SC/61/RMP 2

Abundance of minke whales in the Northeast Atlantic based on survey data collected over the period 2002-2007

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ABSTRACT

To estimate abundance of Northern minke whales (*Balaenoptera acutorostrata*) in the Northeast Atlantic, partial surveys have been conducted over the period 2002-2007. Each year two vessels equipped with two independent observer platforms each, surveyed an area approximately corresponding to a *Small Area* as used in the RMP implementation for North Atlantic minke whales. The total abundance for the areas covered over the period 2002-2007 is 108,000 (CV 0.23). Of these, 81,000 (CV 0.23) minke whales are within the Eastern Medium Area. These estimates are in accordance with the corresponding estimates from the previous survey period 1996-2001, but the uncertainty is larger. The uncertainty estimates are corrected for inter-annual variation in the spatial distribution of minke whales (additional variance).

MINKE WHALES, NORTH ATLANTIC, ABUNDANCE ESTIMATE, VESSEL SURVEY

INTRODUCTION

Minke whales (*Balaenoptera 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).

We present an estimate of minke whale abundance based on data collected over the period 2002-2007. The analysis method is that of Skaug et al. (2004), with some modifications. A preliminary abundance estimate was presented at last years SC meeting (Bøthun et al., 2008a). In the discussion that followed the presentation a number of issues where raised. These have since been addressed (see Discussion), and in particular the duplicate identification criterion has been revised. Also, the uncertainty estimates for the current abundance estimate have been corrected for inter-annual variation in the spatial distribution of minke whales (additional variance). For comparison purposes we also estimated block wise abundance using Distance (Thomas et al., 2006), using the point independence option.

MATERIAL AND METHODS

Data collection 2002-2007

Over the period 2002-2007 annual surveys were conducted that covered the Northeast Atlantic from the North Sea (southern boundary 56ºN) to the ice edge, and from the Greenland Sea in the west to the Barents Sea in the east (Figure 1). The survey area was divided into blocks with assumed uniform densities based on previous knowledge. When the survey series 2002-2007 started, the structure of the Small Management Areas (*SMA*) was that of the North Atlantic Implementation (IWC, 1994) and the block structure was fitted accordingly. However, at the 2003 meeting's Implementation Review some changes were made to the SMA structure of the Medium Area E (IWC, 2004): The previous (referring to the block structure as used in Skaug et al. 2004) *SMA* EC was included in a new *SMA* EW, which was separated from the eastern Barents Sea at 28ºE. The northern boundary of *SMA* EN was also moved southwards to 62ºN. For a practical organization of the surveys in the years following the review decision, the previous blocks BAW and FI were divided into two blocks each (following

28ºE), and the previous block NSC into two blocks following 62ºN. During the analysis, the block FI covered in 2002 was restratified into the two blocks FI1 and FI2. An overview of the block structure is given in Figure 1.

In 2002 the western part of the *SMA* EB, comprising coastal waters off northern Norway and the eastern Norwegian Sea, was surveyed, in 2003 the Svalbard area, in 2004 the North Sea, in 2005 the Jan Mayen area, in 2006 the new *SMA* EW and in 2007 the eastern Barents Sea.

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 estimated eye-heights above sea level varied between 11.6 and 16.5 m for the upper platforms and between 6.0 and 12.2 m for the lower platforms. 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 $r \in [100\text{m}, 2000\text{m}]$.

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 2). 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). Before the matching, missing values of radial distance and and/or angle are imputed by interpolation between adjacent surfacing and taking into consideration the movement of the vessel. An initial sighting has three possible outcomes, 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. A bias correction is then applied to account for measurement error and duplicate identification errors, as well as other factors not directly incorporated into the likelihood function (see below). From the bias corrected parameter estimates 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)

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

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 A is the area of the survey block.

For a few survey blocks two different abundance estimates (from different years, see Table 1) were available. For the purpose of constructing the abundance estimate for the total area these were combined by weighting in proportion to realized transect length.

The parameters of the hazard probability model may be explained qualitatively 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 48.56 blows/hour, which gives the parameter $\alpha = 0.0135$.

