Examination of correction the effect of skip on the abundance estimate for Antarctic minke whales in JARPA

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Abstract
There are four kinds of skip in JARPA survey: Type (A) which is caused by night steaming to the start point of next day; Type (B) which is due to catch up with the schedule of survey; Type (C) which is caused by closing and chase a targeted minke whale and Type (D) which is caused by bad weather condition. Hakamada *et al*., (2006) suggested that there was a significant correlation with minke whale density for skip type (A) and (C). The bias of abundance estimate due to type (C) was corrected in SC/M06/J6. This paper deals with bias correction due to skip type (A) by using a modified method of Burt and Borchers (1997). Corrected abundance estimate in Area IV obtained from SSV data were 32,630 (CV=0.142) in 1989/90 and 34,982 (CV=0.171) in 1991/92. Those in Area V were 108,457 (0.124) in 1990/91 and 84,813 (CV=0.162) in 1992/93. Abundance estimates were larger after the correction and therefore we considered that the effect of skip (A) was corrected. The annual rate of change estimates are -1.10% [-4.25%, 2.02%] in Area IV and -2.16% [-4.83%, 0.44%] in Area V. Both estimates are not significantly different from 0. It was shown that neither significant increase nor decrease in abundance at the 5% level was detected during 1989/90- 2004/05 in Areas IV and V even if we consider the effect of the skip type (A)

KEY WORDS: ABUNDANCE ESTIMATE, ANTARCTIC MINKE WHALES

INTRODUCTION

At JARPA review meeting in 1997, possible bias of abundance estimate due to under-surveying in higher density area was pointed out (IWC, 1998). Burt and Borchers (1997) attempted to correct the bias by extrapolating skipped interval during night from encounter rate of the day. Hakamada *et al*., (2006) classified type of skip and examined if each type of skip cause bias of abundance. They showed that skipping distance after the end of the survey of the day (skip type (A) defined later) correlate to encounter rate of the day from 1989/90 to 1992/93 and that skipping distance that occurs after detection (skip type (C) defined later) could cause bias of abundance estimate while other types of skip didn't cause bias.

It was shown that skip type (C) caused underestimate of abundance and corrected by estimating correction factor between survey mode in case of IWC-IDCR (Haw, 1991). The correction the bias of abundance due to skip type (C) in JARPA, was dealt with in paper SC/M06/06 presented at this meeting.

The IWC Scientific Committee recommended that since skip type (A) occurred only during the first four years of JARPA, the resulting potential negative bias in estimates for these years should be accounted for before including these estimates when examining trends in abundance (IWC, 2006). In order to address this recommendation, this paper attempt to correct abundance due to skip type (A).

MATERIALS AND METHODS

Skip of sighting surveys during JARPA surveys

Process of sighting surveys in a day

Fig. 1 illustrates movement of a SSV in a day. SSV started from point A in the morning. It had planned to proceed to point C in the day. A school was detected and sighting survey was interrupted at point D1. SSV closed to the detected school to confirm species and school size. If the detected school was identified as Antarctic minke whales, SSV chased targeted minke whale to sample it. After SSV sampled it, SSV transport it to Research Base Vessel, returned to point E1 on the trackline and resumed sighting survey. As a result, trackline between D1 and E1 was skipped. The same situation occurred between D2 and E2 and between D3 and E3. However, sometimes the trackline wasn't skipped as in the case of trackline between D2 and E2. In this case, D2 and E2 are the same position. When the time to end the daily survey came, SSV arrived at the point B. If SSV didn't reach point C, SSV moved without surveying from B to C until the beginning of the survey next day. Conversely, if SSV reached to C or proceed over the point C, SSV stayed there until the next morning. As far as the pre-determined distance per day is concerned, it was applied until 1992/93.

The skips occurred during JARPA are classified into three types as follows.

(A) Skip occurring after end of daily survey (proceeding along the trackline in the night without sighting surveys), in order to fulfill the pre-determined distance per day.
(B) Skip due to catch up with the schedule within a stratum. When time shortage occurred in a stratum, vessel skipped some part of planned trackline.
(C) Skip accompanied a detection of whales due to closing to a detected school and chasing a targeted minke whale.
(D) Skip due to bad weather conditions.

