

Minke whale abundance estimation from the 2004/2005 IWC SOWER Antarctic cruise in Area III

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ABSTRACT

Estimates of minke whale abundance in the part of Area III surveyed in 2004/2005 were obtained using standard IWC methods. A variety of pooling options to estimate the effective strip half-width (w_s) and mean school size were considered but small numbers of sightings meant that all sightings had to be pooled to estimate a single w_s for each mode and a single mean school size. The combined closing and IO mode estimate of minke abundance in the survey area is 8,347 whales (cv=24.5%) with a 95% confidence interval (5,200; 13,400). We also estimated whale abundance when sightings classified as 'like minke' were included. Comparisons with previous surveys conducted in Area III were difficult because of the different survey regions, however, some density estimates from these surveys are presented.

INTRODUCTION

The twenty-seventh IWC-SOWER circumpolar cruise consisted of a minke whale survey component and several research components. This report presents the results of the minke whale survey, which was conducted from 12 January to 8 February 2005. The scheduled research area covered 0°E to 35°E. The region 0°E to 20°W was surveyed in two contiguous strata (northern and southern) from 64°30S to the ice edge. Poor weather limited the coverage of the region 20°E to 35°E to the southern stratum only. Collaborative studies with the Japanese icebreaker *Shirase* took place from 10 to 22 February 2005 between 35°E to 50°E and sighting rates from these are given (Table 7). Two vessels participated in the survey; the *Shonan Maru* (SM1) and the *Shonan Maru No. 2* (SM2). Full details of the survey are given in Ensor *et al.* (2005).

The survey region and tracklines are shown in Figure 1. SM2 surveyed the northern part (WN) and both SM1 and SM2 surveyed the southern part (WS and ES). Stratum ES2 was surveyed during the collaborative studies with the icebreaker.

For the base case analysis, schools identified as minke (species code 04) and 'undetermined minke' (code 91), seen while searching under full effort, were included and are referred to as 'minke'. There were no schools identified as 'minke, like Antarctic' (code 92). Schools identified as 'like minke' (code 39) were also included in an analysis. The numbers of sightings for each species code are shown in Table 1. We estimated whale abundance in the area from both closing mode data and IO mode data. For consistency with previous abundance estimates, we used the correction factor estimated by Branch and Butterworth (2001) to convert closing to 'Pseudo-passing' and hence obtained a combined-mode abundance estimate. We also updated this correction factor to include the more recent surveys.

DISTANCE AND ANGLE BIAS EXPERIMENTS

Estimated angle and distance experiments were conducted on both vessels in order to correct bias in estimated angles and distances to whales. As in previous analyses, bias was estimated for each platform separately (Table 2).

Distance estimation bias

Using linear regression models with standard error proportional to true (radar) distance, significant bias (at the 5% level) was found on all platforms for SM2. It was possible to correct this bias in the usual way by dividing the estimated distances by the estimated slope of the regression through the origin.

Angle estimation bias

Angle estimation bias is estimated using linear regression models with constant variance. Significant bias was found on the Bridge for SM1 and on the Barrel for SM2. It was possible to correct the bias in the usual way by dividing the estimated angles by the estimated slope of the regression through the origin.

ABUNDANCE ESTIMATION RESULTS AND DISCUSSION¹

Abundance estimation was based on the standard methodology described in Branch and Butterworth (2001). Estimation was performed separately for data from closing mode and data from Independent Observer (IO) mode, except that in both cases confirmed school sizes from closing mode were used to estimate mean school sizes. Full effort in closing mode is comprised of 'BA', 'BC' and 'BR' effort codes, while in IO mode full effort is comprised of 'BI' and 'BO' effort codes. Probability of detection on the trackline, $g(0)$, was assumed to be one.

Sighting rate

Sighting rates and their variances were estimated separately in each stratum (Table 4). The variances were estimated on the basis of inter-

¹ The Appendix contains a summary of the notation used in the text and in the tables.

transect variation within each stratum. SM2 conducted very little search effort in IO mode in the southern strata (7 nm) and so this has been ignored in the calculations. Table 7 contains sighting rates obtained during the collaborative studies with the icebreaker.

