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The influence of climate changes and sockeye escapement on state of ecosystem in the Kuril Lake (South Kamchatka).

by
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ABSTRACT

In 1980-2000 in the Kuril Lake rise of the air temperature and quantity of precipitation was observed along with fall of the water temperature and high fish productivity of the lake. Productivity of forage zooplankton was not limited by the trophic factor but was dependent on the water temperature which determined biomass growth rate. And, through predation, it was dependent on the abundance of feeding sockeye salmon. During periods of high sockeye salmon abundance in the Kuril Lake (a reservoir with limited feeding capacity) when the water temperature decreases the level of forage base also sharply decreases and does not meet food requirements of juvenile. Decrease in food supply for sockeye salmon juvenile caused decrease in smolt weight.

INTRODUCTION

The Kuril Lake is located in southern Kamchatka and drains into the Ozernaya River. The Kuril Lake is the hatchery and nursery area for the largest Asian stock of sockeye salmon (*Oncorhynchus nerka*) within Ozernaya River watershed. The lake has a surface area of 77.1 km^2 and a volume of 14.6 km^3 (Resursy…, 1966). The maximum and mean depths are 316 and 180 m, respectively, and mean water residence time is 17.4 years. The littoral is poorly developed. The Kuril Lake is basically an oligotrophic lake, but in some years it demonstrates mesotrophic features. Phytoplankton in the Kuril Lake is dominated by diatoms (mainly *Aulacoseira, Stephanodiscus, Cyclotella*, and *Synedra* (Lepskaya, in press). *Aulacoseira subarctica* is the major phytoplankton species and the basic food source for zooplankton. Zooplankton in the Kuril Lake comprises two copepods (*Cyclops scutifer* and *Megacyclops gigas*), two cladocerans (*Daphnia longiremis* and *Bosmina longirostris*), and eleven Rotifer species. *C. scutifer* and *D. longiremis* are main prey for sockeye salmon fry in the Kuril Lake. Sockeye salmon juvenile stay in the lake for feeding for the period of 1-3 years. The majority of smolts is of 2+ age. The lake was fertilized in 1981, 1982, 1985, 1987, and 1989 in attempt to increase the zooplankton forage base and ultimately to benefit sockeye fry rearing.

The range of changes in some parameters of the ecosystem in 1980-2000 is shown in table 1.

Table 1. The range of changes in some parameters of the Kurile Lake ecosystem in 1980-2000

Variable	Range in 1980-2000	Mean annual	n (years)
Average annual air temperature, °C	0.7-3.3	1.5	57
Average annual water temperature in the lake at depth 0-100 m, °C	2.1-4.2	3.3	57
Degree days with average water temperature at a depth 0-100 m that is 4°C or greater (Period of active sockeye fry growth), °C-day	259-1199	692	50
Average annual precipitation, mm	604-1150	797	57
Average annual contribution of phosphorus released from sockeye carcasses and chemical fertilizers, tons	1.7-22.4	5.43	57
Average annual biomass of *A. subarctica*, mg C/m^3	0.28-33485		
Average annual crustacean biomass, mg/m^3	19-242	115	51
Average annual crustacean production, mg/m^3	298-1783	921	51
Smolt weight 2+, g	3.5-10.7	7.6	57
Escapement, millions	0.26-6.0	1.46	61

The aim of this work is to analyze the influence of climate changes and sockeye salmon escapement on state of ecosystem in the Kuril Lake during periods of high abundance of Ozernaya sockeye salmon.

The author would like to acknowledge the colleagues: V.A. Dubynin, senior scientist, for permanent cooperation, Y.V. Lepskaya, scientist, who assisted with materials on bacteria plankton, A.V. Maslov, chief of the KamchatNIRO station on the Kuril Lake, who assisted with collection of samples, and V.I. Karpenko, who inspired the author to write this work.

Materials and Methods

Materials

The database of the KamchatNIRO Laboratory "Monitoring of Lake Ecosystems" was used in this study (data on meteorology, hydrology, bacterioplankton, phytoplankton, zooplankton, physiological condition and weight of smolts, escapement) (Table 2).

Table 2. Periods of Sampling

Parameters	Years	Periods of Sampling
Air temperature	1980-2000	daily
Quantity of precipitation	' – '	' – '
Water level in the Ozernaya river	' – '	' – '
Vertical profiles of the water temperature in the layer 0-100 m	1980-2000	1-2 times a month, except during periods of ice-formation and ice breaking
Bacterioplankton *****	1980-2000	Annually from May to October.
Phytoplankton (net sampling)	1980-2000	1-2 times a month, except during periods of ice-formation and ice breaking
Zooplankton (net sampling)	1980-2000	' – '
Spawning escapement and weight of spawners******	1965-2000	annually
Smolt weight ******	' – '	' – '
Gonads of sockeye smolt females *******	1968-1999	annually, except in 1969-1975, 1978, 1989-1995 ??.

NOTES:

In order to calculate annual mean values the following data have been used: quantity of precipitation – since 1941, water temperature in the layer 0-100 m and amount of degree-days and water level – since 1942, air temperature– since 1942, escapement – since 1940, smolt weight – since 1943, crustacean biomass – since 1950 year.