Skip type (A)
The pre-determined distance per day is a task on daily movement on the research track line. It was applied to JARPA from the 1989/90 to the 1992/93 seasons. The SSVs had to steam during the night to the start point of next day, when they did not achieved pre-determined distance during the daytime. This type of skip was caused by shortage of searching distance in a day due to bad weather conditions and/or sampling activity in the high-density area of the minke whales. The concern was that such skip might cause biased population estimate because SSV tended to skip over high-density areas of whales after sampling activity of a day (IWC, 1998). However, pre-determined distance per day was abolished from the 1993/94 season because total distance of planned trackline in one survey was reduced. The survey in the Areas IV and V was conducted once in the peak migration season of the minke whales from the 1992/93 season whereas SSV surveyed whole of Area IV/V twice in a year before then. Type (A) skip is represented as segment BC which is illustrated as blue dotted line in Fig. 1. Pre-determined distance is less in south strata than in north strata because it was expected that whale density is higher in south strata than in north strata.

Skip type (B)
After 1993/94, pre-determined distances were not set. Even if a survey vessel covered a shorter distance than expected, it would not skip the sighting survey in the night. However, in the case that it became difficult to finish the survey in a stratum within the planned schedule, planned trackline would be skipped during night to catch up with the schedule. Compared with skip type (A), daily distance of this skip tends to be much less as shown in Table 1 (Hakamada *et al*., 2006).

Skip type (C)
This type of skip occurs accompanied with the detection of the minke whales. In the case of SV, it is caused by only closing to confirm species and school size of the detected school. In the case of SSVs, it is caused by closing, chasing and sampling of a targeted minke whale. Type (C) skip is the union of the segment D1E1 and D3E3. It should be noted that type (C) skip is same kind of skip examined in Haw (1991), which occurred in the IDCR/SOWER surveys.

Skip type (D)
Clearly, skip due to bad weather is independent of the density of the minke whales. Therefore, skip type (D) would not affect the abundance estimate and is not examined in this study. This type of skip would occur during surveys other than JARPA.

Methods
In correction method in Burt and Borchers (1997), it was assumed that effective half search width and estimated mean school size were not biased due to skip type (A) and that sighting survey was conducted whole of scheduled trackline and that encounter rate in the skipped trackline is same as that surveyed trackline in the day. Original correction method in Burt and Borchers (1997) used estimate corrected encounter rate by following formula;

$$\frac{n}{l} = \frac{\sum_i \left\{ n_i + \frac{n_i}{l_i} d_i (k_i - 1) \right\}}{\sum_i \left\{ l_i + d_i (k_i - 1) \right\}} \qquad (1)$$

where d_i is proceeding distance on the ith day, n_i is the number of sighted school on the ith day, l_i is searching distance on the ith day, k_i is ratio of proceeding distance to pre-determined distance on the ith day. Illustration of l_i, d_i and k_i is given in Fig. 2. Notations and formulation were slightly modified from Burt and Borchers (1997) so as to make easier to describe modified formulas.

Modified method is described as following. There are two differences between our method and that in Burt and Borchers (1997). One is that we assumed skip type (C) would occur as sighting survey in the day and the next day whereas they extrapolated encounter rate to whole of skipped trackline. We corrected the bias due to skip (C) by Haw's correction method later. Another is that they extrapolated encounter rate of the day but we did average of encounter rates of the day and the next day. Corrected encounter rate is estimated by

$$\frac{n}{l} = \frac{\sum_i n_i k_i}{\sum_i l_i k_i} \qquad (2)$$

where if survey vessel proceed more than it had planned, we defined $k_i=1$. In special case of $l_i = d_i$ for all i (i.e. vessels didn't approach to detected schools), encounter rate estimated by formula (1) would equal to that by formula (2). Formula (2) assumes that encounter rate in skipped trackline was equal to encounter rate of the day. But formula (2) can be modified as follows under the assumption that encounter rate in the skipped trackline is average of the encounter rate of the day and the next day taking into account that the method of Burt and Borchers (1997) could cause overestimate of corrected abundance because whole of skipped trackline was not always higher density area.

$$\begin{cases} \dfrac{n}{l} = \dfrac{\sum_i \left\{ n_i + d_i (k_i - 1) \left(\dfrac{n_i + n_{i+1}}{d_i + d_{i+1}} \right) \right\}}{\sum_i \left\{ l_i + d_i (k_i - 1) \left(\dfrac{l_i + l_{i+1}}{d_i + d_{i+1}} \right) \right\}} (i \le N-1) \\ \dfrac{n}{l} = \dfrac{\sum_i n_i k_i}{\sum_i l_i k_i} (i = N) \end{cases} \qquad (3)$$

where d_i is proceeding distance in the ith day.

