Some Considerations on key factors affecting sighting conditions on Antarctic minke whale abundance estimation parameters in the IWC/IDCR-SOWER surveys

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ABSTRACT

Effects of the sighting conditions (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. As the school size decreased, the effective search half-width and the sighting forward distance were decreased. Most of single and two animal schools were sighted by body which was difficult to find in high Beaufort scales in comparison with blow. Proportions of single and two animal schools increased as sighting latitude went to the north. Small school sizes and bad weather conditions prevailed in northern part of survey area. Because survey area was extended to the north, effects of small school size and bad weather conditions were substantial in the third circumpolar survey .The maximum dive duration of the Antarctic minke whale was 7.33 minutes. Sighting survey vessels steam 1.4 n.miles during the diving time. Because the sighting forward distance of single and two animal schools were less than 1.4 n.miles, some proportion of diving animals will be missed by the observers. Therefore, assumption that g(0)=1 is not appropriate at least for single and two animal schools. Current abundance estimation of the Antarctic minke whale was under biased without correction of g(0).

INTRODUCTION

The International Whaling Commission (IWC) has conducted the Antarctic minke whale abundance assessment cruises since 1978/79 in the Antarctic in austral summer. The name of the cruises were firstly called as the International Decade of Cetacean Research programme (IDCR, from 1978/79 to 1995/96) and then changed to the Southern Ocean Whale and Ecosystem Research programme (SOWER, from 1996/97 to present). Matsuoka *et al.* (2001) presented extensive review of the cruises. The cruises covered almost three circumpolar surveys until now for the purpose of comprehensive assessments. Abundance estimation was made using each circumpolar data set; 1978/79-1983/84 (first circumpolar), 1984/85-1990/91 (second circumpolar) and 1991/92-present (third circumpolar). Though the third circumpolar set has not been completed and the estimate is tentative, noticeable abundance decline from second (766,000) to third (268,000) (Branch and Butterworth 2001) brought question whether the decline is true or apparent. Several factors that might affect the apparent abundance change were pointed out (IWC 2002). Butterworth *et al.* (2001) analysed effects of the several factors (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 second to third sets abundance ratio from 35-40% to 65-75%. However, effects of the sighting conditions on the Antarctic minke whale abundance estimation parameters were not fully examined in the context of comparison between the second and third circumpolar sets.

The purpose of this analysis is to see if the sighting conditions affect the effective search half-width (esw), the sighting forward distance (f) and the mean school size (E(s)) which are important parameters to estimate the Antarctic minke whale abundance. Though the sighting forward distance is not directly used as a parameter to estimate the abundance in the standard methods (e.g. Branch and Butterworth 2001), it is considered as an important indicator of change in detectability of whales. Shorter sighting forward distance results in shorter time to find target object. Steaming speed of sighting surveys in IDCR-SOWER is set at 11.5 knots. The maximum dive duration of the Antarctic minke whale was 7.33 minutes (Joyce 1982). During the dive time, sighting survey vessel steam 1.4 n.miles. If sighting forward distance is shorter than 1.4 n.miles, proportion of missed animals will be high. We choose school size, sighting cue, sighting latitude and sea state (Beaufort scale number) as sighting conditions. Underlying hypothesize is that whether sighting forward distance, effective search half-width and mean school size change with sighting condition gradients.

MATERIALS AND METHODS

Data

General

Primary sighting data of the Antarctic minke whale in the 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. Geographical distribution of minke whale sighting positions was shown in Fig. 1-3.

Partition of second and third circumpolar surveys

To see the difference between the second and the third circumpolar sets, data were pooled into each circumpolar set. Data from 1985/86 to 1990/91 and 1991/92 to 1998/99 were treated as the second and third sets, respectively.

Antarctic minke whale species code

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

Survey mode

To see the effect of the closing mode and IO mode, sighting records were pooled by each survey mode based on the effort codes as described by Branch and Butterworth (2001).

Separation of South-North stratum

Data were separated into northern and southern strata to see the difference between them. In general, the northern stratum was noted as "X"N, and the Southern part of the sea was noted as "X"S, (usually "X" replaced by either "E" (east) or "W" (west)). There were some exceptions of above mentioned rule. They were classified with following rules.

- EM (1985/86) was treated as the southern stratum because it was the northern half part of the Ross Sea.
- WBAY and EBAY were treated as the southern stratum.
- EM (1986/87) was treated as the northern stratum because the most part of it was same as the northern part of 3rd circumpolar survey (1996/97 and 1997/98).
- BN (1988/89) was treated as the southern stratum because, in this case, the N denoted northern part of the Prydz Bay.
- ESBAY (1989/90) was treated as the southern stratum.
- EN (1991/92) was treated as the southern stratum because it was the half of northern side in the Ross Sea.
- PRYDZ (1989/90) was treated as the southern stratum.

Sighting angle, width and forward distance

For the sighting width, "Estimated Perp Distance" which was recorded in DESS and already bias correction was made, was used. "Estimated Perp Distance" more than 1.5 n.miles were excluded. "Recalculated Angle" was used for the forward distance calculation but above 90 degrees data were excluded from the analysis. The sighting forward distance was calculated from "Recalculated Angle" and "Estimated Perp Distance" using trigonometric function. Definition of the sighting width and the forward distance was schematically shown in Fig. 4.

School size

"Best estimated school size" which was recorded in DESS was used. Only confirmed school size data was used to estimate the mean school size. To see the effects of school size on sighting forward distance and effective search width, confirmed "Best estimated school size" were separated into three groups (1, 2 and 3≤ individuals).

