Yearly trend in the age at sexual maturity of Antarctic minke whales examined by transition phase in earplugs collected during JARPA and JARPAII surveys

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ABSTRACT
Yearly trend of age at sexual maturity in Antarctic minke whales was examined by age and transition phase (TP) data from earplugs collected during 1987/88-2004/05 JARPA and 2005/06-2010/11 JARPAII surveys. Analysis was conducted by sex and stocks that were separated at 165ºE. Truncation bias was corrected by standard method. The results confirmed that the age at sexual maturity of both stocks declined from the mid 1940s cohorts at around 10-12 years old to the early 1970s cohorts at around 7-8 years old, presumably as response to improved nutritional conditions at that time. Age at sexual maturity remained constant at 7-8 years old till the 1990s cohorts. Statistical analysis to investigate trend from the 1970s cohorts showed slight but statistically significant increasing trend for the I stock (both sexes) and P stock (females). It is noted that the level of current changes in response to deteriorated conditions is not the same as the decreasing trend level observed from the 1940's cohorts in response to improved nutritional conditions at that time. Continuous monitoring of age at sexual maturity is needed to detect possible changes in nutritional conditions of Antarctic minke whales.

KEYWORDS: ANTARCTIC MINKE WHALE, AGE AT SEXUAL MATURITY, TRENDS

INTRODUCTION

It is generally known that the transition phase in earplugs of large baleen whales indicates the age at sexual maturity (Lockyer, 1972; Masaki, 1979; Kato, 1983a; Ohsumi, 1986a). Several authors have reported a decline of Antarctic minke whales age at sexual maturity from 14 years in the 1940s cohorts to 7 years in the late 1960s cohorts from the analysis of transition phase in earplugs collected by commercial whaling (Masaki, 1979; Best, 1982; Kato, 1983b; 1985; Thomson *et al.*, 1999). It was considered that the decline of age at sexual maturity in the Antarctic minke whales was caused by reduction in the abundance of other large baleen whale stocks, which led to greater availability of food for Antarctic minke whales (Masaki, 1979; Best, 1982; Kato, 1983b; 1985; 1987; Kato and Sakuramoto, 1991).

At the JARPA review meeting held in Tokyo in 2006, results of long-term changes in age at sexual maturity of Antarctic minke whales from the 1940s to the 1991 cohorts were reported by newly identified Eastern Indian Ocean Stock (I-stock) and Western South Pacific Ocean Stock (P-stock) (Zenitani and Kato, 2006). The age at sexual maturity estimated using transition phase in earplugs as an indicator of sexual maturity *(tmp)* of both stocks declined from the mid-1940s cohorts or the mid-1950s cohorts at around 10-12 years to the late 1960s cohorts or the early 1970s cohorts at around 7 years. However, *tmp* for both stocks and sexes remained constant at 7-8 years or slightly increased in the early 1970s cohorts onwards (Zenitani and Kato, 2006). They interpreted this trend as a reflection of nutritional conditions for Antarctic minke whales that supported the decline of *tmp* which then shifted to conditions that did not to support a further decline.

In recent years, increasing abundance in large baleen whale species such as blue, fin and humpback whales has been reported (Branch, 2011; Hakamada and Matsuoka, 2014; Matsuoka *et al*., 2011; Matsuoka and Hakamada, 2014). Furthermore, blubber thickness and stomach contents weight of Antarctic minke whales has been reported to have decreased during the JARPA/JARPA II period (Konishi *et al*., 2008; Konishi and Walløe, 2014a; 2014b), which implies that nutritional conditions for Antarctic minke whales might be deteriorating.

JARPA II started in 2005/06 and new data from six years of surveys were accumulated. In this paper, yearly trend of age at sexual maturity in Antarctic minke whales was examined over the long-term and for recent cohorts by sex and stocks.