Derivation of formula (3) is as follows. After the end of the survey on the ith day, skipped distance can be expressed as $d_i(k_i-1)$. Searching distance in the skipped trackline is calculated as

$$d_i (k_i - 1) \left(\frac{l_i + l_{i+1}}{d_i + d_{i+1}} \right) \qquad (4)$$

under the assumption that ratio of proceeding distance and searching distance equals in the skipped trackline to average of those in the day and the next day. Average of encounter rate of the day and the next day is

$$\left(\frac{n_i + n_{i+1}}{l_i + l_{i+1}} \right) \qquad (5).$$

From formulas (4) and (5), the estimated number of detected school in the skipped trackline is

$$d_i (k_i - 1) \left(\frac{n_i + n_{i+1}}{d_i + d_{i+1}} \right) \qquad (6).$$

In the case of the last day of the survey, there was no searching effort and detection in the next day (i.e. $n_{N+1} = 0$、$l_{N+1} = 0$), formula (3) would be same as formula (2).

CV of the corrected encounter rate was estimated by bootstrap. We took resamples 100 times under condition that sampling unit is a day.

Abundance trend

To estimate abundance trend, we should correct the bias due to skip type (C). We applied Haw (1991)'s correction method to the abundance estimates after correction by the formula (3). Estimates are shown in Table 3. Abundance trend are estimated by linear regression model weighted by inverse-variance. For more details of these methods, see SC/D06/J6.

RESULTS

Table 2 shows that comparison uncorrected abundance and corrected ones and their CV's. Corrected abundance estimate are more than uncorrected. This suggested skip type (A) caused underestimate of abundance but degree of underestimate was not substantial. Corrected abundances using formula (3) is smaller than those using formula (2) in most of the cases.

Table 3 shows that abundance series obtained by applying Haw(1991)'s method to the corrected abundance by formula (3) in order to estimate abundance trend in Areas IV and V. Estimated annual increase rates and their CV's are shown in Table 4. The estimates are -1.10% [-4.25%, 2.02%] in Area IV and -2.16% [-4.83%, 0.44%] in Area V. Both estimates are not significantly different from 0.

DISCUSSION

Comparison of corrected abundance by formula (2) and (3)

Corrected abundance estimate are more than uncorrected. Hakamada *et al.*, (2006) showed that positive correlation between distance of skip type (A) and density was observed. It can be thought that underestimate of abundance was occurred due to skip type (A), and as seen in Table 1, abundances corrected by formula (2) are more than those corrected by formula (3) in most of the cases, as expected. This is due to that the whole of skipped trackline after the end of daily survey is not always high density. This means the assumption that density in skipped trackline was same as that in surveyed trackline of the day was not appropriate. Tanaka (1999) estimated the length of higher density areas to be 10-20 n.miles and assumed this in his simulation study, based on the geographical distribution of detected minke whales in southern strata observed during 1992/93 JARPA surveys. He showed that abundance estimate derived from Burt and Borchers (1997) was overestimated (Tanaka, 1999). By adopting the assumption that density in skipped area is average of density in the day and next day (i.e. using formula (3) instead of formula (2)), overestimate of corrected abundance would be improved.

Abundance trend using corrected abundance

Comparing to abundance trend in Table 5, abundance trend was not substantially different. Even if we consider the correction of bias due to skip type (A), it was shown that neither significant increase nor decrease was detected during 1989/90- 2004/05 in Areas IV and V.

Skip type (D) (skip due to bad weather condition)

We couldn't examine correlations between the density and the distance of skip of type (D). It is impossible to do because we didn't conduct sighting survey under such bad weather conditions and we don't have data to estimate density under such bad weather condition as sighting survey was suspended. We can assume that the effect of skip type (D) on abundance could be small as there is no clear reason why we would expect minke whale density to be correlated with changes in weather conditions because this type of skip didn't occur intentionally.

ACKNOWLEGMENT

We thank all the researches and crew involved JARPA. We also thank Drs. Hiroshi Hatanaka and Doug Butterworth (University of Cape Town) for their valuable comments to improve earlier manuscripts.

