Preliminary abundance estimates of common minke whales in the Northeast Atlantic based on survey data collected over the period 2008-2013

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ABSTRACT

A preliminary estimate of abundance of common minke whales in the northeast Atlantic based on data collected over the period 2008-2013 is presented. The preliminary estimations indicate that the estimate for the total area has decreased compared to the two preceding survey periods, i.e. from about 108,000 to about 94,000 minke whales. The decrease seems to have occurred within the Small Management Area CM with an estimate now being 40 % of those from the 1996-2001 and 2002-2007 cycles. Within the E region, the estimate is of the same magnitude as in the previous two cycles, i.e. about 83,000 animals. However, there are signs of a northwards distributional shift within this region from the Norwegian Sea to the Svalbard area.

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 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 a preliminary estimate of minke whale abundance in the northeast Atlantic based on data collected over the years 2008-2013. The estimate needs further refinement as well as calculation of variance estimates, including additional variance due to the multi-year survey design.

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) 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

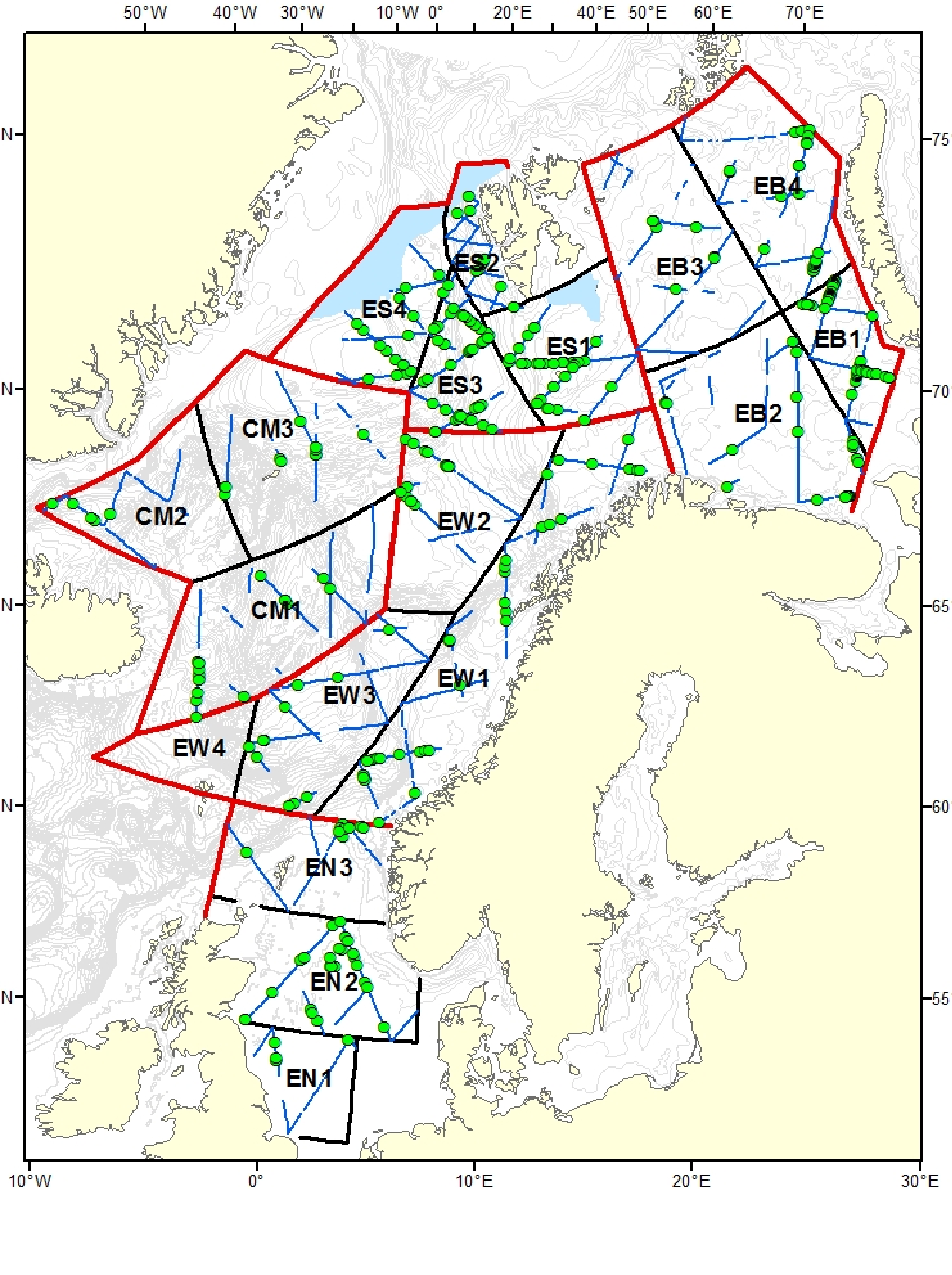

Figure 1. *The total survey area for the Norwegian surveys 2008-2013. The Small Management Areas as decided at the Implementation Review in 2003 are shown with the stratum structure used during these surveys. Also shown are transect lines covered in primary search mode (realised survey effort) and primary 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.*

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.

