SC/66a/RMP/8

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INTERNATIONAL WHALING COMMISSION

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ABSTRACT

An estimate of abundance of common minke whales in the northeast Atlantic based on data collected over the period 2008-2013 is presented. The abundance estimate for the total covered area has decreased by 7 % compared to the two preceding survey periods, i.e. from about 108,000 to about 101,000 minke whales. The decrease is attributed to a considerable change within the Small Management Area CM with an estimate now being 40 % of those from the 1996-2001 and 2002-2007 survey cycles. Within the Eastern Medium Area, the recent estimate is 10 % higher than in the previous two cycles, i.e. about 90,000 animals. However, within this region there are signs of a north- and eastwards distributional shift from the Norwegian Sea towards the Svalbard area and the Barents Sea.

MINKE WHALES, NORTH ATLANTIC, ABUNDANCE ESTIMATE, VESSEL SURVEY

INTRODUCTION

Common minke whales (*Balaenoptera acutorostrata acutorostrata*) are widely distributed throughout the North Atlantic. They are especially associated with continental shelf structures and their slopes. They are thought to undergo an annual cycle which includes feeding migrations in summer to higher latitudes and an assumed winter stay in warmer waters where mating and calving take place. From 1920 onwards Norwegian small-type whaling with minke whales as the main target species developed. It started as an operation in Norwegian coastal waters but later expanded to wide areas in the northeast Atlantic. After a five-year break in the minke whaling, initiated by uncertainty about the status of minke whales in the Northeast Atlantic, whaling was reopened in 1993 under regulation by the Revised Management Procedure developed by the IWC Scientific Committee. This management regime requires abundance estimates on a regular basis, and thus sightings surveys have been established and conducted in recent years to collect data for such estimation. Results from surveys in 1988 and 1989 combined and from a survey in 1995 were presented in Schweder et al. (1997). After 1995, annual partial surveys have been conducted that over a six-year period provide data for estimating total abundance in the northeast Atlantic (Skaug et al. 2004, Bøthun et al. 2009). Here we present an estimate of minke whale abundance in the northeast Atlantic based on data collected over the years 2008-2013. The total abundance over the surveyed area is 100,615 minke whales with a coefficient of variation c.v. = 0.11 or c.v = 0.17 when additional variance due to the multi-year survey design is accounted for.

MATERIAL AND METHODS

Data collection 2008-2013

Over the period 2008-2013 annual surveys (except for 2012) were conducted that covered the Northeast Atlantic from the North Sea (southern boundary 52ºN) to the ice edge, and from the Greenland Sea in the west to the Barents Sea in the east (Figure 1). When the survey plans 2008-2013 were presented in 2008 (Øien and Bøthun 2008), we suggested to preferably cover one *Small Management Area* (as implemented in Berlin 2003 (IWC 2004)) during one year's survey as the basic approach. In 2008 the survey cycle started by covering the Svalbard area (*Small Management Area* ES); in 2009 the North Sea area of the *Small Management Area* EN was covered; in 2010 the areas around Jan Mayen, the *Small Management Area* CM, was covered; in 2011 the eastern Norwegian Sea, the *Small Management Area* EW, was covered, and finally, in 2013, the *Small Management Area* EB was covered and fulfilled the mosaic coverage. The stratum structure was redesigned for this survey cycle since the block structure used in earlier surveys had been fragmented through redefinitions of *Small Management Area* boundaries (Bøthun et al. 2009), see Figure 1.

Whales were searched by naked eye from two platforms each manned with two observers. The platforms were designed to be independent by being visually and audibly separated. The upper platform, referred to as platform A, was typically a barrel on the mast and the lower platform, platform B, was an arrangement on the wheelhouse roof. Usually the two platforms were approximately above each other; otherwise the barrel was in a stern mast. The observers worked in teams of two on two-hour shifts and there were four teams on each vessel.

The survey and sightings protocols are detailed in Øien (1995). The main points in the procedures were: Primary searching speed was intended to be 10 knots and the surveys were conducted in passing mode. When searching, one of the observers in the team was instructed to scan the port 45º sector from the transect line while the other was to scan the starboard 45º sector. Sightings were made outside these sectors and all initial sightings before abeam have been used in the analyses. Acceptable conditions for primary searching were defined as meteorological visibility greater than 1 km and Beaufort sea state of 4 or less.

