Temporal trend of age at sexual maturity of Antarctic minke whales based on transition phase in earplugs obtained under JARPA surveys from 1987/88-2004/05

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ABSTRACT

Using transition phase (TP) and age readings from a total of 2,803 individuals collected in 1987/88 to 2004/05 special permit cruise under JARPA research program, the present study examined temporal trend of age at sexual maturity of the Antarctic minke whales following by the new stock boundary for I (Eastern Indian Ocean Stock) and P (Western South Pacific Ocean stock) stocks. Through analyses the present study confirmed again the similarly decline of age at sexual maturity of Antarctic minke whale from 1940s cohorts to late of 1960s cohorts which was identified by previous studies; the mean age at sexual maturity of both stocks declined from the mid 1940s cohort or the mid 1950s cohorts at around 10-12 years to the late 1960s cohorts or the early 1970s cohorts at around 7 years with statistical significance at 5% level. However, it was newly identified that mean age at sexual maturity for both stocks and sexes until the early 1970s cohorts no longer declined and remained constant at 7-8 years or slightly increased in the early 1970s cohorts onward to the early 1990s cohorts. These temporal trends represent changes in nutritional condition for Antarctic minke whales.

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

INTRODUCTION

One of the objectives of the Japanese Whale Research Program under Special Permit in the Antarctic (JARPA) is 'estimation of the biological parameters to improve the stock management of Antarctic minke whales'. After the moratorium on commercial whaling, the JARPA has been collecting data in order to achieve the stated objective. There are some methods of estimation of age at sexual maturity. Among which age at sexual maturity estimated from transition phase in earplug data (*tmp*) and mean age at first ovulation (*tmov*) are considered free from biases due to the reproductive segregation and the catch selectivity (Kato, 1987).

It is generally known that transition phase in earplug indicated the age at sexual maturity (Lockyer, 1972; Masaki, 1979; Kato, 1983a). The indirect indicator of the age at sexual maturity of baleen whales was discovered by Lockyer (1972). Several authors have reported a decline of Antarctic minke whales age at sexual maturity from 14 years in 1940s cohort to 6 years in late 1960s cohort from the analysis of transition phase in earplugs collected commercial whaling (Masaki, 1979; Best 1982; Kato 1983b, 1985). It was considered that the changes of biological parameters estimated such as decline of age at sexual maturity and increase of the growth rate using commercial data in the Antarctic minke whales, were caused by reduction of blue and fin whales populations which are in strong competition with 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 the estimation of age at sexual maturity and growth curve. They concluded and argued that the observed decline in age at sexual maturity in the mid 1940s (12-13 years) to the early 1970s (7-8 years) cohorts is real because it is free from possible truncation biases (Kato, 1987; Kato and Sakuramoto, 1991). Although many studies have been carried out in this field, nevertheless, IWC/SC is still not able to reach a general consensus on the decline of the age at sexual maturity of the Antarctic minke whales (IWC, 1985). Only agreement is reached at the mid-term JARPA review meeting in 1997 in which 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 a*l., 1997).

In January 2005, JARPA review meeting was hosted by the government of JAPAN, we showed long-term changes in age at sexual maturity of Antarctic minke whales from 1940s cohort to 1980s cohort in Area IV by using transition phase data (Zenitani and Kato, 2005). The present study examines a temporal trend in age at sexual maturity of Antarctic minke whales by the new stock boundary for I (Eastern Indian Ocean Stock) and P (Western South Pacific Ocean stock) stocks which are revealed from several analyses using JARPA data (Pastene, 2006).

MATERIALS AND METHODS

Biological data used

The present study used a total of 2,803 age and transition phase (TP: age at transition phase layer) data collected in 1987/88-2004/05 JARPA in Area IIIE, IV, V and VIW. Furthermore, data of the age at first ovulation in 1987/88-2004/05 JARPA in Area IIIE, IV, V and VIW were also used. Data in Areas IIIE, IV and VW for I-stock and data in Areas VE and VIW for P-stock which are newly identified biological stocks were used (Pastene, 2006).