Sighting cue

Though there were eight sighting cue code (1: blow; 2: jump or splash, 3: animal (body); 4: slick or rings; blow and animal simultaneously; 6: colour under water; 7: associated wildlife; 8: other), only blow and body were used in the analysis because of sample size. Sighting cue was recorded at the time of first sighting.

Sea state (Beaufort scale)

Beaufort scale numbers were recorded as the sea state. In this analysis, Beaufort scales were separated into three categories (0-2, 3 and 4≤) as in Gunnlaugsson and Sigurjónsson (1990). Because sea state data were recorded once in an hour, and they weren't recorded at the time of sighting, we dealt the hourly weather records as the weather conditions at the time of sighting.

Latitudinal separation

Sighting and weather data were latitudinally separated into 4 groups per 3 degrees (60-62, 63-65,66-68 and 69-°S) to have enough sample size for each category.

Analysis

Data stratification

Data were stratified by circumpolar survey, by survey mode and by north-south stratum. Each stratified data set was given unique name based on the following rule. Names of used data sets were shown below.

Circumpolar set - Whale species - Survey mode – Stratum (South or North)

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

Those data sets were further stratified by school size, sighting cue and sea state. We didn't stratify the latitudinal stratified data set into South or North stratum.

Effective search half-width

The effective search half-widths along school size, sighting cue, latitude and sea state gradients were estimated using hazard-rate-model with no adjustment term. Truncation distance was set at 1.5 n.miles. Distance ver. 3.5 was used for the estimation. No smearing was applied to data sets. Z-tests were carried out to see whether there were statistically significant differences in the estimates along given gradients.

Sighting forward distance

The model which can estimate the effective search forward distance hasn't developed at this moment. For that reason, we simply used median to see the change of the sighting forward distance along school size, sighting cue latitude and sea state gradients. To test the difference among medians with given the gradients, multisampling median test (Zar 1999) was applied. Because the median test only showed whether all populations have the same median or not, existence of trends along environmental variables were qualitatively analyzed with graphs.

School size

Confirmed school size sighted during closing mode was used to estimate the mean school size. Mean school size estimation method that was described in Branch and Butterworth (2001) was used.

RESULTS

Effect of school size

The median search forward distance increased as the school size increased (Fig. 5(a)). At least one of the median search forward distance among three school size groups was statistically significant at 5% level in four data sets (2-Mi-CL-N, 3-Mi-CL-N, 2-Mi-CL-S and 3-Mi-CL-S). Combined with graphical analysis with results of median test suggested that there were decrease trends of forward distance if school size was decreased from more than 3 individuals to 1 individual. There was no notable difference between the second and third circumpolar sets. The effective search half-widths also decreased as school sizes decreased (Fig. 5(b)). The effective search half-widths were statistically significant at 5% levels in all pairs except between single and two animal schools in 2-Mi-CL-N.

Effect of sighting cue

The median search forward distances of sightings by body were shorter than those by blow in all eight data sets (Fig. 6(a)). The differences were statistically significant at 5% level in all data sets. The effective half-widths of sightings by body were also narrower than those by blow (Fig. 6(b)). The mean school sizes of sightings by body were smaller than by blow (Fig. 6(c)). The mean school sizes of the second and the third circumpolar surveys at each sighting cue were statistically significant at 5% level. Proportions of single animals sighted by body were higher than those by blow (Fig. 7).

Effect of sighting latitude

The median sighting forward distances were decreased as the latitude went to north (Fig. 8(a)). The effects were large in 60-62°S in the third circumpolar data sets. The effective search half-widths were the narrowest in 60-62°S except 3-Mi-IO (Fig. 8(b)). School size decreased as latitude went to north in third circumpolar survey (Fig. 8(c)). The school sizes were lower in the third circumpolar set than the second circumpolar set. Fig. 9 showed the school size compositions in each latitude bound. Proportion of single animal schools was high in the northern latitude in the third circumpolar set, while no apparent change in proportion was observed in the second circumpolar set. Proportions of sightings with body were high in the northern latitude in the third circumpolar data, whereas proportions of blow were high in the second circumpolar data regardless of latitude (Fig 10).

Effect of sea state (Beaufort scale)

No consistent trend of the search forward distance was observed along Beaufort scales gradient, when all school sizes were used in the estimation. However, there were decreasing trends as Beaufort scale increased in 3-Mi-CL-N and 3-Mi-IO-N data sets, when only single animal schools were used (Fig. 11(a)). At least one of the variables was statistically significant at 5% level in those two data sets. The effective search half-widths also showed decreasing trends as Beaufort scale increased in those two data sets (Fig. 11 (b)).

DISCUSSION

Survey effort in the northern strata in the third circumpolar survey increased 30-50% more than the second circumpolar survey, because survey area was extended to the north in the third circumpolar survey (Matsuoka *et al.* 2002). Proportions of single and two animal schools increased as the latitude went to 60°S in the third circumpolar data set. This was supported by the fact that small body size immature male Antarctic minke whales with small school sizes prevailed in the northern part of the survey area based on JARPA data (Fujise *et al.* 1999). Those small size schools were sighted mainly by body. It was difficult to find small size schools with body in comparison with the sighting of large size schools by blow because the sighting range (sighting forward distance and effective search half-width) was greatly reduced. The median sighting forward distances of single animal, two animals and more than two animal schools were in ranges of 0.47-0.74, 0.49-1.13 and 1.2-1.57 n.miles, respectively. The maximum dive duration of Antarctic minke whale was 7.33 minutes (Joyce 1982). Within the dive time, sighting survey vessels steam 1.4 n.miles. Because the sighting forward distance of single and two animal schools were less than 1.4 n.miles, some proportion of diving animals will be missed by observers. Because longer diving durations of minke whale were recorded as 8.33 minutes (Øien *et al.* 1990) and 13.43 minutes (Stockin *et al.* 2001) in the North Atlantic, probability of missing animal could not be ignored to estimate the abundance. Shorter sighting forward distance resulted in shorter confirmation time. Even if schools that were potentially minke whales were sighted once, some proportion of them were not resighted at all, if confirmation time was short. As the results, those sightings were recorded as like minke. The proportion of like minke increased in the third circumpolar survey (Branch and Butterworth 2001). The reason can be partially explained by short sighting forward distance.