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 < 2nm, High > 2nm
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

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 bias correction for measurement errors, duplicate identification errors, clustering and other factors applied for in earlier estimations through simulations, have not been performed on the present data. The plan is to investigate other possibilities that can substitute the rather complicated simulation procedure.

For the chosen covariate model, the parameter estimates were used for calculating the effective strip half widths w_A and w_B are calculated. 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 variance of the abundance estimates have not been calculated for these preliminary estimates.

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. As is seen, most sightings were made within a 1000 m strip on each side of the transect line.

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 + 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 survey area is 93 821, while the estimate for the Eastern North Atlantic Medium Area in the RMP terminology is 82 572.

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 SMA CM. We have not provided cv's for the estimates given here, so the

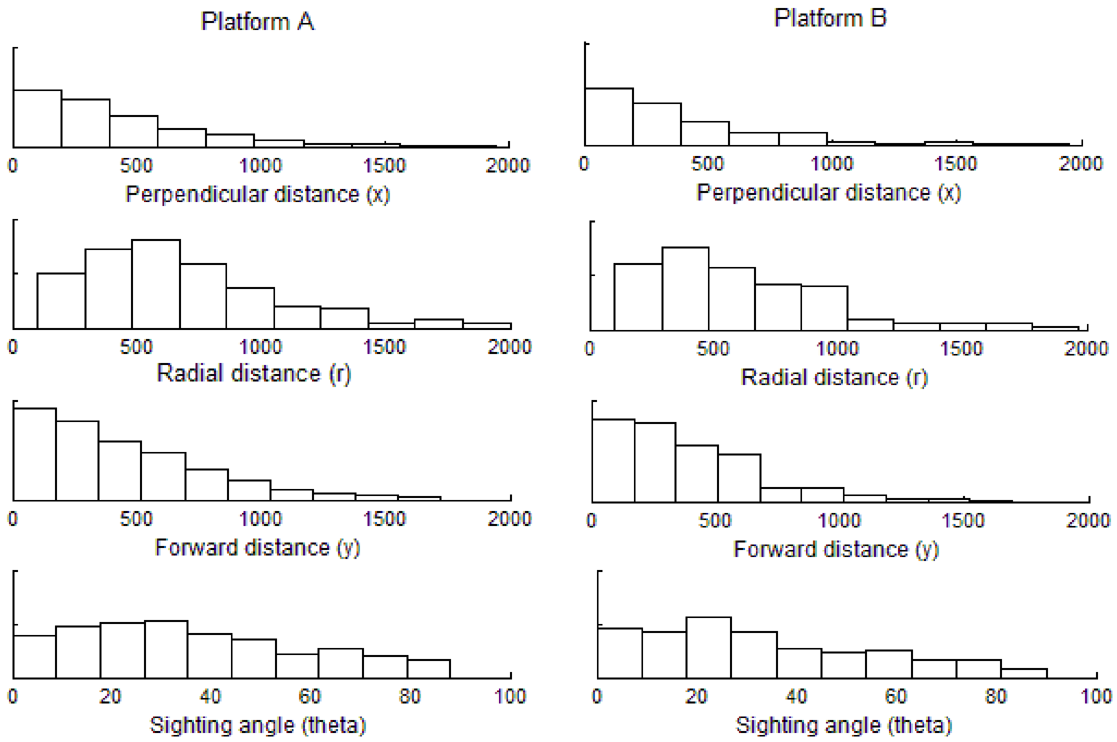

Figure 2. *Frequency distributions of collected distance data by observer platform. Panels are given for perpendicular distances, radial distances (truncated to [100m, 2000m]), forward distances and sighting angles.*

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 a northward shift in distribution from the Norwegian Sea area (EW) to Svalbard (ES).