Effective strip half-width

Pooling across strata is often necessary for reliable estimation of the detection function and the effective strip half-width (w_s) when the sample size within a stratum (n_s) is small, as in this case. Branch and Butterworth (2001) suggested that a total of 15 confirmed and unconfirmed sightings in a stratum was the minimum required to avoid pooling. Due to the small number of sightings there were only two combinations possible for pooling sightings and Akaike's Information Criterion (AIC; Akaike 1973) was used to decide between pooling options. The AIC, shown in Table 3, suggested that all sightings made in closing mode should be pooled to obtain a single estimate of w_s . The small number of sightings in IO mode meant that these were also pooled to obtain a single estimate of w_s . The main results are presented using these pooling options and are shown in Table 4; the fitted detection functions are shown in Figure 3. The estimate of w_s in closing mode is wider than typically estimated (e.g. Branch and Butterworth, 2001). The majority of sightings were detected in the western strata where survey effort was carried out in good conditions (Ensor *et al.* 2005). Examination of the radial distances and estimated angles does not suggest that there was systematic bias in these measurements (Figure 4).

Mean school size

Estimates of mean school size are obtained from closing mode sightings with confirmed school sizes and these estimates are used to convert estimates of school density to estimates of whale density for both closing and IO mode data. We used the $\log(\text{size})$ vs. $g(x)$ regression method of Buckland *et al.* (2001) to estimate mean school size. The estimates of $g(x)$ for confirmed schools were obtained using the same level of pooling as that used for estimating the detection functions for all schools (Figure 3). *A priori*, we expected that school sizes would be larger in the south, than in the north. The average school size in WS was 2.80 (cv=7.3%), in ES it was 1.57 (12.9%) and in WN it was 1.38 (13.3%) and so we estimated separate estimates using the regression method for each strata. However, for WN and ES this produced a correlation of $\log(\text{size})$ vs. $g(x)$ that was positive. In this case, the recommended method is to replace the regression estimate by the average school size of sightings within a perpendicular distance of 0.5 nm of the trackline. However, there were so few sightings made within 0.5 nm of the trackline for these strata that it was decided to pool all sightings together and estimate a single school size using the regression method.

Density and abundance

Estimates of minke whale density and abundance are shown in Table 4. The estimated abundance for each stratum and vessel is given by \hat{P} . For strata surveyed by more than one vessel (WS and ES), the estimated abundance (\hat{P}_{avg}) is a weighted mean of \hat{P} , weighting by the vessel effort (L) in the stratum. The stratum abundance estimates were multiplied by the factor $m = 0.985$ (cv=0.0%) used by the IWC to correct for whale movement.

The combined closing mode and IO mode estimate for 2004/05 was obtained using the method of IWC (1991, p117). This involves converting the closing mode estimate to 'pseudo-passing' mode by dividing it by a calibration factor, R , estimated from a series of closing mode and IO mode density estimates, and then taking an inverse-variance weighted average of the IO and 'pseudo-passing' mode estimates. For comparability with previous abundance estimates we used the correction factor of Branch and Butterworth (2001), $R=0.826$ (cv=8.9%). The resulting weighted mean whale abundance for the 2004/05 survey is 8,347 whales (cv=24.5%), with an estimated 95% confidence interval of (5,200; 13,400).

Inter-survey comparisons

Area III was previously surveyed in 1979/80, 1987/88, 1992/93 and 1994/95 (Figure 2). The two earlier surveys covered the longitudinal range of Area III (0°E-70°E) but not the entire latitudinal range (ice-edge to 60°S). The two later surveys covered the entire latitudinal range but only a limited longitudinal range (0°E-40°E in 1992/93 and 40°E-70°E in 1994/95). The lack of overlap between years and the different location of the ice-edge between years renders comparisons based on the area common to all surveys virtually meaningless. However, in Table 6 we tabulate some density and abundance estimates of strata that overlap with the 2004/05 survey.

Inclusion of 'like minke' whales

Abundance estimates including 'like minke' sightings are presented in Table 5. To estimate whale abundance, estimates of mean school size were obtained from closing mode data using only confirmed minke schools as previously described. When 'like minke' sightings are included the closing mode abundance estimate is 6,740 whales (cv=27.7%) which is 6% more than the minke only estimate. The IO mode abundance estimate including 'like minke' is 10,976 whales (cv=30.2%) which is 4% more. These difference are small because small increases in sighting rate due to like minke sightings (5 in closing mode and 13 in IO mode) have been offset by small increases in the estimates of w_s .