In addition to increasing number of small school sizes, bad weather conditions prevailed in the northern stratum in the third circumpolar survey in general as described in the recent cruise reports (e.g. Ensor *et al.* 2001). The higher the Beaufort scale was, the smaller the sighting range of single animal school was. Bad weather condition made the sighting condition of small school size schools worse. As the result, proportion of missed small sized schools sighted under bad weather condition must be high. The probability of duplicate sightings was about 20% smaller in the third circumpolar survey than that in the second circumpolar survey (Mori *et al.* 2002). The result indicated that decline in g(0) in the third circumpolar survey occurred, especially in the northern stratum. Decline in the number of duplicate was explained by prevalence of small school size and bad weather conditions in the third circumpolar survey. Tentative analysis using the hazard probability model based on the perpendicular distance and forward distance data revealed that g(0) was smaller for single animal schools than more than single animal schools (Okamura *et al.* 2002). Current standard abundance estimation methods are based on an assumption that g(0) is equal to 1 (Branch and Butterworth 2001), but it is obvious that the assumption is violated at least in northern stratum in third circumpolar survey. Without correction of g(0), current abundance estimate of the Antarctic minke whale in third circumpolar survey must be underestimated. General trends of the search forward distance, the effective search half-width and the mean school size along the sighting condition gradients were identified in the circumpolar data sets in this analysis. But regional and temporal effects must be considered when the corrections of g(0) are made because regional and temporal heterogeneities exist in those parameters.

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REFERENCES

Branch, T. A. and Butterworth, D. S. 2001. S Southern Hemisphere minke whales: standardised abundance estimates from the 1978/79 to 1997/98 IDCR-SOWER surveys. *J. Cetacean Rea and Manage.* 3:143-174.

Butterworth, D. S., Rademeyer, R. A. and Brandão. 2001. First attempt to quantify some factors that potentially confound temporal comparisons of minke whale abundance estimates from the IWC/IDCR-SOWER surveys. Paper SC/53/IA27 presented to the IWC Scientific Committee, July 2001 (unpublished). 21pp. [Paper available from the Office of this Journal]

Ensor, P. Matsuoka, K., Marques, F., Miura, T., Murase, H., Pitman, R., Sakai, K. and Van Waerebeek, K. 2001. 2000-2001 International Whaling Commission –Southern Ocean Whale and Ecosystem Research (IWC-SOWER) circumpolar cruise, Area V, VI and I. Paper SC/53/IA5 presented to the IWC Scientific Committee, July 2001 (unpublished). 21pp.

Fujise, Y., Tamura, T., Ichihashi, H. and Kishino, H. 1999. Further examinations of the segregation pattern of minke whales in the Antarctic Area IV using a logistic regression model, with consideration on pack ice distribution. Paper SC/51/CAWS18 presented to the Scientific Committee of the International Whaling Commission, May 1999 (unpublished). [Paper available from the Office of this Journal]

Gunnlaugsson, T. and Sigurjónsson, J. 1990. NASS-87: Estimation of whale abundance based on observations made onboard Icelandic and Faroese survey vessels. *Rep. Int. Whal. Commn.* 40: 571-580.

International Whaling Commission. 2002. Report of Scientific Committee, Annex G. Report of the Sub-Committee on Stock Assessment - In Depth Assessments. *J. Cetacean Rea and Manage. (Suppl.)* in press.

Joyce, G. G. 1982. Blow patterns as sighting cues for censusing minke whales in Antarctic waters. Rep. Int. Whal. Commn. 32:787-790.

Matsuoka, K., Ensor, P., Hakamada, T., Shimada, H., Nishiwaki, S., Kasamatsu, F. and Kato, H. 2001. Overview of the minke whale sighting survey in IWC/IDCR and SOWER Antarctic cruises from 1878.79 to 2000/01. Submitted to *J. Cetacean Rea and Manage.*

Mori, M., Butterworth, D. and Matsuda, H. 2002. Factors that affect duplicate sightings and its trend for the IWC/IDCR-SOWER survey. Paper SC/54/IA16 presented to the IWC Scientific Committee, April 2002 (unpublished). 13pp. [Paper available from the Office of this Journal]

Øien, N. Folkow, L. and Lydersen, C. 1990. Dive time experiments on minke whales in Norwegian waters during the 1988 Season. Rep. Int. Whal. Commn. 40:337-341.

Okamura. A, H., Kitakado, T., Hiramatsu, K. and Mori, M. 2002. A new variant of hazard probability model for abundance estimation of minke whales in the Antarctic. Paper SC/54/IA10 presented to the IWC Scientific Committee, April 2002 (unpublished). 13pp. [Paper available from the Office of this Journal]

Stockin, K.A., Fairbairns, R.S., Parsons, E.C.M. and Sims, D. W. 2001. Effects of dial and seasonal cycles on the dive duration of the minke whale (*Balanenoptera acutorostrata*). J. Mar. Biol. Ass. 81:189-19

Strindberg, S. and Burt, L. 2000. IWC Database-Estimation System Software (DESS) User Manual, May 2000. Research Unit for Wildlife Population Assessment, Mathematical Institute, University of St Andrews. 300pp.

