Journal: Fisheries Science

Title:

Changes in growth of marbled sole *Pseudopleuronectes yokohamae* between high and low stock-size periods in Tokyo Bay, Japan

Authors:

Jeong-Hoon Lee[1,2*], Keita Kodama[1], Masaaki Oyama[1], Gen Kume[3], Yuji Takao[4], Hiroaki Shiraishi[1] and Toshihiro Horiguchi[1]

Affiliations:

[1]Research Center for Environmental Risk, National Institute for Environmental Studies, Tsukuba, Ibaraki 305-8506, Japan; [2]Graduate School of Science and Technology, Nagasaki University, Nagasaki, Nagasaki 852-8521, Japan; [3]Faculty of Fisheries, Nagasaki University, Nagasaki, Nagasaki 852-8521, Japan; [4]Faculty of Environmental studies, Nagasaki University, Nagasaki, Nagasaki 852-8521, Japan

---

[*] **Corresponding author:**

Tel: +81-29-850-2852. Fax: +81-29-850-2870. E-mail: lee.jeong.hoon@nies.go.jp

Abstract

We examined age and growth of the marbled sole *Pseudopleuronectes yokohamae* collected from Tokyo Bay, Japan, during 2002–2008 when the stock size remained low. The von Bertalanffy growth equations differed significantly between sexes, and females attained a larger standard length than males of the same age. We compared the results with those reported for 1974–1983 and 1986–1988, when the stock size was high. The growth of marbled sole in Tokyo Bay during the 2000s was significantly higher than the growth in the 1970s and 1980s for both sexes. To explore possible factors causing changes in the growth, we examined bottom water temperature and population density. We found that the population density decreased and the bottom water temperature increased between the late 1970s and the 2000s. However, despite evidence of changes in population densities and water temperatures, further study is needed to determine the main factors causing the observed changes in growth.

Keywords: Growth, *Pseudopleuronectes yokohamae*, Stock size, Tokyo Bay, Water temperature

Introduction

Marbled sole *Pseudopleuronectes yokohamae* is widely distributed in Japan, from southern Hokkaido to Oita Prefecture in Kyushu, the Yellow Sea, the Bohai Sea, and into the northern part of the East China Sea [1]. This species showed high dominance in the demersal assemblage in Tokyo Bay during the mid-1980s, according to a long-term bottom trawl survey [2]. Abundance of marbled sole in Tokyo Bay, however, has decreased markedly since the late 1980s. According to the fisheries statistics of the Shiba Branch of the Yokohama City Fisheries Cooperative Association, the annual catch of marbled sole in Tokyo Bay exceeded 500 t in the mid-1980s, but decreased substantially to around 50 t in the 2000s although fishing effort maintained (Fig. 1). However, the cause of this decline is still unknown.

For elucidating the cause of the population decline, biological investigations are indispensable. Investigations into the fundamental life history traits of marbled sole in Tokyo Bay between 2002 and 2004, including the growth rates and standard length at age suggested that a change in growth rates for both sexes had occurred along with the decrease in abundance [3]. However, the period of this investigation (2002−2004) might be insufficient to prove any changes in growth during the 2000s. To investigate the apparent growth change of marbled sole in Tokyo Bay during the 2000s, we carried out an additional investigation in the late 2000s (2006−2008). In this report, we compare growth rates using the data from the 2000s combined with those from the late 1970s and 1980s, when the stock size was high. We also consider several factors that could have affected changes in growth rate, such as water temperature and population density.

Materials and methods

Growth

To determine the growth rate of marbled sole during the 2000s, a total of 921 individuals were obtained from Tokyo Bay between 2006 and 2008. Some samples were collected from the fishermen’s unions at Yokosuka (gill-net fishery), and at Shiba and Koitogawa (bottom-trawl fishery) between November 2006 and June 2008 (Fig. 2). Samples were also obtained from seasonal bottom-trawl surveys in February, May, August, and November in 2006 and 2007, during which 10-min tows were conducted at 20 stations in Tokyo Bay (Fig. 2). Detailed methods for the bottom trawl surveys have been previously described [2]. All specimens were brought back to the laboratory without fixation. Standard length (SL) was measured to the nearest 1 mm. Sex was determined by external observation and histological examination of the gonad [3, 4]. Sagittal otoliths were dissected out, cleaned with 70% ethanol, and stored dry.

To compare the growth of marbled sole among different studies, we applied the same aging method as the previous studies [3, 5, 6]. Sagittal otoliths from the blind side of the fish were used for age determination and subsequent growth analysis. These otoliths are suitable for reading annuli because the innermost opaque region is located in the center of the otolith [7]. They were immersed in 50% glycerol solution and observed under reflected light against a dark background using a stereomicroscope at 16× magnification (SZX-ILLB100; Olympus Optical Co., Ltd, Tokyo, Japan). The number of annuli (opaque zones) on the otoliths was regarded as the age, because previous studies [3, 7] have shown that the number of annuli indicate age in marbled sole. The opaque zones are formed only once a year between January and July [7]. We used a digital camera attached to the microscope to capture images of sagittal otoliths, and these images were used to measure the otolith radius (R) from the center to the postrostrum. We also measured the ring radii ($r_{n,}$ radius of the *n*th annulus) from the center of the otolith to the inner edge of each opaque zone toward the postrostrum. All measurements were made to the nearest 0.01 mm with the help of image measurement software (WinROOF; Mitani Corp., Fukui, Japan).

