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ABSTRACT

An estimate of abundance of common minke whales in parts of the northeast Atlantic based on data collected in the first two years of the Norwegian survey cycle 2014-2019 and NASS-2015 extension survey is presented. The 40 % drop in abundance in the Jan Mayen area which was observed in the survey cycle 2008-2013 as compared to the abundances recorded in the two foregoing survey cycles, seems to have been reversed in 2015. In one major survey block (CM3) at Jan Mayen, the abundance in 2015 was three times that of 2011. The minke whale abundance attributed to the Norwegian Sea is apparently stable. In the Svalbard area (*ES*) the minke whale abundance in 2014 had decreased to 45 % of the abundance level observed in 2008. This indicates that distributional shifts and scale of the shifts are important to understand to get a better handle on estimating population abundances.

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 which over a six-year period provide data for estimating total abundance in the northeast Atlantic; estimates have been presented for three such cycles: 1996-2001, 2002-2007 and 2008-2013 (Skaug et al. 2004, Bøthun et al. 2009, Solvang et al. 2015). In 2014 a new survey cycle 2014-2019 was started and here we present a preliminary estimate of minke whale abundance in the survey areas covered in the first two years of the ongoing cycle: In 2014 at Svalbard and in 2015 in the Norwegian Sea including major parts of the Jan Mayen area.

MATERIAL AND METHODS

Data collection 2014-2015

In 2014 a new survey cycle 2014-19 was started (Øien 2013). In 2014 this survey cycle started by covering the Svalbard area (*Small Management Area* ES) (Øien 2015). In 2015 the planned area to cover was the Small Management Area *EW*, the Norwegian Sea. However, coordination of survey effort within NASS-2015 (North Atlantic sightings Surveys) eventually led to relocation of survey effort to the Jan Mayen area to get a synoptic distributional picture of potential important feeding areas in the Northeast Atlantic for the target species of the participating nations (Faroe Islands, Greenland, Iceland and Norway). A report of the 2015 survey is presented in Øien (2016).

Whales have been 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

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	2 vessels	Ve	TRO, FTR	
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

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. The approach developed in Skaug & Solvang (2015) will be implemented when more data have been accumulated from the present survey cycle. 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.

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 $\alpha = 0.0127$.

The estimates presented here are based on a limited data set and are preliminary. When more data is available the variance of the abundance estimates as well as inter-annual variation in spatial distribution (additional variance) will be estimated (Skaug et al. 2004, Skaug & Solvang 2015).

RESULTS AND DISCUSSION

Over the the two years 2014-2015 a total primary effort of 13 960 km was conducted (Table 2, Figure 1). The total survey area was 1,774,684 km^2. The planned survey block EW4 within the EW Small Management Area was not covered due to scarcity of ship time.

A total of 250 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. Generally, the diagnostic plots show a good relationship between distributions and model predictions. However, for platform B there seems to be deviations from the instructed sighting behavior of primarily covering the 45° sector from the trackline. 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 + G + Ve + 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 areas surveyed in 2014 and 2015 is 48 232.

Even if we have just started the survey cycle, it is quite evident that distributional changes are going on in the Northeast Atlantic. In the previous cycle 2008-2013 we observed an increase in minke whale abundance in the Svalbard area (*ES*). In 2014 the corresponding abundance was only 45 % of that observed in 2008 and the lowest number since 1995. For the Norwegian Sea (*EW*) the estimate was similar to the previous survey in 2011. Also, for the Jan Mayen area we observed an increase in numbers, but since we did not have a complete coverage of the area in our survey, it is hard to evaluate the size of the change. However, the comparable survey block CM3 had an estimate nearly three times as high in 2015 as the corresponding result in 2011.