MATERIALS AND METHODS

Biological data used

The present study used a total of 2,801 age and transition phase (TP: age at transition phase layer) data collected in 1987/88-2004/05 JARPA and 1,374 data collected in 2005/06-2010/11 JARPA II surveys in Areas IIIE, IV, V and VIW. Samples from Areas IIIE, IV and VW were assumed as I-stock and samples from Areas VE and VIW were assumed as P-stock (Pastene, 2006). It should be noted here that the stock structure hypothesis has been refined recently (e.g. Kitakado *et al*., 2014) and that new grouping for estimating age at sexual maturity would be necessary in future.

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 from 1987/88-1989/90 and 1992/93 JARPA samples were mainly read by reader-K. Individual ages of 1990/91 and 1993/94-2004/05 JARPA samples were read by reader-Z. Individual ages of 2005/06-2010/11 JARPA II samples were read by new reader (reader-B). The age at transition layer was recorded if it was present.

Cohort (= year of birth)

Cohorts (Year classes) were defined as; Cohort = (starting year of research season) – (age at capture).

Terminology for age at sexual maturity

"*Tmp*" (Kato, 1987): Mean age at sexual maturity estimated using transition phase in earplugs as an indicator of sexual maturity.

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

Correction of truncation bias

Truncation bias was corrected by the method of Kato (1985). For JARPA samples, we only used TP data for animals older than the following ages in each cohort group which was same as Zenitani and Kato (2006); 36 years (1951-55 cohort group), 29 years (1956-60), 25 years (1961-65), 19 years (1966-70), 15 years (1971-75), 12 years (1976-80), 13 years (1981-85) and 13 years (1986-95). For JARPA II samples we used TP data older than the following ages in each cohort group; 12 years (1991-1995 cohort group), 12 years (1996-2000), no data was used from the 2001-2005 cohort group because age of this group was less than 10 years.

Statistical analysis

Linear regression analysis was applied to two periods. First, regression analysis was applied to *tmp* and 1970-1997 cohorts for male of I-stock, 1968-1997 cohorts for female of I-stock, 1971-1998 cohorts for male of P-stock, 1969-1998 cohorts for female of P-stock, following Zenitani and Kato (2006), to examine long term trend from 1970s. The null hypothesis was set that the slope = 0 (H_0) and we examined whether the null hypothesis can be rejected at 5% level. Regression analysis was also applied to 1992 and younger cohorts (new data provided by JARPAII) for both sex and stocks.

RESULTS

Evaluation of new reader

Age and *tmp* data of reader-K and reader-Z were thought to almost coincide (Zenitani and Kato 2006). We examined difference of *tmp* recorded by the new reader (reader-B) and the previous reader group (reader-K and reader-Z). Figure 1 shows *tmp* against cohort based on TP data read by the two reader groups by sex and stock. The temporal trends of the two reader groups were similar and *tmp* values almost coincide with each other.

Temporal trend of age at sexual maturity by transition phase

As described above, no differences of temporal trend in *tmp* were found between the two reader groups. We estimated *tmp* using all TP data. Figure 2 and Table 1 shows *tmp* against cohort based on TP data by sex and stocks.

In both sex and stocks, *tmp* declined from the 1940s cohorts to the early 1970s cohorts from 10-12 to 7-8 years old. From early 1970s onwards, the *tmp* remained stable or slightly fluctuated at 7-8 years old. *Tmp* of the 1990s cohorts, which were newly added in this study from JARPAII surveys, were 7-8 years and no distinct difference was observed from previous cohorts (Figure 2, Table 1).

Significant increasing trend was detected by linear regression analysis between *tmp* and cohorts for male of I-stock (p=0.044, 1970-1997 cohorts), female of I-stock (p=0.022, 1968-1997 cohorts), and female of P-stock (p=0.004, 1969-1998 cohorts) (Table 2). Furthermore, significant decreasing trend was detected between *tmp* and 1992 and younger cohorts in female of P-stock (p=0.042, Table 3).

DISCUSSION

In the previous study *tmp* was estimated until the 1991 cohort based on JARPA samples (Zenitani and Kato, 2006), and this study examined a further seven cohorts since then. *Tmp* in recent cohorts was in general stable, at about 7-8 years.

