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CHANGES IN THE GROWTH AND STOCK STRUCTURE OF BALTIC SPRAT (*Sprattus sprattus balticus*) IN THE GULF OF FINLAND IN 1986–97

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Abstract. The abundance of Baltic sprat increased in the Gulf of Finland in 1986–97 due to its low natural mortality and recruitment of abundant year-classes in the 1980s and 1990s. Since 1992, the share of both larger length- and weight-classes has dropped in the Gulf of Finland. The mean length and weight at age of Baltic sprat increased slightly in the late 1980s, but dropped sharply in the 1990s. All these changes in the growth and stock structure of Baltic sprat in the Gulf of Finland are obviously induced by hydrological conditions prevailing in the Gulf of Finland since the mid-1980s. The simultaneous occurrence of slowly growing younger age groups and fast growing older age groups from the 1980s in the stock has caused a decrease in the coefficient *K* for length and an increase in the asymptotic length of sprat in the 1990s. On the basis of growth parameters the Baltic sprat can be regarded as a fast growing fish species in young age groups. Sprat reach nearly 90% of their asymptotic length and weight already in the fourth year of life (at age 3).

Key words: Baltic sprat, growth, stock structure, Gulf of Finland.

INTRODUCTION

Baltic sprat (*Sprattus sprattus balticus* Schn.) is a relatively well investigated fish species in the Baltic Sea. In the Gulf of Finland, systematic studies on Baltic sprat were initiated at the end of the last century (Schneider, 1901; Heinemann, 1905). In the 1970s and 1980s essential population characteristics of the Baltic sprat of the Gulf of Finland, such as age composition and growth parameters, were studied by Veldre (Veldre & Polivajko, 1975; Veldre, 1978, 1986) and Aps (1977, 1980, 1981a, 1981b, 1985, 1986). An increased abundance of Baltic sprat, a decrease in the cod stock, and significant changes in the ecosystems of the Baltic Proper and the Gulf of Finland in the 1980s and 1990s, such as decreased salinity and increased intensity of vertical mixing due to the lack of significant inflows of saline waters into the Baltic Sea, have caused changes in the living, breeding, and feeding conditions of Baltic sprat.

The present paper analyses changes in the stock structure (age, length, and weight structure) and growth parameters of Baltic sprat in the Gulf of Finland in 1986–97 on the basis of commercial pelagic and semipelagic trawl catches.

MATERIAL AND METHODS

A total of 22 090 sprats were collected in 1986–97 from Estonian commercial trawl catches taken in the Gulf of Finland. Sprat samples were taken quarterly more or less evenly (a total of 5459 sprats were collected from the first, 5817 from the second, 4319 from the third, and 6495 from the fourth quarter). Estonian trawlers are using trawls with a 10 mm mesh size codend (bar length). Therefore, no substantial selectivity is observed in the adult fraction of catches and one can assume that the structure of catches represents well the structure of the adult stock. According to selectivity studies only 23.2% of immature (smaller than 10 cm) sprat escape from trawls (Shevtsov, 1982).

The total length and weight of the fish were measured. The age was determined using otoliths according to Aps (1977, 1981a, 1986). The growth of sprat was approximated using the von Bertalanffy growth equation (Ricker, 1979) with Statgraphics software.

RESULTS

Stock structure and growth

The age composition of commercial catches of sprat in the Gulf of Finland was dominated by the 1982, 1984, 1986, 1988, 1989, 1991, and 1994 year-classes in 1986–97 (Table 1). In general, annual commercial catches of sprat in the Gulf of Finland were dominated by one or two age groups, mainly ages from 1 to 4.

The length and weight structure of Baltic sprat have changed in the Gulf of Finland since 1992. That change became particularly evident after the recruitment of 1994 year-class into the commercial stock. The share of both larger length- and weight-classes has dropped (Fig. 1). This is caused by slower growth of year-classes dominating these years. Dominance of considerably smaller length- and weight-classes of sprat in the Gulf of Finland in 1995 was