Each observer was equipped with a microphone with a push button. All microphones and buttons were connected to a central computer also equipped with a GPS unit. Time delay due to software and hardware is expected to be less than one second for initial sightings and for resightings there is no time delay. For each sighting, species, radial distance as estimated by eye, angle from the transect line as read from an angle board, school size and swimming direction were reported. If the species was assumed to be a minke whale, specific tracking procedures were followed, as the observer then tried to follow the whale and report the positional data (radial distance, angle) of all its surfacings until the whale passed, or was assumed to have passed, behind abeam. All sightings and resightings received a time and position stamp from the GPS unit. For the minke whale analyses presented here, the units of observation are the tracks of observed surfacings.

The selection criteria for sightings used in the analyses are that they have been recorded from platform A or B when in primary search mode, the species has been confirmed and the initial sighting has been done before abeam. In addition, sightings have been truncated by confining radial distance $r \in [100m, 2000m]$.

Data on weather conditions, Beaufort sea state, sightability and glare were recorded regularly on an hourly basis and then additionally when conditions had changed notably. After some exploration, certain levels of these covariates were combined (Table 1). As in previous applications, individual observers were grouped into three categories according to their ability to detect whales at long distances, based on a general impression by team leaders. From this list, all combinations of observers were classified as either *long* or *short* according to their presumed ability to detect minke whales at long distance.

Abundance estimation

The basic observational units, the minke whale tracks, from the two platforms A and B were compared for matching by an automatic routine (duplicate identification rule) that has as its criterion difference in timing, bearing and radial distances (Schweder et al. 1997, Skaug et al. 2004, Bøthun & Skaug 2009). Before the matching, missing values of radial distance and and/or angle are imputed by interpolation between adjacent surfacings and taking into consideration the movement of the vessel. An initial sighting has three possible outcomes which are: seen by either platform or by both simultaneously. If one platform detects the whale before the other platform, it sets up Bernoulli trials where the outcome is seen or not seen by the other platform.

A hazard probability model is developed as described in Skaug et al. (2004), where parameters are estimated by maximizing the likelihood based on the observed data. The simulation part of the earlier estimation processes (Skaug et al. 2004, Bøthun et al. 2009) which took care of bias correction for measurement errors, duplicate identification errors, clustering and other factors have not been performed on the present data. Instead other approaches have been chosen. After investigating measurement errors from the experiments during the 2008-2013 survey cycle (Solvang et al. 2015) we decided to use the recorded data uncorrected. Clustering has been taken care of through the variance estimation process (Skaug & Solvang 2015).

For the chosen covariate model, the parameter estimates were used for calculating the effective strip half widths w_A and w_B. These are in turn used to obtain an abundance estimate (by survey block)

$$N = \frac{n_A + n_B}{2(w_A + w_B)L} Area$$

where n_A and n_B are the total number of sighted whales from platforms A and B, L is the realized transect length, and *Area* is the area of the survey block.

The quantities w_A and w_B are obtained from the fitted hazard probability model, which is parameterized using a GLM approach as follows (see Skaug et al. 2004 for details): The radial distance at which the hazard probability has dropped by 50% is $\exp(\eta_r)$, where η_r is a linear predictor. The linear predictor consists of the intercept β_r and covariate effects. Similarly, there is a linear predictor associated with the effect of sighting angle (inctercept β_θ). The hazard probability at the origin ($r = 0$) is parameterized as $\mu = [1+\exp(-\beta_\mu)]^{-1}$.

The hazard probability model involves one additional parameter, the surfacing rate intensity α, which is determined from external data. For that purpose we used dive time data collected by radio-tagging of 20 minke whales (Øien et al. 2009) over the period 2001-2008. The mean surfacing rate α was estimated from those data, and where sea state information was available, truncated for Beaufort > 4. The estimate is 45.78 blows/hour, which gives the parameter α = 0.0127.

The variance of the abundance estimates have been calculated using a new approach (Skaug & Solvang 2015). The inter-annual variation in spatial distribution (additional variance) of the minke whales has been included as in earlier estimates (Skaug et al. 2004, Skaug & Solvang 2015).