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Table 1. Skipping distance of type (A) for 1989/90 and 1990/91 and type (B) for 1993/94, 1994/95, 2000/01 in each stratum (Hakamada *et al*., 2006)

	1989/90	1993/94	2001/02
stratum	Type (A)	Type(B)	Type(B)
NW	397.6	0.0	0.0
NE	314.3	158.4	0.0
SW	167.4	61.8	0.0
SE	225.6	76.6	0.0
PB	15.6	0.0	0.0

	1990/91	1994/95	2000/01
stratum	Type (A)	Type(B)	Type(B)
NW	284.3	126.6	69.2
NE	369.0	4.8	368.8
SW	295.3	64.4	0.0
SE	286.0	0.0	152.9

Table 2. Uncorrected abundance estimate and corrected ones using formula (2) and (3). Formula (2) is extrapolating encounter rate of the day and (3) is extrapolating average encounter rate of the day and the next day. Numbers in the parentheses are CV's.

Area IV

	1989/90		
strata	uncorrected	Formula (2)	Formula (3)
North-West (NW)	8,334 (0.336)	9,765 (0.289)	9,614 (0.292)
North-East (NE)	10,521 (0.222)	12,421 (0.301)	11,822 (0.291)
South-West (SW)	2,463 (0.184)	2,645 (0.189)	2,583 (0.184)
South-East (SE)	6,494 (0.230)	6,856 (0.152)	6,446 (0.160)
Prydz Bay (PB)	2,181 (0.357)	2,193 (0.306)	2,165 (0.311)
total	29,993 (0.135)	33,881 (0.144)	32,630 (0.142)

	1991/92		
strata	uncorrected	Formula (2)	Formula (3)
North-West (NW)	12,894 (0.191)	14,315 (0.203)	13,234 (0.223)
North-East (NE)	2,809 (0.443)	3,869 (0.595)	3,869 (0.503)
South-West (SW)	2,700 (0.250)	3,374 (0.248)	3,229 (0.219)
South-East (SE)	2,171 (0.270)	3,505 (0.291)	3,212 (0.341)
Prydz Bay (PB)	12,097 (0.567)	11,815 (0.393)	11,438 (0.406)
total	32,670 (0.228)	36,878 (0.165)	34,982 (0.171)

Area V

	1990/91		
strata	uncorrected	Formula (2)	Formula (3)
North-West (NW)	28,692 (0.172)	32,110 (0.178)	29,978 (0.184)
North-East (NE)	26,342 (0.414)	29,443 (0.331)	29,178 (0.329)
South-West (SW)	6,416 (0.187)	9,228 (0.194)	8,248 (0.188)
South-East (SE)	39,296 (0.178)	47,240 (0.204)	41,053 (0.183)
total	100,745 (0.135)	118,020 (0.127)	108,457 (0.124)

	199293		
strata	uncorrected	Formula (2)	Formula (3)
North-West (NW)	15,525 (0.313)	24,846 (0.360)	26,175 (0.289)
North-East (NE)	13,746 (0.279)	13,993 (0.331)	12,970 (0.338)
South-West (SW)	6,879 (0.286)	10,625 (0.307)	9,302 (0.302)
South-East (SE)	29,997 (0.466)	35,260 (0.289)	36,366 (0.282)
total	66,147 (0.233)	84,724 (0.174)	84,813 (0.162)

Table 3. Corrected abundance by applying Haw's method to the abundance estimates using formula (3) in Table 1 in Areas IV and V. Correction factors $R1$=0.821 (CV=0.086) and $R2$=0.759 (CV=0.126) were used.