Bias correction of parameter estimates was conducted through a simulation program which incorporates spatial clustering of whales, measurement errors in distance and angle and errors that may arise from the matching process of tracks. The program simulates a virtual sighting vessel surveying with two independent platforms. The virtual whales are available for detection at discrete time points determined by dive time series collected from radio-tagged minke whales within the survey area. In these simulations all series (Øien et al. 2009) have been used. The spatial distribution of minke whales is generated from a Neyman-Scott cluster process (Hagen and Schweder 1994). The Neyman-Scott process is characterized by three parameters: the intensity of clusters; the average number of whales per cluster; and the cluster radius. The method used to obtain blockwise estimates of these parameters is explained in Skaug (2009). In the bias correction simulations the estimates for the survey block BAW1 were used. The choice of the survey block BAW1 was based on the same criterion as used by Skaug et al. (2004).

The simulation program was also used to estimate the variance of the abundance estimates, using what is often called a "parametric bootstrap". For this purpose separate Neyman-Scott parameters were used for each survey block. We simulated 1000 datasets with the same conditions (survey effort, covariate setting, etc.) as in the real surveys, using estimated parameters for the hazard probability model. The simulations were scaled within survey block so that the average (simulated) abundance estimate matched the real abundance estimate. Finally, the empirical covariance matrix of the abundance vector was estimated empirically across the 1000 simulations.

The measurement error model, which forms an important component of the simulation model described above, is the mechanism by which errors in radial distance, sighting angle, time point of observation, incomplete tracking and missing positional values are generated. Different measurement error models have been fit to the data collected in the surveys 2002-2007 (Bøthun 2008, Bøthun et al. 2009b). The selection of model to be used in the present analysis, which was based on statistical criteria in combination earlier practice (see Discussion), lead to the following models for radial distance (meters) and angle (degrees):

$$\log(R) = \log(r) + \varepsilon_1, \qquad \varepsilon_1 \sim N(0, 0.30^2),$$

$$\Theta = 1.072\cdot\theta + \varepsilon_2, \qquad \varepsilon_2 \sim N(0, 5.48^2),$$

where (r,θ) are the true values and (R,Θ). The error model for time has been carried over from earlier work (Schweder 1997, Skaug et al. 2004):

$$T = t + \max[0.7 + 3.4^* N(0,1)]$$

where t and T denote true and measured time points (in seconds), respectively.

The additional variance, caused by non-synoptic coverage of the survey area, was estimated using all available survey data (1989, 1995, 1996-2001 and 2002-2007). Following Skaug et al. (2004) we assume a closed population and an exponential growth/decrease over the time period. The exception is the year 1989 which is given its own abundance parameter, due to the fact that the survey methodology differed from that used in 1995 and onwards. The estimates from 1989 do however provide information about the relative distribution of whales that is useful for estimating additional variance. Let $p_{a,y}$ denote the proportion of the population present in survey block a in year y. The following model is used

$$p_{a,y} = \frac{\exp(\mu_a + \xi_{a,y})}{\sum_a \exp(\mu_a + \xi_{a,y})}, \tag{1}$$

where μ_a are fixed effects determining the relative abundance in survey block *a*, and $\xi_{a,y} \sim N(0,\sigma^2)$ are random effects accounting for inter-annual changes in whale distribution. The *p*'s are correlated within year due to the constraint that they must add to 1. To account for short range correlation we allow the ξ's to be correlated with correlation function $\exp(-\lambda d)$ where *d* is the distance between two survey blocks and λ is a parameter to be estimated. For the purpose of estimating the variance parameter σ the REML (restricted maximum likelihood) method of estimation was used, i.e. the likelihood was integrated with respect to the μ's.

The additional variance, defined as a multiplier *c* by which to scale the standard deviation (and CV) of the total abundance estimate was obtained in the following way. With σ (and λ) fixed at the values estimated above the above model was refitted to data only from the years 2002-2007. The parameters to be estimated are then *N* (total abundance) and the μ's. As second version of this model, with the random effects ξ fixed at zero, was also fit. We define c as a ration of posterior standard deviations

$$c = \frac{SD(N \mid 2002-2007 \text{ data}; \xi \text{ random})}{SD(N \mid 2002-2007 \text{ data}; \xi \text{ fixed})}.$$