Zar, J, H. 1999. Biostatistical analysis. 4th ed. Prentice Hall, Upper Saddle River, New Jersey, USA. 663pp.

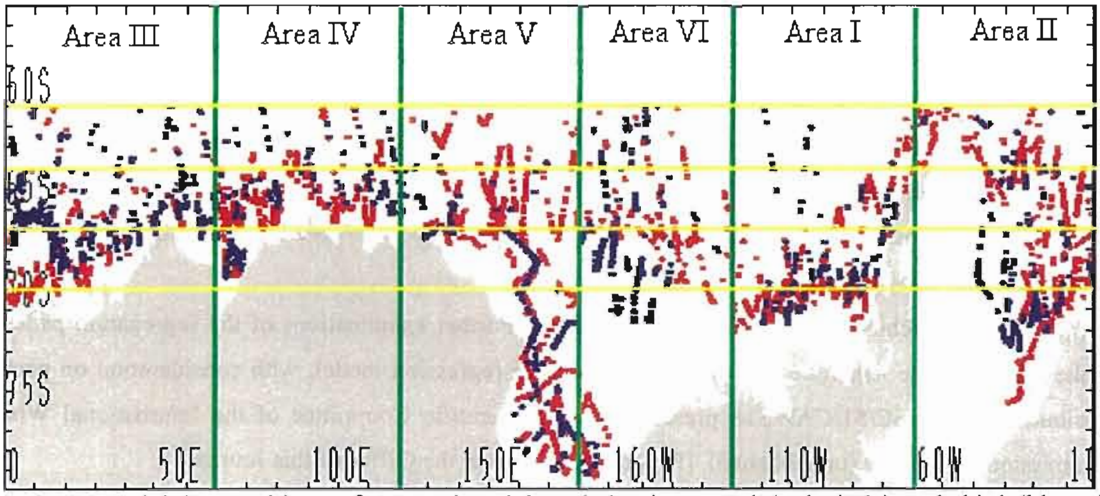


Fig. 1. Primary sighting positions of Antarctic minke whales in second (red circle) and third (blue circle) circumpolar surveys.

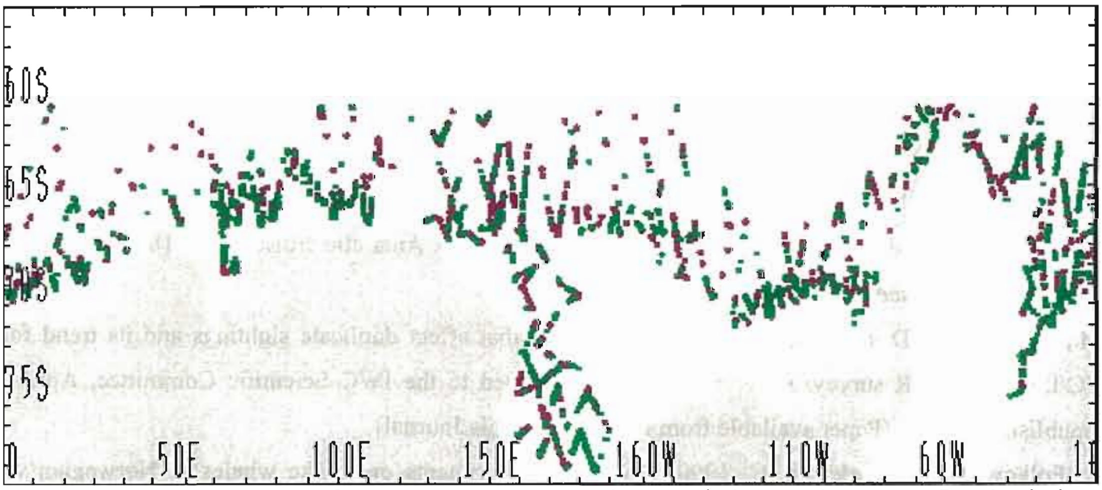


Fig. 2. Primary sighting positions of Antarctic minke whales in second circumpolar survey. Purple circle: single animal school; green circle: more than one animal school.

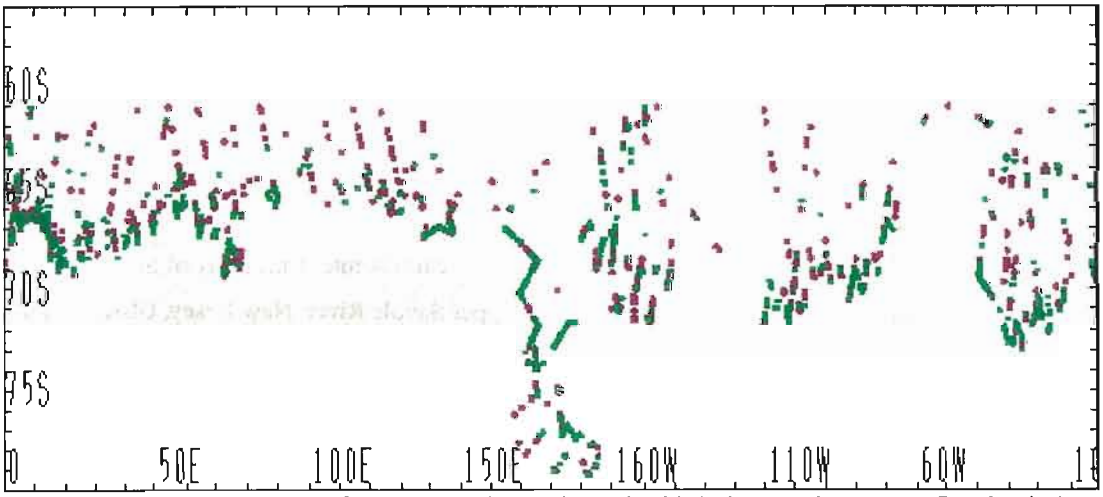


Fig. 3. Primary sighting positions of Antarctic minke whales in third circumpolar survey. Purple circle: single animal school; green circle: more than one animal school.