Updated estimates of R

Branch and Butterworth (2001) calculated an updated estimate of R based on all surveys from 1985/86 to 1997/98. Their estimate of 0.826 (cv=8.9%) is somewhat higher than the previous estimate of $R=0.751$ (cv=15.2%). Updating this estimate of R to include the 1998/99 to 2004/05 surveys gives a combined estimate of 0.872 (cv=7.5%). It is not significantly different from 1 ($z=-1.88$) at the 5% level testing $H_0: \ln(R)=0$ vs $H_1: \ln(R) \neq 0$. Thus, we cannot reject the null hypothesis of no difference between closing mode and IO mode bias at the 5% significance level.

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APPENDIX

Notation

D_s	Density of schools (schools per nm ²).
D_w	Density of whales (whales per nm ²).
$\hat{E}[s_{sc}]$	Estimated mean school size of confirmed schools sighted in closing mode used in abundance estimation.
$g(x)$	Detection function where x is the perpendicular distance at which the cluster was observed.
h	Correction for whales missed on the trackline. ($h=1.0$, $cv=0.0\%$ by assumption).
k_L	Number of transects/waypoint legs. (A waypoint leg is a stretch of primary effort between waypoints.)
L	Primary effort in nm.
m	Correction for whale movement. ($m=0.985$, $cv=0.0\%$ by assumption)
nm	Nautical miles.
n_s	Number of schools sighted, after smearing and truncation at 1.5 nm. n_s is given by stratum and vessel and overall.
n_{sc}	Number of schools of confirmed size sighted, after smearing and truncation at 1.5 nm used in size-bias regression.
n_s/L	Sighting rate after smearing and truncation at 1.5 nm.
P	Abundance (of whales).
P_{avg}	Weighted average abundance for stratum where stratum has been surveyed by more than one vessel. Weighting is by effort L .
\hat{w}_s	Estimated effective search half-width of schools seen.
\hat{w}_{sc}	Estimated effective search half-width of confirmed schools seen during closing mode survey.

Table 1 Numbers of sightings for species codes within a perpendicular distance of 1.5nm of the trackline. The species codes are: 04 Antarctic minke; 92 minke, like Antarctic; 91 undetermined minke; and 39 like minke.

Vessel	Stratum	Closing mode				IO mode			
		04	92	91	39	04	92	91	39
SM1	WS	41		1	4	25		12	10
	ES	4		1	1	1		2	3
	ES2	2		1		5		2	1
SM2	WN	7		1		9			
	WS	6							
	ES	2							
	ES2	1				1		1	
Total		63		4	5	41		17	14

Table 2 Estimated observer bias in distance and angle estimation. Estimated biases are the slopes of the regressions through the origin. Only slopes significant at the 5% level are shown.

Vessel	Platform	Estimated bias	
		Distance	Angle
SM1	Barrel	-	-
	IOP	-	-
	Bridge	-	1.117
SM2	Barrel	1.165	0.908
	IOP	1.180	-
	Bridge	1.174	-

Table 3 AIC values for the different pooling options based on unsmeared sightings truncated at 1.5 nm, where n is the number of sightings.

Pooling options		Closing		IO mode	
Vessel	Geographic strata	n	AIC	n	AIC
SM1+SM2	All	63	340.4	49	254.6
SM1	WS+ES	47	256.0	40	213.5
SM2	WN	16	87.9	9	40.8
Total			343.9		254.3

Table 4a Minke whales (codes 04 and 91) during Closing mode: Estimates of the components of the density estimator. Notation is given in the Appendix but note that the subscript s refers to schools and sc refers to confirmed schools. Figures in parentheses are %cv's.

Stratum	Vessel	k_L	n_s	L	n_s/L	n_s	\hat{w}_s	n_{sc}	\hat{w}_{sc}	$\hat{E}[s_{sc}]$
WN	SM2	8	8.0	347.03	0.0231 (59.2)	60.8	1.188 (11.1)	57.0	1.172 (12.8)	2.34 (7.8)
WS	SM1	11	39.9	248.22	0.1608 (26.9)					
	SM2	4	5.9	141.96	0.0415 (67.2)					
ES	SM1	5	5.0	167.33	0.0299 (42.2)					
	SM2	3	2.0	73.42	0.0272 (105.6)					
Total		31	60.8	977.96						

Table 4b Minke whales (codes 04 and 91) during IO mode: Estimates of the components of the density estimator. Notation is given in the Appendix but note that the subscript s refers to schools and sc refers to confirmed schools. Figures in parentheses are %cv's.

