Long-term trend of age at sexual maturity of Antarctic minke whales by counting transition phase in earplugs

Zenitani, R.*and Kato, H.**

* : *The Institute of Cetacean Research, 4-5, Toyomi-cho, Chuo-ku, Tokyo 104-0055, Japan.*
**: *Fisheries Research Agency, National Research Institute of Far Seas Fisheries, 5-7-1, Shimizu-Orido, Shizuoka 424-8633, Japan.*

ABSTRACT

The present study examined longer term changes in age at sexual maturity of the Antarctic minke whales by counting transition phase layer in earplug using a total of 4,547 earplugs collected in 1971/72 to 1986/87 commercial whaling and in 1987/88 to 2003/04 special permit cruise under JARPA research program in Area IV. We incorporated same correction methods for biases due to the truncation and the 'age-specific' effects that were addressed in the past debates. No systematic aging errors were detected between two major age readers. The present analysis revealed again the mean age at sexual maturity declined from 1945s cohorts at around 12-13 years to late of 1960s at 7 years. By incorporating new data set by JARPA, it was newly found that the mean age remained constant at 7-8 years or slightly increased in the early 1970s to the late 1980s cohorts. Although we need carefully consider time gap to result of the trend in age at sexual maturity, we should assume possibilities that expanding of carrying capacity for the minke whales has ceased and begun to return toward to previous environmental circumstance before the expanding had taken place.

KEYWOPDS: ANTARCTIC MINKE WHALE, AGE AT SEXUAL MATURITY, TREND

INTRODUCTION

It is generally known that the growth layer of change (the transition phase) in earplug indicated the age at sexual maturity (Lockyer, 1972; Masaki, 1979; Kato, 1983a). By using this characteristic, it is possible to estimate the age at which an animal became sexually mature and calculate its year class by back-calculation from its age at capture. The indirect indicator of the age at sexual maturity of baleen whales was discovered by Lockyer (1972). Several authors have reported a decline in age at sexual maturity by the analysis of transition phase in earplugs of fin, sei and minke whales collected commercial whaling (Lockyer, 1972, 1974; Masaki, 1978, 1979; Best, 1982; Kato, 1983b).

Decline of Antarctic minke whale age at sexual maturity from 14 years in 1940s cohort to 6 years in late 1960s cohort was suggested by the analysis of transition phase in earplug (Masaki, 1979; Best 1982; Kato 1983b, 1985). It was considered that the changes of biological parameters estimated using commercial data in the Antarctic minke whale such as decline of age at sexual maturity and increase of the growth rate were caused by reduction of populations of blue and fin whales having a strong competitive relation to minke whales, which led to greater availability of food for minke whales (Masaki, 1979; Best, 1982; Kato, 1983b, 1985, 1987, Kato and Sakuramoto, 1991).

However, Cooke and de la Mare (1983) argued that the observed decline trend of the age at sexual maturity was equally explainable as a result of aging error and truncation sampling problem in the data set used. Kato (1987) and Kato and Sakuramoto (1991) examined the possible biases affecting to estimation of age at sexual maturity and growth curve. They concluded that the observed decline in age at sexual maturity from 12-13 years in the mid 1940S to 7-8 years in the early 1970 cohort is real because it is free from possible truncation biases (Kato, 1987; Kato and Sakuramoto, 1991). However, since then, for the decline of the age at sexual maturity of the Antarctic minke whales, no general consensus has been obtained in IWC/SC in spite of many studies of age at sexual maturity. During the JARPA review meeting in 1997, the decline of the age at sexual maturity of the Antarctic minke whales had also discussed, the

Working Group agreed that there had been a real decline in age at sexual maturity of minke whales (Thomson *et al*., 1997; Cooke *et al*., 1997).

Because Kato (1987) indicated that the mean age at sexual maturity by analysis of transition phase in earplug is potentially free from biases due to the reproductive segregation and the catching selectivity, the age at sexual maturity can be used as an indication for long-term monitoring proposes even the data sets were obtained from different operation types such as JARPA and the commercial whaling. Thus, we investigate this parameter under the one of JARPA objectives is 'estimation of the biological parameters to improve the stock management of Antarctic minke whales".

MATERIAL AND METHODS

Biological data used

The present study used age and transition phase (TP: age at transition phase layer) data collected in 1987/88-2003/04 JARPA (9 years) and 1971/72-1986/87 commercial whaling expeditions (16 years) in Area IV. Furthermore data on the age at first ovulation in 1987/88-2003/04 JARPA in Area IV were used.

Age determination

Age of whales was determined by reading growth layers appearing on the bisected surface of the earplug, assuming an annual deposition of growth layers (i.e. one pair of dark and pale laminae accumulated per year) in accordance with Best (1982) and Lockyer (1984). Individual ages in 1971/72-1986/87 commercial whaling and 1987/88-1989/90 JARPA were determined using growth layers in earplug that were mainly counted by reader-K. Individual ages of 1991/92-2003/04 JARPA were determined using growth layers in earplug that were counted by reader-Z. The age at transition layer was recorded if it was present.

Cohort (= year of birth)

Cohorts (Year classes) were defined by;

Cohort = (starting year of season) – (age at capture).

Age at sexual maturity

"*Tmp*" (Kato, 1987): Mean age at sexual maturity estimated for both sexes using transition phase in earplug as an indicator of sexual maturity (Lockyer, 1972; Kato, 1983; Ohsumi, 1986).

"*Tmov*" (Kato, 1987): Mean age at the first ovulation is defined as mean age of females identified by the presence of a corpus luteum and no corpus luteum in both ovaries.

Statistical analyses

The t-test by SPSS (SPSS Co Ltd) was used for testing difference in mean age at sexual maturity used.