To determine the growth in the 2000s, we combined data from 2002–2004 (raw data are available) [3] and 2006–2008 (the present study). For estimating the growth equations for 1974−1983 and 1986−1988, we used the previously published [5, 6] back-calculated SLs for which the raw data used for the back-calculated SLs at each age are available (Table 1). Back-calculated SLs for the 2000s were estimated from the relationship between R and SL expressed by the allometric curve. To estimate the growth of marbled sole in Tokyo Bay during each study period (1974−1983, 1986−1988, and the 2000s), the von Bertalanffy growth equation was fitted to the back-calculated SL at each age:

$$SL_t = SL_\infty\{1 - \exp[-K\,(t - t_0)]\}$$

where SL_t is the back-calculated SL (mm) at age in year t, and SL_∞, K, and t_0 are the asymptotic SL, the growth coefficient, and the hypothetical age at which SL = 0, respectively. Parameters of the von Bertalanffy growth equation were estimated using the Solver tool in MS-Excel (Microsoft Corp., Redmond, Washington, USA), which implements a quasi-Newtonian method for nonlinear least squares parameter estimation [8, 9]. We conducted *F*-tests to determine whether the parameters of the von Bertalanffy growth equation were significantly different between sexes or among study periods (1974−1983, 1986−1988, and the 2000s) [10].

Temperature data

Monthly bottom water temperature data were obtained from public data records from 1979 to 2003 (Tokyo Bay Environmental Information Center website: http://www.tbeic.go.jp/WEBGIS/Download01.asp) for 5 locations in Tokyo Bay (Fig. 2). Annual mean bottom water temperatures were calculated by averaging monthly water temperatures between January and December for each year. Linear regression analysis was used to examine the temporal trend of the annual mean bottom water temperature from 1979 to 2003. To investigate long-term fluctuations in the monthly bottom water temperature, we generated contour map of the monthly bottom water temperatures using the computer software package Surfer 8 (Golden Software Inc., Golden, Colorado, USA).

Population density

To determine the relative abundance of marbled sole in Tokyo Bay, we used data from the bottom-trawl surveys at 20 sampling stations conducted between 1977 and 1995, and between 2003 and 2008 (Fig. 2; see previous “Growth” sub-section for the sampling methods). Because the number of bottom trawl surveys differed among years (2–7 per year), we analyzed the summer and autumn catch-per-unit-effort (CPUE; number of individuals per tow) for each year. We regarded CPUE as a population density index for marbled sole, and conducted *t*-tests to compare the differences in the population density index between 1977−1988 (during which CPUE data covering the period of the previous growth studies are available) and the 2000s (2003−2008).

Results

In the 2000s, most of the specimens were 1 or 2 years old, accounting for 55.6% and 28.0% of the total fish collected, respectively. The largest male specimen was 314 mm SL at an age of 5 years, whereas the largest female was 400 mm SL at age 6 years. The mean r_n values for males and females at each estimated age are shown in Table 2. The relationships between R and SL could be best described by the following allometric equations:

Male: $SL = 79.1R^{1.16}$ ($r^2 = 0.82$; $P < 0.01$)

Female: $SL = 76.7R^{1.23}$ ($r^2 = 0.84$; $P < 0.01$)

Two separate equations were determined because analysis of covariance showed a significant difference in SL between males and females ($P < 0.05$). SL at each age was back-calculated by substituting the mean r_n into the allometric equations, and parameters of the von Bertalanffy growth equations for the 2000s were estimated from the back-calculated SLs (Fig. 3):

Male: $SL_t = 272.2\{1 - \exp[-0.768\ (t - 0.239)]\}$

Female: $SL_t = 440.3\{1 - \exp[-0.300\ (t + 0.161)]\}$

For 1974−1983 and 1986−1988, the von Bertalanffy growth equations were re-estimated using the back-calculated SLs included in the original publications (Fig. 3, Table 1) [5, 6]:

Male: 1974−1983; $SL_t = 265.8\{1 - \exp[-0.441(t + 0.240)]\}$

1986−1988; $SL_t = 255.9\{1 - \exp[-0.507(t + 0.136)]\}$

Female: 1974−1983; $SL_t = 362.9\{1 - \exp[-0.311(t + 0.283)]\}$

1986−1988; $SL_t = 375.2\{1 - \exp[-0.285(t + 0.262)]\}$

Significant differences in parameters of the growth equations were found between sexes in all periods examined (1974−1983, 1986–1988, and 2000s; *F*-test, $P < 0.01$ for all periods). Females grew to larger SL and lived longer than males (Fig. 3, Table 2). The back-calculated SL at each estimated age was the largest in 2002−2008 for both sexes among all periods. However, the back-calculated SL of individuals at 1-year seemed to be almost unchanged. Significant differences in the growth equations were observed for both sexes between 1974−1983 and the 2000s as well as between 1986−1988 and the 2000s, whereas there was no difference between 1974–1983 and 1986–1988 (Table 3).

The annual mean bottom water temperature showed a slight increasing trend from 1979 to

2003 (Fig. 4; $P < 0.05$). In addition, the contour map of the monthly bottom water temperature showed that the periods with low temperatures (below 10°C) during January–March have been getting shorter and less frequent while the periods with higher temperatures (above 22°C) during August–October have occurred more frequently beginning in the 1990s (Fig. 5).

The CPUE, representing the annual population density of marbled sole, ranged from 0.30 to 19.75 individuals per tow during the survey periods (1977−1995, n = 3990; 2003−2008, n = 441). High population densities were observed in the late 1970s and the 1980s, and low population densities were observed in the 2000s. The mean population density between 2003 and 2008 was significantly lower than that observed between 1977 and 1988 (Fig. 6; *t*-test, $P < 0.01$).

Discussion

In the 2000s, the von Bertalanffy growth equations for each sex were significantly different, and females attained larger back-calculated SLs than males at the same age. Growth of fish of both sexes decelerated as they got older (Fig. 3). These results are almost the same as those reported for the 1980s when the stock size was high [5, 6].

Back-calculated SLs for both sexes in the 2000s were larger than those in 1974–1983 and 1986–1988, except for 1-year individuals, suggesting that the growth of marbled sole could have changed between the 1970s and 1980s and the 2000s (Fig. 3, Table 3). Regarding the change in growth of 1-year individuals among those periods, however, it was unclear. It was difficult to judge whether back-calculated SLs in 1-year individuals for both sexes in the 2000s were also larger than those in 1974–1983 and 1986–1988, because the variance of back-calculated SLs in 1-year individuals was unknown. Nevertheless, it may also suggest that the growth in 1-year individuals in the 2000s would have been inhibited by several factors in early life history (e.g., abundance of suitable prey and hypoxic stress). Further investigation is needed to evaluate possible effects of environmental and biological factors to survival and growth in early life history.