RESULTS AND DISCUSSION

Over the survey period 2008-2013 a total effort of 24 190 km was conducted (Table 2, Figure 1). The total survey area was 3,352,868 km^2. One of the planned survey blocks was not covered due to scarcity of ship time: EW4 within the EW SMA.

A total of 779 sightings of groups (sum platform A and B) were made during primary search effort. They were distributed all over the survey areas although at varying densities (Figure 1). Characteristics of the collected distance data are shown in Figure 2. The diagnostic plots show a good relationship between distributions and model predictions. For example the sighting angle distribution qualitatively shows a good agreement with the instructed sighting behavior of primarily covering the 45° sector from the trackline. As is seen, most sightings were made within a 1000 m strip on each side of the transect line. In Figure 3 the estimated success probabilities by radial distance for the Bernoulli trials are shown.

Table 1 describes the covariates collected during the surveys and how they have been aggregated for the analyses. The results for a selection of covariate models are shown in Table 3. Based on these results the model with linear predictor η_r = B + W + Vi + P + G + T was chosen to be used for the abundance estimation. Abundance estimates are given by survey block in Table 2. Estimates for the IWC Small Management Areas were calculated by combining the contributions from the appropriate survey blocks (Table 4). The total estimate for the survey area is 100 615, with a cv corrected for the multiyear survey pattern equal to 0.17. The estimate for the Eastern North Atlantic Medium Area in the RMP terminology is 89 623 with an additional variance corrected cv = 0.18.

In previous analyses, a simulation approach was used to correct bias. However, this correction procedure has had a modest impact on the input estimates based on the survey cycles 1996-2001 and 2002-2008; -2.5 % and -3.7 %, respectively. The demanding bias correction procedure has therefore been substituted by other approaches. Firstly, measurement error has not been included in the estimations. The reason for this is that the preanalysis of the experimental data (Solvang et al. 2015) showed that the abundance estimates taking into account the measurement error are larger than the abundance estimates calculated without any measurement error correction. Secondly, the Neyman-Scott process used previously to account for clumping of animals has been replaced by the Markov modulated Poisson process to estimate variance in whale counts on individual transect legs (Skaug & Solvang 2015). This approach has been applied to the 1996-2001 survey cycle to validate it towards the simulation method. The outcomes have been discussed in Skaug & Solvang (2015). It has also been shown in two different studies that ignoring animal clustering leads to an upwards bias in the effective strip half width, and hence a negative bias in the abundance estimate. The first of these studies (Langrock, Borchers et al. (2013), Table 2) used only single platform data, while the second (Skaug, Schweder et al. (2009), Table 3, Model 2).

The point estimates of total abundance in the ***Eastern Medium Area*** are very similar over the survey periods 1996-2001, 2002-2007 and 2008-2013. There has, however, been a considerable decrease to about 40 % of previously estimated numbers in the *Small Management Area* CM. The significance of this decrease is uncertain. However, this observation may have some connection to the large decrease in abundance of minke whales on the shelves off Iceland (*SMA* CIC). Within the eastern Medium Area the point estimates indicate an east- and northward shift in distribution from the Norwegian Sea area (EW) to Svalbard (ES) and the eastern Barents Sea (EB). The high estimates of the additional variance also reflect the possibility of large year-to-year shifts. Such shifts in overall distributions are well known and discussed from long-term series of catch statistics (Øien et al. 1987, Skaug et al. 2004).

CONCLUSION

The point estimate for the total area has decreased (however, not significantly) compared to the two preceding survey periods. The decrease seems to have occurred within the Small Management Area CM (the Jan Mayen area, part of the C region), with an estimate being 40 % of those from the 1996-2001 and 2002-2007 cycles. This may have some unrevealed connection to the recent observed drop in minke whale abundance in the coastal waters of Iceland. Within the E region, the point estimate is a bit higher than in the previous two cycles. However, there are signs of a north- and eastwards distributional shift within this region from the Norwegian Sea to the Svalbard area and the Barents Sea.