Based on perpendicular distances only we also constructed alternative block-wise abundance estimates, using the software Distance 5.0 with its mark-recapture distance sampling (MRDS) option (Thomas et al., 2006). This was done primarily as a quality control, yielding an estimate based on a completely independent estimation framework. In Distance we modeled the distance data as a hazard function and the mark-recapture data (dependent probabilities) as a logistic function, assuming point independence at the transect line. The estimate of perpendicular distance for each whale was based on the initial sighting, regardless of whether one or two observers detected this cue. Covariates enter the Distance model and hazard probability model (present paper) in different ways. Covariates were selected in Distance based on the AIC criterion, yielding Beaufort, Vessel and Glare as the covariates in the DS part, and Beaufort, Perpendicular distance and Platform in the MR part. We used the same set of duplicates in Distance as was used in the present analysis. The Distance estimates were not corrected for measurement error or error in duplicate identification.

RESULTS

Over the survey period 2002-2007 a total effort of 27 061 km was conducted (Table 1, Figure 2). Two of the planned survey blocks were not covered: VSI and SVI within the ES SMA. During the survey of the Svalbard area in 2003, the VSI block was covered with ice and thus not possible for us to survey, and problems with weather made it impossible to survey the SVI block within the time frame available. It is not expected that this introduces a large bias to the total abundance as in the previous survey cycle (1996-2001) the abundance in SVI was estimated at about 1 900 animals with a large SD of 1 300. All other blocks received a reasonable coverage.

A total of 834 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 2). After imputing and applying the selection criteria mentioned above, there are 811 sightings of groups left, which corrected for group size, resulted in 841 individual minke whales to be used in the estimation of abundance. Characteristics of the collected distance data are shown in Figure 3. As is seen, most sightings were made within a 1000 m strip on each side of the transect line. The track matching analysis resulted in 147 duplicate whales. Number of initial sightings for the combined platform AUB was 633, and the number of Bernoulli trials was 617.

In the analysis of data from previous survey periods the slope parameter for the sighting angle has been fixed at $\lambda_\theta = 0.1$ (Schweder et al. 1997, Skaug et al. 2004). In the present paper λ_θ was been estimated to 0.037, which is smaller than the value $\lambda_\theta = 0.1$ used previously. The deviances for a selection of covariate models are shown in Table 3. Based on these results the model with linear predictor η_r = B + P + T was chosen to be used for abundance estimation (See Discussion). Uncorrected and bias corrected parameter estimates are shown in Table 4. In Table 5 are shown the effective strip half-widths associated with twelve different combinations of covariate levels.

Diagnostics plots are shown in Figure 3. The fit to the data is in general good, but there are more successes in the Bernoulli trials at large distance, especially at platform A, than predicted by the model. The histogram of

sighting angles drops off more quickly at θ = 45° (Figure 3) than in earlier surveys. This is in line with the survey protocol (Øien, 1995). With λ_θ being a parameter that is estimated the model is able to account for this.

Abundance estimates were calculated for each survey block (Table 1). Estimates for the IWC Small Areas were calculated by combining the contributions from the appropriate survey blocks (Table 6). The total estimate for the survey area is 108 140 (CV 0.23), while the estimate for the Eastern North Atlantic Medium Area in the RMP terminology is 81 401 (CV 0.23).

The multiyear model used to estimate additional variance from yielded the estimates $\sigma = 0.41$ for the variance parameter and $\lambda = -10$ (lower limit for the numerical optimizer) for the correlation parameter. Hence, there is no evidence for a positive correlation in abundance between spatially adjacent survey blocks. Note that there is a general negative correlation between all survey blocks induced by equation (1), reflecting the fact that the total abundance is fixed. The corresponding scaling factors for the CV were $c = 1.11$ for the total area and $c = 1.14$ for the Eastern medium area. These factors are incorporated in the CVs reported in the above paragraph.

DISCUSSION

Comparison with earlier estimates

The point estimates of total abundance for the current (2002-2007) and previous (1996-2001) survey period are very similar (Table 1), but the estimated uncertainty is larger for the current period as will be discussed below. Although the estimation methodology in most parts is the same as that used by Skaug et al. (2004), there are several differences at a detailed level. The duplicate identification rule has been modified, the structure of the measurement error model has been changed and the method used to estimate the Neyman-Scott parameters is new. The motivation and effect of these changes is discussed below. Also, we also summarize the changes that has been made in response to the recommendation from last year's SC.