The growth change might have been influenced by several factors. In this study, we investigated bottom water temperature and population density during the study period. Bottom water temperature might be important for explaining the geographical variation in growth rate of flounders along the northern boundary of East Sea (Japan Sea) [11, 12]. A difference in annual mean temperatures of 1−2°C could influence growth rates of plaice *Pleuronectes platessa* and flounder *Platichthys flesus* [13]. Takahashi et al. [14] reported that daily feeding rate (% wet body weight per day) of marbled sole increased as water temperature was getting higher under an experimental condition below 24°C. In Tokyo Bay, the annual mean bottom water temperature showed a slightly increasing trend from 1979 to 2003. Therefore, the increase in the growth of marbled sole in Tokyo Bay might have been influenced by the increase in water temperature in their habitats, although the optimum temperature for growth of marbled sole has not been identified.

However, the temperature change alone would not have caused the observed change in growth of marbled sole in Tokyo Bay. The reduction in the growth of plaice between periods with different stock sizes has been attributed to density-dependent regulation; for example the increase in abundance resulting from the cessation of fishing activity during the Second World War probably regulated growth [15]. In Tokyo Bay, we found a significant difference in the population density of marbled sole between the 1970s−1980s and the 2000s (Fig. 6). Growth increased in the 2000s, when the population density had decreased compared with the 1970s−1980s. Therefore, the decrease in population density might be one possible explanation for the increase in the growth rate of marbled sole in Tokyo Bay in the 2000s. Tanda et al. [16] also suggested that the decrease of population density might be one of possible explanations for the increase in the growth rate of marbled sole in Harima Nada and Osaka Bay.

In the present study, we have shown that there were changes in the growth of marbled sole with change of water temperature and population density in Tokyo Bay between the late 1970s−1980s and the 2000s. However, complex or interactive response to various factors, including food availability and sexual maturation which were not investigated in the present study, might have caused the observed changes in growth. Therefore, further studies are needed on the effects of biological, environmental and anthropogenic factors on growth—for example, changes in the allocation of energy between somatic growth and reproduction, changes in age at sexual maturity, or possible changes in metabolic rate induced by hypoxic stress—to elucidate the causes of changes in growth of marbled sole in Tokyo Bay.

Acknowledgments

The authors thank the commercial fishermen of Yokosuka, Shiba, and Koitogawa for their help in sample collection.

References

1. Sakamoto K (1984) Pleuronectidae righteye flounders. In: Masuda H, Amoaoka K, Araga C, Ueno T, Yoshino T (eds) The Fishes of the Japanese Archipelago. Tokai University Press, Tokyo (in Japanese)

2. Kodama K, Aoki I, Shimizu M, Taniuchi T (2002) Long-term changes in the assemblage of demersal fishes and invertebrates in relation to environmental variations in Tokyo Bay, Japan. Fish Manage Ecol 9:303−313

3. Kume G, Horiguchi T, Goto A, Shiraishi H, Shibata Y, Morita M, Shimizu M (2006) Seasonal distribution, age, growth, and reproductive biology of marbled sole *Pleuronectes yokohamae* in Tokyo bay, Japan. Fish Sci 72:289–298

4. Masaki Y, Ito H, Kamijyo H, Yokomatsu Y, Ogawa H, Yamaguchi Y, Yokomatsu Y (1987) Sexual maturity and spawning season of Japanese flounder in Suō-Nada. Nippon Suisan Gakkaishi 53:1181–1190 (in Japanese with English abstract)

5. Solomon G, Sano M, Shimizu M, Nose Y (1987) Age and growth of the pleuronectid flounder *Limanda yokohamae* in Tokyo Bay, Japan. Nippon Suisan Gakkaishi 53:711–716

6. Park JS (1988) A study on the pleuronectid flounder *Limanda yokohamae* population in Tokyo Bay. PhD Dissertation, University of Tokyo, Tokyo (in Japanese)

7. Lee JH, Kodama K, Kume G, Oyama M, Katayama S, Takao Y, Horiguchi T (2009) Comparison

between surface-reading and cross-section methods using sagittal otolith for age determination of the marbled sole *Pseudopleuronectes yokohamae.* Fish Sci 75: 379–385

8. Tokai T (1997) Maximum likelihood parameter estimates of a mesh selectivity logistic model through Solver on MS-Excel. Bull Jpn Soc Fish Oceanogr 61:288–298 (in Japanese with English abstract)

9. Gorie S (2001) Estimation of the parameters in von Bertalanffy's growth formula by MS-Excel. Suisanzoshoku 49:519–527 (in Japanese with English abstract)

10. Akamine T (2004) Statistical test and model selection of fish growth formula. Bull Jpn Soc Fish Oceanogr 68:44–51 (in Japanese with English abstract)

11. Kitagawa D, Ishito Y, Sakurai Y, Fukunaga T (1994) Age, growth and maturation of the Japanese flounder *Paralichthys olivaceus* in coastal waters of the northern Sanriku district. Bull Tohoku Natl Fish Res Inst 56:69–76 (in Japanese with English abstract)

12. Takahashi T, Hayakawa Y, Kamiharako T, Nakatami T, Takatsu T (1995) Age and growth of brown sole *Pleuronectes herzensteini* in the coastal waters of western Aomori Prefecture, Japan. Fish Sci 61:893–897

13. Fonds M, Cronie R, Vethaak AD, van der Puyl P (1992) Metabolism, food consumption and growth of plaice (*Pleuronectes platessa*) and flounder (*Platichthys flesus*) in relation to fish size and temperature. Neth J Sea Res 29:127–143

