Abundance of harbour porpoises (*Phocoena phocoena*) on the Dutch Continental Shelf, aerial surveys 2012-2017

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Abstract: The harbour porpoise (*Phocoena phocoena*) is the most abundant marine mammal species in Dutch waters. Aerial surveys along predesigned track lines in 2012-2017 provided density and abundance estimates for the Dutch Continental Shelf (DCS) in spring (Mar/Apr 2012, 2013) and summer (Jul 2014, 2015, 2017). The abundance estimates in spring (*n*=63,408-66,685) were in the same order of magnitude as summer (*n*=41,299-76,773). Distribution patterns of porpoises differed between seasons and years, but a band of higher densities from the southern part of the DCS to the area north of the western Wadden Isles was visible in all seasons. Calves were only seen in July. The total abundance estimates in spring and summer correspond to a maximum of 17-21% and 7-23% of the southern North Sea population respectively, which implies that a large part of the North Sea population resides in Dutch waters during both seasons.

Keywords: abundance, aerial survey, distance sampling, distribution, harbour porpoise, Dutch Continental Shelf, North Sea, *Phocoena phocoena*, population size.

Introduction

The harbour porpoise (*Phocoena phocoena*) is the most abundant marine mammal species on the Dutch Continental Shelf. After it almost disappeared in the first half of the 20th century, the occurrence of harbour porpoises on the Dutch Continental Shelf has increased significantly in the last decades (Camphuysen 2011). This is probably a result of a southward shift in distribution as shown by a series of three large-scale dedicated cetacean surveys (SCANS, SCANS II and SCANS III) in the summers of 1994, 2005, and 2016 (Hammond et al. 2002, 2013, 2017). The reasons for this shift that occurred between the 1990s and 2000s, are not clear. Changes in prey species distribution, abundance and availability are a likely cause (Camphuysen 2004), although this remains a matter of debate (MacLeod et al. 2007).

The fore mentioned SCANS surveys resulted in abundance estimates of harbour porpoises in European shelf waters, but the survey design did not allow for national abundance estimates. Systematically collected survey data on harbour porpoise abundance and distribution in Dutch waters were virtually lacking until a decade ago. Since May 2008, dedicated aerial surveys were conducted in parts of the Dutch Continental Shelf (Scheidat et al. 2012). In 2010-2011 dedicated surveys of the entire Dutch Continental Shelf were conducted for the first time, in three different seasons (Geelhoed et al. 2013). Since then, surveys have been undertaken almost annually in spring or in summer, and once in autumn.

The objective of this paper is to present the distribution, density and abundance of the harbour porpoise on the entire Dutch Continental Shelf resulting from dedicated aerial surveys conducted in 2012-2017.

Methods

Study area, survey design and data acquisition

Aerial line transect surveys were conducted on the Dutch Continental Shelf, which was divided into four areas (figure 1): A (Dogger Bank; 9615 km²), B (Offshore; 16,892 km²), C (Frisian Front; 12,023 km²) and D (Delta; 20,797 km²). The areas were surveyed by aircraft along predesigned track lines ensuring equal coverage probability. The design of the track lines was parallel in 'near shore' areas C and D and zigzag in offshore areas A and B (figure 1). Two sets of track lines were designed per area. Surveying one set allows for a robust abundance estimate. The direction of transects in areas C and D followed depth gradients in order to minimise potential variance in encounter rate within transect lines caused by depth (Buckland et al. 2001). The zigzag design of the offshore areas aimed at maximising the endurance of the plane and cover as large an area as possible.