The increase in the CV of the total abundance estimate, relative to the previous survey period, can not be caused by a difference in the estimates of additional variance. Using numbers from Skaug et al. (2004) we get $c = 13937/10821 = 1.29$ which is larger than the estimate $c = 1.11$ for the current period. A partial explanation for the increase in CV is that a larger number of minke whales were seen in 1996-2001 (1078 versus 843; sum both platforms). The number of observations affects both the precision of parameter estimates and the estimated encounter rate.

Since the estimate for the SMA CM (26 739, CV 0.39) is in accordance with that from 1996-2001 (26 718, CV 0.14) there is no indication of a shift in distribution between the regional area E and other areas (i.e. C). Neither is there evidence for shifts within E, however, with a possible displacement of minke whales from the North Sea northwards to the Lofoten area.

The abundance estimates obtained with Distance are on average 20-30% lower than those obtained with the present approach (Table 1). Note that no bias correction has been applied to the Distance estimates, but since the bias correction does not change the abundance estimates of the present method much, a direct comparison should be relevant. Distance does not directly account for the discrete availability of the whales. Ignoring this type of heterogeneity has been shown to yield negative bias in the abundance estimate around 30% in a minke whale like situation (Skaug and Schweder, 1999). However, the with its "point independence" option Distance will account for some of the heterogeneity caused by discrete cues, but now studies has been conducted to investigate exactly how much. In addition, there are other differences that can explain the discrepancy between the abundance estimates. Distance uses a subset (only perpendicular distances) of the information used the present analysis. Hence, the uncertainty should be larger. Further, the underlying statistical model is different, also in the way the covariates affects the effective strip half-width.

Details about the estimation process

The chosen covariate model η_r = B + P + T is not the model with the best model according to the AIC criterion (Table 3). The difference on the AIC with the best fitting model (B+W+Vi+P+T) 10 units. However, we experience convergence problems in the iterative bias correction with the larger covariate models, and this prevented the further use of these models. It should be noted that the abundance estimate for the chosen model differs by at maximum 2500 whales from the more complex covariate models.

Response to last years recommendations

Last year's discussion in the SC recommended that the duplicate identification rule should be revised (IWC, 2008). A version of the rule with a stricter time criterion was developed (Bøthun and Skaug, 2009) and has been employed in the present analysis. This new rule was found to perform well in terms of giving a good balance between type I and II errors. (A type I error occurs when cues from distinct individuals get matched up, while a type II error is the failure to correctly identify truly matching cues). The probability of these errors depends on the several characteristic (measurement error structure, animal density etc.) of the dataset applied to. In Skaug et al (2004) the previously employed (more liberal) rule performed well, but for the current dataset the type I error rate is much higher than that for type II errors, i.e. many unrelated individuals end up being matched with the liberal rule. On this ground we argue that the strict rule is more appropriate.

The measurement error models used previously (Schweder et al. 1997, Aldrin et al. 2003, Bøthun et al. 2008) have not contained observer effects, i.e. the systematic part of the model has been the same for all observers, and there has been no serial correlation within track in the stochastic part. By accounting for serial correlation in the residuals and also accounting for observer specific effects in the bias part of the model Bøthun (2009) showed that the observers on average estimated the radial distance fairly unbiased. In 1997 the abundance estimation working group for NA minke whales agreed on using a common measurement error model for all vessels and observers (SC/48/Rep1, 1997) after accounting for random effects. Further the working group recommended using the experiment data to estimate the systematic part of the model and sighting data to estimate the stochastic part of the model. We have followed those recommendations, but also note that there was very little difference between the estimated stochastic part from the experiment data and the sighting survey data (Bøthun 2009).

The method used to estimate the Neyman Scott parameters is described in Skaug (2009), and differs from that underlying the analysis in Skaug et al. (2004). The main reason for the methodology change was that the previously applied approach was operationally too demanding. The approach in Skaug (2009) involves an intermediate model, the so-called Markov modulated Poisson process, which was shown to have in some respects rather different properties from the Neyman-Scott process. However, because the key properties of the model (cluster radius, the number of whales per cluster, and the overall whale density) are the same for the two models there is no reason to believe that the approach of Skaug (2009) would lead to severely biased estimates the Neyman-Scott parameters.

