An Estimate of Average Natural Mortality Coefficient of Antarctic Minke Whales Using JARPA data

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ABSTRACT

This paper shows an estimate of natural mortality coefficient of the Eastern Indian Ocean Stock (I-stock) and the Western South Pacific Stock (P-stock) of Antarctic minke whales using JARPA data, by modifying the original method proposed by Tanaka (1990). Net rate of natural increase by stock basis 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 for component of age classes over ten years old were 0.038 (per year, SE=0.036) for the I-stock and 0.040 (SE=0.035)for the P-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 Antarctic minke whales (Sakuramoto and Tanaka, 1985, 1986; Butterworth *et al*., 1996, 1997; Kitakado *et al*, 2005; Mori *et al*, 2005a, 2005b, 2006), 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 Implementation 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 in the recruits, was 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 is a program for investigating the biological aspect of the Antarctic minke whales and one of the objectives of the program is to estimate such parameters as the natural mortality coefficient. JARPA survey aims to direct estimation of the biological parameters because estimation based on mathematical dynamical models needs for assumption to be proved by new research. Term of the planed survey is so long as sixteen years in order to have a precise estimate using stock abundances and age compositions and many studies for the estimation have been presented (Sakuramoto and Tanaka, 1989; de la Mare, 1990; Tanaka, 1990; Tanaka *et al*., 1992; Nakamura, 1991; Tanaka and Nakakura, 1995; Butterworth *et al*, 1996, 1997; Cooke *et al*, 1997; Tanaka and Fujise, 1997; Kitakado *et al*, 2005; Mori *et al*, 2005a; Mori *et al*, 2006; Tanaka *et al*., 2005).

In the JARPA mid-term 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 classes of young ages less than ten years old would be lower than the true frequency for the whole stock and therefore the estimate of the natural mortality using directly the data would be possible for classes over the ages. Many of the young age classes consist of immature component of the stock.

Pastene *et al* (2005) proposed new biological evidences of stock boundary that are different from the stock boundaries of the traditional division of the IWC. 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, estimation of biological parameters is carried out for each of the stocks other than the traditional division of stocks.

This paper infers an estimation of the natural mortality coefficient of each of the two stocks using JARPA data, by the original method proposed by Tanaka (1990). Issues relating the estimation were discussed.

MATERIALS AND METHODS

Data

Data used for estimation of natural mortality coefficient are the annual abundance estimates from the SSV data stratified by area and school size (Bando *et al*, 2006), and estimates of age composition by area, school size and sex. The age composition in survey area was estimated using 1) abundance estimation by sub-area, school size (solitary or not) and 2) age composition by sub-area, school size and sex (Kato *et al*, 1991, Kishino *et al*., 1991). The estimated age compositions by year, area, and sex are illustrated in Figures 1-3.

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 fraction of the research takes to total population is negligible.

Let $N_{t,a,x}$ be size of stock at age in years a(=1,2,3,…) in year t(=1,3,5,…,T) in survey stratum x(=1,2,3, for Area IV, V/W, V/E). Basic model for the dynamics are expressed by

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

$$N_{t,a,*} = \sum_x N_{t,a,x} \ , \qquad (2)$$

$$N_{t,a,x} = N_{t,*,x} \, p_{t,a,x} \ , \qquad (3)$$

Here $N_{t,a,*}$: stock size at age,

$N_{t,*,x}$: stock size by survey stratum,

$p_{t,a,x}$: age composition by year, age and survey stratum,

M_a : natural mortality coefficient (per year).

Estimation Procedures for Average Natural Mortality Coefficient

Let $\overline{M}$ be the average natural mortality coefficient. When age composition is fairly stable, $\overline{M}$ for population component consisting of age classes equal to and over *b* years old is expressed by

$$\overline{M} = \frac{1}{2}\ln\left(\frac{\sum_{a=b}^{\infty} N_{t,a,*}}{\sum_{a=b}^{\infty} N_{a+2,t+2,*}}\right) = \frac{1}{2}\ln\left(\frac{N_{t,*,*}}{N_{t+2,*,*}}\right) + \frac{1}{2}\ln\left(\frac{\sum_{a=b}^{\infty} p_{t,a.*}}{\sum_{a=b+2}^{\infty} p_{t+2,a,*}}\right) = -r + X_{b,t} \qquad (4)$$