The surveys were conducted using distance sampling methodology (Buckland et al. 2001, Buckland et al. 2004). Surveys were conducted by a team of three people, using a high-winged twin-engine airplane, the *Partenavia 68*, equipped with so-called bubble windows (allowing observations directly under the plane). The plane flew at an altitude of 183 m (600 feet) with a speed of ca. 186 km.h^{-1} (ca. 100 knots). Every four seconds, time and the aircraft's position were recorded automatically onto a Toughbook laptop connected to a GPS. Details on environmental conditions were entered in a database by the so-called navigator at the beginning of each transect and whenever conditions changed. Observations were made by two dedicated observers each seated at the bubble windows on the left and right side of the aircraft. For each observation, the observers acquired data that were entered in real time into a database by the navigator using VOR-software. Observation data included species (all cetaceans and seals), declination angle measured with an inclinometer from the aircraft abeam to the individual or group, group size, presence of calves, behaviour, swimming direction relative to the transect, detection cue, whether the individual or group was above or below the sea surface when abeam, and reaction to the survey plane. Environmental data included sea state (Beaufort scale), turbidity (assessed by visibility of objects below the sea surface), cloud cover (in octaves), glare (observation area covered and strength) and subjec-

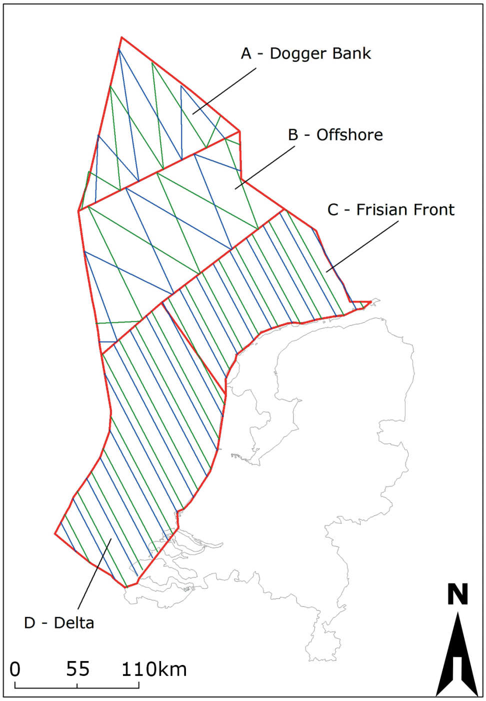

Figure 1. Map of the Dutch Continental Shelf with the planned track lines in study areas A - Dogger Bank, B - Offshore, C - Frisian Front and D - Delta. Colours indicate sets of track lines.

tive sighting conditions. These sighting conditions represent each observer's subjective view of the likelihood that the observer would see a harbour porpoise within the search area should one be present. These conditions could be good, moderate or poor. Furthermore, a category X "not possible to observe" is used. Sighting conditions could differ between the left and right side of the plane.

Surveys were undertaken in weather conditions safe for flying operations (no fog or rain, no chance of freezing rain, visibility >3 km) and suitable for porpoise surveys (sea state ≤3 Beaufort).

Data analysis

The survey data were collected using distance sampling techniques (Buckland et al. 2001, Buckland et al. 2004). The collected sightings and effort were used to calculate densities and abundance estimates, and to produce distribution maps. Line-transect distance sampling allows for obtaining estimates of absolute densities, i.e. the number of animals/km² with the associated 95% confidence interval (CI) and coefficient of variation (CV; Buckland et al. 2001). Animal abundance in each stratum v (i.e. area A, B, C and D) was estimated using a Horvitz-Thompson-like estimator (Buckland et al. 2001, Buckland et al. 2004) as follows:

$$\hat{N}_v = \frac{A_v}{L_v}\left(\frac{n_{\mathrm{gs}v}}{\hat{\mu}_{\mathrm{g}}} + \frac{n_{\mathrm{ms}v}}{\hat{\mu}_{\mathrm{m}}}\right)\bar{s}_v$$

where Av 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, $\hat{\mu}_{\mathrm{g}}$ is the estimated total effective strip width (ESW) in good conditions, $\hat{\mu}_{\mathrm{m}}$ is the estimated total effective strip width in moderate conditions and $\bar{s}_v$ is the mean observed school size in the stratum.

The effective strip width is the distance at which the number of animals detected outside the strip width equals the number of animals missed inside the strip width. The ESW is corrected for the proportion of animals missed on the track line by a factor called g(0). For the current surveys, the g(0) values obtained in a similar German study (Scheidat et al. 2008) were applied. These g(0) values are 0.37 for good conditions and 0.14 for moderate conditions, resulting in effective strip widths of 153 m and 54 m, respectively.

