Effects of observed covariates (school size, sighting cue, latitude and sea state) on the Antarctic minke whale abundance estimation parameters in the IWC/IDCR-SOWER surveys

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ABSTRACT

The effects of observed covariates (school size, sighting cue, latitude and sea state) on Antarctic minke whale abundance estimation parameters (effective search half-width, sighting forward distance and mean school size) were examined qualitatively. As the school size decreased, the effective search half-width and the sighting forward distance decreased. Most single and two animal schools were sighted by body, which was difficult in high sea states in comparison with those sighted by blow. Proportions of single and two animal schools increased as sighting latitude moved north. Small school sizes and bad weather conditions prevailed in the northern part of the survey area. As the survey area was extended to the north, the effects of small school size and bad weather conditions could be substantial in the third circumpolar survey. Observed covariates analysed in this paper should be incorporated into the estimation of effective search half-width and mean school size as covariates.

KEWORDS: ABUNDANCE ESTIMATE; ANTARCTIC MINKE WHALE; *g*(0); ANTARCTIC; SOWER; SURVEY-VESSEL; TRENDS

INTRODUCTION

The International Whaling Commission (IWC) has conducted the Antarctic minke whale (*Balaenoptera bonaerensis*) abundance assessment cruises since 1978/79 in the Antarctic austral summer. The cruises began under the International Decade of Cetacean Research programme (IDCR, from 1978/79 to 1995/96) which then became the Southern Ocean Whale and Ecosystem Research programme (SOWER, from 1996/97 to present). Matsuoka *et al.* (2003) presented an extensive review of these cruises. At the time of writing, these cruises have covered almost three circumpolar surveys. Abundance estimates have been calculated using each circumpolar dataset: 1978/79-1983/84 (first circumpolar, CPI); 1984/85-1990/91 (second circumpolar, CPII); and 1991/92-present (third circumpolar, CPIII). Although the third circumpolar set is currently incomplete and the estimate is tentative, a noticeable abundance decline from the second (766,000) to the third (268,000) circumpolar surveys using the IWC standard abundance estimation method (Branch and Butterworth, 2001) has raised questions as to whether the decline is true or apparent. Several factors that might affect the apparent abundance change have been identified (IWC, 2002). Butterworth *et al.* (2001) analysed the effects of a number of these (proportion of like-minke whale sightings, change in area coverage, mean school size estimation methods, efficiency of sighting survey observer and change in survey timing) and concluded that the net effect of those factors increased the third to second survey abundance ratio from 35-40% to 65-75%. However, effects of the observed covariates (i.e. those that affect the detectability of cetaceans) on the Antarctic minke whale abundance estimation parameters were not fully examined. The effect of Beaufort sea state on estimated mean school size and the effective search half-width (ESW) have been shown for fin whales (*Balaenoptera physalus*) in the North Atlantic (Buckland *et al.*, 1992). Similarly, the sighting rate of common minke whales (*B. acutorostrata*) decreased as sea state increased in Icelandic waters (Gunnlaugsson, 1991) and the school size of Antarctic minke whales affected the ESW in the 1987/88 Japanese feasibility study (Kasamatsu *et al.*, 1990). Sea state has also been shown to affect the sighting rate of harbour porpoises (*Phocoena phocoena*) along the coasts of California, Oregon and Washington (Barlow, 1988) and in the Gulf of Maine (Palka, 1996). These results indicated that $g(0)$ could be less than 1 in some circumstances but that the changes could also be a result of changes in detection functions. These covariates require further examination in the context of Antarctic minke whale abundance estimation using the IDCR/SOWER data. Although covariate adjustment methods (e.g. Ramsey *et al.*, 1987; Schweder *et al.*, 1997; Beavers and Ramsey, 1998) have been developed to account for the influence of observed covariates in line transect surveys, it is sensible to examine the effects of the individual factors in order to better understand how they affect the sightings of Antarctic minke whales in order to develop appropriate models.

The purpose of this qualitative analysis is to see if the observed covariates affect the ESW, the sighting forward (or radial) distance (f) and the mean school size ($E(s)$) which are important parameters in estimating Antarctic minke whale abundance. Although f is not directly used as a parameter to estimate the abundance in the standard methods (e.g. Branch and Butterworth, 2001), it is treated as a covariate in the detection function in the spatial hazard probability model (Schweder, 1999). Therefore it is also important to consider the effects of observed covariates on f. The observed covariates chosen were: school size, sighting cue, sighting latitude and sea state (Beaufort scale). The underlying hypothesis is that f, ESW and $E(s)$ change along observed covariate gradients.

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MATERIALS AND METHODS

Data

General

Primary sightings data of Antarctic minke whales south of 60°S from 1985/86 to 1998/99 were used. Data stored in DESS Version 3.1 (Strindberg and Burt, 2000) were extracted for this analysis. The geographical distributions of minke whale sighting positions are shown in Figs 1-3.

Partition of second and third circumpolar surveys

To examine differences between the CPII and CPIII sets, data were pooled into each circumpolar set. Data from 1985/86-1990/91 and 1991/92-1998/99 were treated as CPII and CPIII, respectively. Since no independent observer mode (IO mode) surveying (see 'Survey mode' section for details) was conducted during CPI, it has not been included in this analysis.

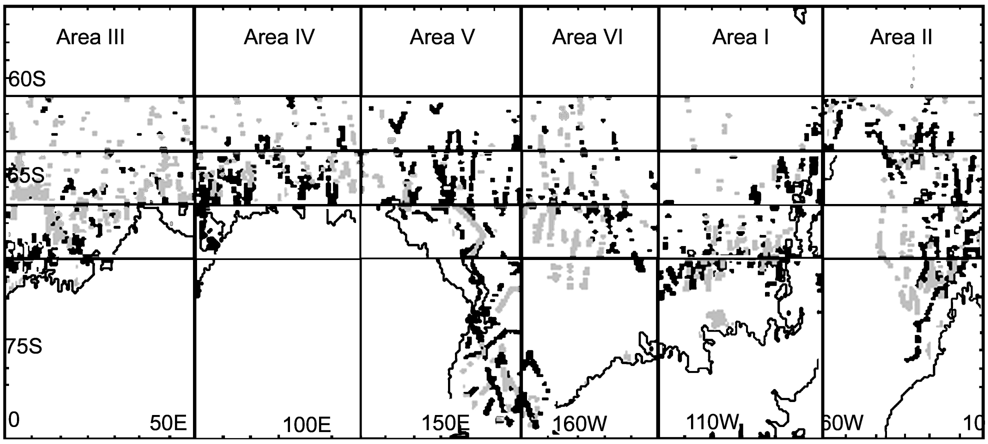

Fig. 1. Primary sighting positions of Antarctic minke whales in CPII (black circle) and CPIII (grey circle).