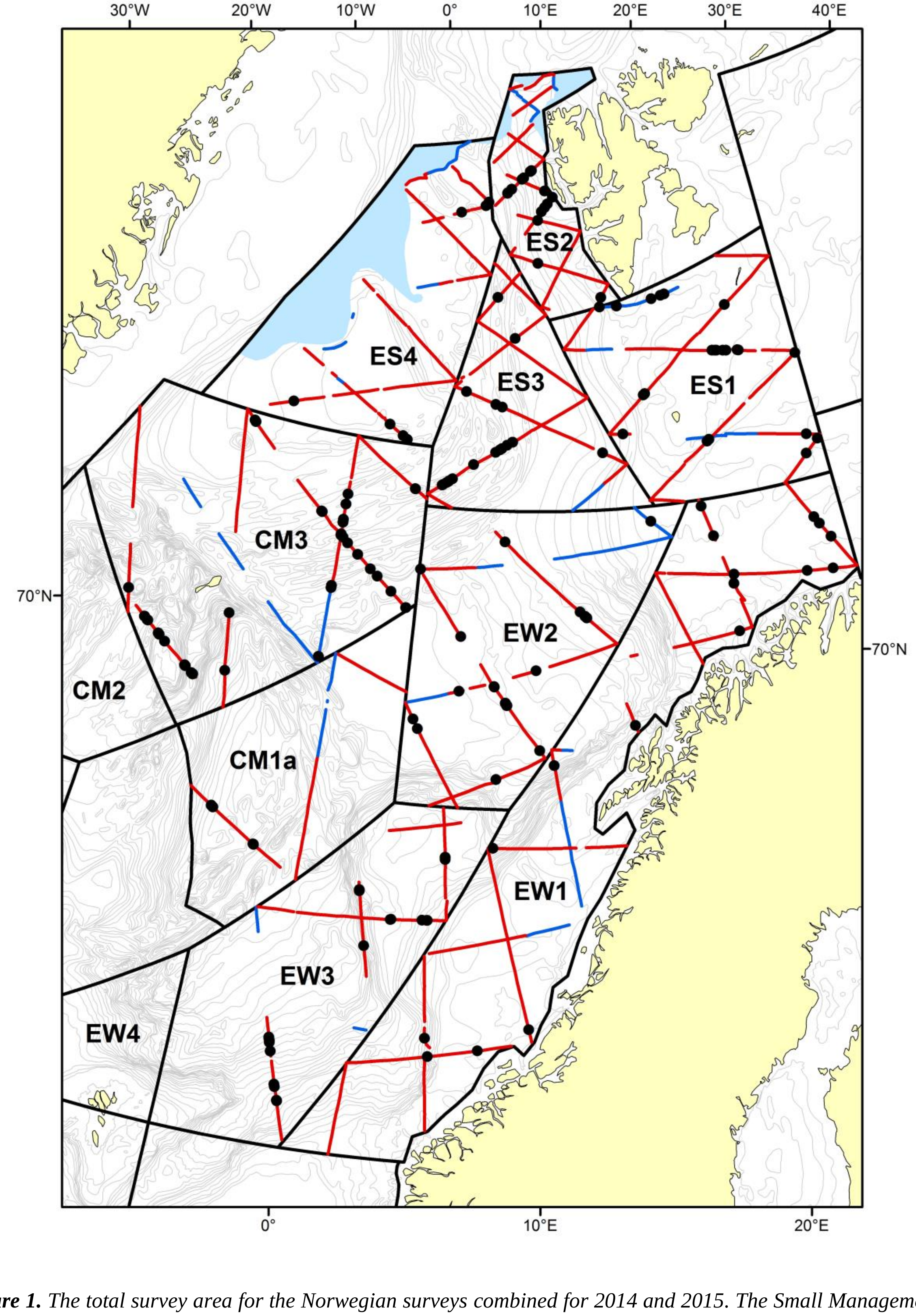

__Figure 1.__ The total survey area for the Norwegian surveys combined for 2014 and 2015. The Small Management Areas as decided at the Implementation Review in 2003 have been further divided into survey blocks carrying the SMA name and a number. Also shown are transect lines covered in primary search mode (realised survey effort - red lines. The blue lines are additional single platform effort) and primary minke whale sightings (black dots) made from platform A. The stratum EW4 did not receive any coverage. The ice coverage in SMA ES is based on mid-July 2014 maps from the Norwegian Meteorological Institute.