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 data were determined using growth layers in earplug that were mainly counted by reader-K. Individual ages of 1990/91 and 1993/94-2004/05 JARPA were determined using growth layers in earplug that were counted by reader-Z. The age at transition layer was recorded as 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, 1983a; 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 albicansin both ovaries.

Statistical analyses

When declining, constant or increasing trend was observed in the range of cohorts, we fitted a regression line and examined whether it was significantly different from zero or not at 5 % level.

Corrected truncation bias

We corrected truncation bias using the same method of Kato (1985). To estimate *tmp* we only used TP data for animals older than following ages in cohort groups; 36 years (1951-55), 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).

RESULTS

Evaluation of two readers

Individual ages were determined using growth layers in earplug that were counted by reader-K for samples collected 1987/88-1989/90 and 1992/93 and by reader-Z for others. We examine difference of *tmp* between two readers. Fig. 1 shows *tmp* against cohort based on TP data for each sex and stock. The temporal trends of two readers both sexes were similar and *tmp* values of two readers almost coincide with each other. No differences of temporal trend of *tmp* were found between two readers by cohort.

Examination of among sampling years

In order to examine that there is no truncation of sampling problem in sampling years, *tmp* plots against cohort based on crude data: three groups of sampling years (1987/88-1992/93, 1993/94-1998/99, and 1999/00-2004/05) were examined. Fig. 2 shows *tmp* against cohort based on TP data by sampling year groups, sex and stocks. The temporal trends of four sampling groups of both sexes and stocks were similar. The *tmp* values by cohort almost coincide to different sampling years. No differences of temporal trend of *tmp* were found among three sampling years.

Temporal trend of mean age at sexual maturity by transition phase

As described above, no differences of temporal trend of *tmp* were found between two readers and among four sampling years. We estimated *tmp* using all TP data combined two readers and four sampling groups. Fig.3 shows *tmp* against cohort based on TP data by sex and stocks.

In I-stock, *tmp* of male declined from the mid 1940s cohorts at around 12 years to the late 1960s cohort at around 7 years. The decline of *tmp* had been stopped in the late 1960s cohorts to the early 1970s cohorts, it was found that the mean age remained constant at 7-8 years or slightly increased in the early 1970s cohorts to the early 1990s cohorts. The *tmp* of female declined from the early 1950s cohorts at around 12 years to the late 1960s at around 7 years. From the early 1970s cohorts to the early 1990s cohorts the temporal trend of *tmp* similar to the male was found.

In P-stock, *tmp* of male declined from half of 1950s cohorts at around 10 years to the late 1960s at around 7 years. The decline of *tmp* had been stopped in the late 1960s cohorts to the early 1970s cohorts, it was found that the mean age remained constant at 7-8 years or slightly increased in the early 1970s to the early 1990s cohorts. The *tmp* of female declined from the early 1955 cohorts at around 11 years to the late 1960s at around 7 years. From the early 1970s to 1990s cohorts, the temporal trend of *tmp* similar to the male was found.

We fitted regression line in cohort range and the regressions of *tmp* weighted by sample size for both sexes and stocks are expressed by the following formulae;

I-stock male: *tmp*＝－0.207×cohort＋415.410 （1946 cohorts-1970 cohorts）
tmp＝ 0.012×cohort－17.167 （1970 cohorts-1991 cohorts）
female: *tmp*＝－0.256×cohort＋509.558 （1952 cohorts-1968 cohorts）
tmp＝ 0.043×cohort－78.068 （1968cohorts-1991cohorts）
P-stock male: *tmp*＝－0.177×cohort＋356.570 （1955 cohorts-1971 cohorts）
tmp＝ 0.020×cohort－31.793 （1971 cohorts-1991 cohorts）
female : *tmp*＝－0.256×cohort＋510.519 （1957 cohort-1969 cohort）
tmp＝ 0.008×cohort－8.956 （1969 cohorts-1991cohorts）

All slopes in cohort range at declining trend were significantly different from zero at 5 % level (both sexes and both stocks: $p<0.001$). In cohort range at constant or slightly increase trend, except for a slope of female in P-stock other slops were significantly different from zero (I-stock male: $p<0.001$, I-stock female: $p<0.001$, P-stock male: $p=0.028$, P-stock female: $p=0.064$).