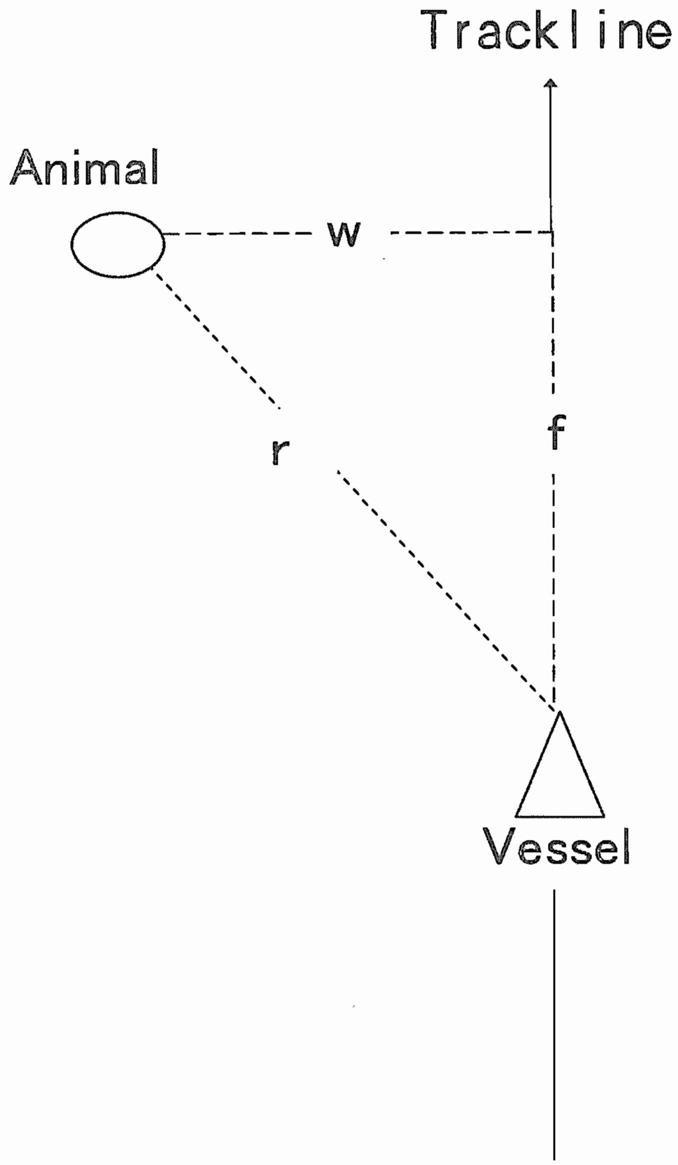


Fig. 4. Definition of the sighting radial distance (r), the perpendicular distance (w) and the sighting forward distance (f).

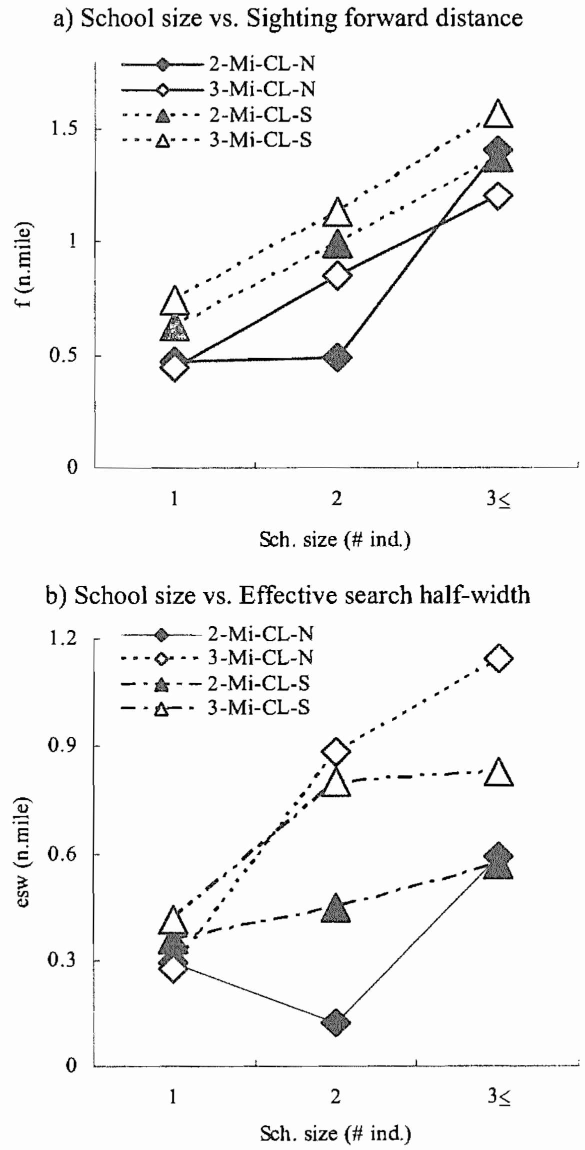


Fig. 5. Change in the search forward distance (f) (a) and the effective search half-width (esw) (b) with school size gradient. Only confirmed school size data were used.