$$X_{b,t} = \frac{1}{2}\ln\left(\frac{\sum_{a=b}^{\infty} p_{t,a,*}}{\sum_{a=b+2}^{\infty} p_{t+2,a,*}}\right), \qquad (5)$$

$$p_{t,a,*} = \frac{N_{t,a,*}}{N_{t,*,*}} = \frac{\sum_x N_{t,a,x}}{\sum_a \sum_x N_{t,a,x}}, \qquad (6)$$

$$r = \frac{1}{2}\ln\left(\frac{N_{t+2}}{N_t}\right), \qquad (7)$$

Here *r* (per year) is the net rate of increase of stock size. The point and variance estimates for *r* and X_b are expressed by

$$\hat{\overline{M}} = \hat{X} - \hat{r} \ , \qquad (8)$$

$$\hat{X}_b = \frac{1}{T/2-1}\sum_{k=1}^{T/2-1} X_{b,2(k-1)} \ , \qquad (9)$$

$$\hat{\mathrm{V}}\left(\hat{\overline{M}}\right) = \hat{\mathrm{V}}\left(\hat{X}_b\right) + \hat{\mathrm{V}}(\hat{r}) + 2\hat{\mathrm{C}}\mathrm{ov}\left(\hat{X}_b, \hat{r}\right). \qquad (10)$$

Here $\hat{r}$ is estimate of *r* and its estimation procedure is explained in the below paragraphs. The first and third terms in right-hand side of equation 10 can be computed using one thousand of bootstrap samples (Efron, 1979). The re-sample of the age composition is made as follows: 1) using the estimates of sex ratio by sub-area and school size and the size of biological samples by sub-area and school size, size of re-samples by sub-area, school size and sex are made using binomial distribution; 2) using the re-sample size and the estimates of age-composition by sub-area, school size and sex, the age composition are generated using multinomial distribution; 3) set of abundance estimates by sub-area and school size are simulated using the abundance estimates with the associated CV by sub-area and school size; 4) age composition for the stock is calculated using the generated sex ratio, age composition by sex, and abundance estimate.

Estimation of r

Denoted rate of size of stock in survey area to the total by $\delta_{t,x}$ and supposed that

$$\delta_{t,1} + \delta_{t,2} = 1, \tag{11}$$

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

$$\mathrm{E}\left[N_{t,*,x}\right] = \begin{cases} \delta N_{\mathrm{I}} \exp(rt), & (x=1), \quad (12a) \\ (1-\delta) N_{\mathrm{I}} \exp(rt), & (x=2). \quad (12b) \end{cases}$$

Here N_{I} and δ are abundance of I-stock in the first year of surveys and mean of proportion of stock size in Area IV to that in Areas IV+V/W, respectively. For the I-stock, *r* is estimated by maximizing the following log-likelihood:

$$LL_{\mathrm{I}} = LL_{\mathrm{IV}} + LL_{\mathrm{VW}}, \tag{13}$$

$$LL_{\mathrm{IV}} = -\frac{1}{2}\sum_t \left[\ln\left\{2\pi\left(\hat{\sigma}_{t,1}^2 + \upsilon_1^2\right)\right\} + \frac{\left\{\ln\left(\hat{N}_{t,*,1}\right) - \ln(\delta) - \ln\left(N_{\mathrm{I}}\right) - r_{\mathrm{I}}(t-1)\right\}^2}{2\left(\hat{\sigma}_{t,1}^2 + \upsilon_1^2\right)} \right], \tag{14}$$

$$LL_{\mathrm{VW}} = -\frac{1}{2}\sum_t \left[\ln\left\{2\pi\left(\hat{\sigma}_{t,2}^2 + \upsilon_2^2\right)\right\} + \frac{\left\{\ln\left(\hat{N}_{t,*,2}\right) - \ln(1-\delta) - \ln\left(N_1\right) - r_{\mathrm{I}}(t-1)\right\}^2}{2\left(\hat{\sigma}_{t,2}^2 + \upsilon_2^2\right)} \right], \tag{15}$$

where υ_x^2 : additional variance by stock and area,

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

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

$$LL_{\mathrm{P}} = -\frac{1}{2}\sum_t \left[\ln\left\{2\pi\left(\hat{\sigma}_{t,3}^2 + \upsilon_3^2\right)\right\} + \frac{\left\{\ln\left(\hat{N}_{t,*,3}\right) - \ln\left(N_{\mathrm{P}}\right) - r_{\mathrm{P}}(t-1)\right\}^2}{2\left(\hat{\sigma}_{t,3}^2 + \upsilon_3^2\right)} \right], \tag{16}$$

where N_{P} is abundance of P-stock in the first year of surveys. The statistically best model is selected by the c-AIC. Variance estimates of $\hat{r}$ are expressed by