In the analyses underlying previous abundance estimates for NA minke whales (Schweder et al. 1997, Skaug et al. 2004) there has been a lack of fit to the Bernoulli data at large radial distance (there are more successes than predicted by the model). The same is the case for the Bernoulli trials for platform A in the present analysis (Figure 3), although to a lesser extent. The lack of fit is caused by heterogeneity in detectability of individual whales or individual cues within whales (Skaug, Schweder and Laake 2009). This heterogeneity has been shown to lead to negative bias in the abundance estimate, and is hence not a concern from a conservation perspective.

We have now collected dive time data from 20 whales distributed over all SMAs (Øien et al. 2009). The appropriateness of the surfacing rate estimates collected by VHF tagging as compared to survey data has been discussed by Skaug, Bøthun and Øien (2009). They concluded that there is no evidence of negative bias in VHF surfacing rate estimates and thus no evidence for introducing positive bias in the abundance estimate.

CONCLUSION

There is no reason why abundance estimates in the present paper should be positively biased, and they should hence be appropriate for use in the RMP.

ACKNOWLEDGEMENTS

The surveys have been partially funded by grant no. 111043/S40 from the Norwegian Research Council. We are very grateful to the Norwegian Coastguard for providing vessels as well as the chartered vessels *'Ulvos'* and *'Havsel'*, the observers and the team leaders on all participating vessels for 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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Table 1. Summary of survey results by survey block as arranged within the RMP *Small Areas* (IWC, 2004). The information given are 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), average total effective strip half-width (w_A+w_B), abundance estimate N and associated standard deviation (SD). The two rightmost columns are obtained using the program Distance.

Small Area	Block	Year	Area (km^2)	L (km)	n_{A+B}	Hazard probability method			Distance
						w_{A+B}	N	SE	N
CM	JMC	2005	66 640	583	69	382.3	10 310.2	3 679.8	7 400.8
	NVN	2005	351 564	1 721	48	349.3	14 035.6	9 315.8	9 344.0
	NVS	2005	310 009	1 843	18	430.2	3 518.4	1 978.7	1 632.4
EB	BAE	2007	394 951	1 789	55	440.3	13 790.4	5 077.0	10 672.1
	BAW	2003	12 514	197	1	432.0	73.3	61.0	66.7
	BÂW	2007	34 850	243	0	299.8	0	0	0
	FÎ2	2002	16 033	389	5	362.6	284.3	243.3	196.2
	FI2	2007	16 033	130	0	238.3	0	0	0
	GA	2007	160 910	1 318	65	471.2	8 422.8	3 388.0	9 089.7
	KO	2007	95 957	770	39	331.2	7 336.2	2 777.6	5 907.9
EN	NC2	2004	99 531	373	16	611.4	3 488.6	2 550.1	1 529.2
	NS	2004	261 301	2 156	23	466.5	2 987.4	1 406.3	1 939.3
ES	BAW	2003	73 933	671	24	371.3	3 560.0	1 819.3	2 403.1
	BJ	2003	75 466	1 232	80	509.8	4 805.7	1 563.6	4 332.4
	NON	2003	90 390	765	18	326.5	3 257.4	1 230.3	2 121.6
	SV	2003	79 944	796	45	307.2	7 357.6	4 570.2	4 142.6
	VSN	2003	18 259	344	7	570.4	325.9	225.6	249.2
	VSS	2003	28 891	487	14	470.0	883.0	505.3	617.3
	VSI	2003		Ice cover					
	SVI	2003		Not surveyed					
EW	FI1	2002	78 605	1 618	49	424.8	2 801.6	1 207.8	1 981.1
	FI1	2006	78 605	466	2	326.1	516.8	389.2	415.7
	LOC	2006	97 355	1 261	44	472.4	3 597.0	1 718.0	1 892.5
	NC1	2004	211 580	1 305	13	295.8	3 562.8	1 759.9	1 633.7
	NC1	2006	211 580	816	20	430.3	6 029.6	2 029.9	4 828.2
	NOS	2002	396 724	4 344	134	348.1	17 576.9	4 953.1	9 035.6
	NOS	2006	396 724	1 563	52	356.6	18 509.0	7 154.2	12 953.9

Table 2. Covariates recorded hourly or more often during the surveys.