Area IV

year	P	CV
1989/90	52,402	0.208
1991/92	56,180	0.229
1993/94	41,398	0.192
1995/96	42,363	0.203
1997/98	25,922	0.220
1999/00	44,931	0.151
2001/02	48,280	0.188
2003/04	44,564	0.291

Area V

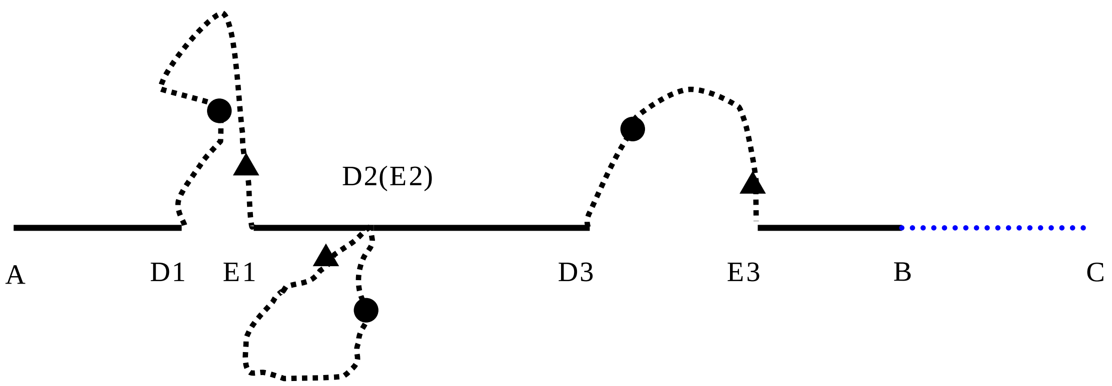
year	P	CV
1990/91	174,176	0.196
1992/93	150,123	0.191
1994/95	166,830	0.234
1996/97	145,021	0.229
1998/99	184,914	0.225
2000/01	164,789	0.205
2002/03	201,883	0.154
2004/05	91,819	0.147

Table 4. Estimated annual increasing rate in Areas IV and V after the correction of the bias due to skip type (A).

	estimate	95%CILL	95%CIUL
Area IV	-1.10%	-4.25%	2.02%
Area V	-2.16%	-4.83%	0.44%

Table 5. Estimated annual increasing rate in Areas IV and V not taking the correction of the bias due to skip type (A) into account. (SC/D06/J6)

Area	estimate	95%CILL	95%CIUL
Area IV	-0.42%	-3.58%	2.68%
Area V	-1.54%	-4.01%	1.21%



A: Starting position of the day,
B: Ending position of the day
C: Starting position of the next day
D1,D2,D3: Sighting position of the 1st, 2nd and 3rd detection of the day, respectively.
E1,E2, E3: Position of restarting sighting survey after the 1st, 2nd and 3rd detection of the day, respectively.
In this case, point D2 and E2 are the same position.
Bold line indicates track line where sighting survey was actually conducted.
Dotted line indicates survey vessel proceeded without sighting surveys
Filled circle indicates point where both species and size of detected school were confirmed.
Filled triangle indicates point where a targeted minke whale was taken.

Fig. 1. Illustration of skip type (A) and (C).
Type (C) skip is the union of the segment D1E1 and D3E3. Type (A) skip is the segment BC. It had been planned sighting survey on the segment AC. If there had been no detection on the day, survey vessel could be proceed to point C. Bold black line represent actually surveyed, vessel go along dotted curves to close a detected school and chase a targeted whale. Blue dotted line indicates trackline skipped in the night.

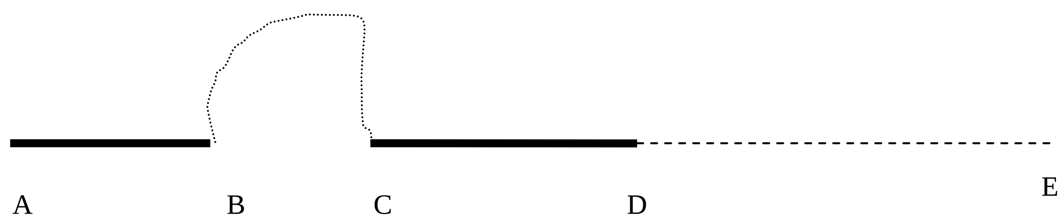


Fig 2. Illustration for variables l_i , d_i , k_i ,in formulas (1)-(7). A is the starting position on the *i* th day. B is position where sighting survey was stopped due to detection of a school. C is position where sighting survey was restarted. D is position at the end of daily survey. E is the starting position on the (*i*+1) th day. Bold line indicates track line where sighting survey was actually conducted. Dotted line indicates survey vessel proceeded without sighting surveys

$$l_i = \overline{AB} + \overline{CD}$$

$$d_i = \overline{AD}$$

$$k_i = \overline{AE} / \overline{AD}$$

$\overline{AD}$ indicates length of segment AD.