14. Takahashi T, Tominaga O, Maeda T (1987) Effects of water temperature on feeding and survival

righteye flounders *Limanda herzensteini* and *Limanda yokohamae*. Nippon Suisan Gakkaishi 53:1905–1911 (in Japanese with English abstract)

15. Rijnsdorp AD, van Leeuwen PI (1992) Density-dependent and independent changes in somatic growth of female North Sea plaice *Pleuronectes platessa* between 1930 and 1985 as revealed by back-calculation of otoliths. Mar Ecol Prog Ser 88:19–32

16. Tanda M, Gorie S, Nakamura Y, Okamoto S (2008) Age and growth of marbled sole *Pleuronectes yokohamae* in Harima Nada and Osaka Bay, the Seto Inland Sea, Japan. Nippon Suisan Gakkaishi 74:1–7 (in Japanese with English abstract)

Figure legends

Fig. 1 Annual catch of *Pseudopleuronectes yokohamae* in Tokyo Bay, Japan, between 1986 and 2007. Data from the Shiba Branch, Yokohama City Fisheries Cooperative Association

Fig. 2 Locations of 20 bottom-trawl survey stations (black circles) and 3 commercial fishing ports (black triangles) in Tokyo Bay, Japan. White squares show the locations of the bottom water temperature observations

Fig. 3 The von Bertalanffy growth curves for *Pseudopleuronectes yokohamae* males (a) and females (b) in Tokyo Bay, Japan, during periods of high stock size (1973−1983 and 1986−1988) and low stock size (2003–2008). The symbols indicate the mean back-calculated standard lengths during the study periods

Fig. 4 Annual mean bottom water temperature in Tokyo Bay, Japan, between 1979 and 2003. Open circles and vertical lines denote means and standard deviations, respectively. The linear regression trend line for temperature (y) vs. year (x) is also shown (solid line)

Fig. 5 Monthly bottom water temperatures in Tokyo Bay, Japan, from 1979 to 2003

Fig. 6 Population density index (CPUE; catch-per-unit-effort) for *Pseudopleuronectes yokohamae* in Tokyo Bay, Japan, for 1977−1988 and 2003−2008. Black circles and vertical lines denote means and standard deviations, respectively

Table 1 Mean back-calculated standard length (SL) of *Pseudopleuronectes yokohamae* in Tokyo Bay, Japan, during 1974−1983 and 1986−1988 used to estimate the parameters of the von Bertalanffy growth curve [5, 6]

Estimated age	Mean back-calculated SL (mm)			
	1974−1983		1986−1988	
	Male	Female	Male	Female
1	109.4	119.6	112.2	111.9
2	174.5	187.2	168.4	180.4
3	199.9	233.9	204.8	228.8
4	214.9	261.4	233.9	260.2
5	246.5	286.2		288.2
6		313.6		316.7
7				326.7

Table 2 Mean and standard deviation (SD) for radii of otolith rings at the estimated ages for male and female *Pseudopleuronectes yokohamae* from Tokyo Bay, Japan, in 2002–2004 and 2006–2008

Sex	Estimated age (year)	Sample size	Mean radius of otolith ring (mm)					
			1st	2nd	3rd	4th	5th	6th
Male								
	1	360	1.38 ± 0.28					
	2	174	1.53 ± 0.23	2.22 ± 0.22				
	3	39	1.55 ± 0.20	2.25 ± 0.21	2.60 ± 0.21			
	4	6	1.51 ± 0.19	2.30 ± 0.23	2.66 ± 0.24	2.78 ± 0.11		
	5	1	1.54	2.63	2.80	2.77	2.82	
	Mean ± SD		1.44 ± 0.27	2.22 ± 0.23	2.61 ± 0.21	2.78 ± 0.10	2.82	
	Mean back-calculated SL ± SD (mm)		120.9 ± 26.4	200.1 ± 24.0	241.0 ± 22.8	258.8 ± 10.6	263.3	
Female								
	1	422	1.46 ± 0.31					
	2	220	1.55 ± 0.23	2.33 ± 0.31				
	3	45	1.51 ± 0.24	2.34 ± 0.25	2.75 ± 0.40			
	4	5	1.46 ± 0.29	2.48 ± 0.11	2.74 ± 0.27	3.10 ± 0.31		
	5	3	1.50 ± 0.38	2.30 ± 0.14	2.82 ± 0.14	3.22 ± 0.20	3.31 ± 0.26	
	6	1	1.31	2.21	2.92	3.18	3.29	3.67
	Mean ± SD		1.49 ± 0.29	2.33 ± 0.29	2.76 ± 0.37	3.15 ± 0.26	3.31 ± 0.26	3.67
	Mean back-calculated SL ± SD (mm)		126.0 ± 29.9	217.9 ± 33.5	267.7 ± 43.1	315.3 ± 31.6	334.3 ± 32.1	379.6

Table 3 Results of *F*-test for differences in the von Bertalanffy growth curves of *Pseudopleuronectes yokohamae* in Tokyo Bay, Japan, between the study periods