1, (17)

$$\hat{V}[\hat{r}_P] = \frac{\sum_{t=1}^{T/2} \hat{w}_{t,3}^2 \{2(t-1) - \bar{t}_3\}^2 \hat{\tau}_{t,3}^2}{\left[\sum_{t=1}^{T/2} \hat{w}_{t,3} \{2(t-1) - \bar{t}_3\}^2\right]^2}, \quad (18)$$

$$\hat{w}_{t,x} = \frac{1/\hat{\tau}_{t,x}^2}{\sum_{k=1}^{T/2} 1/\hat{\tau}_{t,x}^2}, \quad (19)$$

$$\hat{\tau}_{t,x}^2 = \hat{\sigma}_{t,x}^2 + \hat{\upsilon}_x, \quad (20)$$

$$\bar{t}_x = \sum_{t=1}^{T/2} 2\hat{w}_{t,x}(t-1). \quad (21)$$

Results

Tables 1-2 summarize the results of estimations. The point estimates of natural mortality coefficient for component of age classes over ten years old were 0.038 (per year, SE=0.036) for the Eastern Indian Ocean Stock and 0.040 (SE=0.035) for Western South Pacific Stock.

Discussions

Although the estimates of *M* are close to that by the ADAPT-VPA (Mori *et al*., 2006), the present estimates of SE (0.036 for the I-stock and 0.035 for P-stock) are larger than SE estimates by Mori *et al* (2006a). The present estimates of SE are larger than the projected level (about 0.02) as the pessimistic cases (Tanaka, 1992).and the following reasons are considered.

As for available sample sizes for estimating the age composition, in the middle of the JARPA survey, it was pointed that the young animals are not fully immigrated into the survey areas (Annon., 1998) and biological samples of whales over ten years old are available for estimating *M*. In addition, comparable sample size is smaller than total sample size because samples for investigating seasonal variation are not available. Decrease of available sample size for estimating age composition leads to increase in SE of $\hat{X}$.

As for abundance estimation, $\hat{N}_{t,x}$ is annually fluctuating and the achieved levels of the CV of $\hat{N}_{t,x}$ are higher than the perspective, because of the annual and geographical fluctuation. The unexpected variability in $\hat{N}_{t,x}$ affects both $\hat{r}$ and X_b.

The abundance estimate used in the paper was computed using the only data from sighting and sampling 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 sighting 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 be improved by using the SV data. However, estimation method of age composition has to be modified in the case of introducing the SV data and this is an issue to be examined in the near future.

As the same as the ADAPT-VPA, the *M* estimates are lower than the value of *M* used in the Implementation Simulations for the Antarctic minke whales (Annon., 1993) and also that in the assessment by Hitter runs (Annon. 1991). Use of these estimates will lead to some results different from those in the past and will be expected to reduce the extent of uncertainty in *M*.

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Table 1. Results of estimation of r, δ and υ_k, and N_1.

Stock	Model	c-AIC	*LL*	*n*	*p*	*r*	N_1	υ_1	υ_2	υ_3	δ
I-stock	Full	39.76	-11.88	16	5	0.0389	45,043	0.310	0.502	-	0.565
	$\upsilon_1=\upsilon_2$	36.15	-12.26	16	4	0.0396	45,623	0.421	0.421	-	0.565
	r=0	37.45	-12.91	16	4	-	58,599	0.351	0.522	-	0.553
	$\upsilon_1=\upsilon_2, r=0$	34.34	-13.17	16	3	-	59,632	0.455	0.455	-	0.556
	$r=\upsilon_1=\upsilon_2=0$	56.66	-25.87	16	2	-	62,965	-	-	-	0.474
P-stock	Full	15.71	-1.86	8	3	0.0064	55,929	-	-	0.209	-
	$\upsilon_3=0$	13.10	-3.35	8	2	0.0026	56,719	-	-	0.000	-
	r=0	10.20	-1.90	8	2	-	58,982	-	-	0.209	-
	$r=\upsilon_3=0$	9.41	-3.37	8	1	-	57,891	-	-	0.000	-