DISCUSSION

The present analysis revealed a temporal trend of age at sexual maturity in I and P stocks in the Antarctic minke whales from the mid 1940s cohorts to the early 1990s cohorts using TP data accumulated by JARPA surveys. Several authors have reported a decline of age at sexual maturity from the 1940s cohorts to the late 1960s cohorts using transition phase earplugs in Antarctic minke whales collected during commercial whaling (Masaki, 1979; Best, 1982; Kato, 1983b, 1985, 1987, Kato and Sakuramoto, 1991, Thomson *et al*., 1997; Cooke *et al*., 1997). Through the present analysis incorporating bias correction confirmed again similarly declined of *tmp* of Antarctic minke whale from 1940s cohorts to late of 1960s cohorts which was identified by previous studies. The *tmp* of I and P 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 with statistical significance at 5% level. However, it was newly identified that *tmp* for both stocks and sexes until the early 1970s cohorts no longer declined and remained constant at 7-8 years or slightly increased in the early 1970s cohorts onward to the early 1990s cohorts. Except for one trend, these slightly increasing trends in recent cohorts are statistical significant at 5 % level.

The *tmov* and *tmp* are considered to be free from the segregation and catch selectivity (Kato, 1987). Although the number of first ovulation data is very small, the values of *tmov* in both stocks are similar to *tmp* and remain almost constant from the 1978 cohort to the 1995 cohort. The trend of remaining constant of *tmp* is supported by direct estimates from *tmov* (shown in Fig. 4).

Kato (1983b, 1987) argued that one possible mechanism for decline of age at sexual maturity in the Antarctic minke whales is the result of an increased growth rate by improvements of nutrition in the adolescent growth spurt stage due to the increase of food availability per capita in the Antarctic feeding ground. However, the present analysis found that the decline of *tmp* until the early 1970s cohort no longer continued. The constant or slightly increased trend of *tmp* in the recent cohort suggest the nutritional condition for Antarctic minke whales to support their decline of age at sexual maturity have shifted to condition not to support decline trend of *tmp*. It is consider that these temporal trends of *tmp* represent change in nutritional condition for Antarctic minke whales.

Thus, the age at sexual maturity can understand for stock condition therefore the age at sexual maturity can be useful indicator in monitoring for population level. Continuous monitoring of the age at sexual maturity can contribute improvement the stock management of the Antarctic minke whales.

