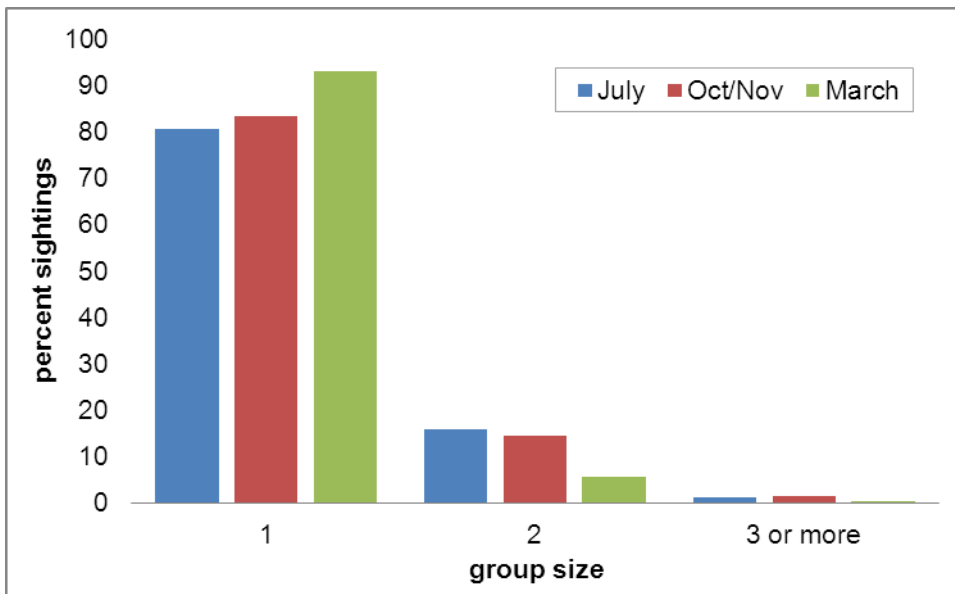
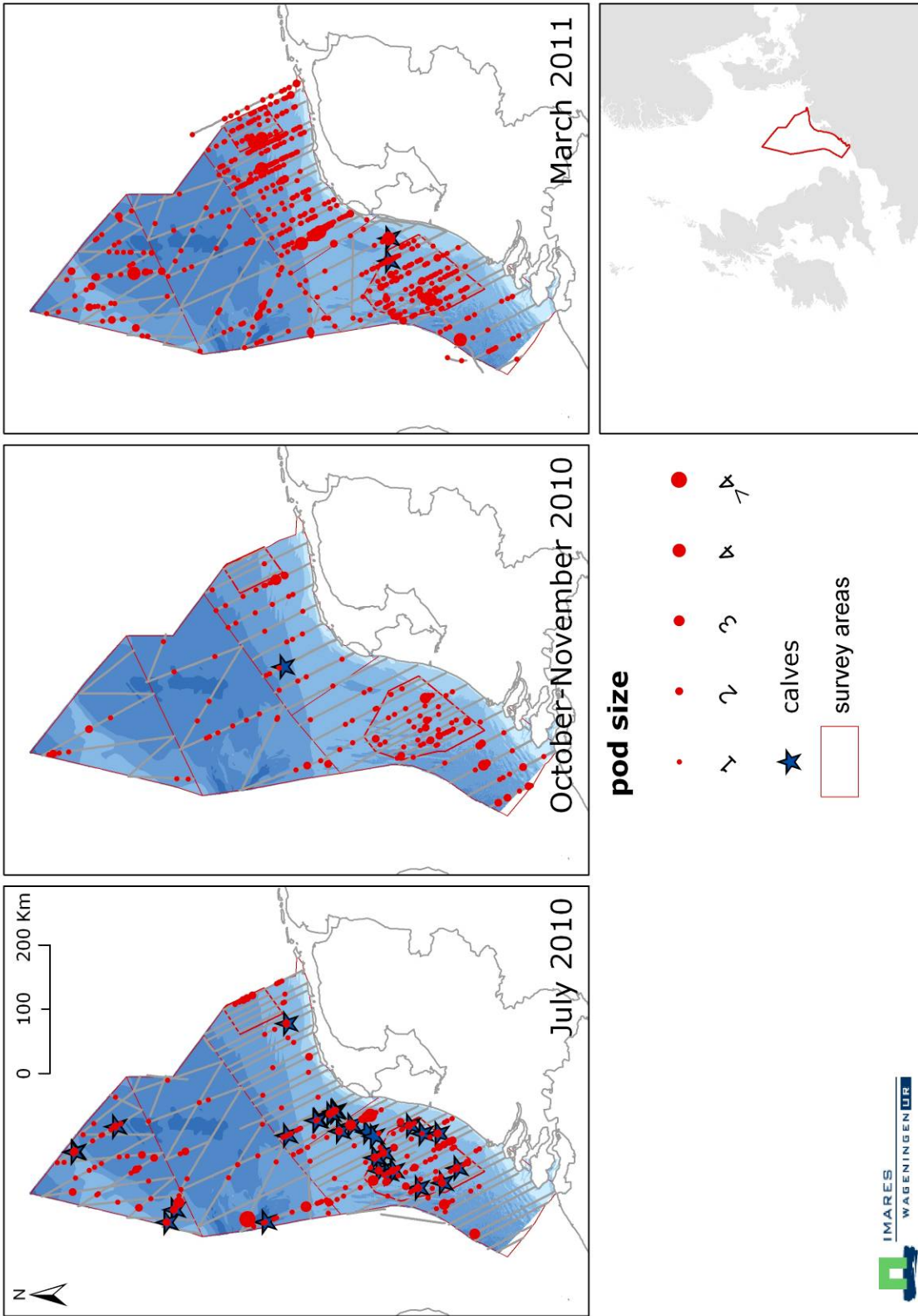


Figure 5. Distribution of harbour porpoise group sizes for the aerial surveys.



4.2 Sightings of other marine mammals

The only other cetacean species that was sighted during all surveys was the white-beaked dolphin *Lagenorhynchus albirostris*. In total 5 sightings of 8 animals were made. Group sizes varied from 1 to 4 (Figure 7). In addition, twelve unidentified dolphins were recorded in one pod of six animals and three pods of two individuals each in a confined area in D on 14 October 2010.

Seals were only recorded when they were in the water, they were not recorded when they were hauled out. In total 66 animals were seen (64 sightings), with most of the sightings close to the coast (Figure 7). The majority (85%) of the seals could not be identified to species level. Of the identified seals (n = 10) 5 were harbour seal *Phoca vitulina* and 5 were grey seal *Halichoerus grypus*.

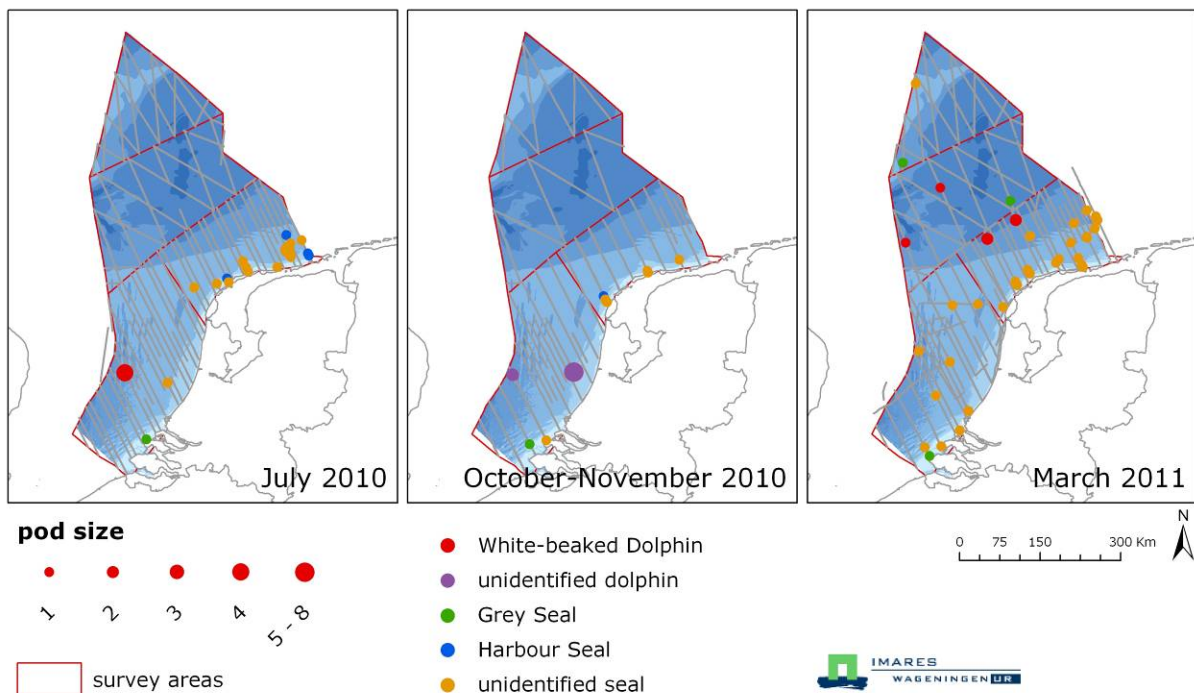


Figure 7. Sightings of other marine mammal species.

4.3 Distribution of harbour porpoises

Using the effectively covered strip width during the survey, grid maps were created showing the distribution pattern density of porpoises (animals/km²) per 1/9 ICES grid cell (Figures 8-10). In summer (July), a higher density can be seen in the offshore area B, close to the UK border, as well as in the area around the W1 study area (within area D). The latter pattern is also visible in the autumn surveys (October/November) and the spring surveys (March). In autumn the offshore density in area B is lower and more evenly distributed than in the other two survey periods. In spring the overall density is much higher. The densities in area B and D almost tripled, but area C, including the W2 study area, shows an even stronger increase.

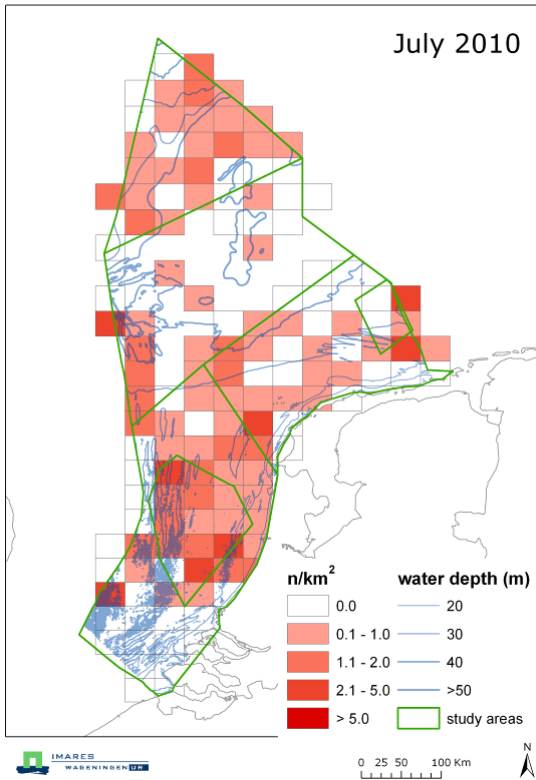


Figure 8. Summer density distribution of harbour porpoises (animals/km²) per 1/9 ICES grid cell, July 2010. Grid cells with low effort (< 1 km²) are omitted.