ACKNOWLEDGEMENTS

The surveys have been partially funded by grant no. 111043/S40 from the Norwegian Research Council. We are very grateful to the crew onboard the chartered vessels, the observers and the team leaders for their dedicated and pleasant cooperation in conducting the research. The hard work spent by K.A. Fagerheim and S. Hartvedt on validating and coding the survey data is much appreciated.

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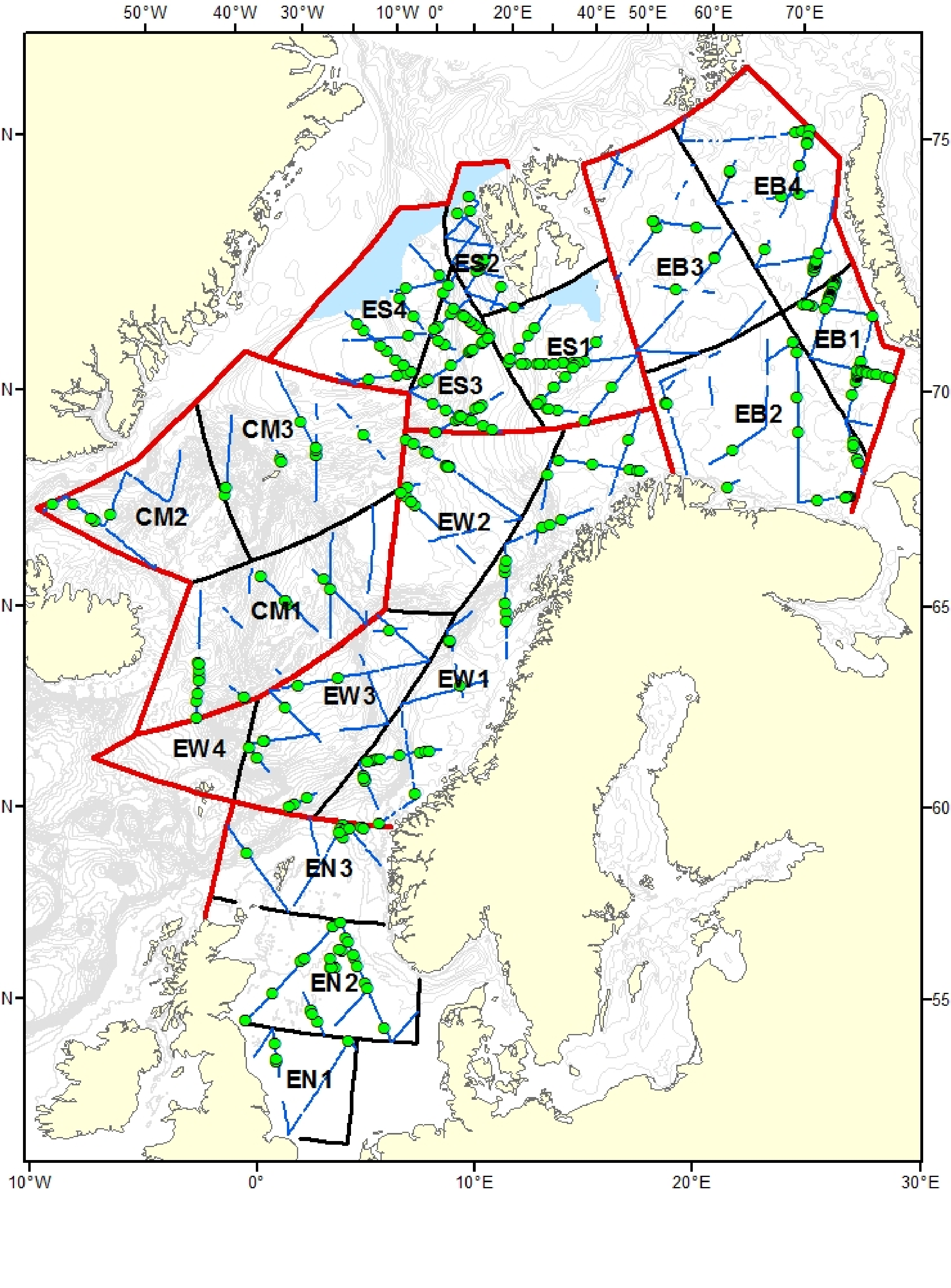