The present analysis confirmed a temporal trend of age at sexual maturity in I and P stock of Antarctic minke whales over the long term as suggested in previous studies. The results confirmed that the age at sexual maturity of both stocks declined from the mid 1940s cohorts at around 10-12 years old to the early 1970s cohorts at around 7-8 years old, and it has remained at this range in recent cohorts.

Zenitani and Kato (2006) reported slightly increasing trend of *tmp* from the 1970s to the early 1990s cohorts and suggested that nutritional condition for Antarctic minke whale might have negatively changed. Similar trend was also detected in the present study from the 1970s to the late 1990s cohorts. Supporting evidence for the deteriorated conditions hypothesis is the increasing abundance of other krill-eater baleen whale stocks (Branch, 2011; Hakamada and Matsuoka, 2014; Matsuoka *et al*., 2011; Matsuoka and Hakamada, 2014). It should be noted that the level of current changes in response to deteriorated conditions is not the same as the decreasing trend level observed from the 1940's cohorts in response to improved nutritional conditions at that time.

Regarding the statistical analysis of the cohorts after 1992 a significant decreasing trend was detected in P-stock for females. However *tmov*, which was considered to be free from the segregation and catch selectivity (Kato, 1987), did not show a decreasing trend in the 1990s cohorts for this stock, although the analysis involved a small sample size (Figure 3). This means that reliability of the decreasing trend detected in P-stock for females after 1992 was uncertain and further analysis and continuous monitoring is needed.

Sexual maturity of baleen whales depends on body size rather than age, and growth speed of body size is largely affected by nutritional condition of each individual (Kato, 1987; Lockyer, 1981: Ohsumi, 1986b). Therefore, age at sexual maturity can be a useful indicator for monitoring the status of Antarctic minke whale stocks. Continuous monitoring of age at sexual maturity is a valuable tool to detect possible changes in nutritional conditions for Antarctic minke whales.

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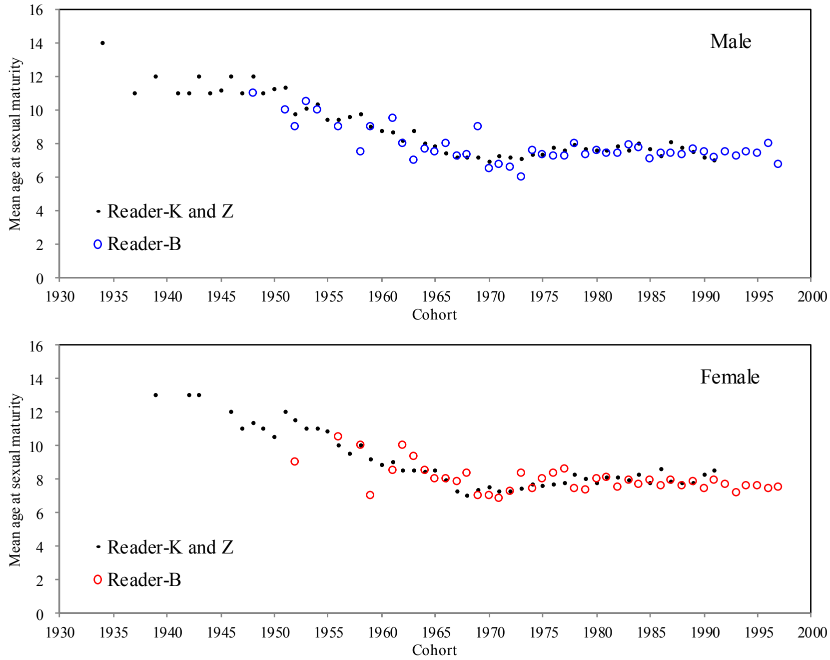
I-stock