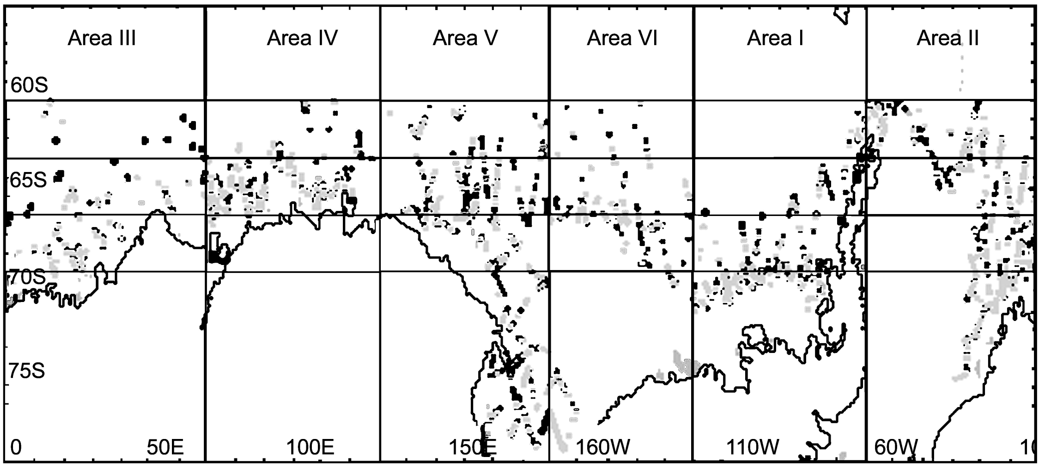

Fig. 2. Primary sighting positions of Antarctic minke whales in CPII. Black circles: single animal schools; grey circles: schools of more than one animal.

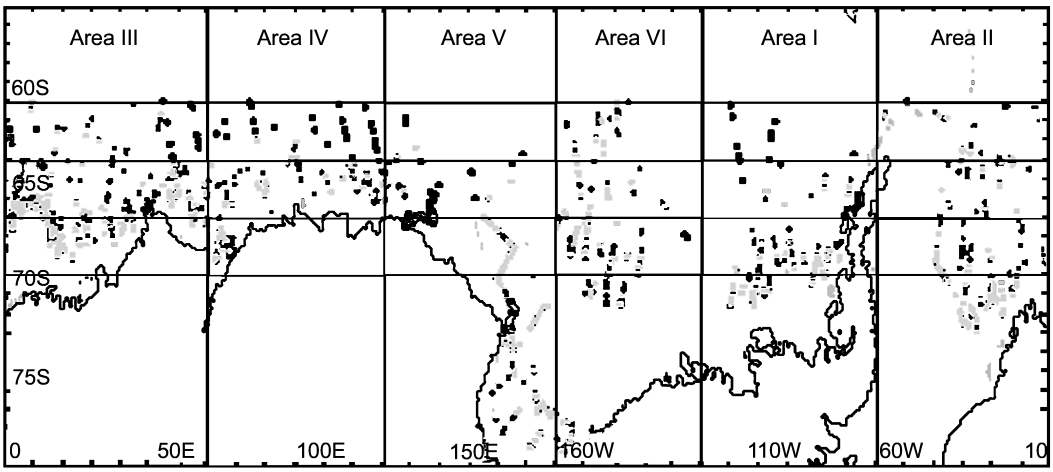

Fig. 3. Primary sighting positions of Antarctic minke whales in CPIII. Black circles: single animal schools; grey circles: schools of more than one animal.

Antarctic minke whale species code
Minke whale species codes listed in Branch and Butterworth (2001) were used.

Survey mode
To see the effect of closing mode and passing mode with IO mode, sighting records were pooled by each survey mode based on the effort codes as described by Branch and Butterworth (2001). In closing mode, two observers were stationed in the top barrel while no observer was stationed on the independent observation platform (IOP). Once a sighting was made, the ship approached the sighting to confirm species and school size. In IO mode, two observers were stationed in the top barrel while an observer was stationed on the IOP. No approach was made to the sightings. A detailed explanation of survey modes is given in Branch and Butterworth (2001).

Separation of South-North stratum
Data were separated into northern and southern strata to examine possible differences between them. Southern strata were set near the ice-edge while northern strata were set north of southern strata. In general, the northern stratum was noted as 'X'N, and the southern stratum was noted as 'X'S, (where 'X' is replaced by either 'E' (east) or 'W' (west)). However, there were some exceptions to the above rule as given below (abbreviations are given in Branch and Butterworth, 2001):

(1) EM (1985/86) was treated as the southern stratum because it was the northern half of the Ross Sea.
(2) WBAY and EBAY were treated as the southern stratum.
(3) EM (1986/87) was treated as the northern stratum because the majority of it was the same as the northern part of CPIII (1996/97 and 1997/98).
(4) BN (1988/89) was treated as the southern stratum because, in this case, the 'N' denoted the northern part of Prydz Bay.
(5) ESBAY (1989/90) was treated as the southern stratum.
(6) EN (1991/92) was treated as the southern stratum because it was half of the northern side in the Ross Sea.
(7) PRYDZ (1989/90) was treated as the southern stratum.

Sighting angle, perpendicular distance and forward distance
'Estimated Perp Distance' and 'Recalculated Angle' recorded in DESS (Strindberg and Burt, 2000) were used. For the sightings width, 'Estimated Perp Distance' was used. 'Estimated Perp Distance' was calculated with bias corrected radial distances and angles. Values of 'Estimated Perp Distance' exceeding 1.5 n.miles were excluded. 'Recalculated Angle' was used for the forward distance calculation, but values above 90 degrees were excluded from the analysis. Angle bias was corrected in 'Recalculated Angle'. *f* was calculated from 'Recalculated Angle' and 'Estimated Perp Distance' using a trigonometric function. A definition of the sighting width and *f* is shown in Fig. 4.