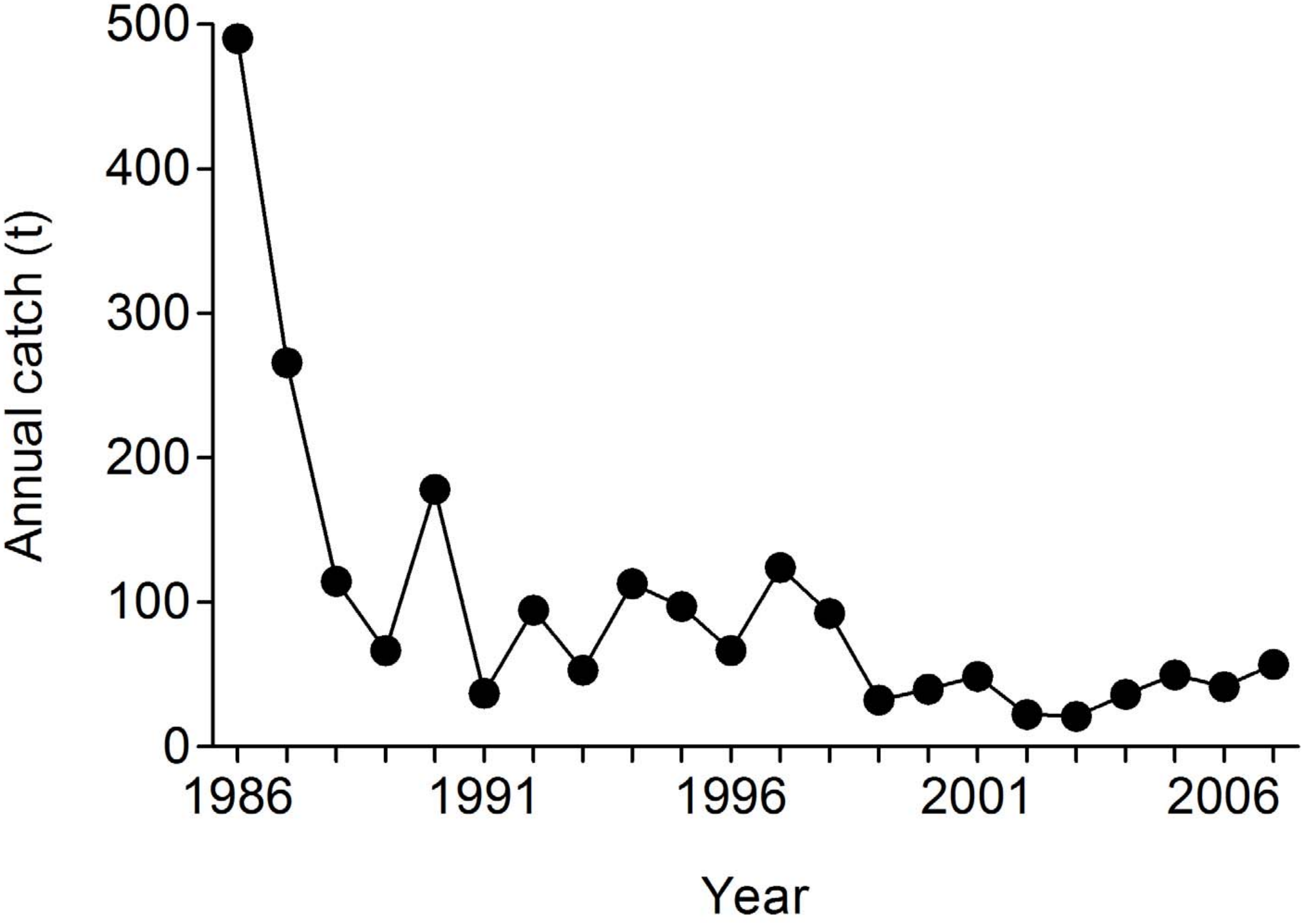
		Male		Female	
Year		1986–1988	2000s	1986–1988	2000s
1974–1983	*df*	3, 3	3, 3	3, 7	3, 6
	F	0.02	12.64*	2.66	28.89**
1986–1988	*df*		3, 3		3, 7
	F		127.78**		42.65**