Stratum	Vessel	k_L	n_s	L	n_s/L	n_s	\hat{w}_s	n_{sc}	\hat{w}_{sc}	$\hat{E}[s_{sc}]$
WN	SM2	9	8.6	451.03	0.0190 (45.2)	47.23	0.626 (30.4)	57.0	1.172 (12.8)	2.34 (7.8)
WS	SM1	10	36.0	327.46	0.1100 (32.4)					
ES	SM1	3	2.6	125.52	0.0209 (62.9)					
Total		22	47.2	904.01						

Table 4c Minke whales (codes 4 and 91) during Closing mode: Estimates of density and abundance. Notation is given in the Appendix but note that the subscript s refers to schools and w to whales. Figures in parentheses are %cv's.

Stratum	Vessel	Area (nm ²)	\hat{D}_s	\hat{D}_w	\hat{P}	\hat{P}_{avg}	$mh\hat{P}_{avg}$
WN	SM2	107 329	0.0097 (60.2)	0.0227 (60.7)	2 437 (60.7)	2 437 (60.7)	2 401 (60.7)
WS	SM1	28 290	0.0677 (29.1)	0.1584 (30.1)	4 480 (30.1)	3 271 (28.4)	3 222 (28.4)
	SM2		0.0175 (68.1)	0.0409 (68.5)	1 157 (68.5)		
ES	SM1	26 374	0.0126 (43.6)	0.0294 (44.3)	776 (44.3)	755 (44.7)	744 (44.7)
	SM2		0.0115 (106.1)	0.0268 (106.4)	708 (106.4)		
Total		161 993					6 367 (28.9)

Table 4d Minke whales (codes 4 and 91) during IO mode: Estimates of density and abundance. Notation is given in the Appendix but note that the subscript s refers to schools and w to whales. Figures in parentheses are %cv's.

Stratum	Vessel	Area (nm ²)	\hat{D}_s	\hat{D}_w	\hat{P}	$mh\hat{P}_{avg}$
WN	SM2	107 329	0.0152 (54.5)	0.0356 (55.1)	3 818 (55.1)	3 760 (55.1)
WS	SM1	28 290	0.0879 (44.4)	0.2057 (45.1)	5 821 (45.1)	5 733 (45.1)
ES	SM1	26 374	0.0167 (69.9)	0.0391 (70.3)	1 032 (70.3)	1 017 (70.3)
Total		161 993				10 511 (40.8)

Table 5a Minke and like minke whales (codes 04, 91 and 39) during Closing mode: Estimates of the components of the density estimator. Notation is given in the Appendix but note that the subscript s refers to schools and sc refers to confirmed schools of minke whales. Figures in parentheses are %cv's.

Stratum	Vessel	k_L	n_s	L	n_s/L	n_s	\hat{w}_s	n_{sc}	\hat{w}_{sc}	$\hat{E}[s_{sc}]$
WN	SM2	8	8.0	347.03	0.0231 (59.2)	65.8	1.189 (10.0)	57.0	1.172 (12.8)	2.34 (7.8)
WS	SM1	11	43.9	248.22	0.1767 (27.2)					
	SM2	4	5.9	141.96	0.0415 (67.2)					
ES	SM1	5	6.0	167.33	0.0359 (30.8)					
	SM2	3	2.0	73.42	0.0272 (105.6)					
	Total	31	65.8	977.96						

Table 5b Minke and like minke whales (codes 04, 91 and 39) during IO mode: Estimates of the components of the density estimator. Notation is given in the Appendix but note that the subscript s refers to schools and sc refers to confirmed schools. Figures in parentheses are %cv's.

Stratum	Vessel	k_L	n_s	L	n_s/L	n_s	\hat{w}_s	n_{sc}	\hat{w}_{sc}	$\hat{E}[s_{sc}]$
WN	SM2	9	8.6	451.03	0.0191 (45.3)	60.7	0.762 (21.3)	57.0	1.172 (12.8)	2.34 (7.8)
WS	SM1	10	46.4	327.46	0.1416 (27.4)					
ES	SM1	3	5.7	125.52	0.0454 (62.9)					
Total		22	60.7	904.01						

Table 5c Minke and like minke whales (codes 04, 91 and 39) during Closing mode: Estimates of density and abundance. Notation is given in the Appendix but note that the subscript s refers to schools and w to whales. Figures in parentheses are %cv's.