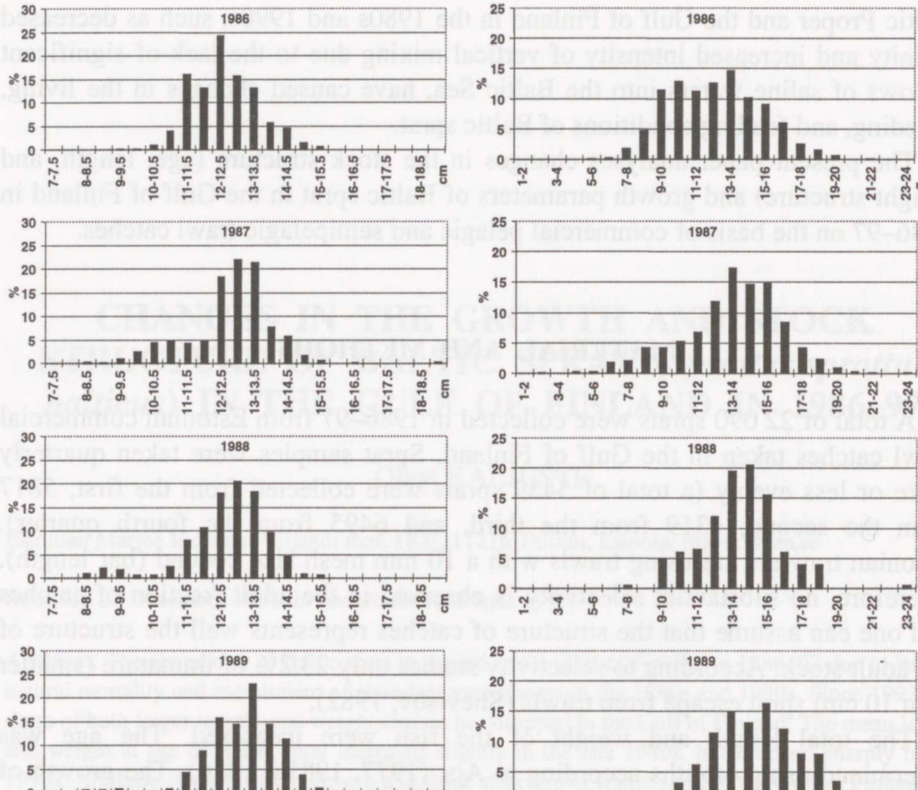

Fig. 1. The length and weight structure of Baltic sprat (%) in the Gulf of Finland in 1986–97.