Table 2. Results of point estimates of average *M* (SE)

Stock	I-stock		P-stock	
$\hat{r}$	0 (0.0287)		0 (0.0130)	
b	11	16	11	16
$\hat{X}$	0.0379 (0.0115)	0.0313(0.0132)	0.0401 (0.0315)	0.0414(0.0336)
$\hat{\bar{M}}$	0.0379 (0.0356)	0.0313(0.0362)	0.0401 (0.0352)	0.0414(0.0371)

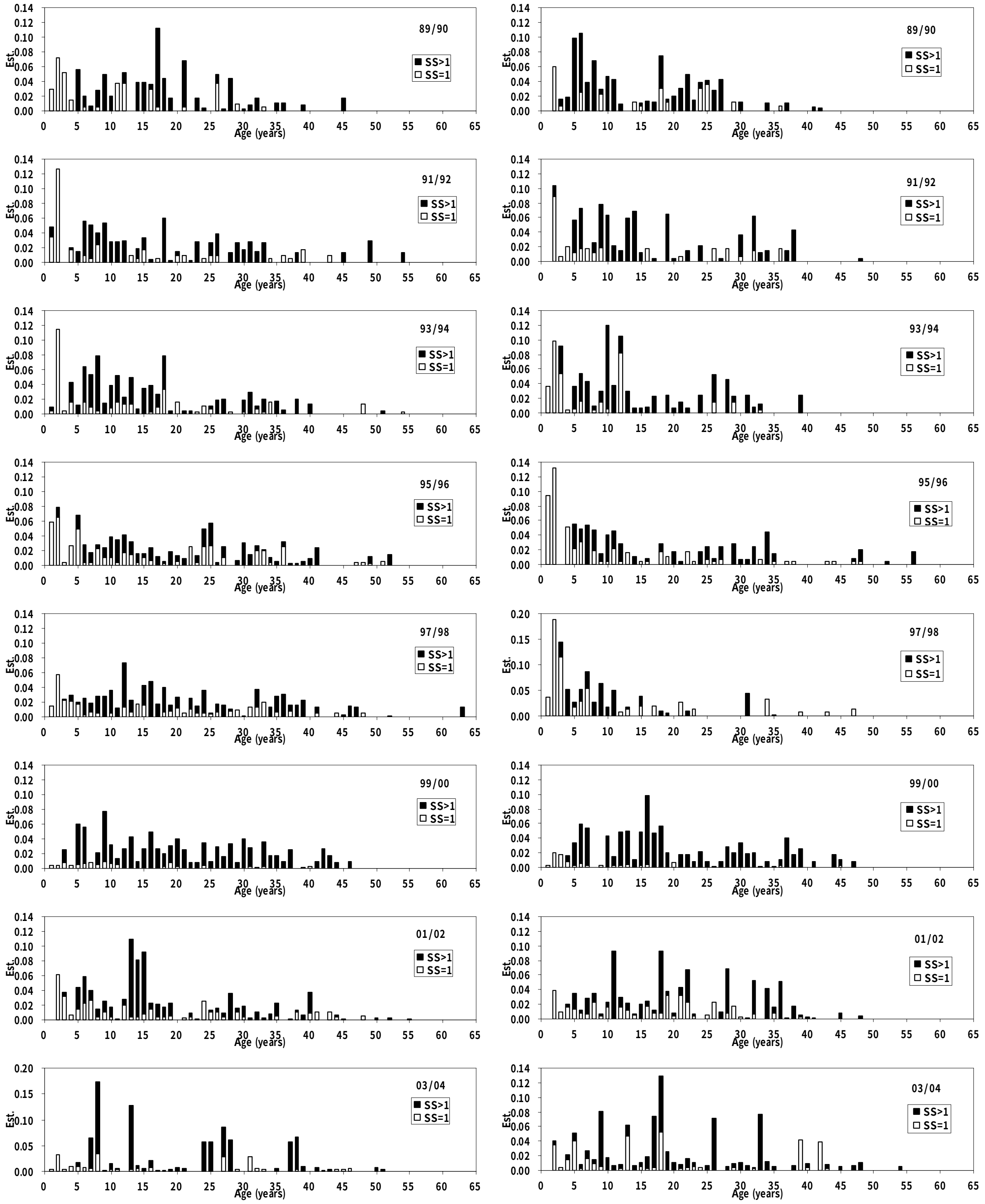

Figure 1. Estimated age compositions for 1989/90-2003/04 seasons in Area IV. Left and right panels show those of males and females.