		Transformed (aggregated) covariates		
Covariate	**Description**	**Abbreviation**	**Levels**	**Definition**
Beaufort	5 categories	B	0 - 4	
Weather	12 categories	W	rain, no rain	no rain: W01-W04, rain: W05-W12
Vessel	5 vessels	Ve	short, medium, long	short: ULV, Medium: PJA, NYS, HAV, Long: THO
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

Table 3. Comparison of different covariate models for the linear predictor η_r (radial distance), with the selected model in bold face. Deviance and number of parameters are shown relative to the maximal model. Abundances estimates are without bias correction.

Model	**Δ Deviance**	**Δ #Parameters**	**AIC**	**Abundance**
B+W+Vi+P+T	3.1	3	11607.48	109 920
B+W+Ve+Vi+G+P+T	0	0	11610.38	110 840
B+W+P+T	9.3	4	11611.70	112 638
B+P+T	**16.9**	**5**	**11617.30**	**112 257**
B+T	29.8	6	11628.16	113 775
B	48.9	7	11645.30	113 530
T	120.0	7	11716.40	107 316
Ve	124.4	6	11722.80	110 302
P	126.9	7	11723.30	106 470
W	136.6	7	11505.08	107 962
G	138.5	7	11734.84	107 069
null	143.9	8	11738.32	107 413
Vi	143.9	7	11740.32	107 373

Table 4. Estimated regression coefficients for the chosen hazard probability model. $\tilde{\beta}$ denotes the parameter estimates without bias correction, while $\hat{\beta}$ is the estimates with bias correction. Standard deviations are given for the bias corrected parameter estimate.

	β_r	**Beaufort**	**Team long**	**Platform B**	β_0	β_μ	λ_r	λ_0
$\tilde{\beta}$	5.9385	-0.3321	0.1338	-0.1945	4.0734	0.1343	0.004970	0.03657
$\hat{\beta}$	6.2221	-0.2619	0.1047	-0.1555	4.0095	0.1361	0.006383	0.03675

SD($\hat{\beta}$)	0.3171	0.1598	0.0892	0.2105	1.2023	0.3738	0.0002	0.0149

Table 5. Effective strip half-widths *w* (meters) for platforms A and B for selected combinations of covariate levels. *Time* indicates the combination's proportion of primary search effort.

Beaufort	Team A	Team B	w_A	w_B	$g_A(0)$	$g_B(0)$	Time (%)
0	short	short	451	360	0.72	0.66	0.9
0	short	long	451	489	0.72	0.74	0.4
0	long	short	615	360	0.79	0.66	0.8
0	long	long	615	489	0.79	0.74	1.2
2	short	short	217	178	0.54	0.50	7.8
2	short	long	217	233	0.54	0.56	4.5
2	long	short	287	178	0.61	0.50	3.9
2	long	long	287	233	0.61	0.56	9.6
4	short	short	123	108	0.41	0.39	8.4
4	short	long	123	129	0.41	0.42	6.4
4	long	short	150	108	0.46	0.39	6.5
4	long	long	150	129	0.46	0.42	12.6

