A Point Estimate of Natural Mortality Coefficient of Southern Minke Whales Using JARPA data

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ABSTRACT

This paper shows a point estimate of natural mortality coefficient of Southern minke whales using JARPA data, by modifying the original method proposed by Tanaka (1990). Skew age composition by mature/immature segregation was corrected using maturity area at age. Net rate of natural increase of size of stock by a new interpretation of stock boundary was estimated by maximum likelihood. Using the zero increase rate of stock size from the statistical model selected by the c-AIC, the point estimates of natural mortality coefficient were 0.0486 (per year) for both the Eastern Indian Ocean Stock and 0.0490 for Western South Pacific Stock.

INTRODUCTION

Natural mortality coefficient is one of most important biological parameters for both population dynamics and stock management. The changes in number of recruits and carrying capacity on Southern minke whales (Sakuramoto and Tanaka, 1985, 1986; Butterworth *et al*., 1996,1997), which relates to those in the ecosystems of the Antarctic, have been estimated using the mortality coefficient.

In the Revised Management Procedure (RMP) which is a current conservative tool of the whale stock management in IWC, an assumed coefficient of natural mortality was used in the Implement Simulation of the RMP. In the results of simulation trials, such performance statistics as realized protection (RP) level was used for one of criteria of stock conservation, and was depending upon the extent of the natural mortality. The effect of the changes in the carrying capacity , which causes those of the recruits, were examined in the past robustness simulation trials for developing the RMP. The estimate of the extent of changes depends upon the mortality estimate. Thus the natural mortality coefficient has directly and indirectly been used in the RMP.

JARPA survey a program for investigating the biological aspect of the Southern minke whales and one of the objectives of the program is to estimate such parameters as the natural mortality coefficient. Term of the planned survey is so long as sixteen years in order to have a precise estimate using stock abundances and age compositions (Tanaka,1990, Tanaka *et al*., 1992; Cooke *et al*, 1997; Tanaka and Fujise, 1997). Studies on the estimation with such research takes under random sampling have been presented (Sakuramoto and Tanaka, 1989; de la Mare, 1990, Nakamura, 1991).

In the JARPA review meeting in 1997, however, information on age segregation was recognized, irrespective of random sampling. A portion of young whales does not migrate into the Antarctic survey areas where is south of 60° S. The observed frequency in the young age class could be lower than the true frequency for the whole stock and therefore the estimate of the natural mortality using directly the data would be biased. Many of the young age classes consist of immature component of the stock. If the frequency of this component is corrected, we could make unbiased estimate of age composition.

In addition, Luis *et al* (2005) proposed a new scenario of stock boundary that is different from the traditional IWC stock division. In the scenario the boundary is 165° E, There were two stocks in Area III/E, IV, V, and VI/W, and the Eastern Indian Ocean Stock (I-stock) and the Western South Pacific Stock (P-stock). Therefore, new method is necessary for handling and/or analyzing the data because the JARPA survey was planned and conducted by the traditional division.

This paper proposed an estimation of the natural mortality coefficient introducing a method for correction of the observed age composition and natural increase rate with segregation parameters. Issues relating the estimation were discussed.

MATERIALS AND METHODS

Data

Data used for natural mortality coefficient are the annual abundance estimate stratified by area, sex, mature/immature and age, and estimated curve for maturity rate at age (Bando *et al*, 2005).

Basic Models for Dynamics of Stock Size

We consider whale population that stock size is changed due to natural mortality and recruitment, and that stock is consisting of mature and immature components, and that a portion of each component is annually migrating into the JARPA survey area. We assume that natural mortality coefficient is independent of year and that proportion of mature or immature stock is independent of age.

Let $N_{t,s,a}$, $R_{t,s,a}$, $U_{t,s,a}$, $R'_{t,x,s,a}$, and $U'_{t,x,s,a}$ be size of stock of sex s(=1,2) at age in years a(=1,2,3,…) in year t(=1,3,5,…,T), mature stock size, immature one, mature stock size in Area x(=1,2,3, for Area IV, V/W, V/E), and immature one, respectively. Basic model for the dynamics are expressed by

$$N_{t+1,s,a+1} = N_{t,s,a} \exp(-M_a) \quad (1)$$

$$N_t = \sum_s \sum_a N_{t,s,a} \quad (2)$$

$$R_{t,s,a} = \beta_{s,a} N_{t,s,a} \quad (3)$$

$$U_{t,s,a} = (1-\beta_{s,a}) N_{t,s,a} \quad (4)$$

$$\beta_{s,a} = \frac{1}{1+e^{-c_s(a-a_s)}} \tag{5}$$

$$N_{t,s,a} = U_{t,s,a} + R_{t,s,a} \tag{6}$$

$$R'_{t,x,s,a} = \delta_{t,x} R_{t,s,a} \tag{7}$$

$$U'_{t,x,s,a} = \gamma_{t,x} U_{t,x,a} \tag{8}$$

Here $\gamma_{t,x}$: rate of size of immature stock in survey area to total immature stock(>0)

$\delta_{t,x}$: rate of size of mature stock in survey area to total mature stock(>0)

N_t : stock size in total

$\beta_{s,a}$: maturity rate at age

M_a : natural mortality coefficient (per year).