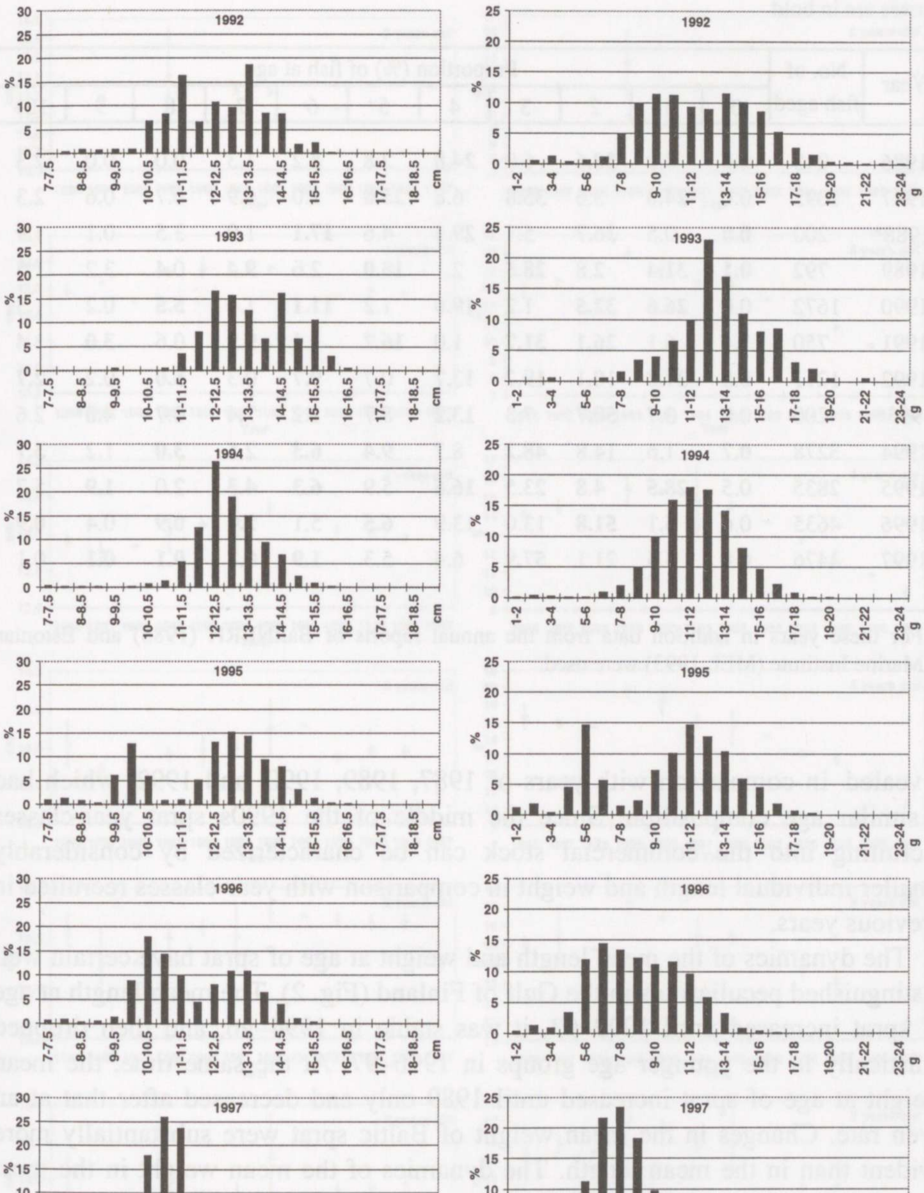

Fig. 1. *Continued.*

Table 1. The age composition of sprat (%) in the Gulf of Finland in 1986–97. Abundant year-classes are in bold

Year	No. of fish aged	Proportion (%) of fish at age										
		0	1	2	3	4	5	6	7	8	9	10+
1986	948	**0.0**	8.0	**50.6**	6.0	**24.8**	2.8	8.2	1.3	0.0	0.0	2.3
1987	1093	0.0	**24.0**	3.6	**35.8**	6.8	**25.0**	1.0	6.9	0.7	0.6	2.3
1988*	200	**0.0**	0.5	**36.7**	5.7	**29.1**	4.6	**17.1**	1.0	3.5	0.1	1.9
1989	792	**0.1**	**31.4**	2.8	**28.5**	2.1	**18.0**	2.6	**9.4**	0.4	3.2	1.5
1990	1672	0.0	**26.6**	**32.5**	1.2	**19.0**	1.2	**11.1**	1.4	**5.5**	0.2	1.3
1991	750	**1.4**	6.1	**26.1**	**31.7**	1.0	**16.7**	1.3	**9.9**	0.6	**3.0**	1.4
1992	1211	0.5	**37.8**	10.1	**19.2**	**13.7**	0.7	**9.7**	0.3	**5.0**	0.2	**2.7**
1993*	200	0.0	3.7	**50.7**	7.3	**13.2**	**8.7**	1.2	**7.4**	0.7	**4.0**	2.6
1994	3278	**0.7**	1.6	14.8	**48.2**	8.7	**9.4**	**6.3**	2.5	**3.0**	1.2	**3.7**
1995	2835	0.5	**28.5**	4.8	23.5	**16.6**	5.9	**6.3**	**4.3**	2.0	**1.9**	5.7
1996	4635	0.6	5.1	**51.8**	13.0	13.9	**6.5**	5.1	**2.0**	**0.9**	0.4	**0.9**
1997	4476	0.8	5.5	21.1	**57.9**	6.4	5.3	**1.9**	0.8	**0.1**	**0.1**	0.1

* For these years in addition data from the annual reports of BaltNIIRH (1988) and Estonian Marine Institute (MEI, 1993) were used.

revealed in comparison with years of 1987, 1989, 1990, and 1992, which had a similar age composition. Since the middle of the 1990s sprat year-classes recruiting into the commercial stock can be characterized by considerably smaller individual length and weight in comparison with year-classes recruited in previous years.

The dynamics of the mean length and weight at age of sprat have certain well distinguished peculiarities in the Gulf of Finland (Fig. 2). The mean length at age of sprat increased until 1992–93, it was stable in 1994–96, and then dropped drastically in the younger age groups in 1996–97. At the same time, the mean weight at age of sprat increased until 1989 only and decreased after that at an even rate. Changes in the mean weight of Baltic sprat were substantially more evident than in the mean length. The dynamics of the mean weight in the most abundant length group (12.0–12.5 cm) is in agreement with the dynamics of the mean weight at age (Fig. 3).