School size
'Best estimated school size' values (i.e. estimated visually by the observers) recorded in DESS were used. Only confirmed school size data were used to estimate E(*s*) because estimates of school size using unconfirmed data may be negatively biased (Butterworth, 1988). To examine the effects of school size on *f* and ESW, confirmed 'Best estimated school size' results were separated into three groups (1, 2 and 3+ individuals).

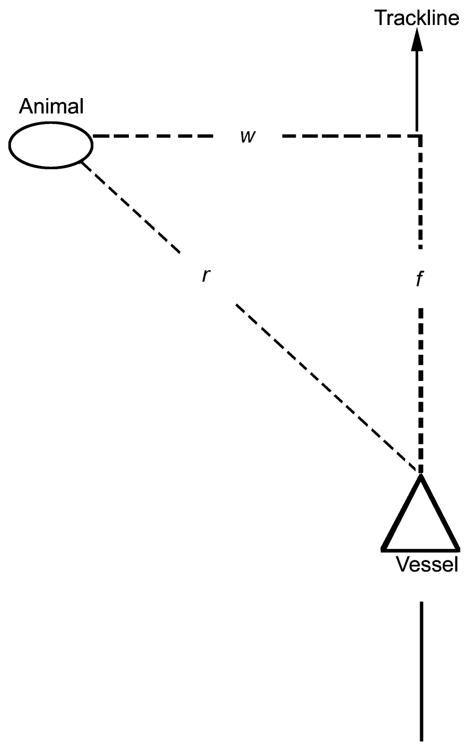

Fig. 4. Definition of sighting radial distance (*r*), perpendicular distance (*w*) and search forward distance (*f*).

Sighting cue
Eight sighting cue codes were used: 1=blow; 2=jump or splash; 3=animal (body); 4=slick or rings; 5=blow and animal simultaneously; 6=colour under water; 7=associated wildlife; 8=other. When all sightings data from CPII and CPIII were combined, proportions of sightings by blow, body and other cues were 54%, 28% and 18%, respectively. To estimate ESW and E(*s*), a minimum of 15 sightings in each stratified dataset was required, in accordance with the IWC standard abundance estimation procedure (e.g. Branch and Butterworth, 2001). If sighting cues were stratified for the estimation, the number of sightings for cues other than blow and body was smaller than the required samples in some stratified datasets because of the small sample size. Therefore, only sightings of blow and body were used in the analysis. Sighting cue was recorded at the time of first sighting.

Sea state (Beaufort scale)
The Beaufort scale was used to record sea state. In this analysis, Beaufort numbers were separated into three categories (0-2, 3 and 4+) as in Gunnlaugsson and Sigurjónsson (1990). Their categorisation was used to investigate the similarity of the observed covariates between the North Atlantic and Antarctic. Since sea state data were recorded only once per hour and not recorded at the time of sighting, the hourly weather records were used as the weather conditions at the time of sighting. Data recorded during the hour prior to the time of the sighting were used.

Latitudinal separation
Sighting and weather data were latitudinally separated into four groups of three degrees (60-62, 63-65, 66-68 and 69+°S) in order to provide a large enough sample size for each category.

Analysis
Data stratification
Data were stratified by circumpolar survey, by survey mode and by north-south stratum. Sample size in each stratified dataset was maintained at a minimum of 15 sightings in accordance with the IWC standard abundance estimation procedure (e.g. Branch and Butterworth, 2001). Each stratified dataset was given a unique name based on the following rule. Names of datasets used are shown below:

Circumpolar set – Survey mode – Stratum (South or North)

2-CL-N	2-IO-S	3-CL-S
2-IO-N	3-CL-N	3-IO-S
2-CL-S	3-IO-N	

These datasets were further stratified by school size, sighting cue and sea state. The latitudinal stratified dataset was not stratified into South or North strata because north-south observed covariate differences were already taken into account with respect to latitudinal gradient.

Effective search half-width
The ESWs with school size, sighting cue, latitude and sea state gradients were estimated using a hazard-rate model with no adjustment term. Truncation distance was set at 1.5 n.miles. DISTANCE Version 3.5 (Thomas *et al.*, 1998) was used for the estimation. Z-tests as described in Buckland *et al.* (1993) were carried out to see whether there were statistically significant differences in the estimates along given gradients.

Sighting forward distance
No models which can estimate the effective search forward distance have yet been developed. For this reason, the median value was used to examine changes in *f* with school size, sighting cue latitude and sea state. As the distribution of *f* was skewed towards shorter distances and was highly variable (range of CV in each stratified group was 0.5–1.0), using the median instead of the mean was adequate. To test the difference among medians along given gradients, a multi-sampling median test (Zar, 1999) was applied. This test only reveals if all populations have the same median or not, therefore the existence of trends along environmental variables was qualitatively analysed graphically.

School size
Confirmed school size sighted during closing mode was used to estimate the mean school size following Branch and Butterworth (2001). Z-tests as described in Buckland *et al.* (1993) were carried out to see whether there were statistically significant differences in the estimates along given gradients.

RESULTS

Searching forward distance, ESW and E(*s*) by each observed covariate are shown in Appendix Tables 1-3, respectively.

Effect of school size
The median *f* increased as school size increased (Appendix Table 1(a), Fig. 5(a)). At least one of the median *f* values among three school size groups was statistically significant at the 5% level when the median test was applied to four datasets (2-CL-N, 3-CL-N, 2-CL-S and 3-CL-S). Combined with graphical analysis, results of the median test suggested a decreasing trend in *f* as school size decreased from more than three individuals to one individual. There was no notable difference between CPII and CPIII. ESWs also decreased as school sizes decreased (Appendix Table 2(a), Fig. 5(b)). ESWs in CPIII were wider than those in CPII. The ESWs were statistically significant at 5% levels for the Z-test in all pairs, except between single and two animal schools in 2-CL-N.