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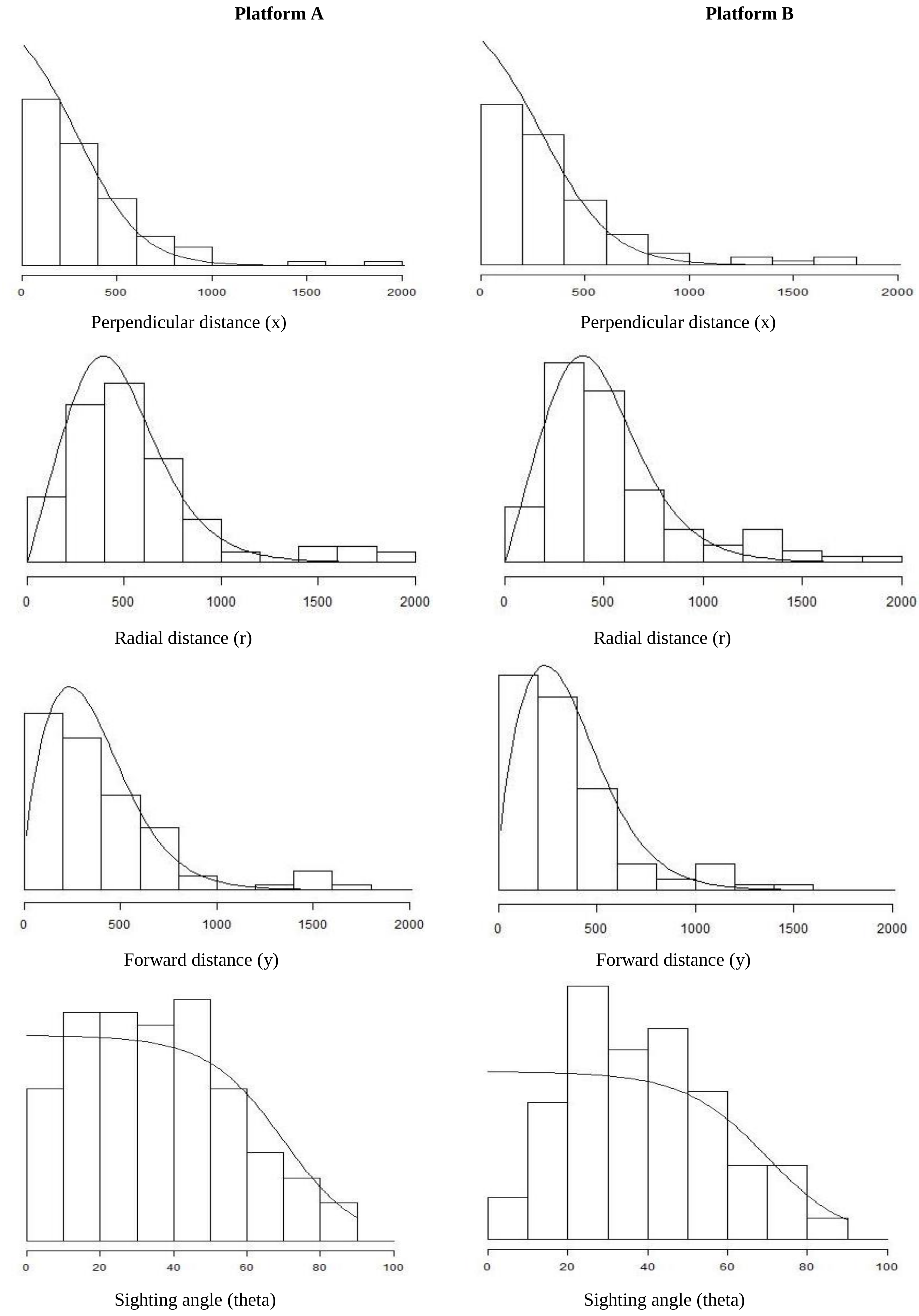

Figure 2. *Frequency distributions of collected distance data by observer platform together with fitted probability densities (solid lines). Panels are given for perpendicular distances, radial distances (truncated to [100m, 2000m]), forward distances and sighting angles.*