RESULTS

Evaluation of two readers

Individual ages were determined using growth layers in earplug that were counted by reader-K for samples collected 1971/72-1989/90 and by reader-Z for 1991/92-2003/04. We examine difference of mean age at sexual maturity between two readers. Fig.1 indicates *tmp* against cohorts based on crude TP data for each sex. The *tmp* of males of two readers declined from 1945 cohort to 1969 cohort and remained constant from 1969 to 1974 cohort. Then *tmp* of reader-K declined again to 1982 cohort. On the other hand, *tmp* of reader-Z remained constant from 1969 to around 1990 cohort and since 1990 cohort slightly decline again.

The *tmp* of females of two readers declined from 1945 cohort to 1968 cohort and remained constant from 1968 to 1972 cohort. Then *tmp* of reader-K declined again to 1982 cohort. On the other hand, *tmp* of reader-Z remained constant from 1968 to around 1990 cohort and since then slightly decline again.

The decline trend of *tmp* by two readers almost coincided until around 1970 cohort. But since around 1975 cohort the *tmp* of reader-K showed younger age. The phenomenon showed the actual state of truncation sampling problem that an estimate of *tmp* biased towards younger ages. It is well known that using the transition phase technique, the age at maturity in recent age class will be underestimated due to the under-representation of late maturing individuals (truncation bias).

Understanding of truncation bias

In order to understand of truncation sampling problem in sampling years, *tmp* plots against cohort based on crude data, with five groups of sampling years (commercial whaling: 1971/72-1975/76, 1976/77-1980/81, 1981/82-1986/87, JARPA: 1987/88-1995/96, 1997/98-2003/04) and shown in Fig.2.

The decline trends of *tmp* of males from 1950 cohort to 1967 cohort in the five groups were found. The *tmp* of 1971/72-1975/76 group in around 1958 to 1967 cohorts are lower than those of other sampling groups. The *tmp* of 1976/77-1980/81 group more decline from 1965 cohort to 1971 cohort. Since 1968 cohort, *tmp* of 1981/82-1986/87, 1987/88-1995/96 and 1997/98-2003/04 groups remain constant. The *tmp* declined again from 1973 cohort in1981/82-1986/87 group, from 1980 cohort in 1987/88-1995/96 group and from 1990 cohort in 1997/98-2003/04 group.

The trends of *tmp* of females in five sampling groups are almost similar to the trend of male.

The *tmp* in sampling groups show the same trend in early cohort. But the decline trends of *tmp* in more recent cohort were seen. Similarly to Fig.1, five sampling groups in Fig.2 confirmed the influence of truncation bias in plots of *tmp* against cohort.

Corrected truncation and other bias

In order to avoid truncated sampling problems seen above two sections, we correct truncation bias using method of Kato (1985). The data from commercial whaling and JARPA were combined for examination of truncation bias because the JARPA data size was very small. The cohort group pooled 5 or 10 years class. Fig. 3 plots *tmp* against age at capture in each cohort groups (1951-55, 1956-60, 1961-65, 1966-70, 1971-75, 1976-85, 1986-95) using combined data. As age at capture increased, the maximum age at maturity reached a plateau. This age at capture corresponded to maximum expected age at maturity. Fig. 3 show that the plateaus is reached declines by cohort group from about 20 years (1951-55), 16 years (1956-60), 13 years (1961-65), 14 years (1971-75), 12 years (1976-85), 13 years (1986-95). Therefore data from after these values should be free of truncation bias. We re-examine *tmp* only used TP data for animals older than those values in cohort groups.

Fig. 4 shows *tmp* against cohort based on corrected TP data. Differences of trend in *tmp* of two readers such as Fig.1 were not found in Fig 4. The trends of two readers were similar and *tmp* values of two readers almost coincide each other. No significant differences of *tmp* were found between two readers by cohort (Table 1). By means of using method of Kato (1985), the *tmp* corrected for truncation bias sufficiently could be obtained.

Bengtson and Laws (1985) reported ‘age-specific’ effects on the observed temporal trend of age at sexual maturity derived from transition phase in the crabeater seal analysis. The data were collected in two periods about 8 years apart. The first samples showed a decline in *tmp* from 4.5 years in 1945 to 3.5 years in the 1965 cohort, while the second showed a decline from 4.5 years in 1953 to 3.5 years in the 1973 cohort. The plots of *tmp* and age at capture for the two sample sets coincided, although *tmp* still declined with age at capture. This ‘age-specific’ effect on the observed temporal trend in *tmp* was examined by using method of Kato and Sakuramoto (1991).

Fig. 5 shows *tmp* against cohort based on corrected TP data by sampling year groups. The *tmp* values by cohort almost coincide although sampling years was difference. In addition, we plotted *tmp* against age at capture separately by two data sets of samples taken about 10 years apart (Fig.6). The values of *tmp* in the first set are higher than in the second set in the most age at capture classes. Both Figs 5 and 6 show different pattern from those in the crabeater seal analyses of Bengtson and Laws (1985) and show the data to free ‘age-specific effect.

Long-term trend of mean age at sexual maturity by transition phase

As described above, we consider that these TP data were free from truncation bias and the ‘age-specific’ effects and re-estimated *tmp* using corrected data combined commercial whaling and JARPA.

Table 2 and Fig.7 shows the values of *tmp* and its standard deviation estimated using corrected TP data by cohort of each sex. The present analysis revealed again *tmp* declined from 1945 cohorts at around 12-13 years to late of 1960s at 7 years. By recruitment of new data set by JARPA, it was found that the mean age remained constant at 7-8 years or slightly increased in the early 1970s to the late 1980s cohorts.

Comparison of two kinds of estimation of age at sexual maturity for females was shown in Fig. 8. The *tmov* is also considered to be free from the segregation and catching selectivity the same as t*mp*. Though the number of first ovulation data is very small, the values of *tmov* are similar to *tmp* and remain almost constant in from 1978 cohort to 1995 cohort. The decline trend of *tmov* by cohort is not seen.