Group abundance by stratum (areas A, B, C and D) was estimated by:

$$\hat{N}_{v(\mathrm{group})} = \hat{N}_v / \bar{s}_v .$$

Total animal and group abundances of the entire study area were estimated by

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

respectively. Densities were estimated by dividing the abundance estimates by the area of the associated stratum. Average group size across strata was estimated by

$$\hat{E}[s] = \hat{N} / \hat{N}_{(\mathrm{group})} .$$

Coefficients of variation (CV) and 95% confidence intervals (CI) were estimated by a non-parametric bootstrap (999 replicates) within strata, using transect segments as the sampling units. The variance due to estimation of ESW was incorporated using a parametric bootstrap procedure assuming the ESW estimates to be normally distributed random variables. More details on this method can be found in Scheidat et al. (2008, 2012).

Distribution maps

The distribution of harbour porpoises is shown as densities represented spatially on a 1/9 ICES grid. This grid has latitudinal rows at intervals of 10' and longitudinal columns

Table 1. Total survey days, effort (surveyed distance), sighting conditions (g – good, m – moderate, p – poor, x – not possible to observe) and harbour porpoise sightings during the aerial surveys. Calves are included in the number of individuals. Navigator sightings are excluded.

Survey	Effort (km)	Sighting conditions (%)			Harbour Porpoise sightings (*n*)		
		g	m	p/x	Sightings	Individuals	Calves
Mar 2013 (18, 19, 21)	950	20.9	69.7	9.4	76	87	-
Apr 2013 (6, 7, 21, 22)	2496	10.2	70.1	19.7	121	136	-
Mar 2012 (6, 13-15, 17)	3666	25.3	70.2	4.5	232	285	-
Jul 2017 (7-10, 17, 18)	2362	18.9	61.6	19.5	230	299	21
Jul 2015 (13-16, 20)	2333	0.7	95.2	3.9	144	172	13
Jul 2014 (11-13, 15, 16)	2791	20.0	72.7	7.3	229	273	20
Nov 2012 (14, 16, 18)	1157	0	82.9	17.1	28	35	-
Total	15,755	15.2	74.0	10.8	1060	1287	54

at intervals of 20’. Within the DCS, this corresponds to approximately 20x20 km grid cells, with areas ranging from 388 to 409 km^2. 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 effective strip width (ESW). Grid cells with low effort, such as grid cells extending outside the borders of the surveyed area, tend to be less reliable. Therefore, grid cells with an effort less than one km^2 were omitted from the maps (but the estimated numbers in these grid cells were used for the abundance estimates).

Results

Effort and sightings of harbour porpoises

Surveys were conducted in spring (2012, 2013), summer (2014, 2015, 2017) and autumn (2012), with a total of 15,755 km on effort (table 1). The spring surveys had the best coverage with 7122 km on effort. During both spring surveys, some track lines could be surveyed twice to ensure they were flown in moderate or good conditions. Even though yearly effort was lower in summer (7486 km), one set of track lines in areas A-D could be surveyed during the three survey periods. The survey effort in autumn 2012 was very low (1157 km), and apart from a complete set of track lines in area C – Frisian Front, only a proportion of the track lines in areas A-B and no track lines in area D – Delta could be surveyed. The coverage of the DCS and the number of sightings in autumn 2012 were too low to warrant sensible densities and abundance estimates.

In total, 1060 sightings of 1287 harbour porpoises were collected. Average group size for all surveys combined was 1.21 animals. Average group size was 1.18 (CV 0.36) animals in spring, and 1.25 (CV 0.51) animals in summer and autumn. The largest group size was a pod of eight animals in July. In all seasons over 80% of the sightings consisted of single animals. Calves were sighted during the summer surveys only (n=54), comprising 7.3% of the sighted individuals (n=744). The group size for sightings in July without calves was 1.14 animals.

Density and abundance of harbour porpoises

Tables 2 and 3 give an overview of density (animals/km^2) as well as abundance (number of animals) per survey area and survey period.

The overall DCS density in summer ranged from 0.70 to 1.29 animals/km^2 annually. Den-

Table 2. Density and abundance estimates and the associated 95% confidence intervals (CI) and coefficients of variation (CV) of Harbour Porpoises obtained in spring 2012 and 2013.