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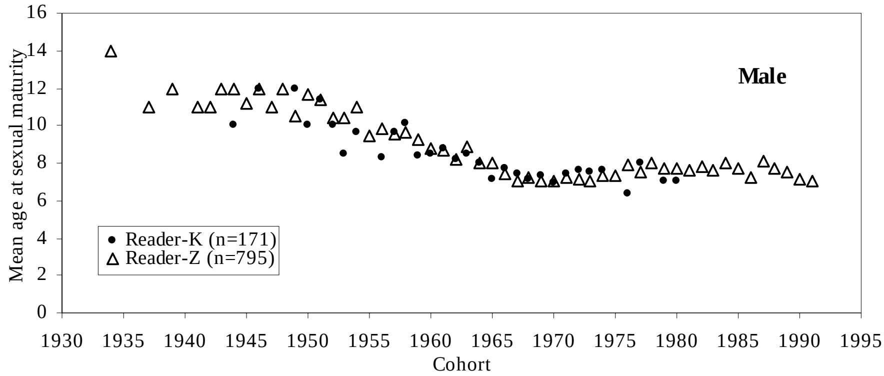
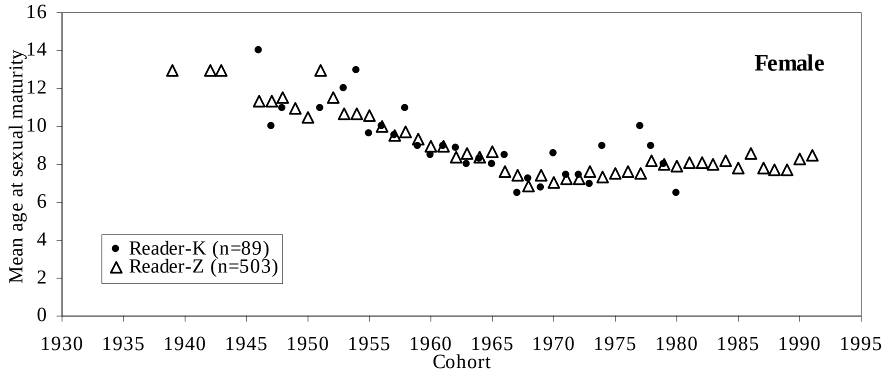
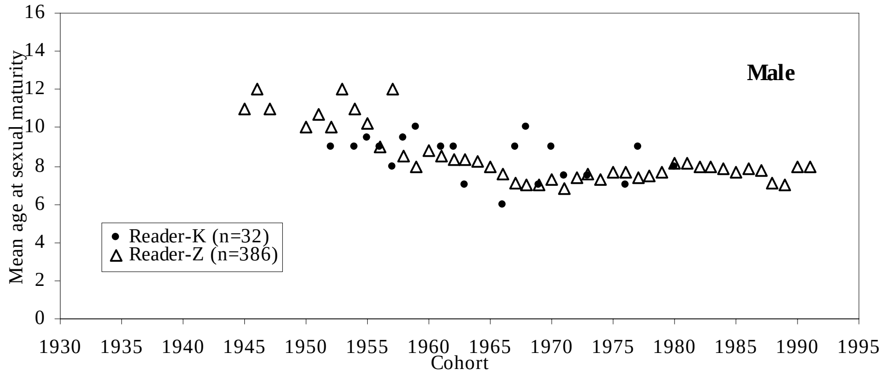
I-stock