df, degrees of freedom

*$P < 0.05$

**$P < 0.01$

Fig. 1



500
400
300
200
100
0
Annual catch (t)
1986
1991
1996
2001
2006
Year

Fig. 2

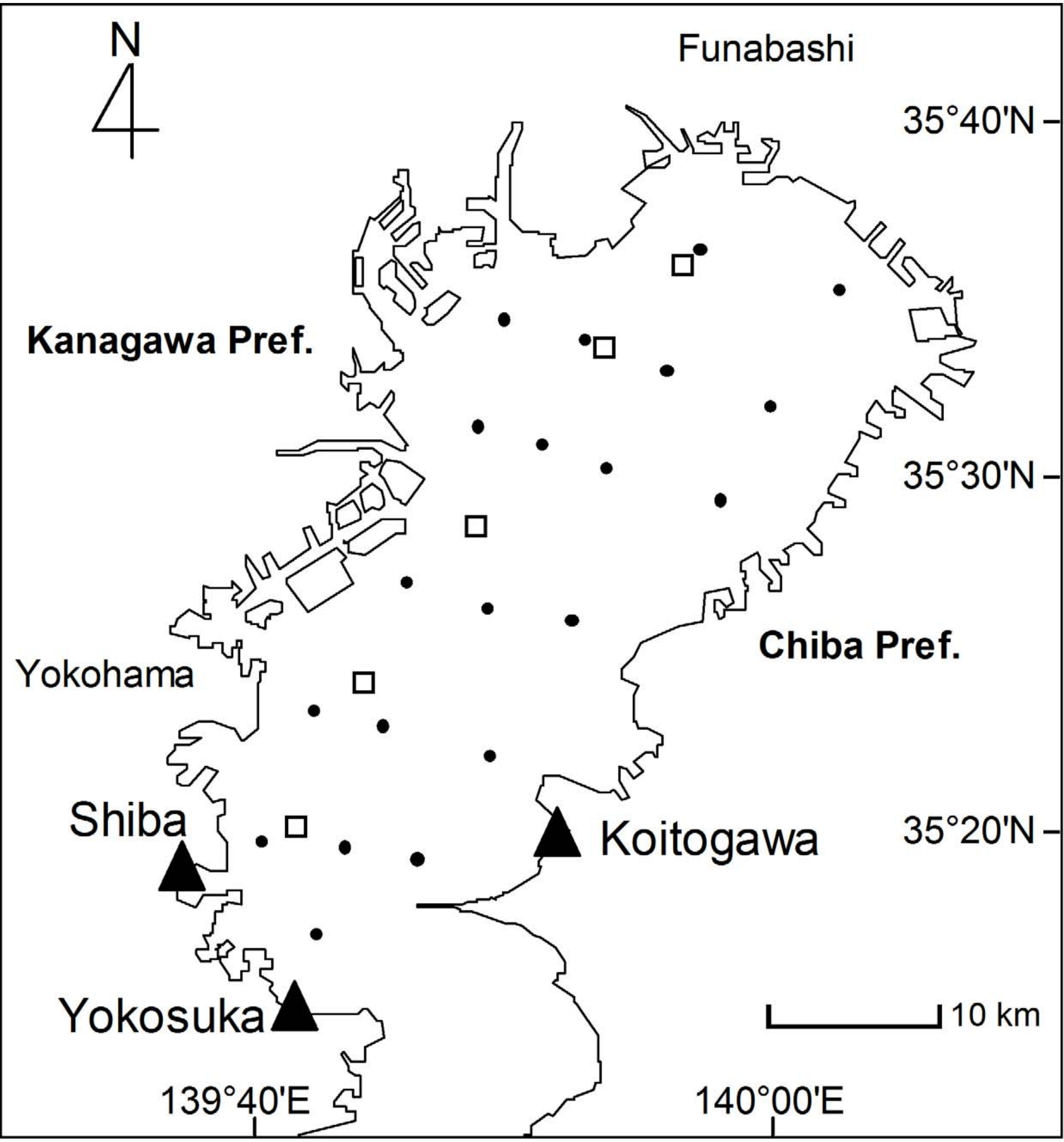

N
Funabashi