March-April 2013	Density (animals/km^2)	C95% CI	Abundance (*n* animals)	95% CI	CV
Area A – Dogger Bank	0.47	0.18-1.20	4492	1768–11,505	0.49
Area B – Offshore	1.44	0.47–3.48	24,268	7856–58,820	0.51
Area C – Frisian Front	0.59	0.31-1.24	7046	3663–14,907	0.36
Area D - Delta	1.32	0.66–2.83	27,602	13,815-58,987	0.36
Total DCS	1.07	0.55–2.17	63,408	32,478–128,588	0.35
March 2012					
Area A – Dogger Bank	1.44	0.69-2.72	13,860	6601-26,156	0.36
Area B – Offshore	0.70	0.25-1.51	11,877	4285-25,557	0.42
Area C – Frisian Front	0.94	0.33-2.09	11,252	4023–25,079	0.48
Area D - Delta	1.42	0.77-2.91	29,696	15,992–60,810	0.35
Total DCS	1.12	0.63-2.20	66,685	37,284-130,549	0.33

Table 3. Density and abundance estimates and the associated 95% confidence intervals (CI) and coefficients of variation (CV) of harbour porpoises obtained in summer 2014, 2015 and 2017.

July 2017	Density (animals/km^2)	C95% CI	Abundance (n animals)	95% CI	CV
Area A – Dogger Bank	0.14	0.01-0.29	1325	167–2833	0.46
Area B – Offshore	1.28	0.55-2.92	21,584	9229–49,331	0.44
Area C – Frisian Front	0.53	0.08-1.53	6360	991-18,402	0.64
Area D - Delta	0.85	0.41-1.66	17,631	8595–34,552	0.37
Total DCS	0.79	0.41–1.86	46,902	24,389–93,532	0.35
July 2015					
Area A – Dogger Bank	1.12	0.43-2.25	10,748	4113–21,676	0.39
Area B – Offshore	0.80	0.17-1.20	13,573	7 002–26,606	0.35
Area C – Frisian Front	0.44	0.20-0.98	5304	2354-11,798	0.43
Area D - Delta	0.56	0.41-1.58	11,674	3542-24,958	0.45
Total DCS	0.70	0.36-1.34	41,299	21,194-79,256	0.33
July 2014					
Area A – Dogger Bank	3.08	1.50-6.45	29,689	14,375–61,995	0.37
Area B – Offshore	0.37	0.00–1.21	6297	0–20,509	0.96
Area C – Frisian Front	1.83	0.97–4.11	22,010	11,623–49,439	0.39
Area D - Delta	0.90	9.46–1.84	18,778	9548–38,167	0.36
Total DCS	1.29	0.73–2.60	76,773	43,414-154,265	0.34

sities per area showed more variation, ranging from 0.14 to 3.08 animals/km^2. The overall DCS density in spring ranged 1.07-1.12 animals/km^2. For the areas A-D, the lowest density was 0.47 and the highest density 1.44 animals/km^2.

Absolute abundance of harbour porpoises on the Dutch Continental Shelf in summer was estimated at a minimum of 41,299 (CI: 21,194-79,256) in 2015 and a maximum of 76,773 (CI: 43,141–154,265) in 2014. The abundance estimate in 2017 numbered 46,902 (CI: 21,194-79,256) animals. The abundance estimate in March comprised 63,408 (CI: 34,478-128,588)