P-stock



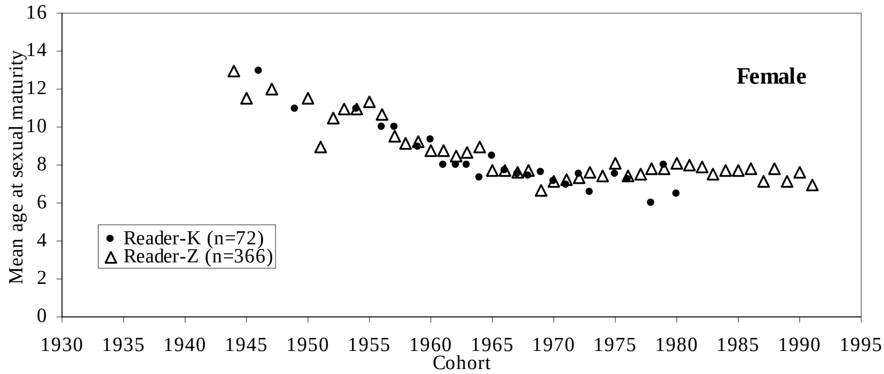
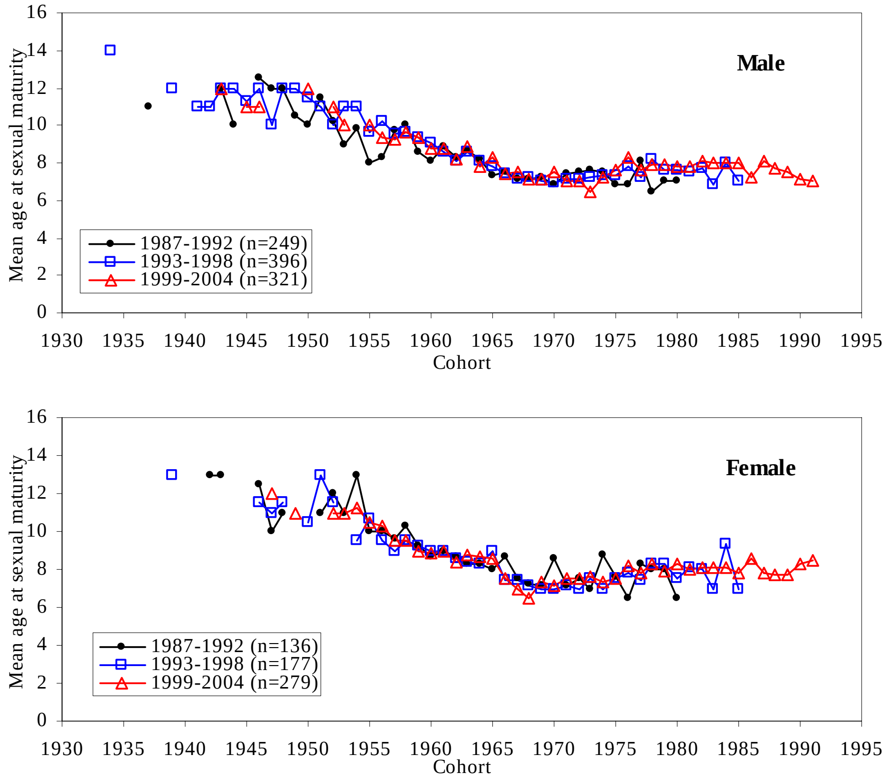


Fig.1. A plot of mean age at sexual maturity against cohorts based on transition phase data of both stocks separated by two age readers.