***** – data by Y.V. Lepskaya

******– data by V.A. Dubynin

*******– data by M.Y. Ievleva, S. B.Gorodovskaya and T.I. Tolstiak.

Methods

Data of standard daily hydrometeo observations (air temperature, level, quantity of precipitation) obtained from the KamchatNIRO station (located on the Kuril Lake) were calculated for ten-day and monthly periods. Annual values were calculated on the basis of mean monthly values.

Recording of vertical profiles of the water temperature and hydrobiological sampling took place at the standard station in the pelagial of the central part of the lake (1950-2000). In the 80s the above mentioned recording and sampling were carried out in the west-east horizontal section, and totally 6 stations participated (the central station inclusive). Comparative analysis of the data obtained on the line and at the central station showed that the results were identical. Therefore further observations took place only at the central station. Calculations of mean temperature for the layer 0-100 m (the most dynamic layer in the lake) were based on the records of vertical profiles of water temperature in the lake (obtained with thermozond).

The total amount of degree-days was calculated for the period when the mean temperature of the layer 0-100 m was 4°C and above.

Contents of phosphorus (P_2O_5) in sockeye carcasses was calculated as 0.28 % of the biomass of spawners (Kizevetter,1948), and then pure phosphorus was calculated. Total contribution of phosphorus was calculated as total annual contribution of phosphorus released from sockeye spawners and fertilizers (in the years of fertilization of the lake) for 16 previous years (this indirectly shows accumulative effect) which showed the best approximation of the results when compared to dynamics of *A. subarctica* biomass (Milovskaya 2000).

Sampling of zooplankton and net phytoplankton was carried out the whole year round with Juday net (diameter of the input hole was 11.2 cm, mesh #68) by total catching at the central station in the layer 0-200 m 1-2 times a month depending on the season. Calculation of abundance of net phytoplankton was based on total counting of a 1 ml sample in the Nauman chamber and further calculation for the volume of the catch layer. The amount of phytoplancton carbon was calculated on the basis of the cell volume and coefficient of organic carbon calculation, equal to 0.1 (Vinberg,1971).

Zooplankton samples were analyzed under the standard method: species composition was specified. In crustacean the abundance in age groups, fecundity and biomass were calculated. Rotifer were identified by Kutikova's (1970) and Laxhuber's (1987) methods. Calculation of the cyclop and daphnia biomass (basic forage species for sockeye salmon juvenile in the Kuril Lake) was based on the weight in individual age stages identified by I.A.Nosova for C. scutifer, the Kuril Lake (1970) and by I.I. Kurenkov for D. longiremis (1971).

Products of crustacean were calculated by the modified G.G. Vinberg's formula (Methods… 1968), temperature in the habitation area of the population was taken into consideration (mean temperature in the layer 0-100 m for cyclop copepodite stages I-III and mean temperature in the layer 0-200 m for daphnia and other age stages of cyclops). Periods of development and weight growth in crustacean in correlation with temperature were taken from works by I.I. Kurenkov (1971, 1975). Graphics were based on these data, and intermediate values were taken from them.

Eliminated biomass (B_{elim}) was calculated by summing up biomass (B) and production (P), for the previous year, and subtraction of the current year biomass. For example, $B_{elim\ 1980} = B_{1980} + P_{1980} - B_{1981}$.

Conditional juvenile food supply (CFS) was calculated as quotient from division of eliminated biomass (B_{elim}) for the year of general growth of smolts by the number of spawners ($E_1 + E_2$), whose descendants of 0+ and 1+ a were feeding simultaneously. For example, $CFS = B_{elim} /(E_1 + E_2)$.

The results were analyzed on the basis of mathematical statistics methods (STATISTICA program).

RESULTS

In 1980-2000 precipitation and mean annual air temperature were growing, while mean annual water temperature and the number of degree-days with temperature of 4°C and higher, in the most dynamic layer of the lake, 0-100 m, was gradually decreasing since the second half of the 80s until late 90s (Fig.1).

Different trends in dynamics of air temperature in the area of the lake and of the water temperature in the lake can be explained by the following: increase in the mean annual air temperature in mild winters followed by abcent of ice-formation. Mean annual water temperature in the most dynamic layer 0-100 m decreases due to wind cooling in the winter which is not compensated by summer warming up.

In the 80s enthalpy of the lake waters in general was higher than annual mean average. But in the 90s the water temperature decreased as well as the amount of degree-days with the temperature of 4° C and above which accompany higher productivity of forage zooplankton, and this caused slowing down of the development and decrease in the growth rate of crustacean biomass.

For the first trophic level in the Kuril Lake the major limitation biogen is phosphorus. In the 80s -90s increase in precipitation caused increase of phosphorus inflow. It was impossible to calculate total phosphorus inflow with surface and ground waters for each year as actual data on surface and ground water inflow and on phosphorus contents were not available. And this problem was solved by the indirect way. As variation in amount of precipitation causes variation in the inflow the amount of precipitation was used for the analyses. In the 80s the contribution of phosphorus released from fertilizers was gradually decreasing while that of carcass phosphorus was growing. In the 90s the inflow of carcass phosphorus was gradually decreasing (Fig. 2) and the inflow of phosphorus contributed by precipitation was growing (Fig. 1).

Preliminary analysis showed the correlation of biomass *A. subarctica* with contribution of carcass phosphorus in the previous year ($r=0.585$; $p<0.05$) and with the amount of precipitation of the current year ($r=0.528$; $p<0.01$). But if there is a correlation between phosphorus inflow and biomass *A. subarctica*, why then biomass of this diatom was maximum when the escapement was going down?