In fact, the mean length at age of sprat has not decreased in the Gulf of Finland in the 1990s, if we consider the dynamics of the mean length in year-classes. The variation in data has caused an observed "decrease" in the mean length in old age groups. At the same time, the decrease in the mean weight at age of sprat in different year-classes is not caused by variation in data, but

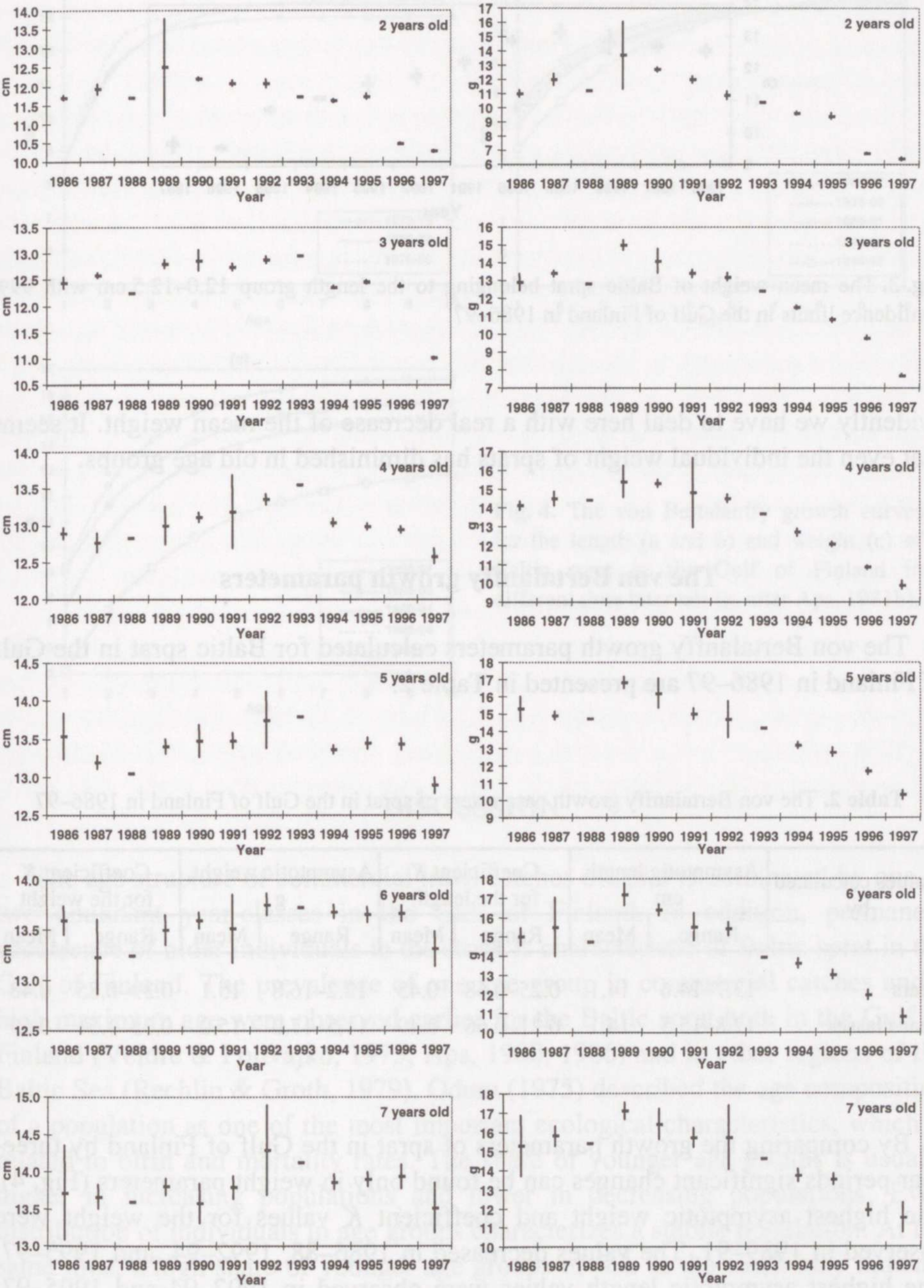

Fig. 2. The dynamics of mean length and weight of Baltic sprat at age with 95% confidence limits in the Gulf of Finland in 1986–97.