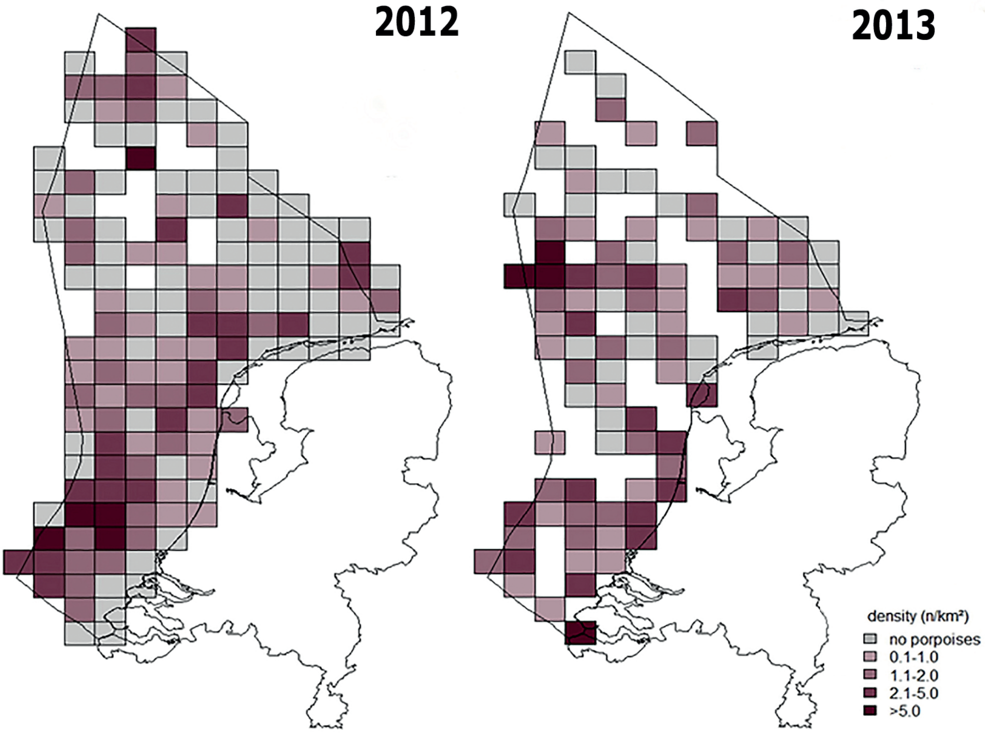

Figure 2. Density distribution of harbour porpoises (animals/km^2) per 1/9 ICES grid cell, spring 2012 and 2013. Grid cells with low effort (<1 km^2) are omitted.

and 66,685 animals (CI: 37,284-130,549) in 2013 and 2012 respectively (tables 2 and 3).

Distribution of harbour porpoises

Figures 2-3 show densities of porpoises (animals/km^2) per 1/9 ICES grid cell. In spring, the distribution (figure 2) was homogeneous in the southern part of the DCS, from area D – Delta extending north of the Wadden Isles in area C – Frisian Front and B – offshore. In the eastern part of the latter areas, and further north in area A – Dogger Bank, the distribution was more heterogeneous, with low densities in bigger areas, especially in 2012. The summer distribution (figure 3) showed a consistent broad band of high(er) densities from area D – Delta to area C – Frisian Front north of the Wadden Isles in all three summers. In 2014, and to a lesser extent in 2015, this band of high densities continued to the German border in areas B – offshore and C – Frisian Front, whereas this area contained virtually no porpoises in 2017. In 2015 and 2017, high densities were present in large areas of area B – offshore, whereas densities in area A – Dogger Bank were lower. In 2014, however, densities in this area were the highest ever recorded.

Discussion

The results show distinct differences in densities, abundance and distribution of harbour porpoises between surveys. The summer densities for the years 2014-2017 varied between 0.14-3.08 animals/km^2 in the areas A-D, highlighting that the density between the sub-