The thing is that the Kuril Lake has low water residence, and this is what distinguishes this lake from other hatchery and nursery lakes of Kamchatka. With this low water residence only 1/17 of the water volume can annually be replaced. It means that phosphorus contributed into the lake during the previous 16 years continues to circulate in the ecosystem.

To assess the accumulative effect regression equations were computed for biomass *A. subarctica* and total contribution of phosphorus for 2, 3, 4 etc. years, until total contribution for 16 years has been determined. The same was done in respect of precipitation. It was found out that the strongest correlation exists between biomass of this diatom and total contribution of phosphorus, starting from the total amount for 8 previous years ($r=0.800$) up to the total amount for 16 years ($r=0.812$). No such strong correlation was found for precipitation, which means there was no accumulative effect. Inflow of phosphorus with surface and ground waters obviously has significant effect on diatom biomass already in the current year. The total pool of phosphorus circulating in the ecosystem was growing from the 80s to the late 90s. (Fig. 3).

Correlation between biomass of A. *subarctica* and annual precipitation and total contribution of carcass phosphorus (including phosphorus released from fertilizers in the 80s) can be described by the following equation (Milovskaya, 2000):

$$Z= -34.177+14.791x+99.101y-6.846x^2 +38.792xy-81.763y^2 \ (r=0.812;\ p<0.05)$$

where X – total contribution of phosphorus for the previous 16 years, tons; Y – precipitation of the current year, mm; Z – natural logarithm of *A. subarctica* biomass calculated for carbon.

Due to the decrease of the water temperature phytoplankton in the lake is actually represented by the monoculture of diatom A. subarctica. A. subarctica biomass was adequate to the total phosphorous pool. The trophic factor has not been a limitation factor for pelagic crustacean since mid-80s.

Biomass of bacterioplankton is dependent on contribution of organic substance inflowing with sockeye spawners and on phytoplankton biomass after destruction. In the first half of the 90s contents of organic substance in the lake passed the lower limit of mesotrophic level, but in the second half of the 90s oligotrophic status of the lake recovered. The abundance of rotifers was regulated by bacterioplankton biomass (Fig. 4).

Increase in contents of organic substance caused growth of abundance of rotifers who are not a prey to sockeye juvenile. Due to the decrease in the water temperature (which is responsible for the growth rate) and the growing pressure caused by sockeye salmon juvenile the abundance of crustacean in the lake began to decrease. This caused changes in the zooplankton community.

If in the early 80s the community could be described as copepod-rotifers**,** from mid-80s through the present the community can be described as rotifer-copepods**.** It was lowering of water temperature and growth of abundance of feeding sockeye salmon juvenile that caused decrease of abundance of species whose development cycle is longer, cyclops first of all (Fig. 5).

The forage base level depends on crustacean production, which is determined by the water temperature and elimination, which depends on the abundance of feeding juvenile (Fig. 6).

In the first half of the 80s production exceeded elimination, and the biomass was growing. In the late 80s due to the highest water temperature the peak of abundance in forage zooplankton was observed. However, since the abundance of feeding juvenile had significantly increased elimination exceeded production and the biomass of crustacean started to decrease.

The most unfavorable changes took place in the early 90s. The water temperature began to decrease, and the abundance of feeding juvenile reached its peak which caused the depression of forage base.

In the second half of the 90s the lowest water temperature was observed causing low productivity in forage zooplankton. Though escapement of mature sockeye salmon was rather low, and the abundance of feeding juvenile was also not high, the elimination either exceeded the production or was equal to it. In that period low temperature of the water was the major factor not allowing the forage base to recover.

The growth rate in smolts was determined by food supply and length of the active feeding period calculated by the number of degree-days. In general, the trends in food supply, length of feeding period and growth rate of juvenile in the 80s-90s had descending one-direction pattern. However, in the second half of the 90s food supply somewhat increased due to decreasing of escapement and of feeding juvenile abundance. Though smolt weight kept to remain low since active feeding period became shorter (Fig. 7).

To investigate the conditions influencing the development of sex cells in Ozernaya sockeye smolts the data obtained both in the years of low abundance (second half of the 60s - the 70s) and of high abundance(80s-90s) were used. Unfortunately the period of maximum abundance (the first half of the 90s) was missed, because investigations in this period were cancelled as low informative. However the dynamics of food supply allows to believe that smolts with the highest meiocyte contents and, correspondingly, with minimum proportion of sells of the period of protoplasmatic growth were found in smolts having migrated to sea in 1993 (from 6 mln spawners in 1990) and in 1994. (Fig. 8).

Meiocyte contents has a direct correlation with escapement and water temperature. And it has an inverse correlation with smolt weight (Figure 9). Aggregate influence of escapement, smolt weight and water temperature over meiocyte contents is very strong (r=0.989). It has the character of functional dependence and explains 97.85% of cases (Milovskaya et.al., in press). Proportion and size of cells of the period of protoplasmatic growth depends on meiocyte contents.

High escapement along with low level of forage base cause increase in meiocyte contents and decrease contents of the mostly developed oocytes of the period of protoplasmatic growth along with simultaneous decrease in their diameter. Smolts migrating to sea are small in size and their sex sells are less developed, which most likely, results in the fact that marine period becomes longer, age composition of the stock changes, mortality grows and fecundity decreases.