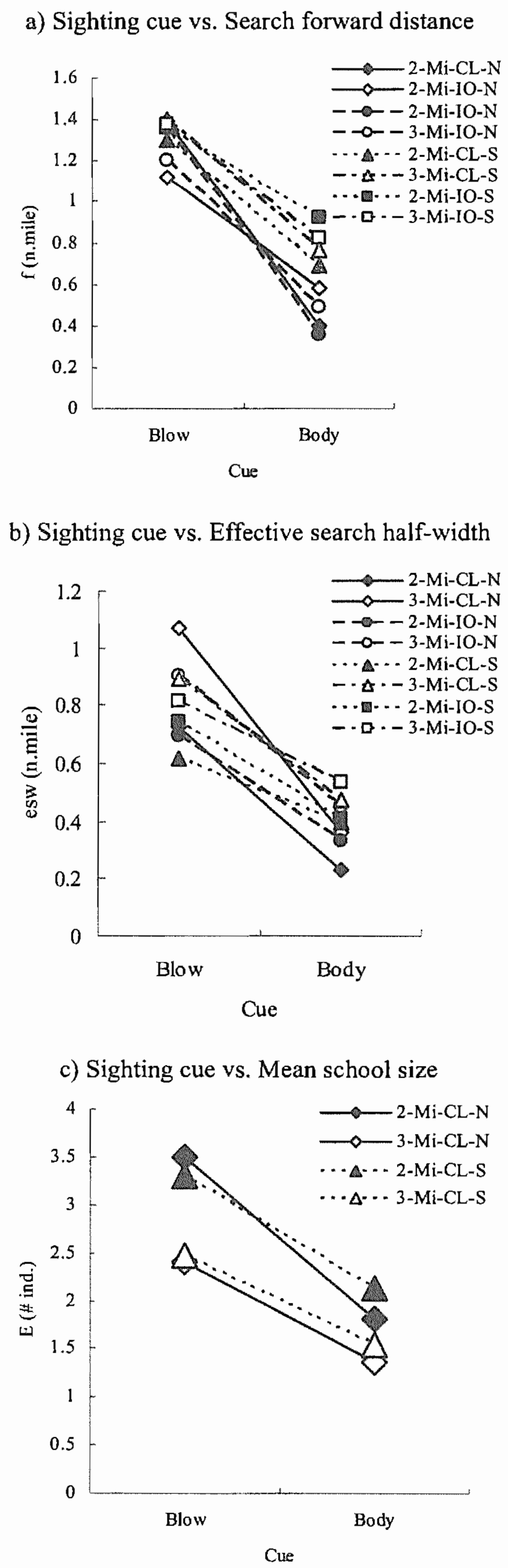
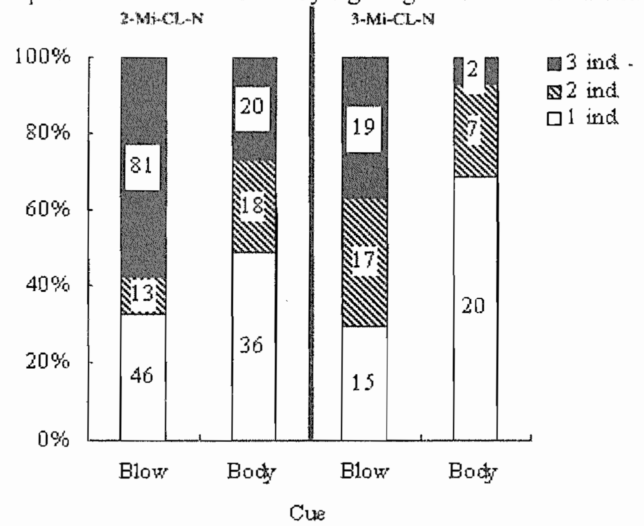


Fig. 6. Difference of the search forward distance (f) (a), the effective search half-width (esw) (b) and mean school size (E) at different sighting cues (blow and body).

a) Compositions of school sizes by sighting cues in northern stratum



b) Compositions of school sizes by sighting cues in southern stratum

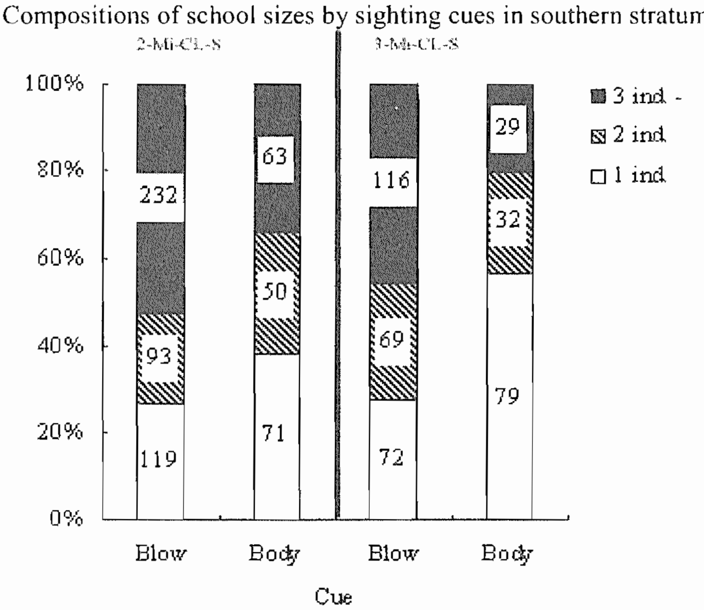


Fig. 7. Compositions of school sizes by sighting cues. (a): northern stratum; (b): southern stratum. Numbers in bars denoting actual numbers of sighted schools.