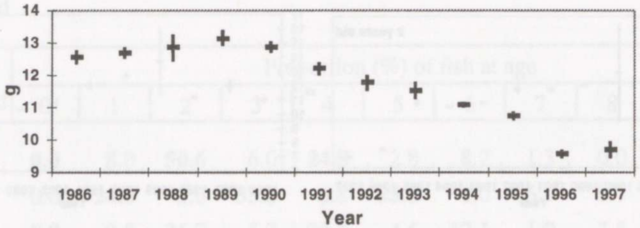

Fig. 3. The mean weight of Baltic sprat belonging to the length group 12.0–12.5 cm with 99% confidence limits in the Gulf of Finland in 1986–97.

evidently we have to deal here with a real decrease of the mean weight. It seems that even the individual weight of sprats has diminished in old age groups.

The von Bertalanffy growth parameters

The von Bertalanffy growth parameters calculated for Baltic sprat in the Gulf of Finland in 1986–97 are presented in Table 2.

Table 2. The von Bertalanffy growth parameters of sprat in the Gulf of Finland in 1986–97

Values calculated by	Asymptotic length, cm		Coefficient *K* for the length		Asymptotic weight, g		Coefficient *K* for the weight	
	Range	Mean	Range	Mean	Range	Mean	Range	Mean
Years	13.7–14.6	14.1	0.25–0.68	0.43	12.2–16.8	15.1	0.39–0.85	0.48
Year-classes	12.8–15.5	14.1	0.21–0.66	0.49	11.5–17.0	15.0	0.35–1.51	0.69

By comparing the growth parameters of sprat in the Gulf of Finland by three-year periods significant changes can be found only in weight parameters (Fig. 4). The highest asymptotic weight and coefficient *K* values for the weight were observed in 1989–91. The values decreased in 1986–88, 1992–94, and 1995–97. The highest asymptotic length values were observed in 1992–94 and 1995–97. The values decreased in 1986–88 and 1989–91. At the same time, the highest value of the coefficient *K* for the length was observed in 1989–91. Its values decreased in 1986–88, 1992–94, and 1995–97.

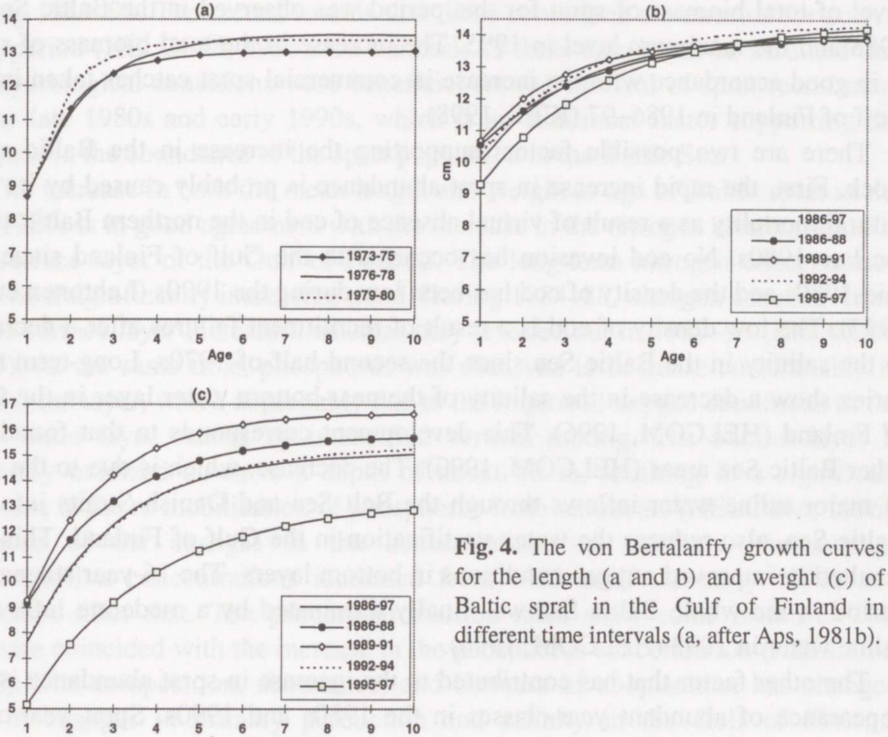

Fig. 4. The von Bertalanffy growth curves for the length (a and b) and weight (c) of Baltic sprat in the Gulf of Finland in different time intervals (a, after Aps, 1981b).