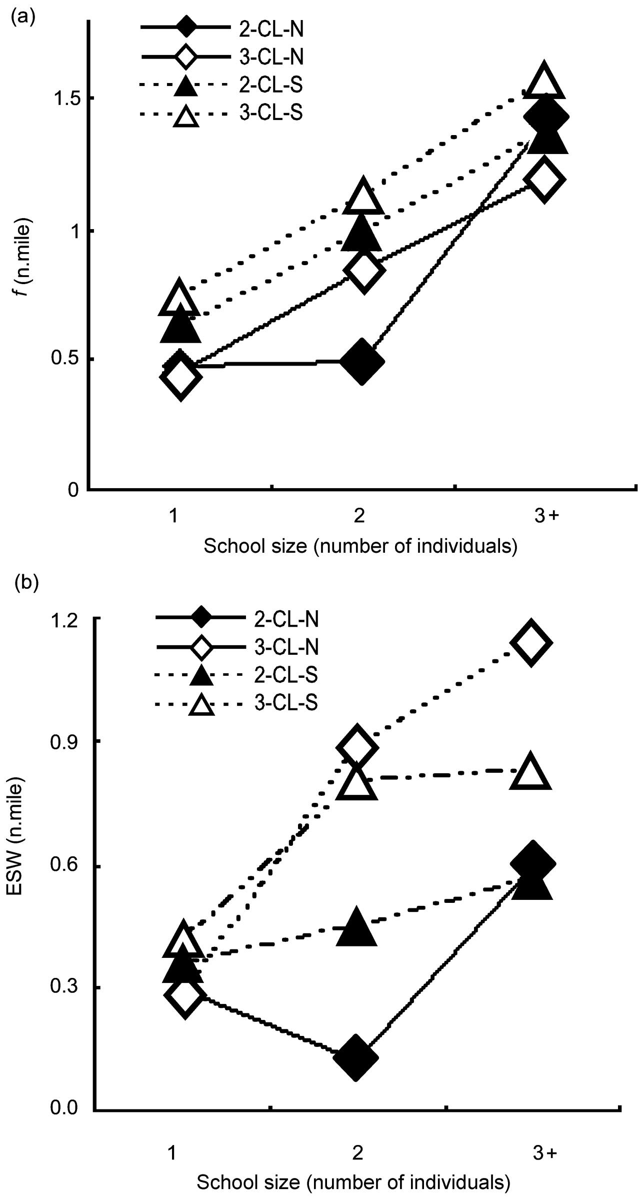

Fig. 5. Changes in: (a) search forward distance (*f*) and (b) effective search half-width (ESW) with school size. Only confirmed school size data were used.

Effect of sighting cue
The median *f* values where the initial sighting cue was body were shorter than those for blow in all eight datasets (Appendix Table 1(b), Fig. 6(a)). The differences were statistically significant at 5% levels using the median test for all datasets. There was no significant difference between CPII and CPIII. The ESWs of sightings by body were also narrower than those of sightings by blow (Appendix Table

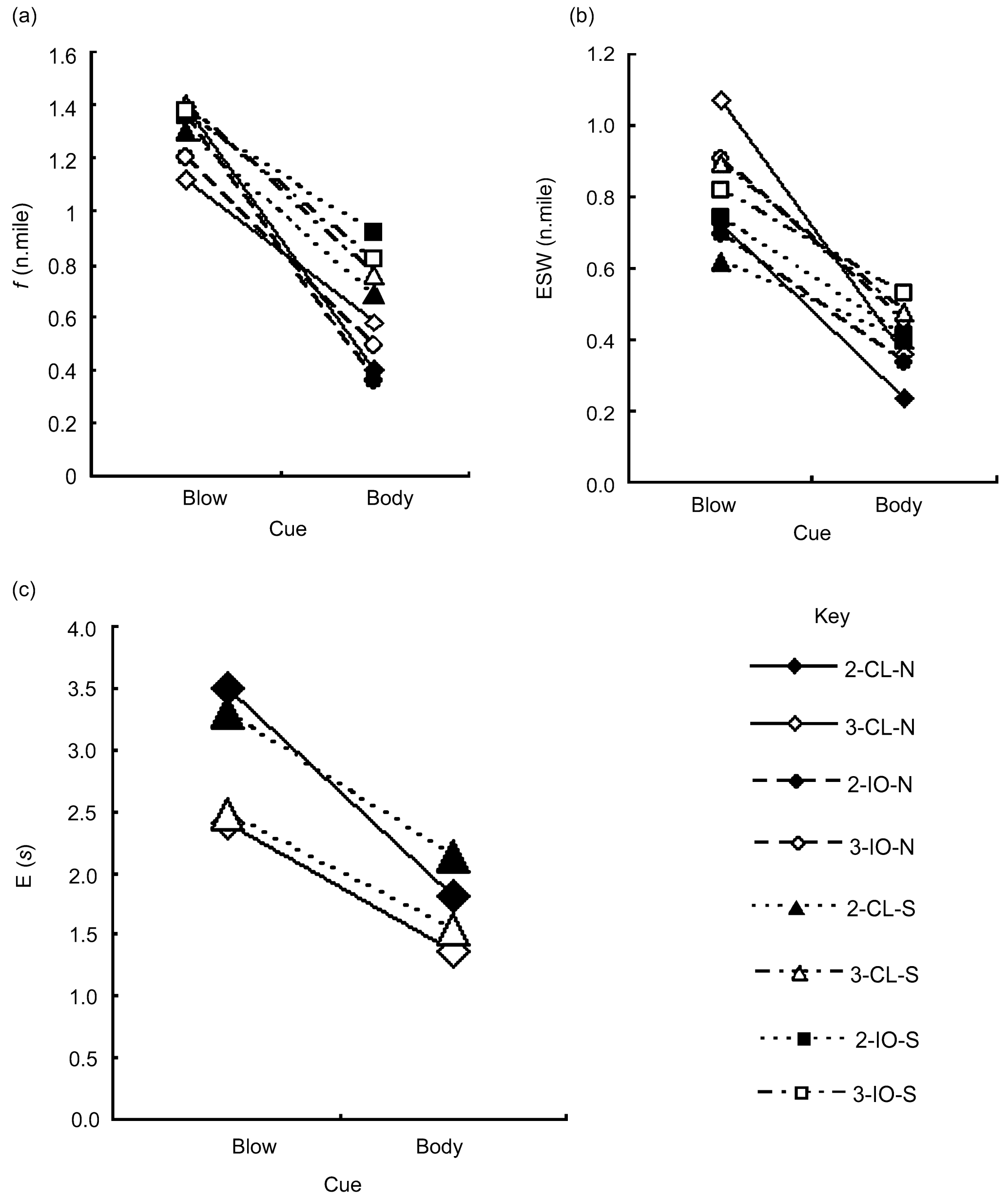

Fig. 6. Changes in: (a) search forward distance (*f*), (b) effective search half-width (ESW) and (c) mean school size (E(*s*)) with different initial sighting cues (blow and body).