DISCUSSION

It was considered that *tmp* estimated from transition phase in earplug is potentially free from biases due to the reproductive segregation and the catching selectivity (Kato, 1987). Though the sampling area and method were different between commercial whaling and JARPA, the present study showed long-term changes in age at sexual maturity of Antarctic minke whales from 1940s cohort to 1980s cohort by using transition phase data. We incorporated same correction methods for biases due to the truncation and the 'age-specific' effects (Kato and Sakuramoto, 1991) that were addressed in the past debates. By means of correction method of Kato (1985), *tmp* corrected sufficiently for truncation bias was obtained. The present study found no evidence for existing ''age-specific' effect in the transition phase data that have been used for estimating temporal trends of *tmp*. It is consider that observed trend in mean age at sexual maturity is real, because it is free from truncation bias and 'age-specific' effect.

The present analysis revealed again *tmp* declined from 1945s cohorts at around 12-13 years to late of 1960s at 7 years. By incorporating of new data set by JARPA, it was newly found that the mean age remained constant at 7-8 years or slightly increased from the early 1970s to the late 1980s cohorts. The trend of remaining constant is supported by direct estimates from *tmov*.

Decline of Antarctic minke whale age at sexual maturity from 14 years in 1940s year-class to 6 years in late 1960s year class was suggested by the analysis of transition phase in earplug (Masaki, 1979; Best, 1982; Kato, 1983b). Kato (1983b, 1987) considered that one possible mechanism for decline of age at sexual maturity is that it is the result of an increased growth rate by improve of nutrition in the adolescent growth spurt stage due to the increase of food availability of Antarctic minke whales in the Antarctic feeding ground, which is considered to have been produced by the depletion of the other krill feeding whale stocks such as blue, fin and humpback which share an ecological niche with minke whales (Gambell, 1973, 1975; Laws, 1977a, 1977b).

Kato (1987) considered decline in age at sexual maturity was caused to an increase in food availability *per capita* in adolescent stage of each individual. Through the present analysis it was clearly found that the decline of *tmp* until 1970 cohort which was identified by previous studies no longer continued and *tmp* remained constant at 7-8 years or slightly increased in the early 1970s onward to the late 1980s cohorts; so that the present study may suggest the environmental circumstances for Antarctic minke whales to support their decline of age at sexual maturity had switched to condition not to support decline trend and it is likely constant or slightly increases in age at sexual maturity. Although we need carefully consider time gap to result of the trend in age at sexual maturity, we should assume possibilities that expanding of carrying capacity for the Antarctic minke whales has ceased and begun to return toward to previous environmental circumstance before the expanding had taken place.

Because the age at sexual maturity is useful indicator of not only the population level but also environmental circumstance, furthermore continuous monitoring of the age at sexual maturity can provided important information to improve the stock management of Antarctic minke whales.

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Table 1. Mean age at sexual maturity estimated from corrected transition phase in earplug by cohort for each sex and reader in Area IV. Statistical comparison of age at sexual maturity between two readers each cohort using t-test. P-values smaller 5% are shown in bold.