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

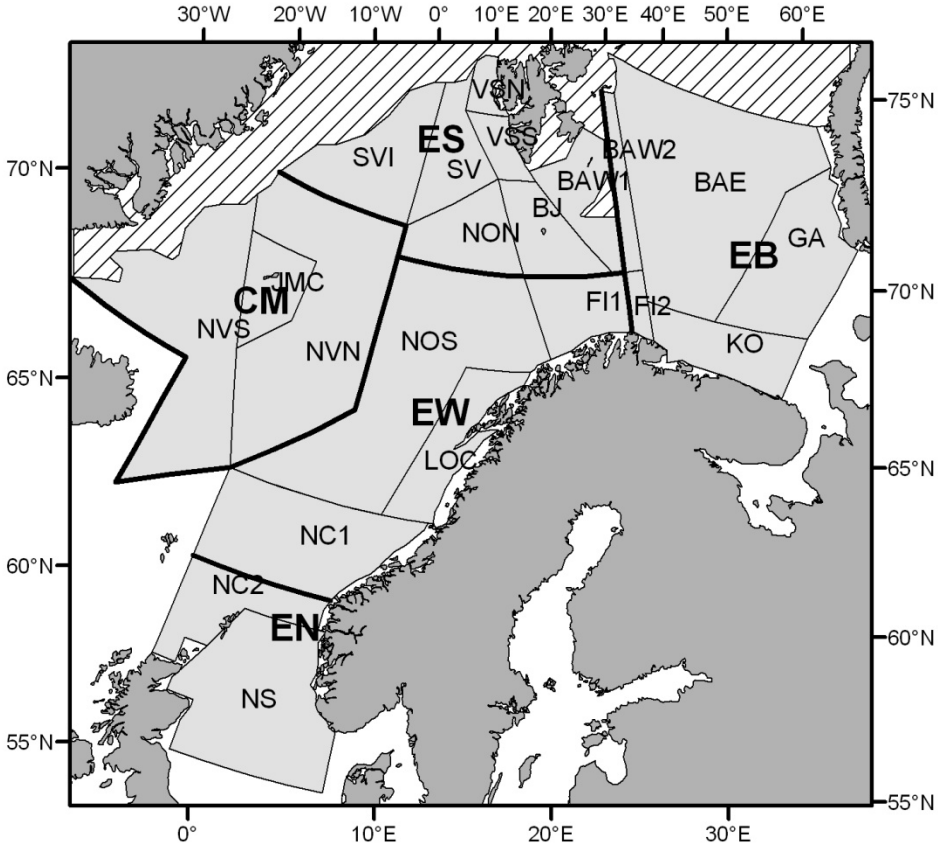

Figure 1. The total survey area for the Norwegian surveys. *Small Management Areas* are as decided at the Implementation Review in 2003 when some changes were made in the previous definitions. Stratum structure is shown as used in the present analyses. The ice edges are based on maps for mid-July for the year when the adjacent survey blocks were covered.

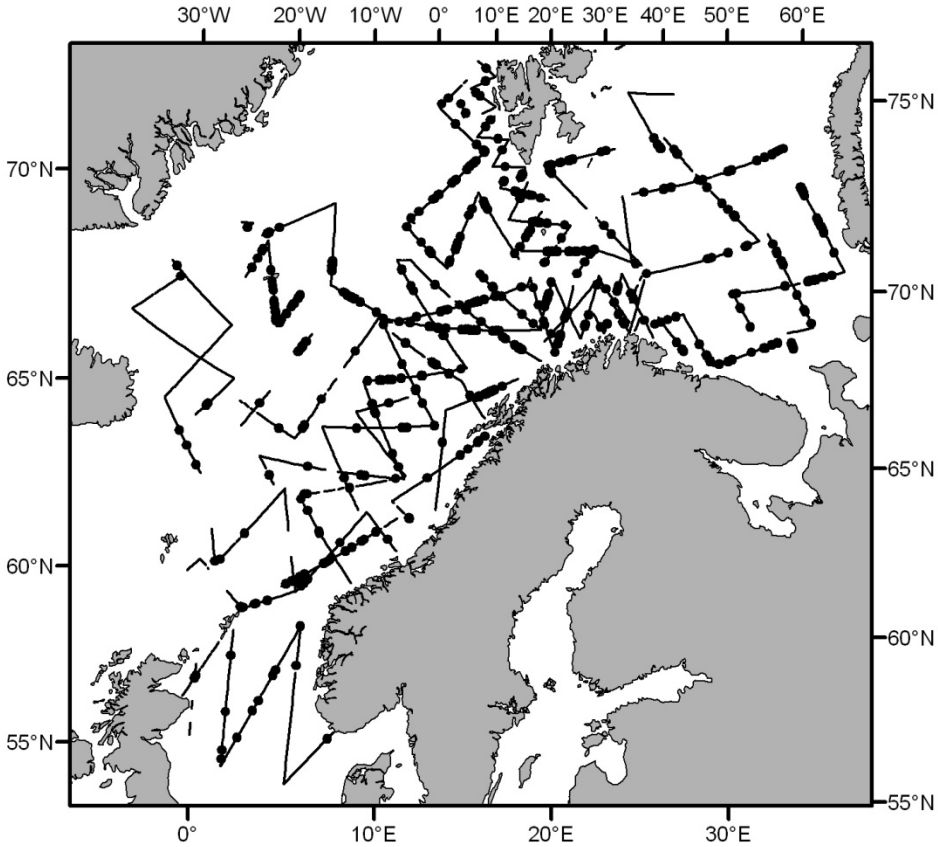

Figure 2. Transect lines covered in primary search mode (realized survey effort) and primary minke whale sightings (dots) made from platform A, 2002-2007.