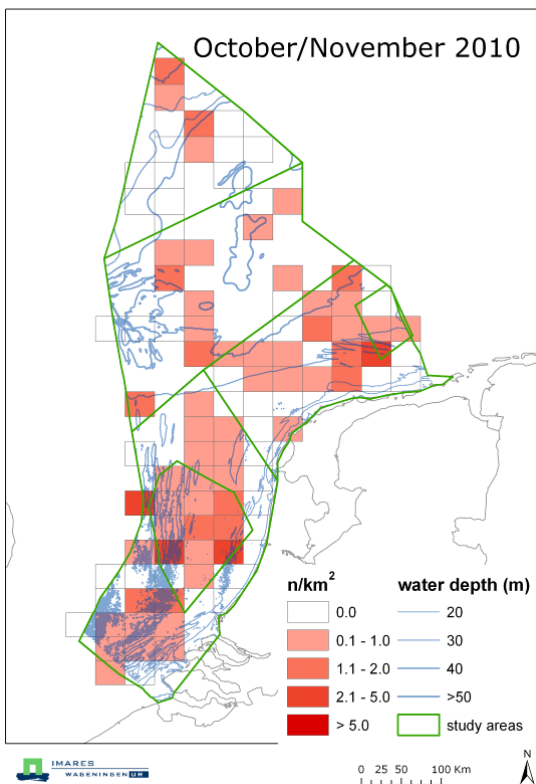


Figure 9. Autumn density distribution of harbour porpoises (animals/km²) per 1/9 ICES grid cell, October/November 2010. Grid cells with low effort (< 1 km²) are omitted.

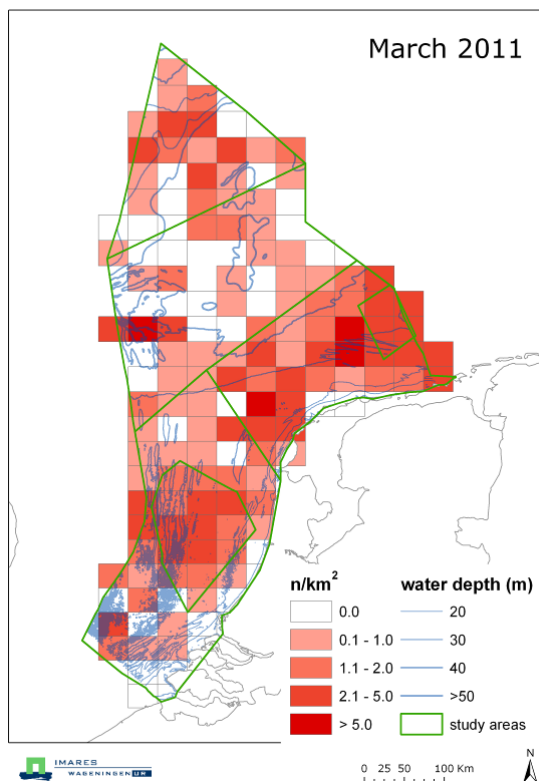


Figure 10. Spring density distribution of harbour porpoises (animals/km²) per 1/9 ICES grid cell, March 2011. Grid cells with low effort (< 1 km²) are omitted.

4.4 Density and abundance of harbour porpoises

The density of harbour porpoises was estimated for each survey stratum separately (areas A-D) as well as for the whole DCS. This was done for each of the three surveys. Table 4 gives an overview of density (animals/km²) as well as abundance (number of animals) per survey area and survey period. The overall density was similar for the summer (July) and the autumn (October/November) survey, with 0.44 and 0.51 animals/km² respectively. Density was about three times higher during the March survey with 1.44 animals/km². The highest density was found in area C, north of the Wadden Isles (Figure 11). The high density area in the Dutch part of the Borkumer Reef extended to the German part.

The total numbers of harbour porpoises on the Dutch Continental Shelf (areas A-D) were estimated at ca. 26000 (C.I.: 14000-54000) and 30000 (C.I.: 16000-59000) animals in summer and autumn respectively. The abundance in March comprised ca. 86000 animals (C.I.: 49000-165000, Table 4). Obtaining abundance estimates with the same reliability (e.g. acceptable C.V. and C.I.) in smaller areas (such as W1 and W2) is made more difficult by a number of challenges. The smaller the area, the higher the survey effort needed to obtain a minimum sample size (i.c. track lines). As the survey effort is also affected by the survey conditions (larger esw in good conditions), whether or not the effort is sufficiently high to calculate densities, always contains some aspect of 'chance'. The smaller the area, the larger the effect of this stochasticity. Unfortunately, given the survey conditions, the number of track lines in areas W1 and W2 was too low to calculate abundance estimates with an acceptable reliability for these areas. Since the highest priority of the survey was to cover the DCS, the financial and logistical constraints did not allow us to increase the coverage of the smaller areas further. It is also important to note that

Table 4. Estimates of density and abundance of harbour porpoises.

July 2010						
Survey Area	Density (animals/km ²)	(95 % C.I.)	Abundance (n animals)	(95 % C.I.)	C.V.	
A	0.396	0.181 - 0.849	3806	1738 – 8165	0.404	
B	0.477	0.212 – 1.058	8055	3589 – 17872	0.416	
C	0.336	0.046 – 0.890	4039	553 – 10701	0.622	
D	0.484	0.208 – 1.056	10098	4341 – 22024	0.403	
Overall	0.438	0.236 - 0.903	25998	13988 – 53623	0.336	
October / November 2010						
Survey Area	Density (animals/km ²)	(95 % C.I.)	Abundance (n animals)	(95 % C.I.)	C.V.	
A	0.391	0.117 - 0.872	3763	1124 – 8384	0.461	
B	0.573	0.298 - 1.157	9679	5035 – 19543	0.352	
C	0.683	0.287 - 1.610	8216	3451 – 19351	0.459	
D	0.398	0.212 - 0.733	8304	4431 – 15296	0.317	
Overall	0.505	0.271 - 0.994	29963	16098 – 59011	0.332	
March 2011						
Survey Area	Density (animals/km ²)	(95 % C.I.)	Abundance (n animals)	(95 % C.I.)	C.V.	
A	1.029	0.522 - 2.144	9890	5018 – 20618	0.386	
B	0.908	0.521 - 1.791	15331	8795 – 30249	0.312	
C	2.982	1.645 - 5.806	35850	19772 – 69808	0.325	
D	1.174	0.658 - 2.389	24501	13726 – 49833	0.344	
Overall	1.441	0.830 - 2.786	85572	49324 -165443	0.316	

harbour porpoises are highly mobile animals and the smaller the study area the more likely it is that the measured density will represent a temporary situation only. For example, if the studied animals shift their distribution only a few tens of kilometres, this can cause a decrease or increase in the local study area within a very short time. Interpreting a point estimate for such small areas can thus be problematic and it is not advisable to use this approach for management measures in such small areas. With the given results, we would advise to use the overall density and distribution patterns derived from the DCS survey to evaluate the smaller study areas.

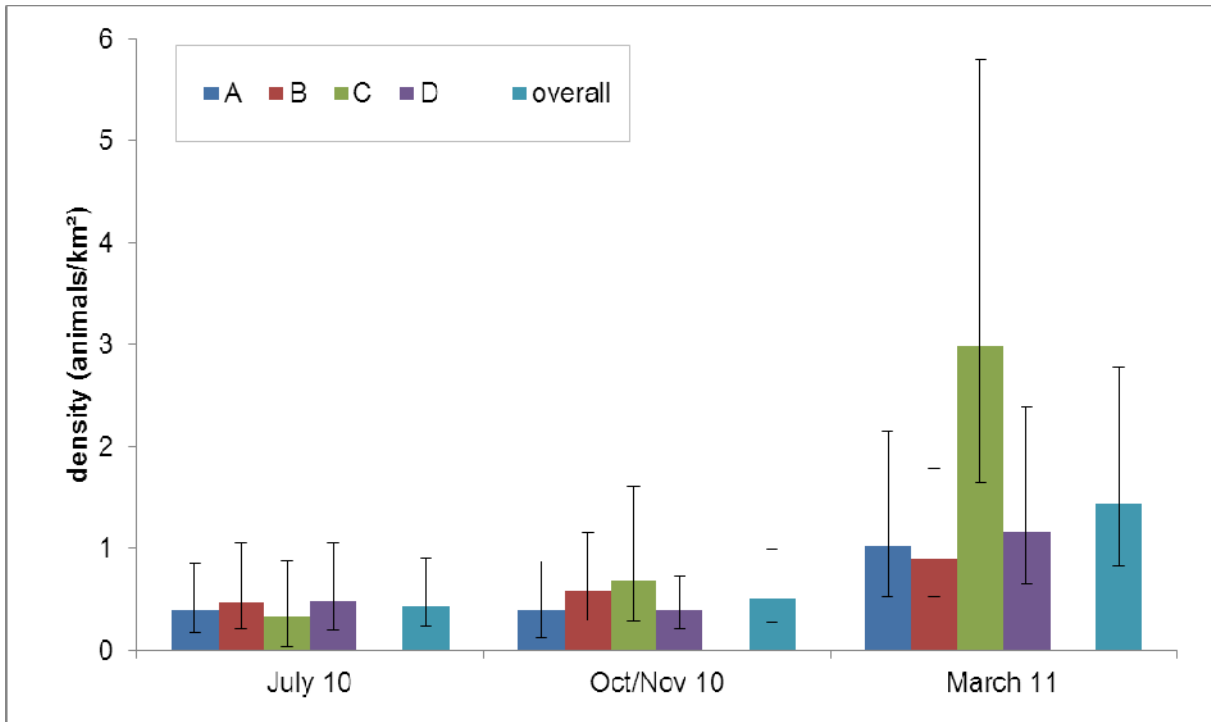


Figure 11. Density of harbour porpoises during the three surveys in the different survey regions. The black bars show the 95% Confidence Interval of the estimates.

4.5 Modelling of harbour porpoise distribution

Table 5 shows the results of the forward model selection procedure. In all cases the spatial smooth is selected first, which means that the distribution of porpoise sightings, corrected for subjective sighting conditions (i.e. good and moderate) as depicted in Figure 8-Figure 10, is not uniform in space. In all three models the sea state is selected as well (Table 5, Figure 12). In all seasons, increasing sea state leads to lower sighting probability, even after accounting for the effect of the subjective conditions (good and moderate). For July 2010, relatively more porpoise are sighted in the afternoon. Turbidity negatively influences the sighting rate, particularly in very turbid waters (e.g. near the coast). In March 2011, most sightings occur at intermediate cloud cover (4/8). No clouds (0/8, often resulting in sun glare) and full cloud cover (8/8, leading to lower light penetration) may lead to lower sighting probability, however, the opposite pattern was observed in July 2010. The relative large decrease in the AIC (see Table 5) after adding the effect of hour of the data to the model, suggest this covariate significantly influences the variability in porpoise sightings. The reason for this is unclear, but it may be possible that time of day is correlated with another variable (e.g. tidal state) not included in the analysis.