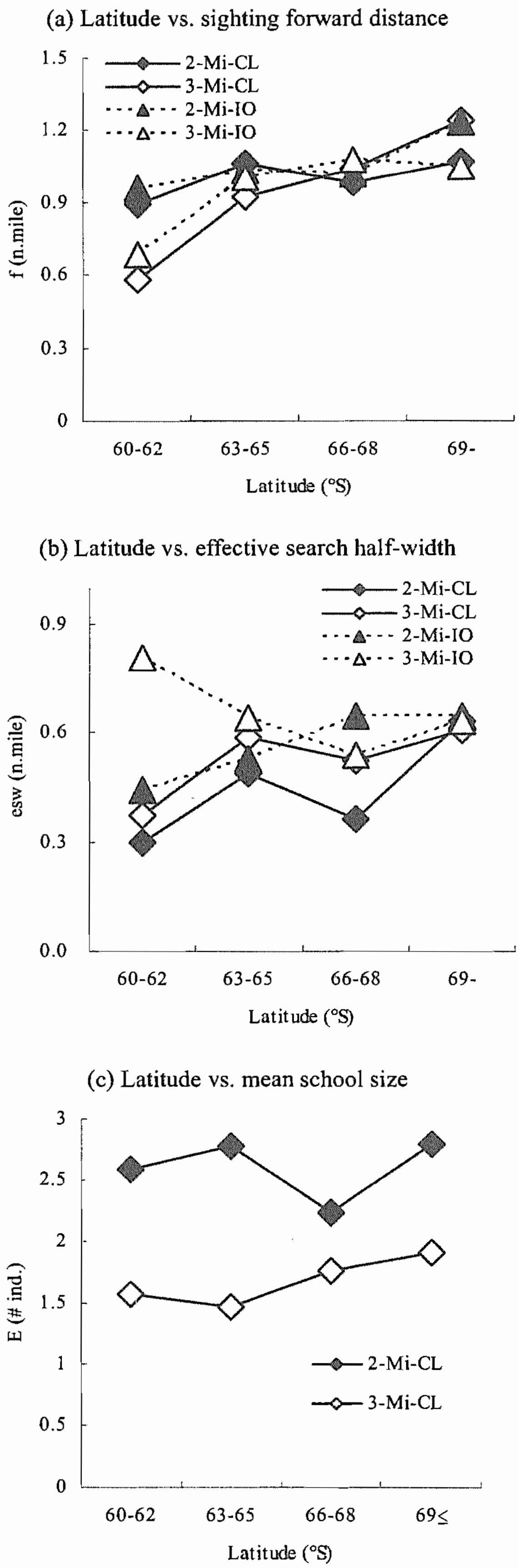
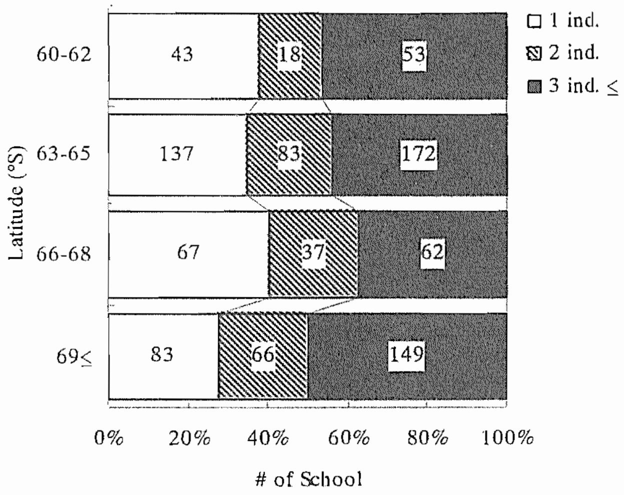


Fig. 8. Changes in the search forward distance (f) (a), effective search half-width (esw) (b) and mean school size (E) with latitudinal gradients.

(a) School size compositions along latitudinal gradients in the second circumpolar survey



(b) School size compositions along latitudinal gradients in the third circumpolar survey

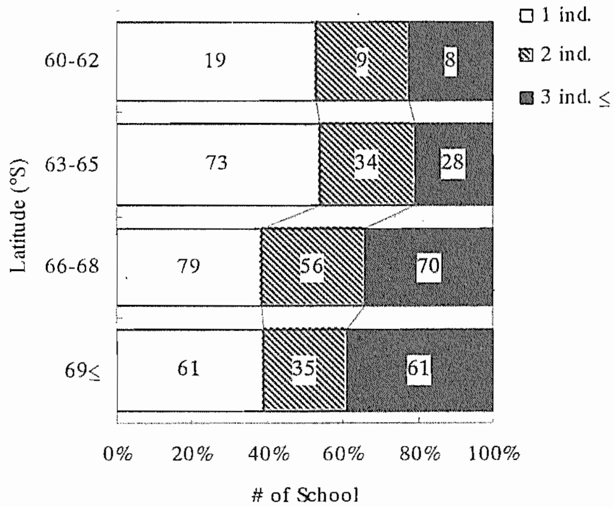


Fig. 9. Change in the school size compositions along latitudinal gradients. (a): second circumpolar data set; (b): third circumpolar data set. Numbers in bars denoting actual numbers of sighted schools. Note that sightings in Area II accounted for 68% (77 out of 114) in 60-62°S in the second circumpolar survey.