Estimation Procedures for Average Natural Mortality Coefficient

From equation (1), we have

$$M_a = \ln\left(\frac{N_{t,a}}{N_{t+2,a+2}}\right) = \ln\left(\frac{N_t}{N_{t+2}}\right) + \ln\left(\frac{p_{t,a}}{p_{t+2,a+2}}\right) = -2r + 2z_a \tag{9}$$

$$r = \frac{1}{2}\ln\left(\frac{N_{t+2}}{N_t}\right) \tag{10}$$

$$z_a = \frac{1}{2}\ln\frac{p_{t,a}}{p_{t+2,a+2}} \tag{11}$$

$$N_{t,a} = N_t \, p_{t,a} \tag{12}$$

$$p_{t,a} = \frac{N_{a,t}}{N_t} = \frac{\sum_i N_{t,i,a}}{\sum_i \sum_j N_{t,i,j}} \tag{13}$$

Here r(per year) is the net rate of increase of stock size. When age composition is fairly stable, the average natural mortality coefficient is expressed by

$$\overline{M} = \ln\left(\frac{N_t}{N_{t+2}}\right) - \ln\left(1 - \sum_{a\sim 1}^{\infty} p_{a,t+2}\right) = -2r + 2\overline{z} \tag{14}$$

$$\bar{z} = -\ln\left(1 - \sum_{a\sim 1}^{\infty} p_{a,t+2}\right) \tag{15}$$

Therefore those estimates are expressed by

$$\hat{\bar{M}} = \hat{\bar{z}} - \hat{r} \tag{16}$$

$$\hat{\bar{z}} = -\frac{1}{(T-1)}\sum_{t=3}^{T}\ln\left(1 - \sum_{k=2}^{\infty} p_{t,a+k}\right) \tag{17}$$

Correction of Age Composition

Age composition in the survey area was corrected by abundance by school size and age composition by school size (Fujise *et al*, 1992). However, if the value of $\gamma_{t,x}$ is different from that of $\delta_{t,x}$, the age composition is biased and therefore should be corrected. Assuming that $N_{t,s,a}$ in some age classes are close to each other and using equation (3), (4), (7) and (8), an estimate $\lambda_{t,x}$ is approximately expressed by

$$\frac{\dfrac{\sum_s\sum_a R'_{t,x,s,a}}{\sum_s\sum_a \beta_{s,a}}}{\dfrac{\sum_s\sum_a U'_{t,x,s,a}}{\sum_s\sum_a (1-\beta_{s,a})}} = \frac{\delta_{t,x}\dfrac{\sum_s\sum_a \beta_{s,a}N_{t,s,a}}{\sum_s\sum_a \beta_{s,a}}}{\gamma_{t,x}\dfrac{\sum_s\sum_a (1-\beta_{s,a})N_{t,s,a}}{\sum_s\sum_a (1-\beta_{s,a})}} \approx \frac{\delta_{t,x}}{\gamma_{t,x}} = \hat{\lambda}_{t,x} \tag{18}$$

Using equation (18), we reduce the following equations:

$$\frac{\sum_s\left(R'_{t,x,s,a} + \hat{\lambda}_{t,x}U'_{t,x,s,a}\right)}{\sum_s\sum_a\left(R'_{t,x,s,a} + \hat{\lambda}_{t,x}U'_{t,x,s,a}\right)} = \frac{\delta_{t,x}\sum_s\left(R_{t,s,a} + U_{t,s,a}\right)}{\delta_{t,x}\sum_s\sum_a\left(R_{t,s,a} + U_{t,s,a}\right)} = \frac{N_{t,a}}{N_t} = p_{t,a}$$

$$\therefore\ \hat{p}_{t,a} = \frac{\sum_s\left(R'_{t,x,s,a} + \hat{\lambda}_{t,x}U'_{t,x,s,a}\right)}{\sum_s\sum_a\left(R'_{t,x,s,a} + \hat{\lambda}_{t,x}U'_{t,x,s,a}\right)} \tag{19}$$

Estimation of r

Suppose that

$$\delta_{t,1} + \delta_{t,2} = 1 \tag{20}$$

then the stock size in Area IV or V/W is expressed by

$$N_{t,x} = \sum_s \sum_a \left(R'_{t,x,s,a} + \hat{\lambda}_{t,x} U'_{t,x,s,a} \right) = \delta_{t,x} \sum_s \sum_a \left(R_{t,s,a} + U_{t,s,a} \right) = \delta_{t,x} N_t \tag{21}$$