Stratum	Vessel	Area (nm ²)	\hat{D}_s	\hat{D}_w	\hat{P}	\hat{P}_{avg}	$mh\hat{P}_{avg}$
WN	SM2	107 329	0.0097 (60.0)	0.0227 (60.5)	2 435 (60.5)	2 435 (60.5)	2 398 (60.5)
WS	SM1	28 290	0.0743 (29.0)	0.1739 (30.0)	4 919 (30.0)	3 549 (28.3)	3 496 (28.3)
	SM2		0.0174 (67.9)	0.0408 (68.4)	1 154 (68.3)		
ES	SM1	26 374	0.0151 (32.4)	0.0353 (33.3)	931 (33.3)	862 (37.3)	849 (37.3)
	SM2		0.0115 (106.0)	0.0268 (106.3)	707 (106.3)		
Total		161 993					6 744 (27.7)

Table 5d Minke and like minke whales (codes 04, 91 and 39) during IO mode: Estimates of density and abundance. Notation is given in the Appendix but note that the subscript s refers to schools and w to whales. Figures in parentheses are %cv's.

Stratum	Vessel	Area (nm ²)	\hat{D}_s	\hat{D}_w	\hat{P}	$mh\hat{P}_{avg}$
WN	SM2	107 329	0.0126 (50.1)	0.0294 (50.7)	3 154 (50.7)	3 107 (50.7)
WS	SM1	28 290	0.0929 (34.7)	0.2175 (35.5)	6 152 (35.5)	6 060 (35.5)
ES	SM1	26 374	0.0298 (66.4)	0.0697 (66.8)	1 838 (66.8)	1 810 (66.8)
Total		161 993				10 979 (30.2)

Table 6 Comparison of strata from previous surveys in Area V which overlap with the 2004/05 survey;
Estimates taken from Branch and Butterworth (2001). Abundance estimates are uncorrected for whale movement.

Survey	Strata	Area of strata nm ²	Abundance estimate		Whale density estimate	
			Closing mode	IO mode	Closing mode	IO mode
1979/80	WN	200 724	23 950 (43.7)	-	0.119 (43.7)	-
	WS	33 619	24 944 (31.1)	-	0.742 (31.1)	-
	Total	234 343	48 894 (26.6)			
1987/88	WN	148 821	33 513 (125.4)	53 914 (53.0)	0.225 (125.4)	0.362 (53.0)
	WS	74 351	42 334 (63.8)	60 799 (33.9)	0.569 (63.8)	0.818 (33.9)
	Total	223 172	75 847 (65.6)	114 713 (30.7)		
1992/93	ES	23 207	2 017 (103.6)	802 (42.5)	0.087 (103.6)	0.345 (42.5)
	WN (SM1)	210 035	12 882 (96.1)	7 412 (51.1)	0.061 (96.1)	0.035 (51.1)
	EN	150 547	2 477 (44.8)	4 033 (51.6)	0.165 (44.8)	0.027 (51.6)
	WS (SM1)	61 527	8 105 (117.0)	2 029 (25.9)	0.132 (117.0)	0.033 (25.9)
	WS (SM2)	61 527	8 161 (38.6)	13 620 (28.1)	0.133 (38.6)	0.221 (28.1)
	Total	445 316	23 322 (56.4)	24 970 (23.9)		

Table 7 Sighting rates of minke whales (code 04 and 91) in ES2. Sightings have been truncated at 1.5 nm.
The notation is given in the Appendix. Figures in parentheses are %cv's.

Mode	Vessel	k_L	n_s	L	n_s/L
Closing	SM1	7	3	146.0	0.021 (70.2)
	SM2	6	1	136.1	0.007 (77.3)
	Total	13	4	282.1	
IO	SM1	7	7	169.4	0.041 (27.6)
	SM1	6	2	139.3	0.014 (58.7)
	Total	13	9	478.1	

Figure 1 **The 2004/05 survey region showing strata and cruise tracks.** a) Minke whale survey. Stratum WN was surveyed by SM2. Stratum WS was surveyed by SM1 with additional effort from SM2 in the region 10°-20°E. Stratum ES was surveyed by both vessels. b) Region surveyed during collaborative research with Japanese icebreaker, *Shirase*. Both vessels surveyed in this region.