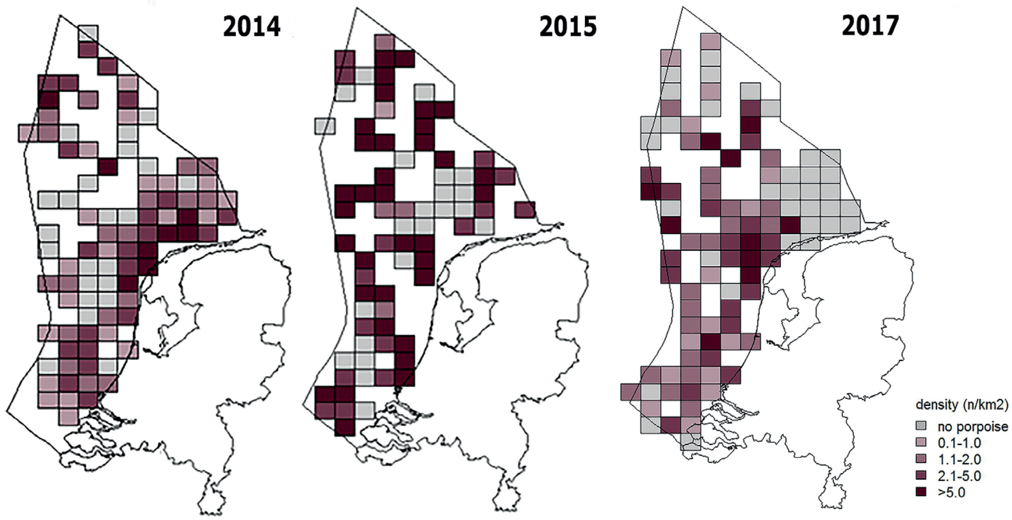

Figure 3. Density distribution of Harbour Porpoises (animals/km^2) per 1/9 ICES grid cell, summer 2014, 2015 and 2017. Grid cells with low effort (<1 km^2) are omitted.

areas is highly variable. The spring densities in 2012-2013 showed less variation (0.47-1.44 animals/km^2), and fell within the range of the 2011 spring survey. In March 2011, the estimated densities of harbour porpoises on the Dutch Continental Shelf ranged from 0.90–2.98 animals/km^2, whereas the densities in summer 2010 ranged from 0.34–0.48 animals/km^2 (Geelhoed et al. 2013).

Based on the results of (aerial) surveys in Belgium, the Netherlands, Germany, Denmark, and the entire North Sea and the wider Dogger Bank region, Gilles et al. (2016) calculated an average density of 0.88 and 0.91 animals/km^2 in spring and summer, 2005-2013 respectively.

Despite inter-annual differences in abundance estimates for the DCS, the spring and summer numbers in 2012-2017 were of the same order of magnitude, whereas the numbers in spring 2010-2011 were three times as high as the numbers in summer and autumn (Geelhoed et al. 2013). The 2012-2017 spring and summer numbers are consistent with North Sea wide model-based abundance estimates, using SCANS II data and national surveys 2005-2013. These spring (n=372,167; CI: 260,658-531,380) and summer (n=361,000; CI: 243,827-534,913) estimates were similar, whereas the abundance estimate in autumn (n=228,913; CI: 159,264-329,022) was lower (Gilles et al. 2016).

Harbour porpoise in the Atlantic can be divided into several populations or management units (MUs). Evans et al. (2009) assessed these for the north-eastern Atlantic, and concluded that the North Sea should be divided into two MUs along an arbitrary line running NNW–SSE from northern Scotland to Germany-Denmark. The 'Dutch porpoises' would belong to the MU south of this line: the south-western North Sea and the eastern Channel MU. The boundaries of this MU are not well defined and an abundance estimate for this MU is lacking.

The wider North Sea, however, was surveyed during the summers of 2005 and 2016 (SCANS-II and SCANS-III), resulting in abundance estimates of 355,000 (CV 0.22) or 345,000 (CV 0.18) individuals respectively (using effective strip widths of 138 m for good conditions and 109 m for moderate conditions Hammond et al. 2017, revised from Hammond et al. 2013). Using EWS's of 170 m for good conditions, and 67 m for moderate conditions, Gilles et al. (2016) estimated the population size as numbering 361,000 individuals in summer 2005-2013. Smaller EWS's result in relatively high abundance estimates. With this in mind, however, these estimates indicate that a maximum of 7-21% of the North Sea population can be present on the Dutch Continental Shelf in summer (this study, and Geelhoed et al. 2013). In spring, the population size in the North Sea is estimated at 372,000 animals (Gilles et al. 2016). This corresponds to a proportion of at maximum 17-23% on the Dutch Continental Shelf (this study, and Geelhoed et al. 2013). At least part of the year, a substantial proportion of the porpoise population in the southern North Sea and the eastern Channel utilises the Dutch Continental Shelf.