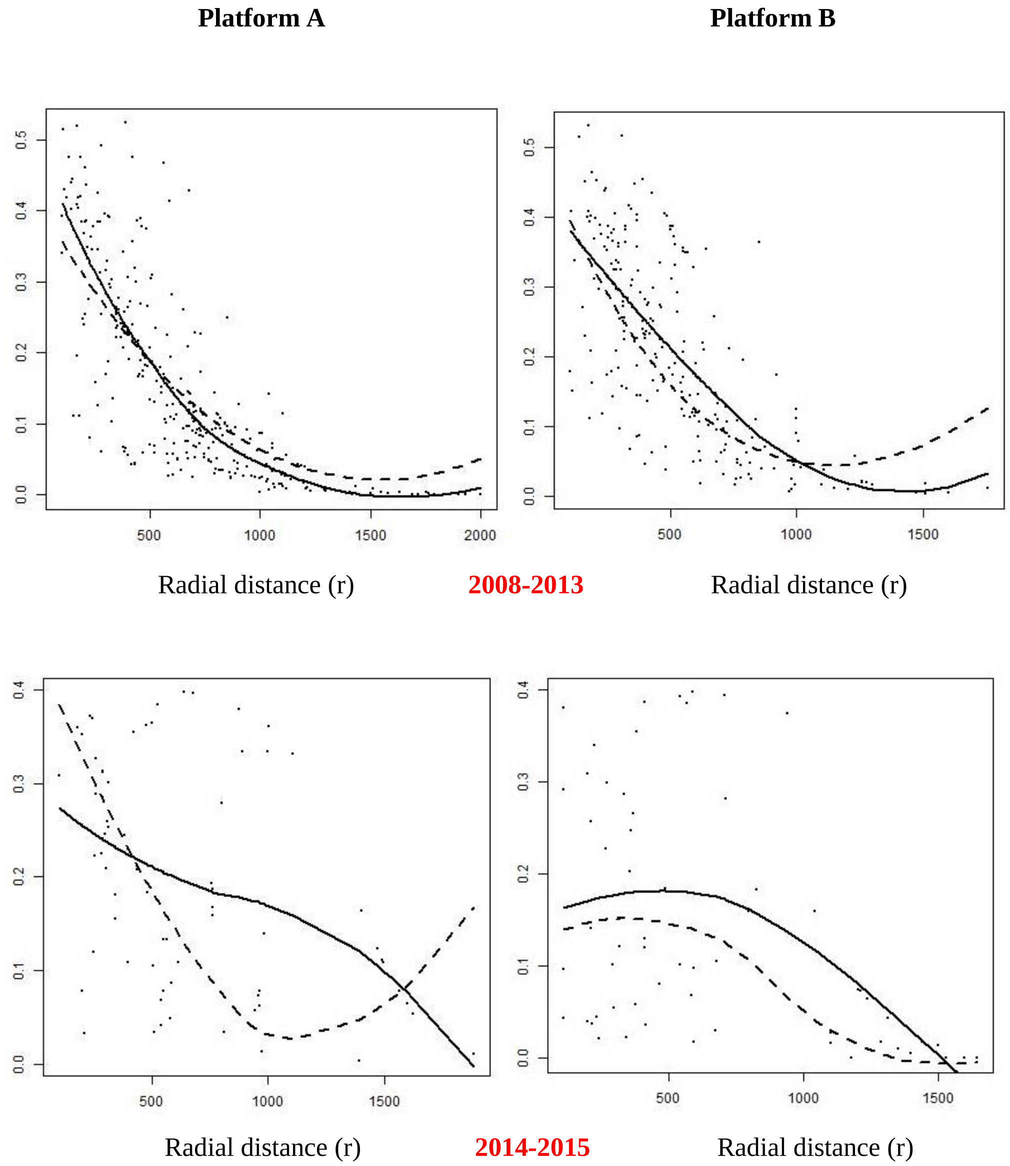

Figure 3. *Estimated success probabilities by radial distance for the Bernoulli trials (dots). The empirical probability is described by the solid line while the dashed line is a nonparametric smoother applied to the data. For comparative purposes the corresponding success probabilities for the survey cycle 2008-2013 are shown in the upper panel.*

Table 2. Summary of survey results 2014-2015 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. For comparisons an additional table with results from the survey cycle 2008-2013 is added.