CONCLUSIONS

1.Warm periods when mean annual air temperature grows under the conditions of the Kuril Lake are accompanied by gradual decreasing of mean annual water temperature because no ice is formed and in the winter the water is cooled by the wind.

2. The major factors affecting fish productivity of the Kuril Lake are the water temperature and sockeye salmon escapement. Phosphorus directly influences the first trophic level and has little influence of the productivity of the second trophic level.

3. Analysis of changes in the ecosystem of the lake during the most dynamic period 1980-2000 allowed to determine the reasons causing disbalance between some parameters of the ecosystem.

4. The first trophic level adequately reacts to growth of the amount of phosphorus circulating in the ecosystem by growth of plankton biomass the main flow of which has been utilized by the detrit way.

5. The proportion of microzooplankton, which is not a prey for fish, was growing along with the growth of organic substance while the proportion of forage zooplankton was decreasing. Productivity of forage zooplankton upon reaching a certain threshold value was no longer limited by the trophic factor and depended on the water temperature, which determines the biomass growth rate, and through predation, it depended on the abundance of the feeding sockeye salmon juvenile.

6. During periods of high abundance of sockeye salmon in the Kuril Lake as ecosystem with limited feeding capacity, especially with decreasing water enthalphy, the level of forage base sharply decreases and does not meet food requirements of sockeye salmon juvenile, and this results in worsening of quality indicators in smolts.

7. Unique conditions of the Kuril Lake do not allow to use fertilization as a method to increase productivity of the lake.

8. Data analysis allows to predict trends of changes in productivity of the lake ecosystem for a rather long term.

9. In order to study the mechanism of formation of the lake fish productivity the major parameters of the ecosystem should be analyzed for the years of low escapement. And, as the data base on oogenesis in smolts of Ozernaya sockeye salmon increases, it is necessary to investigate how the rate of sex cells development influences on duration of the marine period (i.e. formation of age composition) and final fecundity in broods.

10. Analysis of conditions for formation of productivity of Ozernaya sockeye salmon during fresh water period showed that in the second half of the 90s there were no factors which caused high return in 2002. To determine the factors having caused high survival of these broods it is necessary to analyze the changed conditions of the marine period.

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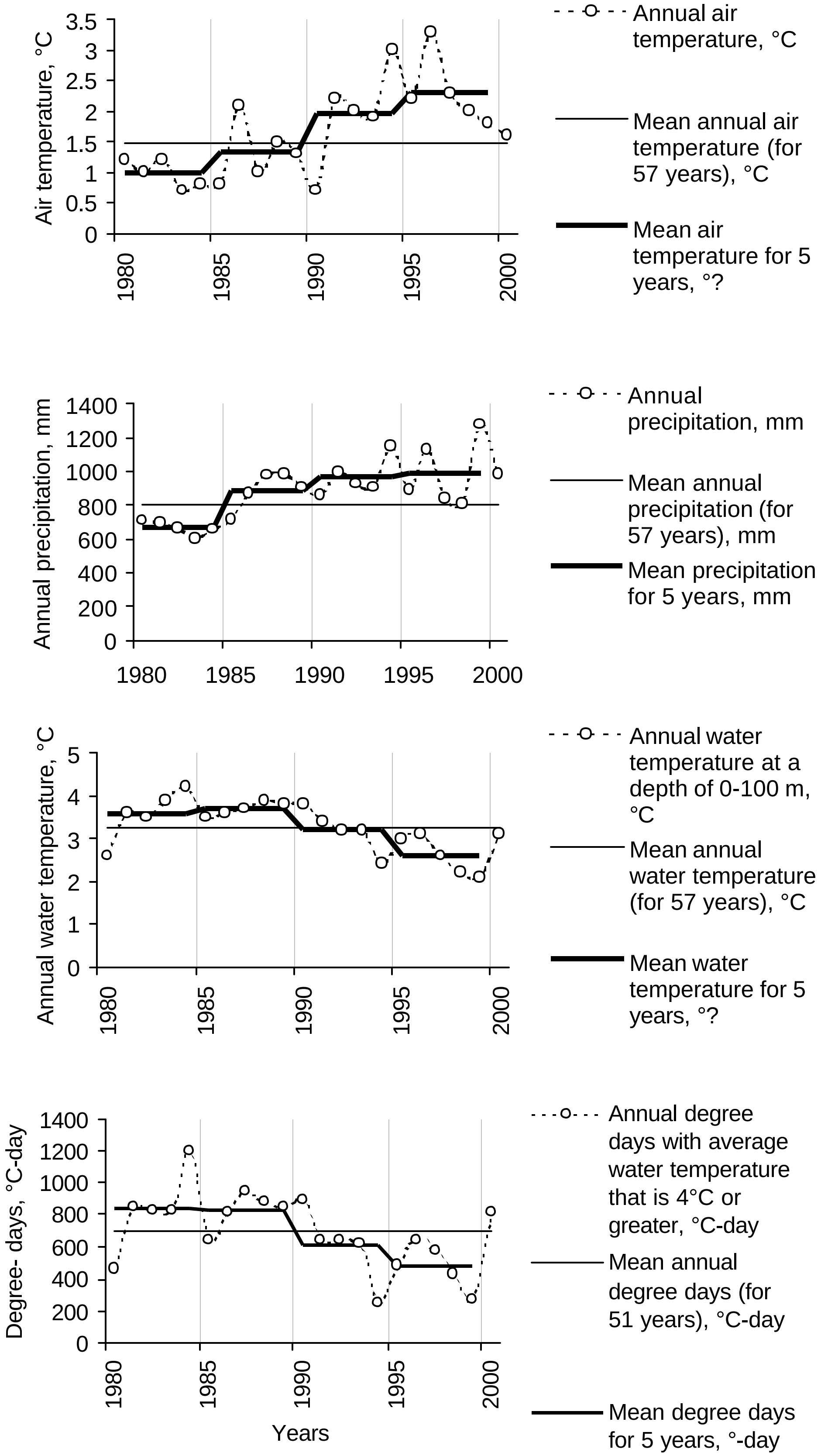