Figure 1. *The total survey area for the Norwegian surveys 2008-2013. The Small Management Areas as decided at the Implementation Review in 2003 are shown with the stratum structure used during these surveys. Also shown are transect lines covered in primary search mode (realised survey effort) and primary minke whale sightings (green dots) made from platform A. The stratum EW4 did not receive any coverage. The ice coverage in SMA ES is based on mid-July 2008 maps from the Norwegian Meteorological Institute.*

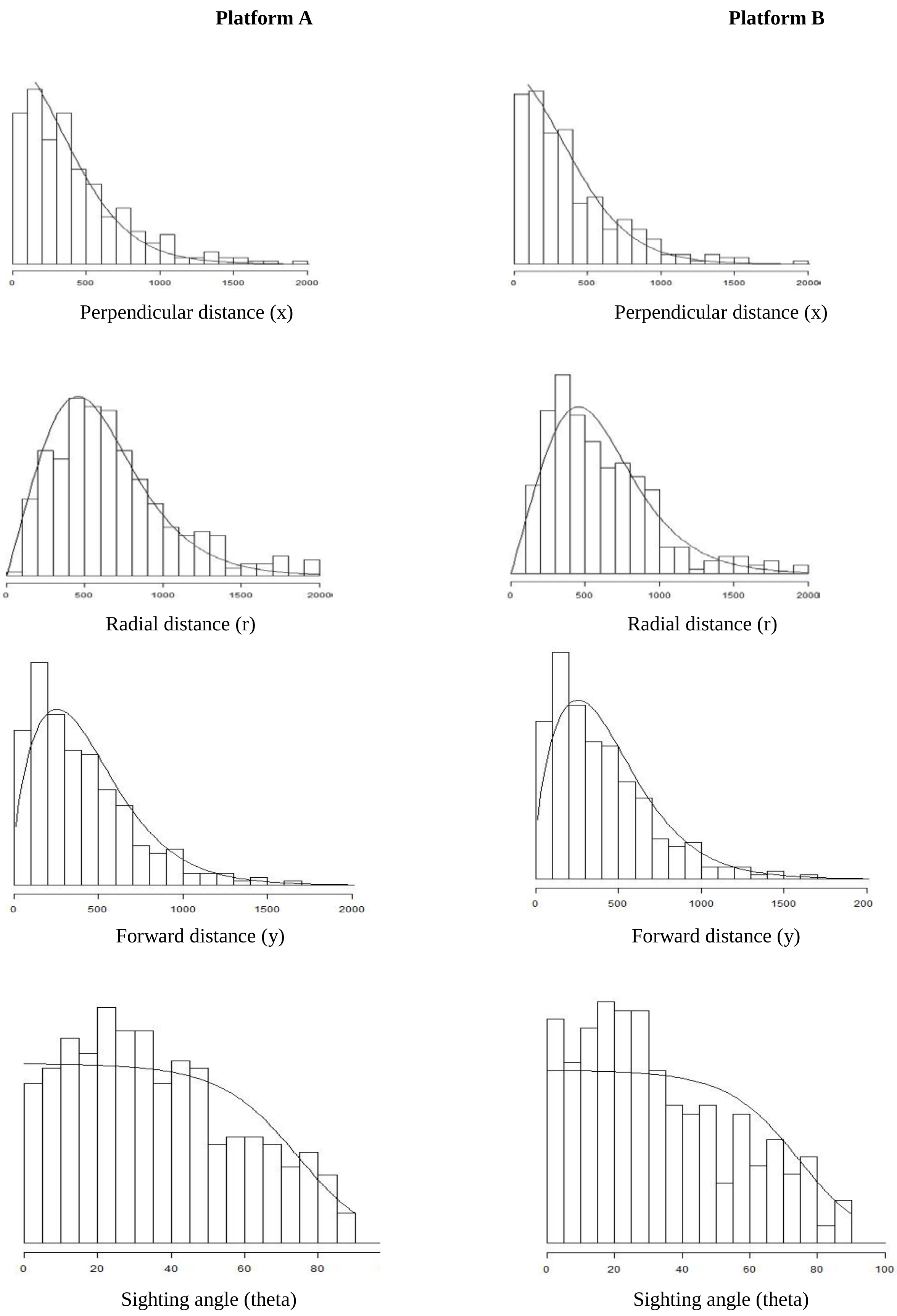

Figure 2. *Frequency distributions of collected distance data by observer platform together with fitted probability densities (solid lines). Panels are given for perpendicular distances, radial distances (truncated to [100m, 2000m]), forward distances and sighting angles.*