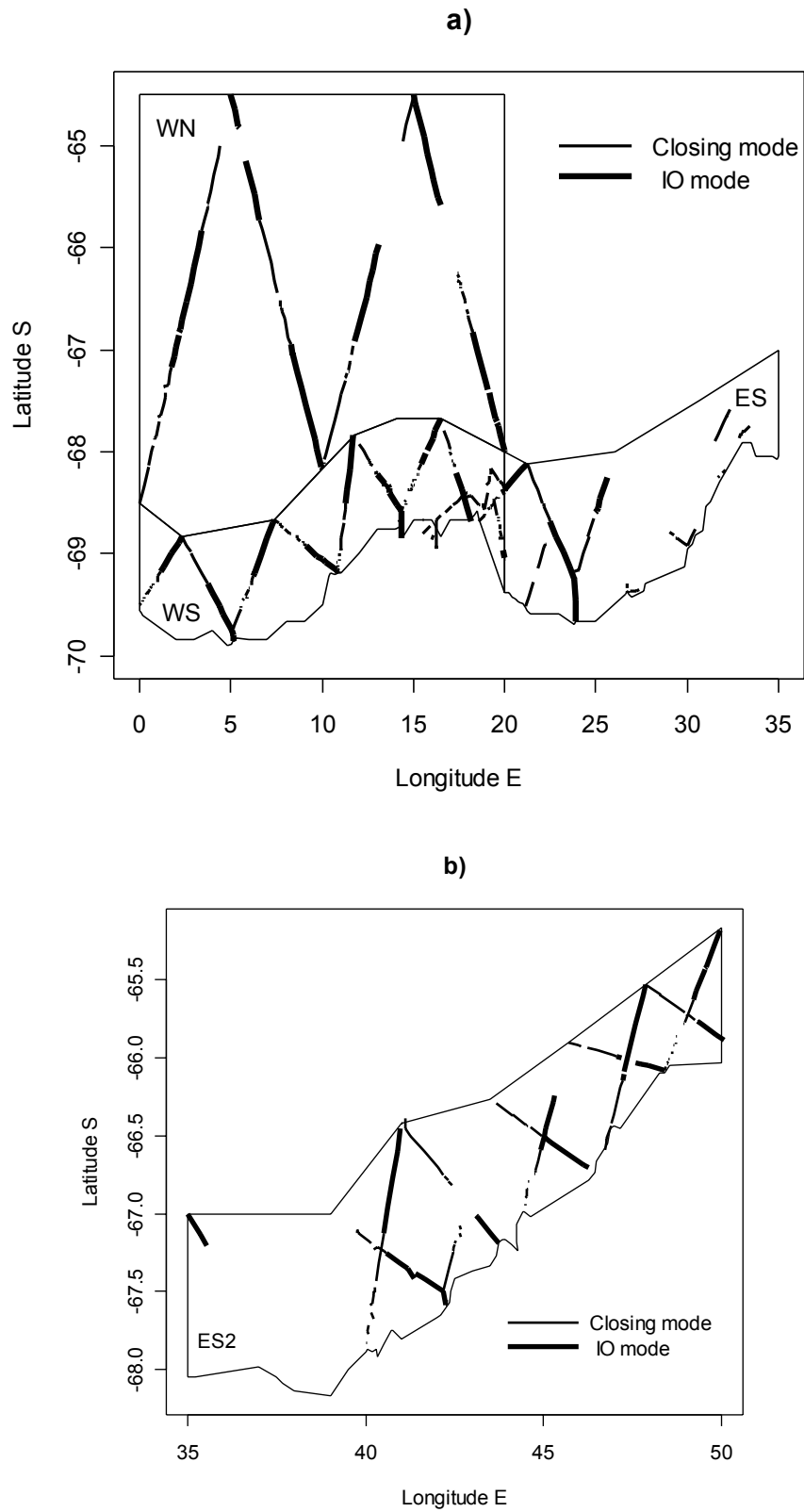


Figure 2 **The regions surveyed previously in Area III.** In a) one vessel closely followed the ice-edge in stratum WS and WUS was not surveyed. The main minke whale research component in 2004/05 was between 0°-35°E: in a), b) and c) this is the region to the left of the vertical dashed line and below the horizontal dashed line. The collaborative research with the icebreaker *Shirase* took place between 35°-50°E. This the region to the left of the vertical dashed line in d).