Table 5. Forward model selection results. Covariates are added sequentially (i.e. most explanatory covariate is retained first, etc.). The model with the lowest AIC is considered as the best model. E.g. for March 2011, the best model contains a smooth of x- and y-coordinates, cloud cover and sea state. See Figure 12.

July 2010		Oct./Nov 2010		March 2011	
Covariate	AIC	Covariate	AIC	Covariate	AIC
te(x,y)	1593.33	te(x,y)	968.74	te(x,y)	2956.41
s(Sea state)	1550.24	s(Sea state)	967.78	s(Cloud cover)	2953.27
s(Hour)	1535.78	s(Hour)	969.80	s(Sea state)	2951.57
s(Turbidity)	1532.60	s(Turbidity)	971.68	s(Turbidity)	2953.53
s(Cloud cover)	1532.31	s(Cloud cover)	977.03	s(Hour)	2958.13

These models were used to make spatial predictions of 'true' porpoise density. The objective is to estimate the 'true' distribution of porpoises, by correcting for any sighting related artefact. Figures 13-18 show the estimated distribution of harbour porpoises as well as the uncertainty (standard error of the log of porpoise density, note that the scales of the uncertainty differ between the maps) for July 2010, October/November 2010 and March 2011. Since other variables influence the porpoise sighting rate as well, for the spatial prediction it is necessary to fix these other covariates. In this study, predictions were made for sea state 2, turbidity 1, cloud cover 4 and for 1PM UTC. Predicting porpoise density at other conditions, won't change the spatial heterogeneity, but will only influence the height of the density estimates. The absolute uncertainty is larger for high density areas, which is a general property of count data. Furthermore predictions in regions with less survey effort, near the edges of the study area, are less accurate.

These maps may deviate from the distribution of sightings and even Figures 8-10, because they account for additional effects of sighting conditions, such as sea state. So if a relative large number of porpoises are observed under relative poor conditions, this may lead to a high estimated density. In July 2010, compared to the other surveys, the distribution seems most patchy. Particularly the area near Zeeland and the eastern side of area B is characterized by very low densities. Highest densities are present in a huge area around the Brown Ridge, the Borkumer Reef and to a lesser extent the area around the Botney Cut and the (southern) Dogger Bank. The porpoise distribution in October/November seems more homogenous in space. Finally, most porpoise sightings were made in March 2011 resulting in relatively high densities in large areas distributed all over the DCS. However, very low densities are estimated just near the coast. Low densities are also estimated in area B and the southern part of area D.

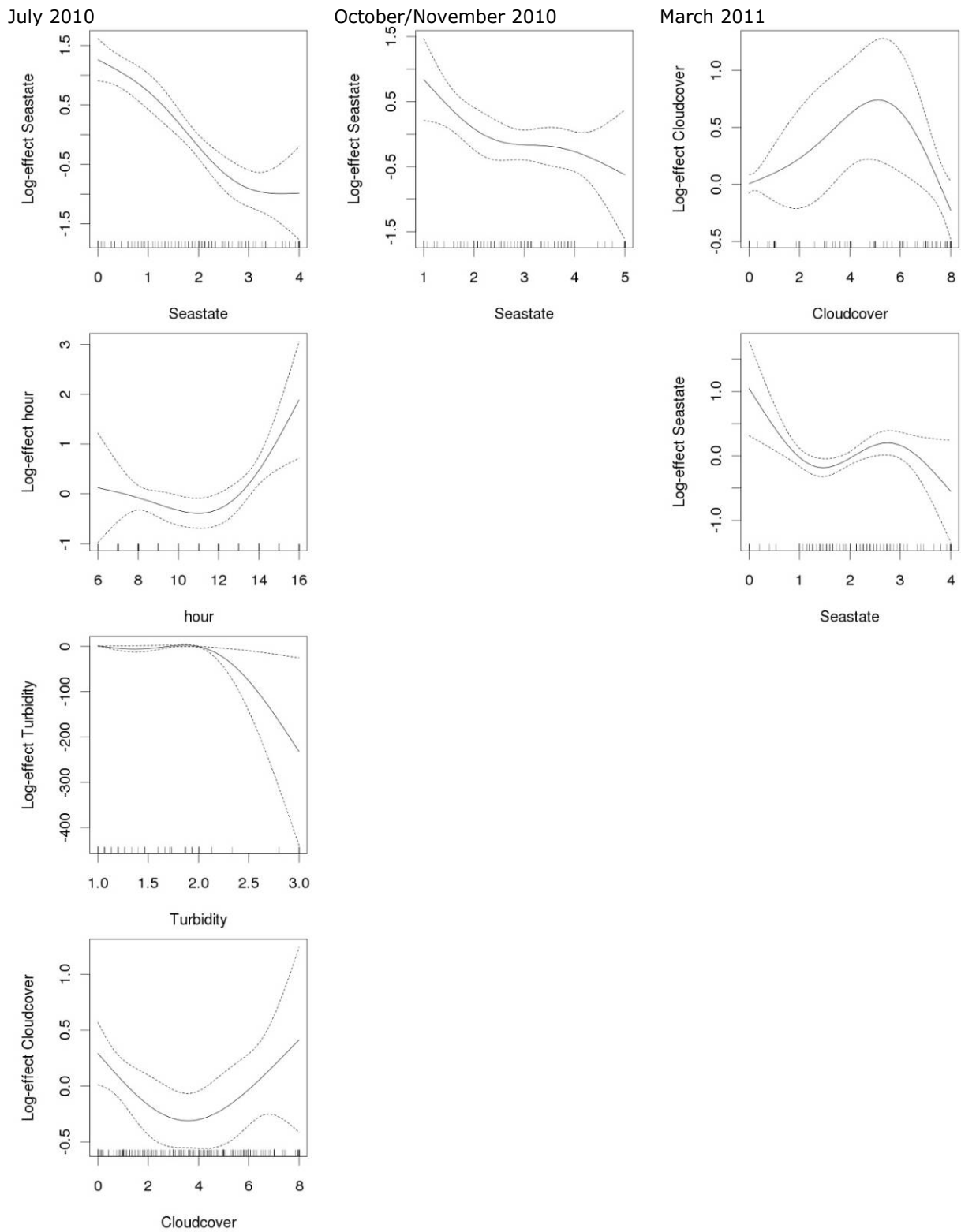


Figure 12. The effect (on the log-scale) of non-spatial environmental covariates on the sighting rate (solid line). The dotted lines represent the 95% confidence limits.

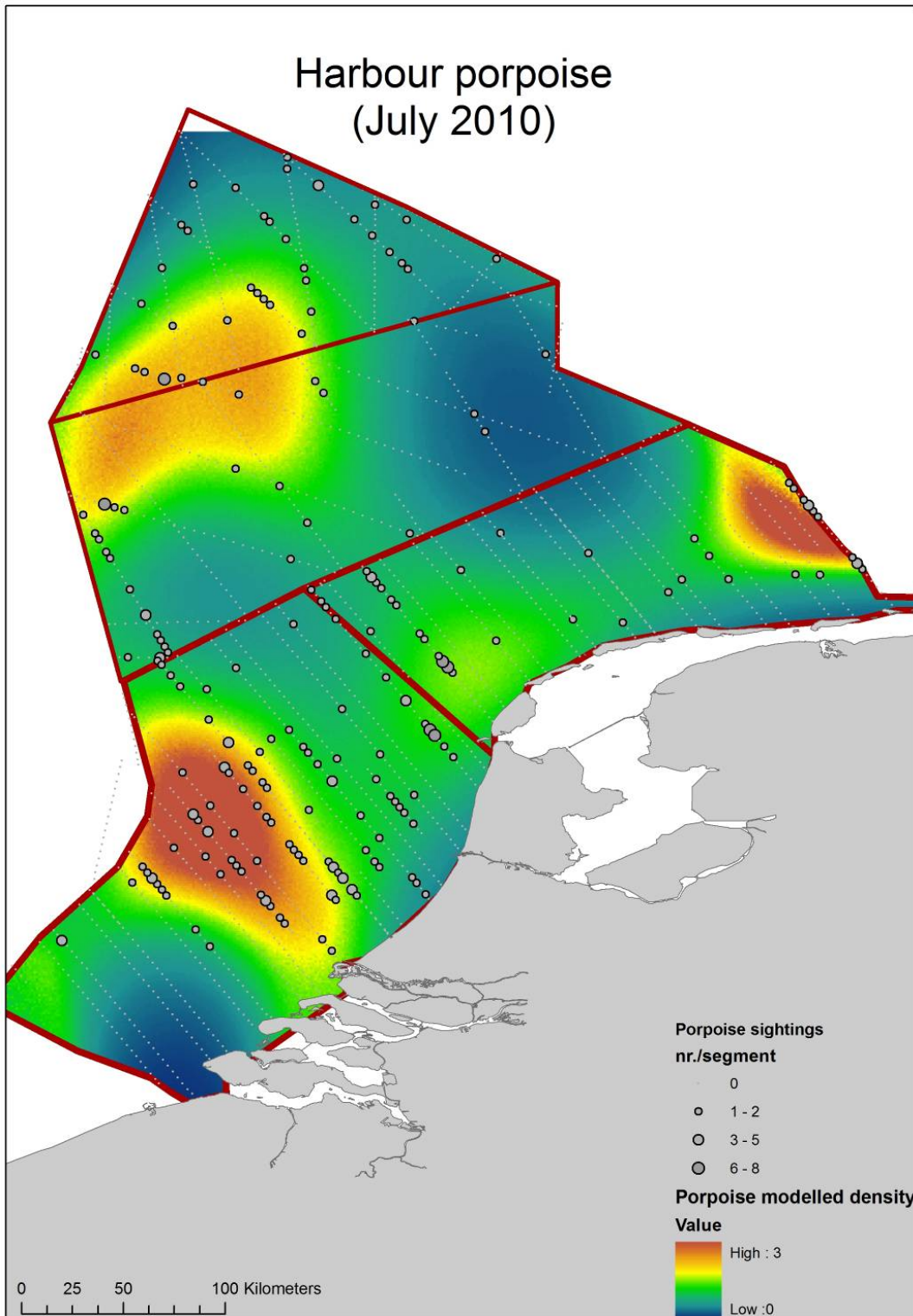


Figure 13. Estimated distribution of harbour porpoises (animals/km²), July 2010. Predictions were made for sea state 2, turbidity 1, cloud cover 4/8 and for 1 PM UTC. The density could differ for different values of these parameters, and should be interpreted in conjunction with the corresponding uncertainty map.