DISCUSSION

The age structure of commercial trawl catches of sprat is dominated by one or two abundant year-classes in the Gulf of Finland. In addition, permanent occurrence of older individuals in the stock is characteristic of Baltic sprat in the Gulf of Finland. The prevalence of one age group in commercial catches and a high maximum age were observed earlier for the Baltic sprat both in the Gulf of Finland (Veldre & Polivajko, 1975; Aps, 1980, 1986) and in other regions of the Baltic Sea (Rechlin & Groth, 1979). Odum (1975) described the age composition of a population as one of the most important ecological characteristics, which is related to birth and mortality rates. The share of younger age groups is usually higher in increasing populations and lower in decreasing populations. Even distribution of individuals in age groups characterizes a stabile population. At the same time, a high share of younger age groups of fish in the catch may indicate overfishing. Keeping in mind these principles and the sprat age composition it can be assumed that in the Gulf of Finland, like elsewhere in the Baltic Sea, the abundance of Baltic sprat increased in 1986–97. In this period the total biomass of sprat increased almost six times in the Baltic Sea (ICES, 1998). The minimum level of total biomass of sprat for this period was observed in the Baltic Sea in 1988 and the maximum level in 1995. The increase in the total biomass of sprat is in good accordance with the increase in commercial sprat catches taken in the Gulf of Finland in 1986–97 (ICES, 1998).

There are two possible factors supporting the increase in the Baltic sprat stock. First, the rapid increase in sprat abundance is probably caused by its low natural mortality as a result of virtual absence of cod in the northern Baltic since the late 1980s. No cod invasion has occurred to the Gulf of Finland since the mid-1980s and the density of cod has been low during the 1990s (Lehtonen et al., 1997). The low density of cod is a result of recruitment failures after a decrease in the salinity in the Baltic Sea since the second half of 1970s. Long-term time series show a decrease in the salinity of the near-bottom water layer in the Gulf of Finland (HELCOM, 1996). This development corresponds to that found for other Baltic Sea areas (HELCOM, 1990). The decrease, which is due to the lack of major saline water inflows through the Belt Sea and Danish Straits into the Baltic Sea, also reduces the water stratification in the Gulf of Finland. This has resulted in improved oxygen conditions in bottom layers. The 16-year stagnation period in the whole Baltic Sea was finally terminated by a moderate inflow of saline water in 1993 (HELCOM, 1996).

The other factor that has contributed to the increase in sprat abundance is the appearance of abundant year-classes in the 1980s and 1990s. Sprat year-class strengths show a high variation in the Gulf of Finland. During the period of 1964–94 the strong and weak year-classes appeared more or less regularly every second year (Lehtonen et al., 1997). According to that study, the strong (abundant) year-classes appeared in 1967, 1971, 1975, 1980, 1982, 1984, 1986, 1991, and 1994. The abundance ratio between the most abundant and the least abundant year-classes was about 14/1 in 1986–97. Some researchers (Veldre & Polivajko, 1975; Ojaveer et al., 1985) have observed as high as 60/1 abundance ratio between the most abundant and the least abundant year-classes. It was suggested that the sprat year-class strength can change considerably during the first wintering period (Ojaveer et al., 1985). This means that a cold winter can cause high natural mortality of young sprat. According to the HELCOM data (HELCOM, 1996) the records of mean annual air temperatures since the late 19th century for the stations of Haparanda, Helsinki, Gotska Sandön, and Falsterbo show an upward temperature trend to a maximum during the warm period of the 1930s, and then a decrease in the northern Baltic Sea and variable conditions in the southern Baltic Sea until the recent warm period, which began in the late 1980s and was more pronounced in the northern Baltic Sea. The mean annual temperature over the Baltic Sea was much above normal for the assessment period 1989–93. The anomalies are mainly concentrated in the winter and spring (HELCOM, 1996). The ice conditions of the Baltic Sea are strongly related to the severity of the winter season. The ice coverage was very modest during 1989–93. The record reveals that those conditions are unusual for such a long period (HELCOM, 1996). On the basis of these data it can be assumed that the hydrological conditions were beneficial for the survival of sprat recruitment in the late 1980s and early 1990s, which is an additional factor supporting the increase in the abundance of the sprat population in the Baltic Sea.