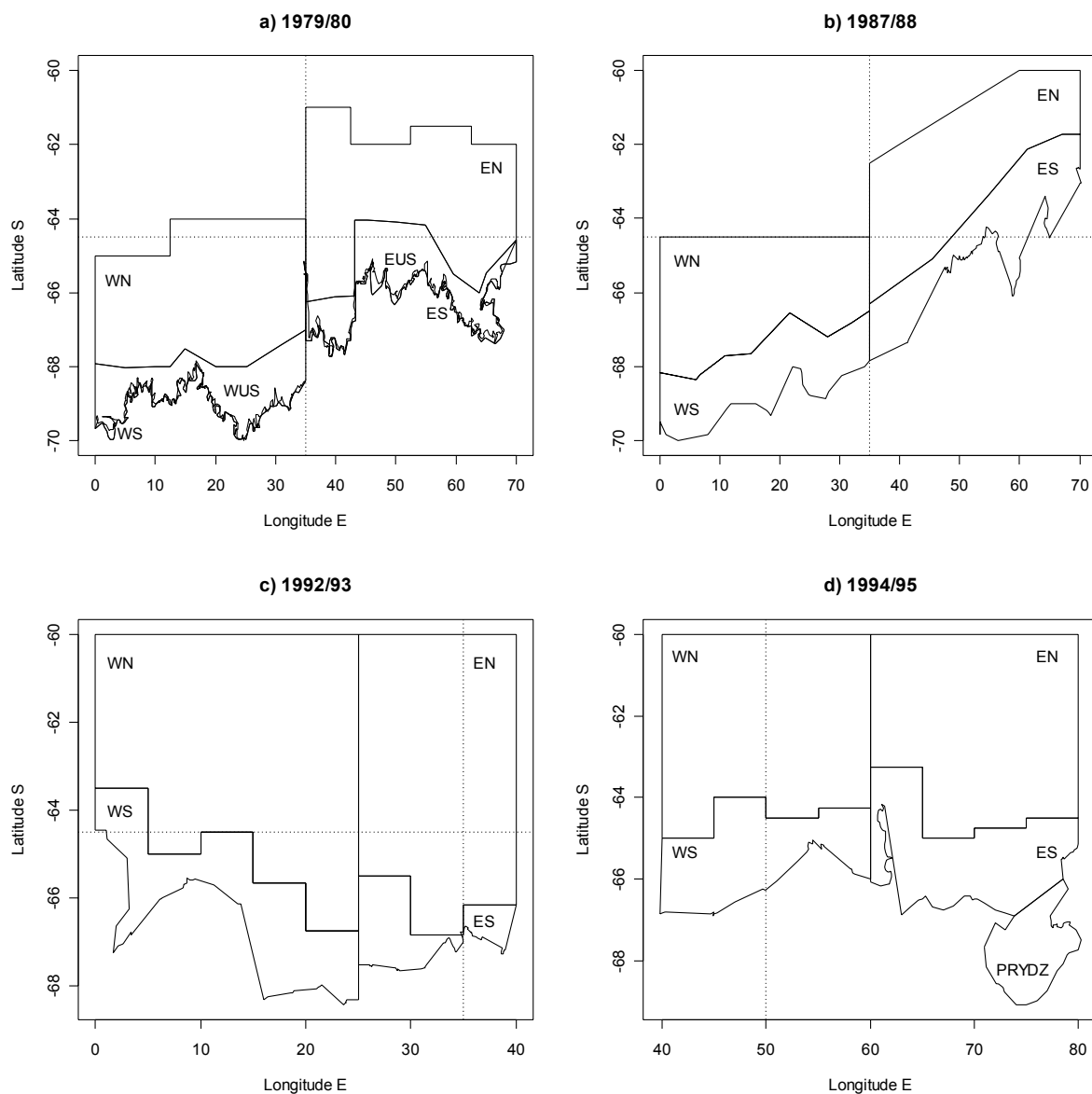


Figure 3 **Smearred perpendicular distance distributions of schools and fitted hazard rate detection functions.** The figures in parentheses are effective strip half-widths and number of minke schools sighted after smearing and truncation at 1.5 nm. a) Closing mode; b) IO mode; c) Closing mode including like minke sightings; d) IO mode including like minke sightings and e) Closing mode using only minke sightings with confirmed school sizes.