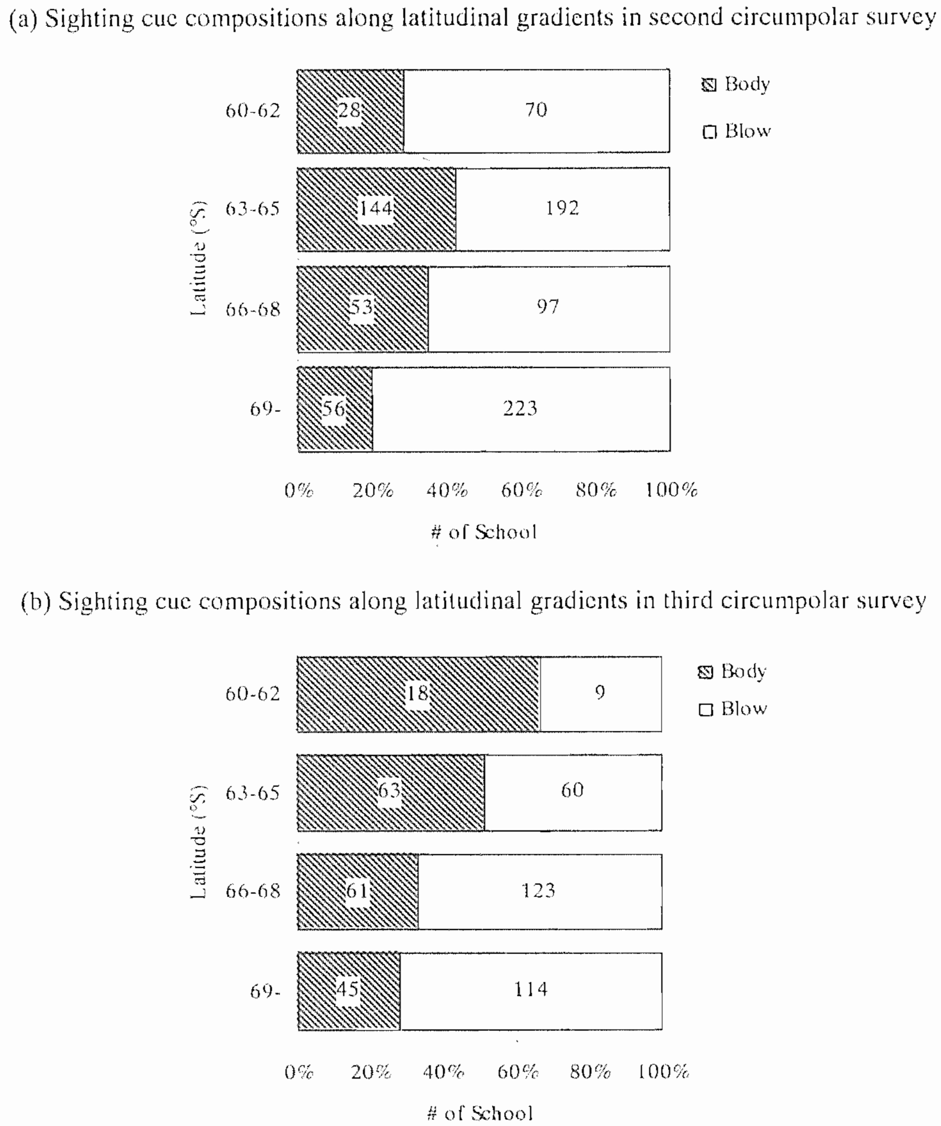


Fig. 10. Change in the proportion of sighting cues along latitudinal gradients. (a): second circumpolar data set; (b): third circumpolar data set.

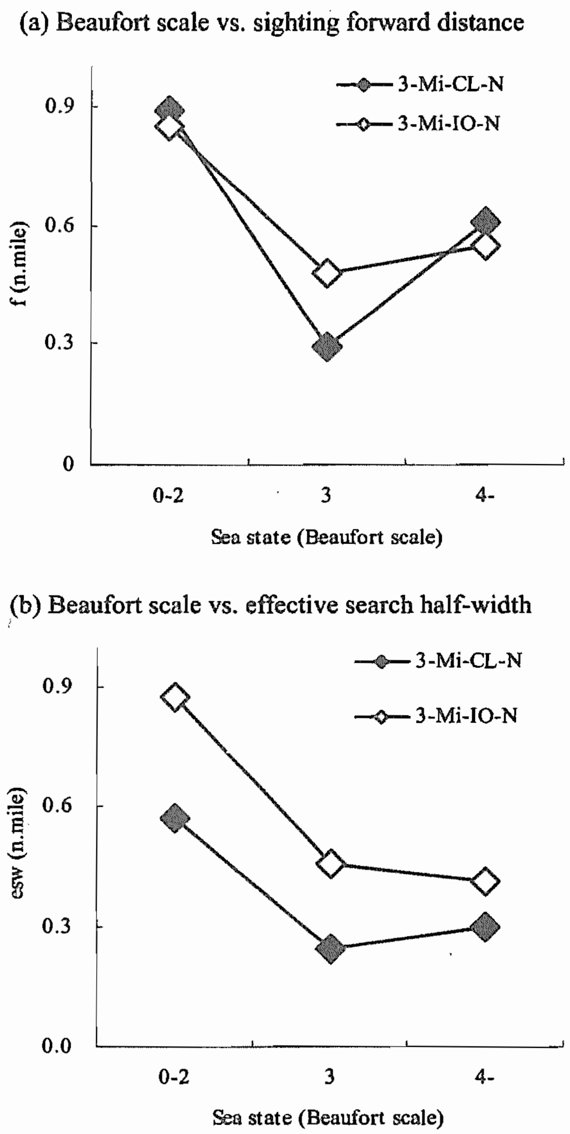


Fig. 11. Changes in the search forward distance (f) (a) and the effective search half-width (esw) (b) of single animal schools by Beaufort scales.