35°40'N
Kanagawa Pref.
35°30'N
Chiba Pref.
Yokohama
Shiba
35°20'N
Koitogawa
Yokosuka
10 km
139°40'E
140°00'E

Fig. 3

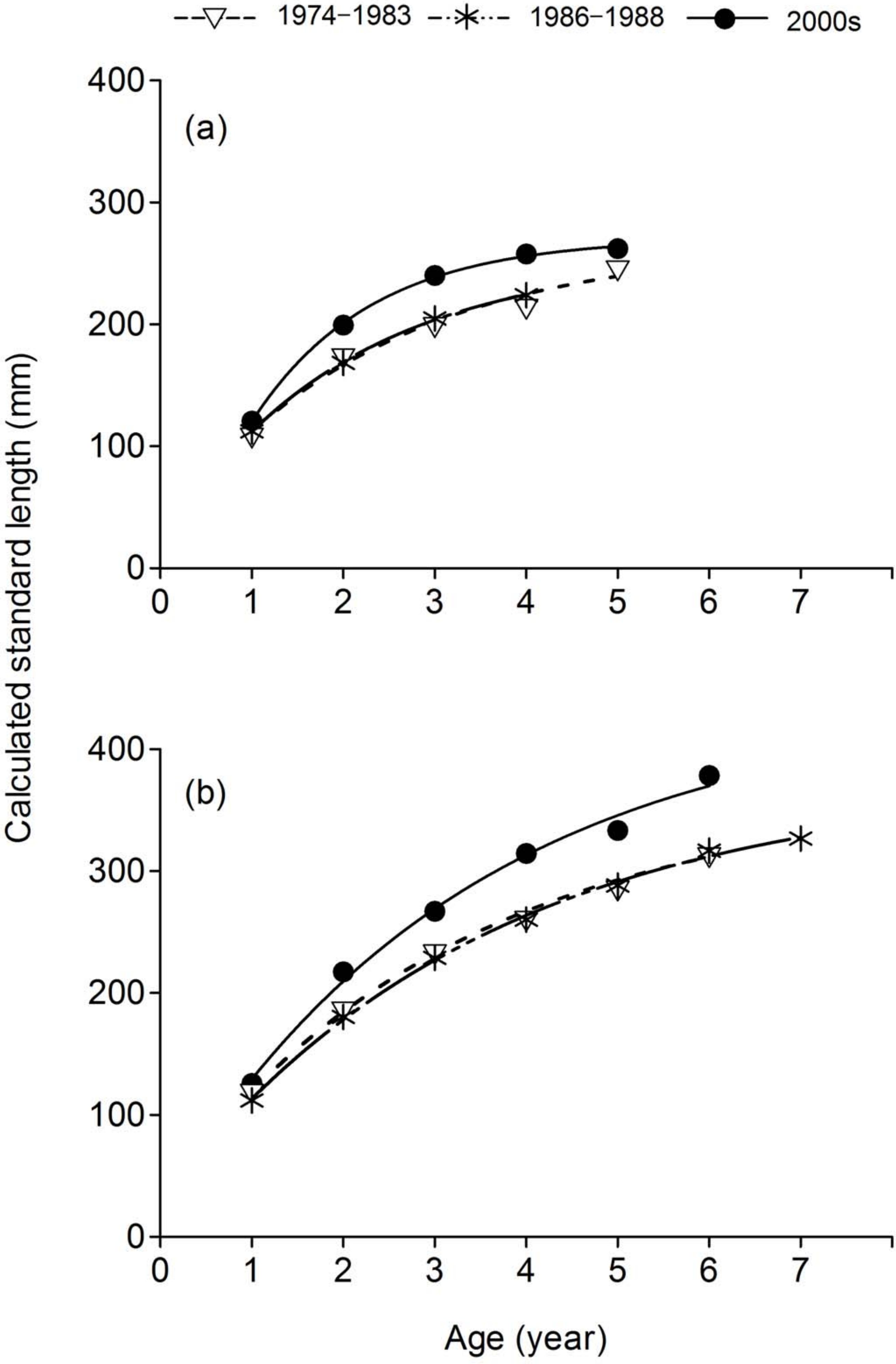
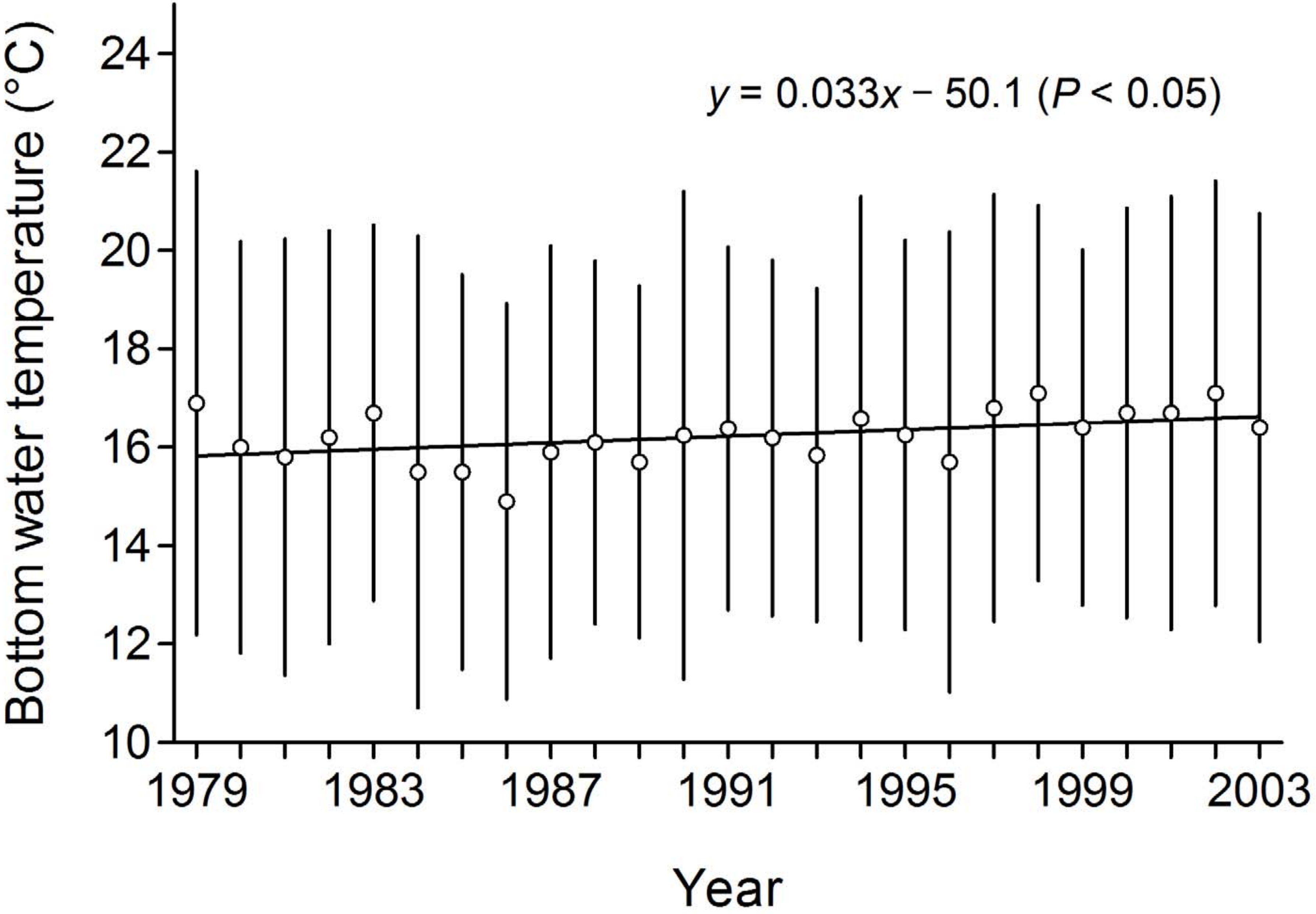