The increase in both the mean length and weight at age of Baltic sprat in the late 1980s is in good agreement with the increase in the nitrogen concentration in the surface layer of the Gulf of Finland. The long-term nitrogen concentration showed a significantly increasing trend. During 1984–88, nitrogen concentrations in the surface layer increased, whereas they levelled out in 1989–93 (HELCOM, 1996). At the same time, phosphorus was observed to decrease considerably in the bottom layer, which is probably due to the improved oxygen conditions in the deep water layer caused by intensified vertical mixing. The bottom layer is presently oxidized down to a depth of about 80 m, resulting in a significant decrease in the re-mobilization of phosphorus from sediments (HELCOM, 1996). Because of the changes in the concentrations of nutrients, the average chlorophyll *a* concentrations increased from 1983 until the early 1990s and decreased after that. The primary production rates show some increase. This increase coincided with the increase in the phosphorus concentration (HELCOM, 1996). The composition, abundance, and biomass of zooplankton has changed due to changes in primary production and salinity in the Gulf of Finland. Temperature has also had substantial influence on the composition, abundance, and biomass of zooplankton. In recent decades a period of high zooplankton abundance in the Gulf of Finland was observed from 1983 till the end of the 1980s (HELCOM, 1996; Lumberg & Ojaveer, 1997). The increase in the abundance of cladocerans and the decrease in that of copepods in the 1980s resulted in considerable changes in the zooplankton structure, numbers, and biomass (Lumberg & Ojaveer, 1991). Extremely low zooplankton numbers were observed in August of 1994 in the western and eastern parts of the Gulf of Finland, the numbers were small even compared with the period 1988–92 (Põllumäe, 1998).

The results of feeding investigations, conducted in 1982–92, show changes in prey composition and an increase in the share of fish with empty stomachs (Raid & Lankov, 1997). Those alterations, probably induced by hydrological conditions prevailing since the mid-1980s, could be at least partly responsible for drastic changes in growth. The analyses of sprat feeding data revealed very similar to the herring trends of increase in the abundance of starving fish and shrinkage of prey spectrum in 1982–92. So, while the mean share of sprat with no food in the stomach was found to be around 50–60% in the 1980s, the respective value in the 1990s has reached almost the same level as in case of herring, i.e. 80–90%. *Temora* has become the mean prey for sprat in spring and particulary in autumn 1991–93 while other copepods, e.g. *Acartia* and *Pseudocalanus*, have disappeared from its diet (Raid & Lankov, 1997). The mean weight of herring began to increase in most regions of the Baltic Sea since the 1970s (Raid & Lankov, 1991, 1995). High values of mean weight and length in all age groups were observed until the mid-1980s, when the sudden drop in all growth parameters followed. In 1986–90 the mean weight of herring decreased in the most abundant age groups (1–6) to the level of 1976–80. The decline of mean weight was particularly remarkable in 1991–93. So, in 1993 the mean weight of herring of older age groups made up approximately 50% of the level of the mid-1980s or even less. Comparison of changes in the growth of herring and sprat shows clearly the same trends, though a subsequent start of decrease of mean weight of sprat was observed. The decrease of salinity and active vertical mixing in the Baltic Sea in the 1980s and 1990s and the increase in the herring stock density can be assumed to have been the main background for the slower growth rate in recent years (Raid & Lankov, 1991, 1995; Parmanne, 1992). Despite the inflow of saline water into the Baltic Sea in 1993, the growth of herring in the Gulf of Finland remained slow in 1995 and 1996 (Parmanne et al., 1997).

Veldre (1986) observed that the mean weight at age of sprat belonging to different year-classes can be very different and it depends, like the mean length, on the abundance of both the relevant year-class and of the total population. By comparing the length growth of different year-classes of sprat in the Gulf of Finland, Aps (1981b) found a negative correlation between the growth rate and year-class abundance, which is more evident in younger age groups (2–4). Relying on these statements, we can suppose that the decrease in the mean length and weight of sprat occurred during the period of its increasing population abundance in the Gulf of Finland. The 1991 and 1994 abundant year-classes are distinguished by a slower growth rate as well. Obviously the decrease in the mean length and weight of sprat is caused by a joint effect of a number of adverse factors, such as hydrological conditions, high population abundance, and appearance of abundant year-classes, in the Gulf of Finland in the 1990s.