	Male							Female						
	Reader-K			Reader-Z			P-value	Reader-K			Reader-Z			P-value
Cohort	Mean	S.D.	n	Mean	S.D.	n		Mean	S.D.	n	Mean	S.D.	n	
1931	17.25	3.96	4					22.50	2.50	2				
1932	15.00	0.00	2					22.00	0.00	1				
1933	18.00	0.00	1					13.00	0.00	1				
1934	18.75	5.07	4	14.00	0.00	1	0.520	16.00	2.94	3				
1935	14.67	4.50	3					13.00	2.28	5				
1936	13.50	4.77	4					13.50	3.95	6				
1937	13.33	5.73	3	11.00	0.00	1	0.801	14.67	3.09	3				
1938	16.50	2.50	2					15.00	5.00	6				
1939	15.14	3.98	7	12.00	0.00	1	0.520	14.00	3.27	6	13.00	0.00	1	0.806
1940	14.67	4.42	6					12.67	3.56	9				
1941	10.80	4.45	5					14.78	1.81	9				
1942	9.78	4.61	9	11.00	0.00	1	0.819	14.56	3.50	9				
1943	13.70	2.76	10	12.00	0.00	1	0.591	13.57	1.92	7	13.00	0.00	1	0.805
1944	11.50	3.38	10	12.00	0.00	1	0.897	12.53	1.50	15				
1945	13.56	2.01	9	10.67	1.25	3	0.058	11.75	2.95	16	12.00	0.00	1	0.938
1946	11.88	3.50	17	12.00	1.00	4	0.950	13.57	3.62	14				
1947	11.36	3.52	11	10.00	0.00	1	0.731	12.96	3.10	28	12.00	0.00	1	0.766
1948	11.86	2.51	21	12.00	0.00	1	0.957	11.87	2.77	30	11.50	0.50	2	0.857
1949	11.22	2.15	23	11.50	0.50	2	0.860	11.97	2.78	37	11.00	0.00	1	0.735
1950	11.94	3.05	33	12.00	0.00	1	0.985	11.44	2.36	41	10.50	0.50	2	0.586
1951	10.97	2.59	37	10.00	0.00	1	0.717	11.17	2.71	35	13.00	0.00	1	0.516
1952	11.10	2.49	42	10.50	0.87	4	0.644	11.00	2.31	39	11.50	0.50	2	0.767
1953	10.83	2.45	29	10.50	0.87	8	0.720	10.55	2.51	38	11.00	0.00	2	0.807
1954	10.52	2.46	29	11.20	0.75	5	0.554	10.67	2.26	36	10.40	0.49	5	0.799
1955	9.64	2.21	22	10.00	0.63	5	0.728	10.46	2.25	37	10.75	0.43	4	0.803
1956	9.86	1.99	42	9.83	0.69	6	0.977	10.03	2.19	77	10.25	0.43	4	0.841
1957	9.66	2.16	53	9.67	0.82	9	0.993	10.07	1.82	54	10.00	0.82	3	0.945
1958	9.54	2.32	48	9.50	0.50	10	0.956	9.57	2.41	58	9.67	0.47	3	0.945
1959	8.89	2.25	54	9.30	0.78	10	0.576	9.96	2.22	55	9.33	0.47	3	0.631
1960	9.15	2.28	47	8.86	0.83	14	0.646	9.29	1.71	65	9.09	0.79	11	0.706
1961	8.89	1.96	72	8.75	0.75	16	0.784	9.05	1.92	94	9.00	0.85	11	0.929
1962	8.18	1.69	55	8.36	0.64	11	0.729	9.15	1.88	74	8.44	0.50	9	0.272
1963	8.08	2.13	72	9.27	0.45	11	0.071	8.91	1.88	95	9.11	0.57	9	0.747
1964	8.10	1.84	49	8.17	0.90	6	0.934	8.65	2.03	80	8.78	0.42	9	0.853
1965	8.50	2.06	60	8.21	0.69	19	0.554	8.66	2.12	83	8.80	0.60	10	0.841
1966	7.76	1.92	49	7.43	0.82	23	0.452	8.26	1.58	65	7.63	0.70	8	0.271
1967	7.64	1.80	39	7.10	0.83	10	0.370	8.02	1.71	49	7.29	0.70	7	0.274
1968	7.48	1.57	27	7.19	0.73	16	0.495	7.59	1.58	41	6.83	1.07	6	0.274
1969	6.93	1.77	30	6.80	0.75	10	0.823	7.45	1.64	42	7.20	0.75	10	0.643
1970	6.92	1.29	25	7.00	0.96	13	0.849	7.59	1.70	37	7.00	1.18	10	0.314
1971	7.30	1.41	27	6.96	0.81	23	0.321	6.66	1.98	44	7.17	0.69	6	0.544
1972	7.43	1.58	23	7.20	0.83	15	0.610	7.10	1.27	21	7.67	1.05	9	0.261
1973	6.77	1.56	22	7.47	1.02	15	0.151	7.17	1.71	18	7.50	1.12	6	0.673
1974	7.60	1.62	15	7.27	0.75	11	0.556	7.18	1.75	11	7.44	1.07	9	0.713
1975	7.25	1.48	4	7.46	1.05	28	0.730	7.00	0.00	4	7.60	0.92	10	0.249
1976	7.00	1.00	2	7.94	1.35	17	0.378				7.62	1.15	13	
1977	8.00	1.10	5	7.58	1.26	12	0.553				8.18	0.94	11	
1978				8.07	0.80	14					7.86	0.64	7	
1979				7.88	0.78	16					7.90	0.70	10	
1980				7.45	0.92	20					8.00	1.25	9	
1981				7.46	1.01	13					8.00	0.60	11	
1982				7.52	0.90	25					8.16	0.93	19	
1983				7.53	1.04	19					8.00	1.10	15	
1984				7.67	0.85	12					7.92	0.64	12	
1985				7.75	1.30	12					7.78	1.13	9	
1986				7.33	1.25	9					8.25	1.09	8	
1987				8.50	0.50	4					8.00	0.93	7	
1988				6.67	0.94	3					7.71	0.70	7	
1989				7.50	0.50	2					7.50	0.50	2	
1990				6.80	0.40	5					8.25	0.83	4	

Table 2. Mean age at sexual maturity and standard deviation estimated from transition phase in earplug for Antarctic minke whales collected from 1971/72-1986/87 Japanese Antarctic whaling and 1987/88-2003/04 JARPA in Area IV

	Male			Female		
Cohort	Mean	S.D.	n	Mean	S.D.	n
1931	17.25	3.96	4	22.50	2.50	2
1932	15.00	0.00	2	22.00	0.00	1
1933	18.00	0.00	1	13.00	0.00	1
1934	17.80	4.92	5	16.00	2.94	3
1935	14.67	4.50	3	13.00	2.28	5
1936	13.50	4.77	4	13.50	3.95	6
1937	12.75	5.07	4	14.67	3.09	3
1938	16.50	2.50	2	15.00	5.00	6
1939	14.75	3.86	8	13.86	3.04	7
1940	14.67	4.42	6	12.67	3.56	9
1941	10.80	4.45	5	14.78	1.81	9
1942	9.90	4.39	10	14.56	3.50	9
1943	13.55	2.68	11	13.50	1.80	8
1944	11.55	3.23	11	12.53	1.50	15
1945	12.83	2.23	12	11.76	2.86	17
1946	11.90	3.18	21	13.57	3.62	14
1947	11.25	3.39	12	12.93	3.05	29
1948	11.86	2.45	22	11.84	2.68	32
1949	11.24	2.06	25	11.95	2.74	38
1950	11.94	3.01	34	11.40	2.31	43
1951	10.95	2.56	38	11.22	2.69	36
1952	11.04	2.40	46	11.02	2.26	41
1953	10.76	2.21	37	10.58	2.45	40
1954	10.62	2.30	34	10.63	2.13	41
1955	9.70	2.02	27	10.49	2.14	41
1956	9.85	1.88	48	10.04	2.14	81
1957	9.66	2.02	62	10.07	1.79	57
1958	9.53	2.12	58	9.57	2.36	61
1959	8.95	2.09	64	9.93	2.16	58
1960	9.08	2.04	61	9.26	1.61	76
1961	8.86	1.80	88	9.05	1.84	105
1962	8.21	1.56	66	9.07	1.80	83
1963	8.24	2.03	83	8.92	1.81	104
1964	8.11	1.77	55	8.66	1.93	89
1965	8.43	1.83	79	8.68	2.01	93
1966	7.65	1.66	72	8.19	1.52	73
1967	7.53	1.67	49	7.93	1.64	56
1968	7.37	1.33	43	7.49	1.54	47
1969	6.90	1.58	40	7.40	1.51	52
1970	6.95	1.19	38	7.47	1.62	47
1971	7.14	1.18	50	6.72	1.88	50
1972	7.34	1.34	38	7.27	1.24	30
1973	7.05	1.41	37	7.25	1.59	24
1974	7.46	1.34	26	7.30	1.49	20
1975	7.44	1.12	32	7.43	0.82	14
1976	7.84	1.35	19	7.62	1.15	13
1977	7.71	1.23	17	8.18	0.94	11
1978	8.07	0.80	14	7.86	0.64	7
1979	7.88	0.78	16	7.90	0.70	10
1980	7.45	0.92	20	8.00	1.25	9
1981	7.46	1.01	13	8.00	0.60	11
1982	7.52	0.90	25	8.16	0.93	19
1983	7.53	1.04	19	8.00	1.10	15
1984	7.67	0.85	12	7.92	0.64	12
1985	7.75	1.30	12	7.78	1.13	9
1986	7.33	1.25	9	8.25	1.09	8
1987	8.50	0.50	4	8.00	0.93	7
1988	6.67	0.94	3	7.71	0.70	7
1989	7.50	0.50	2	7.50	0.50	2
1990	6.80	0.40	5	8.25	0.83	4