1974–1983
1986–1988
2000s
(a)
(b)
Calculated standard length (mm)
Age (year)
0
100
200
300
400
0
1
2
3
4
5
6
7

Fig. 4



Bottom water temperature (°C)
24
22
20
18
16
14
12
10
$y = 0.033x - 50.1$ ($P < 0.05$)
1979
1983
1987
1991
1995
1999
2003
Year

Fig. 5

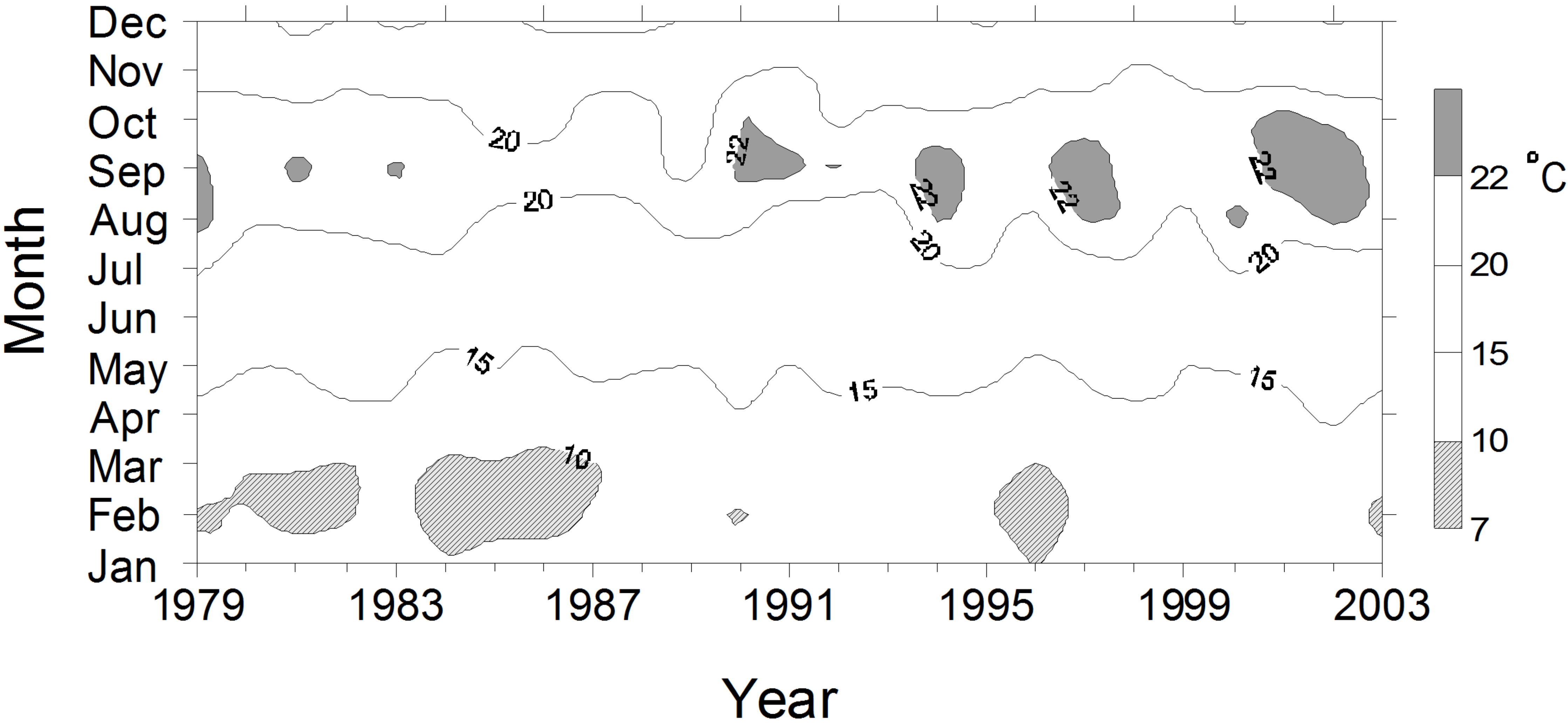
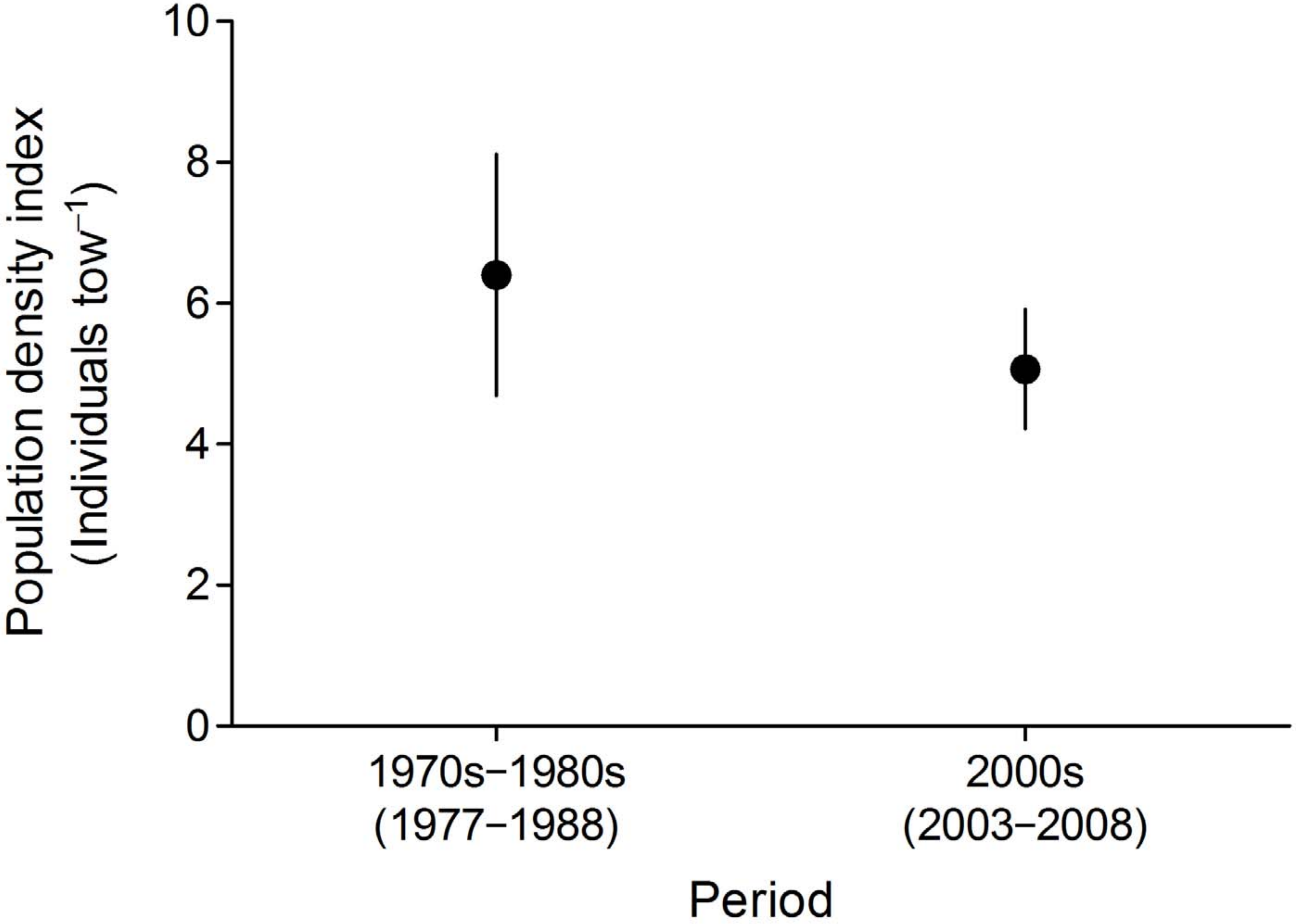

Dec
Nov
Oct
Sep
Aug
Jul
Jun
May
Apr
Mar
Feb
Jan
Month
1979
1983
1987
1991
1995
1999
2003
Year
20
20
22
22
22
22
20
20
15
15
15
10
22
20
15
10
7
°C

Fig. 6


Population density index
(Individuals tow^{-1})
10
8
6
4
2
0
1970s–1980s
(1977–1988)
2000s
(2003–2008)
Period