In 1962–82 the coefficient K of sprat ranged from 0.7 to 1.0 for the length and from 0.9 to 1.2 for the weight in the von Bertalanffy growth equation in the Gulf of Finland (Aps, 1985). Both the asymptotic length and weight of sprat had an increasing trend during that period. So, in 1962–82 the asymptotic length and weight of sprat increased in the Gulf of Finland from 120 mm and 10.1 g to 135 mm and 14.9 g respectively. Some studies give much lower values of the coefficient K than those observed by Aps (1985). For example, Veldre & Polivajko (1975) found that the coefficient K for both length and weight of Baltic sprat ranges from 0.34 to 0.36 in the northeastern Baltic Sea and in the Gulf of Finland. The growth coefficients of sprat calculated in the present work fall between the values published in the works referred to above. Still, they are closer to the low values published by Veldre & Polivajko (1975). At the same time, the values of the asymptotic length and weight of sprat calculated in the present work exceed substantially the values published by Aps in 1985. Obviously we have to deal here with a negative correlation between the coefficient *K* and the asymptotic length and weight, as observed earlier by Hohendorf (1970).

Aps (1985) assumed that the changes in growth are related to the improvement in the feeding conditions of sprat due to the decrease in its abundance and the effect of the ever-growing eutrophication of the Baltic Sea in 1962–82. As the 1990s are characterized by a high abundance of sprat and retardation of eutrophication of the Gulf of Finland, it can be assumed that the feeding conditions of sprat have deteriorated there. This is in accordance with the increase in the abundance of starving fish and shrinkage of the prey spectrum. This study established a decrease in the asymptotic weight of sprat. The fact that the asymptotic length of sprat increased at the same time is conditioned by the different character of length growth. Namely, unlike the weight, the length of fish cannot diminish generally. The simultaneous occurrence of slowly growing younger age groups and fast growing older age groups from the 1980s in the stock has caused a fall of the coefficient *K* for the length and an increase in the asymptotic length of sprat in the 1990s. In the 1970s, however, the sprat stock was characterized by a simultaneous occurrence of fast growing younger age groups and slowly growing older age groups in the Gulf of Finland. This caused the high values of the coefficient *K* for the length and lower values of asymptotic length compared with the values calculated in the present work. This is the reason why the von Bertalanffy growth curves calculated by Aps (1981b) are steeper than ours (see Fig. 4).

On the basis of its growth parameters the Baltic sprat can be regarded as a fish species reaching quickly its asymptotic length and weight in the Gulf of Finland. Sprat reach close to 90% of their asymptotic length and weight already in the fourth year of life (at age 3). The data published by Aps (1981b) on the growth of sprat year-class 1975 are of the same magnitude as our results.

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LÄÄNEMERE KILU (*Sprattus sprattus balticus*) KASVU JA VARU STRUKTUURI MUUTUSED SOOME LAHES AASTATEL 1986–97

Olavi KALJUSTE

Kilu arvukus Soome lahes on ajavahemikul 1986–97 suurenenud tänu madalale looduslikule suremusele ja arvukate põlvkondade ilmumisele. Alates 1992. aastast on tööndusIikes traalpüükides vähenenud kilu suuremate pikkus- ja kaalurühmade osakaal, mis eriti teravalt tuleb esile 1994. aasta põlvkonna lülitumisel tööndusIikesse traalpüükidesse. Kilu keskmine pikkus ja kaal on olnud 1980. aastate lõpul tõusuteel ja langenud 1990. aastatel järsult. Kilu kasvu Soome lahes kirjeldavad hästi von Bertalanffy kasvukõverad. Aeglasema kasvutempoga nooremate ja kiirekasvuliste vanemate kilupõlvkondade samaaegne esinemine populatsioonis on põhjustanud kilu pikkuse kasvukoefitsiendi languse ja asümptootilise pikkuse kasvu 1990. aastatel. Lähtudes Läänemere kilu kasvuparameetritest Soome lahes võib kilu pidada kiirekasvuliseks kalaks. Neljandal eluaastal (kolme aasta vanuselt) saavutab kilu juba ligi 90% oma keskmisest piirpikkusest ja -massist.