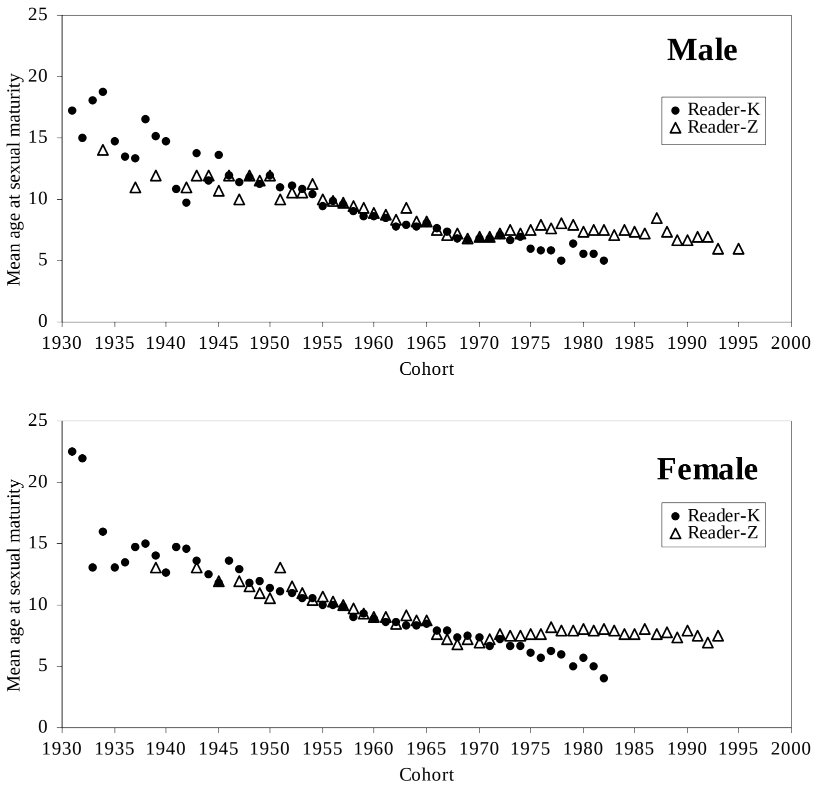


Fig. 1. A plot of mean age at sexual maturity against cohorts based on crude transition phase data in Area IV separated by two age readers.

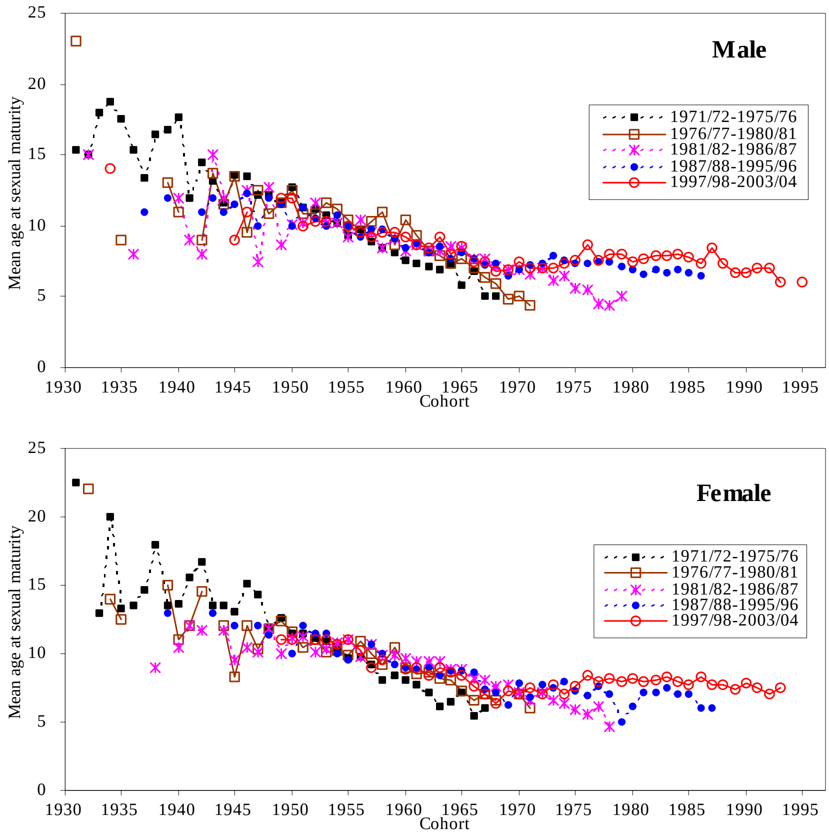


Fig. 2. A plot of mean age at sexual maturity against cohort based on crude transition phase data separated by 5 groups of catch years with pooling catch years each sex in Area IV.