P-stock

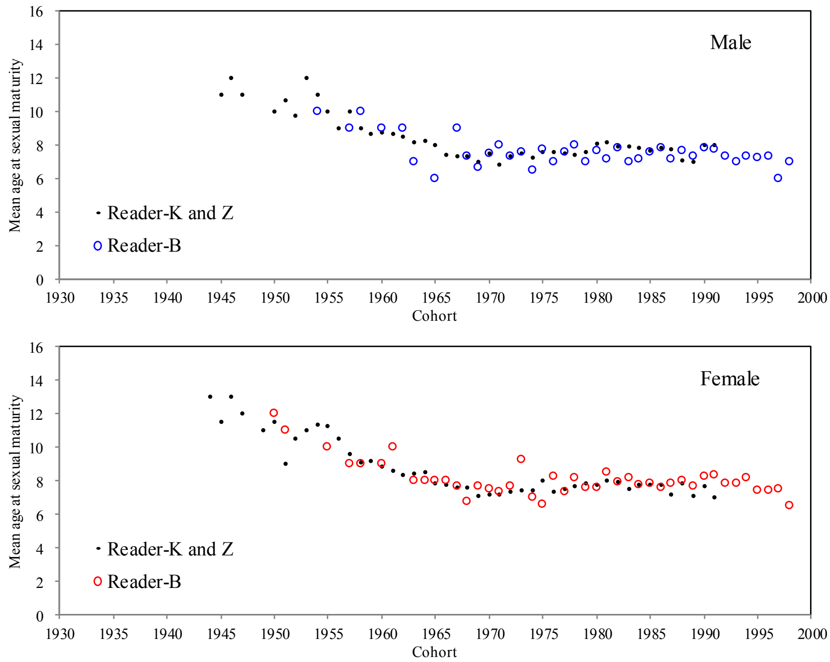
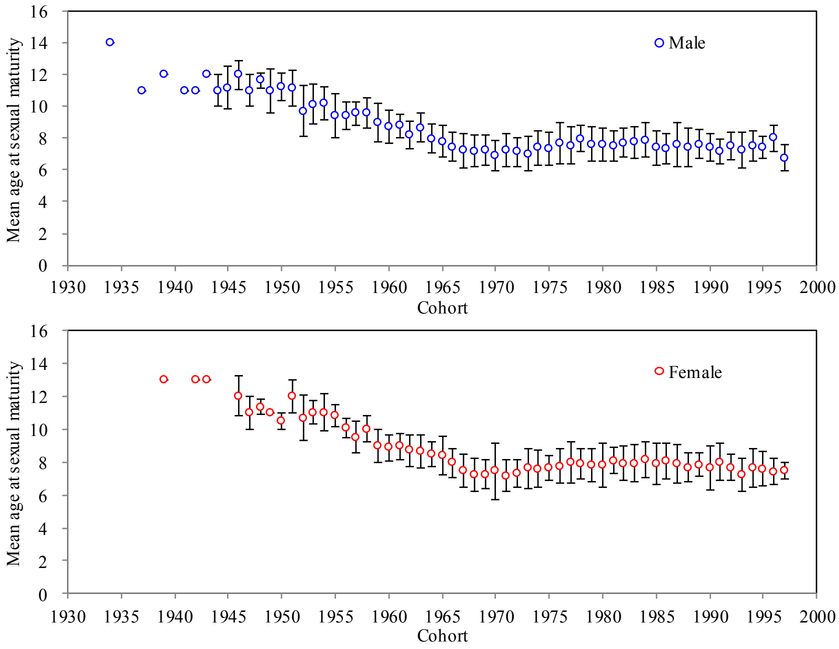


Figure 1. A plot of *tmp* against cohorts based on TP data of I and P stocks separated by two age reader groups. Reader-K and reader-Z read JARPA (1987/88-2004/05) samples and reader-B read JARPA II (2005/06-2010/11) samples.