Fig. 1. Annual changes in air temperature, precipitation, water temperature at the depth of 0-100 m, and degree days with average water temperature that is 4° C or greater.

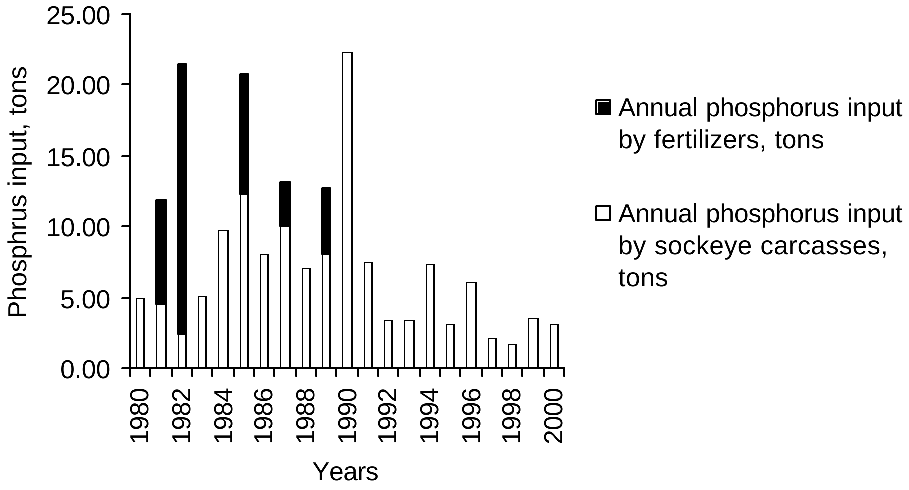

Fig. 2. Annual phosphorus input with sockeye salmon carcasses in 80-90's years.

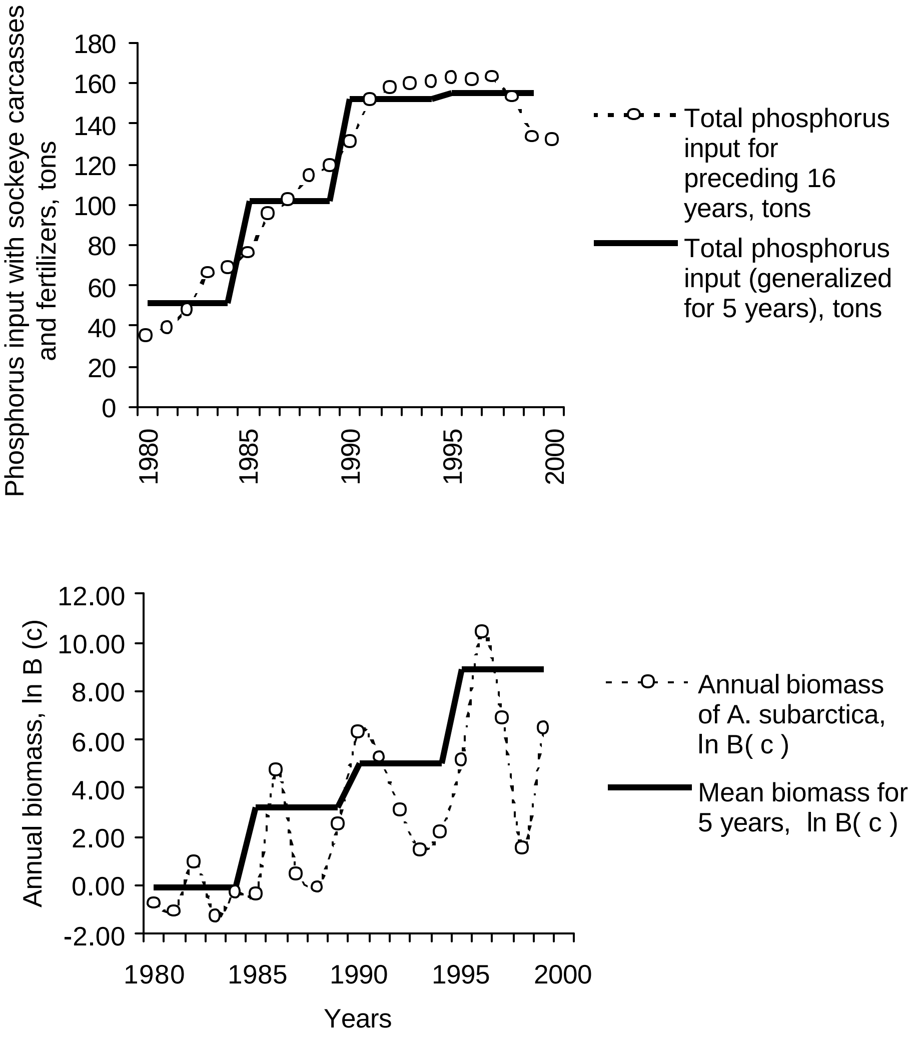

Fig. 3. Changes in biomass A. subarctica and phosphorus accumulation.