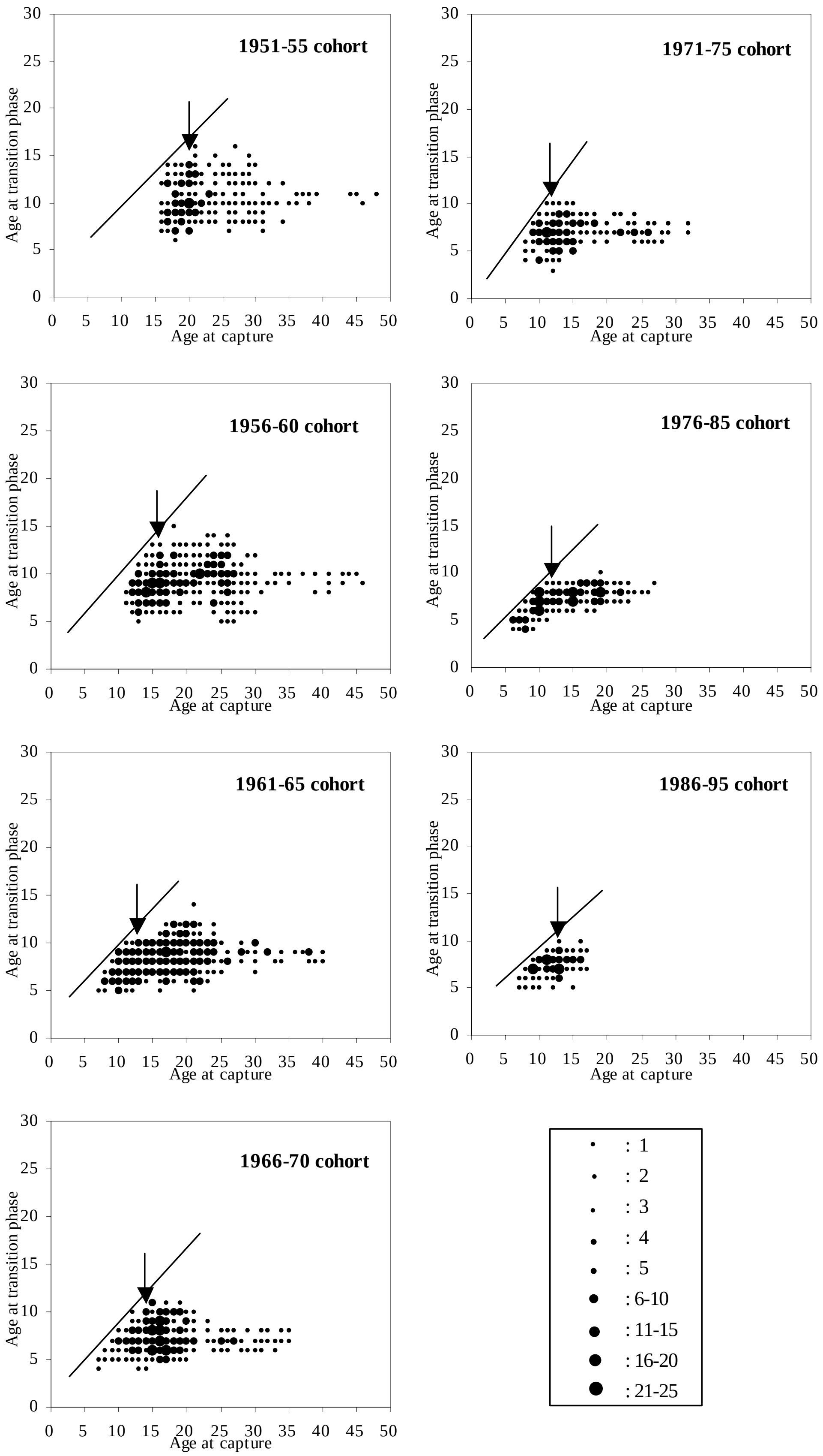


Fig. 3. Distribution of age at sexual maturity (transition phase counts) against age at capture, pooling every five or ten cohort. The line corresponding to the maximum age at transition phase limited by truncation bias and arrow indicated the threshold age at which the truncation bias is negligible if older samples than that age are used

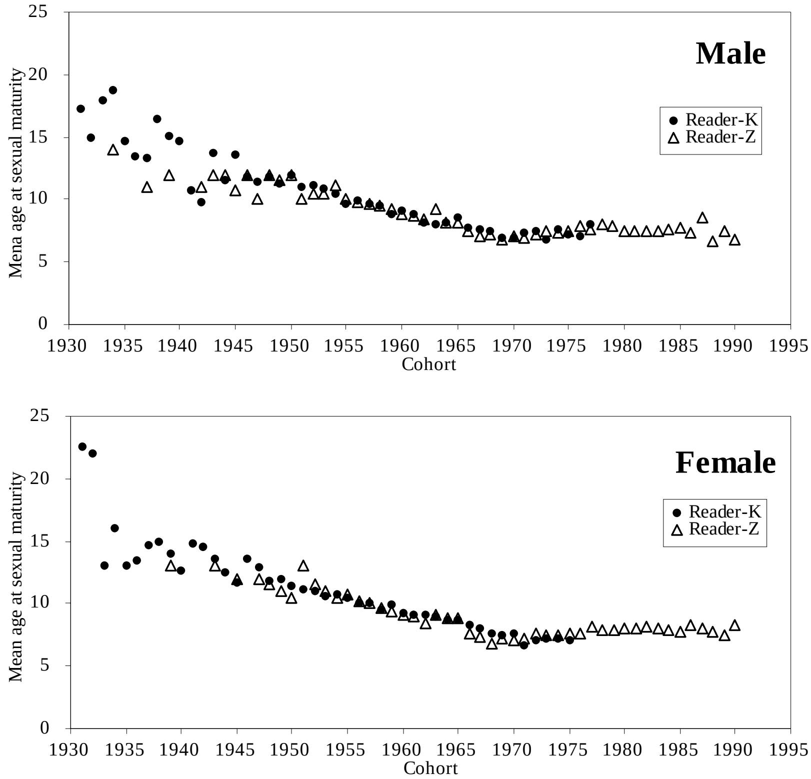


Fig. 4. A plot of mean age at sexual maturity against cohorts based on corrected transition phase data in Area IV separated by two age readers.