I-stock



P-stock

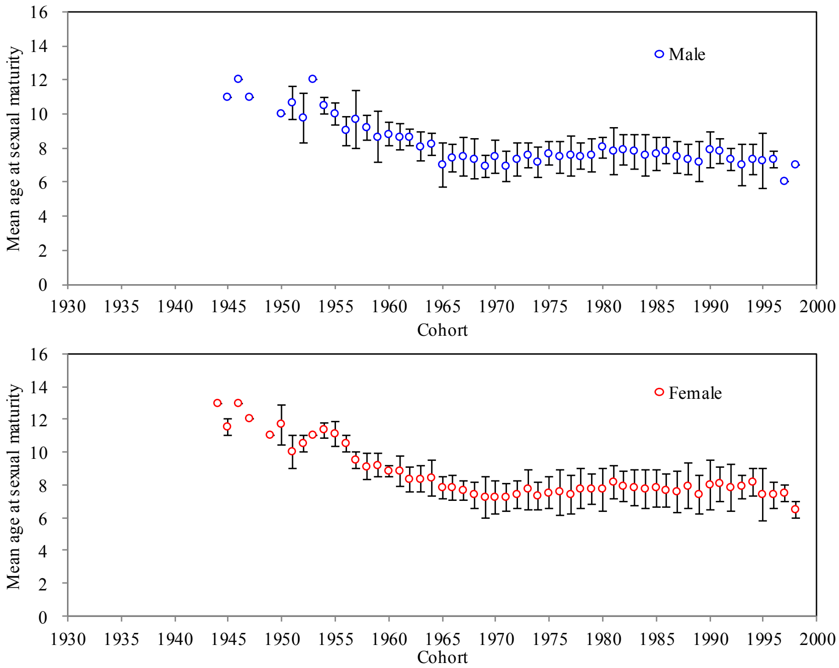


Figure 2. Temporal trend of *tmp* by cohort for each sex and stocks. Open circle is mean age and solid bar is range of standard deviation. All JARPA and JARPA II samples were combined.

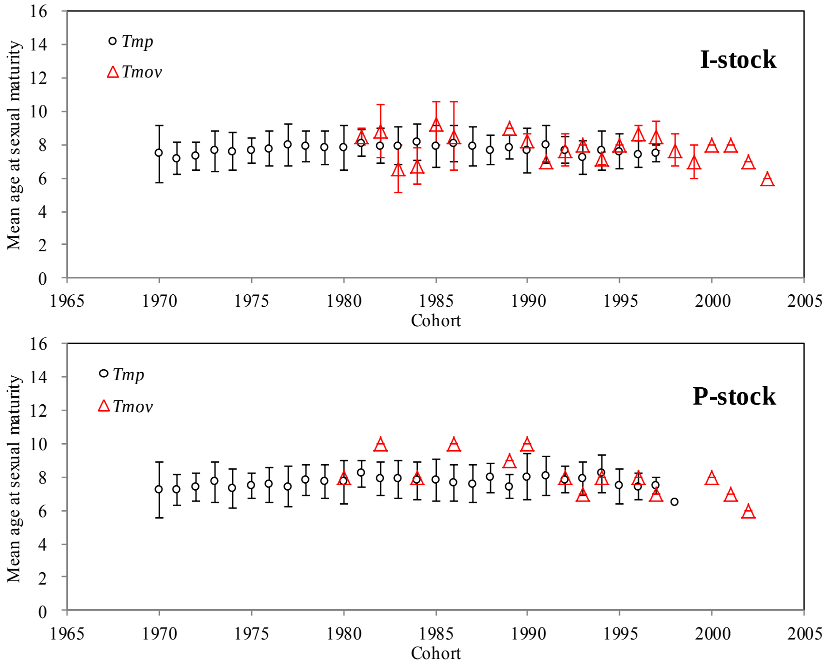


Figure 3. Comparison of two kinds of estimates of age at sexual maturity for females in each stock. *Tmp* is mean age at sexual maturity estimated using transition phase in earplug and *tmov* is mean age at first ovulation. Open circle and triangle shows mean age and solid bar shows range of standard deviation.

Table 1. Mean age at sexual maturity of Antarctic minke whales derived from TP. All JARPA and JARPA II samples were combined.