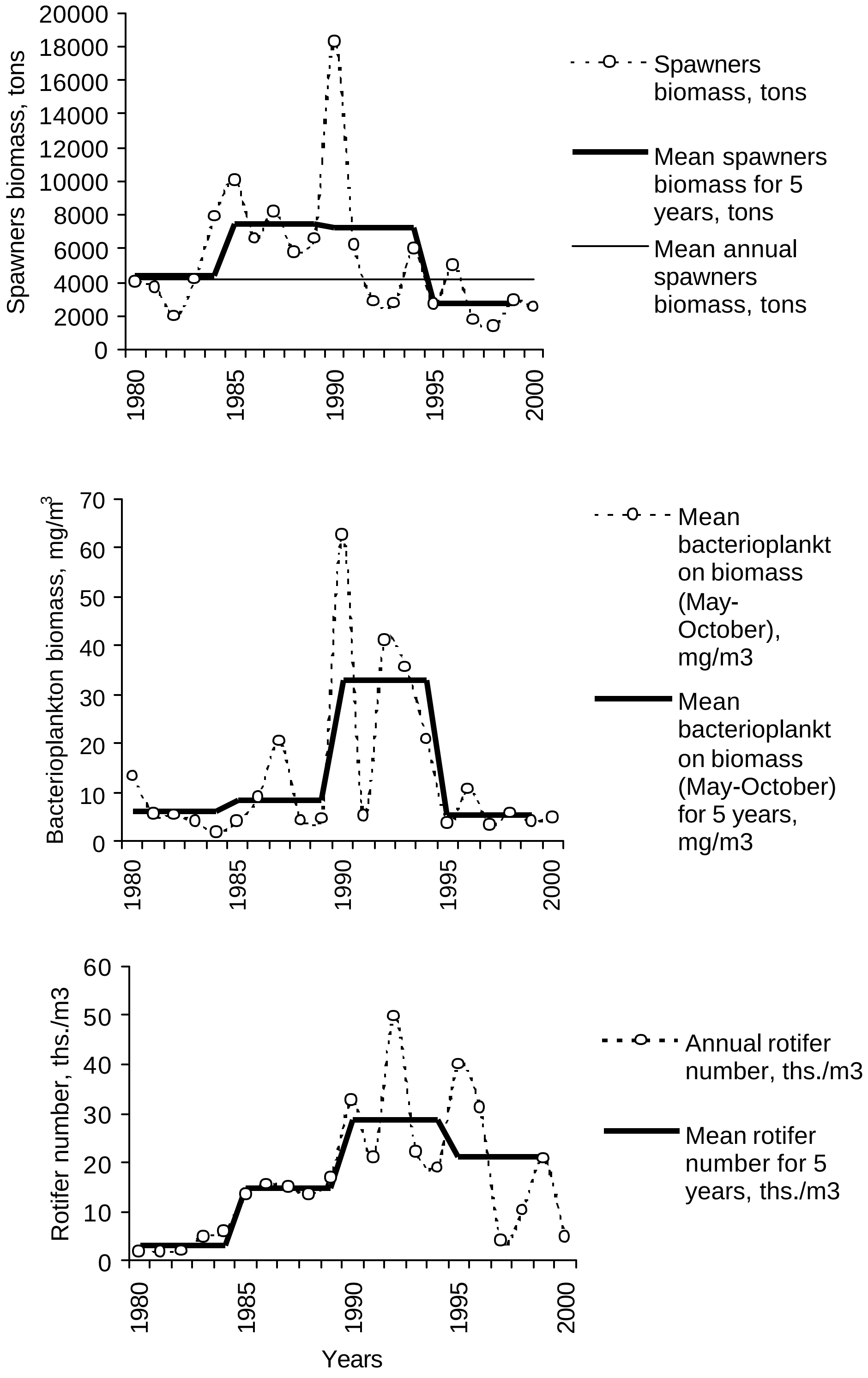

Fig. 4. Annual changes in spawners biomass, bacterioplankton biomass, and rotifer abundance.