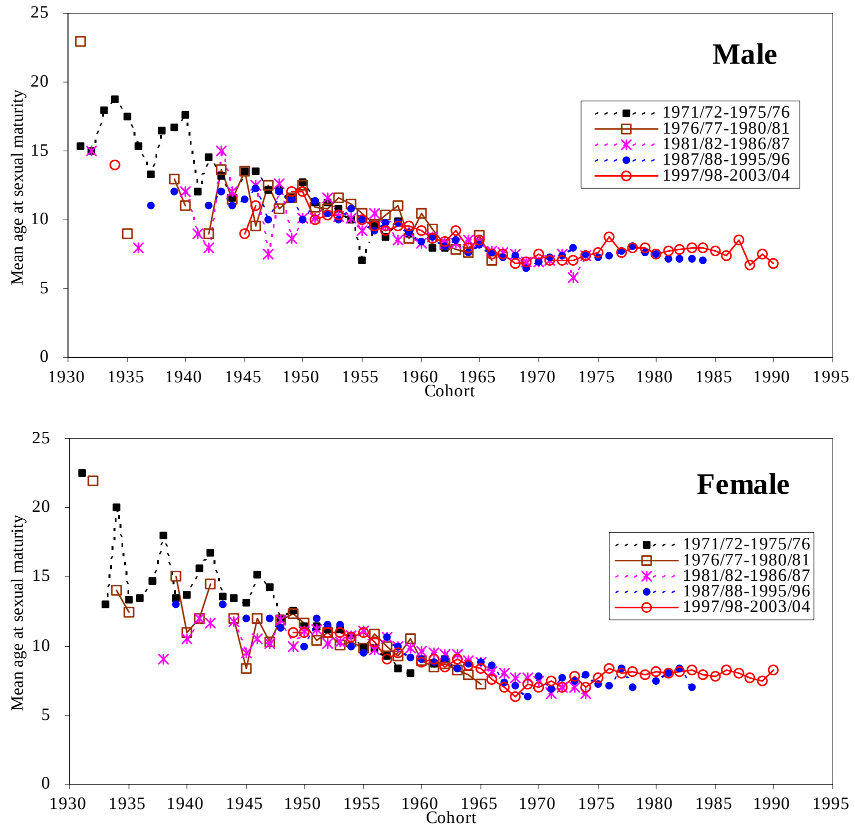


Fig. 5. A plot of mean age at sexual maturity against cohort based on corrected transition phase data separated by 5 groups of catch years with pooling catch years each sex in Area IV.

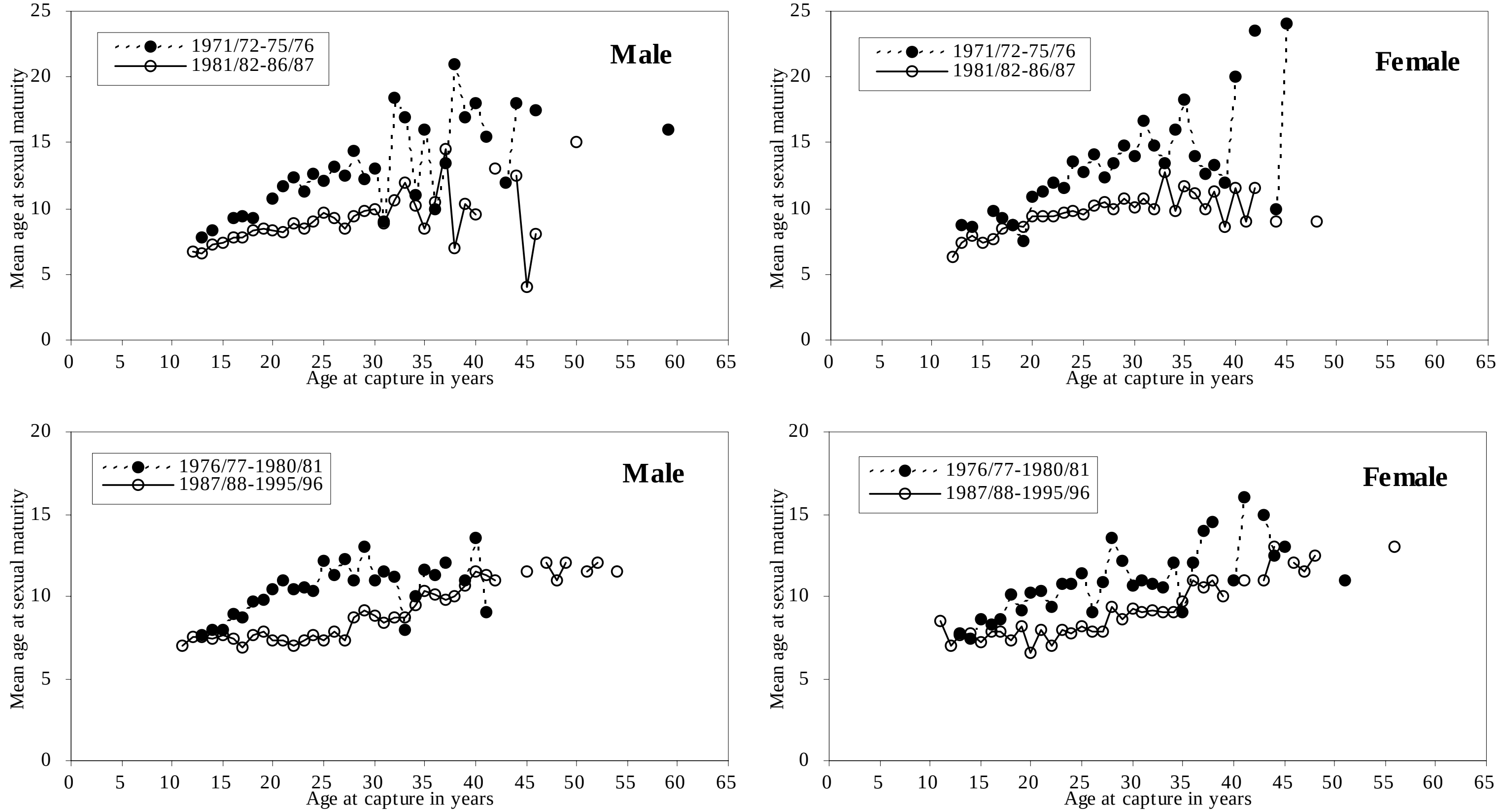
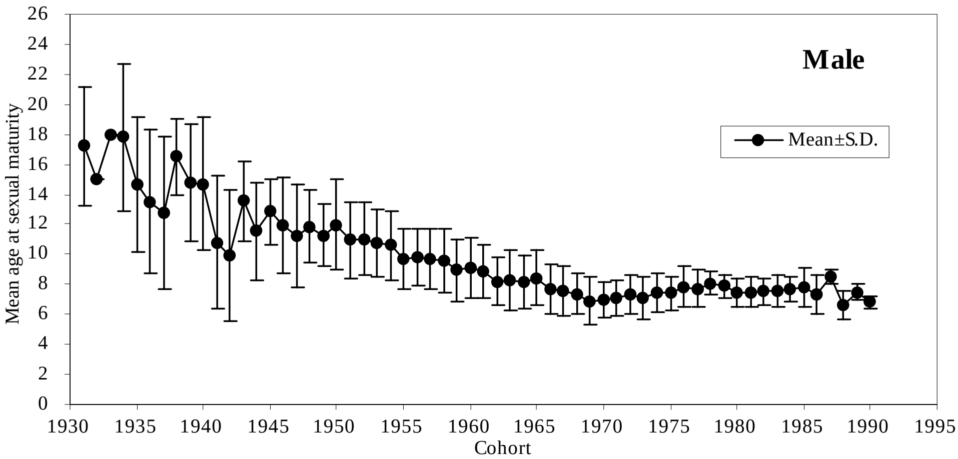