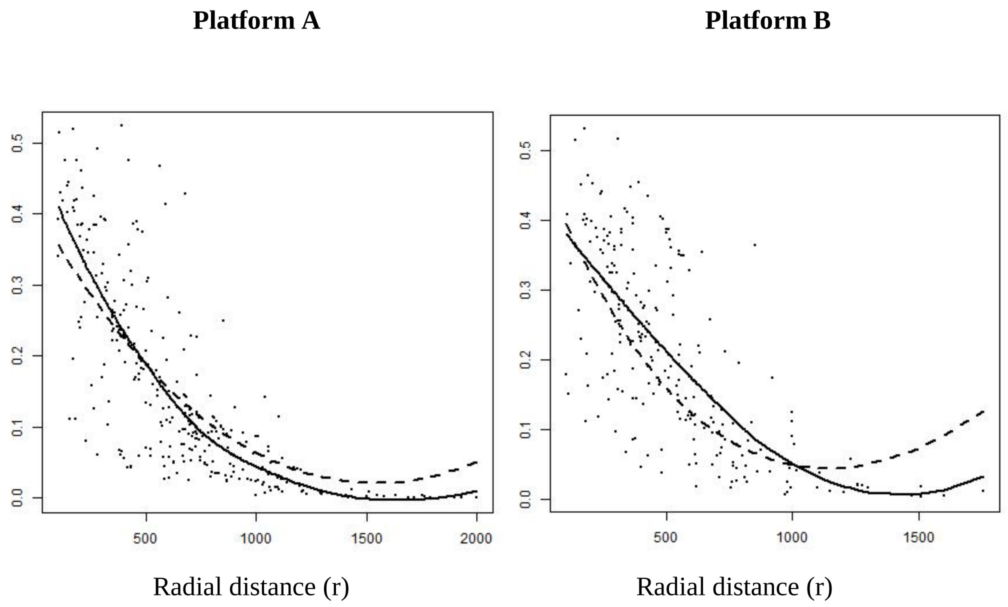

Figure 3. *Estimated success probabilities by radial distance for the Bernoulli trials (dots). The empirical probability is described by the solid line while the dashed line is a nonparametric smoother applied to the data.*

Table 1. Covariates recorded hourly or more often during the surveys.

		Transformed (aggregated) covariates		
Covariate	**Description**	**Abbreviation**	**Levels**	**Definition**
Beaufort	5 categories	B	BI, BII, BIII	BI:[0-1], BII:[2], BIII:[3-4]
Weather	12 categories	W	good, bad	good: W01-W04, bad: W05-W12
Vessel	7 vessels	Ve	ERO,THO,JHJ,HGU,BGU,HMO,BHO	
Visibility	Numerical	Vi	High, Low	Low < 15,000 meters, High > 15,000 meters
Glare	4 categories	G	Glare, no glare	G0: no glare, G1: glare
Platform	Platform indicator	P	A,B	
Team	Individual observer codes	T	short, long	subjective classification

Table 2. Summary of survey results by survey block as arranged according to the RMP *Small Areas* (IWC, 2004). The information given is area of survey block, year in which the blocks were surveyed, realized transect length i.e. primary search effort (L), total number of sightings combined for the double platform (n_A+n_B), half strip widths w, and abundance estimates N. The last column is showing τ, which is the overdispersion as explained in Skaug & Solvang (2015).