The mean of proportion of stock size in Area IV to that in Areas IV+V/W is denoted by δ.For the I-stock, *r* is estimated by maximizing the following log-likelihood:

$$LL_W = LL_1 + LL_2 \tag{22}$$

$$LL_1 = -\frac{1}{2} \sum_t \left[\ln\left\{ 2\pi \left(\sigma_{t,1}^2 + \upsilon_1^2 \right) \right\} + \frac{\left\{ \ln\left(N_{t,1} \right) - \ln(\delta) - \ln\left(\hat{N}_1 \right) - \hat{r}(t-1) \right\}^2}{\sigma_{t,1}^2 + \upsilon_1^2} \right] \tag{23}$$

$$LL_2 = -\frac{1}{2} \sum_t \left[\ln\left\{ 2\pi \left(\sigma_{t,2}^2 + \upsilon_2^2 \right) \right\} + \frac{\left\{ \ln\left(N_{t,2} \right) - \ln(1-\delta) - \ln\left(\hat{N}_1 \right) - \hat{r}(t-2) \right\}^2}{\sigma_{t,2}^2 + \upsilon_2^2} \right] \tag{24}$$

For the P-stock, assuming δ =1, *r* is estimated by maximizing the following log-likelihood:

$$LL_E = -\frac{1}{2} \sum_t \left[\ln\left\{ 2\pi \left(\sigma_{t,3}^2 + \upsilon_3^2 \right) \right\} + \frac{\left\{ \ln\left(N_{t,3} \right) - \ln\left(\hat{N}_1 \right) - \hat{r}(t-1) \right\}^2}{\sigma_{t,3}^2 + \upsilon_3^2} \right] \tag{25}$$

where υ_x^2 : additional variance by stock

$\hat{\sigma}_{t,x}^2$: measurement error of abundance estimate.

Results

Tables 1-3 summarize the results of estimations and Figures 1 and 2 illustrate the average of the corrected age compositions. Comparing the compositions before and after the correction in Figure 1, the corrections seemed to be effective in the Area V, but not in Area IV. From the c-AIC values in Table 2, the models using *r*=0 were selected and the point estimates of natural mortality coefficient were 0.0486 (per year) for both the Eastern Indian Ocean Stock and 0.0490 for Western South Pacific Stock.

Discussions

The corrected age composition will be useful for estimating the selectivity of research takes by the JARPA comparing the corrected abundance at age and the catch at age. Also the composition will be available for monitoring changes in number of recruits, which relates to stock dynamics.

The performance of the presented method for correcting age compositions depends upon precision of the age composition and maturity rate at age. The age composition in survey area was estimated by 1) abundance estimation by sub-area and school size and 2) age composition by sub-area and school size (Kato *et al*, 1991, Kishino *et al*., 1991).

The abundance estimate used in the paper was computed using the only data from sampling and scouting vessels (SSV) because the bootstrap samples for CV computation are made by pair of the abundance and age composition from SSV and the data size for scouting vessel (SV) is too small to estimate abundance by sub-area and school size. However, abundance estimate adopted in the JARPA survey was made from the combined data because the estimate is expected to modify by using the SV data. The age composition will be modified introducing the SV data.

The maturity rate at age (Bando *et al*, 2005) was estimated by the raw data and might have uncertainty due to segregation. However, the estimate was much revised than that from the commercial catch data and will be reliable.

In the estimated value of *r*, we note that the *r* estimate may reflect changes in δ_t. The discrimination, in particular for the P-stock, was difficult because the only data in Area V/E was available and such comparison of the trend for the same stock as trend in Area IV and V/W was impossible. In that sense, statistical criterion is not applicable and the comparable data are necessary for the discrimination.

The estimate of *M* is close to that by the ADAPT VPA (Butterworth *et al*, 2002) and that for Area V (Kitakado *et al*., 2005). The CV was not yet estimated but that can be computed using bootstrap samples (Efron, 1979). This is an issue in the near future.

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Table 1. Results of estimation of $\lambda_{t,x}$.

a) Area IV

Area / Season	1989/90	1991/92	1993/94	1995/96	1997/98	1999/00	2001/02	2003/04
IV(x=1)	0.894	3.125	2.046	0.531	0.224	0.879	0.987	0.929

b) Areas V/W and V/E

Area / Season	1990/91	1992/93	1994/95	1996/97	1998/99	2000/01	2002/03	2004/05
V/W(x=2)	1.027	4.331	1.207	0.225	0.702	0.042	5.778	-
V/E(x=3)	0.507	3.001	0.981	0.804	4.026	3.983	2.388	-

Table 2. Results of estimation of r, δ_x and υ, and N_1.