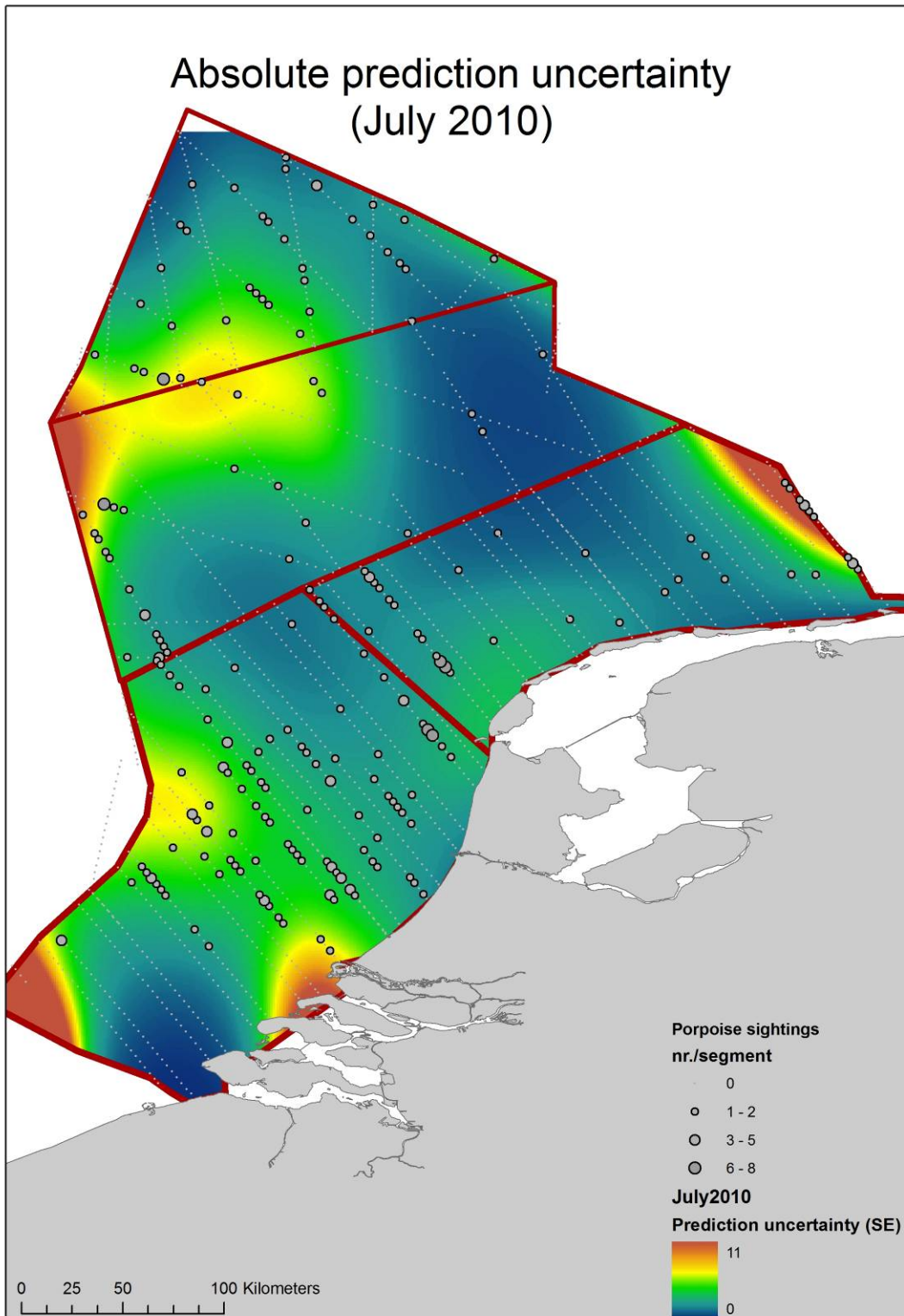


Figure 14. Uncertainty in the porpoise density estimation based on the estimated standard errors of the log of mean density, July 2010. Predictions were made for sea state 2, turbidity 1, cloud cover 4/8 and for 1 PM UTC.

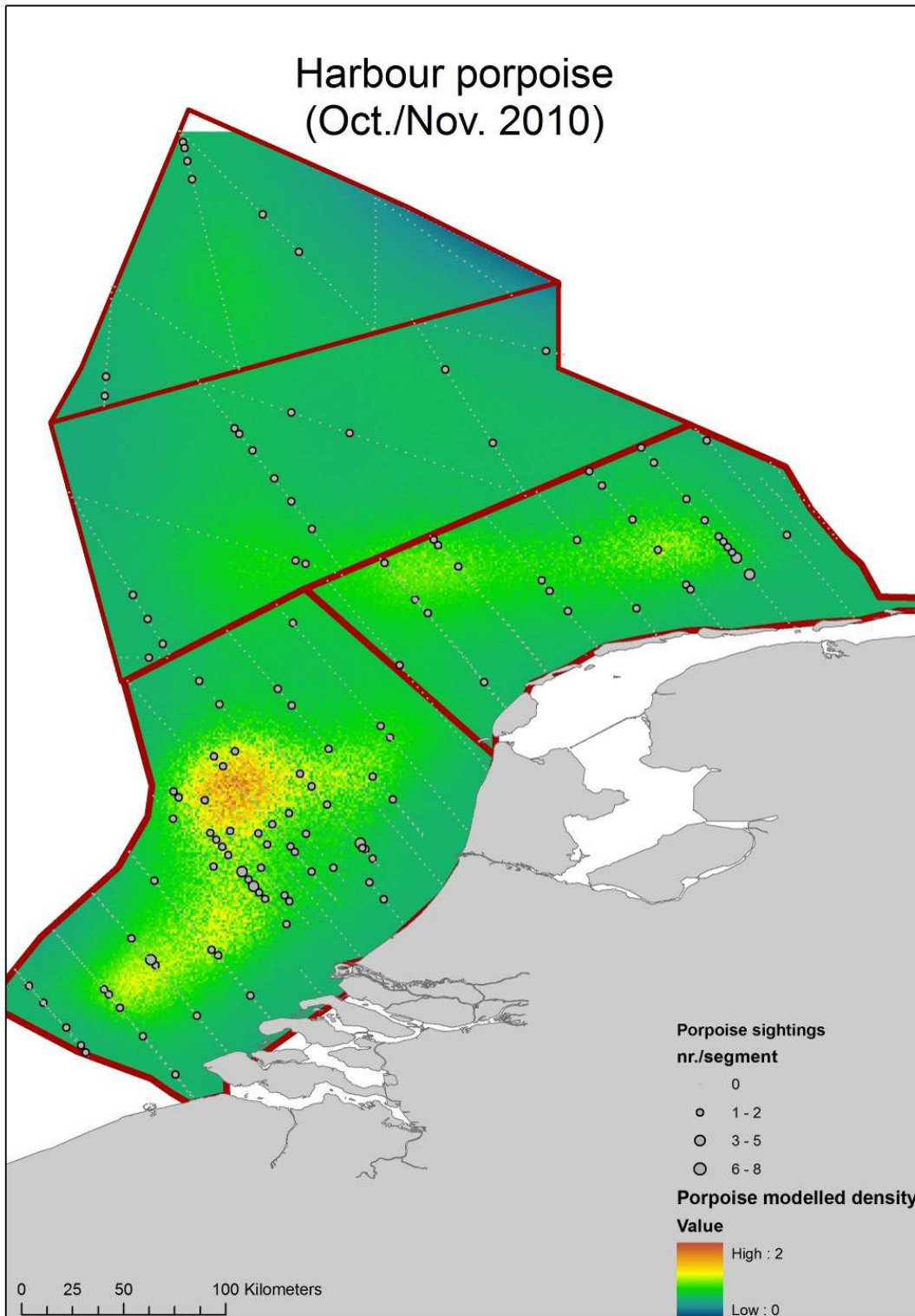


Figure 15. Estimated distribution of harbour porpoises (animals/km²), October/November 2010. Predictions were made for sea state 2, turbidity 1, cloud cover 4/8 and for 1 PM UTC. The density could differ for different values of these parameters, and should be interpreted in conjunction with corresponding uncertainty map.

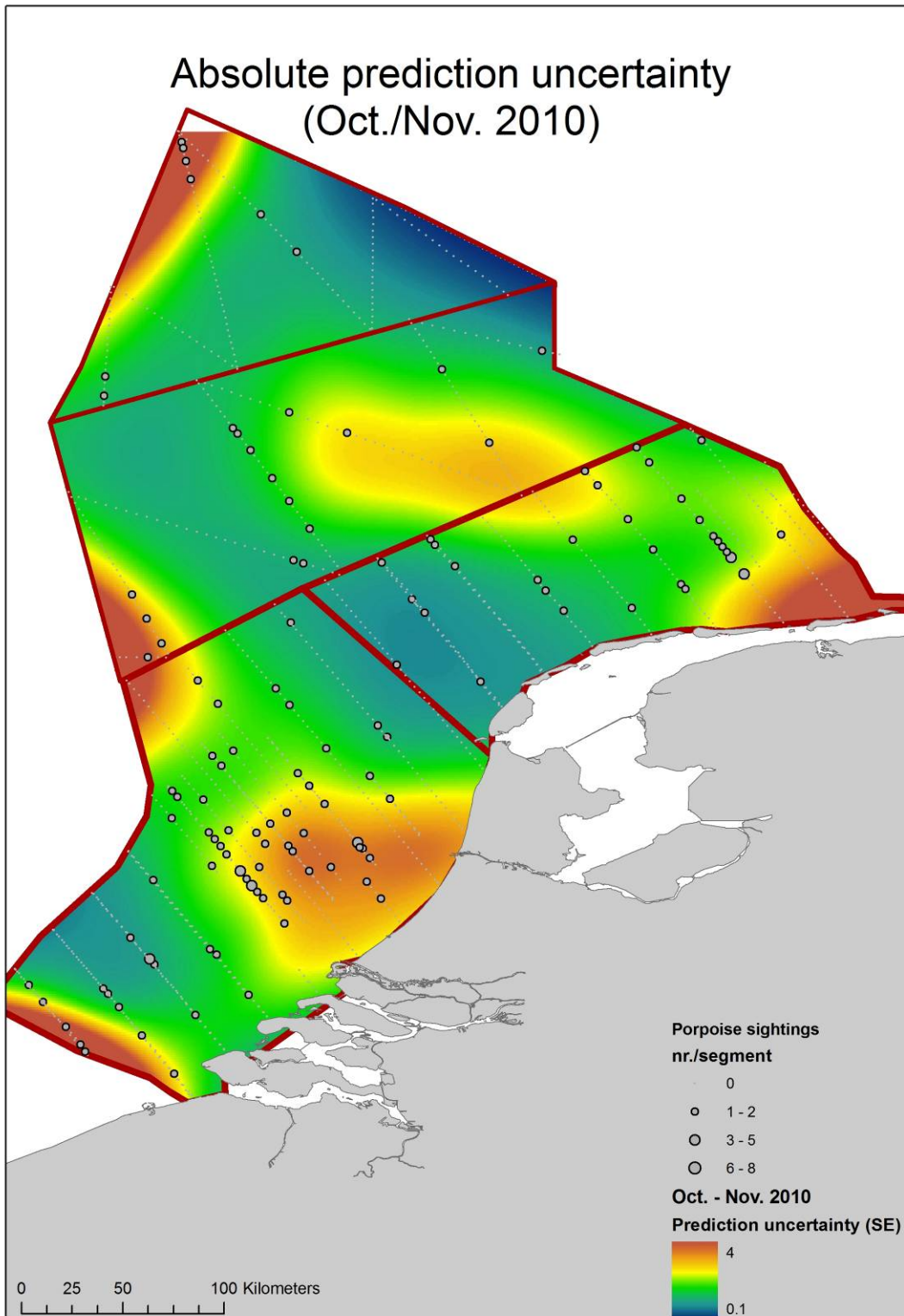


Figure 16. Uncertainty in the porpoise density estimation based on the estimated standard errors of the log of mean density, October/November 2010. Predictions were made for sea state 2, turbidity 1, cloud cover 4/8 and for 1 PM UTC.