I-stock



P-stock

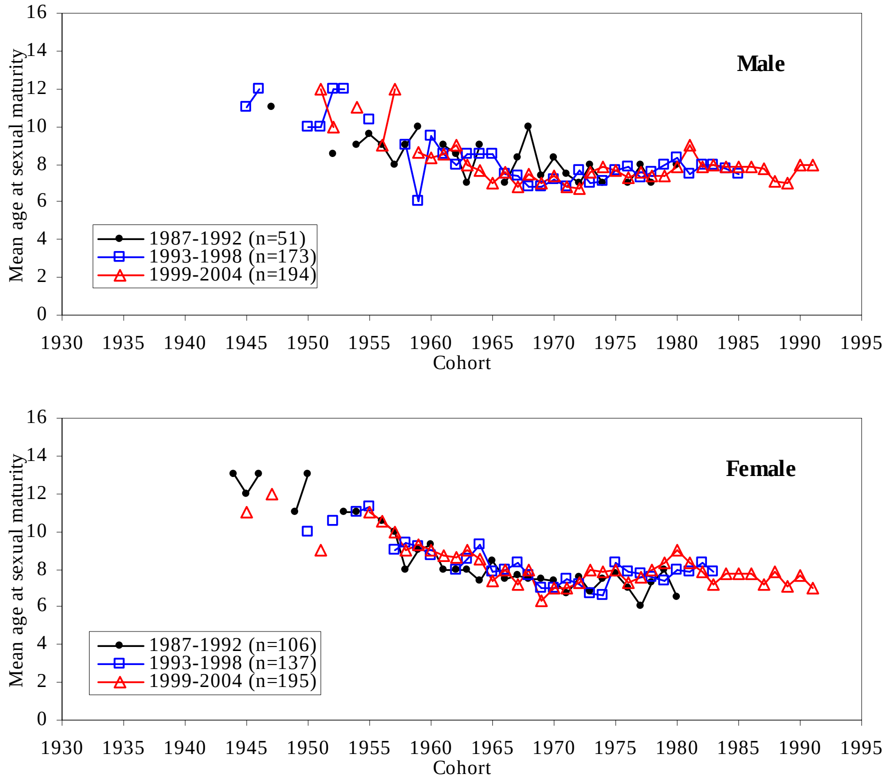
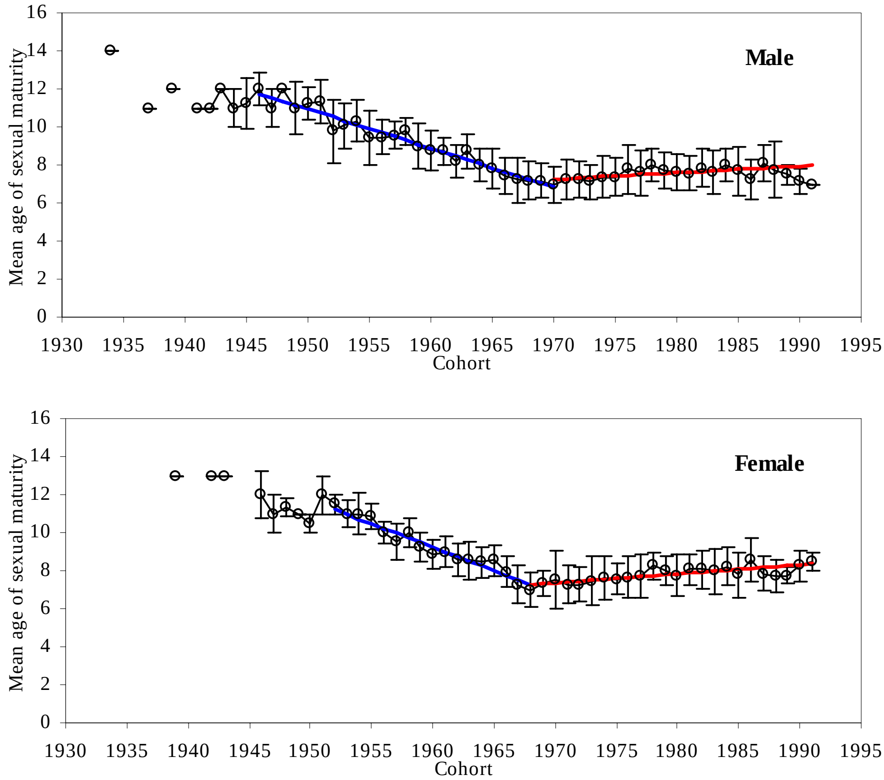


Fig.2. A plot of mean age at sexual maturity against cohorts based on transition phase data separated by 3 groups of sampling years each sex and stock.