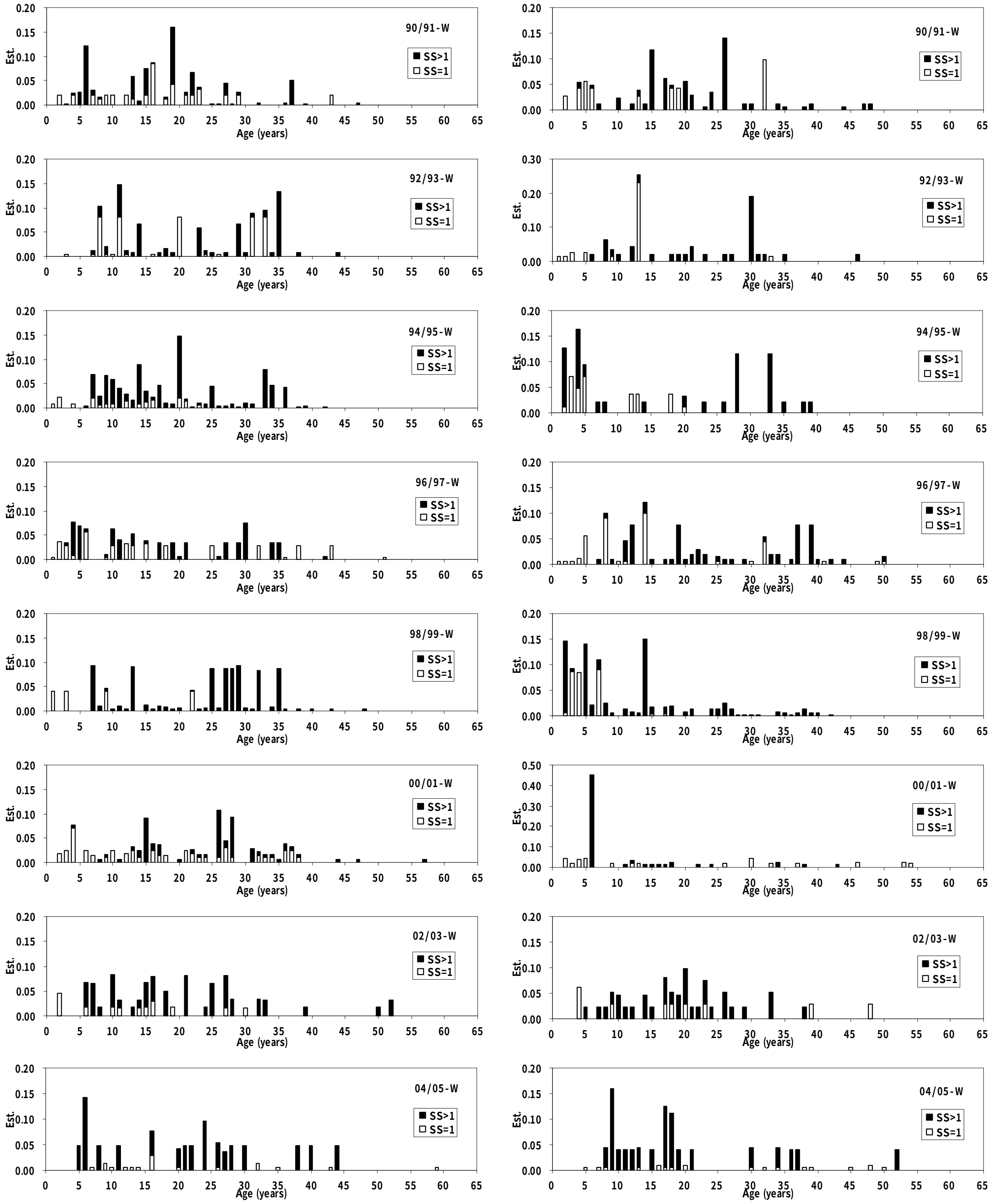

Figure 2. Estimated age compositions for 1990/91-2004/05 in Area VW. Left and right panels show those of males and females.