Cohort	I-stock						P-stock					
	Female			Male			Female			Male		
	mean	n	S.D.	mean	n	S.D.	mean	n	S.D.	mean	n	S.D.
1934				14.00	1	0.00						
1935												
1936												
1937				11.00	1	0.00						
1938												
1939	13.00	1	0.00	12.00	1	0.00						
1940												
1941				11.00	1	0.00						
1942	13.00	1	0.00	11.00	1	0.00						
1943	13.00	1	0.00	12.00	3	0.00						
1944				11.00	2	1.00	13.00	1	0.00			
1945				11.20	5	1.33	11.50	2	0.50	11.00	1	0.00
1946	12.00	4	1.22	12.00	5	0.89	13.00	1	0.00	12.00	1	0.00
1947	11.00	4	1.00	11.00	2	1.00	12.00	1	0.00	11.00	1	0.00
1948	11.33	3	0.47	11.67	3	0.47						
1949	11.00	1	0.00	11.00	3	1.41	11.00	1	0.00			
1950	10.50	2	0.50	11.25	4	0.83	11.67	3	1.25	10.00	1	0.00
1951	12.00	2	1.00	11.14	7	1.12	10.00	2	1.00	10.67	3	0.94
1952	10.67	6	1.37	9.70	10	1.62	10.50	2	0.50	9.75	4	1.48
1953	11.00	4	0.71	10.13	15	1.26	11.00	1	0.00	12.00	1	0.00
1954	11.00	8	1.12	10.22	9	1.03	11.33	3	0.47	10.50	2	0.50
1955	10.83	6	0.69	9.43	7	1.40	11.13	8	0.78	10.00	5	0.63
1956	10.06	16	0.56	9.42	12	0.86	10.50	4	0.50	9.00	3	0.82
1957	9.50	6	0.96	9.57	14	0.73	9.50	6	0.50	9.67	3	1.70
1958	10.00	12	0.82	9.60	25	0.94	9.13	8	0.78	9.20	5	0.75
1959	9.00	10	1.00	9.00	18	1.20	9.18	11	0.72	8.67	6	1.49
1960	8.88	16	0.78	8.77	22	1.04	8.86	7	0.35	8.83	6	0.69
1961	8.94	17	0.80	8.77	31	0.71	8.83	6	0.90	8.67	6	0.75
1962	8.68	22	0.92	8.17	23	0.87	8.33	6	0.75	8.60	5	0.49
1963	8.64	22	0.98	8.68	28	0.93	8.36	11	0.77	8.08	12	0.86
1964	8.44	18	0.76	7.96	25	0.92	8.40	10	1.11	8.25	8	0.66
1965	8.41	22	1.15	7.81	32	1.01	7.85	13	0.66	7.00	6	1.29
1966	7.95	20	0.86	7.47	47	0.92	7.80	15	0.75	7.43	14	0.82
1967	7.48	21	1.01	7.22	27	1.10	7.64	14	0.61	7.50	14	1.12
1968	7.22	18	0.97	7.19	37	0.98	7.40	20	0.80	7.36	11	1.15
1969	7.25	20	0.89	7.24	29	0.93	7.21	14	1.26	6.94	16	0.66
1970	7.44	16	1.69	6.91	33	0.93	7.22	18	1.03	7.50	16	1.00
1971	7.15	26	0.95	7.22	50	1.04	7.23	22	0.85	6.94	18	0.91
1972	7.29	28	0.84	7.13	48	0.95	7.41	29	0.81	7.35	17	0.97
1973	7.61	18	1.21	7.03	33	1.06	7.71	24	1.24	7.57	28	0.73
1974	7.59	22	1.15	7.41	37	1.08	7.32	22	0.87	7.17	24	0.90
1975	7.65	17	0.76	7.35	43	1.03	7.50	20	0.97	7.67	24	0.69
1976	7.75	20	1.04	7.72	36	1.30	7.55	22	1.37	7.48	23	0.93
1977	7.95	20	1.24	7.54	41	1.15	7.42	26	1.18	7.56	16	1.17
1978	7.86	22	0.92	7.97	35	0.81	7.77	30	1.20	7.54	13	0.75
1979	7.81	27	0.98	7.63	32	1.08	7.74	23	0.94	7.58	24	0.95
1980	7.81	27	1.31	7.62	39	1.03	7.71	17	1.27	8.05	19	0.60
1981	8.07	27	0.81	7.53	38	0.94	8.19	16	1.01	7.82	17	1.34
1982	7.93	40	1.01	7.70	43	0.90	7.92	24	0.91	7.92	25	0.89
1983	7.93	42	1.12	7.74	43	1.01	7.86	28	1.09	7.80	25	1.02
1984	8.11	27	1.10	7.89	37	1.06	7.77	26	1.19	7.60	20	1.20
1985	7.89	36	1.24	7.39	28	1.11	7.79	28	1.18	7.65	20	0.96
1986	8.08	25	1.09	7.32	37	0.96	7.66	29	0.99	7.86	14	0.74
1987	7.89	27	1.13	7.62	42	1.40	7.57	14	1.29	7.46	28	0.94
1988	7.67	36	0.88	7.44	27	1.20	7.95	20	1.40	7.35	17	0.90
1989	7.82	17	0.71	7.63	19	0.93	7.40	15	1.20	7.19	16	1.18
1990	7.63	16	1.36	7.42	24	0.86	8.00	14	1.51	7.88	8	1.05
1991	8.00	23	1.14	7.18	22	0.78	8.07	15	1.06	7.82	11	0.72
1992	7.67	18	0.82	7.52	23	0.88	7.84	19	1.42	7.33	9	0.67
1993	7.21	24	1.00	7.24	29	1.10	7.89	18	0.74	7.00	11	1.21
1994	7.61	18	1.16	7.50	14	0.98	8.18	11	0.83	7.36	14	0.89
1995	7.57	14	1.05	7.44	16	0.70	7.43	7	1.59	7.25	4	1.64
1996	7.40	5	0.80	8.00	3	0.82	7.40	5	0.80	7.38	8	0.48
1997	7.50	4	0.50	6.75	4	0.83	7.50	2	0.50	6.00	1	0.00
1998							6.50	4	0.50	7.00	1	0.00