I-stock



P-stock

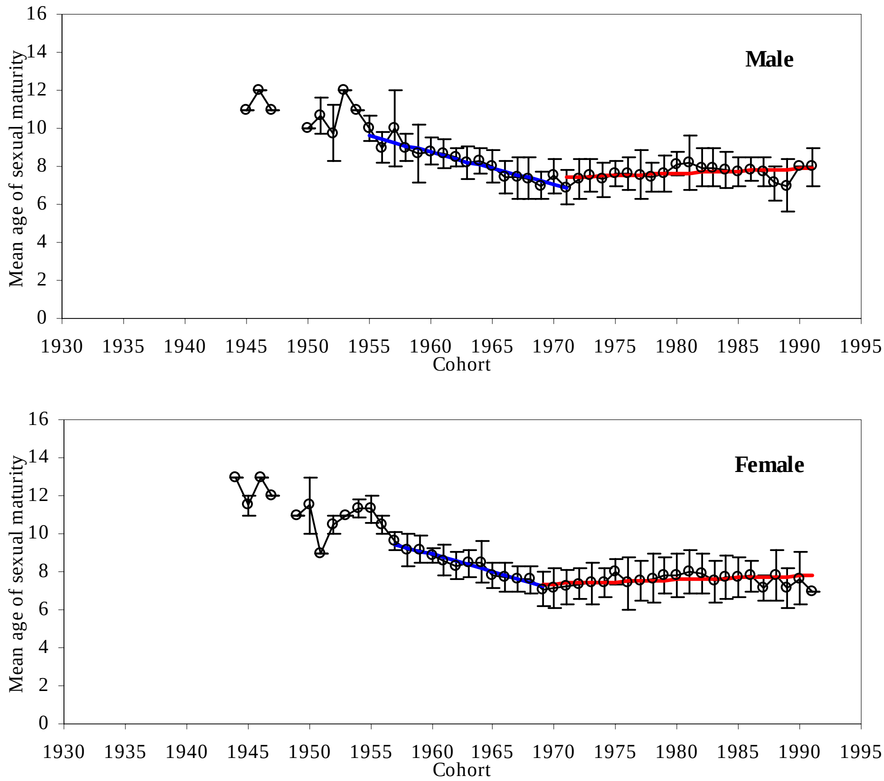


Fig.3. Temporal trend of mean age at sexual maturity derived from transition phase in earplug by cohort for each sex and stock.

Open circle is mean age and solid line is range of standard deviation.

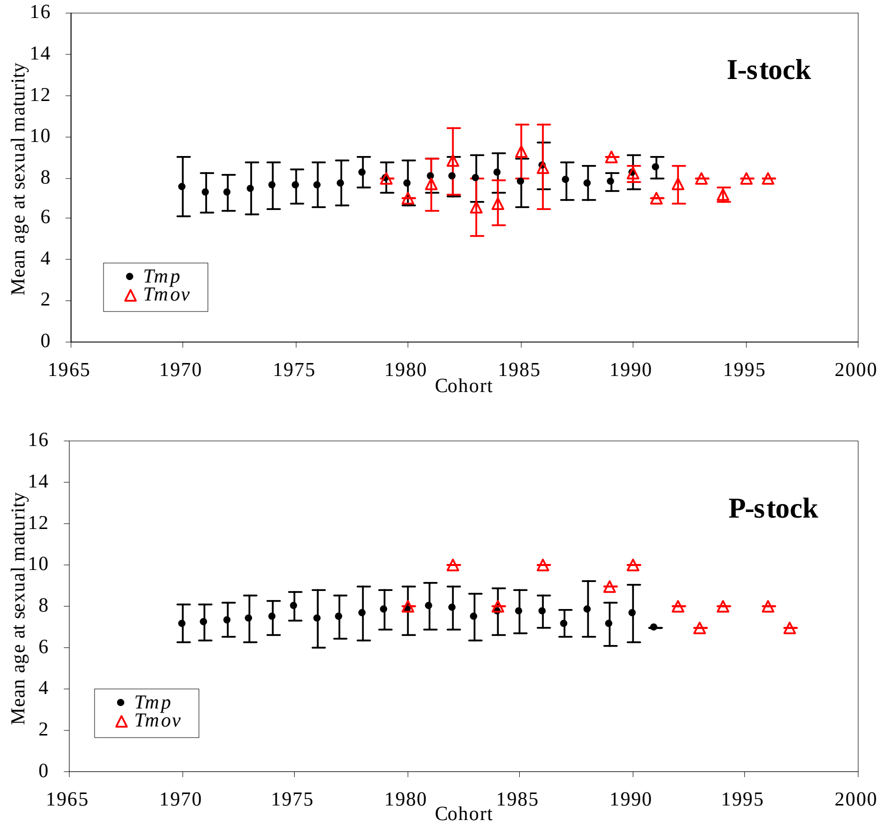


Fig.4. Comparison of two kinds of estimates of age at sexual maturity for female in each stock.