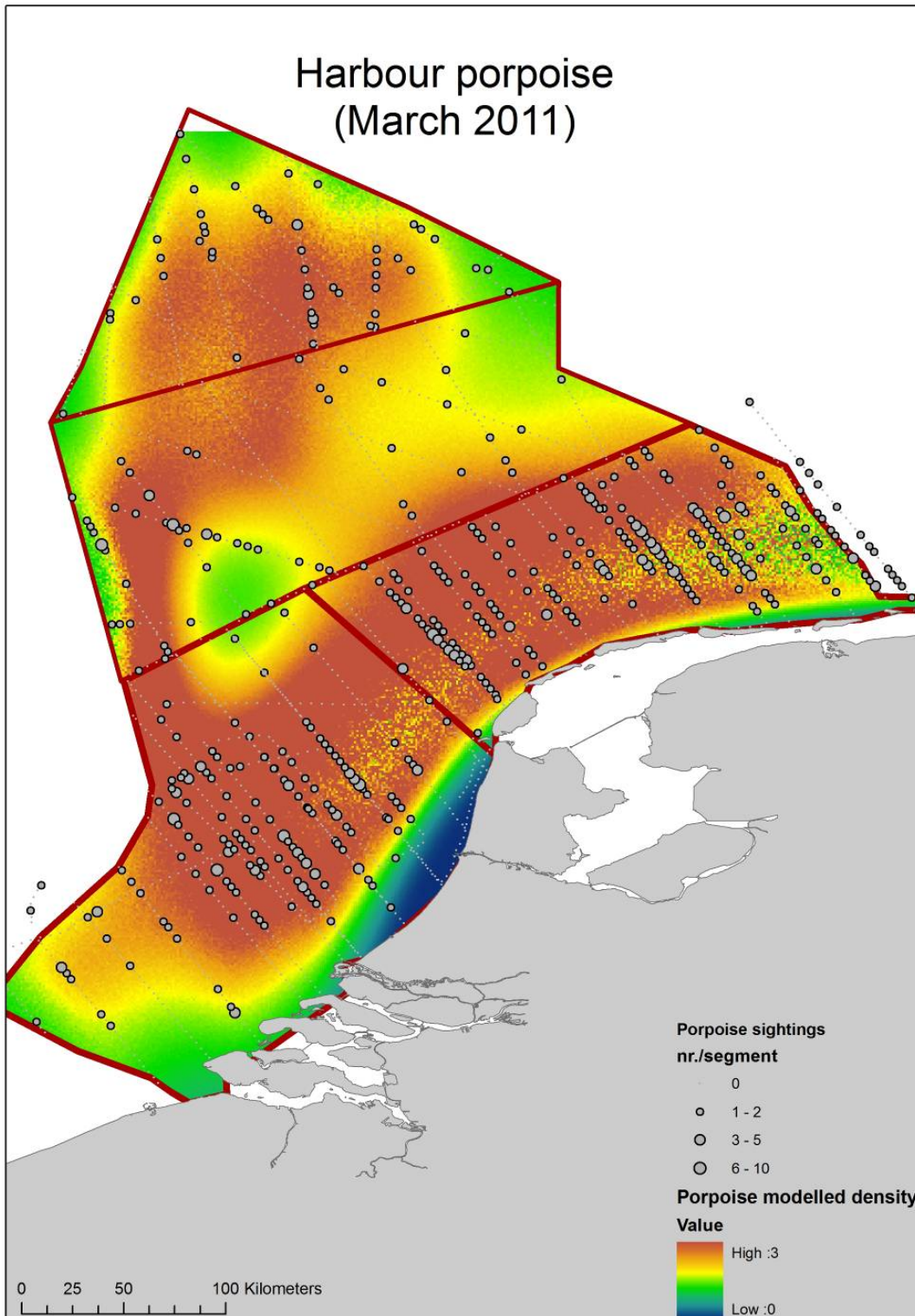


Figure 17. Estimated distribution of harbour porpoises (animals/km²), March 2011. Predictions were made for sea state 2, turbidity 1, cloud cover 4/8 and for 1 PM UTC. The density could differ for different values of these parameters, and should be interpreted in conjunction with the corresponding uncertainty map.

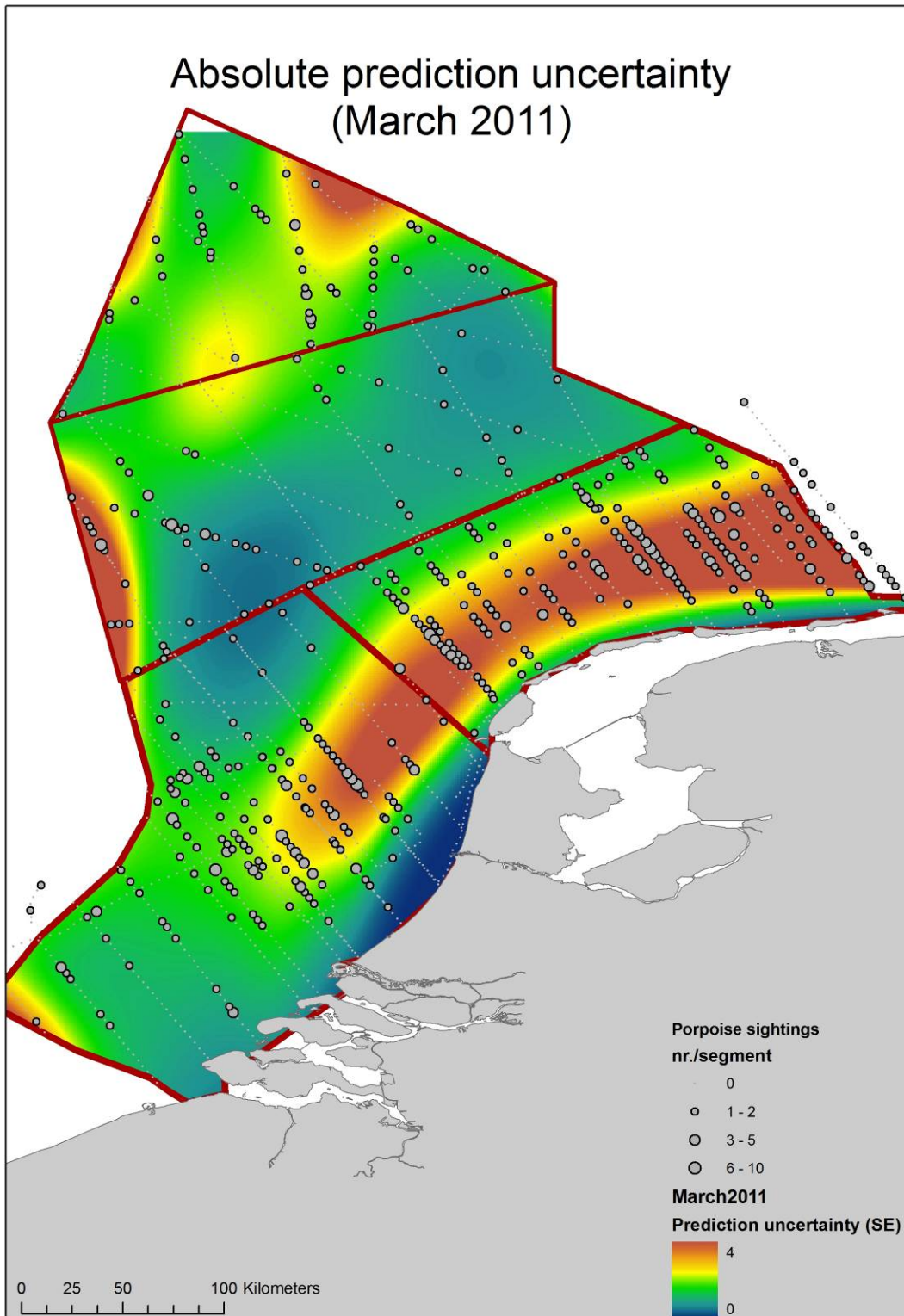


Figure 18. Uncertainty in the porpoise density estimation based on the estimated standard errors of the log of mean density, March 2011. Predictions were made for sea state 2, turbidity 1, cloud cover 4/8 and for 1 PM UTC.

5. Discussion

5.1 Sightings of harbour porpoises (and other marine mammals)

Although some white-beaked dolphins (8 individuals) and grey or harbour seals (66) were observed, the harbour porpoise was by far the most often (1236) sighted species, some of which were identified as calves (28). The harbour porpoise sightings show a strong seasonal pattern, with most sightings in March 2011 (684). Most calves were sighted in July 2010. The average group size during the surveys was lowest in March (1.09) and highest in July (1.25). The highest average group size seems to coincide with a more patchy distribution. A reason for the occurrence of larger group sizes could be the availability of patchy prey (e.g. schooling fish) or social aggregation. Another reason for the larger group size is the presence of calves which reached the highest percentage in summer (7.9%).

In recent years stranding records of harbour porpoises along the Dutch and Belgian coasts showed increasing numbers of neonates in late summer (e.g. Haelters & Camphuysen, 2008). These strandings are assumed to reflect their occurrence in coastal waters. Figure 6 clearly shows a more offshore occurrence of calves as well. Although overall numbers of calf sightings are still too few to allow a solid interpretation of the results, the July flights suggest that harbour porpoises reproduce in Dutch waters. Sexually mature female porpoises can give birth to one calf each year (Gaskin *et al.*, 1974). This means that mating will take place shortly after parturition, indicating that areas with calves are important in the life cycle of porpoises. Based on the size of the foetus in by-caught porpoises, Börjesson & Read (2003) estimated the mean conception date in the North Sea to be 25 July ($\pm 20,3$ days). With a gestation period between 10 and 11 months (Gaskin *et al.*, 1974), a mean birth peak can be expected from the end of May till the end of June. In the German Baltic and North Sea the majority of births takes place in May-July, with the first births in March (Hasselmeijer *et al.*, 2004).