2(b), Fig. 6(b)). The ESW in CPIII was wider than that of CPII. The E(*s*) values for sightings where the initial cue was body were smaller than those for blow (Appendix Table 3(a), Fig. 6(c)). E(*s*) values in CPIII were smaller than those in CPII. The proportions of single animals for which body was the initial cue were also higher (Fig. 7).

Effect of sighting latitude

The median *f* values decreased with decreasing latitude (Appendix Table 1(c)). The effects were large for 60-62°S in CPIII. Most of the *f* values for CPIII were less than for CPII. The ESWs were narrowest for 60-62°S except 3-IO (Appendix Table 2(c)). Mean school size decreased with decreasing latitude in CPIII (Appendix Table 3(b)). ESWs in CPIII were wider than those in CPII in most cases. Mean school sizes were lower for CPIII than CPII. Fig. 8 shows the school size composition by latitude. The proportion of single animal schools was higher in the northern latitudes in CPIII, while no apparent change in proportion was observed in CPII. Proportions of sightings with body as the initial cue were higher in the northern latitudes in CPIII, whereas in CPII proportions with blow as the initial cue were high regardless of latitude (Fig. 9).

Effect of sea state (Beaufort scale)

No consistent trend in *f* values was observed along the sea state gradient when all school sizes were used in the estimation (Appendix Table 1(d)). However, decreasing trends with increasing sea state were observed in the 3-CL-N and 3-IO-N datasets, if only single animal schools were used (Appendix Table 1(e), Fig. 10(a)). At least one of the variables was statistically significant at the 5% level in each circumpolar dataset when the median test was applied. The ESWs also showed decreasing trends with increasing sea state in these two datasets (Appendix Table 2(e), Fig. 10(b)). ESWs in CPIII were wider than those in CPII in most of cases. E(*s*) values in CPIII were smaller than those in CPII.

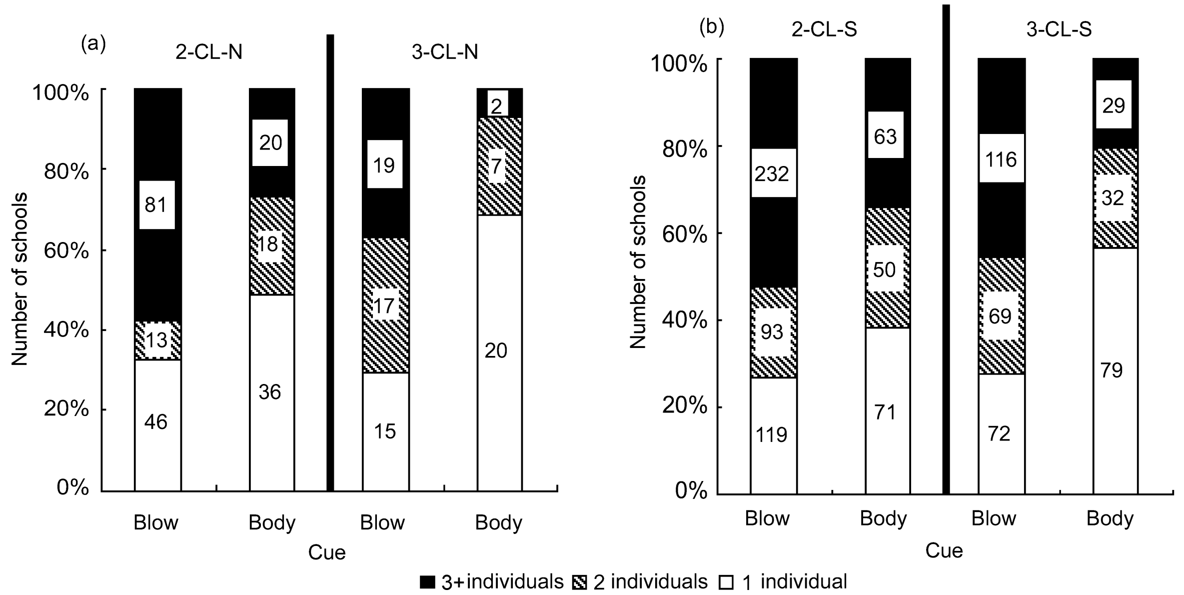

Fig. 7. School sizes by sighting cue for (a) the northern stratum and (b) the southern stratum. Numbers in bars denote actual numbers of sighted schools.

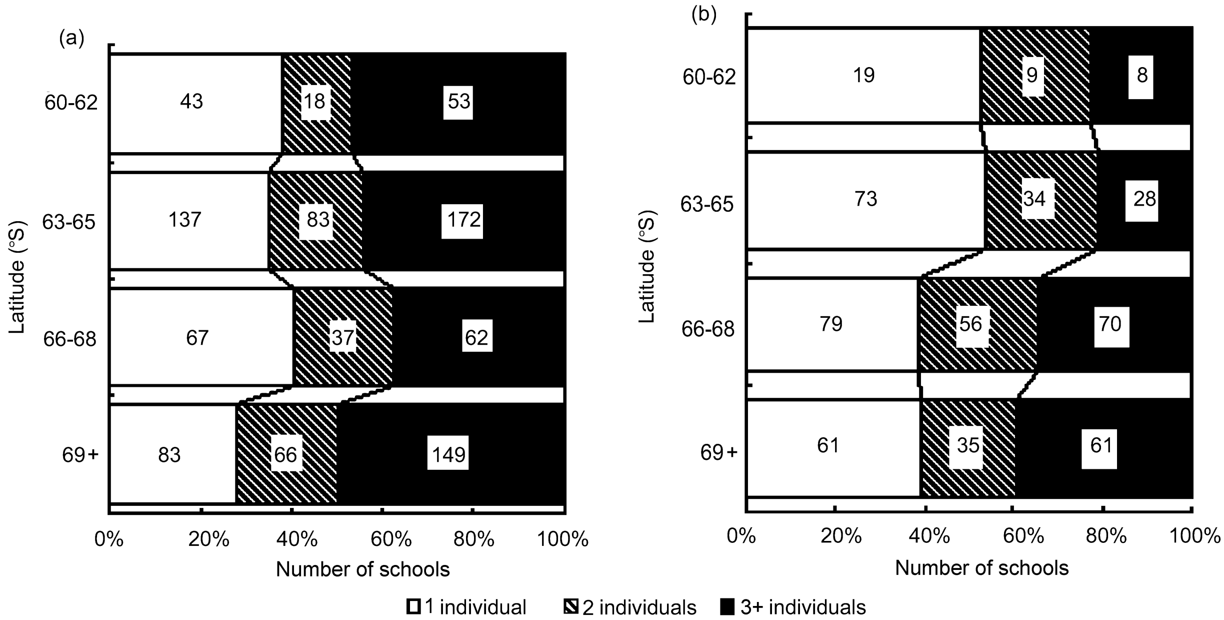

Fig. 8. Changes in school sizes along latitudinal gradients for (a) CPII and (b) CPIII. Numbers in bars denote actual numbers of sighted schools. Note that sightings in Area II accounted for 68% (77 out of 114) for 60-62°S in CPII.