The way forward

The analyses presented here are not completed. One thing is that we need to ensure the quality of the calculations, another that there are several steps left towards a final estimate. The analyses so far have been conducted in the same way as the previous analyses reported (Skaug et al. 2004, Bøthun et al. 2009), but further work required includes:

- A substitute for the bias correction of parameters by simulation. In previous analyses, the bias 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 plan is to substitute the demanding bias correction simulation with other approaches to account for measurement errors and other aspects.

- Finalize calculations of uncertainties in parameters and estimates, including the variance-covariance matrix-of abundance estimates.

- Inclusion of a model for accommodating inter-annual variation in spatial distribution (additional variance) of minke whales, as have been included in earlier estimates (Skaug et al. 2004, Bøthun et al. 2009).

- Quality assurance of estimates, including calculation of Distance estimates as a supportive exercise, knowing that those mark-recapture estimates may be 20-30 % lower due to availability and heterogeneity issues.

Table 2. Summary of survey results by survey block as arranged within 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), and abundance estimates N. The mean half strip widths were 262.4 m (sd 45.4) for platform A and 220.1 m (sd 33.6) for platform B.

Small Area	Block	Year	Area (km^2)	L (km)	n_{A+B}	Hazard probability method		
						w_{A+B}	N	SE
CM	CM1	2010	296 008	1 765	28		4865.5	
	CM2	2010	177 074	971	8		1511.2	
	CM3	2010	294 335	1 002	16		4871.8	
EB	EB1	2013	106 524	1 199	150		11434.3	
	EB2	2013	277 471	2 114	57		2923.5	
	EB3	2013	267 448	1 675	15		2574.9	
	EB4	2013	232 494	1 705	64		10403.5	
EN	EN1	2009	94 642	765	9		1154.2	
	EN2	2009	196 731	1 283	36		5720.8	
	EN3	2009	160 102	916	11		1991.8	
ES	ES1	2008	174 474	1 378	87		11542.3	
	ES2	2008	59 975	1 116	16		891.0	
	ES3	2008	118 084	1 414	105		9435.7	
	ES4	2008	188 322	1 348	30		4342.2	
EW	EW1	2011	331 607	2 734	66		8422.2	
	EW2	2011	217 796	959	38		9182.2	
	EW3	2011	227 427	1 846	19		2553.6	
	EW4	-	84 292	0	n.a.		n.a.	

[source Areal_trans_sights]

CONCLUSION

The preliminary estimations indicate that the estimate for the total area has decreased (however, probably 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 connection to the recent observed drop in minke whale abundance in the coastal waters of Iceland. Within the E region, the estimate is of the same magnitude as in the previous two cycles. However, there are signs of a northwards distributional shift within this region from the Norwegian Sea to the Svalbard area.

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REFERENCES

Bøthun, G., 2009. Further analysis of measurement error in radial distance. SC/61/RMP4.

Bøthun, G., Skaug, H.J., 2009. Description and performance of an automatic duplicate identification routine. SC/61/RMP3.

Bøthun, G., Skaug, H.J., Øien, N. 2008. Abundance of minke whales in the Northeast Atlantic based on survey data collected over the period 2002-2007. Paper SC/60/PFI 4.

Bøthun, G., Øien, N., Skaug, H.J. 2008b. Measurement error in survey and experiment, Norwegian minke whale surveys 2002-2007. Paper SC/60/PFI5.

Bøthun, G., Skaug, H.J., Øien, N. 2009. Abundance of minke whales in the Northeast Atlantic based on survey data collected over the period 2002-2007. Paper SC/61/RMP 2.

Hagen, G. and Schweder, T. 1994. Point clustering of minke whales in the Northeastern Atlantic. *In*: Developments in marine biology: Vol. 4. Whales, seals, fish and man. Edited by A.S. Blix, L. Walløe and Ø. Ulltang. Elsevier Science BV, Amsterdam, pp. 27-34.

International Whaling Commission. 1994. Report of the Scientific Committee. Annex K. Area definitions for RMP implementations. *Rep.int.Whal.Commn 44:*175-176.

International Whaling Commission. 2004. Report of the Scientific Committee. Annex D, Appendix 14. Report of the working group on North Atlantic minke whales RMP *Implementation Review*. *J. Cetacean Res. Manage. 6 (Suppl.):*171-183.

International Whaling Commission. 2008. Report of the Scientific Committee. Annex D, Appendix 7. North Atlantic Minke Whales RMP Implementation Review.

Øien, N. 1995. Norwegian Independent Linetransect Survey 1995. *Interne notat, nr. 8 - 1995,* Havforskningsinstituttet, 58 pp (internal report).

Øien, N., Bøthun, G. and Kleivane, L. 2009. Summary of available data on northeastern Atlantic minke whale surfacing rates. SC/61/RMP7.