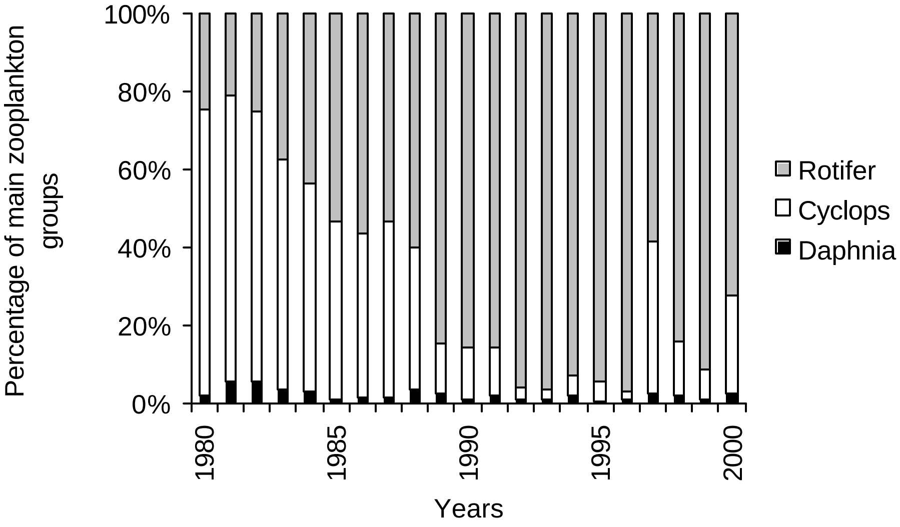

Fig. 5. Annual changes in percentage of abundance of main zooplancton groups.

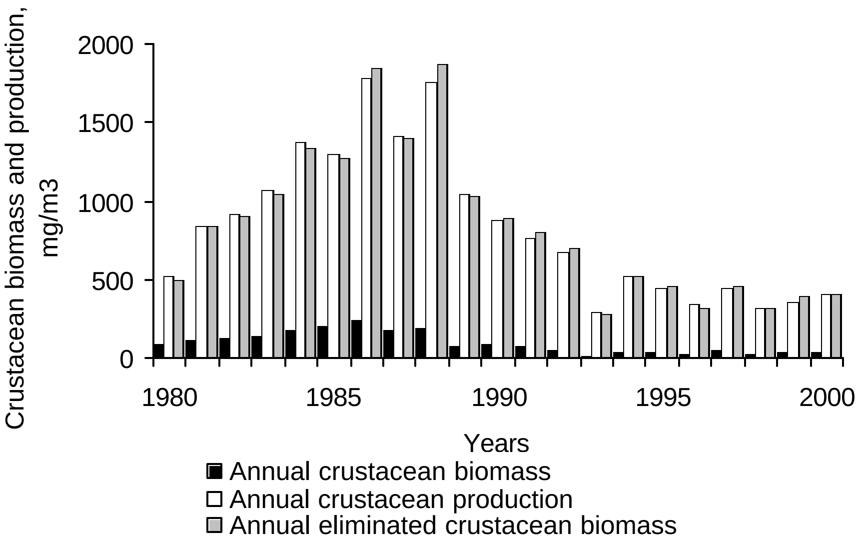

Fig. 6. Annual changes in biomass, production, and eliminated biomass of crustaceans.