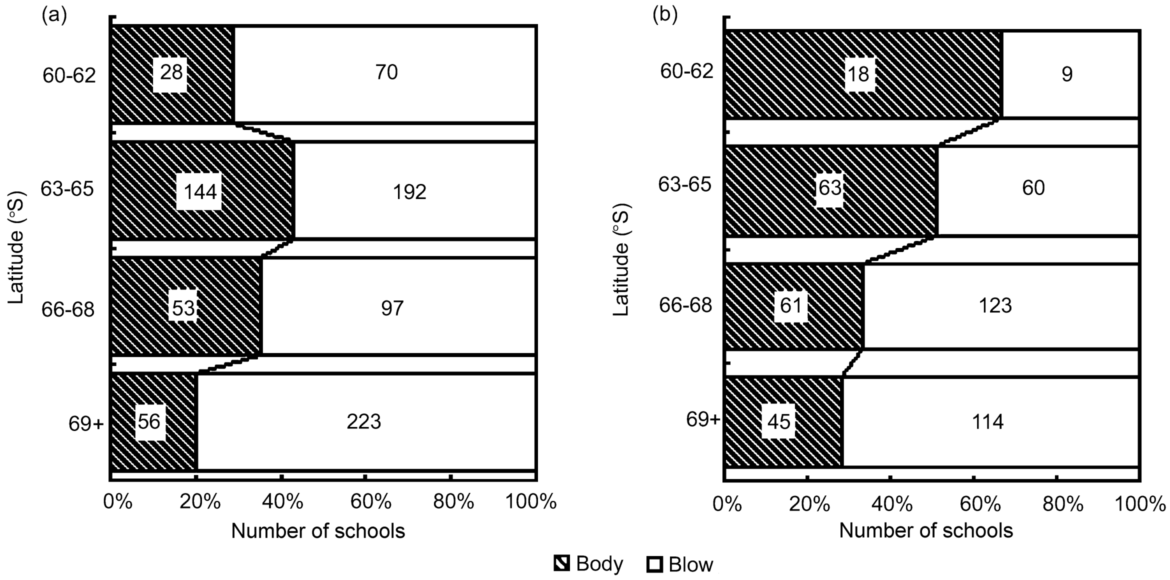

Fig. 9. Changes in type of sighting cue along latitudinal gradients for (a) CPII and (b) CPIII.

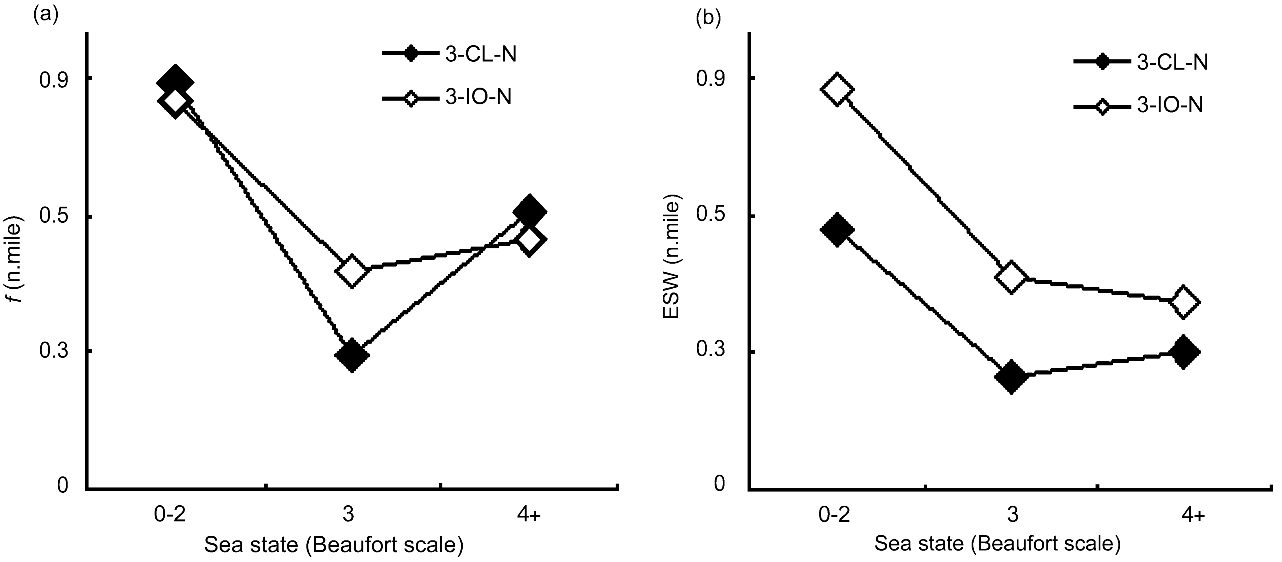

Fig. 10. Changes in: (a) search forward distance (*f*) and (b) effective search half-width (ESW) with sea state for single animal schools.