Stock	Model	c-AIC	*LL*	*n*	*p*	*r*	N_1	υ_1	υ_2	υ_3	δ
I-stock	Full	349.8	-166.5	15	5	0.0272	45,245	0.413	0.703	-	0.553
	r=0	345.7	-166.9	15	4	-	54,103	0.417	0.726	-	0.548
P-stock	Full	168.5	-77.2	7	3	0.0470	54,380	-	-	0.000	-
	r=0	168.2	-80.2	7	2	-	73,556	-	-	0.241	-

Table 3. Results of point estimates of average M

Stock	I-stock	P-stock
$\overline{M}$	0.0486	0.0490

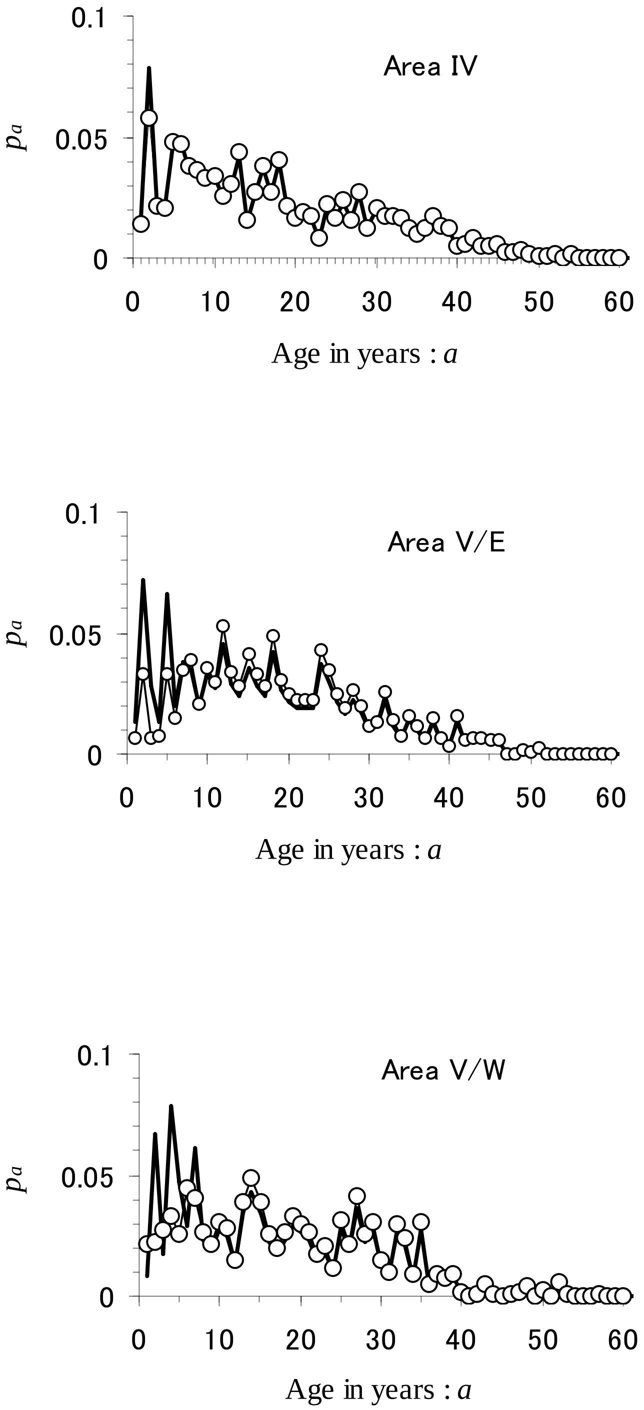

Figure 1. Comparison of uncorrected age compositions (open circles) and corrected one (solid curves).

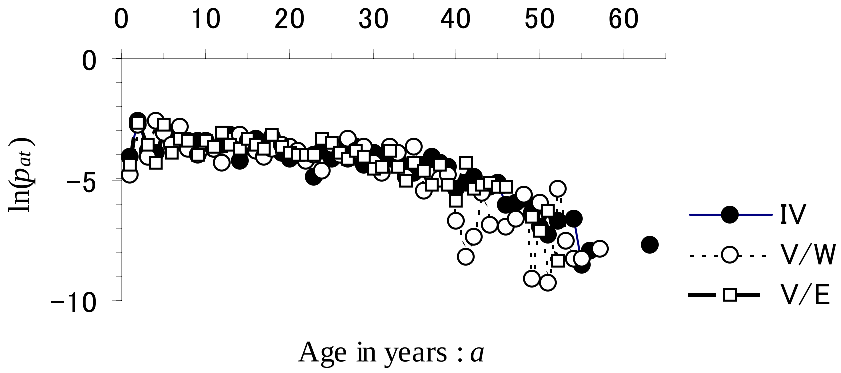

Figure 2. Comparison of the age composition in three areas.