Determining porpoise behaviour accurately from an aircraft is challenging. Nevertheless, a fairly high percentage of porpoises was seen to be swimming slowly or resting at the surface (logging). It is possible that the survey conditions (generally low wind speeds, good weather) influence the behaviour of porpoises. To determine and interpret how behaviour relates to their distribution patterns (e.g. if they choose particular areas for feeding), more detailed analysis is necessary.

5.2 Density and abundance of harbour porpoises

The aerial surveys show a distinct seasonal pattern in abundance and distribution of harbour porpoises: in summer and autumn similar numbers and densities occur, whilst in March the numbers almost tripled. This pattern fits the general temporal occurrence as seen along the Dutch coast during systematic land-based observations of seabird migration (and marine mammals) by members of the Working Group 'Club van Zeetrekwaarnemers' from the Dutch Seabird Group (CvZ/NZG). These dedicated observations show that harbour porpoises are present in coastal waters throughout the year. Peak numbers are observed in winter and early spring (Dec-Mar), after which the numbers drop. Observations in June are relatively scarce, but the numbers slightly increase from July onwards again (e.g. Camphuysen, 2004).

Bi-monthly aerial surveys in the MWTL programme (e.g. Arts, 2010) confirm the occurrence of harbour porpoises on the Dutch Continental Shelf (DCS) throughout the year, but show a slightly different seasonal distribution pattern. Peak densities occur in April-May and a dip in numbers occurs between August and January, followed by increasing densities in February-March. The bi-monthly distribution seems to indicate an inshore and southward movement in February-March, whereas peak numbers in April-May occur in the north-west of the DCS, north of the Wadden Isles and in the Central North Sea (Figure 20). The southern North Sea was described as virtually devoid of porpoises in June-July (Arts, 2010). In the German North Sea bordering Dutch waters (area C) the highest densities (derived from

aerial surveys) were present in spring. The area further northwards along the German coast, is characterized by a peak in June (Gilles *et al.*, 2009). Further north, along the Danish west coast, aerial surveys show that harbour porpoise densities are highest between April and August, with a peak in August (data for June-July are lacking however: Teilmann *et al.*, 2008). This would suggest a northwards seasonal shift in distribution along the Dutch coast up to Denmark.

The estimated average densities for harbour porpoises in Dutch waters ranged from 0.34–2.98 animals/km². These densities lie within the range obtained during comparable studies in adjacent waters in the southern German North Sea (Gilles *et al.*, 2009; Thomsen *et al.*, 2006), in Belgian waters (Haelters *et al.*, 2010), and in the relevant survey blocks during the two large scale SCANS surveys (Figure 19, Hammond, 2002; SCANS, 2008). Data from Gilles *et al.* (2009) reveal that the highest densities in the German North Sea EEZ were obtained in spring with an overall density of 1.34 animals/km² and a density of 0.85 animals/km² in the area closest to the Dutch border (East Frisia). In March 2011 both Belgian and German waters were surveyed simultaneous with the Dutch surveys. The Belgian waters were surveyed by MUMM on 24-25 and 29 March, covering almost 1400 km on effort (Jan Haelters, MUMM, in lit). The south-western part of the German EEZ, bordering area C was surveyed by the FTZ on 20 March (Anita Gilles, FTZ, in lit). The estimated densities of harbour porpoises were high, with 2.53 and 2.09 animals/km² respectively. These densities correspond well with the maximum density of 2.98 animals/km² in area C, whereas the density in area D of 1.17 animals/km² was somewhat lower.

The SCANS-II survey (SCANS, 2008) showed that the porpoise density increased in the southern North Sea from an estimated density of 0.10 animals/km² for SCANS-block H between June and July 1994 to a density of 0.36 animals/km² in June-July 2005 (Table 6). In the Channel (SCANS-block B) no animals had been sighted in 1994 but a density of 0.33 was estimated for 2005 (Table 6). This density corresponds well with the 0.48 animals/km² estimated for the Dutch survey area D in July, which overlaps with SCANS-block B.

The ASCOBANS-HELCOM small cetacean population structure Working Group recently made an assessment of the population and stock structure of harbour porpoises in the north-eastern Atlantic (Evans *et al.*, 2009). Based on Danish telemetry data (Sveegaard *et al.*, 2011) amongst other available data (e.g. genetics) they concluded that the North Sea has to be divided into two so-called management units (MU) along a -at this stage arbitrary- line running NNW-SSE from northern Scotland to Germany-Denmark. The Dutch porpoises would belong to the management unit south of this line: the South-western North Sea and the Eastern Channel MU. The boundaries of this management unit are not well defined, but the MU lies within the survey blocks V, U, H and B during SCANS II, the most recent North Sea wide survey of harbour porpoises (Figure 19). Therefore an exact abundance estimate for this management unit is lacking, but it has to be less than the total number in these survey blocks. An overview of the (summer) population estimates for the SCANS and SCANS II surveys for the central and southern North Sea is presented in Table 6. Assuming that the Central and southern North Sea population stays in this area throughout the year and that the population size did not change much since 2005, the estimated number of porpoises in this management unit is less than ca. 180000 animals. The estimates for the Dutch national waters in March thus comprise at least 48% of the population present in the central and southern North Sea. In July this proportion drops to at least 14%.

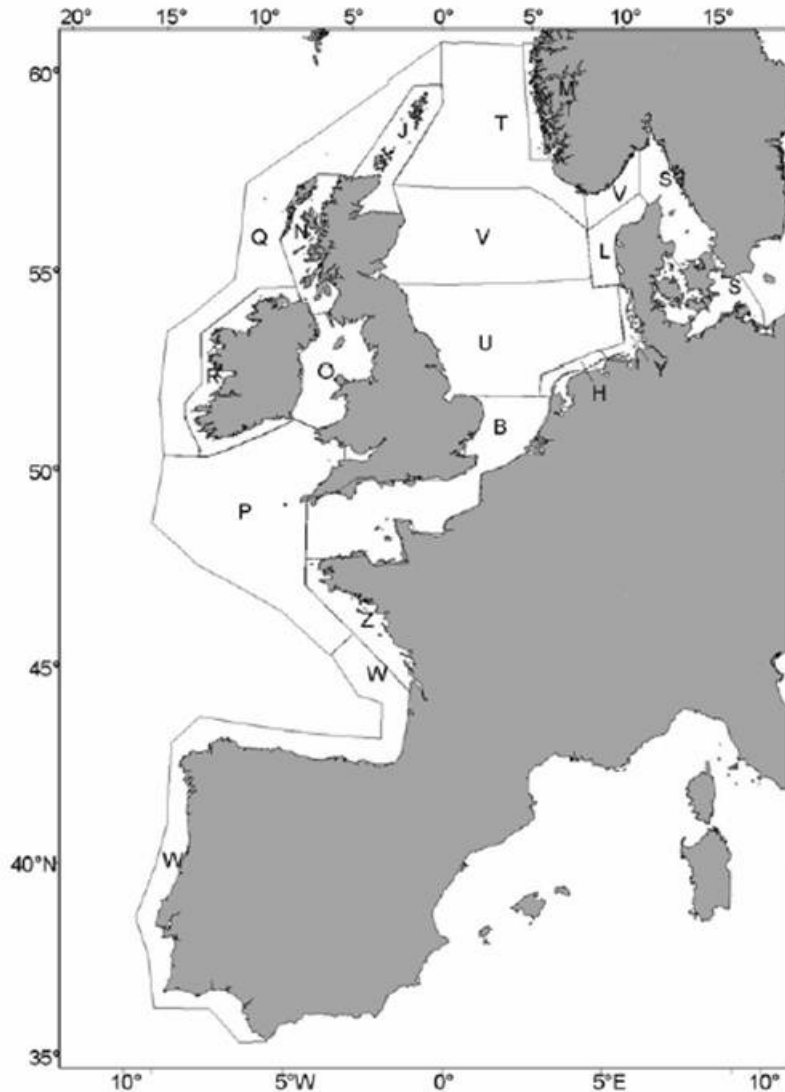


Figure 19. Survey blocks defined for the SCANS II surveys. Those surveyed by ship were S, T, V, U, Q, P and W. The remaining blocks were surveyed from aircraft (SCANS, 2008).

5.3 Modelling of harbour porpoise density distribution

For several years, data on porpoise distribution on the Dutch continental shelf has been collected during several aerial survey programs (e.g. BUWA, MWTL and IMARES, see 5.4). Although sighting conditions heavily influence the probability of detection (e.g. Teilmann, 2003), this has not been appropriately addressed in the reports describing the survey results. As a consequence, the distribution of sightings presented, may poorly represent the actual distribution of porpoises in space and time (e.g. Arts, 2010; Poot *et al.*, 2011). Therefore, before being able to draw valid biological conclusions about porpoise distribution, a first necessity is to correct the distribution of sightings for the effect of sighting conditions (Pabst *et al.*, 2006). Given the availability of the survey data and lack of other ecological data, this can be done in a model framework, in which the effect of spatial, temporal and sighting related factors are investigated simultaneously. Nevertheless, doing so is difficult due to strong correlation between covariates. For example if the survey takes place under moderate conditions in one region, and at excellent conditions in another, leading to heterogeneity in porpoise sightings, it is not possible to differentiate between a spatial and a sighting condition effect. However, when the number of surveys

increase, a more consistent relation between the number of sightings and e.g. sea state is likely to emerge. This function can then be used to correct the porpoise sightings for sea state, revealing the heterogeneity in porpoise distribution. It should be noted, that this spatial estimation can only be done if the most important variables influencing porpoise sightings are measured and included in the model.

Table 6. Abundance and densities of harbour porpoises in the Central and southern North Sea (C-Y) and adjacent waters during SCANS as estimated by Hammond *et al.* (1995) and SCANS II as estimated by SCANS (2008). Numbers in round brackets are coefficients of variation; numbers in square brackets are 95% confidence intervals. See Figure 19 for the location of the survey blocks.