DISCUSSION

Effect of school size

The survey effort in the northern strata during CPIII was 30-50% greater than for CPII because the survey area was extended to the north (Matsuoka *et al.*, 2003). Proportions of smaller (1 and 2 animal) schools increased as the latitude moved to 60°S in CPIII. This concurs with JARPA data findings (Fujise *et al.*, 1999) that small immature male Antarctic minke whales with small school sizes prevailed in the northern part of the survey area. For these small schools, the initial cue was usually the body as is also found with common minke whales in the North Atlantic[1] (e.g. Gunnlaugsson and Sigurjónsson, 1990). Such small schools are more difficult to see than large schools (with blow the initial cue); the sighting ranges (*f* and ESW) are greatly reduced. The median *f* values for single animals, pairs and 3+ schools were in the ranges of 0.47-0.74, 0.49-1.13 and 1.2-1.57 n.miles, respectively. The maximum blow interval of Antarctic minke whales was estimated at 7.33 minutes by Joyce (1982), within which time a survey vessel would steam around 1.4 n.miles. Since the *f* values for singles and pairs were less than 1.4 n.miles, some proportion of diving animals is likely to have been missed by observers. Longer diving durations of common minke whales in the North Atlantic (8.33 minutes, Øien *et al.*, 1990; 13.43 minutes, Stockin *et al.*, 2001) have been recorded and studies using telemetry show that some surfacings may be missed e.g. (Joyce *et al.*, 1990) emphasising that the probability of missing animals cannot be ignored. Smaller *f* values may also result in shorter confirmation times (see 'like-minke consideration' below). Average Antarctic minke whale blow intervals for 1 animal, 2-5 animals, 6-20 animals and more than 20 animal schools within the sighting range of 0.25-0.5 n.miles were reported as 1.50, 0.43, 0.15 and 0.11 minutes, respectively by Joyce (1982). Given the difficulty in seeing animals that are not blowing visibly, the reported surfacing rates for small group sizes sighted by body would be even lower than the blow interval studies suggest. The surfacing rates of small groups, especially in the northern stratum, should thus be measured in future and interactions between surfacing rate and *f* should be examined using a surfacing based abundance estimation model such as that of Cooke (1997).

[1] In the North Atlantic, common minke whale blows are rarely visible.

Effect of sighting latitude

Even though changes in the abundance estimation parameters by latitude elucidated the differences in north-south observed covariates at the first attempt, there are some difficulties in interpreting the results because topographical heterogeneities along latitudinal lines (e.g. the extension of the Antarctic Peninsula) exist at the circumpolar level. Changes in the abundance estimation parameters by the distance from the ice-edge could be more informative since they may eliminate topographic variation effects.

'Like-minke' consideration

Even if schools of potential minke whales are sighted once, some proportion of them may not be resighted at all, if confirmation time is short (see above). As a result, those sightings will be recorded as 'like-minke' rather than minke.

Effect of sea state

Bad weather conditions generally prevailed in the northern stratum in CPIII as described in the recent cruise reports (e.g. Ensor *et al.*, 2001). The higher the sea state, the smaller the sighting range of single animal schools. Poor weather makes the sighting of small schools (which predominate in the north) even more difficult. This was confirmed in the North Atlantic where the sighting rate of minke whales decreased as sea state increased (Gunnlaugsson and Sigurjónsson, 1990).

Recommendations

General trends in *f*, ESW and E(*s*) along the observed covariate gradients were identified in the circumpolar datasets in this analysis. However, regional and temporal effects must be considered when corrections of *g*(0) are made. The observed covariates examined in this paper should be incorporated using covariate adjustment methods (e.g. Beavers and Ramsey, 1998; Ramsey *et al.*, 1987; Schweder *et al.*, 1997) to adjust for their influence in the IDCR-SOWER Antarctic minke whale abundance estimates. In addition, the effect of distance from the ice-edge and the proportions of like-minke sightings should also be considered in future analyses.

In CPIII, mean school sizes were smaller than those in CPII in most cases, suggesting that $g(0)$ in CPIII may be smaller than in CPII. If this effect is considered, the CPIII/CPII abundance ratio for closing mode would increase by some 15% assuming a strip half-width of 0.2 n.miles and $g(0)=0.3$ for single animal schools (Butterworth *et al.*, 2003). Wider ESW in CPIII may also be linked to E(s) changes. A change in school size between CPII and CPIII is a possibility, but it is difficult to tell whether the change is apparent or absolute. Possible causes of change such as modifications to the survey design and biotic and abiotic environmental factors should be considered further.

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Appendix Table 1

Medians of searching forward distances (*f*) by: school size; sighting cue; latitude; Beaufort number (include all school sizes); and Beaufort number (single animal schools only).

	2-CL-N			3-CL-N			2-CL-S			3-CL-S		
(a) School size (individual)	n	Median	CV	n	Median	CV	n	Median	CV	n	Median	CV
1	105	0.47	100.00	59	0.45	93.75	227	0.63	94.2	175	0.74	75.9
2	39	0.49	100.00	28	0.85	71.59	165	0.99	82.8	108	1.13	60.8
3+	113	1.41	64.47	23	1.2	58.82	323	1.37	62.7	144	1.57	56.3
	2-CL-N			3-CL-N			2-IO-N			3-IO-N		
(b) Sighting cue	n	Median	CV	n	Median	CV	n	Median	CV	n	Median	CV
Blow	157	1.39	61.07	64	1.12	50.43	242	1.36	56.55	77	1.2	53.60
Body	87	0.4	98.39	42	0.58	72.88	87	0.36	81.82	91	0.49	83.08
	2-CL-S			3-CL-S			2-IO-S			3-IO-S		
(b) Sighting cue	n	Median	CV	n	Median	CV	n	Median	CV	n	Median	CV
Blow	558	1.3	65.10	274	1.4	57.69	810	1.36	58.94	409	1.38	51.66
Body	227	0.69	88.64	173	0.76	73.03	364	0.92	75.49	318	0.82	71.88
	2-CL			3-CL			2-IO			3-IO		
(c) Latitude (degrees south)	n	Median	CV	n	Median	CV	n	Median	CV	n	Median	CV
60-62	135	0.89	84.62	47	0.58	88.46	196	0.96	67.89	83	0.68	75.61
63-65	477	1.06	77.31	173	0.92	72.73	441	1.03	72.41	331	1	69.44
66-68	212	0.98	78.07	252	1.04	71.17	520	1.02	70.09	448	1.08	65.83
69+	405	1.07	74.62	188	1.24	66.42	666	1.23	66.91	284	1.05	65.22
	2-CL-N			3-CL-N			2-IO-N			3-IO-N		
(d) Beaufort number (all school sizes)	n	Median	CV	n	Median	CV	n	Median	CV	n	Median	CV
0-2	72	1.05	82.03	43	0.78	59.78	69	0.89	70.19	59	0.99	62.38
3	101	0.76	89.36	33	0.39	101.61	214	1.08	74.02	92	0.72	78.41
4+	126	0.88	78.50	69	0.79	73.33	160	0.82	71.43	72	0.64	85.90
	2-CL-S			3-CL-S			2-IO-S			3-IO-S		
(d) Beaufort number (all school sizes)	n	Median	CV	n	Median	CV	n	Median	CV	n	Median	CV
0-2	234	1.28	68.09	215	1.14	72.31	532	1.28	68.53	349	1.06	63.48
3	317	1.04	81.40	146	1.15	65.04	369	1.04	68.91	281	1.1	63.20
4+	382	0.99	72.81	158	1.08	69.49	486	1.03	65.83	297	1	69.83
	2-CL-N			3-CL-N			2-IO-N			3-IO-N		
(e) Beaufort number (single animal school)	n	Median	CV	n	Median	CV	n	Median	CV	n	Median	CV
0-2	26	0.54	86.59	26	0.89	51.49	45	0.76	69.57	40	0.85	61.62
3	48	0.47	97.30	21	0.29	105.13	126	0.98	64.49	58	0.48	88.00
4+	62	0.58	93.67	41	0.61	84.93	105	0.98	64.49	56	0.55	85.29
	2-CL-S			3-CL-S			2-IO-S			3-IO-S		
(e) Beaufort number (single animal school)	n	Median	CV	n	Median	CV	n	Median	CV	n	Median	CV
0-2	92	1.03	75.96	99	0.88	72.63	292	1.04	62.07	189	0.99	67.96
3	98	0.86	80.61	61	0.98	73.53	201	0.91	66.33	162	0.9	71.43
4+	171	0.65	87.78	81	0.74	75.56	331	0.94	63.11	178	0.76	69.23