	2014-	2015												
SMA	**Block**	**Year**	**Area (km^2)**	**L (km)**	**n_{A+B}**	**wA**	**SD wA**	**wB**	**SD wB**	**wAUB**	**SD wAUB**	**N**		
CM	CM1													
	CM2													
	CM3	2015	294335	1788	51	170.2	24.233	171.65	24.392	273.21	33.272	12281.22		
	C1A	2015	162664	622	7	110	14.191	112.61	14.432	187.51	21.236	4113.36		
EB	EB1													
	EB2													
	EB3													
	EB4													
EN	EN1													
	EN2													
	EN3													
ES	ES1	2014	174474	1746	43	215.73	22.33	214.04	22.089	331.64	29.171	4999.19		
	ES2	2014	59975	1279	32	193.1	20.041	201.29	20.727	308.33	27.284	1901.96		
	ES3	2014	118084	1559	41	221.62	23.269	227.35	23.337	347.11	30.341	3457.72		
	ES4	2014	188322	1435	14	221.55	22.377	213.84	21.601	336.42	28.564	2109.57		
EW	EW1	2015	331607	2976	17	128.06	16.571	131.29	16.968	213.71	24.034	3651.56		
	EW2	2015	217796	1509	21	107.91	14.145	110.69	14.381	183.96	21.273	6934.01		
	EW3	2015	227427	1046	24	147.9	19.673	149.23	19.95	238.65	27.215	8784.74		
	EW4	n.a.	n.a.	n.a.	n.a.									

	2008-	**2013**												
SMA	**Block**	**Year**	**Area (km^2)**	**L (km)**	**n_{A+B}**	**wA**	**SD wA**	**wB**	**SD wB**	**wAUB**	**SD wAUB**	**N**		
CM	CM1	2010	296008	1765	28	232.55		205.21		348.98		5363.53		
	CM2	2010	177074	971	8	277.40		236.71		400.55		1418.86		
	CM3	2010	294335	1002	16	303.45		254.89		431.35		4208.869		
	C1A	n.a.												
EB	EB1	2013	106524	1199	150	246.70		215.24		366.44		14249.4		
	EB2	2013	277471	2114	57	233.78		206.08		350.40		8504.387		
	EB3	2013	267448	1675	15	261.71		226.00		382.36		2455.411		
	EB4	2013	232494	1705	64	268.63		230.57		391.42		8741.033		
EN	EN1	2009	94642	765	9	264.90		228.09		387.84		1129.268		
	EN2	2009	196731	1283	36	398.35		322.94		534.87		3826.562		
	EN3	2009	160102	916	11	267.18		229.64		388.90		1934.928		
ES	ES1	2008	174474	1378	87	241.88		205.77		356.62		12303.6		
	ES2	2008	59975	1116	16	267.45		228.76		390.83		866.4241		
	ES3	2008	118084	1414	105	254.62		221.39		376.26		9210.535		
	ES4	2008	188322	1348	30	219.39		198.97		335.90		5009.014		
EW	EW1	2011	331607	2734	66	268.50		228.51		390.44		8053.302		
	EW2	2011	217796	959	38	223.35		200.80		338.83		10173.38		
	EW3	2011	227427	1846	19	206.59		184.73		316.97		2990.9		
	EW4	n.a.	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	-1680.73	3373.46	178.79 (16.4)	178.79 (16.4)	43 505
B+T	7	-1674.02	3362.04	177.84 (16.6)	179.6 (16.7)	43 522
B+Ve+T	8	-1672.68	3361.36	176.01 (16.5)	177.23 (16.6)	44 040
B+G+Ve+T	**9**	**-1668.99**	**3355.98**	**171.3 (16.0)**	**173.03 (16.1)**	**45 179**
B+G+Ve+P+T	10	-1668.44	3356.88	179.54 (18.3)	165.58 (17.1)	45 076
B+W+G+Ve+P+T	11	-1668.4	3358.66	177.81 (18.4)	163.75 (17.3)	45 546
B+W+Vi+G+P+Ve+T	-	n.a.				

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**			**2014-2015**
Small Area	**N**	**CV**	**N**	**CV**	**N**	**CV**	**N**	**CV**	**N**	**CV**	**CV additional**	**N**
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**	**12 468**
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**	**19 370**
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**	**16 394++**
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**	