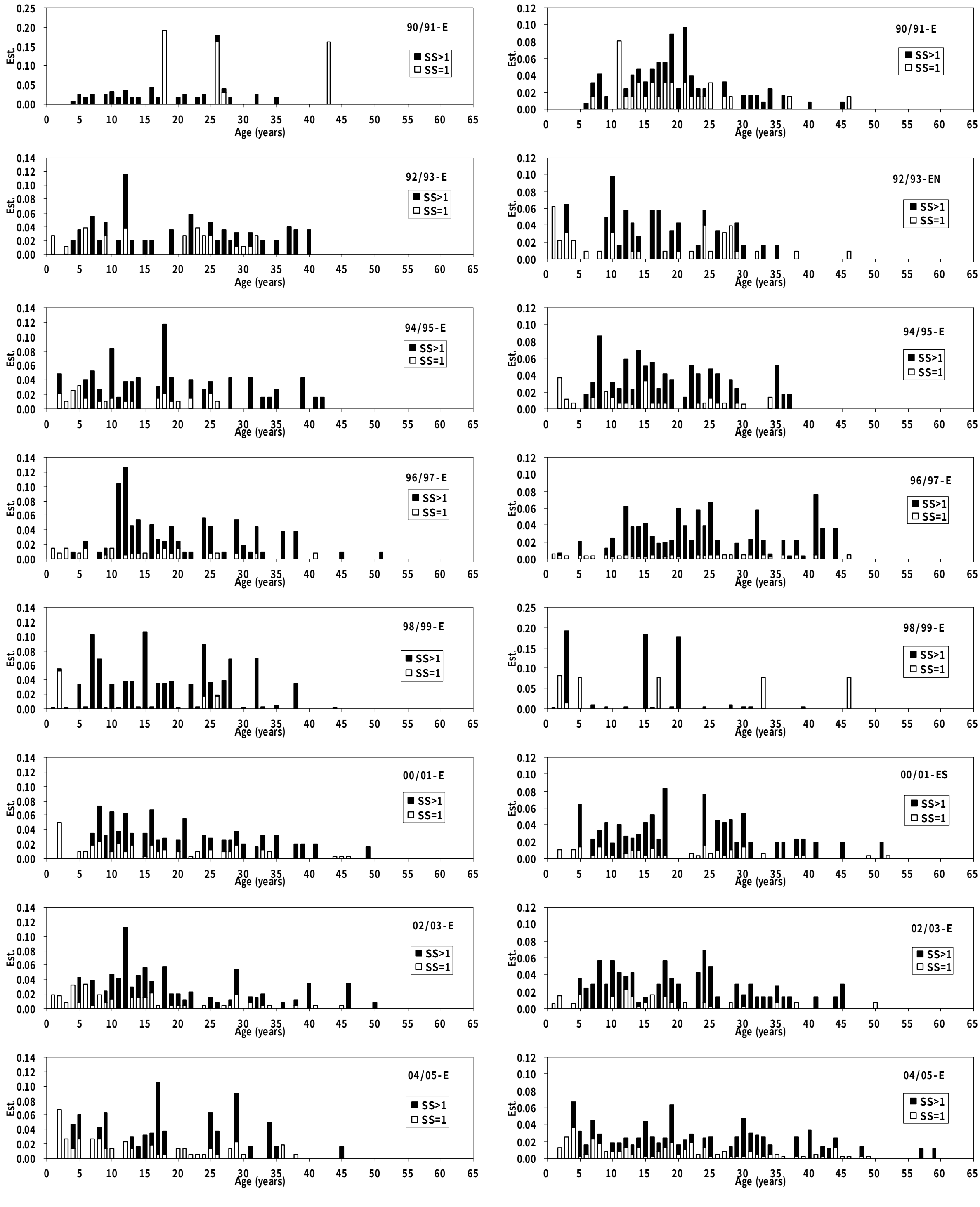

Figure 3. Estimated age compositions, 1990/91-2004/04 in Area VE. Left and right panels show those of males and females.