Table 2. Results of linear regression analysis applied to cohort and age at sexual maturity by sexes and stocks. Regression analysis was applied to 1970-1997 cohorts for male of I-stock, 1968-1997 cohorts for female of I-stock, 1971-1998 cohorts for male of P-stock, 1969-1998 cohorts for female of P-stock, respectively.

Male: I-stock (1970-1997 cohorts)

	value	SE	t	p-value	
Intercept	-12.664	10.004	-1.266	0.206	
Coefficient	0.01016	0.005	2.012	0.044	*

Female: I-stock (1968-1997 cohorts)

	value	SE	t	p-value	
Intercept	-17.525	11.031	-1.589	0.113	
Coefficient	0.01274	0.006	2.288	0.022	*

Male: P-stock (1971-1998 cohorts)

	value	SE	t	p-value
Intercept	7.121	13.318	0.535	0.593
Coefficient	0.00021	0.007	0.031	0.975

Female: P-stock (1969-1998 cohorts)

	value	SE	t	p-value	
Intercept	-30.031	12.915	-2.325	0.020	*
Coefficient	0.01902	0.007	2.919	0.004	*

Table 3. Results of linear regression analysis applied to cohort and age at sexual maturity by sexes and stocks. Cohorts of 1992 and younger were used for analysis.

Male: I-stock

	value	SE	t	p-value
Intercept	65.916	151.163	0.436	0.664
Coefficient	-0.02936	0.076	-0.387	0.700

Female: I-stock

	value	SE	t	p-value
Intercept	0.384	159.752	0.002	0.998
Coefficient	0.00356	0.080	0.044	0.965

Male: P-stock

	value	SE	t	p-value
Intercept	35.714	192.894	0.185	0.854
Coefficient	-0.01429	0.097	-0.148	0.883

Female: P-stock

	value	SE	t	p-value	
Intercept	342.796	161.115	2.128	0.037	*
Coefficient	-0.16805	0.081	-2.080	0.042	*