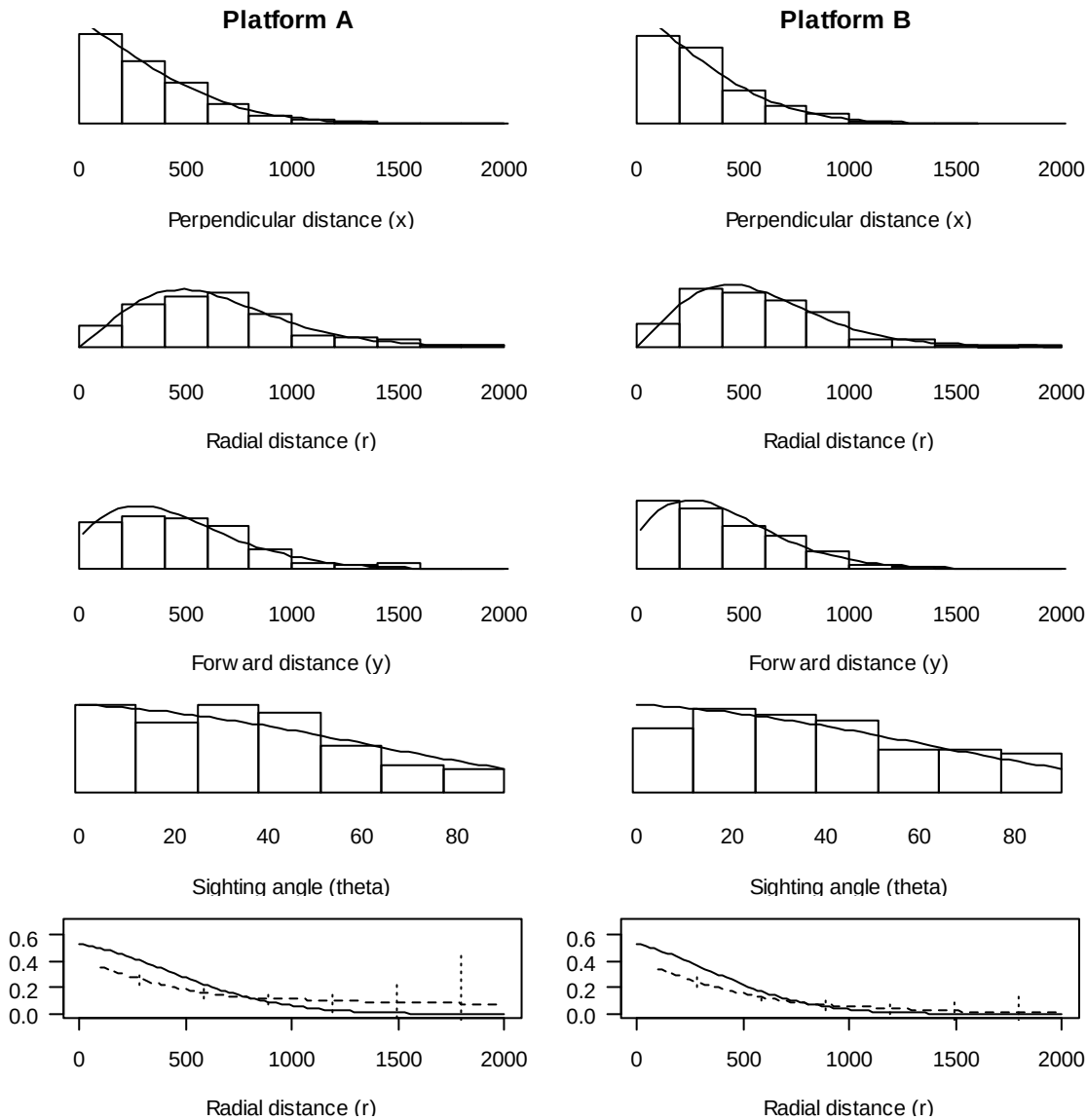

Figure 3. Normalized frequency distributions of observed perpendicular distances by observer platform with fitted probability densities shown as solid lines. Corresponding panels are given for radial distances, forward distances and sighting angles. The bottom two panels show estimated success probabilities by radial distance for Bernoulli trials. The solid line is the model predicted success probability while the broken line is a nonparametric smoother applied to the data; the vertical lines are 95 % confidence intervals.