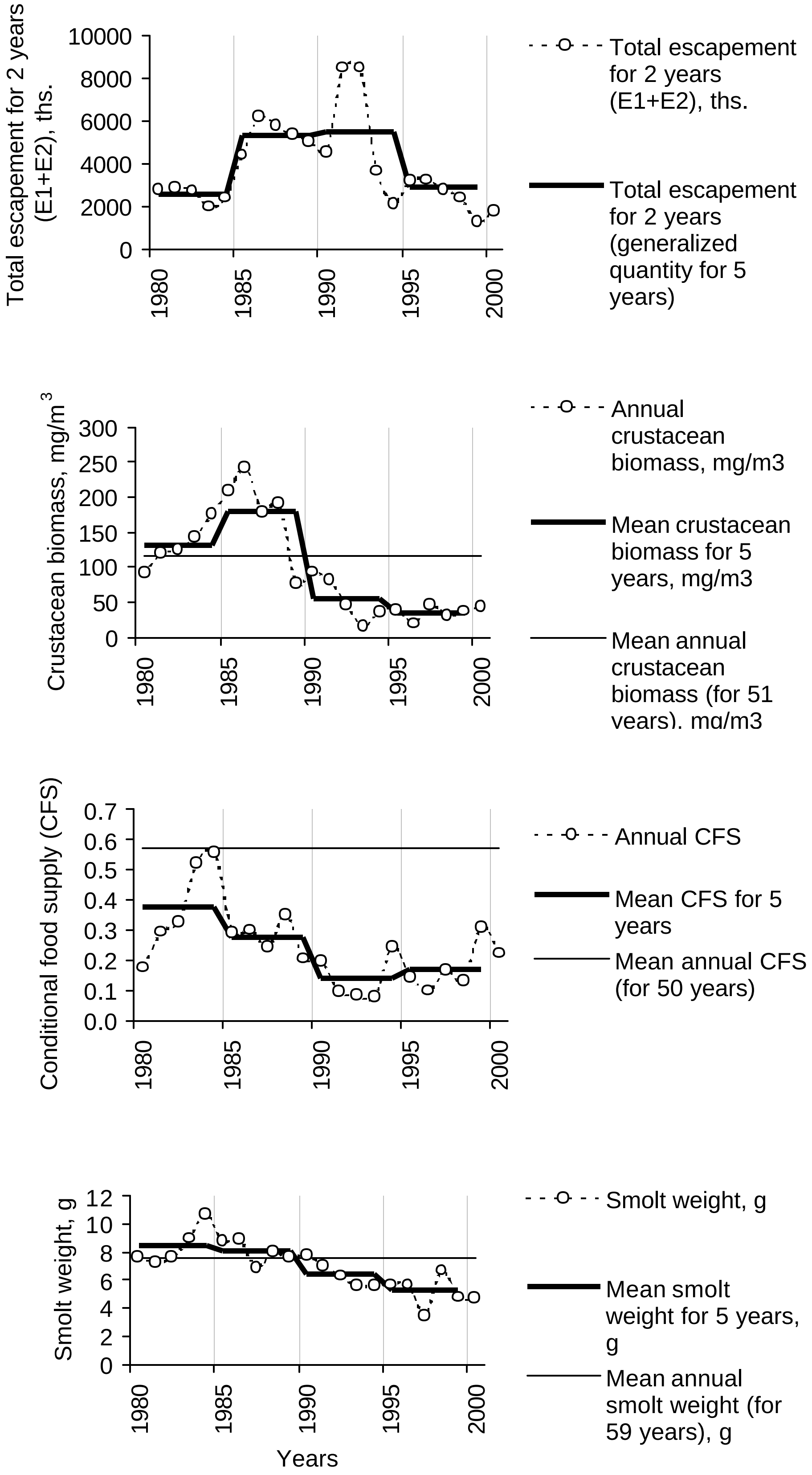

Fig. 7. Annual changes in crustacean biomass, conditional food supply, smolt weight, and sockeye escapement for 2 adjacent years.

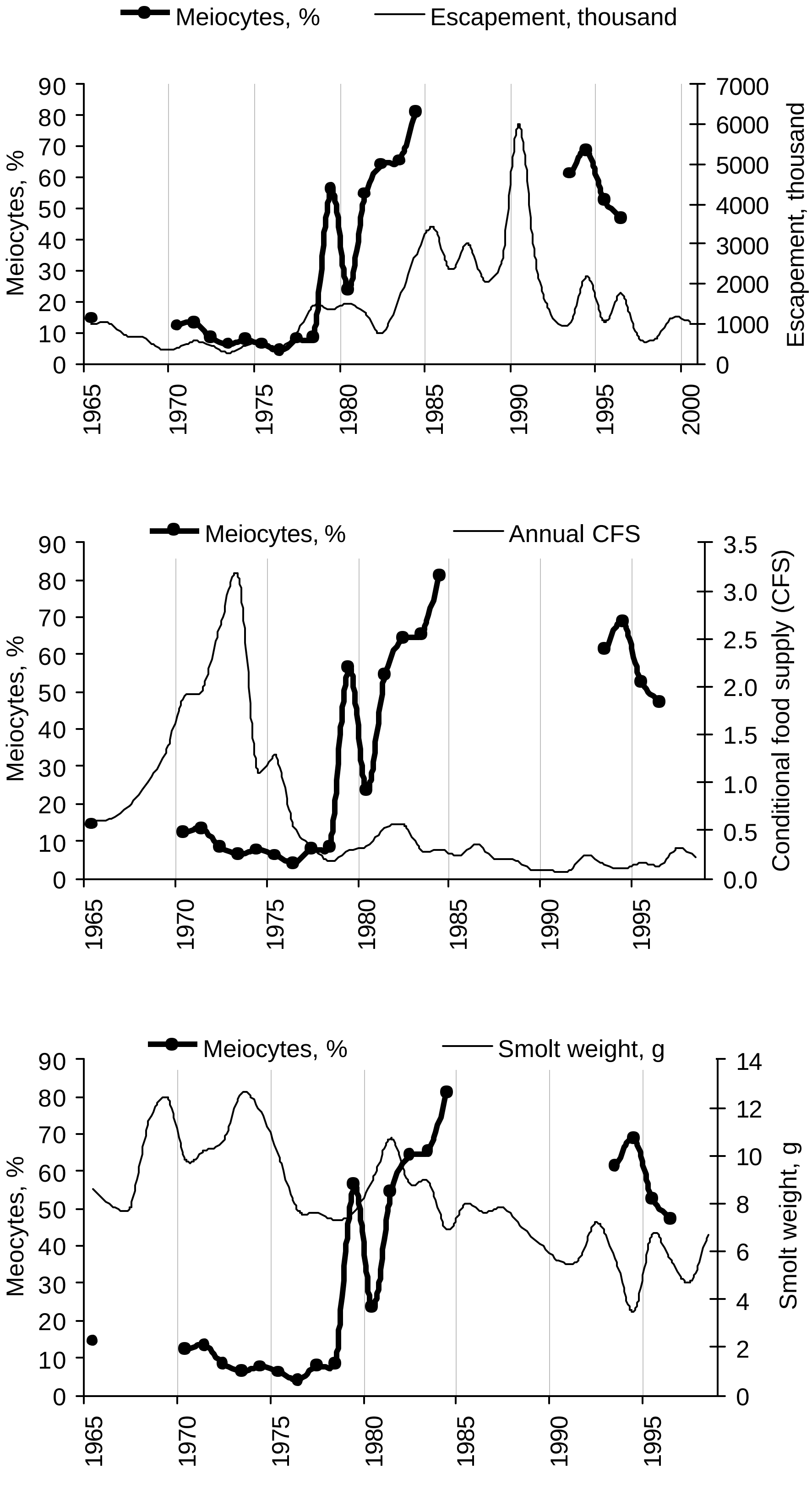

Fig. 8. Annual changes in percentage of meiocytes, sockeye escapement, conditional food supply, and smolt weight.