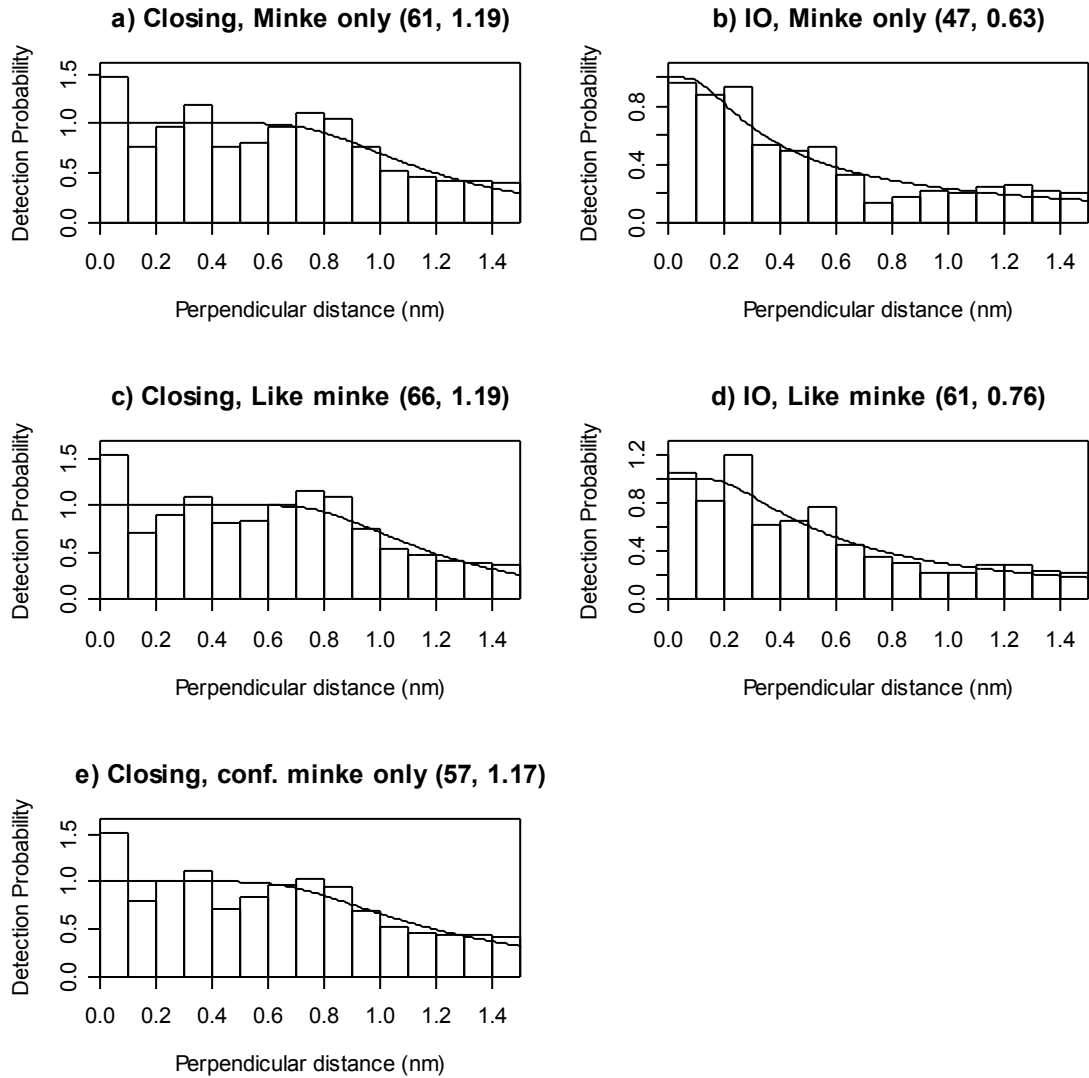


Figure 4 **Plots of radial distances against estimated angles for minke and like minke sightings (codes 04, 91 and 39).** Distances and angles are corrected for any bias. The dash line indicates a perpendicular distance of 1.5 nm.