Small Area	Block	Year	Area (km^2)	L (km)	n_{A+B}	Hazard probability method			
						w_{A+B}	N	SD	tau
CM	CM1	2010	296 008	1 765	28	348.98	5363.53	2351	5.3
	CM2	2010	177 074	971	8	400.35	1418.86	808	2.5
	CM3	2010	294 335	1 002	16	431.35	4208.87	1800	2.8
EB	EB1	2013	106 524	1 199	150	366.44	14424.61	5414	19.9
	EB2	2013	277 471	2 114	57	350.40	8504.39	5421	22.7
	EB3	2013	267 448	1 675	15	382.36	2455.41	908	2
	EB4	2013	232 494	1 705	64	391.42	8741.03	3592	10.5
EN	EN1	2009	94 642	765	9	387.84	1129.27	781	4.2
	EN2	2009	196 731	1 283	36	534.87	3826.56	833	1.5
	EN3	2009	160 102	916	11	388.90	1934.93	725	1.5
ES	ES1	2008	174 474	1 378	87	356.62	12303.6	3740	7.7
	ES2	2008	59 975	1 116	16	390.83	866.42	309	2
	ES3	2008	118 084	1 414	105	376.26	9210.54	1385	1.9
	ES4	2008	188 322	1 348	30	335.90	5009.01	1438	2.3
EW	EW1	2011	331 607	2 734	66	390.44	8053.30	1938	3.6
	EW2	2011	217 796	959	38	338.83	10173.38	3970	5.6
	EW3	2011	227 427	1 846	19	316.97	2990.9	825	1.4
	EW4	-	84 292	0	n.a.	n.a.	n.a.	n.a.	

Table 3. Comparison of different covariate models for the linear predictor η_r (radial distance), with the selected model in bold face. The best model combination (AIC) within a number of covariates group is shown. Abundances estimates are without bias correction.

Model	Modelling of covariates			Mean half strip width (sd)		Abundance
Covariate	**# parameters**	**log-likelihood**	**AIC**	**Platform A**	**Platform B**	**total**
Beaufort (B)	6	-5129.74	10271.48	233.9 (11.8)	233.9 (11.8)	103 007
B+W	7	-5121.79	10257.58	229.95 (12.1)	229.95 (12.1)	102 905
B+W+Vi	8	-5115.15	10246.3	235.04 (12.1)	235.04 (12.1)	101 532
B+W+P+Ve	14	-5104.28	10236.56	276.79 (16.9)	230.09 (14.8)	98 459
B+W+G+P+Ve	15	-5101.55	10233.1	276.63 (16.6)	229.46 (14.3)	98 746
B+W+Vi+P+G+T	**11**	**-5104.43**	**10230.86**	**258.23 (14.3)**	**222.85 (12.7)**	**100 615**
B+W+Vi+G+P+Ve+T	17	-5099.48	10232.96	273.42 (16.8)	228.64 (14.3)	98 905

Table 4. Abundance estimates with associated coefficients of variation (CV) by *Small Area* and for the Eastern Medium Area as currently defined by the International Whaling Commission (IWC, 2004). Small Areas with an asterix (*) are the 'old' management areas defined by the first implementation (IWC, 1994). For the combined areas (Total and Eastern) the CV's in parenthesis excludes additional variance. Estimates from earlier surveys are given for comparison; 1989 and 1995 from Schweder et al. (1997) and 1996-2001 from Skaug et al. (2004).

	1989		**1995**		**1996-2001**		**2002-2007**		**2008-2013**		
Small Area	**N**	**CV**	**N**	**CV**	**N**	**CV**	**N**	**CV**	**N**	**CV**	**CV additional**
ES*	13 370	0.192	25 969	0.112	18 174	0.25	19 409				
ES							19 377	0.33	**27 390**	**0.16**	**0.29**
EB*	34 712	0.203	56 330	0.136	43 835	0.15	47 968				
EC*	2 602	0.249	2 462	0.228	584	0.26	3 457				
EB							28 625	0.26	**34 125**	**0.23**	**0.34**
EW							27 152	0.22	**21 218**	**0.21**	**0.32**
EN*	14 046	0.276	27 364	0.206	17 895	0.25	10 568				
EN							6 246	0.48	**6 891**	**0.19**	**0.31**
CM	2 650	0.484	6 174	0.357	26 718	0.14	26 739	0.39	**10 991**	**0.26**	**0.36**
Total	67 380	0.190	118 299	0.103	107 205	0.13	108 140	0.23 (0.21)	**100 615**	**0.11**	**0.17**
Eastern (E)	64 730	0.192	112 125	0.104	80 487	0.15	81 401	0.23 (0.20)	**89 623**	**0.12**	**0.18**