Fig. 6. A plot of mean age at sexual maturity against age at capture separated by two sets of years samples taken 10 years apart.



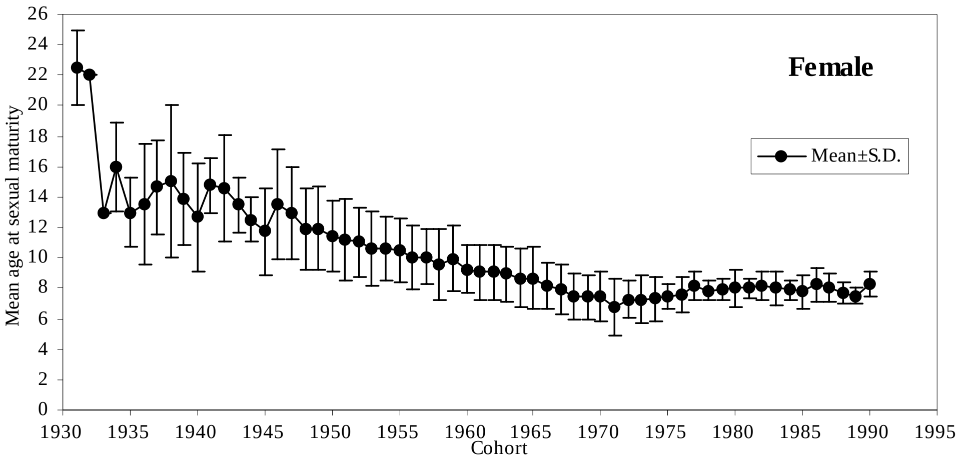


Fig. 7. Long term trend of mean age at sexual maturity derived from transition phase in earplug by cohort for each sex in Area IV. Closed circle is mean age and solid line is range of standard deviation.

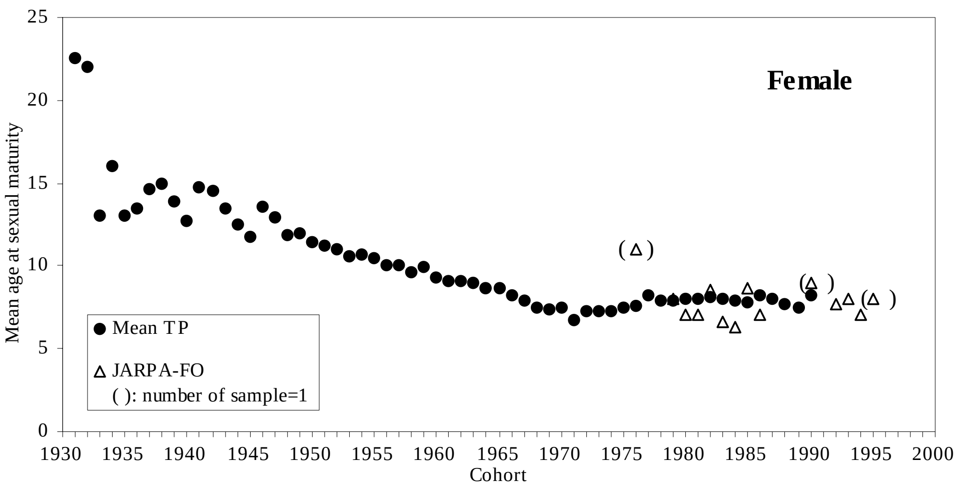


Fig. 8. Comparison of two kinds of estimates of age at sexual maturity for female in Area IV. Parentheses indicate number of sample is one.