SCANS 1994			SCANS II 2005		
Survey Block	Abundance (n animals)	Density (animals/km ²)	Survey Block	Abundance (n animals)	Density (animals/km ²)
C	16939 (0.18)	0.39	/*	/	/
F	92340 (0.25)	0.78	V	47181 (0.37)	
G	38616 (0.54)	0.34	U	88143 (0.25)	0.56
H	4211 (0.29)	0.10	H*	3891 (0.45)	0.36
L	11870 (0.47)	0.64	L	11575 (0.43)	0.56
Y	5912 (0.27)	0.81	Y	1473 (0.47)	0.38
Subtotal	169888			152213	NA
	[124121-232530]				
B	0		B	40927 (0.38)	0.33
A	36280 (0.57)		P*	80613 (0.50)	0.41

In this report the multi-covariate model incorporates the effect of space (x and y-coordinates), time of day, and sighting conditions (turbidity, sea state, cloud cover) on the porpoise sighting rate. Although this may improve the estimates and our understanding of porpoise distribution, a non-linear smooth of spatial coordinates is probably a rather simplistic descriptor of their actual distribution, which may be very patchy. Ultimately, the distribution of harbour porpoises is shaped by a multitude of demographic and environmental processes (Embling *et al.*, 2010; Friedlaender *et al.*, 2008 & 2009, Gilles *et al.*, 2009). Future studies should attempt to also include environmental conditions such as sediment type, depth and preferably fish distribution, and time-varying covariates such as temperature and current wind speed and direction and possibly even porpoise-related factors like behaviour and group size into the model. It should be stressed that the resulting distribution maps are a mere abstraction. The maps, however, indicate the existence of temporal and spatial high density areas, especially around the Brown Ridge, the Borkumer Reef and the Botney Cut-Dogger Bank area. The distribution in March 2011 can be compared with the distribution in March 2010 obtained by IMARES aerial surveys of area B, C and D (Scheidat *et al.*, in prep). In general the densities in offshore area B were lower, whereas the higher densities in area C and D were restricted to a smaller area than in 2011, roughly extending from IJmuiden to north of Terschelling. The overall density of 1.33 animals/km² lies in the same magnitude as the density of 1.44 animals/km² in March 2011 (see 5.4 for details).

5.4 Comparison with other Dutch surveys

The results from our surveys can be compared with the results from ship-based and aerial bird surveys in the SMW-programme by IMARES and Bureau Waardenburg respectively (Van Bemmelen *et al.*, 2011; Poot *et al.*, 2011), and with results from the aerial surveys in the long running monitoring scheme of Rijkswaterstaat under the umbrella of the Monitoring van de Waterstaatkundige Toestand des Lands programme (MWTL: e.g. Arts. 2010). All three surveys are primarily aimed at seabirds, but harbour porpoises are recorded as well. The results from the other surveys can be used to put our results in

perspective. A thorough comparison of the data lies beyond the scope of this report, but such a comparison would be useful in the future, as it can increase our understanding of the consistency of the patterns which are observed in the data, and show patterns which are only obvious when all data is combined. It could also highlight potential weak spots in each of the individual approaches.

The IMARES and BUWA surveys were conducted monthly from April 2010 till March 2011, the MWTL surveys are conducted every two months since the early nineties. The BUWA surveys were restricted to our areas C and D. The other surveys covered the whole DCS, but the ship-based surveys show large gaps in survey effort. The advantages and disadvantages of aerial surveys and ship-based surveys have been discussed elsewhere (e.g. Camphuysen & Leopold, 1994; Poot *et al.*, 2011), and conclude that diving bird species are under-recorded from an airplane. These species are supposed to have a bigger chance of being sub-merged and thus invisible for the duration an airplane passes than the duration a ship passes, leading to a higher proportion of animals missed from an airplane. This can be partly counter-acted by flying slower or flying higher than during a standard bird survey (500 ft). The minimum flight speed is restricted by the type of used airplanes. Our flight altitude was 600 ft, whereas the BUWA survey was conducted at 250 ft.

Apart from the different methods used, the survey effort and survey dates differ between all surveys (Table 7). Nevertheless, a rough comparison shows that the effort corrected numbers of observed harbour porpoises are highest during our survey in all periods, and lowest during the other aerial surveys (Table 7). The sighting conditions during the BUWA aerial surveys and the IMARES ship-based surveys in July, October and to a lesser extent November were mostly moderate to poor for detecting porpoises, and can partly explain the lower numbers in comparison with the MWTL and our surveys.

Table 7. Comparison of three surveys in the SMW-programme and the MWTL surveys. The actual sightings are presented, corrected for survey effort. March 2011 the aerial surveys by Bureau Waardenburg (BUWA) and the ship-based surveys by IMARES could not be conducted.

Period	Survey	Survey dates	Effort (km)	Sightings (n)	n/km
Jun/Jul 2010	IMARES aerial	5,6; 8-11; 18-20 Jul	6040	330	0.055
	BUWA aerial	16-19 Jul	6089	35	0.006
	IMARES ship	19-23 Jul	1246	50	0.040
	MWTL aerial	21, 23, 26 Jun	3006	71	0.024
Oct/Nov 2010	IMARES aerial	12-14 Oct; 19, 21, 24 Nov	4028	163	0.040
	BUWA aerial	11-12, 19 Oct; 26-30 Nov	12517	100	0.008
	IMARES ship	11-15 Oct; 8-10 Nov	1195	16	0.013
	MWTL aerial	26 Oct, 6, 6 Nov	2925	14	0.005
Feb/Mar 2011	IMARES aerial	18, 19, 21-27 Mar	5945	743	0.125
	MWTL aerial	28 Feb; 1, 7 Mar	4866	10	0.002

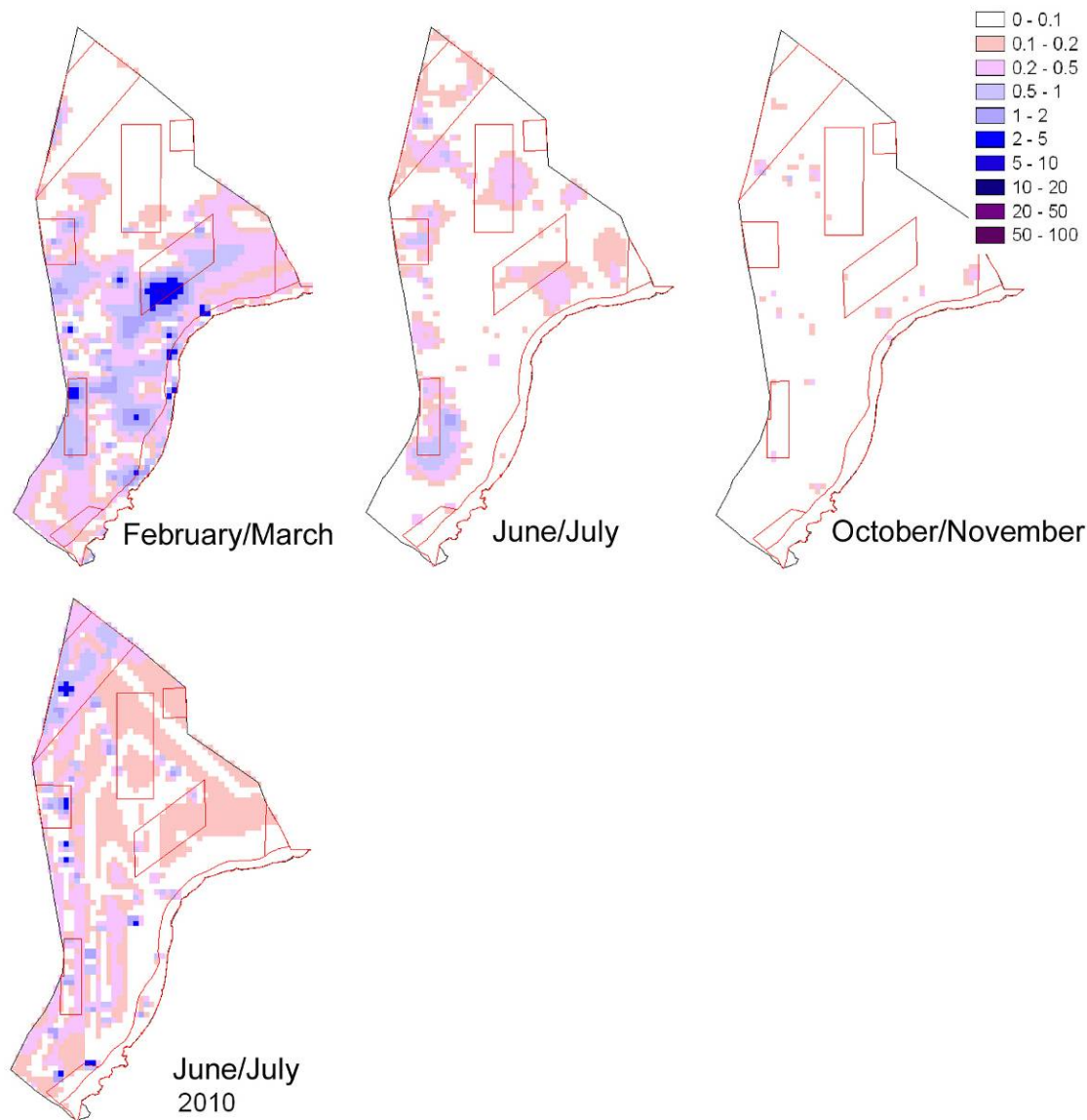


Figure 20. Average predicted density of the Harbour Porpoise (animals/km²) for two-monthly periods on the Dutch Continental Shelf. Above mean densities in 2004-2009; below density in June/July 2010. Red lines are the borders of ecological important areas (Arts, 2010).

The distribution of harbour porpoises (Figure 8-Figure 10) can be compared with the distribution as predicted based on the MWTL aerial surveys for 2005-2009 and June/July 2010 (Figure 20). The number of sightings during the MWTL surveys in July 2010 and March 2011 was too low (< 25) to model the distribution on DCS scale (Floor Arts, DPM, in lit). Although the MWTL surveys show overall lower densities, both surveys show more or less the same pattern in February/March with highest densities in area C and D, and in the south-western part of area B. Albeit the MWTL distribution in summer (June-July) shows low densities in 2005-2009, the predicted patches with the highest densities are situated around wind farm survey area W1 in D and in the western part of areas A and B. This pattern is more obvious in 2010, and resembles the distribution in Figure 8. The MWTL densities in autumn are too low to compare the distribution with our distribution map. To conclude, surveys presented in this report result in the highest –and probably most realistic– densities. As a result of the low MWTL densities distribution

patterns are difficult to compare. The distribution patterns of both survey programmes, however, do not contradict each other, and show the same broad scale patterns.

Table 8 Comparison between density and abundance estimates obtained in the same areas and months (2008 to 2011) using results from the current study as well as from Scheidat et al. (in prep).