Conclusions

By correcting for biases in the detection probability, aerial surveys provided un-biased abundance estimates of harbour porpoises on the Dutch Continental Shelf in spring and summer, 2012-2017. The results show that there is a strong seasonal and annual variation in density and abundance. In 2010-2011, the spring densities of porpoises were threefold higher than in summer. The recent results show that the summer occurrence of porpoises on the Dutch Continental Shelf increased and densities are now in the same order of magnitude as in spring. This higher number of porpoises, as well as the regular presence of mother-calf pairs, confirms that the Dutch Continental Shelf is of growing importance for porpoise reproduction.

Although the abundance estimates may show (large) variability, at least in spring and summer, a substantial proportion of the harbour porpoise population in the southern North Sea and the eastern Channel utilises the Dutch Continental Shelf. This emphasises the importance to fulfil requirements of the EU Habitats Directive and the EU Marine Strategy Framework Directive, to achieve and maintain a favourable conservation status for the harbour porpoise in Dutch waters. As recommended in the Dutch Harbour Porpoise Conservation Plan (Camphuysen & Siemensma 2011), repeated aerial surveys of the Dutch Continental Shelf have been conducted, providing information to assess trends and seasonal distribution patterns of harbour porpoises. However, as 'Dutch' porpoises belong to the southern North Sea and the eastern Channel population, transboundary surveys with larger spatial coverage should be conducted on a regular basis as well. A combination of six-yearly North Sea wide SCANS-type surveys and more frequent (national) smaller scale surveys would fulfil the fore mentioned requirements. Using such data in combination with a model based approach (e.g. Gilles et al. 2016) would allow predictions on how anthropogenic activities impact porpoises. This information is necessary to develop and implement management and protection measures in relation to anthropogenic activities for harbour porpoises in the North Sea.

Acknowledgements: First of all, we would like to thank the pilots from Ravenair, Sylt Air and ZeelandAir for safe and professional flying, and the observers Geert Aarts, Martin Baptist, Rob van Bemmelen, Nicole Janinhoff, Sander Lagerveld, Linn Lehnert, Klaus Lucke, Hans Verdaat, and Richard Witte for their survey effort. Geert, Rob and Sander were instrumental in the analyses of the data. These surveys were conducted under the umbrella of the Shortlist Masterplan Wind programme commissioned by Rijkswaterstaat Waterdienst (2010-2011), the BO-programme commissioned by the Ministry of Economic Affairs (2006-2009, 2012-2015), and the KRM monitoring programme commissioned by the Ministry of Economic Affairs and Rijkswaterstaat Waterdienst.

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Samenvatting

Het voorkomen van bruinvissen (*Phocoena phocoena*) op het Nederlands Continentaal Plat: vliegtuigtellingen in de jaren 2012-2017

De bruinvis (*Phocoena phocoena*) is de algemeenste zeezoogdiersoort in Nederlandse wateren. In voorjaar, zomer en najaar 2012-2017 werden vliegtuigtellingen langs vooraf ontworpen *track lines* uitgevoerd op het Nederlands Continentaal Plat (NCP). Met deze gegevens was het mogelijk dichtheden en aantalsschattingen van bruinvissen op het

NCP te berekenen voor voorjaar en zomer. Het was niet mogelijk om dichtheden en aantalsschattingen voor het najaar te berekenen. De aantallen in het voorjaar (n=63.408-66.685) lagen in de zelfde ordegrootte als in de zomer (n=41.299-76.773). Het verspreidingspatroon verschilde per telperiode, maar gedurende alle telperioden was een strook met hogere dichtheden aanwezig van het zuidelijk deel van het NCP tot een gebied ten noorden van de westelijke Waddeneilanden. In juli werden kalfjes gezien, hetgeen een bevestiging vormt dat bruinvissen zich regelmatig in Nederlandse wateren voortplanten. De aantalsschattingen voor het voorjaar en de zomer corresponderen met respectievelijk maximaal 17-21% en 7-23% van de populatie in de zuidelijke Noordzee; een groot deel van de Noordzeepopulatie verblijft in die periode in Nederlandse wateren.

Received: 8 April 2018
Accepted: 15 August 2018