Schweder, T. 1997. Measurement error models for the Norwegian minke whale survey in 1995. *Rep.int.Whal.Commn*. 47: 485-488.

Schweder, T., Skaug, H.J., Dimakos, X., Langaas, M., Øien, N. 1997. Abundance estimates for Northeastern Atlantic minke whales. Estimates for 1989 and 1995. Rep.int.Whal.Comm. 47:453-484.

Skaug, H.J., Øien, N., Schweder, T., Bøthun, G. 2004. Abundance of minke whales (*Balaenoptera acutorostrata*) in the Northeast Atlantic: variability in time and space. *Can.J.Fish.Aquat.Sci.* 61:871-886.

Skaug, H.J., Schweder, T., Laake, J. 2009. The effect of heterogeneity in line transect surveys with discrete cues. SC/61/O2.

Skaug, H.J., Bøthun, G., Øien, N., 2009. A comparison of observed surfacing rates in minke whales between surveys and VHF tagged animals. SC/61/RMP6.

Skaug, H.J., Schweder, 1999. Hazard models for line transect surveys with independent observers, Biometrics, 55, p. 29-36.

Skaug, H.J. 2009. Inferring spatial cluster structure from line transect data. SC/61/RMP5.

Thomas, L., Laake, J.L., Strindberg, S., Marques, F.F.C., Buckland, S.T., Borchers, D.L., Anderson, D.R., Burnham, K.P., Hedley, S.L., Pollard, J.H., Bishop, J.R.B. and Marques, T.A. **2006**. Distance 5.0. Release 2. 1. Research Unit for Wildlife Population Assessment, University of St. Andrews, UK. http://www.ruwpa.st-and.ac.uk/distance/

Table 3. Comparison of different covariate models for the linear predictor η_r (radial distance), with the selected model in bold face. Abundances estimates are without bias correction.

Model	Modelling of covariates			Mean half strip width (sd)		Abundance
Covariate	**# parameters**	**log-likelihood**	**AIC**	**A**	**B**	**total**
Beaufort (B)	7	-5317.06	10648.12	229.825 (19.317)	229.825 (19.317)	98 487
Weather (W)	6	-5328.14	10668.28	243.766 (13.912)	243.766 (13.912)	92 855
Visibility (Vi)	6	-5335.82	10683.64	235.844 (12.530)	235.845 (12.530)	95 973
Glare (G)	6	-5336.82	10685.64	235.096 (17.050)	235.096 (17.050)	96 279
Platform (P)	6	-5335.15	10682.3	249.290 (14.108)	220.900 (13.022)	96 279
Vessel (Ve)	11	-5327.32	10676.64	257.926 (32.429)	257.926 (32.429)	87 757
Team (T)	6	-5335.99	10683.98	238.327 (14.335)	237.935 (14.369)	95 052
Null	5	-5337.65	10685.3	234.880 (11.919)	234.880 (11.919)	96 368
B+T	8	-5311.34	10638.68	233.796 (22.111)	232.944 (22.028)	96 991
B+W+P	9	-5305.96	10629.92	252.816 (26.567)	214.399 (20.057)	96 893
B+W+P+Ve	15	-5294.51	10619.02	266.332 (44.406)	221.420 (32.306)	92 813
B+W+Vi+P+Ve	16	-5292.69	10617.38	266.916 (43.518)	222.318 (32.241)	92 532
B+W+Vi+P+Ve+T	**17**	**-5291.07**	**10616.14**	**262.404 (45.438)**	**220.108 (33.564)**	**93 821**
B+W+Vi+G+P+Ve+T	18	-5290.5	10617.	266.320 (46.667)	223.743 (34.143)	92 375

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 Distance**	**N**	**CV**
ES*	13 370	0.192	25 969	0.112	18 174	0.25	19 409				
ES							**19 377**	0.33	13 866	**26 211**	
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	25 847	**27 336**	
EW							**27 152**	0.22	16 458	**20 158**	
EN*	14 046	0.276	27 364	0.206	17 895	0.25	10 568				
EN							**6 246**	0.48	3 469	**8 867**	
CM	2 650	0.484	6 174	0.357	26 718	0.14	**26 739**	0.39	18 377	**11 249**	
Total	67 380	0.190	118 299	0.103	107 205	0.13	**108 140**	0.23 (0.21)	78 016	**93 821**	
Eastern (E)	64 730	0.192	112 125	0.104	80 487	0.15	**81 401**	0.23 (0.20)	59 639	**82 572**	