		Density (animals/km ²)	Abundance (n animals plus C.I.)	C.V.
Area C	Nov 2008	1.02 (0.34 – 2.10)	12 227 (4038 – 25285)	0.42
	Oct/Nov 2010	0.683 (0.29 - 1.61)	8216 (3451 – 19351)	0.46
Area D	Nov/Dec 2008	1.511 (0.91 – 3.08)	31 515 (18976 – 64157)	0.32
	Oct/Nov 2010	0.398 (0.21 - 0.73)	8304 (4431 – 15296)	0.32
Area B	March 2010	0.660 (0.28 – 1.45)	11141 (4692 – 24560)	0.42
	March 2011	0.908 (0.52 - 1.79)	15331 (8795 – 30249)	0.31
Area C	March 2010	1.107 (0.48 – 2.49)	13309 (5819 – 29918)	0.44
	March 2011	2.982 (1.65 - 5.81)	35850 (19772 – 69808)	0.33
Area D	Feb/March 2009	1.468 (0.78-2.70)	30534 (16 265 – 56 161)	0.33
	March 2010	2.007 (0.82 – 4.04)	41878 (17 145 – 84 302)	0.39
	March 2011	1.174 (0.66 - 2.39)	24501 (13726 – 49833)	0.34

IMARES has been conducting aerial surveys in the period May 2008 to March 2010 in Dutch waters. These results are directly comparable to the survey results from this study as the methods are identical. From May 2008 to March 2010 10557 km were covered on effort during 16 survey days in February-May, August, November and December. Porpoise density and abundance were calculated for each sub-area and survey season (Scheidat et al. *in prep.*). Within these projects it was never possible to cover the complete DCS, but a comparison of the estimated density per sub-area is possible (Table 7). The results show that the estimates for the winter months (here combined surveys from October to December) are similar for Area C in 2008 and 2010. For area D the estimates are much higher in 2008 for Area D. One reason might be that even a difference in one month (e.g. between October and November) could make a great difference in local density due to migration. When comparing March 2010 with March 2011, densities in the offshore area B are again similar between years, whereas area C showed a distinct increase in density in 2011 and area D showed a decrease. The resulting summed abundance for areas B, C and D still results in similar numbers (66328 animals in 2010 and 75682 animals in 2011). It seems that the distribution shifted between these two years so that more animals were present in area C in 2011 than in 2010. Density in area D has been fairly stable in 2009, 2010 and 2011, all estimates lie within the confidence intervals of each other.

During the surveys May 2008 to March 2010 calf sightings were very rare (most likely due to the timing of the surveys), so a comparison with the current results is not possible at this time.

6. Conclusions

The abundance of the harbour porpoise in the DCS has greatly increased in recent years. However, due to the species' cryptic nature and wide-spread occurrence, it is extremely difficult to determine its absolute abundance and quantify its spatio-temporal distribution. By correcting for biases in the detection probability, this study provides the first estimate of the population size in Dutch waters and how it differs between three seasons. The highest numbers were observed in March 2011: approximately 86 thousand individuals were present, which comprises approximately 56% of the estimated number of porpoises being present (in summer) in the entire central and southern North Sea (SCANS, 2008). Although the harbour porpoise survey presented here, was initially intended to make population estimates, here we try to disentangle the effect of observation conditions, to estimate their distribution in space and time. The results of this exercise (Figs. 13, 15 & 17) give the best estimate of the actual distribution of porpoises that can be distilled from the data collected in this study. Furthermore, the model presented here is a first step towards understanding which covariates influence the sighting rate. In due time our insight in the behaviour and distribution of the harbour porpoise will probably improve, and as a consequence better distribution estimates may be obtained in the future.

The results show that there is a strong seasonal variation in density and that there are areas with higher density of harbour porpoises in Dutch waters. In March 2011, high densities were found in the whole DCS, except for Zeeland and in close proximity of the mainland coast. These higher density areas thus include the wind farm survey areas W1 and to a lesser extent W2. In July, high densities were found near the Brown Ridge, Botney Cut-Dogger Bank and Borkumer Reef. In October, distribution seems more spatially homogeneous. Mother-calf pairs were mostly sighted in July, around and west of the wind farm survey area W1. Since these patterns may show (large) variability, repeated surveys are deemed necessary to ascertain if the established patterns are consistent within and between years. These surveys could be primarily aimed at surveying high density areas, but repeated DCS wide surveys should provide the broad scale background information.

As porpoises are a wide ranging species, larger scale multi-season surveys in cooperation with adjacent countries such as Belgium, Germany and the United Kingdom would allow a better understanding of the movements and habitat use of porpoises in the southern North Sea. Using such data in combination with an over-arching spatial model including environmental parameters, will provide information on habitat preferences, which is necessary to develop adequate management and protection measures in relation to offshore wind farms for harbour porpoises in the future. As a first step in this process, it is also recommended to perform an in-depth comparison of the results of the different Dutch surveys which take place.

7. Quality Assurance

IMARES utilises an ISO 9001:2008 certified quality management system (certificate number: 57846-2009-AQ-NLD-RvA). This certificate is valid until 15 December 2012. The organisation has been certified since 27 February 2001. The certification was issued by DNV Certification B.V. Furthermore, the chemical laboratory of the Environmental Division has NEN-AND-ISO/IEC 17025:2005 accreditation for test laboratories with number L097. This accreditation is valid until 27 March 2013 and was first issued on 27 March 1997. Accreditation was granted by the Council for Accreditation.

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8. Glossary

Abundance	Number of animals in a given area, e.g the Dutch Continental Shelf
AIC	Akaike's Information Criterion: used for model selection
BUWA	Bureau Waardenburg; consultancy conducting aerial bird surveys for the SMW programme
C.I.	Confidence interval: indicator of reliability of an estimate
C.V.	Coefficient of variation: ratio of standard deviation and mean
DCS	Dutch Continental Shelf; part of North Sea that belongs the Netherlands
Density	Number of animals per surface area i.c. animals/km ²
DPM	Delta Project Management: employees of DPM conduct the MWTL surveys
ESW	Effective strip width: the strip along the track line in which all animals are counted
FTZ	Forschungs- und Technologiezentrum Westküste of the University of Kiel, since July 2011 Institute of Terrestrial and Aquatic Wildlife Research University of Veterinary Medicine Hannover
g(0)	Correction factor for missed animals along the surveyed track line
MUMM	Management Unit of the North Sea Mathematical Models in Belgium
MWTL	Monitoring van de Waterstaatkundige Toestand des Lands: monitoring scheme of seabirds and cetaceans in the North Sea
SCANS	Small Cetacean Abundance in the North Sea and adjacent waters: broad scale survey of cetaceans conducted in summer 1994
SCANS II	Small Cetaceans in the European Atlantic and North Sea: broad scale survey of cetaceans conducted in summer 2005
SMW	Shortlist Masterplan Wind

Appendix I

Comparison of effective strip width (ESW)

To determine if the used effective strip width (ESW) from the German surveys (Scheidat *et al.*, 2005 & 2008) is comparable with the ESW for the Dutch survey team we conducted a distance sampling analysis. We applied the hazard-rate model previously used by Hiby (1999) with the covariates sea state, turbidity, subjective conditions and observer to the Dutch porpoise sightings. The database includes all sightings from the beginning of the surveys in 2008 to May 2011.

For good and moderate conditions the sightings are plotted per distance bin perpendicular to the track line, after which a detection curve is fitted. The results for good conditions are shown in figure 1 and the resulting ESW is 206m. The results for moderate conditions are shown in figure 2 and the resulting ESW is 190m. This is very similar to the results for the German surveys, that found an ESW of 207m for good and an ESW of 193m for moderate conditions. Therefore, it is concluded that the ESW's for the German team can be applied to the Dutch data.

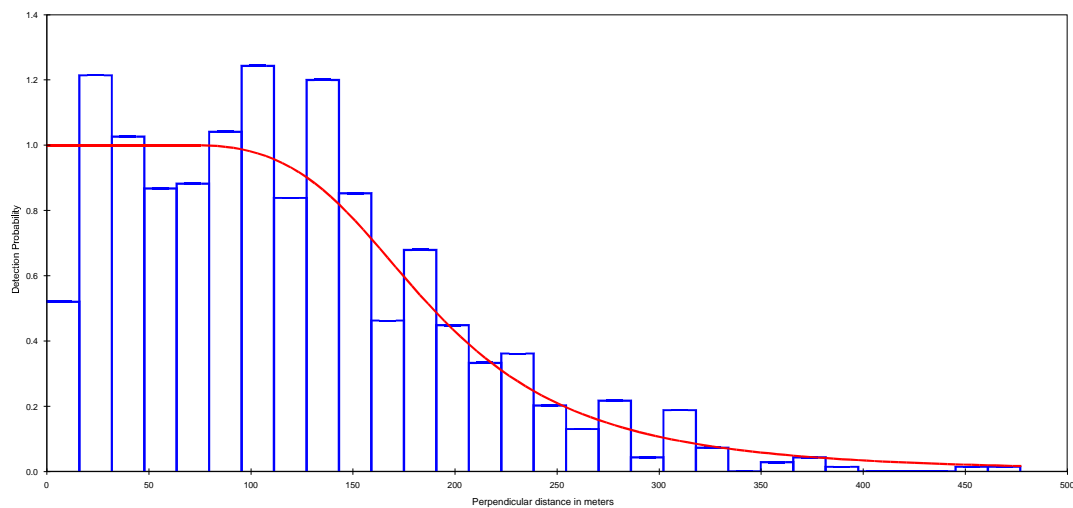


Figure 1. Distance sampling plot of the Dutch porpoise sightings under good conditions.

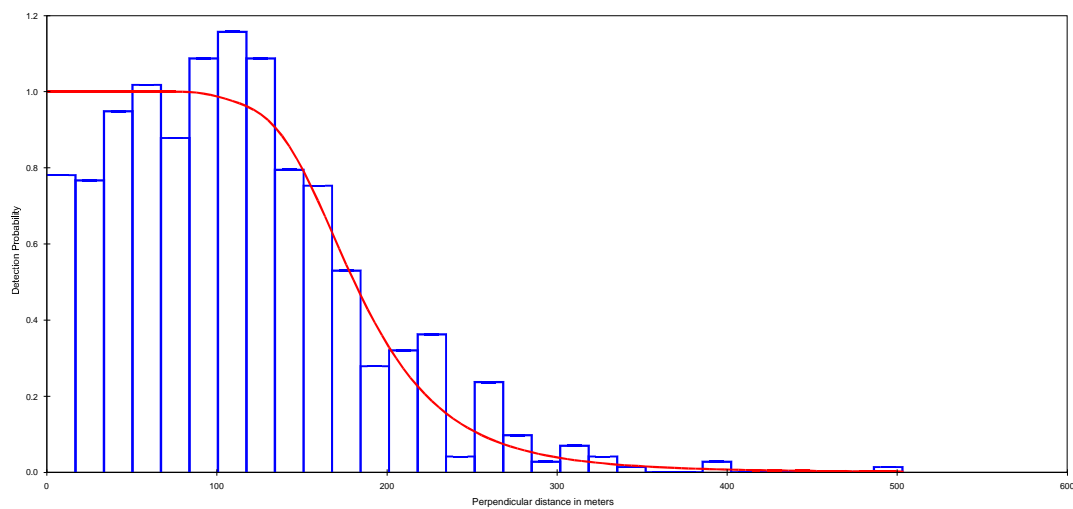


Figure 2. Distance sampling plot of the Dutch porpoise sightings under moderate conditions.

Justification

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The scientific quality of this report has been peer reviewed by a colleague scientist and the head of the department of IMARES, and two external reviewers.

Approved: Erwin Winter Researcher

Signature:



Date: 14 December 2011

Approved: Floris Groenendijk Department head

Signature:



Date: 14 December 2011