Appendix Table 2

Effective search half-width (ESW) by: school size; sighting cue; latitude; Beaufort (include all school sizes); and Beaufort (single animal school only).

	2-CL-N			3-CL-N			2-CL-S			3-CL-S		
(a) School size (individual)	n	ESW	CV	n	ESW	CV	n	ESW	CV	n	ESW	CV
1	105	0.30	17.15	59	0.28	21.60	227	0.36	9.21	175	0.42	11.93
2	39	0.12	140.53	28	0.88	7.81	165	0.45	13.60	108	0.80	11.95
3+	113	0.59	17.67	23	1.14	6.20	323	0.57	9.58	144	0.83	18.80
	2-CL-N			3-CL-N			2-IO-N			3-IO-N		
(b) Sighting cue	n	ESW	CV	n	ESW	CV	n	ESW	CV	n	ESW	CV
Blow	157	0.72	11.33	64	1.07	5.87	242	0.69	10.15	77	0.91	21.73
Body	87	0.23	21.66	42	0.36	18.25	87	0.33	11.81	91	0.45	14.30
	3-CL-S			3-CL-S			2-IO-S			3-IO-S		
(b) Sighting cue	n	ESW	CV	n	ESW	CV	n	ESW	CV	n	ESW	CV
Blow	558	0.62	7.10	274	0.89	7.50	810	0.74	5.17	409	0.82	6.03
Body	227	0.40	8.71	173	0.48	12.95	364	0.41	12.12	318	0.53	8.99
	2-CL			3-CL			2-IO			3-IO		
(c) Latitude (degrees south)	n	ESW	CV	n	ESW	CV	n	ESW	CV	n	ESW	CV
60-62	135	0.30	20.72	47	0.38	30.63	196	0.45	10.15	83	0.81	10.31
63-65	477	0.49	7.94	173	0.59	13.16	441	0.53	9.22	331	0.64	9.60
66-68	212	0.36	13.38	252	0.52	10.35	520	0.64	6.80	448	0.54	13.43
69+	405	0.63	6.43	188	0.61	16.17	666	0.64	6.41	284	0.63	9.19
	2-CL-N			3-CL-N			2-IO-N			3-IO-N		
(d) Beaufort number (all school sizes)	n	ESW	CV	n	ESW	CV	n	ESW	CV	n	ESW	CV
0-2	72	0.47	21.76	43	0.61	18.54	69	0.48	21.49	59	0.90	12.30
3	101	0.29	28.73	33	0.17	77.91	214	0.49	11.48	92	0.51	22.62
4+	126	0.40	16.19	69	0.49	17.60	160	0.49	12.91	72	0.53	18.94
	2-CL-S			3-CL-S			2-IO-S			3-IO-S		
(d) Beaufort number (all school sizes)	n	ESW	CV	n	ESW	CV	n	ESW	CV	n	ESW	CV
0-2	234	0.55	10.69	215	0.65	10.28	532	0.72	7.86	349	0.66	8.42
3	317	0.46	8.86	146	0.65	15.66	369	0.64	9.29	281	0.61	9.99
4+	382	0.48	9.11	158	0.48	17.79	486	0.54	6.32	297	0.65	7.20
	2-CL-N			3-CL-N			2-IO-N			3-IO-N		
(e) Beaufort number (single animal school)	n	ESW	CV	n	ESW	CV	n	ESW	CV	n	ESW	CV
0-2	26	0.45	26.89	26	0.57	17.56	45	0.46	24.79	40	0.87	17.20
3	48	0.32	22.53	21	0.25	36.82	126	0.51	11.70	58	0.47	18.73
4+	62	0.33	20.52	41	0.30	25.96	105	0.49	15.67	56	0.41	26.52
	2-CL-S			3-CL-S			2-IO-S			3-IO-S		
(e) Beaufort number (single animal school)	n	ESW	CV	n	ESW	CV	n	ESW	CV	n	ESW	CV
0-2	92	0.46	14.43	99	0.50	14.19	292	0.55	11.98	189	0.66	12.23
3	98	0.52	10.94	61	0.64	13.16	201	0.55	12.27	162	0.62	8.79
4+	171	0.39	12.10	81	0.32	20.36	331	0.53	6.53	178	0.55	9.12

Appendix Table 3

Mean school size (E(s)) by sighting cue and latitude.

	2-CL-N			3-CL-N			2-CL-S			3-CL-S		
(a) Sighting cue	n	E(*s*)	CV	n	E(*s*)	CV	n	E(*s*)	CV	n	E(*s*)	CV
Blow	136	3.49	9.50	50	2.41	8.73	422	3.30	4.83	227	2.48	4.94
Body	74	1.80	8.24	29	1.36	8.65	180	2.13	5.29	139	1.54	5.00

	2-CL			3-CL		
(b) Latitude (degree south)	n	E(*s*)	CV	n	E(*s*)	CV
60-62	114	2.59	12.35	36	1.57	11.97
63-65	392	2.78	4.87	135	1.47	5.31
66-68	166	2.23	6.32	205	1.77	4.58
69+	298	2.79	4.88	157	1.91	5.99